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Decommissioning offshore concrete platforms

with an Executive Summary by
Graham Morrison
of the Health and Safety Executive

Prepared by
Atkins Process Limited and Olav Olsen A/S
for the Health and Safety Executive 2003

RESEARCH REPORT 058

Decommissioning offshore concrete platforms

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Decommissioning activity offshore is expected to increase significantly in the next few years and will include some very large concrete platforms in the northern North Sea. The two studies included in this report examine possible methods of removal and demolition, including complete removal, part-removal to below the water line and leaving the concrete bases in place after removing the topsides completely.

The studies are prefaced by an introduction from the Health and Safety Executive into the legislative and technical issues that led to this research. The studies examine the risks to people and the environment from decommissioning large concrete platforms. The possibilities of refloating, transporting the structures to shore and disposing of them on land are all evaluated.

The first study was carried out by Atkins Process in the UK, the second by Olav Olsen A/S consultants in Norway and the original designers of the Condeep platforms, the most common type of concrete platform offshore Europe.

Both studies indicate that risks from removal could be very high and refloating may not be possible for some older platforms. For all options, risks of injury to personnel from subsea work, underwater cutting or structural collapse from overloading could exceed the normally accepted risk criteria unless these operations can be very carefully controlled.

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EXECUTIVE SUMMARY

The two Research Reports reported below have been completed recently that assess the risks to people and the enviroment from decommissioning concrete platforms. These studies assess the feasibility of refloating and disposing of the concrete bases of very large platforms of the types found offshore in northern Europe They examine the possible options for removal and demolition, considering the original design of the structures and their current condition and taking account of the present state of engineering knowledge and any likely future developments.

One study was carried out by Atkins Process in the UK, the other by Olav Olsen consultants in Norway and the original designer of the Condeep platforms. Both Joint Industry Projects involved oil companies and contractors who operate offshore and on land, together with the Norwegian Petroleum Directorate and, in Britain, the Health and Safety Executive.

Background information

Under OSPAR Decision 98/3 of the Convention on the Protection of the Marine Environment of the North East Atlantic, disposal at sea of disused offshore installations is prohibited. However, this Decision recognises that there may be difficulty in removing certain types of installation, including the substructures of concrete platforms. As a result, there is provision for derogation from the main rule for these installations. This is not an automatic process and a platform will have to be removed completely unless the company responsible can make a good case to do otherwise. A derogation to leave part of an installation in place is unlikely to be granted except for very good environmental and safety reasons.

Very little industry experience exists at present of decommissioning offshore concrete platforms. Although over 1000 steel structures have been removed throughout the world, only a few relatively small concrete structures have been decommissioned so far. However, some experience of decommissioning large concrete structures on land, eg in the nuclear industry, might also be applicable offshore.

Decommissioning activity is expected to increase significantly in the coming years and could include several very large platforms. (Decommissioning of the concrete installations in the Frigg field, for example, is already under consideration.) Further information on various aspects of decommissioning is available on the DTI website at http://www.og.dti.gov.uk.

Offshore decommissioning work could involve very high risks unless carefully controlled. (On land, the construction industry (including dismantling and demolition) has some of the highest risk work activities recorded.) The companies responsible will have to examine in detail the extent and methods of decommissioning they wish to use. Plans have to be drawn up in the light of the information available to reduce risks to as low as reasonably practicable.

As well as a legal requirement for a Safety Case for decommissioning, the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 require that:

> *The duty holder shall ensure that an installation is decommissioned and dismantled in such a way that, so far as is reasonably practicable, it will maintain sufficient integrity to enable such decommissioning and dismantlement to be carried out safely* [Regulation 10].

Amongst other things, in relation to its design:

> *in the event of reasonably foreseeable damage to the installation it will retain sufficient structural integrity to enable action to be taken to safeguard the health and safety of persons on or near it* [Regulation 5 (1)].

The new ISO codes for offshore structures to be introduced worldwide soon will include the capability for future decommissioning as an essential design requirement.

Concrete platforms installed in the 1970s and early 1980s were not designed and built so as to fully meet modern requirements for decommissioning. The feasibility of refloating, removal and demolition requires to be investigated for each individual structure based on its design, construction, method of installation and history in operation.

Atkins (UK)*: UKCS Concrete Decommissioning Study*

The overall conclusion of this study is that all decommissioning options involve:

- significant risks
- uncertainty and
- technical challenges.

Atkins find that risks of injury and fatalities from subsea work, dropped objects, underwater cutting or collapse from structural overload could exceed normal risk acceptance criteria.

Twelve of over 250 offshore platforms installed on the UK continental shelf are built of concrete. Of these, the two built most recently (in the 1990s, including one hybrid steel/concrete structure) might be considered as fully designed for removal. The other ten were designed and built in the early days of offshore development in the North Sea. These are first generation, very heavy platforms (some over 500,000 tonnes in weight) built in the 1970s and early 1980s. The JIP investigates the feasibility of removing and disposing of these. Atkins conclude that the older concrete structures, in particular, are expected to encounter problems making refloatation uncertain, difficult and very hazardous.

A range of options for removal is considered by the study, from total removal through part removal to leave-in-place. It is likely that in all cases the topsides plant and equipment (and supporting structures) will be removed. Atkins note that previous studies have assumed “as new” structures and may therefore have overestimated how easy certain removal tasks would be. The condition of a platform would have a profound effect on the feasibility of refloating it. Stability could be compromised by adhering masses of foundation soil and unknown quantities of sand accumulated within the oil storage cells, for example. Similarly, repairing and maintaining structural integrity during removal could be very difficult as a result of cracking of the concrete and other defects that have arisen in service.

A significant area of uncertainty surrounds the mechanism of foundation release. The study investigated this using advanced geotechnical analysis software. Atkins conclude that while, in theory, it should be possible to release large concrete structures from the seabed, in practice progress would have to be made in subsea technology so as to place injection wells under the concrete base and to reliably control the refloating operation before such a hazardous operation could be contemplated.

Crucial watertight integrity would have to be maintained and this would rely on technology being developed to effectively seal drilling and other openings in the structure. On some platforms, the internal pipework to control refloatation is very badly corroded and new systems would have to be installed to assure the reliability of the system. Several key components are located within storage cells and other inaccessible areas. Remote operating systems would require to be developed to gain access without putting divers’ lives at risk.

Inshore deconstruction in a sheltered deepwater berth might seem to be a simple reverse of the building operation. What the Atkins study found, though, is that proper control of safety and environmental risks would rely on maintaining the watertight integrity of the concrete structure for several years during the operation. Many safety critical removal tasks depend on maintaining the integrity of critical components such as ballast valves and internal pipework, and it may be impossible to test or inspect these.

The Atkins study also highlights the risk of contamination of sites along the coast resulting from a serious structural failure during the decommissioning process.

Olsen (Norway): ***Removal Offshore Concrete Structures***

This study concludes that theoretically it should be possible to refloat modern Condeep structures built after about 1990 where:

- the structures have been designed and constructed for removal to modern standards and
- reballasting and other safety-critical systems are in good condition.

After refloating, the platform bases could be towed inshore for further demolition and the demolition material transported for eventual disposal on land.

Fewer than nine (all off Norway) of the fourteen Condeep platforms of all ages that have been installed offshore Europe can be considered as fully designed for refloatation. Even there, the full extent of deterioration of safety-critical systems and all the hazards that could be encountered during decommissioning were not foreseen at the design stage.

Olav Olsen managed a team of experts in house and from other consultants and contractors, including several engineers who were involved in the original design. Phase 1 examined the technical challenges to refloating modern concrete structures with the topsides attached, Phase 2 addressed the complete removal of late 1980s and early 1990s Condeep platforms. The removal method investigated was refloating as the reverse of installation.

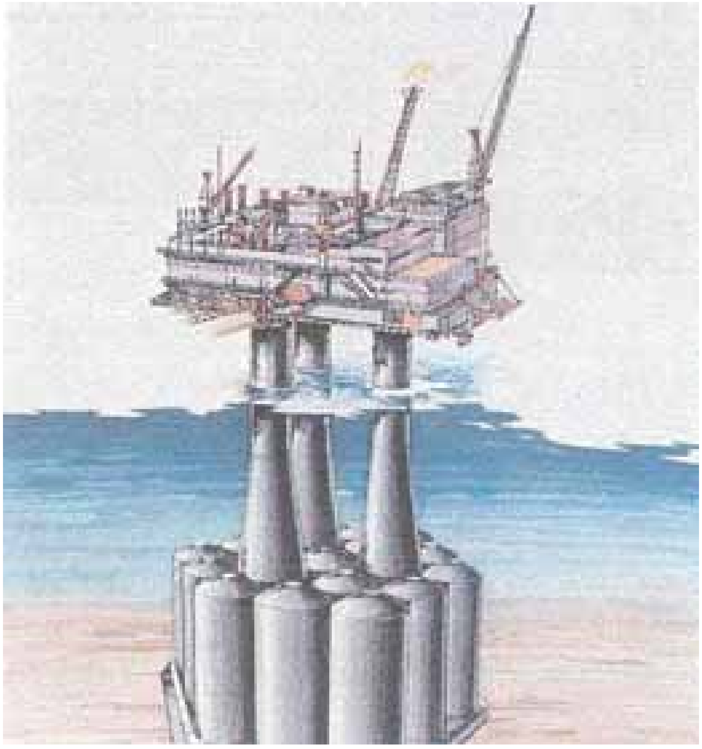
For safety reasons, a platform has to be unmanned during the final stages of removal. Even so, Olsen found that a failure during refloating, towing or demolition would have serious consequences for loss of life and the environment. In the worst cases, for example a dome bursting or excessive pitch on pop-up, failure could cause progressive collapse, leading to disintegration of the structure. Damage might cause the refloated platform to sink, with serious risks to people on board the attendant vessels.

Once refloated, demolition, fragmentation, crushing, disposal and recycling should all be possible in principle, though such extensive demolition work on offshore structures has never been attempted before. Olsen consider that demolition inshore in deep water could be done safely using modern equipment, with the demolition material loaded onto barges for transport to shore. Subsequent disposal on land of the removed concrete should also be feasible although the economics of doing so may be doubtful.

The study refers to the Frigg Field Cessation Plan, which was made public recently, and reports on the extensive evaluation carried out of the feasibility of refloating the three large concrete platforms in the Frigg Field. The Plan concludes that the risks and uncertainties associated with removal are too great and consultations with the Norwegian Government and OSPAR are now under way on the case for leaving these Frigg substructures in place.

Olsen also looked at how the design of offshore concrete structures should be done in future. They conclude that planning for removal requires comprehensive engineering of safety-critical systems as part of the initial design.

Concrete platform during construction



Large concrete platform in operation

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Joint Industry Project

UKCS Concrete Decommissioning Study

Summary Report

1. SUMMARY

Atkins Process Limited [Atkins] has been commissioned by a number of oil companies that operate concrete platforms in the North Sea and the Health and Safety Executive of Great Britain to investigate some of the issues surrounding the decommissioning of 1st generation concrete gravity base structures [GBS] used for offshore production of oil and gas from the UK Continental Shelf. This Joint Industry Project [JIP] has investigated issues that specifically relate to the concrete substructures. Decommissioning issues that may apply in particular to fixed steel offshore platforms are not addressed.

The JIP has investigated the range of options available for decommissioning these concrete structures, including the feasibility of removal and disposal of the complete platform as well as leaving the substructure in place. It should be noted that operations such as deck removal arise in both the leave-in-place and removal options. The studies have addressed environmental, safety and technical issues, but have not considered costs. No attempt has been made to offer preferential recommendations on the various decommissioning options. Rather, the study has attempted to identify risks and some important issues and offer these for subsequent consideration by stakeholders in the decommissioning process.

A particular intent of this study has been to take into account the actual condition of the 1st generation concrete substructures and to collate into one document a holistic view of the decommissioning process. It is noted that most removal studies undertaken to date have assumed ‘as new’ structures and have therefore overestimated how easy certain removal tasks could be. The study also includes an overview of the current legislative regime.

In arriving at the possible risks associated with each decommissioning option, the JIP has used established safety engineering methods to present an auditable risk identification process. The risks associated with the various options have been listed and ranked and the source data referenced.

In the removal case, a significant area of uncertainty surrounds the mechanism of foundation release for large concrete GBS structures and the JIP therefore invested a large effort in investigating this effect using advanced geotechnical analysis software. The study shows that in theory it should be possible to release a large GBS structure from the seabed in a controlled manner. However, subsea technology to place injection wells under the base and to control the whole operation would need to be developed.

Re-floatation of the GBS has been examined in terms of its hydrostatic stability [in effect still water stability]. It is found that the ‘as-is’ condition of the platforms will have a profound effect upon the re-floatation operation. Stability could be compromised, for example, by adhering masses of foundation soil and by an unknown volume of sand accumulated within the oil storage cells. Further, and particularly crucial, watertight integrity would rely on technologies being developed to seal drilling and other openings in the structure which are typically extremely difficult to assess conventionally. On some platforms, the internal piping needed to control re-floatation is corroded and new systems would be have to installed to provide an acceptable degree of system reliability. Since the key components of these systems are located within the storage cells, remote [‘robotic’] piping installation systems would have to be developed. It is noted that most critical operational risks identified by this study are associated with the need to develop new technologies to return the structures to an ‘as new’ condition before removal operations can begin.

Structural integrity of the concrete structures during removal could be compromised by pre-existing structural cracking and other defects which have arisen during the installations’ service lives. Locating and testing such defects subsea would be challenging. However, the industry’s ability to undertake crack assessment and sealing of cracks has developed in response to the discovery of these defects. Overcoming these technical problems may be within the bounds of existing proven technologies, but would need to be considered in relation to the overall risk assessment from failure to achieve a satisfactory repair.

Deck removal is again an area where the risks and means of execution are relatively well understood. For completeness, the study has considered a range of deck removal scenarios and has reported upon the suitability of the prospective ‘single lift’ vessels which may be constructed for platform removal.

Inshore deconstruction of GBS will require a sheltered deepwater berth. The operation is at face value a simple reverse of the building operation. What the study found, however, is that the whole operation’s safety and environmental integrity relies upon maintaining the watertight integrity of the concrete storage structure for several years. Once again, a key operation is found to stand or fall on the integrity of existing components of the GBS which it is currently impossible to test or inspect. Consequently, the study highlights the risk of contamination of a coastal site arising from a loss of structural integrity during an onshore deconstruction operation.

The leave-in-place option appears to offer the lowest environmental impact. This point merits further study and discussion by stakeholders. For example, it may be that this option minimises the number of decommissioning activities and also minimises the number of ‘things that can go wrong’ and therefore offers the lowest overall risks.

It is clear that further research into the very long term relationships in time between oil and wax biological breakdown and the deterioration of concrete structures in seawater could benefit all stakeholders. This study has documented existing knowledge in these areas and offers an opinion on the structural degradation process.

In tandem with these issues, the study has considered the risks surrounding partial leg removal as well as deepsea disposal. These may be technically feasible solutions and are included to ensure a comprehensive technical view of all the possible decommissioning options.

The overall conclusion of the study is that any of the examined decommissioning options carries significant technical challenges and risks and will require further research and development before it can be considered to be an acceptable long-term solution. It should be noted that the leave-in-place option at present appears to offer the least risk.

Many stakeholders may be particularly interested in the potential environmental impacts surrounding the options studied and Table 1 is therefore included as a convenient summary of the environmental issues raised by each option.

Routine Events	**Disposal Options**			
	1	**2**	**3**	**4**
Disposal of large volumes of storage cell flushings	▨	▨	▨	▨
Disposal of GBS ballast water			▨	▨
Recovery/disposal of drill shaft, drill cuttings and contaminated seawater.	▨	▨	▨	▨
Recovery/disposal of drill cuttings [GBS base/cell tops/tricells] and contaminated seawater			▨	▨
Sand placement for [emergency] set down			▨	▨
Levelling of sandy inshore location for [emergency] setdown			▨	▨
Longterm presence of GBS [in part or all] on seabed/release of contamination.	▨	▨		▨
Possible use of explosives to assist GBS flooding				▨
Possible use of explosives to assist controlled GBS collapse				
Longterm presence of 500m safety zone	▨			
Presence of GBS at inshore deconstruction location			▨	
Presence of deck/topsides at inshore deconstruction location		▨	▨	▨
Recovery/disposal of concrete			▨	
Recovery/disposal of sludge/solid ballast			▨	
Longterm maintenance	▨			
Environmental liability in perpetuity	▨	▨	▨	▨
Non routine/accidental/emergency events				
Detachment of grout/soil			▨	▨
Detached grout/soil causing damage to hydrocarbon carrying pipelines [leakage/spill]			▨	▨
Impacts associated with work done to retrieve detached grout/soil if required			▨	▨
Total loss of GBS: seabed presence/gradual disintegration/ release of contaminants.			▨	▨
Loss of GBS buoyancy			▨	▨
Presence of GBS at inshore [emergency] set down location			▨	▨
Release of cell flushings to sea	▨	▨	▨	▨
Oil-in-ballast water levels in excess of consent requirements			▨	▨
Loss of residual oil to sea	▨	▨	▨	▨

▨ Potentially significant environmental issue

Disposal Options:
1 = Leave *in situ*;
2 = Partial removal;
3 = Total removal, inshore deconstruction;
4 = Total removal, deep sea disposal

Table 1: Summary of Potentially Significant Environmental Issues Relevant to the Decommissioning of GBS on the UKCS

REMOVAL OFFSHORE CONCRETE STRUCTURES

Summary report for Phases I and II

1. Conclusions

This report gives a summary of the results of the project *”Removal - Offshore Concrete Structures”,* a joint industry project sponsored by A/S Norske Shell, Statoil ASA, TotalFinaElf Exploration Norge AS (only Phase II), HSE-Offshore Safety Division UK (only Phase II), Norwegian Petroleum Directorate (NPD), Aker Maritime, NCC Anlegg AS (only Phase II), Økobygg (only Phase II) and Dr.techn.Olav Olsen a.s.

The purpose of the studies was to investigate different possibilities for the removal, dismantlement and recycling of offshore concrete structures and to identify possible problems that may affect the feasibility of the operations. Very little experience exists of offshore refloat operations for concrete gravity based structures once they have been decommissioned or of the demolition works required when they arrive onshore. The joint industry project was initiated in order to address these factors. The conclusions reached are, as far as possible, generic.

The project comprised two phases:

- *Phase I*, /1/, which considered the technical challenges related to the refloat of offshore concrete structures with most of the topsides intact, and
- *Phase II, Recycling,* /2/, which examined the technical challenges related to the means of dismantling and demolition, fragmentation and recycling of materials from offshore concrete structures.

Recently the Frigg Field Cessation Plan /3/ has been made public, reporting the results of extensive evaluation of the feasibility to refloat the three concrete structures on the Frigg Field. Results from this report are referred to in this summary report where they complement findings of the two studies, or when it is thought appropriate to highlight certain issues that may not have been fully addressed previously.

The two studies examined two Condeep type platforms, which were designed for removal to the extent normal at the time, as a basis for evaluating the technical feasibility of refloating and to help identify the technical challenges that might arise during the demolition phase onshore. The conclusions might be considered valid for similar, though not identical, Condeep structures built at different times from the study models and, to some extent, for other substructures of the tower and caisson type.

For the structures considered, it seems possible to draw the following conclusions:

- The feasibility of refloat, removal and demolition of any particular type of concrete substructure already in place will have to be investigated for each individual structure based on its design, construction, method of installation and operational history.

- Provided a substructure was initially designed and constructed to allow for future removal operations , it should theoretically be technically feasible to remove it provided it remains in good condition. The current applicability of the codes used in its design and any experience gained in practice from previous attempts at removal of other installations has to be duly considered.

- For new offshore concrete substructures, design and construction for removal implies that:
  - Planning of the removal operation has to be part of the initial platform design concurrently with planning of the construction, float out, transportation and installation phases.
  - The structure, including all structural details, has to be designed to withstand all load cases during demolition, refloat, towing ashore and inshore mooring without overload or leaks.

  - All mechanical systems necessary for the refloat and towing operations have to be designed, fabricated and installed to allow the planned operations and be maintained and refurbished in a way that will ensure safe operability when removal is due.
  - Similarly, vital structural and mechanical components must be designed and constructed so as to allow inspection, maintenance, repair and replacement without subsea intervention of a type and extent that could incur unacceptable risks to the personnel involved, including divers.
  - The foundation, including skirts and dowels, must be of a design that permits refloat without pop-up, pitch or movements that could jeopardise the integrity of the structure or endanger personnel working nearby.

- All analyses of the removal operations should be based on conservative assumptions that reflect any deterioration or other changes over the years and any uncertainties that affect the design. The factors of safety used in design for removal should not be lower than those specified in current codes for construction, installation and operation.

- No concrete platform installed in the seventies was originally designed and constructed to meet these requirements. Later platforms were designed for removal, but the extent of the challenges and possible obstacles and hazards that might occur were not always fully recognised in the original design.

- Demolition, fragmentation, crushing, disposal and recycling of the offshore structure are in principle possible, but such extensive demolition work on offshore structures has never been done before.

- Failure of the refloat, towing or demolition operation could have serious consequences in terms of loss of life, effects on health, environmental impact, as well as the associated economic losses.

- It should be technically possible to clean the inner surface of the concrete storage tanks, even though accessibility to carry out this work offshore may be a problem.

- Once broken out, the steel reinforcement extracted may be shipped to a mill for remelting. The main bulk of the concrete recovered could be used as aggregate for new concrete, or used as stone fill material.

- The revenue likely from the sale of steel and concrete for recycling is negligible relative to total removal and demolition costs. The economic incentive of recycling the materials lies in the saved cost of depositing the recovered material in suitable disposal sites.

- Larger pieces cut out of the structures may be utilised for industrial halls, breakwaters, pipe protection, quay structures and the like.

- To remove and demolish the concrete substructure in a safe and controlled manner a key success factor is thorough and detailed operational planning based on in-depth knowledge and understanding of all technical and operational aspects of the structure and its history.

2. Scope and purpose

The scope of the present summary report is to give an overall presentation of the work performed in Phases I and II of the project "*Removal - Offshore Concrete Structures*"/1/,/2/. This report covers the extent of the challenges to be faced and suggests methods and tools that may be suitable for this work. Technical, operational, environmental, economic and personnel risks and uncertainties are presented. The summary report pinpoints additional items that may not already be fully covered in the initial reports. The assumptions used in the original reports are stated more fully.

The project was conducted by Dr.techn.Olav Olsen a.s (OO) heading teams of experts, both in-house and from consultants and contractors, including several engineers who were involved in the original design work.

The Phase I team comprised Consultas Engineering (UMOE), SINTEF and AMC. The cost of this phase was 0.55 MNOK.

The Phase II team comprised Aker Maritime (AMA), Franzefoss bruk AS, NCC Anlegg AS that have supported the project by free execution of work, and Dames and Moore, Demex and SINTEF. The cost of this phase was 2.2 MNOK.

The joint purpose of the total project was to:
- Improve the basis for decisions with respect to the final disposal of offshore concrete substructures and the possible inshore decommissioning of topside structures
- Present a summary of results from previous work on the subject of refloating
- Perform an in-depth investigation of the challenges related to refloating, identify possible expected/unexpected problems and present practical solution methods
- Give a technical documentation of the possibilities for refloating typical older concrete platforms on the Norwegian continental shelf
- Investigate the challenges related to dismantlement and recycling of offshore concrete structures
- Provide objective input to improve the basis for debate and information available for taking decisions about the disposal of offshore concrete structures.

Prior to the operations discussed in this report the following activities are assumed to have been completed:

- All wells have been plugged and cemented and the outer conductor casing cut beneath the sea bed
- All topside systems have been closed down, purged, cleaned and preserved for the "cold" phase
- All conductors, pipes and cable connections attached to the sea floor have been cut

3. Types of offshore concrete substructures

There are basically three main types of offshore concrete substructures:
- Tower and caisson types with circular caisson cells (Condeep)
- Tower and caisson types with rectangular caisson cells (Sea Tank, Andoc and several small platforms designed by French, British and Dutch companies).
- Jarlan wall types (Doris)

In addition, there are special types of fixed and floating structures such as Troll A, Hibernia, Heidrun, N'kossa, Troll B and platforms designed for waters severely affected by ice floes.

Removal of these types of platforms implies a variety of challenges, each type having its own merits and problems.

The refloat study /1/ is based on an evaluation of one specific Condeep type platform which was designed for removal. The conclusions drawn are mainly valid for those structures that were to some extent designed for removal. The removal method for other tower and caisson platforms may be similar, but the technical limitations will be different. The Condeeps for instance, might have a weak point at the star cells, whereas rectangular caisson cells might be overloaded by excessive differential water pressure across the walls e.g. due to tilt initiated by loss of grout. The challenges in removing a Doris type platform are again quite different.

4. Decommissioning alternatives

The study mainly addresses complete platform removal in the sense that the substructure and most of the topside is relocated and towed from its present position to a suitable location for material recycling. An alternative method would be to tow it for sinking at some predetermined deep water offshore disposal site. Another alternative proposed would be to cut and remove the upper part of the platform at an elevation that would permit free passage of vessels, i.e. –55m, and leave the remains on the sea floor adjacent to the platform base. Finally, the total platform substructure could be left in place. The latter three alternatives have not been considered as part of this project.

Thus, the removal method investigated is based on refloat as a reversal of installation.

5. Refloat

A main advantage of the reversed installation method is that the platform may have sufficient floating stability to carry part of the topside facilities ashore together with the substructure. Offshore work is minimised and dismantling of the remaining deck may be carried out inshore at a sheltered location.

The main steps in the refloating operations will normally be:

- Remove topside facilities to the extent necessary to allow safe refloat and transportation to shore. This operation is beyond the scope of this report.
- Close all penetrations to compartments to be emptied to achieve the necessary buoyancy in the following phases.
- Inspect, upgrade and commission all mechanical systems to be used during the refloat operation
- Pump water out of the shaft and the caisson cells and, if necessary, concurrently fill the caisson cells with compressed air
- Stop the deballasting when the estimated minimum platform weight approaches the buoyancy required
- Inject water under the base slab to mobilise a hydraulic upward force to pull the base skirts out of the subsoil
- When the hydraulic pressure that can be achieved is no longer sufficient to raise the platform, retract the skirts and dowels by further deballasting the shafts

For safety reasons the platform should be unmanned during the final phase of the removal operation.

The feasibility of this operation is dependent on several conditions:

- All penetrations to the cells and shafts to be deballasted must be safely sealed. If not, the open penetration will set limitations to the deballasting scheme or the water pressure across the penetration has to be limited to match the strength of the sealing. Conductor penetrations in drill shafts may be particularly demanding.

- The caisson cells cannot be deballasted so much that the ambient water pressure exceeds their structural strength. The differential pressure may be reduced by introducing compressed air into the cells. Correct air pressure inside the caisson helps to maintain overall integrity and mitigate the stresses in certain structural elements, however this must be balanced against the risk of overstress in other parts of the structure.

- The platform must be deballasted to lower ballast levels during refloat than those used during installation. The differential pressure will be accordingly higher.

- Each individual platform will have its structural characteristics and all elements will have to be subject to thorough analyses of all the applicable load cases.

- The cell joints are vulnerable structural elements, which are also difficult to analyse. The lowest deballasting levels that can be allowed should be decided based on conservative design assumptions.

- During the reballasting operation, if there are potential buoyancy chambers, which for unforeseen reasons are found not to be capable of being emptied, a higher differential pressure within the remaining buoyancy chambers will be necessary.

- The deballasting operation and the under-base water injection requires mechanical systems and monitoring systems of unambiguous operability, reliability and safety. The systems used for the original installation may have deteriorated considerably after many years in seawater. If parts of these systems need to be used for removal, they must be thoroughly inspected, tested and commissioned prior to the operation. If flaws are observed, the pertinent parts of the systems should be replaced. It should be noted that it might often be very difficult or even impossible to replace these systems.

- If the ballast cells have been utilised for oil storage, the oil content in the ballast water should be measured. If the oil content exceeds 40 ppm, the water must be cleaned before discharge to sea.

- Most of the pullout of the skirts should, to the extent possible, be achieved using under-base water pressure rather than by excessive deballasting. However, the final release of the skirts and dowels will require deballasting. After release, the platform could have unbalanced buoyancy that possibly could cause an uncontrolled pop up. Work performed in /1/ for one particular platform indicates that this may not be a problem for platforms in soft clay. Uncertainties in platform weight and centre of gravity, soil resistance to piping and skirt retraction, under base grout lost before, during or after release and possible soil suction during release may contribute to unbalanced buoyancy, leading to unpredicted instability and pitching of the structure after its release from the seabed.

- A platform with compressed air in the caisson might pop up to an elevation where the air pressure exceeds the ambient water pressure. This situation must be avoided as the upper dome might burst, seriously damaging the platform, with risks to any personnel nearby, including on vessels affected by the unstable, even sinking, structure.

- For a platform with straight inner walls, excessive pitch might set up differential water pressures that jeopardise the strength of the inner walls. An inner wall failure might in the worst case release a progressive collapse, leading to unacceptable effects.

Of the 14 Condeep platforms built and installed, 9 of these have been designed for removal. All are on the Norwegian shelf. However, the extent of the challenges to removal and possible obstacles and hazards were in general not fully recognised during the original design.

In order to perform the refloat operation in a safe and controlled manner, knowledge and understanding of the technical and operational aspects as well as the structure and its history are of overall importance. Operational planning is a key success factor to minimise risk to personnel, environment and economy.

6. Tow ashore

The tow ashore should be a direct reversal of the tow out for installation. Once refloated the substructure will be deballasted to a suitable towing draft. If possible the towing supports used for tow out will be reused, otherwise new brackets will need to be installed.

As for the refloat operation, the platform is assumed to be unmanned during the tow ashore.

Most of the Condeep structures were designed to remain afloat even after flooding of one caisson cell. Flooding of a shaft can result in sinking and major damage. By contrast, several other designs of concrete offshore structures cannot survive flooding of a single cell. This was considered acceptable for installation according to their original design specification.

The risk of flooding during the tow could result from malfunction of the mechanical systems, failure of the penetration seals, ramming by a vessel or grounding.

The concrete substructures during tow should normally have the necessary seaworthiness to survive a summer storm of 100 years return period. This would need to be confirmed by calculation.

7. Dismantling of platform

The first step towards dismantling will be to remove the topside facilities and the mechanical outfitting internally and externally from the concrete substructure. This may be accomplished offshore or inshore by a heavy lift vessel or, wholly or partly, by a floating crane. The concrete substructure will normally have sufficient floating stability to refloat and carry the majority of the topsides ashore for inshore removal. Feasibility of his operation is not considered in this report.

The platform should be anchored at a sheltered site with sufficient water depth, if possible in close proximity to a suitable yard. Hanøytangen yard at the western coast of Norway has been used as an example in this report. A floating crane of capacity about 600 tonnes and suitable transportation barges are required.

The proposed method of dismantling the shafts is to slice the shafts in horizontal sections of weight up to 600 tonnes. These slices may be cut by diamond saw or by drilling and blasting the concrete locally for thereafter cutting the main reinforcement. The released slices will be lifted on to a barge and transported ashore for further cutting into pieces of a suitable maximum size.

Caisson cells utilised for oil storage may be cleaned by an assembly of washing nozzles with high jet water/detergent pressure threaded into the cells from above. The contaminated washout water is then pumped onto barges and processed for cleaning.

The caisson cell walls may be cut into pieces and brought ashore, basically in the same way as the shaft slices. The solid ballast will be dredged out of the caisson and brought ashore using conventional grab and lift methods. When the dismantling reaches a level where the freeboard is marginal, the remaining substructure may be moved into a dry dock for final cutting. Whenever found feasible, larger pieces cut out of the structures may be tailored for application as parts of industrial halls, breakwaters, pipe protection, quay structures and the like.

8. Demolition of concrete

Upon arrival ashore the reinforced concrete segments can be crushed by hydraulic tools such as jaw cutters or by explosives. The concrete and the steel reinforcement are then separated using state-of-the-art tools, slightly modified to accommodate the larger concrete dimensions and higher concentration of reinforcement found offshore. The equipment used will be based on crushing and vibrating the material.

Prestressed reinforcement stores a lot of strain energy, which might release suddenly when cutting the tendons. To avoid risk to personnel the reinforcement and its condition must be assessed and the cutting sequence planned accordingly.

9. Recycling

9.1 Concrete

The amount of recycled concrete aggregate generated from a North Sea concrete substructure will be in the order of 120 000 to 550 000 tonnes, i.e. of the same order of magnitude as a one-year production of aggregate from an average Norwegian quarry. This high strength concrete aggregate can be reused in a variety of construction activities in the local market (which is limited) as well as overseas where the demand for such a product is on the rise.

Application area	**Fraction**	**By- products**	**Advantages**	**Challenges**
In construction activities	Precast concrete members Large concrete members	No	Economy Environment	Market Performance and quality Timing and storage
Rip-Rap	Large concrete members	No	Costs and time efficiency	Long term performances Acceptance for reinforced products
Road and highway construction	All-in fraction	No	Market “state of the art” technology	Long term performances Degradation due to frost
Bituminous mixes in road and highway construction				
New concrete production	Coarse aggregates	RCA sand	Documentation High tech; utilizes the properties of the product	The RCA sand Market and costs
Low quality stabilization or binder	RCA sand	Coarse aggregates	Economy High tech; utilizes the properties of the product	R&D work Market
Fill material	All-in	No	Market	No

9.2 Steel

Steel, once free of concrete, will be cut into pieces of suitable size and shipped to a steel mill for re-melting. The steel quantities will be in the order of 10-15 % of the weight of the concrete.

10. Environmental aspects

In the worst case a failure of the refloat and towing operation may result in an uncontrolled diffusion of harmful compounds and release of a pile of broken concrete segments, which could jeopardise ship traffic and fishing activities. Attempts to clear up any marine accident are likely to involve demanding subsea operations involving significant personnel risk and it may be necessary to leave the wreck on the seabed.

In the dismantling and demolition phase rigorous actions such as decontamination pits, dust treatment and measures to reduce noise from blasting and from machines and tools, should mitigate the environmental impact to an acceptable level.

There is no reason to assume that pollution or material degradation could limit future use of recycled aggregate from offshore concrete structures in structural concrete or as backfill material. With respect to environmental concerns concrete used offshore does not differ from other concretes used onshore. The quantity of impurities influences the possible contamination of the environment and the material/durability properties of the recycled concrete. Any possible negative effects may be accounted for by limiting the amount of recycled aggregate to be used in new structures.

The high quality specification used for the production of "offshore concrete" implies fewer unforeseen impurities. The concentrations of heavy metals and organic components that may be present in concrete are found not to lead to leaching that is out of the limits for potable water. Thus, there are no indications that leaching of heavy metals from the cement and mortar will threaten the environment.

Harmful impact on the environment caused by chemical additives used in manufacturing concrete may be recognized as less probable, due to the small quantities of such additives used.

Intrusion of hydrocarbons into the concrete is limited to the concrete on the inner side of oil-storage tanks. Due to the extremely low permeability of the offshore concrete, any penetration into the concrete will be limited.

Chlorides, sulphates, magnesium and other harmful components may influence the durability as well as the mechanical properties of the recycled concrete and the content should therefore be determined through tests.

Components from structures or elements used for storage of poisonous chemicals or radioactive materials should not be used for recycling. However, this is not normally the case for “offshore concrete”.

The energy needed to produce the crushed concrete will be somewhat higher than for crushing and screening rock, i.e. 3-6kWh/tonne. The energy consumption of recycling steel is less than for production of virgin steel, giving a saving of 4000kWh/tonne.

11. Health and safety

Health and safety have a paramount position in the refloat, tow, dismantling and recycling of these platforms.

In the worst case, failure of the refloat, towing or demolition operation could have serious consequences in terms of loss of life and health and environmental impact, as well as economic loss. The safety factors applied during these operations should not be lower than those specified for the original construction, installation and operation phases.

The refloat and transport operations will have to be planned for the summer season. The risk of delays into the autumn or winter is not negligible. If such delays occur, the structure is unlikely to have the required factor of safety against overload by a design storm.

As for the environment, the greatest risk to health and safety is personnel accidents during the refloat and towing operations. Clean up, if required, after a possible total failure implies very high risk /3/. The risk of injury or fatalities related to sub sea work, dropped objects, sub sea cutting, structural overload, etc approaches, and might easily infringe on, recognised acceptance criteria. Experience shows that dismantling and demolition work has a higher personnel risk than other construction work.

Thorough detailed planning and analyses of the entire sequence of operations are indispensable requirements to all the offshore operations. The analyses should be based on conservative assumptions concerning the condition of the structure and it’s outfitting.

12. Cost estimate

12.1 Refloat and transportation

The Phase I study, dealing with the refloat operation, does not include any cost estimates. Refloat and transportation ashore will undoubtedly be responsible for a significant part of the decommissioning cost. The cost figures will differ considerably from one project to another. For one North Sea substructure of the tower and caisson type an order of magnitude cost of 1000 MNOK is indicated /3/. Much higher costs have been estimated for removal of other types of concrete structures.

12.2 Dismantling and demolition

The total costs of inshore dismantling and onshore demolition of a typical Condeep substructure amounts to about 1300 NOK per tonne of concrete (inclusive of revenue from sale of aggregates and steel reinforcement) with an uncertainty of ± 20% /2/. It is to be emphasized that this figure is only indicative. The cost is likely to vary from one platform to another. For other North Sea platforms the cost of inshore/onshore dismantling/demolition is estimated to be three times higher /3/. The cost of removing the platform from its location, towing it to shore, removal of the topsides and internal/external steelworks are not included in the figure above. Only by including the total cost of offshore removal and onshore disposal of a concrete platform a realistic NOK per tonne ratio can be obtained.

Revenue from sales of the concrete of the Condeep substructure used as the example in this study from recycling is estimated to be 5.5 MNOK and of the steel 8-15 MNOK. The costs directly related to demolition and preparation for sale, including rig costs, are estimated at 50-

65 MNOK. The corresponding costs for demolition, disposal and deposit, excluding tax, are estimated to be108 MNOK.

In this estimate, which was made in 1998, the deposit tax has been assumed as 300 NOK/tonne, i.e. 90 MNOK. This tax is assumed to increase in future.

It seems that savings in the deposit tax is much more important than sales revenue in making the decision whether to recycle the materials.

12.3 Economic risk

In all phases of the operations, there are risks associated with maintaining the structural integrity of the platform. Operations such as ballasting and deballasting, the use of explosives, lifting and transport must be properly coordinated so as to avoid unnecessarily overstressing the structure.

Refloating and transporting platforms which were not originally designed for these operations will be particularly hazardous. Probabilities up to 5% of not being able to refloat have been estimated for certain North Sea tower and caisson structures /3/.

The final cost of cleaning up the seabed after a failure of the platform during refloat or tow is likely to be extremely high, up to several thousand MNOK.

13. References

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