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RIGS AND OFFSHORE STRUCTURES

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Introduction

The rapid advance in offshore engineering and physical oceanography has provided mankind with the ability to emplace and maintain structures that support what are effectively small cities in some of the ocean's harshest environments. The majority of these offshore structures are associated with the development of hydrocarbon extraction off the world's continents. Offshore structures have been focal points for controversies concerning pollution and hazard to navigation, yet serve as a basis for many coastal economies. Oil spills, drilling muds, and produced water have been continuous public and regulatory issues. Ironically, oil and gas platforms have also been the target of the locally popular 'rigs to reefs' program since the early 1980s. State and federal governments of the United States have encouraged states and private sector organizations to maintain these structures as artificial reefs as it is perceived that they improve fishing on a local scale. In addition to their ecological value as 'artificial reefs' these platforms are now recognized as excellent facilities for research as we explore our Earth's final frontier.

History

Since the mid 1950s approximately 7000 structures associated with oil and gas development have been emplaced on the continental shelf and slope, and are now approaching the ocean basins (**Figure 1**). The majority of these structures ($>65\%$) are along United States Gulf Coast, and the remainder are concentrated in the North Sea, Middle East, Africa, Australia, Asia, and South America.

The oldest, most well developed, and largest concentration of structures is in the US Gulf of Mexico (GOM). There are currently about 4000 oil and gas platforms off the coasts of Louisiana and Texas, and industry is now challenging depths in excess of 900 m and over 220 km from shore. The GOM now hosts over 99% of structures associated with US offshore petroleum production. The earliest of these structures were installed in the late 1920s, and were wooden structures erected with steam power and human muscle in the shallow bays and near-shore coastal waters. They were later followed by single piled caissons and multiple leg concrete structures. As technology improved, large steel towers supported by multiple, pipe-like legs approaching 200 cm in diameter were used on the continental shelf by the 1950s. Today, engineers use wire-supported towers and floating platforms in water depths not suitable for standard steel frame structures.

Oil and gas structures come in a variety of shapes and sizes (**Figure 2**) that reflect engineering demands depending on water depth, range of sea state conditions, advancements in engineering design, metallurgy, and ocean physics (e.g. currents). Several of the larger platforms have set engineering records for their time, and current structures reach 3.5 km tall. The largest of these structures are found in the North Sea, where ocean conditions are amongst the harshest in the world – winter storm waves can exceed 45 m in height and last for many days. These types of environments demand tremendous feats in engineering. For example, the North Sea 'Troll' weighs over 1 million tons, is over 450 m tall, and is expected to have 70 year lifetimes to exhaust the mineral resources beneath its legs. North Sea structures dwarf those found in the rest of the world.

Environmental Issues

Public perception of oil and gas development has been greatly influenced by oil spills, visual pollution,

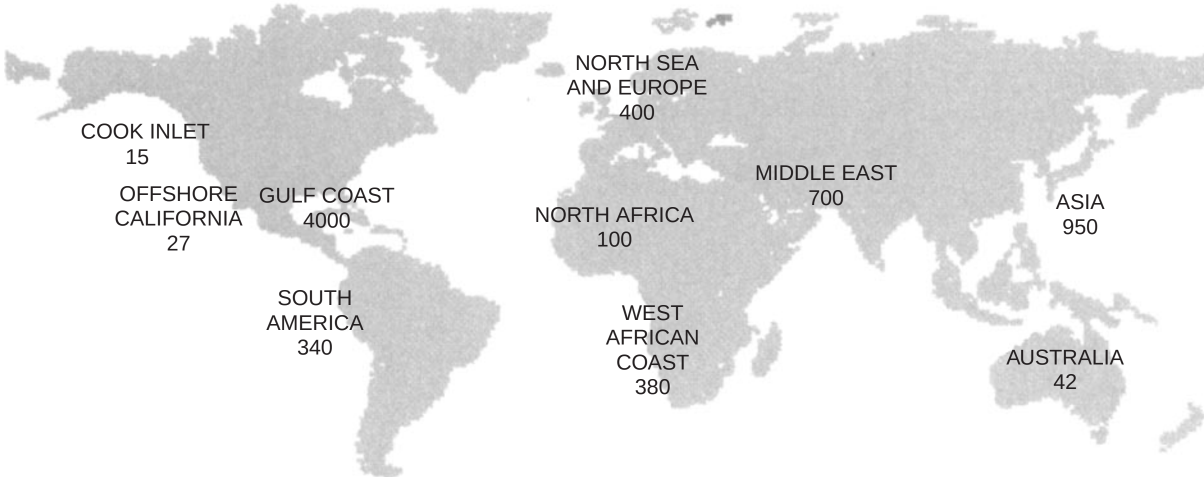

Figure 1 Distribution of the world's offshore platforms in the year 2000. (Information provided by William Griffin.)

drilling discharges, and unrelated but dramatic oil tanker accidents. The greatest wealth of information concerning oil and gas environmental issues comes from regulations enforced by the Environmental Protection Agency of the United States and regulations of the UK government for operations in the North Sea. Otherwise, international treaties guide the environmental conscience of industry such as the International Maritime Organization and the Law of the Treaty of the Sea. During the early exploratory years of offshore drilling there were several recorded instances of oil spills and the occasional 'blow out'. However, over the past 25 years strict regulations, put in place by the developed countries (e.g. the US Minerals Management Service and the Environmental Protection Agency), have provided safeguards to prevent such ecological disasters.

Environmental concern of the 1980s focused on the fate of discharged fluids and drilling mud. Several books have been written about produced waters; these are the hydrocarbon-permeated waters pumped to the surface with oil and gas. Recently US regulations were enacted that require operators of platforms located in 60 m of water or less to re-inject produced waters back into the wells. Farther offshore these fluids are discharged in association with large compressor-driven bubblers that mix produced water with the surrounding water. The fate of the re-injected produced waters is unknown. Drilling muds have also caused a major amount of concern due to the heavy metals present in them. A number of studies have been funded by the US Mineral Management Service to investigate the impact of drilling muds. The general conclusions of these studies were that environmental impacts of drilling muds are confined to the area immediately around the drilling site.

The oil and gas industry in the Gulf of Mexico has enjoyed a much different public relationship with the community than off California and elsewhere. Since the first platform was placed off California there has been strong public objection concerning visual pollution and the potential for chemical pollution. However, the oil and gas industries of Louisiana and Texas have notably had a dramatic impact on coastal economies, and enjoyed a very positive relationship with the recreational and commercial fisherman. These user groups have come to depend upon the industry for infrastructure support as well as fishing opportunity. The oil and gas industry has been friendly toward helping fishermen in distress, providing weather updates, and serving as a visual reference point for navigation prior to the advent of Loran or GPS technology. Most noteworthy is the common knowledge that fishing around platforms is exceptional and that the Gulf Coast oil and gas industry does not object to fishermen mooring to a structure.

The appearance of oil and gas platforms has inadvertently impacted on historic or developing fishing fleets along the world's coastlines. High coastal primary and secondary production serves as the basis for production of commercial and recreational fisheries. Coincident with the large oil and gas fields, the crustacean fishery in the Gulf of Mexico is amongst the world's largest. Likewise, the North Sea has historically been one of the richest trawling fisheries in the world. Offshore structures interfere with net fisheries through their physical presence and the materials that were discarded from the oil and gas platforms during the earlier years of development. These issues have plagued Gulf of Mexico shrimpers for years. In the United States there are federal and state regulations and efforts by

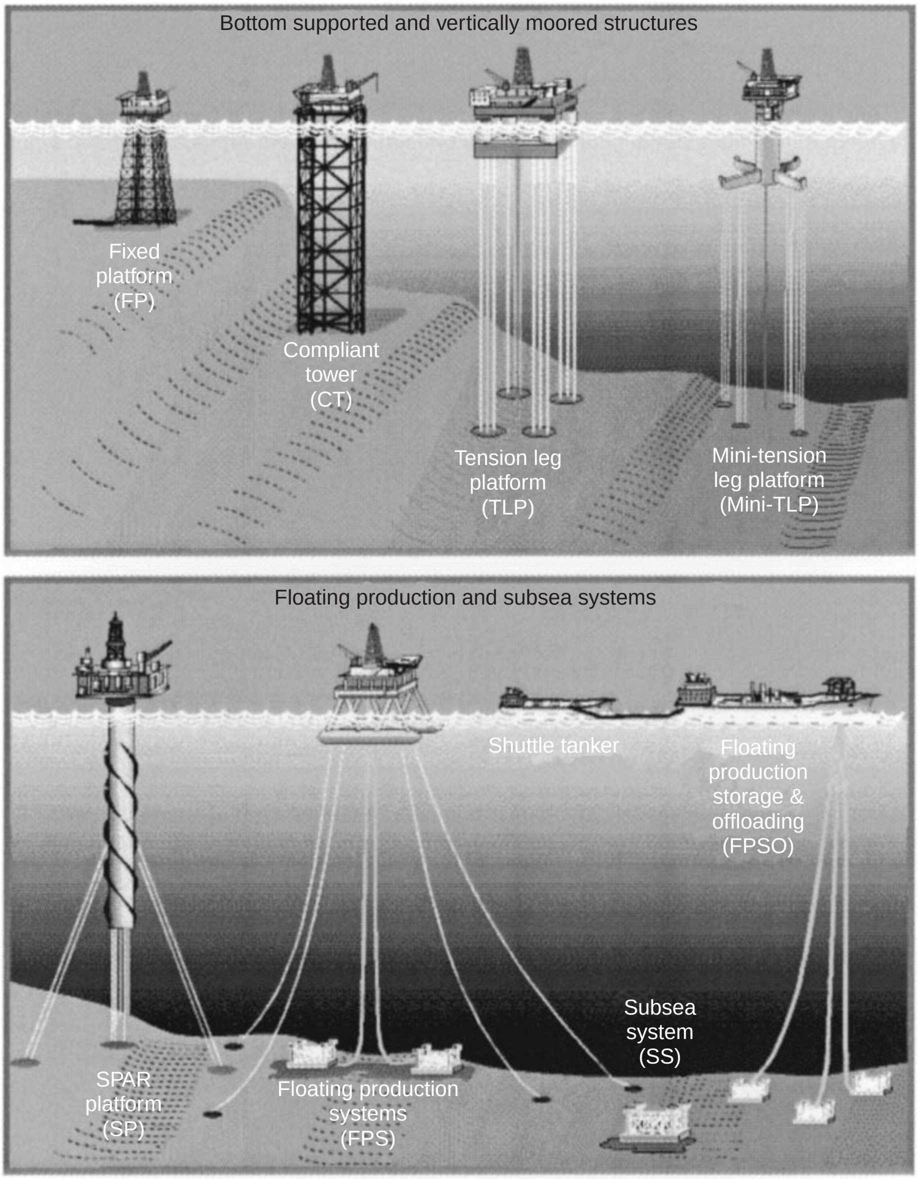

Figure 2 Various shapes and sizes of common offshore platforms (modified from the http://www.gomr.mnms.gov/homepg/offshore/deepwater/options.html/deepwater info).

major oil and gas companies to totally eliminate all debris associated with oil- and gas-related activities. However, fishermen are still catching artifacts which are damaging to their gear, and oil and gas companies have gone to great lengths to provide funding mechanisms to replace the various gear that are damaged. Nevertheless, industries still coexist in most areas.

'Rigs to Reefs'

It is the observation of many federal and state fishery managers throughout the world that fisheries are in a serious state of decline. The last assessment by the FAO indicated that well over 60% of the world's fisheries were in a state of overfishing or overfished and in decline and that the world's fishery harvest is at maximum. As mentioned above many of these fisheries are located in areas of oil and gas development. It has been suggested by some that the presence of oil and gas platforms actually provides a 'safe haven' for many of these fish species that prevents them from being captured. On the contrary, scientists and managers have also proposed that platforms in fact make fish easier to catch for the hook and line fisherman.

Since the first platforms were emplaced in the Gulf of Mexico, off California, and other parts of the world where hook and line fishing activities occur, fishers have realized that these tall steel structures serve as fish havens or ‘artificial reefs’. Scientists have documented that catch rates around platforms in the Gulf of Mexico (number of fish caught per hour per person by hook and line) are amongst the highest in the world. Popular recreational and commercial species such as red snapper, gray snapper, amberjack, mackerel, tuna, marlin, sheepshead, and triggerfish are abundant around the platforms on the continental shelf of the Gulf of Mexico. Charter boat fisheries and commercial fisheries now depend upon many of these structures for income. Pursuant to the public’s perception of the fishery value of oil and gas platforms, several states including Louisiana, Texas, Mississippi, and Florida have established artificial reef programs that encourage the use of oil and gas platforms as artificial reefs. In most cases these are extremely positive and cooperative efforts between state regulators and industry to establish specific areas for the long-term maintenance of fishing opportunity.

However, these programs have their opponents. Scientists have yet to establish whether artificial reefs in general, and specifically oil and gas platforms, concentrate fish and make them easier to catch or if artificial reefs increase productivity and benefit some life stages of a fish species. Most scientists have come to an agreement that artificial reefs and specifically platforms increase productivity for some fish species and concentrate others. However, the extent and value of that habitat has yet to be determined. A major concern for species such as red snapper is that the benefit of increased production and survival may be outweighed by increased vulnerability to human capture. Due to the hook and line vulnerability of some fish species, such as red snapper, regulators continue to pursue the use of obsolete platforms as artificial reefs, ‘rigs to reefs’, with caution.

The Minerals Management Service of the United States has funded a number of ecological investigations off California and in the Gulf of Mexico to explore the ecology and habitat value of platforms. Scientists at Louisiana State University have established that an average of 25 000 fish 12 cm in length inhabit the area immediately around and under oil and gas platforms; such density is 50–1000 times greater than adjacent soft bottom sediment. The fish community associated with offshore platforms includes a number of important recreational and commercial species. Research in the Gulf of Mexico indicates that species composition for near-shore platforms (typically within 50 km offshore) is dominated mostly by estuarine species, while platforms farther offshore contain more pelagic and tropical species. However, this is not the case in the North Sea, where species composition is dominated predominantly by pelagic species. Divers in the GOM have also reported large schools of larval and juvenile species of fish that obviously depend upon the hard steel substrate for protection, orientation, and perhaps food. Scientists in the North Sea report fish densities around large steel towers to be two to three times higher than adjacent water bottoms. Hence, there is little debate regarding the higher numbers of fish living around offshore structures than adjacent water bottoms.

The Rigs to Reef issue is fairly unique to the United States, although there has been limited interest in other parts of the world such as Australia, Japan, and in the Caribbean. In reality the utility of oil and gas platforms as artificial reefs will be limited to the most developed countries where recreational and commercial fishing command attention.

Removal

Federal law in the United States, law in the UK, and EC, as well as international treaty through the International Maritime Organization, requires that once an oil and gas company has completed extraction of oil and gas hydrocarbon reserves the platform must be removed and the bottom returned to its original state. This law was developed through international agreements to protect navigation and military interests, and to preserve ocean ecology.

During the early years of oil and gas development, when the industry was operating in shallow water, technology existed for the removal of these massive structures. Since then the semi-permanent placement of offshore structures has challenged engineering and led to several new disciplines, the most formidable of which is decommissioning. Currently the technology does not exist to remove deep-water structures like the Troll, Mars, and others (**Table 1**). The majority of the structures in shallower waters will be subject to removal over the next 50 years.

The oldest platforms, particularly those in the Gulf of Mexico and off California, are 20–30 years old and are nearing the depletion of their hydrocarbon reserves. Several international organizations continue to debate removal technology, and to explore ocean dumping as an alternative. Most of the environmental groups throughout the world strongly oppose this activity, as the concept of ocean dumping is not palatable to most people. Shell’s North Sea Brent Spar incident in 1995 illustrates the public’s sensitivity to ocean dumping. Greenpeace

Table 1 Company, structure name, water depth, and date of installation of deep-water structures in the Gulf of Mexico, USA[a]

Operator	*Structure name*	*Water depth (m)*	*Date installed*
Shell Offshore Inc.	COGNAC	312	1 Jan. 1978
Shell Offshore Inc.	BULLWINKLE	412	1 Jan. 1988
Conoco Inc.	JOLLIET	536	1 Jan. 1989
BP Exploration & Oil Inc.	A	335	1 Jan. 1991
Exxon Mobil Corporation	A	423	3 Oct. 1991
Shell Deepwater Production Inc.	A	872	5 Feb. 1994
BP Exploration & Oil Inc.	A	393	19 Aug. 1994
EEX Corporation	COOPER	639	7 Jul. 1995
Shell Deepwater Production Inc.	MARS	894	18 Jul. 1996
Kerr-McGee Oil & Gas Corporation	NEPTUNE	588	19 Nov. 1996
Shell Deepwater Production Inc.	RAM-POWELL	980	21 May 1997
Amerada Hess Corporation	BALDPATE	502	31 May 1998
Chevron USA Inc.	GENESIS	789	21 July 1998
British-Borneo Exploration, Inc.	MORPETH EAST	518	10 Aug. 1998
British-Borneo Exploration, Inc.	ALLEGHENY SEA	1004	19 Aug. 1999
Elf Exploration, Inc.	VIRGO	344	17 Sep. 1999

[a]From http://www.gomr.mms.gov/homepg/offshore/deepwater/options.html.

blocked the towing of the Brent Spar out to sea, and gas stations were burned in Germany in association with this highly publicized event. The British Government conceded to public pressure and reversed its decision to allow ocean dumping, and the fate of the Brent Spar is yet undecided. It is however a reality that the oil and gas industry will be faced with some serious engineering questions as these deepwater platforms are retired.

The accepted removal technology along the continental shelf involves the use of explosives where the platform legs are severed 5 m below the mud line. Not only are explosives extremely damaging to the marine environment and the associated explosion kills most of the 10 000–25 000 fish that live around a platform, but also the activity involves risk of human life as divers are frequently lowered down inside the legs to place the explosives. More recently mechanical cutting and cryogenics have been used. Cryogenics is still improving and mechanical cutting is practical only to depths of about 60 m. There are many challenges to removing a large steel platform that is some 3.5 km long. The engineers of deepwater platforms of this size need to provide designs or methods for removal when the structure depletes the petroleum stores.

Research

Not only do the oil and gas platforms serve as a support structure for operations involved in the extraction and transmission in oil and gas; these platforms also serve as excellent research stations. The ocean is a final frontier for exploration, as we know more about the surface of the moon than we do about our continental slopes and ocean basins. To aid in the quest for knowledge, many major and minor oil and gas companies have allowed scientists on their platforms for the purpose of research over the past 20 years.

The US Minerals Management Service has funded a number of ecological investigations to explore the physical, chemical, biological, and meteorological events that occur around oil and gas platforms. These permanent steel structures provide us with the opportunity to collect long-term databases on changes in weather pattern and shallow and deep water currents, to track bird migration, and to monitor the aquatic biological community in many parts of the world. This information will be invaluable in predicting the path and strength of hurricanes, to follow changes in sea life due to global warming, and improve general knowledge of the world's oceans and resolve the impacts of offshore structures and the marine environment. This research activity is carried out at a fraction of the cost that it would be if larger vessels were used to collect this data, and under weather conditions that prevent research vessel operations. Oil and gas companies are often cooperative in providing logistical support (lodging and meals) and transportation for scientists who visit these platforms for such investigations. Obviously information such as hurricane path and current patterns are of extreme interest to the platform engineers as well as to coastal resource managers in state and federal government. The advent of microwave, satellite, and cellular technology allow for the transmission of real-time data collected at these platforms and much of this information is being made online to students around the world, in addition to the scientists that use the data.

Summary

Offshore structures are concentrated in areas of oil and gas development off most coastal countries of the world. Platforms will be a common sight along the world's coastlines for as long as hydrocarbon resources are present. Although the industry provides the energy to fuel the world, the presence of offshore structures has both positive and negative impacts concerning pollution, navigation, and fisheries production. Current development and research is being implemented for the best use of offshore structures concerning these issues. Offshore structures are the result of remarkable feats of engineering, and engineers are continually challenged in the design and in the removal guidelines within the constraints of current technology.

See also

Acoustic Scattering by Marine Organisms. Coral Reef Fishes. Coral Reefs. Demersal Fishes. Metal Pollution. Oil Pollution. Pelagic Fishes.

Further Reading

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RIVER INPUTS

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Introduction

Rivers represent the major link between land and the ocean. Presently rivers annually discharge about $35\,000\,km^3$ of freshwater and $20–22 \times 10^9$ tonnes of solid and dissolved sediment to the global ocean. The freshwater discharge compensates for most of the net evaporation loss over the ocean surface, groundwater and ice-melt discharge accounting for the remainder. As such, rivers can play a major role in defining the physical, chemical, and geological character of the estuaries and coastal areas into which they flow.

Historically many oceanographers have considered the land–ocean boundary to lie at the mouth of an estuary, and some view it as being at the head of an estuary (or, said another way, at the mouth of the river). A more holistic view of the land–ocean interface, however, might include the river basins that drain into the estuary. This rather unconventional view of the land–sea interface is particularly important when considering the impact of short- and medium-term changes in land use and climate, and how they may affect the coastal and global ocean.

Uneven Global Database

A major hurdle in assessing and quantifying fluvial discharge to the global ocean is the uneven quantity and quality of river data. Because they are more