Chapter 8
Decommissioning of Offshore Oil and Gas Installations

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1 Introduction

The offshore oil and gas industry had its beginnings in the Gulf of Mexico in 1947. The first offshore development used a multipiled steel jacket to support the topside production facilities, a design which has since been used extensively. Now there are more than 7000 drilling and production platforms located on the Continental Shelves of 53 countries [1]. Some of these structures have been installed in areas of deep water and treacherous climates, and consequently structure designs have adapted to withstand the environmental conditions of these areas. Some typical designs are shown in Figs. 8.1, 8.2, 8.3, 8.4, and 8.5. In the North Sea, which is an area that experiences some extreme environmental conditions, more than 600 structures have been installed [5], about 25 % of which are in water depths greater than 75 m and can be exposed to maximum storm wave heights of 30 m. This combination of deep waters and extreme storm forces dictates large structures, some with component weights that exceed 50,000 tonnes [6]. For instance, Troll A Platform, which is located in the Northern North Sea and considered one of the heaviest subsea structure in the world, weights 650,000 tonnes. This particular substructure was installed in 1996 and has a height of around 472 m [7] (Petro global news,

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Decom North Sea: *Decom North Sea is working to enhance knowledge transfer and facilitate collaborative activities to deliver "game changing solutions" that minimise decommissioning costs and thus ensure best value for tax payers and maximum business potential for its 300+ European member companies. It is a not for profit members organisation. Website: Decomnorthsea.com*

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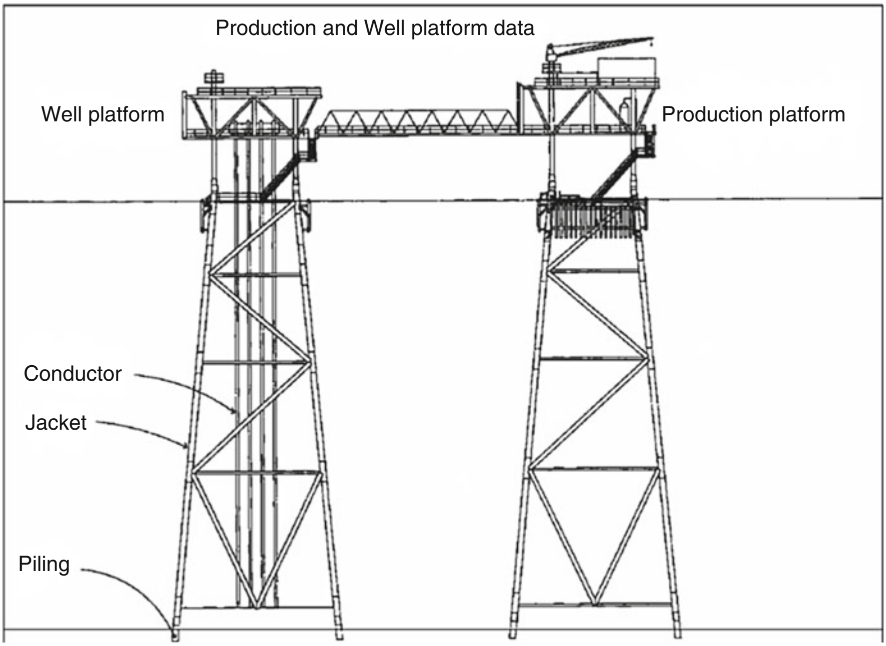


Fig. 8.1 Steel-jacketed structure [2]

2013). Now, as oil and gas fields begin to deplete their reserves, the concern has turned to the removal and disposal of these structures at the end of their producing lives. Estimates indicate that the cost of some removals may exceed the cost of the original installation. The structures located on the Norwegian Continental Shelf contain only 1 % of the world's offshore structures, but will account for nearly 20 % of the worldwide removal costs [4]. Innovative removal and disposal techniques must be developed to limit costs and minimize the impact on the environment. Differently than all the other regions in the world, the offshore structures located within the North East Atlantic have to be removed and disposed onshore. More specifically, the Oslo Paris Convention (OSPAR) 98/3 regulation, issued in 1998, regulates the disposal of offshore structure within the area [5, 8]. Because of this regulation and the fact that decommissioning in the area is a relatively new phenomenon, the Oil and Gas operators operating within the North Sea are under a lot of pressure and are looking for ways to reduce the cost of it [8]. Organisations such as Decom North Sea, are helping the supply chain and operators to interact and collaborate in order to reduce risks and costs of decommissioning process [9].

The Gulf of Mexico, the western and central coasts of Africa, the Persian Gulf, the bulk of the Pacific region and the Mediterranean Sea are all examples of areas with more moderate environments. The majority of structures in these areas are in water depths from 3 to 300 m with maximum storm wave heights of 12 m. With a few exceptions, platforms in these areas will probably be totally removed at the end of their producing lives. The major implication with total removal is in choosing the

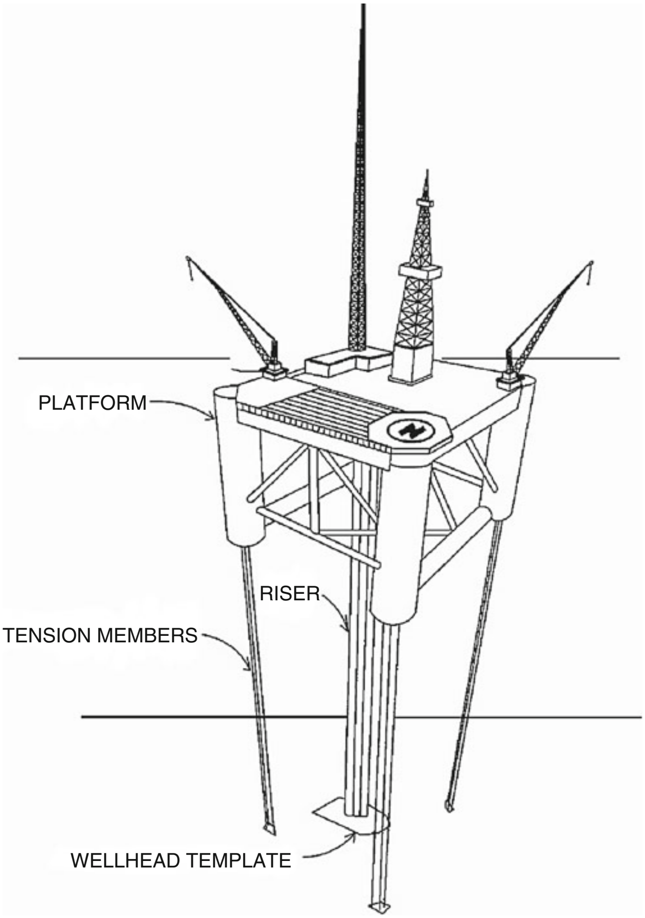


Fig. 8.2 Tension leg platform [3]

method to dislodge the structure from the sea-bed and an issue in remote areas of the world is the availability of support equipment to perform the removals.

2 Legal Framework of Platform Decommissioning

International law provides the basic foundation of the legal requirements for the removal and disposal of offshore structures. The removal of installations was addressed by the 1958 Geneva Convention on the Continental Shelf, which stated that any installations which are abandoned or disused must be entirely removed. However, several parties to the Convention were soon adopting some form of local standards to allow for partial or non-removal. The more widely accepted statement of international law is contained in the United Nations Convention on the Law of

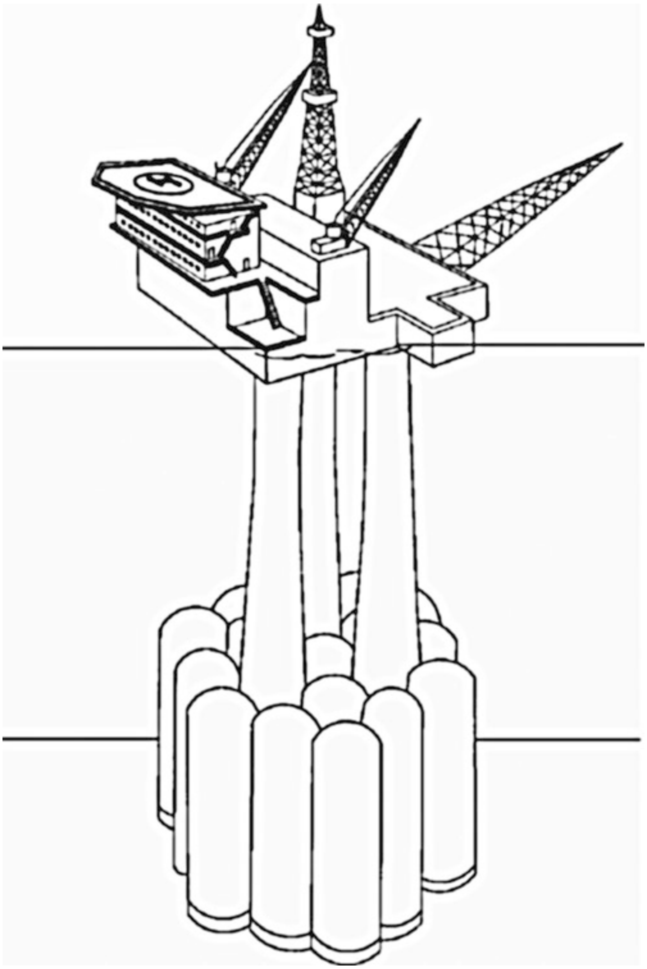


Fig. 8.3 Concrete gravity base structure [3]

the Sea (UNCLOS), which allows for partial removal and has been widely accepted as it appears to represent customary international law in relation to abandonment [10]. The International Maritime Organization (IMO) guidelines were issued using UNCLOS as a basis. These guidelines state that if the structure exists in less than 75 m of water and weighs less than 4000 tonnes, it must be totally removed [10]. Structures installed after January 1988 will have a water depth criterion of 100 m, forcing the owner to plan for the eventual abandonment in the initial design. If the removal is done partially, the installation must maintain a 55 m clear water column. There are exceptions in the guideline that allow for non-removal, e.g. if the structure can serve a new use after hydrocarbon production including enhancement of a living resource, if the structure can be left without causing undue interference

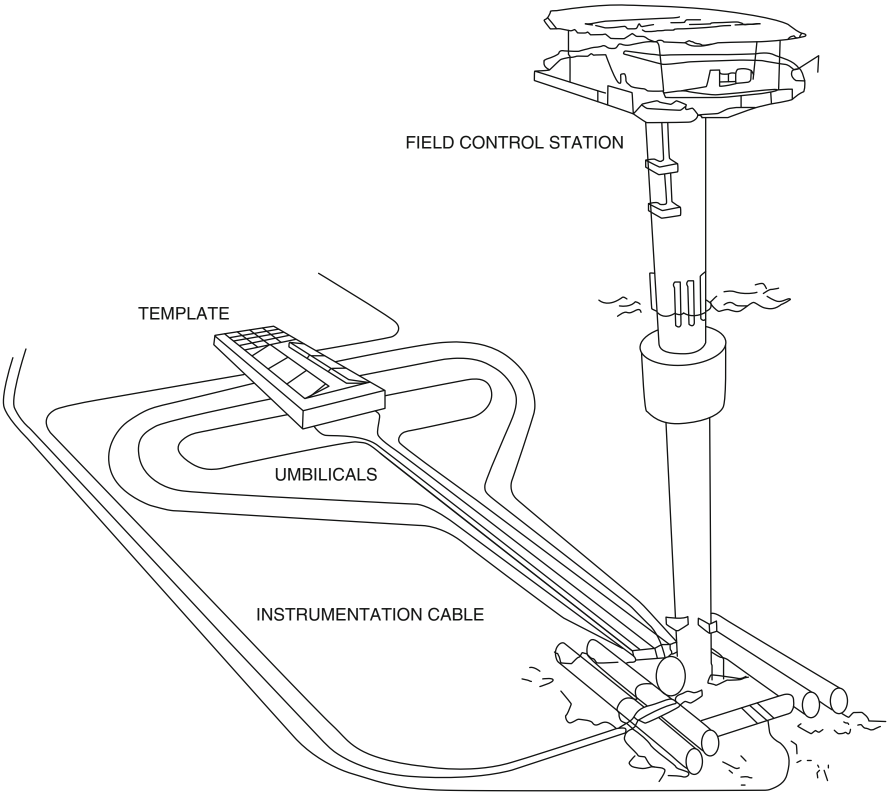


Fig. 8.4 Floating production system [4]

with other uses of the sea or where removal is technically not feasible or an unacceptable risk to the environment or personnel [10]. If the installation is to remain in place, it must be adequately maintained to prevent structural failure.

Basic disposal stipulations can be traced to international dumping conventions. The Oslo Convention of 1972 for the Prevention of Marine Pollution by Dumping from Ships and Aircraft provides some guidelines.

However, it is not clear if this Convention applies to dumping of platforms in place. The London Convention of 1972 on the Prevention of Marine Pollution by Dumping of Wastes and other Matter also supplies guidelines for deliberate disposal of platforms or other artificial structures at sea. UNCLOS deals with dumping, and states that 'dumping within the territorial sea and the exclusive zone or onto their continental shelf will not be carried out without the express prior approval of the coastal state . . .' [10].

The Convention for the Protection of the Marine Environment of the North East Atlantic (Paris 1992) is relevant. It provides that 'no disused structures . . . be dumped and no disused offshore installation shall be left wholly or partly in place in the Maritime area without a permit issued by the appropriate competent authority

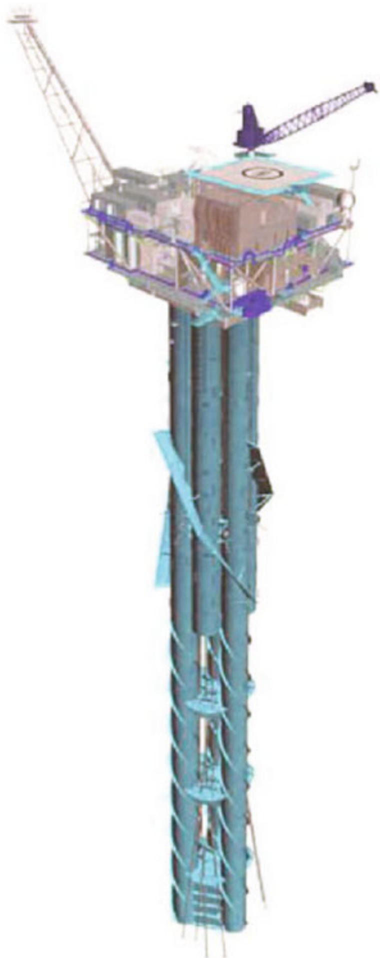


Fig. 8.5 Cell spar (See *color* plates)

of the contracting party on a case-by-case basis', and that 'dumping does not include the leaving wholly or partly in place of a disused installation . . . provided that such operation takes place in accordance with any relevant Convention and with relevant international law' [10].

The body established by the 1991 Oslo Convention, the Oslo Paris (OSPAR) Commission, adopted guidelines on a trial basis to exercise overall supervision over the implementation of the Convention. These guidelines are complementary to the IMO guidelines and aim to minimize pollution to the sea by hazardous residues left in parts of installations disposed of at sea [10]. (The latest regulation of the OSPAR convention about this topic is the 98/3 regulation). The removal of offshore structures in Nord East Atlantic area is regulated by the 98/3 regulation, which prohibit the sea disposal of any offshore structure. However, there are some

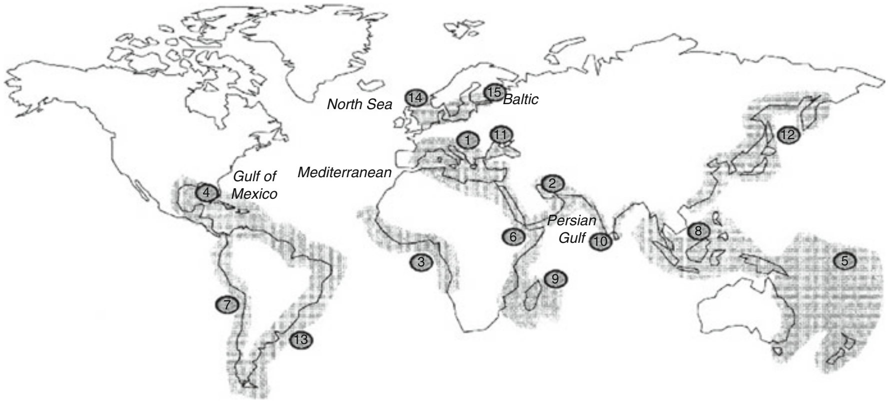


Fig. 8.6 UNEP regional seas program and other conventions

derogations that allow the owner of the structure to ask the permission to leave the structure or part of it in these specific cases:

- The substructure weights more than 10,000 tones
- The removal of a part is considered highly expensive and the operations of removal can highly affect the environment,

While all of the above are basic guidelines to removal and disposal, they do not account for all of the issues involved with the abandonment or disposal of offshore structures. Thus, local states are left to decipher the issues, and to generate legislation to cover loopholes in international law in accordance with their priorities. By 1992, 15 United Nations Environment Programme (UNEP) regional conventions had been held (Fig. 8.6). Here, local states have adopted varying degrees of guidelines for potential legal concerns such as determination of the party responsible for removal, responsibility and methods of payment, responsibility of owners in default situations, owner designation upon non-use, maintenance responsibility and liability for items left in place and such site-specific issues as bottom debris removal and moratoriums for marine migrations.

The complexity of issues has stymied most countries from adopting specific guidelines and standards for platform removal, but most do require abandonment procedures to be submitted to designated regulatory agencies for approval on a case-by-case basis. Some countries, depending on their experience with removals, are fairly mature in their regulatory standards for abandonment, whereas others still have great strides to make in enacting requirements for removals within their coastal waters.

3 Planning

The most critical and time-consuming task of the abandonment process is the planning phase. This phase should be initiated years in advance when depletion plans for a field are recommended. The planning phase can be effectively organized with the aid of commercially available computer software. A software package which allows for input of schedules, tasks, resources and contingencies is recommended. This will be beneficial in establishing the critical path of the project and will help keep the project on schedule for the available construction weather window. A project management software package will enable the project engineer to maintain accurate cost accounting and to keep the project organised, on schedule and within budget.

4 Abandonment Phases

The entire abandonment process, also called decommissioning can be broken down into seven discrete activities [11]:

1. *Well abandonment*: the permanent plugging and abandonment of nonproductive well bores.
2. *Pre-abandonment surveys/data gathering*: information-gathering phase to gain knowledge about the existing platform and its condition. Governing ministries or standards organisations should be contacted to determine permit and environmental requirements.
3. *Engineering*: development of an abandonment plan based on information gathered during pre-abandonment surveys.
4. *Production shutdown*: the shutdown of all process equipment and facilities, removal of waste streams and associated activities to ready the platform for a safe and environmentally sound demolition.
5. *Structure removal*: removal of the deck or floating production facility from the site, followed by removal of the jacket, bottom tether structures or gravity base.
6. *Disposal*: the disposal, recycle, or reuse of platform components onshore or offshore.
7. *Site clearance*: final clean-up of sea-floor debris.

The following is a brief discussion of the sequence of processes involved with structure decommissioning.

4.1 Well Abandonment

The exact timing of cessation of production can be difficult to predict. However, a close working relationship between the reservoir, downhole and salvage engineers should be developed to establish the timing of a well and platform abandonment project. Before abandonment can begin, the salvage engineer must confirm that all wells on the platform are abandoned. The wells should be permanently abandoned according to the recommended procedures of the governing body. Generally this means isolating productive zones of the well with cement, removing some or all of the production tubing and setting a surface cement plug in the well with the top of the plug approximately 30–50 m below the mudline. The inner casing string should be checked to ensure that adequate diameter and depths are available for the lowering of explosives or cutting tools. If the well plug and abandonment are not performed properly, removal of the conductor by explosive or mechanical means becomes unsafe and much more expensive.

There are mainly three ways to operate:

1. Using a mobile drill rig
2. Using a platform rig
3. Using a rigless intervention system

To ensure no delays in structure removal, all well plug and abandonments should be completed several months prior to commencement of offshore decommissioning. After well plug and abandonment responsibility and schedules have been established, the next step is an information-gathering phase.

According to the latest forecast, in the UK continental Shelf area alone, 930 wells are going to be decommissioned in the next decade. [5]

4.2 Pre-abandonment Surveys/Data Gathering

Critical to a successful abandonment program is planning. Proper planning requires that as much as possible about the platform be known. Information must be gathered on the topside deck and support structure design, fabrication and installation as well as any structural modifications that may have occurred since installation. The pre-abandonment survey should assess the condition of the platform facilities and structure prior to beginning the abandonment. The survey should include the following:

(a) *File surveys*. All available documentation concerning the platform design, fabrication, installation, commissioning, start-up and continuing operations should be investigated. The file survey will familiarise the project engineer with the other appurtenances to the platform facility such as living quarters, process equipment, piping, flare system and pipelines and any additions/deletions or structural repairs to the jacket or the topside since the original installation. The project engineer must remain aware that platform records may be incomplete or unreliable. After an extensive search of all available files, the engineer should be able to define the abandonment scope of work and the objectives of subsequent surveys.

(b) *Geophysical survey*. Depending on the results of the file survey, the engineer may choose to have additional data gathered by means of sidescan sonar. This survey will indicate the amount of debris on the seafloor. In the case of deep-sea disposal, the sonar can determine if there are any obstructions at the dump site. Proximity of an available dump site or ‘rigs to reef’ site, water depths and obstructions along the tow route should be investigated as part of the geophysical survey.

(c) *Environmental survey*. This consists of an environmental audit of the offshore platform to identify waste streams or other government controlled materials. At this time items such as naturally occurring radioactive materials (NORM), asbestos, PCBs, sludges, slop oils and hazardous/toxic wastes should be identified and quantified. The problem of dealing with these waste streams should be addressed in the scope of work for handling during the decommissioning phase of the project. The project engineer should determine what permits or operating parameters are required by the host government or international standards.

(d) *Structural survey*. A structural engineer can use observation and non-destructive ultrasonic testing techniques to evaluate the structural integrity. Items inspected will include condition and accessibility of lifting eyes, obstructions on the deck which may require removal and interfaces between production modules/deck and deck/jacket which may require cutting for disassembly. Discrepancies between actual conditions and as-built information identified in the files should be noted during this phase. The platform legs should be checked for damage that may obstruct explosives or cutting tools from accessing the proper cutting depth. If obstruction from damage is anticipated or found, smaller diameter charges or cutting tools should be provided by the removal contractor as a contingency. Information concerning the underwater condition of the structure should be available from previous underwater inspections. If not available, consideration should be given for gathering this information by divers or remote-operated vehicles (ROVs).

4.3 Engineering

Upon completion of pre-abandonment surveys, a strategy for decommissioning and abandonment can be developed. The engineering phase takes all of the data previously gathered and pieces it together to form a logical, planned approach to a safe abandonment. Of major concern during the development of this strategy is the safety of the operations. As with all offshore operations, there exists a high potential for accidents involving bodily injury or loss of life and the accidental discharge of oil and flammable, corrosive or toxic material into the environment.

A risk analysis for all phases of the decommissioning should be performed. The results of this risk analysis are used to develop a decommissioning safety plan. Safety targets can be set and achieved provided the appropriate attention is devoted to the elements of the decommissioning plan. These procedural elements include the following items:

- regularly scheduled safety meetings;
- identification of safe work areas;
- safety equipment and training for emergency situations;

- working at high elevations and over water;
- safe operations of cutting tools and explosives;
- safe demolition to maintain structural integrity;
- proper use of rescue and evacuation equipment;
- diving and ROV operations;
- testing for and monitoring of toxic/explosive gases;
- pollution controls and containment;
- methods for handling and disposal of oil wastes, corrosive, NORM, or toxic materials;
- weather monitoring/night watch procedures;

Addressing each of the above-mentioned elements will help in the development of a safe decommissioning and salvage plan. After all the safety and environmental aspects of the project have been considered, details of the salvage process need to be identified. The sequence of process equipment and structure decommissioning and the salvage and disposal methods need to be determined. Any required government permits should be submitted for approval.

A major determination for an effective and efficient abandonment program is proper selection of the salvage equipment. Equipment selection for lifting purposes is determined by maximum weights of components to be lifted. Heavy Lift Vessels (HLV) currently available to the industry range from approximately 135 to 48,000 tonnes (Fig. 8.7).

Early 2015, a new HLV, called Pioneering Spirit has been launched. It has been considered part of the next generation for HLV, as it has the ability to lift a jacket that weights 25,000 tons max or a topside that weights 48,000 tons max [5, 12]. This vessel will play a fundamental role in the next period since there will be a need for more time efficient removals.

Other lower capacity, less expensive lift spreads can be used if the lift weights can be broken down through equipment removal or by cutting the components into smaller lifts.

Cost comparisons must be made between the time savings afforded by heavier lift, more expensive equipment and time-consuming, lighter lift, less expensive equipment. In addition to costs, the project engineer must assess the safety and environmental risks associated with sectional removal. Sectional removal will require significant time at the site for dismemberment and removal of production piping and equipment prior to cutting the topside deck into pieces. Additional hazardous tasks involved with decommissioning, lifting and rigging operations need to be performed offshore in a sectional removal, thus the time during which personnel will be exposed to increased workplace hazards will be increased. More details pertaining to sectional removal will be addressed in Sect. 4.5.

Once the sizing of equipment is complete, a qualified list of contractors can be generated based on equipment availability and the area of the world in which the salvage is to take place. Awarding of the job based on the list of qualified contractors can be carried out in many ways. Two often used methods are bidding out the job for award to the lowest bidder or by negotiating a contract with the

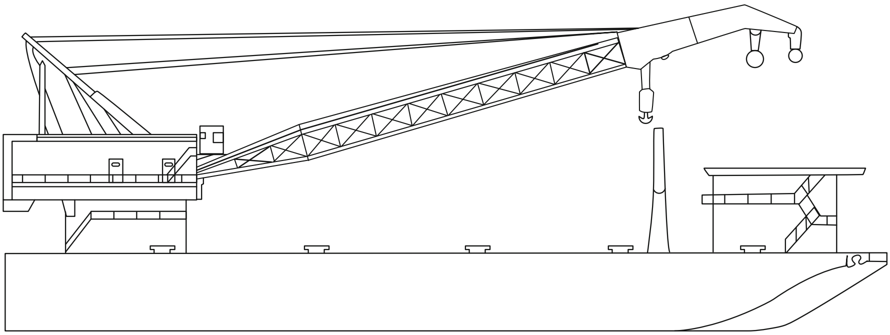


Fig. 8.7 Derrick barge

contractor who is most capable of performing the work. The job scope could include all aspects of the abandonment from the well abandonment to the final site clearance. Another method might be to award each portion of the abandonment and salvage as individual components similar to the breakdown of the seven phases of abandonment.

4.4 Production Shutdown

A primary objective during the production shutdown is to protect the marine environment and the ecosystem by proper collection, control, transport and disposal of various waste streams. Production shutdown is a dangerous phase of the abandonment operation and creates the possibility of environmental pollution. Shutdown and removal or abandonment in place should be carried out by personnel who have specific knowledge and experience in safety, process flows, platform operations, marine transportation, structural systems and pipeline operations. All contractors involved with the shutdown should be brought in early in the planning stage to further assure a smooth decommissioning project.

The sequence of shutting down the process system, utilities, power supplies and life support systems is important. The platform's power, communications and life support systems should be maintained for as long as practicable to support the decommissioning effort.

Process systems throughout the platform will have to be flushed, purged and degassed in order to remove any trapped hydrocarbons. Safe lock-out, tag-out, hot work and vessel entry procedures must be in place to ensure safety. Procedures must outline all duties of the standby/rescue teams including the use of breathing apparatus, air purging and lighting and caution must be exercised in removing all amounts of gases, oils and solids which may still remain in valves, production headers, filter housings, vessels and pipework that could present hazards to the crew.

Platform decommissioning will result in large amounts of waste liquids and solids. Where possible, waste liquids can be dealt with most cost effectively by placing them in existing pipelines and sending them to existing operating facilities. If no ongoing operations are available, then the waste streams will have to be pumped into storage containers and transported onshore for disposal or recycling. The constituents of the waste stream will dictate the cost of disposal. Solid wastes such as discarded batteries, glycol filters and absorbent rags will also have to be handled onshore according to acceptable disposal practices. Many platforms will have chemical treatment additives as well as possible toxic/hazardous materials such as methanol, biocides, antifoams, oxygen scavengers, corrosion inhibitors, paints and solvents, some of which may cause damage to the marine environment if accidentally discharged. Therefore, the procedures for handling and containing should be followed. The presence of radioactive scale, NORM, PCBs, hydrogen sulfide, etc., should have been detected during the environmental survey and a disposal plan developed. Disposal will generally mean transporting this material in drums to disposal wells or approved landfills.

Prior to removal, a detailed plan on how each material will be disposed of should be developed. The plan should identify recyclable materials such as steel, rubber and aluminium and the recycling centres that will take delivery of these materials. For those items not to be recycled, the abandonment plan should include the environmental impact that disposal will have on the dump site.

After the process piping and vessels have been cleaned and it has been determined that there is no future utility for the pipelines, pipeline decommissioning should commence. Pipelines departing the platform will either board another platform or commingle with another pipeline via a sub-sea tie-in. A surface to surface decommissioning is the least costly to perform. This requires pigging the line to vacate any residual hydrocarbons followed by flushing with one line volume of detergent water followed by final rinsing with one line volume of sea water. Upon completion of the pipeline purging operation, pipeline ends should be cut, plugs inserted and the ends buried below the sea-bed. In the case of a sub-sea tie-in, details of the sub-sea tap will have to be obtained so that pipeline decommissioning plans can be developed. The flowline can be pigged, flushed and disconnected if the receiving platform can accept the fluids, otherwise the pipeline segment will have to be isolated from the adjoining trunkline and then decommissioned. This will generally involve a boat capable of mooring over the sub-sea tie-in, connecting flexible piping to the tie-in using divers or ROVs, then pumping pigs, detergent water and rinsing water toward the platform for handling.

Decommissioning involves a variety of waste streams, disposal handling methods and specialty contractors. This phase more than any other will determine the success of the abandonment and salvage.

4.5 Structure Removal

The method of a structure removal will be determined by the structure design, availability of removal equipment, method of disposal and the legal requirements governing the jurisdiction in which the abandonment is to take place. The legal requirements will usually be based on the social, economic, environmental and safety concerns of the local governing bodies. All of these issues are interrelated and will have a direct effect on the overall cost of the removal operation. The economics of the removal are of prime importance to the party responsible for the removal, whether it is a contractor, local government or producer. Each structure consists primarily of the topsides or deck above the water line and the jacket below the waterline.

4.5.1 Deck Removal

Topsides removal is essentially the reverse sequence of the installation. Any piece of equipment obstructing the deck lifting eyes must be removed prior to the lift. The deck section is removed by cutting the welded connection between the piles and the deck legs. Slings are attached to the deck lifting eyes and the crane hook on the heavy lifting vessel (HLV). The HLV's crane lifts the deck section from the jacket. The deck is then placed on the cargo barge and readied for transportation to a land based facility for offloading [13].

4.5.2 Jacket Removal

The jacket portion of the platform consists of the steel template which resides in the water column. Prior to removing the jacket, the piles must be cut to dislodge the jacket from the seafloor. The majority of structures in moderate environments will be totally removed. Most regulatory bodies throughout the world require that the structure be removed anywhere from the mudline to 5 m below. The chief consideration when developing a removal procedure is to determine if the piles or well bores will be severed using explosive or non-explosive methods.

(a) *Removals using explosives*. Severing platform piles and well bores with explosives is relatively effective compared with using non-explosive methods, as multiple cuts can be made in a short period of time. This limits the amount of time that removal support equipment must be on the site and limits personnel exposure to unsafe working conditions. Generally, explosives are the least expensive and the method of choice for structure removal. However, when explosives are used, more stringent regulations may become effective, including consultations with the local fishery or natural resource agencies. A project plan should allow lead time for consultations and permit approval from these agencies. Explosives emit high-energy shock waves that can be harmful to habitat fisheries immediately adjacent to a removal site and some endangered species, such as marine turtles or mammals, in close proximity to the detonations may be mortally affected by these shock waves. Local regulations should be researched to determine limits to the amount and size of charges allowed and to determine if moratorium periods exist during marine migration periods.

In some areas, a condition for approval requires that observers from the local regulatory agencies and/or resource groups be present at the removal site prior to detonations, to observe that permit requirements are being met and to ensure that no harm is done to endangered species that may be in the area. Other conditions that may be imposed to limit the effects of explosives on habitat fisheries are pre-detonation aerial surveys, daylight-only working hours and staggered detonations.

Numerous studies are ongoing to reduce the harmful effects on local fish populations during detonations. Focus or shaped charges concentrate the detonation energy to the target, requiring less explosive weight with the same cut efficiency. The disadvantage of focus charges is that they need to be properly set in the well bore or pile and corrosion scale or damage in the piles can inhibit the charge from applying its full energy to the target.

A technique to reduce the effects of explosives on habitat fisheries is to evacuate the platform piles of all water. This reduces the resistance of the shock wave from the charge to the target. Also, special shock-attenuating blankets can be placed at the mudline to limit the energy emitted from the seafloor. Another technique may be to deter fish from entering the blast area. Small, preset charges set off prior to the detonation of the severing charges, known as scare charges, have been used. However, there are risks that scare charges may actually draw some species of curious fish toward the blast site. The use of strobe lights similar to those used to keep fish away from dam intakes may be effective.

(b) *Non-explosive removals*. An option for the project engineer is to eliminate the use of explosives in the removal. Use of non-explosive removal techniques eliminates the impact due to shock waves. Consequently, costs and time associated with observers and additional permit conditions may be eliminated. However, salvages using non-explosive methods can be more costly since only one pile or well bore can in practice be severed at one time. Each non-explosive cut will typically take several hours to perform. The additional time and cost can be minimised depending on the scope of work and with proper project planning. The project engineer should perform a precise cost estimate, evaluating the costs and risks between using explosive and non-explosive methods of severing. The following is a discussion of some non-explosive severing techniques.

High-pressure water/abrasive cutters. This system uses a high-pressure water jet operating at anywhere from 200 to 4000 bar to perform the cut. In some systems, sand, garnet or other type of abrasive is injected into the water stream to aid in the cutting process. The nozzle is lowered into the hole attached to an umbilical hose line or a hard pipe supply line. The nozzle is rotated 360° inside of the pile or well bore until the cut comes back on itself. One of the advantages to the system is its effective cutting ability. The casing strings do not have to be concentric in the well bore. The wall thickness of the platform piles is typically not a concern. The reaction of the water spray and the returns of the water give the operator an indication that the cut is actually being made. Some disadvantages are the tendency for system breakdowns due to the high working pressures, electrical and mechanical complexities, the delicate characteristics of the abrasive injection and wear and tear on the nozzle. Interrupting the cutting operation requires that the tool be placed in the exact location of the cut to avoid incomplete cuts. The effectiveness of these cuts is reduced at deeper cutting depths owing to the hydrostatic head that the water jet needs to overcome. As with all cutters, the tool must be centred in the pipe to maximize cutting efficiency. This can be difficult in heavily scaled pipes or in battered piles. Topside instrumentation can be used to monitor the position of the cutting tool during the cut. Camera technology has been used to inspect visually the status and effectiveness of a cut.

Mechanical cutters. Mechanical cutters use tungsten bit cutters that are extended from a housing tool with hydraulic rams. The tool is rotated continuously using friction to perform the cut. Disadvantages include frequent breakdowns of the tool due to frictional wear and tear, high labour intensity in handling heavy and bulky tools, the need for a work platform around the piling/well bore to be cut and poor cutting performance on non-concentric casing strings. Also, it can be difficult for the operator to determine if a cut is complete. Shifting of the well strings or platform piles downward can jam the tool into the kerf of the cut.

Diver cut. Internal or external pile or well bore cuts can be made with divers using underwater burning equipment. This type of cut can be made internally if there is access for the diver into a large-diameter casing or piling. If there is no internal access and the cut must be made below the mudline, a trench must be excavated to afford the diver access to the area to be severed. In some soils, keeping a trench open to the required 5 m depth may be impractical and may put the diver at undue risk from trench collapse. If the cut must be made below the mudline, the local regulatory agencies should be consulted as to the required depth of the cut. This may require obtaining a waiver to reduce the required cutting depth due to local soil characteristics and safety concerns for the diver personnel. Another concern to the diver's safety is oxygen entrapment in the soil near the cut or on the backside of the pipe being cut. Oxygen build-up can lead to an explosion if contacted with a flammable source such as a burning rod.

Cryogenics. Cryogenics is a little used technology that consists of freezing the platform pile in the area of a cut with CO_2. A relatively small explosive charge is then placed at the elevation to be cut and detonated. The brittle behaviour of the frozen steel theoretically requires little energy to sever the pile. To use cryogenics, water must be completely evacuated from the pile, which can be a time-consuming operation. Also, the cutting efficiency is hindered by the freezing of the mud on the exterior of the pile to be severed.

Plasma arc cutting. Plasma arc cutting is achieved by an extremely high velocity plasma gas jet formed by an arc and an inert gas flowing from a small-diameter orifice [14]. The arc energy is concentrated on a small area of metal, thus forcing the molten metal through the kerf and out of the backside of the pipe. Water can be used as a shielding agent to cool and constrict the arc [14]. The process requires a high arc voltage provided by specialised power sources. This method has not been used often, and is therefore not highly developed. For it to be effective, the tool must be set properly in the cut pipe. It is difficult to determine if a cut is being made unless camera technology is used.

Whether using explosives or non-explosive methods of severing, obstructions in the pile can hinder the proper placement of charges or cutting tools in the well bore or pile. Examples of obstructions include scale build-up, damaged piling, mud or pile stabbing guides. The removal of mud from the pile is generally accomplished with the use of a combination of a water jet and air lifting tools. When properly designed, these work well. This task is traditionally performed after the topside deck has been removed by the heavy lift contractor. A more cost-effective technique is the use of a submersible pump to excavate mud from the platform pile prior to removal. A small inexpensive work spread can be mobilised to the site prior to the arrival of the heavy lift equipment to perform this task. A window is cut into the jacket leg/pile and the submersible pump is then lowered down the jacket leg on a soft umbilical line.

(c) *Alternative removal techniques*. Most structures are removed with heavy lift equipment such as oceangoing derrick barges. In remote areas of the world, another concern in dislodging the platform from the seafloor is the availability of salvage support equipment. International Maritime Organization (IMO) guidelines permit the host government to allow a structure to remain in place provided that the structure is properly maintained to prevent failure. Maintenance costs over the life of the installation may eventually exceed the cost of the removal. When left in place, the platform may remain a hazard to navigation, exposed to collapse during storms or become a haven for refugees. These risks and liabilities may outweigh high removal costs to the host government and the operator, thus the decision to remove the platform may prevail.

Innovative methods of decommissioning, removal and disposal must be proposed to offset the lack of available salvage equipment and the high cost of equipment mobilisation to remote areas. An alternative approach is cutting the platform into small, manageable components that lighter, more cost-effective equipment work spreads can handle. The equipment that may be used includes crawler cranes, A-frames and portable hydraulic cranes mounted on a cargo barge and these methods use readily available equipment that can be rigged up inexpensively.

Besides additional decommissioning hazards, other precautions must be taken during a sectional removal. Caution should be taken when cutting into a structural member as gases from scale or other sources may have built up over time inside of the member, and flame cutting into the member could result in an explosion. Each member should be drilled and checked for gases prior to any flame cutting operations. Sectional removal requires a detailed plan for lift sling connections and cut locations for each component to be removed. Lift slings should be properly attached so that a safe, level lift can be made, and a level, controlled lift will eliminate load shifting and allow for proper setdown on the transport barge without undo risk to personnel or equipment. Removal of a structure in sections may require multiple cuts underwater. The same concerns with load shifting and sling placement exist for underwater cuts as they do for above-water cuts. These cuts should be performed and/or supervised by skilled divers. Divers' activities can be reduced by using small shaped charges to sever members or by performing cuts with ROVs.

Other forms of less expensive salvage support equipment include bargemounted 'stiff legs' and converted jack-up drilling rigs. Stiff legs have the capability to handle large lifts, but generally have limited hook height and are not easily manoeuvrable during the lifting and setting of components on transport barges. Stiff legs are generally built to work in protected waters and are affected by rough seas.

Converted jack-up drilling rigs are becoming more common in the abandonment industry. Companies are converting obsolete rigs to lift vessels to take advantage of the increased need to supply salvage support equipment. This type of equipment can work in heavy seas when in the jacked-up position, but in the floating condition manoeuvrability is limited.

Extreme caution must be taken when bringing transport barges near the jack-up rig to accept platform components. The legs of a jack-up rig cannot withstand any severe impact loading.

Another technique that can be used for the lifting of platform topsides is the Versatruss system (Fig. 8.8). The method uses a series of A-frames mounted on tandem cargo barges. The combination of the A-frames, tension slings and the topside deck create a catamaran and truss effect for lift stability. This lift method also uses available equipment and requires relatively low-cost preparation.

(d) *Alternative structure uses*. In some areas of the world, the host government is either wholly responsible for structure removal or, through participation by a national oil company, is partially responsible for the cost of structure removal. The political entity may not want to dedicate funds to a nonrevenue generating project. These states may decide that leaving the structure in place is the only alternative. IMO guidelines give local states the discretion to allow offshore structures to remain in place if the removal is not economically feasible. In these situations, operators will need to review the contract terms for possible ongoing or future liabilities.

Alternative uses for the platform should be explored. The benefit of the alternative use should offset the costs to maintain the structure in place. Some alternative uses may be as follows:

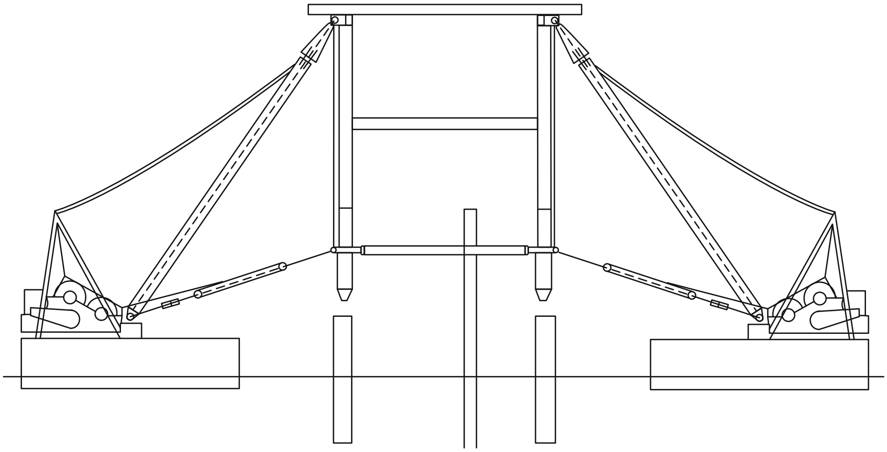


Fig. 8.8 Versatruss method (Source: Versabar Inc)

- fish farm;
- marine laboratory;
- military radar support structure;
- weather station;
- oil loading station;
- spur for deep-water developments;
- aviation/navigation beacon;
- tourism/recreational;
- power generation, i.e. wind/wave.

Leaving the structure in place should not create a hazard to local fishing industries or to navigation in the area.

(e) *Platform reuse*. Reuse is another option. If a potential development can finance the removal of a structure, this relieves the non-revenue producing property from absorbing the salvage costs. Platform reuse can reduce the cycle time to get the new development in production, generating cash. However, an immediate reuse should be identified when decommissioning is undertaken. Storage of the platform onshore prior to identifying a reuse can result in costs that may offset the savings from reuse.

One of the latest examples of platform reuse is the Welland 53/4a, operated by Perenco. The platform topside was refurbished and brought to West Africa, more specifically offshore Cameroon where now is part of a operational gas field [15].

(f) *Partial removals*. The Partial removal consists of leaving part of the structure in the sea. This process is considered beneficial for oil and gas companies and the environment. The cost of the decommissioning process will be reduced and the structure left will generate a new marine ecosystem around it [5, 8]. These partial removal methods will consist of the following (Fig. 8.9):

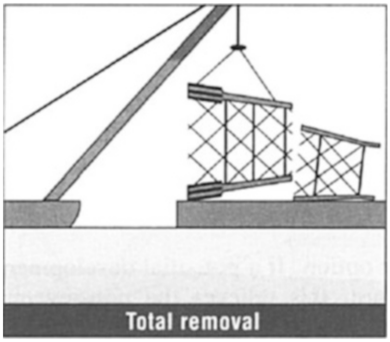


Fig. 8.9 Total removal [16]

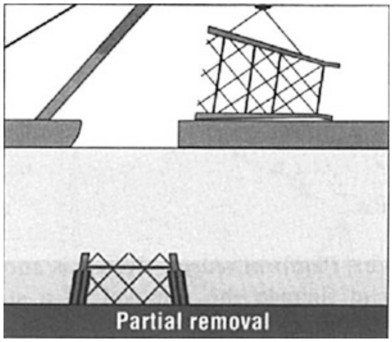


Fig. 8.10 Partial removal [16]

- partial removal of jacket component (Fig 8.10);
- toppling in place (Fig. 8.11);
- total removal of topside and toppling in place of the jacket only (Fig. 8.12);
- emplacement (Fig. 8.13);
- transport to rigs to reef site;
- deep-water dumping.

The choice of removal method will depend on cost, proximity to disposal sites, availability of removal equipment, location of the removal relative to shipping lanes and fishing interests, and safety and environmental issues. In addition, the disposal method will play a key role in the decision on the removal method. The next section summarises the alternatives and key issues concerned with structure disposal.

4.6 Disposal

Once a platform or portions of a platform have been removed, the structure must be disposed of. Some disposal options include the following:

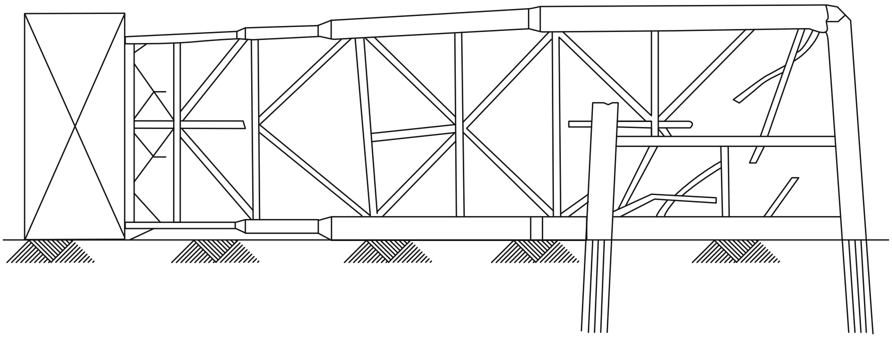


Fig. 8.11 Hinge point in jacket leg

- transport inshore for disposal, storage or recycling;
- toppling in place;
- disposal at a remote rigs to reef site;
- emplacement;
- deep-water dumping.

The owner must be aware of the social and political climate in the area where abandonment and disposal are to occur. Public perception will play a key role in performing a successful disposal program. All environmental issues should be addressed by the operator up front, all stakeholder groups and regulatory agencies should be informed of the disposal plans and environmental effects of the plan and alternatives must be addressed. Miscommunication and misinformation to or from interested stakeholders could lead to the downfall of an otherwise well planned abandonment strategy.

Non-jacketed designs such as floating production systems, concrete structures, steel gravity structures and spar loading buoys will probably be refloated in whole or in part and towed away, and disposed of in deep-ocean disposal sites or brought inland for dismantling. Steel-jacketed structures will probably be disposed of in one or any combination of the ways mentioned above. Explanations of these methods are detailed below.

(a) *Disposal inshore*. Generally, topside deck facilities will be disposed of inshore because of the difficulty and expense in completely removing all of the hydrocarbons and their by-products at the installation site rather than shore-side. When disposal inshore is chosen, the structural component will be either totally or partially cut up for scrap. Portions may be disposed of in landfills or hazardous waste sites or recycled. The component may also be stored for future use or refurbished immediately if a reuse is identified. Once a structure has been removed for inland disposal, possession of the removed structure and their components is usually turned over to the removal contractor in exchange for a portion of the scrap value. The steel in offshore structures is of relatively good quality and is readily taken by steel mills for recycling. The handling and

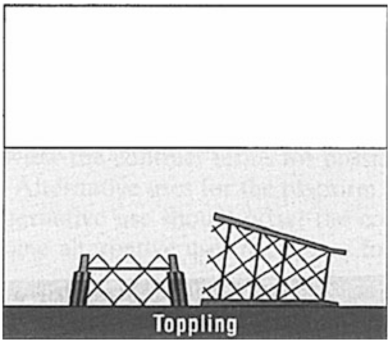


Fig. 8.12 Toppling [17]

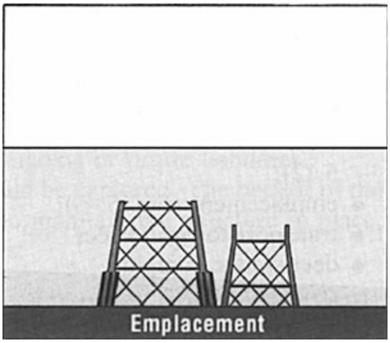


Fig. 8.13 Emplacement [16]

disposal of all other materials associated with the removal should be detailed in the pre-abandonment disposal plan.

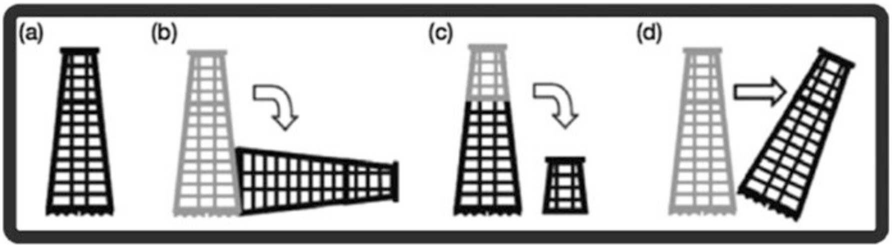
The UK Offshore Operators Association performed a detailed assessment of the amount of waste materials projected from the disposal of offshore structures from the North Sea. Disposal amounts were calculated and the effect on the available landfill space was determined [18]. Another study, performed by planners for a removal in Norway, detailed costs and benefits of recycling an old structure. The study compared the emissions placed in the atmosphere by melting and breakdown to the cost of the energy and associated emissions generated if the same component was built new [4].

An environmental assessment could be made based on these studies. These types of analyses would be beneficial to the operator and regulatory bodies when the decision is made to bring offshore components inshore.

(b) *Rigs to reef*. This technique consists in creating an artificial reef using part of the existing structure of a platform. Normally during this process the topside is removed and the jacket is used to create the reef. When an offshore structure is removed, a habitat for fisheries and a source of recreational fishing is lost. It has been estimated by the Gulf of Mexico Fishery Management Council that oil and gas structures account for 23 % of the hard bottom habitat in that area [2]. Prior to the emplacement of petroleum-related structures, suitable habitats in which new species could expand their range did not exist. Countries may establish a rigs to reef program to maintain the hard bottom habitats that these structures provide. When performing a cost comparison between dumping a platform at a reef site or disposal inshore, the size of the platform, location of the platform in relation to the placement site and the transport costs are the main factors.

There are four main techniques that can be used to generate an artificial reef [8, 19]:

1. Leaving part of the structure as it was during the operations (a).
2. Sinking the entire structure by shifting it (b).
3. Cutting the top part of the structure at 85 ft below the sea and placing the cut part on the sea bed (c).
4. Towing the structure to another site (d).



Rigs to reef options (Source: Mecreadie et al. [19])

By choosing these techniques, both the environment and the operators may benefit. The marine environment will benefit because the created marine habitat won't be entirely destroyed and the pollution generated by the decommissioning operation activities will be reduced (ibid; [8]). In addition, Oil and Gas operators will not face the cost of total removal and will be able to invest more money in other projects [8].

The first two options consist in leaving the structure as it was and in placing it on the sea bed. These two options are easier to perform than the other ones.

The third option consists in toppling the structure. The toppled structure must maintain 85 ft of clear water column clearance as required by IMO guidelines. Another method is to cut the top section completely from the lower section, lift it off, place it on the bottom to the side and topple it with heavy-lift marine equipment. In the Gulf of Mexico, toppling may only be performed in established reef sites. The site should be clearly marked with buoys. In the Gulf of Mexico, the buoys are maintained by the state, whereas in the North Sea the responsibility remains with the operator to mark and maintain the site. In other parts of the world, marking is negotiable between the operator and the host government. The site should also be placed on navigation charts. Similar to the rigs to reef option the toppling in place will reduce costs for the oil and gas companies and will benefit the environment.

A common method of transportation is to tow the structure while on the hook of the removal barge crane. Derrick barges are not constructed for this purpose, so extreme caution should be taken if this method is used. Weather and obstructions both below and above the water along the tow route should be anticipated. If the heavy-lift equipment has to accompany the structure to the placement site, this subjects the project to costly weather and operational delays. The need for the derrick barge at the disposal site can be avoided by setting up a winch and snatch block system to push the structure off the transport barge. These costs have to be weighed against the removal and transport of the platform components inshore. A rigs to reef program benefits the fish population and provides a popular source of recreational fishing while giving the project engineer an additional option to reduce platform removal costs.

The toppled structure must maintain 55 ft clear water column clearance as required by IMO guidelines. Another method is to cut the top section completely from the lower section, lift it off, place it on the bottom to the side and topple it with heavy-lift marine equipment (Fig. 8.12). In the Gulf of Mexico, toppling may only be performed in established reef sites. The site should be clearly marked with buoys. In the Gulf of Mexico, the buoys are maintained by the state, whereas in the North Sea the responsibility remains with the operator to mark and maintain the site. In other parts of the world, marking is negotiable between the operator and the host government. The site should also be placed on navigation charts. Similar to the rigs to reef option the toppling in place will reduce costs for the oil and gas companies and will benefit the environment.

(d) *Emplacement*. Emplacement (Fig. 8.13) is much the same procedure as toppling except that the top section is completely cut from the lower section, lifted off and placed next to the lower section.
(e) *Deep-water dumping*. Essentially, the structure is disconnected from its moorings and towed to the deep ocean waters where it is then flooded and sunk. Prior to any dumping operations, it is important to confirm that all components placed in the ocean waters are free of hydrocarbons in harmful quantities to avoid pollution of the open sea.

Partial removal may consist of any combination of the above-listed options. The method of structure and component disposal should be based on legal, environmental, safety, financial and timing issues. Identification of a disposal site and its proximity to the removal site must be considered to perform a cost analysis on the most effective disposal method.

An inherent concern with any disposal method is tying down the salvaged component on the transport barges, which can be particularly difficult and dangerous in rough weather. A well thought out plan has to be enacted to assure a safe and stable lift and placement on the transport barges. All components should be tied down with a system that provides the same integrity as when the platform was towed offshore for installation.

A marine surveyor should be available on-site to monitor the tie-down operations. The marine surveyor's responsibilities include confirming that the structure is secure for tow, certifying that the tow route is free of overhead, width or bottom obstructions and verifying proper ballast of the transport barge.

4.7 Site Clearance

The final phase of the abandonment process involves restoration of the site to its original predevelopment conditions by clearing the seafloor of debris and obstructions after platform removal. If the abandonment was a partial removal, site clearance procedures may vary from a total removal. In the case of total removal, debris should be removed, leaving the site trawlable and safe for fishing or other maritime uses.

A site clearance plan may consist of two or three phases, depending on the information gathered during the pre-abandonment surveys and the water depth at the location. The first phase may occur before actual removal with divers making sector sweeps around the platform site during pipeline decommissioning. High-frequency sonar can be used to locate obstructions and direct divers to debris. Searches should be performed inside and outside the platform a distance of at least 100 m. Following this initial debris removal, site clearance can be discontinued until the structure removal has taken place.

Once the structure has been removed, the site is ready for a final clean-up if required. In shallow waters, a trawling vessel can be used to simulate typical trawling activities that may occur in the area after the platform removal.

Deeper water sites may not require trawling simulations to clear the area. Proper planning prior to the removal of debris can make a significant difference in controlling the costs. The geophysical survey performed with the side scan sonar during the pre-abandonment survey phase should identify the major debris, and this information will provide the basis for selecting the most effective equipment, personnel and timing. Equipment and personnel can range from a dive crew retrieving debris off a boat during pipeline abandonment, through a small derrick barge with divers to a boat capable of mooring over debris targets away from the platform. In deep waters, it is crucial to determine the amount and type of debris to size the equipment and work crews properly. Upon completion of the bottom clean-up, job completion summaries should be submitted to the proper governing body.

5 Conclusion

The offshore oil and gas industry will be faced with more than 7000 platform removals, each of which will include a multitude of tasks, involving interaction between operators, contractors, regulatory agencies, governing bodies and the public. Of importance to the operator will be the cost effectiveness of the removal. The operator will also share in the public and regulator's concern on the effect that the removal will have on the environment. The operator should focus on early interaction with regulatory agencies, detailed pre-removal planning and engineering, efficient interface and timing of equipment and personnel movements, safety and disposal to assure a cost-effective removal with minimum impact on the environment. Finally, all stakeholders should continuously pursue advances in rulemaking and technology to ensure each abandonment program improves on the one that preceded it.

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