bulletin 18

state-of-art report

Recycling of offshore concrete structures

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CEB-FIP

Recycling of offshore concrete structures

State-of-art report prepared by

Task Group 3.2

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Cover picture: Draugen platform during construction (courtesy Norske Shell)

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Note: Recycling in this context includes all levels, from re-use and recycling of the entire structure to demolition, re-use and recycling of material constituents.

Summary

The report confirms that removal, re-use wholly or in part, and complete demolition and recycling of Concrete Gravity Structures (CGS) are technically feasible.

In order to reach this conclusion a profound knowledge and understanding of the structure, both its technical and operational aspects, are required. An important instrument to acquire such knowledge are the records kept during the platform's history describing the main parameters and events.

For some platforms the most suitable vessel for carrying the topside ashore may prove to be the CGS itself. However, it is most likely that the CGS must be removed from their present sites anyhow. A successful removal requires a well planned and controlled operation. Comprehensive preparations and consequence analyses accounting for inaccuracies and tolerances will contribute to assuring a safe operation with respect to personnel and costs. This is especially important when managing challenging phases such as the moment the platform separates from the seabed.

After the platform has been brought safely to shore it can either be rebuilt and brought to new sites for installation, or dismantled into sections. Dismantling is foreseen to be a process of removing the concrete locally along the borders of the section, before cutting the reinforcement. This is likely to be done while the platform is still floating. The sections are subsequently brought to shore either for reuse or demolition and recycling. Cells that have stored oil must undergo thorough cleaning before dismantling. Durability properties of the concrete in these offshore structures have proven to be excellent, i.e. low permeability and limited depth of oil penetration can be expected.

Governmental policy is consistently moving towards rewarding those industries that contribute to environmentally friendly management. Both the building and road industries are encouraged to use less virgin materials, a fact which will lead to a stronger demand for recycled material in the future. There is no reason to believe that offshore concrete should be less suitable for recycling than other concrete. Because of the stringent demand offshore concrete is produced under, in addition to the proven good durability, this concrete will consist of less impurities and provide a more uniform quality.

Recycled material is an environmentally friendly alternative that incurs reduced consumption of virgin material and less waste disposal. The positive effects are diminished where long transportation is needed, and with it an attendant extra cost. The location of the recycling site is thus an important consideration.

Contents

1 Introduction

1.1 Report objectives

The main objective of this report is to present material, relevant to the subject of removal, reuse and recycling of offshore concrete structures. It is important that existing facts and research are accessible for politicians, planners, environmentalists and decision-makers to enable governments and the industry to take appropriate actions.

The report will give a survey of the aspects and the possibilities / problems involved in a process that spans from the decommissioning of a whole platform to the recycling of the single material constituents.

Decommissioning of offshore concrete structures represents new challenges for the oil and gas industry and will lead to the development of new technology and new techniques in the area of industrial waste management. It may also create new industries.

1.2 Background

Today, more than 30 concrete gravity structures (CGS), in addition to three floating structures, have been installed as oil and gas platforms, the first in 1973. The majority of these have been installed in the North Sea, in water depth ranging from 40 to 300 meters, consisting of 10 000 to 250 000 m^3 of high strength concrete. Table 1-1 shows the main concrete offshore structures.

Some of the platforms are approaching the end of their production life and will need a strategy for removal, reuse and recycling in the near future. For each existing, as well as new platform, it will be necessary to document the removal and the recycling procedures in detail.

1.3 The OSPAR decision

The OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations, is a binding decision to ban the disposal of offshore installations at sea [15: OSPAR (1998)]. It entered into force on 9 February 1999.

The OSPAR decision concerns the contracting parties to the convention for the protection of the marine environment of the Northeast Atlantic.[1] The majority of existing concrete gravity substructures are located within the OSPAR maritime area.

Paragraph 2, in the decision decides:

"The dumping, and the leaving wholly or partly in place, of disused offshore installations within the maritime area is prohibited."

Derogations from Paragraph 2 are possible if an assessment in accordance with Annex 2, in the decision, shows that there are significant reasons why an alternative disposal is preferable to reuse or recycling or final disposal on land.[2] The contracting party may then issue a permit for the actual structure or part of the structure.

Footnotes:

1 The OSPAR Member States are: The European Union States plus Iceland, Norway and Switzerland

2 Annex 2, contains a framework for the assessment of proposals for the disposal at sea.

Operator	Field	Platform type	Design	Depth	Year
Phillips	Ekofisk	Concrete Tank	Doris	70 m	1973
Atlantic Richfield	Ardjuna Field	LPG Barge	ABAM/Berger	43 m	1974
Mobil	Beryl A	Condeep 3 shafts	NC/OO	118 m	1975
Shell	Brent B	Condeep 3 shafts	NC/OO	140 m	1975
Elf	Frigg CDP 1	CGS	Doris	104 m	1975
Shell	Brent D	Condeep 3 shafts	NC/OO	140 m	1976
Elf	Frigg TP1		Sea Tank	104 m	1976
Elf	Frigg MP2		Doris	94 m	1976
Shell	Dunlin A		Andoc	153 m	1977
Elf	Frigg TCP2	Condeep 3 shafts	NC/OO	104 m	1977
Mobil	Statfjord A	Condeep 3 shafts	NC/OO	145 m	1977
Shell	Cormorant A		Sea Tank	149 m	1978
Chevron	Ninian Central		Doris	136 m	1978
Shell	Brent C		Sea Tank	141 m	1978
Mobil	Statfjord B	Condeep 4 shafts	NC/OO	145 m	1981
Amoco Canada	Tarsiut Island	4 hollow caissons		26	1981
Texaco	Schwedeneck A		Doris & IMS	25 m	1983
Texaco	Schwedeneck B		Doris & IMS	16 m	1983
Mobil	Statfjord C	Condeep 4 shafts	NC/OO	145 m	1984
Global Marine	Super CIDS	CGS Island	Global Marine	16 m	1984
Statoil	Gullfaks A	Condeep 4 shafts	NC/OO	135 m	1986
Statoil	Gullfaks B	Condeep 3 shafts	NC/OO	141 m	1987
Norsk Hydro	Oseberg A	Condeep 4 shafts	NC/OO	109 m	1988
Statoil	Gullfaks C	Condeep 4 shafts	NC/OO	216 m	1989
Hamilton Brothers	N Ravenspurn	CGS 3 shafts	Ove Arup	42 m	1989
Phillips	Ekofisk P.B	CGS Protection Ring	Doris	75 m	1990
Elf Congo	N'kossa	Concrete Barge	BOS/Bouygues	170 m	1996
Shell	NAM F3	CGS	Hollandsche Bet.	42 m	1992
Saga	Snorre CFT	3 cells, open skirts	NC/OO	310 m	1992
Statoil	Sleipner A	Condeep 4 shafts	NC/OO	82 m	1993
Shell	Draugen	Condeep monotower	NC/OO	251 m	1993
Conoco	Heidrun Found.	Condeep w/skirts	NC/OO	350 m	1994
BP	Harding	CGS Found.Tank	Taylor Wood. Eng.	106 m	1995
Statoil	Troll A	Condeep 4 shafts	NC/OO	303 m	1995
Conoco	Heidrun TLP	Concrete TLP	NC/OO	350 m	1995
Norsk Hydro	Troll B	Concrete Semi	Doris	340 m	1995
Esso	West Tuna	CGS 3 shafts	Kinhill/Doris	61 m	1995
Esso	Bream B	CGS 1 shaft	Kinhill/Doris	61 m	1995
Ampolex	Wandoo	CGS 4 shafts	Ove Arup	54 m	1996
Mobil	Hibernia	CGS	Doris	80 m	1997
Amarada Hess	South Arne	CGS 1 shaft	Taylor Woodrow	60 m	1999
Shell	Malampaya	CGS 4 shafts	Ove Arup	43 m	2000

Table 1-1: Offshore concrete structures

The decision contains a consultation procedure, which shall be used by the relevant contracting party, which is considering whether to issue a permit. It describes the necessary consultation procedure with all the other contracting parties.

Every permit issued shall follow special permit conditions and contain several specified reports, which are described in the decision. [4: Kværner Engineering (1994)]

In short terms, all existing installations with a jacket weight less than 10,000 tonnes must be completely removed to shore. Footings of large steel jackets, weighing more than 10,000 tonnes and all concrete installations are exceptions from Paragraph 2. However, the topsides of all installations must be returned to shore and a presumption is that all type of structures shall be removed entirely. See also [21: Parmentier (2000)].

The decision will be reviewed by the OSPAR Commission in 2003, to consider possible changes of the decision, in the light of new experience and technical development.

Pipelines are not covered by the OSPAR decision.

1.4 The Sintra statement

The Sintra statement was signed at the end of the OSPAR Ministerial Conference, where OSPAR Decision 98/3 was adopted.

The ministers then re-emphasised their commitments to prevent dumping of waste in the sea. One important part of the statement says:

"Under this Decision, all dumping of steel installations is prohibited. Derogation, subject to assessment and consultation under agreed procedures, may allow the footings of steel installations weighing more than 10,000 tonnes to remain in place. However, we will strive to avoid using such derogation for footings of steel installations, by returning to land for recycling and disposal all steel installations where it is safe and practicable to do so. Derogation will also be available for concrete installations. We have no plans to create new concrete installations in any new oil-field developments in the maritime area. Concrete installations will only be used when it is strictly necessary for safety or technical reasons."

Especially the last part has created dissatisfaction and concern in the offshore concrete industry, see also [21: Parmentier (2000)].

1.5 Removal strategies

The major goal for the offshore industry must be to avoid all sea disposal of offshore structures, existing as well as new built, concrete as well as steel. As always, some exceptions could be necessary. A practice called the Best Practicable Environmental Option (BPEO) is often used. It is the option, which limits damage to the environment to the greatest extent achievable at an acceptable cost to industry and the public.

There are several factors to consider; most important being: safety, environmental, economic and technical issues.

Also, the experience gained from previous offshore operations has been that the industry needs to understand the public environmental concerns and improve information and communication towards both organisations and the general public. To give all interested parties an opportunity to give their opinion is a very important part of the removal process.

The main actions during the decommissioning process are:

- abandonment plan,
- consultations with local politicians, authorities and communities.

- advertisement / information of alternative plans for the platform,
- public meetings,
- planning, engineering,
- topside shutdown / cleaning,
- offshore preparation,
- removal operation
- towing
- dismantling
- re-use / recycling / disposal.

1.5.1 Waste hierarchy

There are decisions / recommendations given for treatment of industrial waste in the form of primary objectives (EU - Waste Management Guidelines), [3].

Applied on an offshore concrete structure the following hierarchy should, if possible, be used:

- Re-use of the structure
- Re-use of structural parts
- Re-use of components
- Recycling of component material constituents
- Reduction of waste movements
- Reduction of disposal
- Safe disposal

This hierarchy is based on studies of consumed energy, transport, environmental and economical aspects and is a good guideline, when working with waste management.

1.5.2 Existing structures

From a design and an operation point of view, removal of all the concrete gravity base structures have been assessed to be feasible. Recent CGS's are designed for re-floating and removal through a reversal of the installation procedure, [1: NPD, Statoil, A/S Norske Shell, Aker Maritime Contractors (1997-1998)]. However, the full extent of the evaluation related to the removal process can not be contemplated in the original design, and must be addressed in the engineering planning process prior to the removal operation. Means of minimising risk is an important issue during this process.

Refloating the concrete gravity base may even be the least expensive way to remove the topside, which has to be removed anyhow, according to OSPAR, see also chapter 2.

The possibilities for re-use of the substructure, as a production unit or with a totally new function, must also be seriously considered.

If not suitable for re-use as a complete structure, the remaining materials and components after partial re-use, should be recycled as far as possible.

1.5.3 New structures

The issue of removal, reuse and recycling of future offshore structures will be an important, maybe crucial, factor in the development of new concepts. New concrete structures should not be ruled out for environmental reasons, rather the opposite. It could in comparison to other concepts be an environmentally preferable alternative for new field developments. Concrete is a neutral and environmentally friendly material, that for example, requires less maintenance than steel structures.

With a mandatory removal at the end of production, the precautions in the design and construction phase will be important tools to reduce the future removal costs.

It is important to take advantage of the possibilities appearing with re-use and recycling strategies. New concrete installations are now designed for complete removal at the end of their productive lives.

1.6 Report disposition

This report covers the whole procedure during decommissioning of offshore structures. It starts with the issue of re-use, wholly or partly, continues with some removal aspects, demolition and recycling of materials. It ends with a discussion over selection of structural materials for new platforms together with a survey of rules and regulations.

2 Re-use of concrete structures

2.1 General

The opportunity to re-use a platform would require favourable circumstances for the old removed, reinstalled and refurbished structure to be considered in comparison to building an entire new and purpose built facility.

It is therefore important that available re-useable platforms are advertised well in advance. The operators must be aware of the re-use option when planning for new field developments. Within some years, the operators may have several existing platforms to choose from, when assessing the best option for the actual new field development.

If a concrete structure has been stated as impossible to re-use as a whole, the issue of partial re-use will be of interest.

2.2 Re-use of whole structure after removal

A platform could either be re-used in situ or removed, reinstalled and reused at its new location. The design purpose, to produce oil and gas, could be changed as well.

Finding another field that will match all the platform properties and production capacity is perhaps impossible but also not necessary. Some modifications and refurbishment must be performed anyway. Successful re-use of concrete gravity structures is dependent on water-depth, seabed conditions and environmental loads.

An advantage for reused structures could be a shorter time-scale from planning to production start.

Another advantage is the good durability of offshore concrete structures, when well designed and well built. A recent major Norwegian joint industry project, Bestandige Betongkonstruksjoner (Durable Concrete Structures), has demonstrated this [25:

Bech/Carlsen (1999)]. Concrete is a non-pollutant material and does not deliquesce to sea water like steel does.

There are also a lot of other proposed uses for old platforms; bridge piers, coastal defences, wind farms, artificial reefs in addition to some more exotic examples as prison, casino and fish farms.

2.2.1 Possibilities and problems

In the Gulf of Mexico (GOM), several platforms have been re-located to other fields to continue their productive life. As mentioned previously, the conditions in the GOM are quite different, with very shallow water and fields with a relatively short life length. However, important questions are:

- Skirts and bottom slabs are designed for particular soil conditions. If the conditions at the new location are totally different, this may make re-location impractical.

- Estimated life remaining (particularly with regards to fatigue) must be equal or longer than the estimated production life for the new field. Assessment of structure life remaining is important in this process.

- Using the platform for new activities requires due consideration of personnel safety, transportation issues and maintenance of the platform.

- There will always be a day for end use and decommissioning for a platform, thus the dismantling process will always be applicable.

2.3 Re-use of structural components and materials

Re-use is here distinguished from recycling by the fact that it is the structural part or equipment that is valuable or re-used rather than the constituent materials.

The topside is presumed de-mated offshore or inshore as a reversal of the mating process.

Deck removal at the offshore location is possible by heavy lift vessels or the new single lift units under development.

Topside equipment is not further discussed in this report.

2.3.1 Second-hand markets

Today, there exists a few second hand markets for used offshore components, especially in the GOM area, but there should be a great potential world-wide. It should also be possible for construction companies to advertise in advance of major future projects, where re-used structural parts could be part of the new construction.

2.3.2 Re-use of structural parts

After removal and towing inshore, major parts of the structures could be dismantled into parts. Shafts could be cut in sections and re-used for different purposes.

2.3.3 Re-use of components

Equipment in shafts and cells, such as pumps, pipes, stairs, hydraulic systems, elevators, cranes etc. should be well suited for re-use. Every valuable component or mechanical system should be dismantled, cleaned and ready to sell or re-use.

Experience with sale of equipment has, at the moment however, shown very little interest for pumps and pipes. It will most likely be more profitable to dismount CMO/MMO (Contractors Mechanical Outfitting/Main Mechanical Outfitting) before sale.

3 Removal of offshore concrete structures

3.1 General

This chapter includes a survey on relevant information on removal and re-floating of concrete structures from previous studies and reports. These studies show that it is technically feasible to remove offshore concrete structures, ref. [NPD, Statoil, A/S Norske Shell, Aker Maritime Contractors (1997-1998) [1]; E&P Forum (1996) [2], The European Commission (1996) [3].

The majority of the CGS have had their topsides installed inshore, prior to tow out. These types of platforms are often anchored to the seabed with the help of skirts (2-30 m long), penetrating the overlaying soil. Some of the CGS´s caisson, a multi-celled construction, is utilised as oil storage.

Several factors have to be taken under consideration before, during and after a removal operation. Each structure has its own history and its own technical aspects. Operational planning and management are thus very important during this process. The removal operation will therefore follow after a detailed engineering and planning process.

Most of the offshore concrete platforms have been designed for a re-floating operation. The platforms at the Norwegian continental shelf, for example, have since 1978 been required designed for this.

The CGS have all been carefully controlled and inspected during their life. Defects, accidents etc have been recorded and monitored, and will provide a important help in planning the removal process.

Some different approaches are possible when decommissioning a CGS:

a) Reverse the installation process; reinstall platform at new location.
b) Reverse the installation process, topside to be removed inshore.
c) Remove topside offshore first, then re-float the substructure.

Regardless of which cases to be studied, general challenges are to be managed. However, this has been accomplished, the conclusion is positive but there are several aspects which demand further attention and these are discussed in more detail in this chapter.

The option to leave the whole structure in-situ is not considered in this report.

3.2 Preparatory work

Several actions must be carried out before the re-floating procedure. All offshore work is expensive, thus should be kept to a minimum.

Preparatory planning and management on site is extremely important in these cases.

3.2.1 Weight documentation

Weight estimations are very important and must be done accurately. Possible deposits in shafts, items on the upper domes/slab, possible deposits in the storage cells and possible grout hanging from the lower domes/bottom slab must be take into account.

If the topside weight has been increased or changed during the production life, weight calculations have to be updated. If necessary, topside weight may have to be decreased offshore to secure stability.

Production installations in the shafts, such as conductors, may have to be removed to reduce the overall vertical centre of gravity.

With all weights together with additional information of ballast water in cells and shafts and required draft etc., the stability of the platform can be calculated.

3.2.2 Structural checks

Checks of the substructure integrity and analyses have to be performed, especially load conditions / water pressures different from the installation have to be considered and may require additional engineering.

Possible degradation of the concrete and the tightness of the pipe penetrations are other aspects that have to be considered.

3.2.3 Sea bed conditions

Depending on the draft limitations it may be necessary to remove scours and/or debris from around the platform prior to lift off.

3.3 Offshore preparatory work

3.3.1 Topside shutdown

After cessation of production, equipment needs to be cleaned in such a way that it may be safely dismantled or removed. If this work is to be performed onshore, all piping and mechanical equipment containing liquids are to be sealed offshore to avoid spillage during removal and transport. However, draining as much remaining liquids as possible should be performed right after production cease.

3.3.2 Visual inspections

A detailed survey of the structure, above and under water, inside and outside the platform, is an important and necessary job. For underwater operations a ROV (Remote Operated Vehicle) should be used.

The survey must be documented in detail and examples of checks are:

- Penetrations of pipes etc.
- Debris on the top slab/upper domes
- Possible damage on top slab/upper domes from dropped objects or debris
- Drill cuttings - Location and quantity

- Assessment of deposits inside shafts
- Marine growth
- Overall assessment of structure status
- Pressure tests campaign in order to check general tightness, status of pipes, status of vent lines, etc.
- Inspection and test of towing and mooring points.

3.3.3 Disconnecting pipelines and cables

As much underwater work as possible should be done with the help of ROV. After disconnection all openings have to be properly sealed.

Decommissioning of pipelines are not discussed further in this report.

3.3.4 Cut conductors

This is one of the main challenges to be solved. The conductors in the drill shafts must be cut and their penetrations through the bottom slab must be safely sealed. The disconnection of the pipes from the slab must be confirmed, because of the grouting below the foundation and possible cement overflow during drilling. New methods may have to be developed.

Current requirements in the North Sea for piles and wells say that conductors are to be cut five metres below the natural seabed.

3.3.5 Plugging the wells

Plugging wells is a standard procedure and existing technology should be used. Typically, a concrete plug may be applied in each well.

3.3.6 Cleaning of storage tanks

The removal of hydrocarbons and other toxic liquids is to be performed offshore before the re-float phase. As much remaining oil, diesel and other liquids as possible are pumped to assisting ships. Thorough cleaning of the storage tanks will be performed inshore.

Applying a high jet water pressure to the inside surfaces of the storage tanks, and pump out the contaminated water gathered in the bottom of the tank, is one method of removing remaining hydrocarbons from the storage cells. Contaminated water can be led out either by applying existing pipe systems or installing new.

Other available techniques may include chemicals, accelerated biodegrading with microbiology or hot water re-circulation.

There have been discussions on whether to clean the storage tanks offshore or inshore. Offshore is more expensive, but may prevent a possible environmental incident if anything should occur during the critical phases, re-floating and towing, leading to uncontrolled leaks and environmental impact. Aker, Dames&Moore, Demex, Franzefoss, NCC, SINTEF (2001) give a detailed description of how the cleaning of storage tanks may be performed [26].

3.3.7 Mechanical systems

All mechanical systems for the operation of the ballasting system are to be tested, pressure tests, NdT, pigging etc. They may need to be refurbished, complemented with pumps or replaced. Many of these systems have been inoperative since the installation phase. If a removal system is installed its capacity must be checked in relation to current removal plans. Platforms without these systems have to install them, including water injection and compressed air pressure systems.

Instrumentation to control the operation may have to be reinstalled / complemented on all platforms. The ability to measure and control several parameters during removal is even more important than during installation, due to weight estimations etc.

Eventually, cells have to be deballasted and a compressed air pressure system may have to be installed to keep the pressure difference through cell walls within specified limits.

3.3.8 Drill cuttings

Cuttings have generally been discharged to the seabed and have thus accumulated in, on and adjacent to the concrete structure. Removal from shafts and top of slab / domes is probably necessary and undue disturbance should be avoided during removal, see further chapter 4.2. Drill cuttings outside the platform may also increase the pull out resistance during re-floating.

Several possibilities are available for the treatment of drill cuttings.

3.3.9 Solid ballast

A number of CGS house solid ballast installed after installation of the CGS at sea bottom in order to achieve the adequate on-bottom weight. This ballast is generally in the form of sand and gravel. In some instances the drill cuttings may be present at the top of the solid ballast. The extent to which this ballast must be removed to facilitate re-floating must be investigated.

3.4 Re-floating the structure

This is the most crucial phase in the removal operation and thus far, no larger CGS has ever been re-floated, therefore no experience exists in this area. However, some of the platforms are designed for these operations, but not always in detail. It is necessary with step by step detail analyses to document the entire re-floating process.

Main phases are:

a) Deballasting, close to zero weight
b) Water Injection
c) Deballasting
d) Break-out
e) Pop-up (dynamic motions during the break out and lifting phase)
f) Stabilising
g) Towing

The acting loads will be somewhat different to the installation phase with adhesive forces under the base, soil and deposit friction and different water pressure due to different ballasting procedures.

A detailed study has been performed on Gullfaks C, see reference [1: NPD, Statoil, A/S Norske Shell, Aker Maritime Contractors (1997-1998)] for how to perform this re-floating procedure.

3.4.1 Deballasting

The principle is identical with the installation phase, with ballasting and deballasting of shafts and cells. The same systems used during installation could be used.

The first ballasting aims to give the platform neutral buoyancy, overpressure forces the skirts to move upwards, to overcome the soil friction.

Some different approaches could eventually be applied to avoid the complicated work with sealing of the conductors in the drill-shafts [1: NPD, Statoil, A/S Norske Shell, Aker Maritime Contractors (1997-1998)].

3.4.2 Water injection

The purpose of applying an overpressure in the skirt compartments is to create a jacking force to raise the platform. The injection continues until no more pressure could be built up, near the breakout point. This injection will create a small overpressure below the storage cells. The overpressure must be limited and well controlled in order to prevent piping.

Some of the platforms have injection systems prepared for the removal operation. Others need to be complemented or given a totally new injection system.

3.4.3 Break out

The breakout time is the time required for withdrawal of the platform from the soil. Estimate of the retrieval rate is dependent on pore pressure, soil, geometry, water injection etc. Time is important, the operation is weather dependent, and has to be considered on a case by case basis.

In addition to geotechnical samples and studies, all available soil information gathered during the installation and production phases must be used to determine the soil characteristics. This information preferably will include pore pressure and settlement records during the life of the platform.

The breakout, when the last part of the platform leaves the soil, could be critical if uncontrolled lift-up movements arose. Therefore weight management is important.

3.4.4 Floating stability

Adequate stability must be maintained to ensure a successful operation.

Examples of things that could destabilise the platform are:

- Failure in mechanical ballasting systems
- Injected grout under the structure giving extra weight and potential shift in the centre of gravity. Loss of grout after re-float could lead to platform oscillations.

- Leakage
- Lack of tightness
- Failure of a penetration through the concrete section
- Structural deficiency or failure
- Wrong assumptions in weight estimations and calculation of centre of gravity
- Inaccuracies in measuring systems

It could be necessary to force the structure to oscillate with the help of water injections and deballasting procedures, to be able to withdraw the skirts from the seabed. That would be considered as a higher risk activity than uniform pressure increase. Environmental conditions during up-lift will may provide sufficiently oscillating motion, however.

It is also possible to reduce the apparent weight during a certain period of time prior to refloat, by partial water deballasting, in order to dissipate part of the pore pressure below the foundation.

Grout, if used, may adhere to the underside of the CGS, and must be accounted for. Sudden drops may occur, and the re-floating scheme should be able to accommodate foreseeable quantities being lost.

In order to achieve a successful operation it must be well planned and controlled. A controlled operation is dependant of reliable measurement system, and good estimation of weights and their distribution. Hence, a detailed evaluation of the consequences of inaccuracies and tolerances connected to weights, measuring and ballasting systems must be incorporated.

3.5 Operational challenges

3.5.1 Safety

The prevention of injury or loss of personnel has first priority during the removal process. This depends, to some degree on the number of man-hours exposure and to the extent of offshore preparatory work needed.

Any underwater preparatory work and stability during re-floating requires particular attention and steps should be taken to minimise the extent of underwater working.

3.5.2 General problems

Generally, most of the activities necessary for re-floating a CGS are straight forward, with a few exceptions. The following activities or parts of the structure may need extra care (no internal ranking):

- Degradation of platform structure
- Scaling of conductor penetrations through the base slab
- Hidden damages, incidents in the past
- Weather, failure in prediction
- Failure in mechanical outfitting during re-float
- Adhesive forces, larger than expected
- Problems with under water work
- If topside to be removed offshore; In some cases the deck provides structural support to the legs, both horizontally and the vertical prestressing effect, and then the substructure integrity must be re-analysed.

- Fail in watertight integrity, "after installation" penetrations of walls have to be examined and sealed

One of the major load cases during the removal process is the de-mating of the topside, that exposes the structure to very high pressures. However, such structures have already experienced the same high pressure during mating, even higher during the deep immersion test. The pipe penetrations must be given special attention, since the pipes are older and creep in the concrete may cause different loads to the ones experienced during deckmating.

In the case of the topside being removed offshore no differential pressure is involved.

3.6 Post-offshore work

After structure removal, the surrounding seabed should be cleared of larger debris. No piles or other parts should rise above seabed level, to avoid the risk of fishing trawls gear being damaged. The area to be surveyed and cleaned could vary but an area with at least a radius of 500 metres should be investigated.

Post-monitoring of possible remaining pollution could be necessary to guarantee the recovery of the seabed. Examples could be levels of heavy metals, hydrocarbons or other contaminants.

If any parts of the structure are to be left at site, special regulations have to be followed. Installation and maintenance of navigational aids will, most likely, be necessary.

3.7 Partial removal

An alternative to the total removal operation is to remove topside and all concrete structural parts down to 55 m below sea level, to comply with the International Maritime Organisation (IMO) guidelines.

The shafts could, in this case, be removed one by one, by cutting at the chosen level. They may be able to maintain their structural integrity and with the help of compressed air and an airtight deck at the top of the shafts, they will also have enough buoyancy to keep floating. They will, however, need support for stability reasons. Towing the shafts to selected reuse / recycling location, is then possible.

Shaped explosive charges and under water cutting technique are available and deemed feasible and applicable under water according to experts. However, diamond cutting and coring techniques are recommended not only from a practical point of view but also because explosive charges do cause harm to marine life.

Removal of the steel items or steel pieces attached to a concrete GBS that would be left in place is also a disposal alternative that has been considered for some recent projects. The items to be removed are particularly the ones that might separate and drift away after a certain period of time, and could offer hazard to the navigation.

4 Demolition methods

4.1 General

A platform will most likely partly be demolished inshore and partly onshore. While the platform, still in a floating phase, is anchored inshore, it can be partly dismantled under controlled circumstances before towed to a dry dock for complete demolition.

The onshore demolition site must or should have equipment necessary for recycling, such as possibilities for separation and crushing of the construction waste. The need to keep the transport distance to a minimum is crucial for an economic and environmentally feasibility of recycling.

Special precautions should be taken before accessing the storage cells in case toxic gases are present.

4.2 Dismantling methods

4.2.1 Explosives

Explosives are probably a necessary tool for dismantling parts of the large concrete structures. The techniques are today very sophisticated and available on the civil market. Different methods could be used, either as in regular quarries or rather with explosives having a directional effect. The method should be complemented with steel "scissors" or similar machines.

Maintaining stability during dismantling is of course necessary and should be analysed in advance.

4.2.2 Cutting methods

Cutting of thick reinforced concrete sections using more common methods:

- Diamond saw
- Diamond wire
- Diamond drilling
- Water Jet
- Abrasive jet
- Concrete crushing (hydraulic jaws)
- Hydraulic hammer
- Hydraulic splitter
- Expansive chemicals
- Thermic lances

Heavy duty mechanical crushes, “scissors”, are then used to break up open reinforced concrete parts and cut the reinforcement.

Cutting the shaft in sections as mentioned in chapter 2.3.2 may be performed while the platform is floating inshore. Cutting, drilling and blasting techniques are applied along the cutting line, to remove the concrete. The section is mounted to a crane before the reinforcement and prestressing tendons are cut.

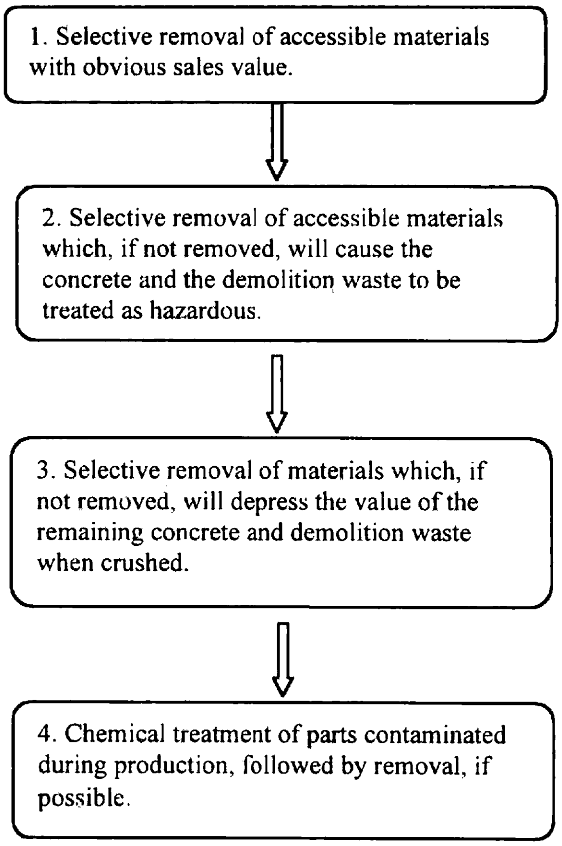
4.3 Dismantling process

Selective dismantling is necessary to be able to re-use and re-cycle as much material and components as possible. It is also the method with best personal safety and economic result according to several studies and existing experience [European Comission (1999)][Norsas as (1999)]. Main actions are:

- Dismantling all components possible
- Breakdown the structure to manageable size
- Bring parts ashore or to recycling site
- Separate into individual types of material, selective demolition should keep this to a minimum.
- Temporary Storage
- Crush to retrieve the steel
- Crush further, into graded material

How can the dismantling nearshore or onshore of these large concrete structures be performed in an effective and rational way?

A commonly used flow of activities is [European Comission (1999)]:



During dismantling of the platform, a study of the construction conditions should be performed documenting concrete strength etc. Such study could give the industry possibilities to improve future constructions.

4.3.1 Dismantling of pre-stressed reinforcement

Experience of dismantling structural parts with pre-stressed reinforcement is limited. Methods and techniques must therefore be studied or developed further. Pre-tensioned reinforcement will normally not give rise to any safety risks, due to the bond between reinforcement and concrete. Post-tensioned reinforcement will require detailed analysis of the reinforcement system and condition. The cables are normally well grouted and the risk of large concentrated energy release is low. However, the cutting of reinforcement must be carefully planned in order to choose robust areas in case of bad grouting and concentrated energy release.

4.4 Crushing methods

There are several mechanical devices available in the market. They crush primary aggregates as well as construction and demolition waste. The principle is simple and the methods have been used for many years

There are smaller mobile machines and larger fixed machines available, the latter capable of handling large concrete pieces (5m long, 2,5 m wide and of variable thickness) [26: Aker, Dames&Moore, Demex, Franzefoss, NCC, SINTEF (2001)] implementing advanced sorting technology to remove remaining unwanted fractions.

Hydraulic jaws for demolition of concrete includes concrete cutters, which are scissor shaped tools, and concrete crushers. Maximum openings for the larger types are well over 1 meter.

5 Recycling of materials

5.1 General

When re-use is not applicable or when everything re-useable has been removed, recycling of the remaining structural materials should be considered.

The offshore industry has much to learn from the onshore construction and demolition waste industry practices, which have been developed during the past decade. One important lesson to be learned is the use of selective demolition, decreasing the quantity of waste needed to be sorted, increasing the efficiency in the recycling process and keeps the materials as clean as possible.

None of the platform materials are new for the onshore industry and a majority of them are already being recycled on a regular basis. The new issue is the dimensions, the size, shape and how to handle the breakdown procedure. Also the amount of reinforcement, prestressing tendons and concrete strength will be above the average land based structure.

Most materials could be recycled in an economic and environmentally favourable way. Materials, which are impossible or not cost-effective to recycle, will be disposed of to landfill. Landfill is the last step in the waste hierarchy process and a growing problem in many countries, due to the huge quantities. Hazardous or environmentally toxic materials should not be used as landfill without special considerations.

The main challenges, when recycling offshore concrete structures, are the size and the large concrete volumes. Special attention has therefore been paid to the recycling of concrete. Steel and many other metals have a high market price and are easy to recycle.

5.1.1 Onshore experiences

Following subjects have shown to be important factors, when recycling material as substitutes for primary material.

- Careful Planning
- Selective removal
- Quality and Environmental Control
- Minimise Transports

Quality control of recycled products appears to be very important. Even in countries where construction and demolition waste derived aggregates are already relatively widely used, the main barrier to greater market acceptance appears to be the buyers doubt about quality and consistency. Formal standards and independent material testing, by independent laboratories, will help the recycled products to be further and widely accepted.

Traditional general resistance against recycled aggregates is:

- Low prices on natural resources
- Lack of experience with recycled aggregates
- Doubt of consistently good quality
- Low taxes on waste disposal
- Lack of legislation and regulations
- Resistance from natural aggregates industry involved in the concrete industry

The major portion of recycled concrete are crushed and still used as road fill material. The level of recycling has a big potential, in Denmark the ratio of recycling C&DW (Construction and Demolition Waste) has increased from 12 % to 81% within a decade, [18: Ministry of Environment and Energy, Denmark (1997)].

5.1.2 Transport of recycled material

Logistics play a major role in the recycling of materials. Transport costs money and increases the use of energy, which may, economically and environmentally, decrease the advantages of recycled materials.

It is shown in the onshore recycling industry that the transport must be kept to a minimum. The majority of recycling today is thus taking place near major cities and urban areas. Different countries and different parts of countries may therefore have different presumptions about how economically feasible recycling is.

The location of the recycling site is thus an economically important factor.

5.1.3 Economic aspects

The economical aspects of the use of recycled materials depend on national deposit taxes, supply of primary aggregates, available landfill deposits and need of transports. When these conditions are satisfying, it is economically favourable to recycle.

The cost to produce these materials may be higher than those for quarrying primary aggregates, especially in regions rich in natural resources. To be successful, recycling must be less expensive compared to primary materials.

There are several factors, which could reduce the recyclable material value. For example, the inner walls of the storage cells would have a thin layer of oil. These parts must therefore be treated separately, and re-use will imply some limitations. Chloride penetration in concrete in contact with sea water must also be taken into account, however in most cases the average chloride content will be low and not give any limitations for reuse.

5.2 Concrete structure materials

A concrete platform is a very complex construction with a lot of different materials, components and structural parts. When decommissioning a platform, it is important that a complete inventory of materials and their special properties, especially those known to be toxic for personnel and the environment is prepared.

Topsides are not discussed in detail in this report. However, there are no mayor differences between a steel jacket topside and a CGS topside, maybe except the size. A topside for a CGS may be simpler to remove as compared to the topside of a jacket due to the different way the structure is arranged.

5.2.1 Concrete

The major part of a CGS consists of reinforced high strength concrete. The largest CGS ever built has a concrete volume of 245 000 m^3.

In some of the structures, part of the concrete volume is lightweight aggregate concrete.

5.2.2 Steel / reinforcement

Offshore concrete structures are heavily reinforced compared to most civil engineering structures (up to 800 kg/m^3 locally, some 300 kg/m^3 in average is common) and in addition to ordinary reinforcement, a large amount of pre-stressed reinforcement has typically been used. Approximately 5-10 percent of all reinforcement should be expected to be pre-stressed.

Steel pipes, decks and stairs in the shafts and embedded steel plates in the concrete walls are also important parts to consider.

Some of the platforms have steel skirts, instead of concrete, penetrating the seabed.

5.2.3 Other materials of interest

In addition to the main materials, steel and concrete, there are other important materials present e.g.:

- Iron ore ballast
- Copper and tin from electric cables and equipment.
- Stainless steel, pipes
- Zinc and aluminium in anodes

For hazardous, radioactive and environmental toxic materials, see Chapter 5.13. Radioactive scale arising from naturally occurring minerals in solution within the reservoir in which the wells are drilled can make deposits inside the piping and the storage cells. This is a factor on any decommissioned platform, particularly the topside's pipework. An appropriate decontamination is required before prospective reuse.

5.3 Traditional use of recycled concrete

The largest single consumer of aggregates, in most countries, is the road construction industry. The construction industry is today often the force behind a change in attitude, leading the way to increased use of recycled construction and demolition waste. Concrete is a major part of this waste.

Traditionally, concrete has been recycled as:

- Unbounded road base and road sub-base
- In road construction, in mixes with 50% concrete and 50% asphaltic material
- General fill

Necessary crushing and sorting into different fractions have often been performed at the demolition site with the help of mobile crushing and sorting units. In several countries major recycling sites have also been established, especially near urban areas.

In most countries construction and demolition waste constitutes between 25% and 50% of all municipal waste. As an average for 1990 to 1994 the following amounts of construction and demolition wastes were produced in the EU member states yearly:

EU – Member State	Core C&DW Arisings (Million tons)	Re-used or Recycled %	Incinerated or Landfilled %
Germany	59	17	83
UK	30	45	55
France	24	15	85
Italy	20	9	91
Spain	13	<5	>95
Netherlands	11	90	10
Belgium	7	87	13
Austria	5	41	59
Portugal	3	<5	>95
Denmark	3	81	19
Greece	2	<5	>95
Sweden	2	21	79
Finland	1	45	55
Ireland	1	<5	>95
Luxembourg	0	Not applicable	Not applicable
Total	**180**	**28**	**72**

Table 5-1: C&DW Arisings and recycling. [3: European Commission (1999)].
"Core" C&DW – Materials obtained when an empty building or other civil engineering structure is demolished, after selective demolition.

As shown in table 5-1, some countries have a better established recycling industry than others. The Netherlands, Belgium and Denmark have always been at the forefront in this area. Lack of local new aggregates and lack of space for disposal may seem likely reasons for the stimulation of an effective recycling industry.

Non-recycled concrete is, together with all other unsorted waste, used for landfill or placed at designated tips. It has historically been the standard solution for all waste produced. During the past years problems with finding new landfill sites have increased. This, in combination with a new consciousness about nature and the environment, has led to a steadily increasing recycling industry.

To find new markets and use recycled concrete in the production of new concrete has consequently become interesting.

There are also experiments of using recycling waste in cement manufacturing [Satish Chandra (1997)]. It is then the fuel which is partly replaced by waste with high heat values, examples given are sludge, waste oil, plastics and rubber.

5.4 Recycled concrete as aggregate in new concrete

A high proportion of demolition waste, particularly the fraction derived from concrete, is well suited for being crushed and recycled as a substitute for newly quarried, primary aggregates in some applications. Crushed and recycled concrete thus has the potential to displace parts of the primary aggregates. As mentioned earlier, crushed concrete could also be used as road fill or as fill in other civil work, not to be set equal to regular landfill.

There is evidence of a general trend for the price of both landfill space and natural (primary) aggregates to rise relative to transport costs [8: Symonds et al. (1999)]. This will help increase the second hand market.

Even in countries with high recycling ratio, the use of recycled aggregates in new concrete was still limited to about one percent of the total recycled aggregates production in 1997, [9: CUR, CSTC and Eerland Recycling (1997)].

5.4.1 Technical aspects

In the end, technical aspects will be the crucial factors for an acceptance of recycled aggregates among concrete customers. Important properties such as

- Strength
- Quality
- Durability
- Consistency

of the concrete will probably have to be documented more carefully before customers will have sufficient confidence to use recycled materials.

Documentation of contamination would further be especially important for an oil or gas platform and the need of keeping the concrete as clean and undisturbed by other materials as possible is obvious. Quality assurance at the recycling plant is then essential.

Concrete Properties could be separated into three categories:

- Mechanical properties
- Physical properties
- Chemical properties

One example of experiments with recycled concrete is a Norwegian study with different ratios of recycled concrete aggregates in pre-stressed precast concrete elements. The study shows an almost unchanged Young's modulus, compressive strength, dehydration and ultimate load strength for up to 100% of recycled aggregates [19: Johansen / Dahl (1999)]

Generally, fractions with aggregates 4-32 mm are easily treated. Fractions below 4 mm have high water absorption and require careful control of the batching and mixing process.

5.4.2 Rules & regulations

Some countries already have national standards or regulations for use of recycled aggregates in new concrete production. Other country standards or regulations have or have had strong limitations for such use.

However, a new joint European standard for aggregate and concrete is under development and should harmonise the approach to the treatment of recycled material across the EU. It is CEN's Technical Committee, CEN/TC154, which has prepared the draft standard, pr EN 12620 - Aggregates for concrete. It will, in time, become a European standard. Another group, CEN/TC154 Ad Hoc group 1998, has in parallel been working with the issue whether to incorporate recycled aggregates into the existing standards or to have separate standards. There is also a proposed amendment to prEN 13043 treating Aggregates for bituminous mixtures and surface dressings for roads and other trafficked areas.

In Norway, in the short-term, 5 % in each fraction (< 4 mm & 4-32 mm), are proposed to be allowed without any limitations, due to an assumption of approximately the same properties as regular concrete aggregates [11: Norsk Betongforening (1999)]. With a classification into type I or type II, according to content, a maximum of 30 % recycled material could be used provided limitations of compressive strength class and environmental class. Otherwise, design is according to national standards.

Due to the complexity of these processes, several EU states, examples given are Germany, the Netherlands, Belgium, Austria and Denmark, have turned to voluntary agreements to promote best practice in management of construction and industrial waste. The arguments are that ordinary rules and legislation can easily be too rigid resulting in less good practice.

5.5 Steel

For steel, carbon steel and stainless steel second hand markets exist. They have been established and working well for many years. It is economically favourable to sell steel, especially high quality structural steel.

The recycling of steel and other ferrous material is, in most cases, achieved through the electric arc method. This method has improved during the last years and represents over one third of the world steel production today [3: The European Commission (1996)].

Reinforcement, steel decks from the shafts, pipes and embedded plates are the major steel parts to be recycled from an offshore concrete structure. The reinforcement and the embedded plates have to be separated from the concrete before recycling, see chapter 8.

5.6 Other materials

All materials must be given an end destination, predefined before the dismantling process starts. Some materials are mentioned below:

- Copper, Aluminium and Zinc are valuable and have existing and well working second hand markets
- Plastics, not PVC, may be separated, granulated and recycled
- Oil and fuels should be re-refined and recycled by the oil companies, assumed free of contamination.
- Batteries should be recycled

Hazardous and toxic materials should have been documented before the recycling process, but must now be sorted out and treated in a satisfactory manner. It is important that these materials do not contaminate the other waste.

5.7 Pollutants

Independent of construction material, deconstruction of installations and their disposal, particularly the platform topsides, could induce greater risks to health and safety than the equivalent construction work.

The topside processing equipment will generally contain hazardous contaminants and residues, which may cause risk of pollution. Also the storage tanks and pipes in shafts and cells could be contaminated.

5.7.1 Hazardous materials

It is important to localise hazardous material before dismantling for several reasons; for personnel safety, the environment, the ability to contaminate normally "clean" waste which would decrease its value.

Examples of materials for special consideration:

- Lead and Nickel/Cadmium in batteries
- Zinc, Anodes, Paints, Galvanised coatings
- Aluminium, anodes
- PVC & EPR, Plastic and synthetic material, control room cable insulation.
- Mercury based lights, fluorescent light tubes
- Halon gas
- Asbestos
- PCB – if not replaced.
- Residual process oil, sludge, diesel etc.
- LSA, see chapter 5.7.4.

The potential environmental impacts from different scenarios are to be considered.

5.7.2 Drill cuttings

Drill cuttings are the deposits of rock removed from the well bore during the drilling process. These materials contain drilling fluid, which modifies their physical character and their environmental effects. There are some different types of drilling fluid on the market. The most common today, is based on water but there are also drilling fluids based on mineral oil and diesel oil. The total volume of drill cuttings could typically be 20 000 –30 000 m^3 for one platform in the North Sea.

Drill cuttings deposits are a general problem for all type of platforms and the deposits are often located around the platform, although depending on the strength of currents. It can also be found above the lower domes/bottom slab and in the drilling shafts. Older cuttings are in general more toxic than younger. Given the toxicity of the first drilling mud mixtures, they should probably never have been dumped in the first place.

There are a lot of proposed ways to treat this material. Examples given:

- Leave as is
- Cover over
- Dispersal
- Removal
- Re-injection

See also [3: The European Commission (1996)].

Each method has its advantages and disadvantages. Drill cuttings are currently the subject of intensive discussions in Europe [17: UKOOA (1999)]. A problem with many of the methods mentioned above is the risk for re-pollution, due to disturbance.

In the Gulf of Mexico, removal of cuttings has been frequently used. The material has been sucked from the seabed, transported onshore and used as landfill. However, the conditions are different with very shallow water.

The UK Offshore Operators Association (UKOOA) is now involved in a detailed study of the issues associated with the accumulation of drill cuttings. The objective is to identify the best environmental practice and the best available technique.

5.7.3 Storage cells

The storage cells will contain seawater together with tons of oily sludge at the bottoms. The walls will in addition have a thin layer of oil and wax, which in total will be many tons.

Seawater in these tanks should be skimmed and the tanks carefully cleaned offshore or onshore.

For example, actual hydrocarbon content of the Brent Spar storage cells was:

Contaminant	**(tons)**
Wax	320
Oil in Tanks	35
Oil in tank bottom sludge	68
Total sludge	550

Source: Shell UK Exploration and Production [6]

Table 5-1: Actual hydrocarbon content of Brent Spar

The hydrocarbon content is also a function of the tank geometry. In the Brent Spar case, the high wax inventory was caused by undersized drainage holes in the internal ring stiffeners of the storage tank.

Estimation of pollutants in these tanks could be difficult. For an example, the estimated quantities of hydrocarbons in the Brent Spar tanks were [6]:

Contaminant	**Shell (tons)**	**DNV (tons)**
Hydrocarbons (wax + oil)	51.0	75 - 100

Source: The Brent Spar Abandonment Impact Hypothesis, December 1994 [6].

Table 5-2: Estimations of Brent Spar

The amount of heavy metals will be different depending of storage tank materials, steel or concrete, as well as platform location, type of oil etc. The heavy metals in the SPAR case, were almost exclusively from the anodes.

5.7.4 Chloride penetration

Concrete in contact with sea water is subjected to chloride penetration. Characteristic chloride load at the surface of the platforms in the North Sea is about 0.7% of concrete weight. Threshold value for initiating corrosion of reinforcement is often set to about 0.07%. The platforms investigated by [25: Bech S.M., Carlsen J.E] will experience this threshold penetrating 50 mm into the concrete after 50 to 200 years, depending primarily on the concrete quality. Typical wall thickness of CGS varies from 0.5 to 1.5 m. This means that crushed concrete from a 0.5m thick wall exposed to seawater for more than 50 years will contain a maximum of 0.04% chloride as an average, i. e. below the threshold value for corrosion. However, chloride penetration must be taken into account when recycling the concrete. Where it is difficult to ensure a uniform recycled aggregate, removing the concrete cover before recycling may be appropriate.

5.7.5 LSA Scale and NORM

Contaminated radioactive LSA scales (LSA-Low Specific Activity), are created by small amounts of naturally occurring radioactive salts from the reservoir formations. LSA scales could be present in the sludge and also in the internals of pipework.

The problem with radioactive contamination in not specific for concrete structures (except for the oil storage tanks) and should in most cases be restricted to the processing and production facilities. However, transport piping used for transport of gas and especially natural gas liquids may be contaminated.

The amounts of LSA are dependent of location of the field and type of production, oil or gas.

The consequences of Naturally Occurring Radioactive Material (NORM) for decommissioning will influence necessary actions. A radioactive survey of the platform will have to be made by a qualified radiation protection officer to identify and label all equipment contaminated by LSA. Work and transportation of this equipment will then be regulated according to international regulations.

In practice very few areas of the platform, considered a LSA platform, will require these special procedures. It is also expected that during dismantling the annual dose due to external exposure never or seldom will exceed the recommended dose limit[1] for members of the public of 1 mSv, due to the short exposure time.

See ref. [6: The European Commission (1996)]

1) Recommended by ICRP – International Commission on Radiological Protection

6 Selection of structural material for new platforms

6.1 General

The choice of structural material for future platform construction must be based on a wider perspective than today. It must be based on environment impact assessments and life cycle analyses in addition to traditional economical and technical analyses.

Thoughts of how to re-use and recycle new platforms may seem far away during construction. However, it is necessary to prepare the platform for deconstruction during construction. It will reduce the re-use and recycling costs and lead to an improved project economy, improved environmental care and probably also a technical better solution.

Comparing risk, cost and environmental benefit and choosing the best practical environmental solution would be one of the oil industry challenges of the future.

Conventional technical and economical aspects have always been important when selecting structural materials for platforms but will not to be further discussed in this report.

6.2 Environmental aspects

The environmental aspects are many and complex. Previous studies dealt with the environmental impacts of decommissioning and with assessments comparing recycling of a structure, to production of a new, see for example: [3: The European Commission (1996); and [14: AURIS Report (1995)]. The latter deals with CO_2 emissions from decommissioning operations and from concrete and steel manufacturing, to replace steel and concrete, which is left in the sea rather than recycled.

6.2.1 Potential environmental impacts

Some important potential impacts on the environment are:

- The effect on the local marine environment.
- The impact of substances left in the sea.
- Use of energy and overall energy balance.
- The impact of production waste.
- Pollution on land and air, due to onshore disposal.
- Disposal of low level radioactive material.

The effects could often be separated into short and long-term effects. The effects should be outlined and studied during the planning process with the help of an environment impact assessment (EIA).

6.3 Environment impact assessment

An environment impact assessment (EIA) is an important tool for assessing different system solutions, constructions techniques etc. All environmental consequences for the different alternatives should be described and judged in the EIA.

Together with the life cycle assessment, the EIA should give enough knowledge to choose the most favourable platform material, which may not be the cheapest option in a short time perspective.

6.4 Life cycle assessment

Life Cycle assessment (LCA) is a method for evaluating and comparing products from an environmental point of view. All environmental loads from cradle to grave are to be taken into account. The products or the constructions must have the same capacity, for example concerning durability or load bearing ability.

Different researchers and organisations have different methods to compare differences in the environmental impacts. Work is going on within ISO to standardise LCA (ISO 14 040).

In reference [27: Jackson/McNulty] life cycle analysis for dry–built CGS is the subject. The paper includes issues as technical-, safety-, environmental-, and energy considerations. It concludes: "The environmental impact of all CGS decommissioning options has been concluded to be relatively low in a number of authoritative studies."

6.4.1 LCA methodology and methods

The Society of Environmental Toxicology and Chemistry (SETAC), divides the LCA procedure in the following steps:

- Goal Definition
- Inventory Analyses
- Impact Assessment
- Improvement Assessment

Translate environmental loads into environmental effects, which are to be weighed against each other, causes several difficulties. Different evaluation methods have been developed from different underlying principles:

- Qualitative Methods - The simplest method based on material inventory analysis.
- Energy Methods - Consider consumed energy in every production step.
- Advanced Methods - Tries to include as much information and effects as possible and to weigh them against each other.

LCA could be performed on a single product as well as on large structures. This method may need to be adapted for offshore concrete structures.

6.5 Economical aspects of recycling

As mentioned before, recycling costs must be considered during construction. Selection of construction materials will then be a key issue. The obvious problem is the prediction of the recycling market in the future. The constructions may be designed for a lifetime of 20-50 years. To make an economic analysis, where recycling costs are to be included, may then prove difficult.

The costs would be dependent on where the platform could be dismantled, thus issues of great importance should be:

- Material Transport Costs
- Access / Price of Primary Materials in the vicinity of decommissioning site.
- Landfill / Deposit Taxes
- Re-use & Recycling Market
- Political Will

The trend today and for the future is a more resource effective community with re-use and recycling as a natural part of a constructions life and the platform decommissioning costs will thus come down as experience grows.

The future way of conceiving and designing new structures may imply a great improvement of removal and decommissioning aspects. Indeed, some concepts may integrate structural dismantleble parts, which could be removed, reused or disposed after cessation of production.

7 Rules and regulations

There are several conventions, guidelines and standards set worldwide, with some especially for Europe & the North Atlantic and some national. The most important ones covering the main parts of all offshore concrete structures are listed below:

7.1 International

- "London Dumping convention" 1972
- UN Convention on the law of the Seas 1982
- *IMO Guidelines and Standards for the Removal of Offshore Installations and Structures on the continental shelf 1989.* (IMO - The International Maritime Organisation)
- *OSPAR Convention 98/3* - This convention protects the marine environment of the North Sea and NorthEast Atlantic by controlling disposal of waste at sea.

7.2 National

In Europe, only UK and Norway have installations in deeper water than 75 metres. Many of these are concrete structures.

7.2.1 The United Kingdom

- Environmental Protection Act 1990
- Radioactive Substances Act 1993
- Petroleum act 1998
- Decommissioning Guidance Notes, DTI´s Offshore Decommissioning Unit, 1999
- Guiding Principles for the Decommissioning of Offshore Installations and Pipelines on the UKCS

7.2.2 Norway

- The Pollution Act 1984
- Petroleum Act 1985
- Safety Regulations 1985
- The Law on Cost Sharing of Abandonment 1985

- Norwegian Petroleum Directorate Guidelines 1990
- Pollution Regulation 1994

8 References

8.1 Literature

[1] NPD, Statoil, A/S Norske Shell, Aker Maritime Contractors: *Phase I, Removal – Offshore Concrete Structures*, 1997-1998.

[2] E & P Forum, *Decommissioning of Concrete Gravity Base Structures*, Report No. 10.13/240, , London, June 1996

[3] The European Commission: *A Technical Review of the possible Methods of Decommissioning and Disposing of Offshore Oil and Gas Installations*, 1996, DG XI and DG XVII, Contract No. B4-3040/96/000259/MAR/D1

[4] Kværner Engineering a.s, *Miljøvurdering av Betongkonstruktioner*, 27 July 1994,

[5] Håndbok i Prosjektering av Betongkonstruksjoner til Havs, SINTEF Konstruktioner og Betong, Juni 1993, SRF70 A93064.

[6] Rudall Blanchard Associates Ltd: *Brent Spar Abandonment BPEO*, and *Brent Spar Abandonment Impact Hypothesis*, Shell U.K. Exploration and Production, December (1994).

[7] Kotter Field & Logger Field, platforms for sale, Conoco Netherlands Oil CO BV April 1996, shallow water, 12 year old.

[8] Symonds, ARGUS, COWI and PRC Bouwcentrum: *Construction and Demolition Waste Management Practices and their Economic Impact*, Report to DGXI, European Commission, Final Report, (1999).

[9] CUR, CSTC and Eerland Recycling: *Use of Recycled Materials as Aggregates in the Construction Industry - State-of-the-Art in Europe*, Report on Brite EuRam III Industrial and Materials Technologies, Contract BRRT-CT-0048, (1997).

[10] Miljøriktig Rivning – Ett Ledd i Byggets Kretslopp, Norsas as – Norsk kompetansesenter for avfall og gjenvinning, Kommuneforlaget AS, Oslo 1999

[11] Norsk Betongforening: *Recycling of concrete and Masonry Materials for Production of Concrete*, NB – Publication no 26, (1999).

[12] Gjenvinning og resirkulering av tunge byggematerialer, Notat DA 1.4 Stabilitet / forurensning, State-of-the-art, SINTEF 1996

[13] Satish Chandra, Waste Materials Used in Concrete Manufactoring, Division of Concrete Structures, Chalmers University of Technology, Göteborg, Sweden 1997. ISBN: 0-8155-1393-3

[14] The AURIS Report: *The Environmental Impacts of Decommissioning*, UKOOA (1995)

[15] OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations

[16] IMO-Guidelines

[17] UKOOA Decommissioning Dialogue Process, Scoping Report, December 1999

[18] Ministry of Environment and Energy, Denmark: *Recycling of Construction and Demolition Waste 1986-1995*, Environmental review no. 6, (1997).

[19] Johansen K., Dahl P. A.: *Hulldekker med Resirkulert Pukk*, BETONGindustrien nr 2, (1999).

[20] Sandahl, Evert, *LCA – Life Cycle Assessment*, Concrete The Green Material II

[21] Parmentier, Remi: *Consequences of OSPAR Decision 98/3 and The Sintra Statement*, IBC Global Conference on the Decommissioning of Offshore Oil and Gas Installations, 20-21 January 2000, London

[22] CEN/TC-154 prEN 12620, Aggregates for Concrete including those for use in roads and pavements

[23] CEN/TC 154 Ad Hoc Group for Recycled Aggregates, Technical Report, Document N 227 E, March 1998.

[24] CEN/TC 154 TG2-347,TG3-108, Proposed Amendments to prEN 13043 to Incorporate Clauses for Recycled Aggregates .

[25] Bech S. M., Carlsen J. E. : *Durability of High-Strength Offshore Concrete Structures*, 5th International Symposium on Utilization of High Strength / High Performance Concrete, June 1999.

[26] Aker, Dames&Moore, Demex, Franzefoss: *Removal - Offshore Concrete Sructures, Phase II - Dismantlement and Recycling Study*, NCC, SINTEF (2001)

[27] Jackson G. and McNulty A. J. W.: *Decommissioning Options for dry-built CGS*, OTC 11024, Arup Energy

8.2 WWW – usable unternet links

http://fib.epfl.ch/	*fib*, Internation. Federation for Structural Concrete
http://www.cenorm.be/	European Committee for Standardisation
http://europa.eu.int/eur-lex/en/index.html	Eur-Lex European Union Law
http://www.greenpeace.org/~odumping/	Greenpeace
http://www.imo.org/	IMO - International Maritime Organisation
http://www.oecd.org/ehs/waste/index.htm	OECD-Work on Waste
http://www.rilem.ens-cachan.fr/|	RILEM
http://www.oilandgas.org.uk/	UKOOA - UK Offshore Operators Association

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