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Review of Offshore Industry and Engineering Development

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ABSTRACT: *This paper introduces a review and literature study of offshore engineering and constructions from 1920s to 2000s. The study was focused on the literature survey and the history of Brown & Root and J. Ray McDermott in the Gulf of Mexico and other offshore areas. The fluctuations of oil and gas prices have been strongly influenced the development of offshore industry since its very beginning. Scientific projects on the space and under the earth had played very important roles in offshore development in 1950s and 1960s. Deepwater developmentshave been influenced by the computer assisted analysis and design in 1970s and 1980s. Innovative technology provided continuous developments of deepwater structures in 1990 and after.*

1. Introduction

This paper introduces a literature survey and review of offshore industry, engineering, and constructions from 1920s to 2000s. The study was focused on the literature survey and the history of Brown & Root and J. Ray McDermott in the Gulf of Mexico and other offshore areas.

Understanding the offshore history and background of offshore development is an essential ingredient for the initial conceptual design. This study was motivated to enhance the capacity of conceptual design and Front end engineering design (FEED) of offshore structures in Korea.

2. Before the Dawn

Industry experience of drilling in inland lakes and protected bays was used for offshore drilling in 1920s and 1930s. Oil had been produced in Caddo Lake in Louisiana since 1911 by drilling from a wooden platform. In 1928, a submarine had been used to survey the seabed at Gulf of Mexico (GOM) by the gravity method. This method was replaced by the coring method in 1934. First geological survey of the Galveston bay was conducted in 1933. The Great Depression in 1934 curtailed most of the inland and offshore activities.

In 1936, the first offshore pipeline was laid from an offshore tank to onshore by Brown & Root. In 1938, a wooden trestle (pier) was built at McFadden beach in Texas near Louisiana. At the end of the 1.6 km long trestle, a drilling platform was constructed (Pratt et al., 1997).

A very large wooden platform was built at Crole field near the coast of Louisiana in 1938. Crole means white descendant of French settlers in Louisiana. The Crole platform was supported by 300 creosoted (coal tar coated) wooden piles of 0.3 m (12 inches) diameters and the system was 55 m by 100 m, with space for derrick, drilling mud, pipe rack, and power supply but no quarters for the working crew. The Crole field production is considered as the first open water oil in GOM.

Larger self-contained platforms were constructed within the sight distance from the shore using the so called the stick-building method in 1930s and 1940s. The most significant design limitation was the lack of knowledge of hurricanes on offshore structures in GOM.

In 1920s and 1930s, many platforms were built at Lake Maracaibo in Venezuela. Lake Maracaibo is surrounded by lands and the sea conditions are very calm. By 1929, Venezuela was second oil producer to the United States (McGhee, 1965; Leathers, 1959).

3. Offshore Industry in 1940s: Birth of Modern Offshore Era

In 1947, a small platform "Kermac 16" was constructed offshore Louisiana at about one-fourth the cost of the larger self-contained platform. Reduction of the cost of the platform was achieved by using a tender (service) vessel to carry much of the equipment and personnel. A 12 m by 22 m non-self-contained platform was much smaller than the most

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previous offshore drilling platforms. The oil production from Kermac 16 platform is called as the birth of modern offshore oil and gas industry because the platform was located beyond the sight from the land (Pratt et al., 1997). Offshore oil had been produced in GOM before 1947, but always in sight from the land. Kermac 16, in 6 m water, 17 km from the shore, exposed to the fury of waves and wind in open water, went a step beyond those previous developments. A new era of technical innovation of producing oil from beyond horizon was started and this idea was spread throughout the world.

In 1940s, larger self-contained platforms were also continued by improvement in the design and construction in GOM. One of the major oil companies, Magnolia, built a large self-contained platform in 1946. Magnolia used hundreds of wooden piles to support the platform structure, but it also used more than fifty steel pilings. This platform marked the birth of the steel age and death of the wood pilings in offshore platforms.

In 1947, an ambitious self-contained platform "Humble Grand Isle 18" was constructed, which was located 10 km from land, in 14 m water depth. In addition to the water depth attained, the size and design of this platform were new. This giant platform was all steel and it was built using templates or "jacket" fabricated onshore.

The logic behind the use of jacket was overwhelming, and their widespread adoption altered the history of offshore platform construction. A New Orleans based J. Ray McDermott developed this critical innovation of jacket for Superior oil company, which provided more strength and solved many problems of the stick-building method.

Table 1 Early platforms till 1940s

Year	Description	Remark
1911	Oil produced in Caddo Lake	Inland lake
1920s	Platforms in Maracaibo, Venezuela	Protected sea
1934	Great Depression	
1936	Pipeline from offshore tank to onshore	First submarine pipeline
1938	Wooden trestle at McFadden beach,	Pier with a rig
1938	Creole field platform	First oil in GOM
1947	Kermac 16 platform	Birth of modern offshore industry
1947	Magnolia platform	First offshore steel
1947	Grand Isle 18 platform	First all steel
1947	Jacket Platform for Superior Oil	First jacket platform

The advantages included easier installation, stronger underwater bracing, and lower costs of onshore fabrication (Lee, 1968).

The templates were adopted quickly on platform construction throughout the world. Table 1 summarizes the early offshore platforms till the 1940s.

4. Offshore Industry in 1950s: First Major Phase

World War II impeded the progress of offshore industry. Offshore industry focused on military ships and supplies. Even after the WWII, indeed after the Korean War, military demands and steel shortages limited the growth of offshore industry. During the same periods, U.S. states and federal government argued over the ownership of offshore area. In 1953, the so called Tidelands Act was established for the ownership of 3-mile of offshore area to the states and beyond area to the federal government. Tideland Act in 1953 accelerated the legal framework for leasing the offshore area. Offshore industry made notable advances of the first major phase of development. Many war surplus ships and barges were converted for offshore oil industry. The race to offer bigger and better offshore equipment had begun (Calvert, 1957).

The geophysical exploration techniques of water-covered area had also advanced. Geologists first used gravity meters in very shallow water. Then the core drillings were followed. But as water depth increases, seismograph, which explored subsurface by recording the reflected sound waves, was widely used to find the accumulation of petroleum.

Submersible type of drilling rigs were used in shallow water but they were replaced by elevating-deck or jack-up rig in mid-1950s. Former U.S. president George Bush founded Zapata Offshore Company in 1955. Mr. Bush, who was truly a pioneer in offshore industry, ordered a unique unproven, untested 3-legged jack-up "Scorpion" in 1956 and other innovative drilling rigs later. The 3-legged jack-up became the most common type of mobile drilling unit for offshore operations. Floating vessels and semi-submersibles also provided important advances during the 1950s.

In 1954, the first truly offshore pipeline was laid 17 km out from Louisiana. The pipeline was 10-inch diameter, concrete-coated gas gathering line and was laid in water depth ranging from 4 m to 10 m at average lay rate of 0.8 km per day by Brown & Root. Another 12-inch, 77 km long pipeline was laid in 1955. A number of full-time pipelayers were constructed in late 1950s. The first purpose-built laybarge "L.E. Minor" was built by Brown & Root in 1958. A novel device called a "stinger" was used to ease the pipeline to the bottom of deep waters in early 1960s.

In 1956, one of the largest platforms to date was constructed at a record depth of 35 m for CATC (Continental, Atlantic Richfield, Tidewater, Cities Service) group offshore Louisiana. The deck measured 30 x 45 m, allowing 12 wells to be drilled. Total height was 145 m, from 46 m below the mudline, to the derrick top 64 m above the water. After analyzing wave, wind, and soil condition, this CATC jacket was designed sixteen 33-inch piles with a batter (slope). It was the first battered-leg platform which provided more stiffness compare to vertical platforms. The CATC platform survived for 50 m/s wind and 6.2 m waves of hurricane Flossie in 1957.

The year 1958 marked the end of what might be called the first major phase of offshore development in GOM. Exploratory drilling dramatically fell off its rapid pace of mid-1950s. A recession and oversupply of U.S. crude oil discouraged oil companies from investing on new exploration. Still, the late 1950s was a transition for the offshore industry rather than an extended slowdown. In stead of drilling for new reserves, companies focused on cultivating the technology to perform all phase of offshore petroleum development. Table 2 summarizes the offshore development in 1950s.

5. Offshore Industry in 1960s: R&D with Computer Analysis

Table 2 Offshore development in 1950s

Year	Description	Remark
1953	Tideland Act was settled.	3 mile boundary
1950s	Geophysical explorations	After Tideland Act
1954	Jack-up rig appeared.	
1954	First offshore pipeline	by Brown & Root
1955	Zapata Offshore was founded.	by George Bush
1956	First 3-leg jack-up was built.	by George Bush
1956	First battered platform	by CATC group
1958	First purpose-built laybarge	by Brown & Root
1958	End of first major offshore development.	

The offshore industries in GOM made a dramatic advance in 1960s. Engineers brought computer-assisted innovations to structural design and pipelining. These advances were made when the oil price remained in the $2 to $3 per barrel. Design considerations were complicated as the platforms and pipelines were built in 60 m of water in 1962 and 100 m by the late 1960s.

One of the most significant innovations was the development of computer programs to analyze the offshore structures in 3-dimension. In late 1960s, offshore industries began to build new research & development (R&D) groups. For example, the Brown & Root set up an R&D organization called the "Marine Technology Department" in 1966. This R&D group was organized after the sudden close of the Project Mohole.

Offshore pipelines were laid in 100 m water in 1965. Laying of a pipeline was performed using up to a 220 m long stinger (Minor, 1966). To avoid the further lengthening of the stingers, patened tensioners and articulated stingers were developed (Hurska and Koehler, 1969). One significant breakthrough in pipelaying technology came in 1969. A computerized microwave survey system was used to control a laybarge during operation. The microwave survey system added technical precision to the pipelaying, while larger barges improved efficiency. By 1970, approximately 10,000 km of submarine pipelines were laid by Brown & Root and 7,000 km by others.

Table 3 Offshore development in 1960s

Year	Description	Remark
1962	First commercial semi-submersible	by Shell
1962	Gulf Oil Platform	65 m water depth
1964	Aircraft software for offshore	IBM software
1965	3-dimensional computer analysis	
1967	Platform by Brown & Root	90 m water depth
1969	First O T C	Houston
1969	First API RP was published	Design code
1969	Microwave survey system	To control barge
1970	Dynamic launching analysis	FEM analysis

By mid-1960s, California had become the world's primary site for deepwater activity. However, the offshore development in California was constrained by political pressures since an offshore blowout and oil spill in 1969. Consequently, the focus of deepwater moved to the GOM and Brazil (Howe, 1969).

From 1960 to 1970, world oil production increased from 18 million to 38 million barrels per day. During the same period, offshore production almost quadrupled. In 1970, offshore oil production accounted for more than 20 % of world production.

In 1969, first annual Offshore Technology Conference (OTC) was held in Houston. The same year, the American Petroleum Institute (API) published its first Recommended Practice (RP) document for the design, fabrication, and installation of offshore structures. Table 3 summarizes the offshore development in 1960s.

6. Scientific Project Mohole's Contribution to Offshore Industry

Project Mohole was a U.S. government sponsored project to drill to earth's crust and upper part of mantle from 1958 to 1966. Motivation of the project was to learn more about the interior composition and geological history of the earth and planet (Tonking, 1966).

The primary objective of Project Mohole was removing samples of the upper mantle. These samples might yield information on the origin and age of the earth and its ocean, cause of earthquakes and volcanoes, nature of the earth's magnetic field, and plate tectonics. A major scientific tie-in of this project was the scheduled offshore drilling simultaneous with the first moon landing in space science. One theory of the planet's evolution was that the moon had spun off the earth into orbit. Scientist believed that comparing samples from the moon and from the mantle could have advanced the theories of the origin of earth and maybe even the origin of life.

Moho is the boundary zone between the earth's crust and mantle and named after a Yugoslavian seismologist's discovery of the layer. Mohole was named to describe a hole drilled beyond the Moho. Drilling was planned offshore because of the thinner part of crust under the ocean. Original plan was to drill in 3,600 m of water and then drilling through an additional 7,000 m of earth's crust to the mantle. The maximum water depth drilled in late 1950s was only 60 m, and drilling in water depth of 3,600 m was totally beyond imagination. This project faced a lot of scientific and engineering challenges. In 1961, scientists had predicted that if the Project Mohole is succeeded, it will be one of the 20th century's most significant achievements.

Phase 1 of the project was from 1958 to 1961. Five holes were drilled to a maximum depth of 200 m in volcano rock beneath 3,600 m of water off the west coast of Mexico. The phase 1 produced the encouraging results.

In 1962, Brown & Root was selected as a prime contractor of Phase 2 of the project among the 87 companies. The company organized a special Mohole division and placed 250 people on the staff, not including outside consultants and subcontractors. The Mohole team faced difficult decisions and tasks at every aspect of the project and required a cooperative effort among many of the nation's most important technology firms. After spending considerable time and effort on selecting a drilling site, geophysicists selected a 4,400 m of water in the Pacific Ocean along the Hawaii in 1965. The drilling was expected to begin in late 1967, but never come true (Hobbs, 1965).

Decision regarding the type of drilling vessel was another complicated choice between a ship-shaped drilling vessel and an experimental semi-submersible type rig. In 1963, the company unveiled a semi-submersible (six column-stabilized platform), whose cost was estimated to be $40 million to build and $9 million to operate. An automatic dynamic positioning system with 6 thrusters was also developed. The U.S. Navy's David Taylor Model Basin and several universities conducted model test to determine the motion of the platform. A $30 million contract for the fabrication of the semi-submersible was given to a San Diego shipyard in 1965.

Table 4 Summary of the Project Mohole

Year	Description	Remark
1958	Test drill and search for the site	First phase
1962	Constructing platform and drilling	Second phase
1968	Study on crust and mantle samples	Third phase (not done)
1961	Trial drilling	950 m water depth
1961	Five holes to 200 m below seabed	3,600 m water
1965	Selection of 7,000 m drilling site	4,400 m water
1965	Semi-submersible with a DP system	by Brown & Root
1966	Cancellation of the project	by politicians

Scientific debate, political and budgetary dilemmas and Vietnam War ultimately cancelled the project in 1966 (Lambert, 1966). The project staffs were not completely disappointed, but they made tremendous advance in developing marine drilling technology.

As of 1966, the project had produced 103 inventions. Many of the innovations created during the project were very invaluable when the oil industry began to develop the North Sea in late 1960s. Table 4 summarizes the Project Mohole and its accomplishments.

Even though the drilling into the earth's mantle was cancelled on the way, the space program was continued to land on the moon. In 1961, the U.S. president J.F. Kennedy declared that 'we will land on the moon within a decade'. Man eventually landed on the moon in 1969, overcoming the first major disaster of the Apollo I accident in 1967.

Concurrently, drilling into the mantling is planning in part of the International Ocean Drilling Program (IODP) by USA, Japan and several other countries. The drillship "Chikyu" was constructed in Japan and preparing for the drilling in the year 2006. The human's sprit of endless challenge is still going.

7. Offshore Industry up to Early 1980s: Deepwater Development

The offshore industry continued to grow during 1970s, extending water depth capacity and redefining the meaning of the deepwater. By the early 1970s, when companies began to work on central North Sea and GOM, a water depth of 120 m was considered deepwater. The edge of the continental shelf at 200 m seemed as truly deepwater. The most common structure in GOM in the 1970s was the minimum self-contained platform (Lee, 1978; Lee, 1982).

The oil embargo of 1973 by the OPEC provided a big impact on the offshore industry. Oil price jumped from $3 to $10 per barrel. The high price of oil stimulated offshore development in GOM, North Sea and non-OPEC locations.

By the early 1970s, platform techniques were up to the 120 m depth level. Engineering was not radically different within this depth range. Platforms in 100 m of water have a natural period of about 2 seconds. The natural period increases with depth, greatly amplifying the wave forces on the structures. In 1973, a platform for Sun Oil in 110 m water was the second deepest platform, but it was the farthest from shore at a distance of 200 km. Then, another record was set by installing a largest steel platform for Tenneco in 115 m of water (LeBlanc, 1978).

Moving into 200 m water and beyond, introduced fundamentally new problems. Structural design had to consider the dynamic interaction between structures and waves. Fabrication and installation had to be revised to handle larger structures. In 1975, a new fabrication yard was opened in Texas. Large fabricated jackets were skidded onto launch barges instead of lifting. Then the barges were towed to the offshore site. At the site, launching method by tilting barges was used.

The period 1976-1984 witnessed stunning achievements in deepwater. Chevron's Garden banks platform, a 216 m length and 12,000 ton steel jacket, was constructed in a water of 195 m at 220 km south of Louisiana in 1979. This platform, costing $43 million, was the farthest offshore structures and largest single-piece jacket. This platform was launched by the world's largest launch barge BAR-376, which was 180 m long by 50 m wide. A year later, a similar single-piece jacket for ARCO was installed. These two platforms may be the deepest single-piece structures, but they were not the largest jacket during this period. Exxon installed the Hondo platform in 260 m of water in the Santa Barbara channel in 1976. This jacket was sectionalized into two pieces and mated horizontally at the site.

In 1978, Shell Oil designed a giant 320 m Cognac platform and installed in GOM. This Cognac jacket was assembled in three pieces and vertically stacked at the site. The installation was the most sophisticated that was ever attempted. It established records for the deepest water (320 m), the most wells (62 wells), heaviest steel platforms (59,000 tons), and most expensive ($275 millions).

But Union Oil proved that a single-piece jacket could be installed at similar depth (292 m) for less money. Computer programs were used for dynamic launch, tow, and in-place loads to reduce the weight and simplify the design. Computer analysis indicated that installation load, which was a governing load for a design, was imposed on only 40% of the entire structure. The single-piece jacket weighed 26,000 tons, less than half of the Cognac jacket. Union Oil cleverly named its platform "Cerverza", the Spanish word for beer, because at $90 millions it was only a beer budget compared to the expensive Cognac's $275 millions. The Cerverza was launched by the McDermott's new largest barge (200 x 52 m) in 1981 (Lee, 1978). The following year, Union Oil installed a companion platform, Cerveza Ligera (or Light Beer) in 285 m of water.

In water beyond 300 m (1000 ft), the standard jacket design became less practical, because the dynamic behavior at these depths was too large. The natural period of conventional jacket in such depth was about 4 to 6 seconds and close to the operating sea states. A new design appeared in late 1970s with a compliant tower whose natural period is larger than the wave period. A compliant tower with guy lines in 300 m of water would have a fundamental period of about 30 seconds.

In 1975, Exxon and twelve other companies built a one-fifth scale test model of a guyed tower designed for 500 m water and placed it 100 m water in GOM (Mangiavacchi et al., 1980). Test data over a 3.5 year period confirmed the design concept and encouraged Exxon to pursue a full scale development of the "Lena tower" in 300 m water in 1978 (Boeng and Howell, 1984). At an estimated $420 million, the guyed tower Lena spent more than a conventional steel jacket in a similar depth. Exxon proceeded with the guyed tower to develop technology in anticipation of the future need in deeper water. The entire Lena weighed 47,000 tons and 396 m in height, which was 15 m taller than the Empire State building (Glasscock and Turner, 1984). The Lena was one of the most sensational and innovative and called as once-in-a-lifetime project. Lasting four years, 1979-1983, from design to installation, the Lena became legendary in the offshore industry. In 1984, OTC devoted an all-day session to Lena. However, Lena was not followed by other guyed towers, which are less desirable in water beyond 600 m. In addition to the high cost, increased tower stiffness was needed for those depths and guyed system was not efficient in deeper waters. Tension leg platform (TLP) or spar platforms had been selected for the deeper waters in 1990 and after (Dunn, 1994). Table 5 summarizes the offshore development up to early 1980s.

Table 5 Offshore development up to early 1980s

Year	Description	Water (m)	$ (million)
1973	Sun Oil platform (farthest)	110	
1973	Tennoco platform (largest)	115	
1976	Hondo platform in deepest water (2-pieces)	260	67
1979	Garden Bank platform (largest single piece)	192	43
1978	Cognac platform (3-pieces, heaviest, most expensive)	320	275
1980	Cerveza (Beer) platform	292	90
1982	Cerveza Ligera (Light Beer)	282	85
1983	Lena guyed tower	305	420

8. End of Boom in Mid-1980s

The booming period 1976-1984 of high oil came to near the end. The Iranian revolution and oil embargo in 1979 made the second oil shock. By the early 1980s, oil prices climbed to as high as $44 per barrel. Prices of $100 per barrel were projected for 1990. Platform and mobile rig cost skyrocketed. New marine yards opened to take new orders. Offshore industry appeared healthy by 1984. In 1984, offshore production was 15 million barrels per day, about 28% of world production (Dhillion 2003). Oil price stopped rising in 1982 and began to decline gradually. The bubble burst in 1985. Oil price dropped to $10 per barrel as crude supplies over pass the demand. Many oil service businesses went bankrupt and restructured. Deepwater development was almost dead until the 1990s (Pratt and Castaneda, 2000).

9. Recent Offshore Industry: Ultra Deepwater Development

In 1990s, deepwater development came back with a high oil price. TLP, Spar, floating production system (FPS), and floating production storage and offloading (FPSO) had been major popular deepwater structures in 1990s and 2000s. There are many articles and well organized data about recent deepwater structures (Barltrop, 1998; Bai, 2003; Guo et al., 2005; Paik and Thayamballi, 2006; Nutter and Albaugh, 2005; Nutter and Albaugh, 2005; Speer et al., 2004).

In the year of 2000, oil price dropped near $10 per barrel, but did not last long. The oil price jumped up again in 2001 and it was over $70 per barrel in 2006 (see Fig. 1). Prices of $100 per barrel were projected again and major oil companies are investing into ultra-deepwater (1,500 m or deeper). Exploration and production (E&P) of oil and gas in deepwater is the clear choice of future projects for the major oil companies. Some Korean companies began to invest for the E&P projects.

By 2005, three major shipyards in Korea remain as competitive contractors in offshore industry throughout the world. Most of the major deepwater structures have been constructed in Korean shipyards in last few years. However, the basic design called as FEED is still in the hands of western offshore industries. The conceptual design and FEED require wide range of knowledge and background of offshore engineering. To enhance the capacity of FEED, there is no doubt that further study on the history and background of offshore engineering should be conducted for Korean offshore engineers.

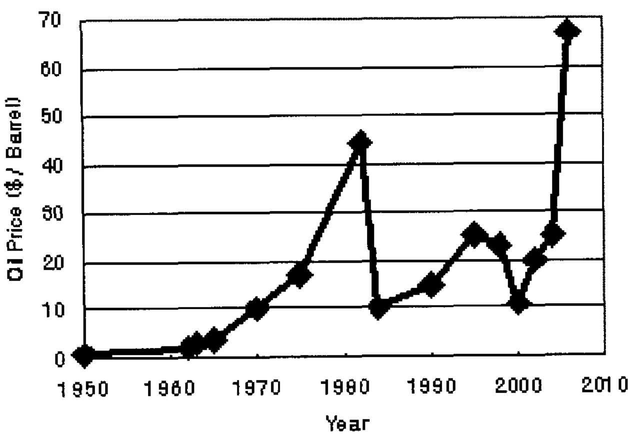

Fig. 1 Trend of oil price per barrel

10. Concluding Remarks

(1) Early offshore developments began in GOM and Venezuela in 1920s and 1930s. Coal tar coated wooden platforms were constructed by the stick-building method at the offshore sites.

(2) Kermac 16, a wooden platform built in 1947, is considered as the birth of modern offshore oil and gas industry because the platform was located beyond the sight from the land.

(3) Wooden platforms were replaced with steel in 1940s. Steel jackets were fabricated onshore and the completed platforms were transported to the sites. The advantages of jacket were easy installation, strength, and low cost. The jackets were adopted quickly on platform construction throughout the world.

(4) After Korean War and Tideland Act in 1953, the first major development occurred in offshore industry.

(5) The battered-leg platforms provided more stiffness and reasonable cost in 1950s.

(6) Dynamic analyses with computers contributed the development of offshore structures in 1960s.

(7) Scientific programs on space (Apollo) and under the earth (Mohole) contributed the drilling technology and semi-submersibles in 1950s and 1960s.

(8) The period 1976-1984 witnessed stunning achievements in deepwater development. Innovative technology provided continuous development of TLP, Spar, FPS, and FPSO for deepwater.

(9) The oil price of $10 per barrel in 1973 stimulated the offshore development, while $10 in 1984 discouraged it. $100 per barrel was projected in 1980s and 2006. The previous projection did not reach to $100 level, but the current price is likely to go up continuously according to the energy experts and major oil companies (see Fig. 1).

(10) Because of the high price of oil and gas, offshore industry is developing the ultra deepwater areas currently. Most of the deepwater structures are expected to be constructed in Korea because of the track records and infrastructures.

(11) Further study of offshore history and background is essential to enhance the capacity of conceptual design or FEED of offshore structures in Korea.

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