Scour and Cable Protection Decommissioning Study

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Peritus International Ltd

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Further information

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Executive summary

The aim of this report is to complete a desk-based study to inform an evidence gap in relation to the feasibility of, and options for, removal of scour prevention and cable protection upon decommissioning of offshore wind farms and to identify potential environmental implications.

The report identifies scour prevention and cable protection types commonly used in the marine environment including rock dump, rock bags, grout bags and concrete, fronded, bitumen and poly mat mattresses. The report assesses removal options, degradation resistance, current ease of removal and availability of future technologies to provide an overall ranking for each type, which were in descending order rock bags, concrete mattresses, grout bags, fronded mattresses, bitumen mattresses, and lastly rock dump.

Quantitative and qualitative evidence was gathered from the renewables and oil and gas sectors on the current ability to decommission scour prevention and cable protection. Input was collated from suppliers and contractors relating to current best practice, possible future improvements and recommendations that could lead to improving outcomes.

For each scour and cable protection type the various decommissioning methods for each were considered including leave in situ, removal by divers, ROV dredgers, rock removal tool, trailing suction hopper dredge, backhoe dredge, crane lift, subsea grapples and lifting baskets, speed loaders, wet store systems, and mass flow excavators. The positives, risks, limitations, and environmental implications for each decommissioning option were assessed to provide an overall (very good to very poor) grade for each method.

Contents

1 Summary

This study identifies potential engineering options for decommissioning offshore windfarm infrastructure, with a particular focus on options for removal of material associated with cable and scour protection including rock dump, concrete mattresses, grout, sand, and rock bags.

Evidence was gathered and opinions were collected from both the renewables and oil and gas sectors on the current ability to decommission scour prevention and cable protection. Input was provided from suppliers and contractors relating to current best practice, as well as thoughts towards future improvements that could lead to cost savings and environmental sustainability for future projects involving scour protection. The responses are presented in this report.

1.1 General

Several cable and scour protection systems are currently in use. The ease of removing them from the seabed varies from relatively simple (rock bags) to almost impossible (rock dump).

Table 1-1 ranks each material in terms of its ability to be decommissioned, based on the information collected in this study. The table ranks each system based on several factors, with a grading system of 1 to 5 (5 – Very Good, 4 – Good, 3 –Neutral, 2 – Poor, 1 – Very Poor). The factors considered were:

- Track Record – Based on the data collected from offshore UK projects for oil and gas projects, rock dump has by far the worst track record, with no known cases of removal. Rock bags have the best record, although their use is rare in UK projects.
- Number of removal options – As concrete mattresses are so widely used, there are several decommissioning options available, some of which can be applied to the other mattress options. Frond mattresses are restricted by the need to de-bury prior to removal.
- Degradation Resistance – Ropes and bags may degrade over time which can make decommissioning an issue for mattresses. Grout bags and Bitumen matts are known to become brittle over time. Material degrading is not a consideration for rock dump.
- Current Ease of Removal – Due to rock dumps loose nature, it is very time-consuming and expensive to totally remove from the seabed with the current methods available. Rock bags are easiest to remove as they can be readily lifted.
- Future Technologies available – an estimate of how likely future technologies are to be developed to assist in the removal process.

Table 1-1: Scour Protection Material Decommission Ranking

Method	Track Record	Removal Options	Degradation Resistance	Current Ease of removal	Availability of Future Technologies	Average Score	Rank
Rock Dump	1	2	5	1	3	2	**6**
Rock Bags	5	5	4	4	3	3.5	**1**
Grout Bags	4	3	2	3	3	2.5	**3**
Concrete Mattresses	4	5	3	3	4	3.2	**2**
Fronded Mattresses	3	2	4	2	3	2.3	**4**
Bitumen Mattresses	3	3	2	2	3	2.2	**5**

1.2 Oil and Gas Projects

As wind farm decommissioning data is not readily available, data from the oil and gas sector was analysed to provide evidence on the current state of the art of decommissioning for scour and cable protection systems. One hundred and eleven projects which had submitted decommissioning plans were reviewed. Figure 1-1 shows the protection systems currently deployed on oil and gas projects in the UK along with the proposed decommissioning activity (Leave in place, remove or partially remove).

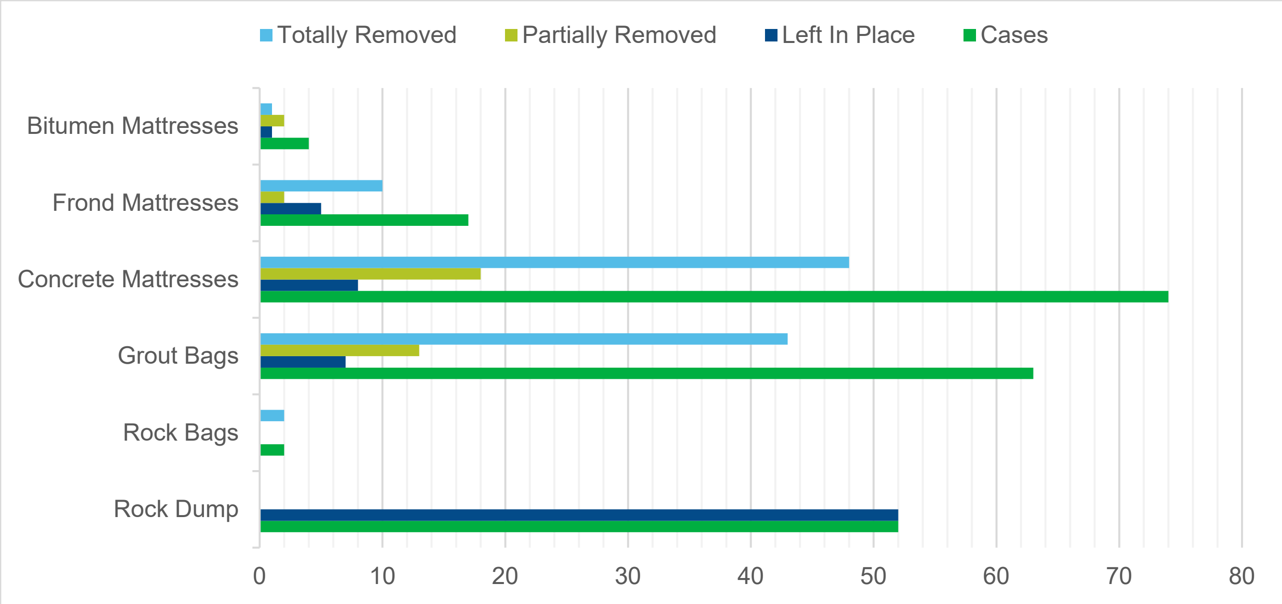

Figure 1-1: Summary of oil and gas decommissioning plans

1.3 Future Improvements

It is noted that alternative, environmentally friendly solutions have been developed, this includes nature inclusive scour protection solutions, such as Eco-Engineered mattresses and Eco-Armor blocks. Of the suppliers and contractors contacted for this report, use of an environmentally friendly solution that could remain on the seabed was the most popular response when asked what improvements could be made to current scour protection decommissioning methods.

1.4 Recommendations

For future projects requiring scour protection, it is recommended that developers consider solutions that produce minimal to no negative environmental impact to the seabed, and therefore can remain in place at the end of the project as evidence suggests this is the most cost effective and sustainable approach.

2 Introduction

2.1 Background and Context

Natural England’s remit is to ensure sustainable stewardship of the land and sea so that people and nature can thrive. They are working to achieve a healthy and biodiverse marine environment which can enable a truly sustainable UK offshore wind sector, to support the achievement of ‘net zero’ and address the climate change emergency. They use their expertise to help facilitate offshore infrastructure that are sensitively located and constructed, whilst protecting marine ecosystems from proposals with significant environmental impacts through statutory advice. This will build the marine environment’s resilience to climate change and its ability to mitigate its effects.

The aim of this project is to undertake a desk-based study to understand, from an engineering perspective, the feasibility of decommissioning options for an offshore windfarm with particular focus on decommissioning of scour prevention and cable protection material and the physical implications decommissioning of these may have on the surrounding habitats for example surrounding sediment removal.

2.1.1 Scope

The scope of this study is to:

- Identify what potential engineering options there are for decommissioning offshore windfarm infrastructure, with a particular focus on options for removal of material associated with cable and scour protection e.g., rock dump, concrete mattresses, grout, sand, and rock bags etc.
- Identify comparable (*to offshore windfarm infrastructure) decommissioning activities for marine structures and associated infrastructure which have been undertaken in the UK/Worldwide NB: Intel. on location, infrastructure being removed, surrounding environment and methodology for removal will inform comparability.
- Gather evidence and/or opinion across industries, on ability to decommission scour prevention/cable protection, including oil and gas industry and responses put into recent OWF NSIP examination (and others).

2.2 Abbreviations

Table 2-1: Abbreviations

Abbreviations	Definition
BHD	Back Hoe Dredger
GRP	Glass Reinforced Plastic
IRM	Inspection, Repair Maintenance
OGA	Oil and Gas Authority
OWF	Offshore Wind Farm
PET	Polyester
ROV	Remotely Operated Vehicle
RRT	Rock Removal Tool
TSHD	Trailing Suction Hopper Dredger
UXO	Unexploded Ordnance

3 Data and Design Premise

3.1 Location

The study is to focus on scour protection materials used in UK North Sea waters in depths of up to 50 m. Therefore, the study will be limited to monopile foundations and subsea cables, however the results are likely to be applicable to other types of foundation and linear infrastructure such as pipelines. Seabed types to be considered are:

- Sand
- Sand Waves
- Mixed sediment (Sand/gravel)
- Cobbles

Hard strata such as rock is excluded.

3.2 Scour Protection Systems

The following scour protection systems are included within this review:

- Rock dump
- Rock bags
- Grout Bags
- Concrete Mattresses
- Fronded Mattresses
- Bitumen Mattresses
- Duramat (Poly) Systems

Concrete and Glass Reinforced Plastic (GRP) protection covers are not used for scour protection; therefore, these are not included.

3.3 Rock Dump

The most common strategy to date to prevent damage caused by scouring is to place rock on the seabed. Before installation of the wind turbine foundations an initial scour protection filter layer can be placed on the seabed at each foundation location. Following the installation of the foundations further erosion protection can be provided by placing larger stones, a so-called armour layer, around the foundations. The rocks are selected so that the increased current around the structure will not be able to wash them away.

Similarly, rock dump can be used to protect cables and limit scour at cable crossings, depending on the environmental conditions a single layer or a filter/armour layer combination may be employed.

Filter layers are typically 1-5”, where armour layers may be 8-18” in size. The grading of rock will depend on the existing sediment along with the environmental conditions (water depth, hydrodynamic loads etc) and is beyond the scope of this report.

3.4 Rock Bags

The principle behind a rock bag is to contain the rocks in discrete units which can be placed on the seabed. Examples of this which have been previously used on wind farms include Secutex and the Ridgeway Rock bag.

3.4.1 Secutex

Secutex® Soft Rock are geotextile sandbags or containers manufactured from needle-punched Secutex® non-woven filter geotextiles. Geotextile sand containers (GSC) are made for encapsulating granular material.

In addition to single-layer nonwoven GSCs for covered applications, double-layer nonwoven GSCs are available. They have an integrated surface protection made of rough fibres for exposed conditions and are visually well suited for a sandy environment. This solution has been employed on the German Amrumbank West offshore wind farm.

3.4.2 Ridgeway Rock Bag

These rock bags also known as (Kyowa Filter units) Made of 99% recycled polyester (PET) and constructed using a unique form of knitting, known as Raschel, the filter unit is a rock filled bag filled with aggregate making it a very flexible solution for marine construction work. Available in 3 sizes (2, 4 & 8 tonne) the Units have a safety factor of 6 and feature a one-point lifting ring for installation.

3.5 Concrete Mattresses

Concrete mattresses have a long track record of offshore deployment. Mattresses are made from concrete which is typically between 2.3 and 2.5 Tonnes per cubic metre. The blocks are connected by U.V. stabilised polypropylene rope. Typically, mattresses are 6 x 3 m and either 15 cm or 30 cm thick.

3.6 Fronded Mattresses

Fronded mattresses are the same as the standard concrete mattress, however, have the addition of buoyant polypropylene fronds that create a drag barrier which reduces current velocity and causes sediment to accumulate on top of the mattress. Note that fronded solutions also exist without the concrete mattress base. These are typically weighted by filling external tubes with gravel.

3.7 Bitumen Mattresses

An alternative mattress design for non-abrasive applications is the bitumen mattress. Bitumen mattresses are heavy, non-abrasive, but may be manufactured from carcinogenic compounds. They tend not to be used for wind farms but may still be in place for legacy oil and gas projects.

3.8 Poly Mat Mattresses

Another alternative to concrete mattresses is poly mats. These may be less abrasive for more sensitive cables or umbilicals. Poly mats are lighter but can be installed with weighted edges. They tend not to be used in wind farms, however, are included in this section for completeness. Moulded in marine grade polyurethane elastomer, during manufacture, the PU is filled with barites that provide ballast and prevent movement

Duramat is ROV and diver installable and is generally supplied with through holes for rope handling Duramat is typically provided in 3000 x 3000 x 40 mm sections.

4 Oil and Gas Decommissioning

The Oil and Gas Authority (OGA) maintain a publicly available database listing all the decommissioning applications and approved decommissioning plans. All the applications and approved plans were downloaded and reviewed. Wherever a scour protection system within the scope of this report was included in the plan, details were recorded. One hundred and eleven (111) entries were reviewed. The results of the review are presented in the following sections.

4.1 Relevance of Data

Offshore equipment and vessel capability improve with time. Therefore, there is a potential risk that some of the older applications for decommissioning do not reflect the current state of the art of the industry. Figure 4-1 shows the number of decommissioning applications considered plotted against their submission date. Most applications have occurred since 2015 and therefore the methodologies contained within them may be considered relevant for the current scope. A summary of all the entries and their approved decommissioning plans are presented in Figure 4-2.

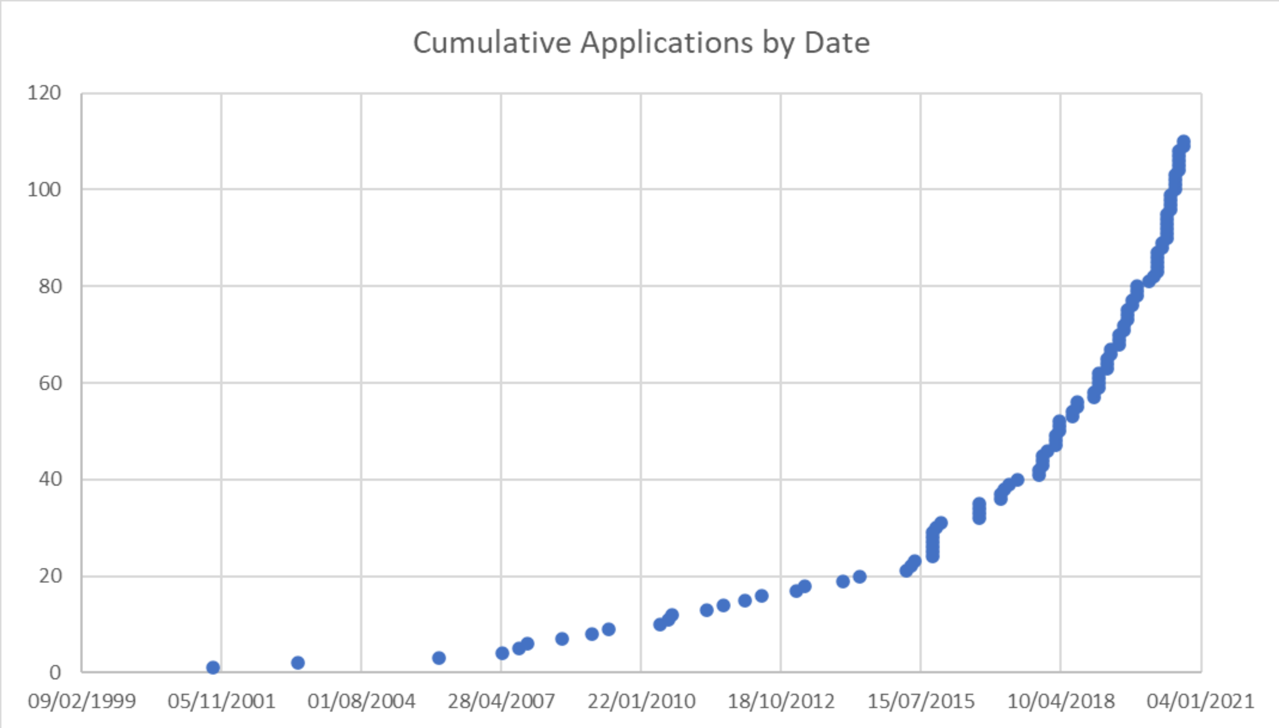

Figure 4-1: Decommissioning applications by date

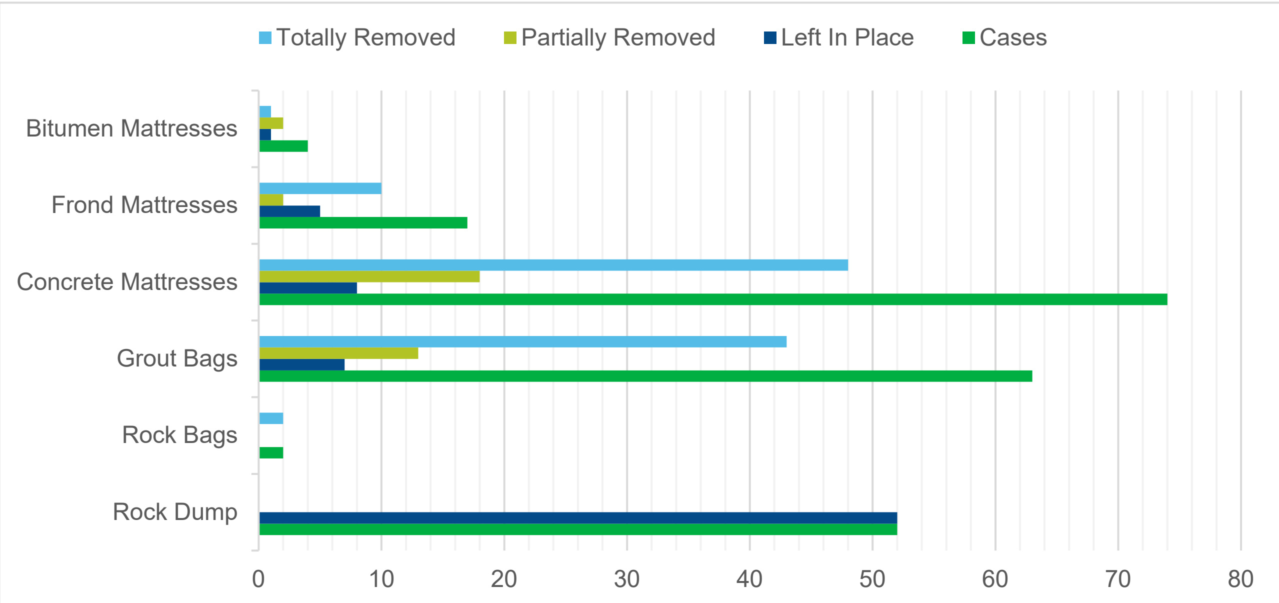

Figure 4-2: Summary of Oil and Gas decommissioning plans

4.2 Rock Dump

Rock dump is commonly used as pipeline protection due to the ow cost and easy installation, when compared to other protection methods. Rock dump has a long track record on successful application in the past and hence is widely used offshore. Of the 111 projects reviewed, 52 of them included some form of rock dumping. Of these projects, all of them (100%) left the rock dump in place. None of the applicants planned to remove rock dump. The split between overall number of projects and those including rock is shown in Figure 4-3.

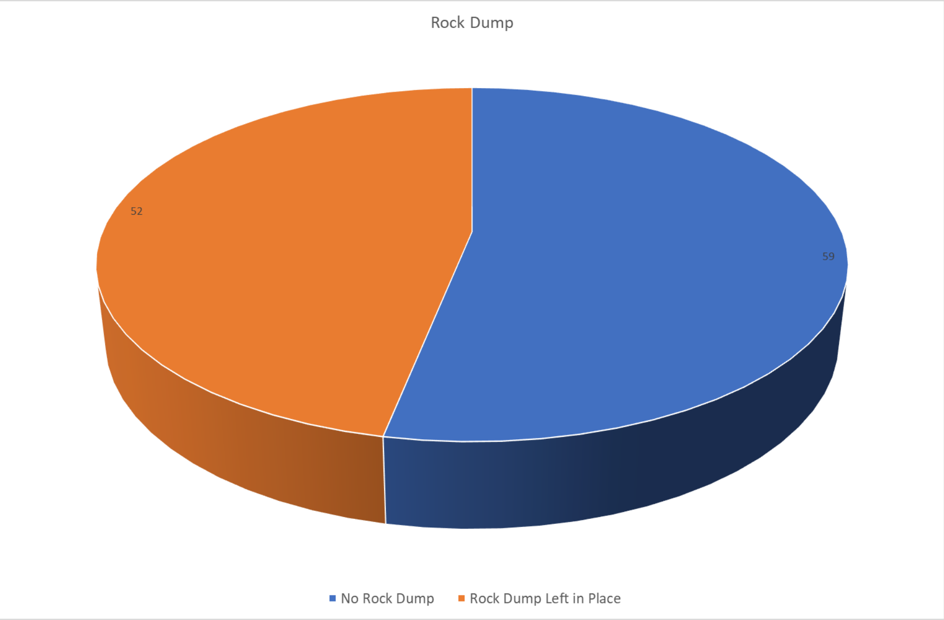

Figure 4-3: Split of projects with/without rock dump

4.3 Rock Bags

The use of rock bags is not very widespread; only two projects included rock bags. Both projects planned to remove the rock bags, as shown in Figure 4-4.

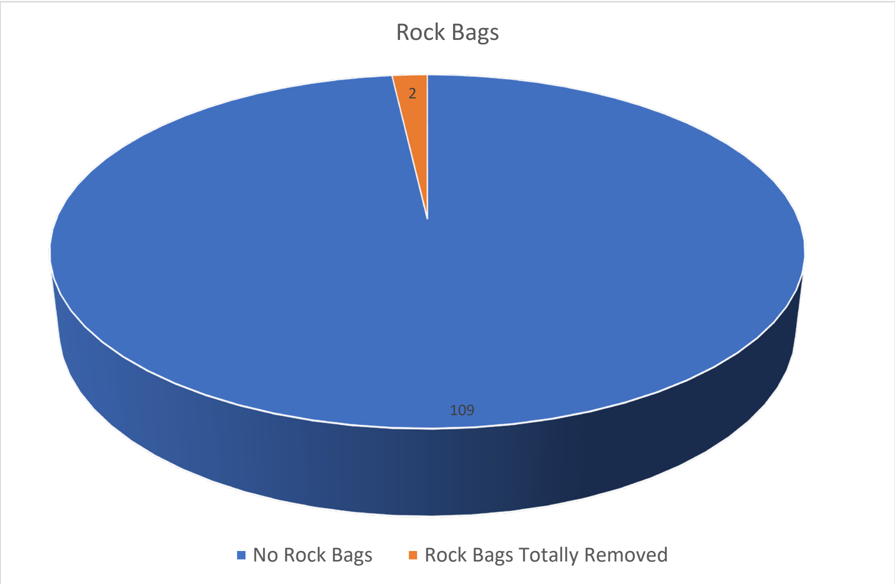

Figure 4-4: Rock bag usage

4.4 Grout Bags

Of the 111 projects 62 contained grout bags. Although grout bags are not primarily used as a form of scour protection in offshore wind, it is possible they will be used for free span correction or to support cables as they cross scour pits. Of the projects that did contain grout bags, Figure 4-5 shows that most of them (circa ~70%) were removed. Table 4-1 presents the rationale behind the grout bags left in situ.

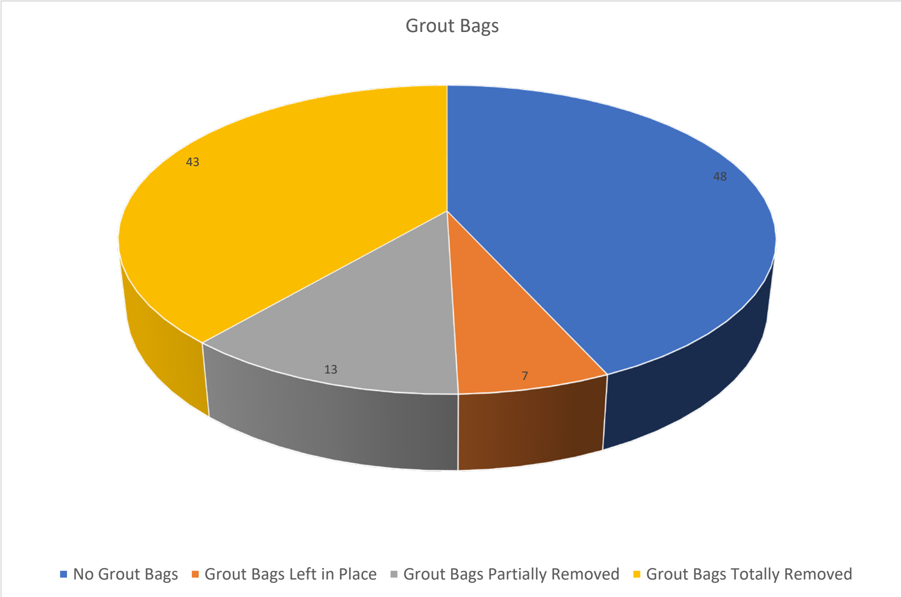

Figure 4-4: Grout Bag Removal Overview

Table 4-1: Grout Bags – Rationale for leaving in situ

Project	Status (Left in Place / Partial Removal)	Reason
LOGGS PR, LOGGS PC, LOGGS PP, LOGGS PA, North Valiant PD, & Associated Pipelines – LDP5	Partial Removal	Left in place if buried
Kingfisher	Partial Removal	Left in place if buried
Brae Alpha, Brae Bravo, Central Brae, West Brae and Sedgwick	Partial Removal	Removed if over 250 m from the footings
Atlantic and Cromarty	Partial Removal	Left in place if buried

Alma & Galia	Partial Removal	Left in place if buried
Ann and Alison	Partial Removal	Left in place if buried
Audrey	Partial Removal	Most pipelines and stabilisation features to be left in situ unless exposed. Minimal seabed disturbance, lower energy usage, reduced risk to personnel engaged in the activity and lower cost.
Brynhild	Left in Place	Buried so left in place
Dunlin Alpha to Cormorant Alpha Pipeline	Left in Place	All grout bags were found to be buried so were left in place
Ganymede Europa Callisto and NW Bell	Partial Removal	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Goldeneye	Partial Removal	Left in place if buried
Juliet	Partial Removal	Left in place if buried
LOGGS Satellites	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
MacCulloch	Partial Removal	Left in place if buried
Schiehallion Loyal Fields Phase 1	Left in Place	Remaining in place to maintain integrity of lines associated with them and prevent risk to other infrastructure
South Morcambe DP3-DP4	Partial Removal	Left in place if buried
Stamford	Partial Removal	UK - remove NL - left in place

		The majority of the pipeline and therefore stabilisation features will be left in situ due to technical difficulty and cost to remove
Victor	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Viking Platforms, Vixen and associated pipelines	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Viking Satellites	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment

4.5 Concrete Mattresses

Of the 111 projects, 74 mentioned subsea mattresses. As shown by Figure 4-6, where a project contained concrete mattresses, the majority (65%) are proposing to completely remove them. Only ~10% are expecting to leave mattresses in situ. The reasons for leaving the mattresses in situ are further detailed in Table 4-2.

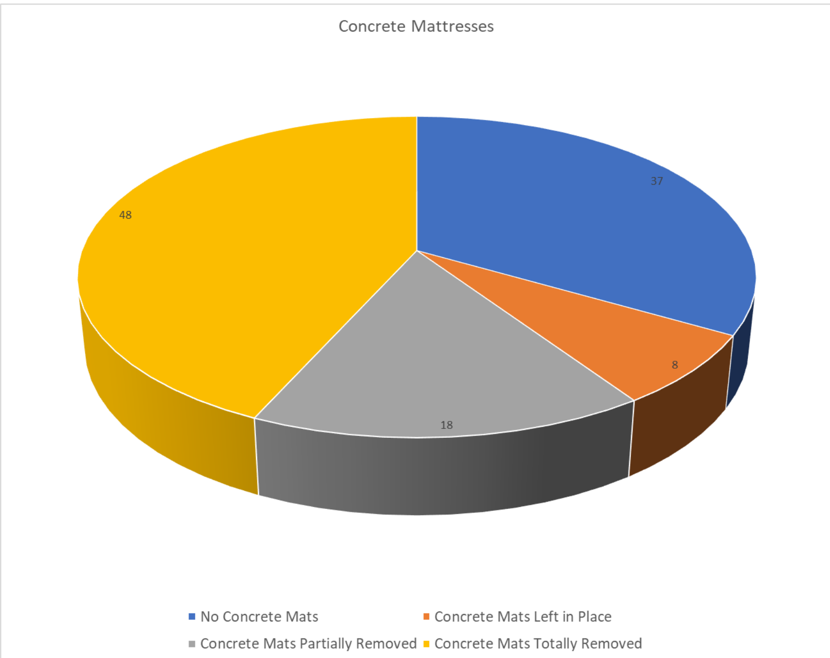

Figure 4-5: Concrete Mattresses Overview

Table 4-2: Rationale for leaving Mattresses in Situ

Project	Status	Reason
LOGGS PR, LOGGS PC, LOGGS PP, LOGGS PA, North Valiant PD, & Associated Pipelines – LDP5	Left in Place	The comparative assessment recommends that the pipelines be left in situ. The pipelines are sufficiently buried and stable. Minimal seabed disturbance, lower energy usage, reduced risk to personnel engaged in the activity.
Kingfisher	Partial Removal	Left in place if buried
Brae Alpha, Brae Bravo, Central Brae, West Brae and Sedgwick	Partial Removal	removed if over 250 m from the footings
Brent	Partial Removal	Left in place if buried
Atlantic and Cromarty	Partial Removal	Left in place if pre-lay
Alma & Galia	Partial Removal	Left in place if buried
Ann and Alison	Partial Removal	Left in place if buried
Audrey	Partial Removal	Most pipelines and stabilisation features to be left in situ unless exposed. Minimal seabed disturbance, lower energy usage, reduced risk to personnel engaged in the activity and lower cost.
Brynhild	Partial Removal	Left in place if buried
Dunlin Alpha to Cormorant Alpha Pipeline	Partial Removal	Left in place if buried

East Brae Topsides and Braemar	Partial Removal	To be reused offshore to stabilise end of cut lines. If not possible to reuse, then they are removed
Ganymede Europa Callisto and NW Bell	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Goldeneye	Partial Removal	Left in place if buried
IVRR Fields	Partial Removal	Mattress with wire rope left in place, mattresses with polypropylene to be removed
Janice James and Affleck	Partial Removal	3 to remain in place under existing rock dump
Juliet	Left in Place	Mattress fully buried
LOGGS Satellites	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
MacCulloch	Partial Removal	Left in place if buried
Minke	Partial Removal	Left in place if buried
Murchison	Partial Removal	4 to be left in place on pipeline crossings
Schiehallion Loyal Fields Phase 1	Left in Place	Remaining in place to maintain integrity of lines associated with them and prevent risk to other infrastructure
South Morcambe DP3-DP4	Partial Removal	Left in place if buried
Stamford	Partial Removal	UK - remove NL - left in place

		The majority of the pipeline and therefore stabilisation features will be left in situ due to technical difficulty and cost to remove
Victor	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Viking Platforms, Vixen and associated pipelines	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Viking Satellites	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment

4.6 Fronded Mattresses

Fronded Mattresses were included in 17 projects. Figure 4-7 shows that of these 17 projects, the fronded mattresses were removed in 10 projects, left in place for 5 projects and were partially removed in the remaining 2 projects. Table 4-3 presents the reasons why some of the mattresses were left in place.

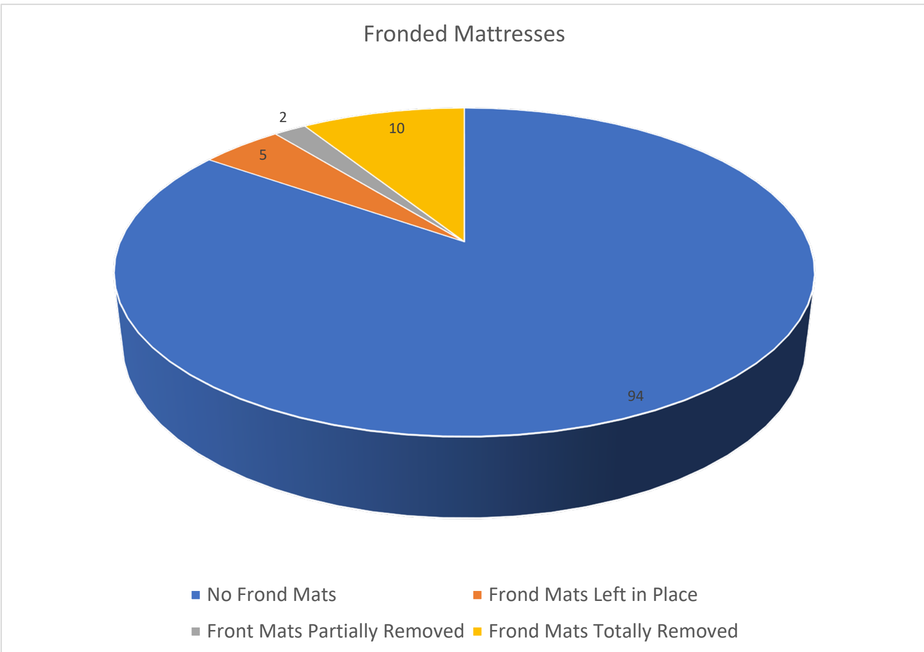

Figure 4-6: Frond Mattress Overview

Table 2-3: Fronded Mattress Reasons For leaving in Place

Project	Status	Reason
Audrey	Left in Place	Most pipelines and stabilisation features to be left in situ unless exposed. Minimal seabed disturbance, lower energy usage, reduced risk to personnel engaged in the activity and lower cost.
Bains	Partial Removal	Left in place if buried
Ganymede Europa Callisto and NW Bell	Partial Removal	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
LOGGS Satellites	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Victor	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Viking Platforms, Vixen and associated pipelines	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment
Viking Satellites	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment

4.7 Bitumen Mattresses

Bitumen mattresses were not common in the projects considered. Only four projects included bitumen mattresses, one of these projects removed all the mattresses, one left them all in place and the remaining two projects partially removed them, as shown in Figure 4-8 and Table 4-4.

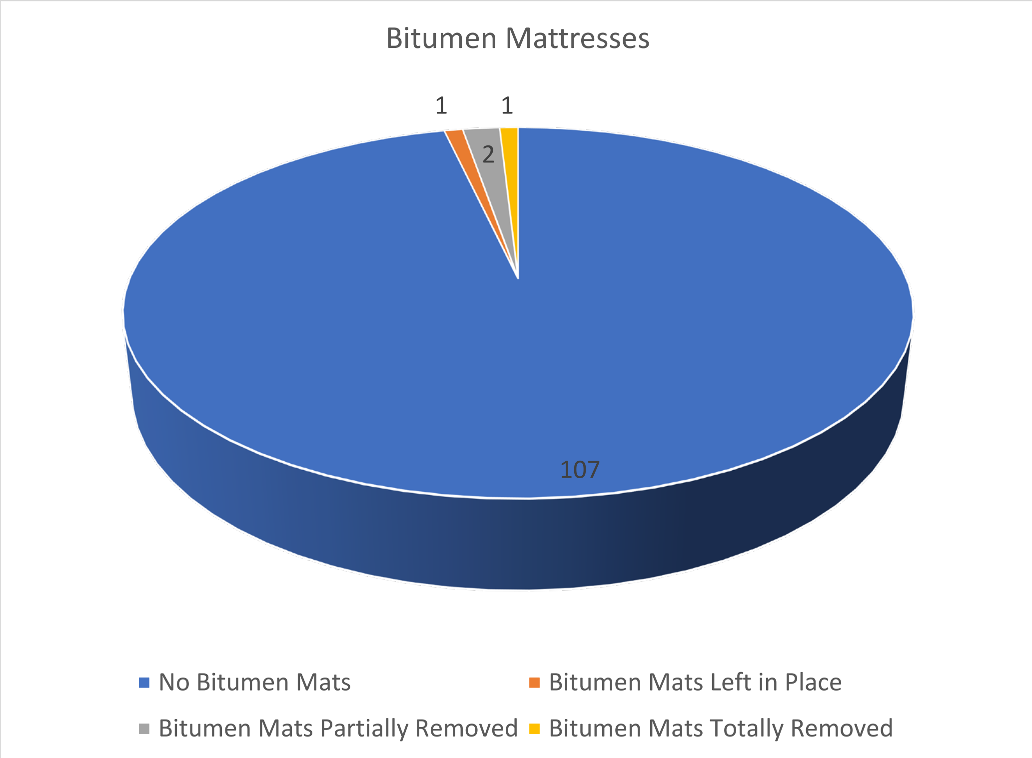

Figure 4-7: Bitumen Mattress

Table 4-4: Bitumen Mattress Reasons For leaving in Place

Project	Status	Reason
South Morecambe DP3-DP4	Partial Removal	Left in place if buried
Victor	Left in Place	Pipelines and stabilisation features left in place to maintain pipeline stabilisation and minimise disturbance of environment

5 Supplier and Contractor Input

Suppliers of scour protection systems (mainly mattresses) were contacted and their input on decommissioning techniques was sought. Potential decommissioning contractors were also contacted with a view to obtaining their capability to decommission the scour protection systems within the scope of this report.

Contact protocol was as follows:

- Initial Email
- Follow up phone call after 2 days
- Follow up phone call after 4 days
- Second email after 5 days
- Considered as no response if no reply

5.1 Suppliers

Suppliers of scour protection systems were contacted, as listed in Table 5-1, and input requested for inclusion within the report.

Table 5-1: Suppliers Contacted

Supplier Company Name	Nature of Items Supplied	Response	Decommissioning Involvement
Subsea Protection Systems (SPS)	Concrete Mattresses, Fronded Mattresses	Yes	Yes
SSCS	Fronded Scour control systems	Yes	Yes
Econcrete	Ecologically friendly “concrete” mattresses	Yes	Yes
Heusker	Concrete mattresses	None	N/A
Pipeshield	Mattresses, Frond mattresses, structures	Yes	Yes
Subcon	Scour collars, from mattress, concrete mattress	None	N/A
ACE Geosynthetics	Geotextile mattresses and sandbags	Yes	None
FLXMAT	Concrete mattresses	None	N/A
Broadline Construction	Concrete mattresses	None	N/A
Shricon Offshore	Concrete mattresses	None	N/A

GeoSintex	Concrete mattresses, Sandbags etc	None	N/A
Maccaferri	Gabion (rock filled) mattresses	None	N/A
Ridgeway	Rock bags	None	N/A

5.2 Contractors

Contractors of scour protection systems were contacted, see Table 5-2, and input requested for inclusion within the report.

Table 5-2: Contractors Contacted

Name	Nature of Activity	Responded	Decommissioning Involvement
WeSubsea UK Ltd	Marine Contractor	Yes	Yes
Neptune Marine Services (MMA Offshore)	Marine Contractor	Yes	Yes
DEME Group	Rock dump/dredging	Yes	None
Boskalis	Rock dump/dredging	Yes	Yes
Van Oord	Rock dump/dredging	None	N/A
Sapura Energy	Marine contractor	None	N/A
IHC	Dredger	None	N/A
James Fisher	Diving and subsea excavation	Yes	Yes

6 Results from Supplier Input

This section presents the responses shared by the suppliers and contractors that were contacted, with regards to decommissioning each scour protection system. Several of the suppliers that responded were only involved with the supply of certain items and were not able to provide decommissioning advice.

6.1 Decommissioning Options and Limitations

The suppliers/contractors that provided input to this section are listed below, as well as their input on decommissioning techniques:

- Company – Boskalis Offshore Subsea Contracting
- Application – Rock Dump
- Response: "Our company owns several floating grab cranes, which can be deployed to remove the specified items. The operations are of course limited to the prevailing weather and sea-state conditions as also the water depth limitations. For each project therefore the local conditions need to be reviewed on practicalities as also governing operational conditions."

- Company – WeSubsea UK Ltd
- Application – Rock Dump
- Response: "WeSubsea ROV/Diver dredge systems are used on a regular basis offshore on a variety of renewable, IRM and decommissioning work scopes such as rock dump removal or rock dump reinstatement work scopes."

- Company – ECOncrete Tech Ltd
- Application – Concrete Mattresses
- Response: "We would advocate for leaving ECO-Engineered concrete mattresses in place post decommissioning, as over the course of their deployment they will have served as diverse and productive benthic seabed habitats that provide multiple ecosystem services that should not be disturbed."

- Company – Pipeshield International Ltd
- Application – Concrete Mattresses
- Response: 'For decommissioning and subsequent mattress retrieval, the 'Wet Storage Base' can be used for recovery from subsea to vessel and then direct to transport for recycling at a Pipeshield facility. The system compromises heavy payload base frames that can be used for multiple mattress installation, wet store and easily converted into a recovery basket configuration for safe effective retrieval of mattresses or equipment.'

- Company – Subsea Protection Systems (SPS)
- Application – Concrete Mattresses

- Response: We supply all major installation companies with these products, but we do not get involved in the offshore works. Our speed loaders have been used on a couple of mattress decommissioning jobs, where contractors use them to bring mattresses back to surface.

- Company – SSCS Ltd
- Application – Frond Mattresses
- Response: "Once the Frond Mats are fully buried, this takes on average 6-12 months. They will have returned the seabed to its natural condition and to date Mats have remained buried in situ. If they are required to be removed, then the sediment on top must be removed by jetting or UXO grabber and the Frond Mats will be fully intact ready to be lifted off the seabed."

- Company – James Fisher Marine Services
- Application – All Scour Protection Methods
- Response: "JFMS have an extensive track record revolving around Air Diving and ROV capability. Supported with specialist grabs of various sizes, half-height baskets and other subsea intervention JFMS can support a multitude of decommissioning projects."

6.2 Improvements and Suggestions

The suppliers/contractors were asked if there are any improvements that could be made to scour protection systems which would facilitate decommissioning. The responses are presented in the section below:

- Company – Boskalis Offshore Subsea Contracting
- Application – Rock Dump
- Response: "We feel that changing the design of the scour protection works, to allow efficient decommissioning of the structure, is not the most effective mitigating solution. Instead we suggest that the principles of the building with nature (https://www.ecoshape.org/en/) are taken on board. This program is focused on developing a new approach to hydraulic engineering that harnesses the forces of nature to benefit environment, economy and society."

- Company – WeSubsea UK Ltd
- Application – Rock Dump
- Response: "Are there any scour protection systems currently in use that are 100% renewable such as artificial coral reefs that would not need decommissioned at the end of an assets life."

- Company – ECOncrete Tech Ltd
- Application – Concrete Mattresses

- Response: “By utilizing nature inclusive scour protection solutions like Eco-Engineered mattresses and Eco-Armor blocks, that incorporate bio-enhancing concrete admixture, complex surface textures and science-based considerations into their design, the scour protection measures will also function as a benthic habitat that is optimal for the development of marine flora and fauna. Nature inclusive scour protection solutions will result in elevated biodiversity and species richness, with the potential enhancement of targeted local species. This design approach would result in a thriving ecosystem inhabiting the surface area of the scour protection and would significantly strengthen the argument to leave the scour protection in place post decommissioning; resulting in tremendous cost savings.”

- Company – Pipeshield International Ltd
- Application – Concrete Mattresses
- Response: “There is ongoing R&D within Pipeshield on the application of the Wet Storage Recovery System discussed we are looking at improving the system by adding GRP gridding to the system to enable the recovery of rock bags / grout bags etc. so the items would be fully supported on the underside.”

- Company – SSCS Ltd
- Application – Frond Mattresses
- Response: “We currently have R&D projects underway that relate to this development but are presently under an NDA.”

- Company – SSCS Ltd
- Application – Frond Mattresses
- Response: “The principal problem in decommissioning for scour protection is that seabed flora and fauna recolonize the area after installation. This process can take months or years and removing the scour protection will completely destroy the habitat once again. So yes, we agree that companies should look for solutions that do not need to be decommissioned. This is one of the main benefits of the Frond Mats, we have been installing Frond Mats since 1984 initially in the Southern North Sea graduating to most other global areas and it has generally been accepted, that if possible it is best to leave the Mats fully buried in situ.”

- Company – James Fisher Marine Services
- Application – All Scour Protection Methods
- Response: “The ideal scenario would be for the requirement of scour protection to be environmentally friendly and exempt from the requirement for decommissioning. In order to achieve this, the materials would be required to be friendly to subsea environment and encourage natural protection.”

7 Decommissioning Options

This section provides a full overview as to all the decommissioning options associated with each external cable and scour protection method, which included everything which has been highlighted in the document thus far, as well some further research into potential options for the future. It should be noted that for each protection method, engineering project criteria and specifics will need to be explored in order to decide which option shall be taken forward.

7.1 Rock Dump Removal

Rock dump is commonly used as either scour protection or to protect cables from damage for external sources. It is also used at crossing locations to provide separation. The options available to decommission installed rock material are listed below, Ref. [3]

7.1.1 Leave In-Situ

Given the nature of the loose rock, it is very difficult and time consuming to remove rock dump. Where rock-dump has previously been used to protect a pipeline or cable it is recognised that removal of the pipeline is unlikely to be practicable and it is generally assumed that the rock-dump and the pipeline will remain in place, Ref. [2].

7.1.2 Partial / Total Removal Methods

There are currently no recorded cases where rock dump has been completely removed from the seabed in the oil and gas industry. It is possible, although uncommon to relocate rock so that the cables underneath can be decommissioned. A list of the proposed removal methods is listed below, as well as techniques used to relocate rock dump.

- Removal by Divers
  One option for rock dump removal is to manually remove the rock dump from the seabed using divers. The rocks can be loaded into a lifting basket which can then be lifted to the surface. This method requires little equipment; however, it is very time consuming, and presents healthy and safety risks to the divers involved. It is not considered to be a practical solution. It is also possible for a diver to use an airlift system for small rocks in shallow waters, however this is not a practical solution for large scale rock.

- ROV Dredgers
  It is possible to relocate rock dump with the use of dredgers. Suppliers such as WeSubsea can provide heavy-duty, high-powered dredgers, that can be mounted to an ROV for quick and easy operation. These dredgers have a lightweight, compact design for easy mobilisation, there are no depth limitations or risk of water ingress. Upon speaking with suppliers there has been no cases where a client has

ever asked for the rock dump to be removed from the seabed and advised that it would likely be unfeasible to do so. The standard practice is to move the rock dump to another location so that the pipeline can be decommissioned, and on certain projects the rock dump is then moved back on site once decommissioning is complete.

- TSHD Equipment
  A Trailing Suction Hopper Dredger is a common dredging vessel. It is a sea-going, self-propelled vessel that is suitable to remove, transport and dispose silty, sandy, gravely, or soft clayey soils. It has been proposed that TSHDs could potentially be used to remove small diameter rock dump. Hopper dredgers available can dredge up to 155 m water depth. However, there is currently no evidence of this technique being used on previous oil and gas projects.

- Backhoe Dredgers
  Another proposed method to remove rock material is the deployment of backhoe dredgers, which can dredge the installed rock berm and load it into barges. Backhoe dredgers are designed to handle hard and stiff ground soils. The backhoe dredger is a common type of dredger, which dredges mechanically. The main component is a hydraulic excavator, performing the rock removal operation, mounted on a pontoon. The BHD is equipped with the latest technology in computer systems, used for on-line positioning and dredging monitoring. Typically, a BHD in deep dredge configuration can remove all rocks to a water depth of maximum 32 m. Because of this, not all rock dump locations are within reach of the BD bucket. Rocks installed on a depth over this limit would have to be removed by a hopper dredger.

- Rock Removal Tools
  The Rock Removal Tool (RRT) is a Boskalis innovation that has been developed for the precise removal and deposition of rock in a subsea environment. The RRT can be used for the installation and removal of non-cohesive materials at subsea structures, including rock dump. The suction process is created by means of the Bernoulli-principle: a high-velocity jet flow in the pump leads to a vacuum near the suction mouth. At the suction mouth the rock is removed, taken into suspension, and transported to the RRT's discharge end, at the selected location. Note that this tool only has the capability to move rock and cannot remove it from the seabed. However, it shows a potential for future developments of rock dump removal. Although the tool is capable of precise removal, its use would still pose risk to existing habitats underneath and next to the rock dump.

7.2 Rock and Grout Bag Removal

7.2.1 Leave In-Situ

In general, rock bags and grout bags are recoverable and able to be recycled, so leaving the bags in-situ is less common unless there are circumstances to justify leaving them on the seabed. Rock bags and grout bags are subject to decompose over time, and many will no longer have lifting points attached. Due to the grouts hardening properties, the integrity of the canvas bag also comes into question during recovery. Often a case is made to seek approval to 'leave in situ' for larger grout bags, due to the high levels of risk associated with their removal.

7.2.2 Partial / Total Removal Methods

- Crane Lift with ROV assistance
  In the situation where the bags' integrity is not at risk, the bags can be collected using a crane, in conjunction with a ROV. Bags may need to be moved along the seabed before lifting if they are in close proximity to any subsea facilities. This could create short term disturbances to the seabed.

- Subsea Grapples and Lifting Baskets
  Grout bags set and harden when immersed in water, and when packed close together they may adhere to each other, forming large heavy masses on the seabed. In such circumstances the grout bags cannot be removed by ROV and the safest and most efficient method is to use a Subsea Grapple, as well as subsea baskets, or cargo nets for smaller grout bags. This would involve minor dragging of the bags along the seabed when being moved to the collection point, which could create short term disturbances to the seabed. Once lifted from the seafloor the grout bags will be recovered to the vessels in debris baskets and transported to an appropriate land-based facility for dismantlement, recycling, and disposal. The removal of rock bags and grout bags will cause very minor, localised, and short-lived disturbances to the seabed and benthic communities in the immediate vicinity, Ref. [4]

7.3 Concrete Mattress Removal

Concrete mattresses have been used widely in the oil and gas industry and within the offshore wind sector to protect cables and pipelines. The current options available for mattress decommissioning are listed below.

7.3.1 Leave in Situ

An estimated 35,000-40,000 mattresses have been deployed around oil and gas structures. However, it is estimated that only 5% (~4,000) have been removed in total to date, and the extent and success of their 'complete removal' is not well documented, Ref.

[5]. The integrity of the mattresses is not designed with end-of-life removal in mind and therefore lifting them from the seabed can be hazardous. Where mattresses are used to cover pipelines and cables, if the pipeline or cable is left in place, so is the mattress.

7.3.2 Partial / Complete Removal

- Subsea Grapples
  Subsea grapples are an existing diver less solution and can be effective when there are small numbers of mattresses to be removed. However, they are not an efficient solution when decommissioning large volumes of mattresses. They also eliminate the potential for re-use as the method of handling commonly damages the mattress as they are lifted out of the water.

- Lifting Baskets
  Mattresses can be recovered using lifting baskets, because it is likely that the ropes which form the lifting points have degraded and may not be strong enough to bear the full weight of the mattresses, especially when lifted out of the water. Lifting baskets are already used for both the installation and decommission of a variety of subsea equipment.

- Speed-Loaders
  Speed loaders have been perhaps the most successfully used mattress removal technology to date in the North Sea. Their design allows mattresses to be easily transported onto the speed-loader, and stacked neatly, allowing several mattresses to be removed from the seabed each lift. On the seabed, the mattresses will be loaded onto the speed-loader using a lifting frame (which would require divers) or a ROV connections hooks. The mechanical mattress grab is unlikely to be able to lift those mattresses that are closely associated with seabed structures, and these mattresses will either be dragged clear or lifted clear using a frame. Speed-loaders can recover up to six mattresses in each load and use less deck space than lifting baskets.

- High Payload Wet Store Systems
  High Payload Wet Store System have been designed for the deployment and recovery of stacks of concrete mattresses and other items through the splash zone, Ref. [6]. Unlike speed-loaders, they comprise of a heavy-duty base frame, and quick release top spreader frame, stacks of mattresses can be removed and decommissioned strategically from the seabed and on board the awaiting vessel The Wet Store System can recover many mattresses in a single lift, more so than a traditional speed loader. Suppliers such as Pipeshield also have many bases and quick release spreader frames, meaning savings can be made on large projects where a high number of mattresses are required to be removed. This is due to the time saved during vessel loading, compared to more traditional methods.

7.4 Fronded Mattress Removal

7.4.1 Leave In-Situ

Fronded mattresses are typically more difficult to recover as they are designed to self-bury, especially in areas where the seabed is more mobile. It is common to seek approval to 'leave in situ' if the burial depth is greater than 0.6 m, at which point re-suspending the sediment would create another period of non-stabilisation of the environment, destroying the new equilibrium created after installation and potentially smothering the adjacent fauna. Furthermore, visibility for the operation would also be greatly reduced and may require a period of downtime before it is safe to recommence operations.

7.4.2 Partial / Total Removal

A problem for most decommissioning scour protection is that over time most scour protection loses its integrity and deteriorates. Frond Mats do not degrade in the marine environment, they retain a very high integrity and so can be removed in one piece. This is due to the non-degradable materials used and the fact that the Frond Mats self-bury, preserving them in the sand and forming part of the natural seabed.

- Mass Flow Excavators
  Recovery of buried mattresses would require a de-burial operation prior to carrying out any lifting. Mass flow excavators can be used to perform this operation. Mass flow excavators work using rotating propellers to create a high-speed, low-pressure column of water to fluidise the seabed material for de-burial operations. ROV mounted water jetting pumps or dredging pumps are the most common forms of mass flow excavators. Once de-burial is complete, standard mattress lifting methods can be used including speed loaders and lifting baskets. However, the implication of this is that it upsets the seabed, which can destroy marine habitats. Seabed flora and fauna will have to recolonize the area, which can take months or even years.

7.5 Bitumen Mattress Removal

Bitumen Mattresses were widely used on older installation projects and are generally no longer considered. It is common for the outer bag to rot over time and for internal bitumastic material to turn brittle. This causes the mattress to break up during lifting. It is possible to retrieve them using mattress removal methods detailed above, it is more common to seek approval to 'leave in situ' as they are difficult to recover and offer no known re-use applications.

7.6 Duramat (Poly) Systems

It is possible to recover Duramats using the mattress removal methods stated above, as they are supplied with through holes for rope handling. They are often used for more sensitive cables and umbilicals, for example at pipeline crossings. As a result, a case is often made to leave Duramats in situ to avoid damaging nearby cables, umbilicals, or other subsea installations.

8 Assessment of Decommissioning Options

Additional considerations for each protection method and the various decommissioning options highlighted in the report, including the positives, risks, limitations, and potential environmental implications are summarised in Table 8-1. A grading system for each was applied and an overall grade for each method assigned (5 – Very Good, 4 – Good, 3 – Neutral, 2 – Poor, 1 – Very Poor).

Table 8-1: Summary of cable and scour protection decommissioning options, positives, risks, limitations, and environmental implications

Protection method	Decommissioning options	Positives	Risks	Limitations	Environmental Implications	Grade
Rock Dump	Leave in situ	-Cost savings -Time savings (5)	-Presents hazard for further offshore projects (3)	-None (5)	-Permanent change of habitat for marine life (2)	2
	Removal by divers	-Needs minimal equipment -Minimal disturbance to seabed (5)	-Health and safety risk to diver (1)	-Very time consuming -Not suitable for large rock (2)	-Minimal short-term changes to seabed due to rock removal (5)	1
	ROV Dredgers and rock removal tool	- Mounted to ROV for quick and easy operation - No depth limitations (5)	- Movement and damage of close by habitats for marine life (2)	- Can relocate rock but not remove from seabed - Not suitable for large rock (2)	- Disturb surrounding seabed, and potential long-term damage to marine habitats (2)	2
	TSHD	- No divers or ROVs required	- Movement and damage of close by	- Not suitable for very large rock	- Disturb surrounding seabed, and potential long-term	2

		(5)	habitats for marine life (2)	- Can dredge up to 155 m depths (2)	damage to marine habitats (2)	
	Backhoe Dredgers	-No subsea equipment required (5)	- Movement and damage of close by habitats for marine life (2)	- Can only dredge up to 32 m depths (2)	- Disturb surrounding seabed, and potential long-term damage to marine habitats (2)	2
Rock Bags	Leave in situ	-Cost savings - Time savings (5)	-Presents hazard for further offshore projects (3)	-None (5)	-Permanent change of habitat for marine life (2)	2
	Crane Lift (ROV hook attachment)	-No divers -No depth limitations (for practical offshore wind purposes) -Designated lifting points for easy pick up	- Bag integrity may weaken over time, risk of dropping rock bags, and damaging subsea facilities, and marine habitats (3)	-Limited to lifting one bag at a time -Dependant on the lifting points being undamaged (2)	-Minimal Impact to seabed (5)	3

		-Minimal dragging on seabed (5)				
	Subsea grapples and lifting baskets	-Safer method if bags integrity comes into question, reducing risk -Able to lift multiple bags at once (5)	-Risk of damaging subsea structures if close by -Risk of damage to bag depositing individual rocks on seabed (4)	-No significant limitations (5)	-Very minor, localised, and short-lived disturbances to the seabed and benthic communities (5)	4
Concrete, Bitumen and Poly Mat Mattresses	Leave in situ	-Cost savings -Time savings (5)	-Presents hazard for further offshore projects (3)	-None (5)	-Permanent change of habitat for marine life (2)	2
	Subsea Grapples and Lifting Baskets	-No ROV required -Safer method if mattress integrity comes into question, reducing risk	-Risk of damaging subsea structures if close by (4)	-No significant limitations (5)	-Very minor, localised, and short-lived disturbances to the seabed and benthic communities (5)	4

		-Able to lift multiple bags at once (5)				
	Speed- Loaders	-Can remove multiple mattress each lift -Lifting frame reduces risk of mattress integrity (5)	-Health and safety risks if divers are used (2)	-Time consuming to align and load mattresses. May not be a practical solution for multiple mattresses (3)	- Potential disturbance of surrounding seabed, where mattresses are dragged onto the seabed loader, resulting in short term disturbances to the seabed (3)	3
	Wet Store Systems	-Efficient removal for many mattresses -Lifting frame eliminates risk of the mattress's integrity (5)	-Health and Safety risks if divers are used (2)	-Time consuming to align and load mattresses (3)	- Potential disturbance of surrounding seabed, where mattresses are dragged onto the seabed loader, resulting in short term disturbances to the seabed (3)	3

Fronded mattresses	Leave in situ	-Reduces decommissioning costs -Saves time -Self burying properties means no further disruption to seabed (5)	-Conditions result in mattress being unable to self-bury, resulting in a permanent change of marine habitats (3)	-Mattress only able to self-bury in the right substrate conditions (4)	-Long term environmental implications would be minimal, assuming mattress is buried, marine life should continue to thrive on the seabed (4)	4
	Mass Flow Excavators	-Exposes the mattresses, creating more available options for lifting methods (5)	-Risk of destroying benthic habitats during unburial, both on site and nearby due to movement of seabed sediments (2)	-Visibility of operation would greatly reduce, resulting in delays before further operations can proceed (2)	- The process would disturb the seabed, which can destroy marine habitats. Seabed flora and fauna will have to recolonize the area, which can take months or even years (2)	2

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