Development of offshore structures: an overview

Development of Offshore Structures — An Overview

Aperçu sur le développement des structures en mer

Entwicklung der Offshorekonstruktionen — ein Überblick

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SUMMARY
With the world demand for oil, gas and coal and other minerals constantly increasing, drilling and production activities in recent years have been extending to more and more inaccessible offshore and arctic areas. Over the past few decades, the technology has changed dramatically because of the need to explore and produce in environments that were prohibitive before the 1970's. The offshore industry has witnessed a remarkable surge in the overall numbers and variety of offshore platforms throughout the world. Since the 1940s, the number of offshore platforms in the bays, gulfs, and oceans of the world today exceeds 10,000. This paper briefly reviews the advancement of offshore structures and the application of new materials used in the development of such structures.

RÉSUMÉ
La consommation de combustibles liquides, de gaz, de charbon et d'autres minéraux ayant sans cesse augmenté, il a fallu ces dernières années intensifier le forage et la production de pétrole tant en mer que dans les régions arctiques, lieux s'avérant d'un accès toujours plus difficile. La technologie de l'industrie marine a réalisé des progrès énormes pendant les dernières décennies, étant donné qu'il a fallu explorer et installer les points de production dans les lieux qui auraient été tout simplement inaccessibles avant les années 70. A partir de 1940, la gamme des plates-formes en mer s'est diversifiée et a augmenté en nombre à l'échelle mondiale. A l'heure actuelle, il y en a plus de 10,000 dispersées dans les baies, les golfes et les océans. Cette communication expose les développements des structures en mer et l'utilisation de nouveaux matériaux pour leur construction.

ZUSAMMENFASSUNG
Wegen der weltweit wachsenden Nachfrage nach Öl, Erdgas, Kohle und Mineralien dehnten sich Exploration und Produktion in den vergangenen Jahren zunehmend auf die offene See und in arktische Gebiete aus. Standortbedingungen, die bis 1970 noch undenkbar waren, führten zu einem Technologieschub mit bemerkenswertem Zuwachs der Offshore-Plattformen in Zahl und Typenvielfalt. Die Gesamtzahl der seit 1940 küstennah und -fern installierten Plattformen übersteigt bereits 10.000. Der folgende Beitrag versucht eine kurze Zusammenschau der unter Einsatz neuer Werkstoffe erzielten Fortschritte.

1. INTRODUCTION

As oil and gas exploration activities moves into more deeper and harsher waters of offshore and arctic areas, new class of structures are becoming increasingly important. During 1940's to 1960's, steel structures were common. The steel templates or jackets which were fabricated onshore and then carried to the site by barge and lowered into the water. When in position, they are fixed to the bottom using steel piles driven through the jacket legs. However, the decade of the 1970s witnessed a remarkable surge in the numbers of offshore platforms. The evolution of many platform designs since 1940's is shown in Fig. 1. Offshore structures are universally designed for functional purposes based on rational and empirical design and the whole is judged primarily on economic grounds. The design and construction of an offshore platform involves many related and interdependent endeavors and include many technologies such as, oceanographic engineering, foundation engineering, structural engineering, marine civil engineering and naval architecture.

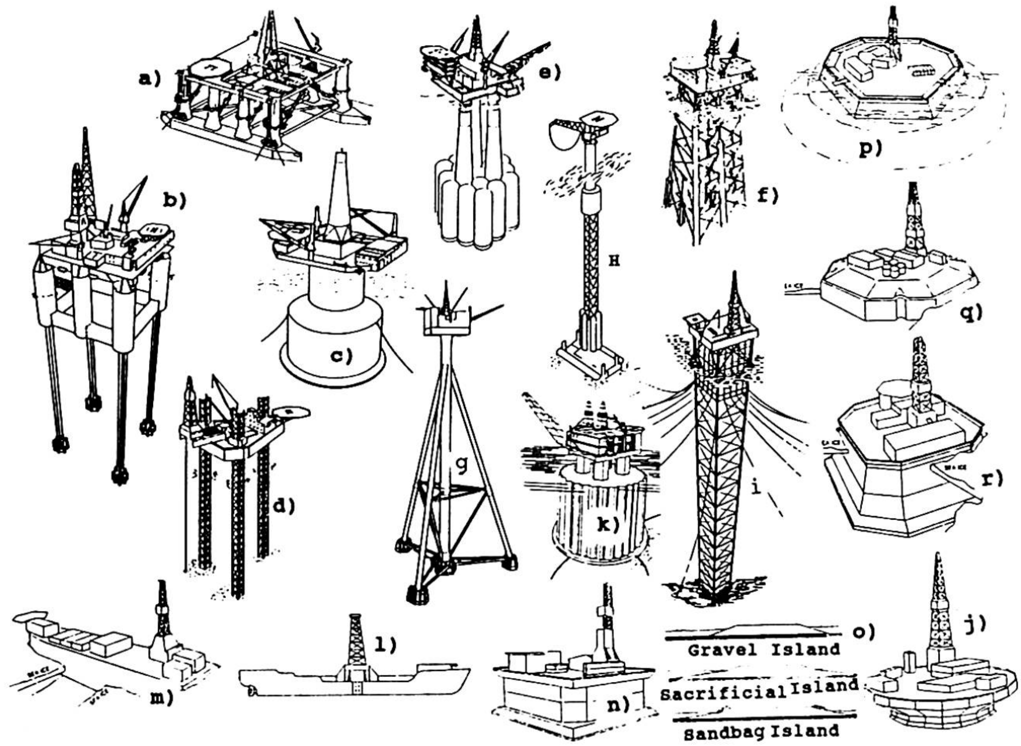

Fig. 1 Selected offshore structures: a) semi-submersible platform; b) tension leg platform; c) buoy-type; d) jack-up; e)gravity platform; f) jacket-type; g) steel tripod; h) articulated tower; i) guyed tower; j) steel caisson; k) GBS platform; l) drillship; m) single steel drilling caisson; n - r) arctic structures /1, 10/.

Over the past 30 years, numerous categories of offshore platforms have been evolved, which can be classified into four major groups:steel jacket-type structures, concrete structures, arctic structures and compliant platforms. The type of structure to be used for a particular application depends to a large extent on the intended use, the conditions at site, water depth and weather conditions. The fabrication and installation of an offshore platform is a specialized task. The whole structure is designed taking into consideration, the total weight of topside facilities and environmental loads. Offshore structures are subjected to large gravity loads and cyclic environmental forces besides corrosion and fouling. The pictorial summary of major loads, environmental forces and corrosion zones at different depths in a typical offshore platform is shown in Fig. 2.

Because of the possibility of miscalculations in the determination of applied loads for offshore structures due to interpretation of fluctuating environmental conditions, safety factors are used in accordance with the principles of limit state design. The estimation of vertical loads on platforms, which are primarily dead loads, can be estimated with reasonable accuracy but the greater uncer–

tainty is involved in the horizontal loads. In general, the magnitude of the horizontal loads vary for about 15 - 35 % of the vertical loads /2/.

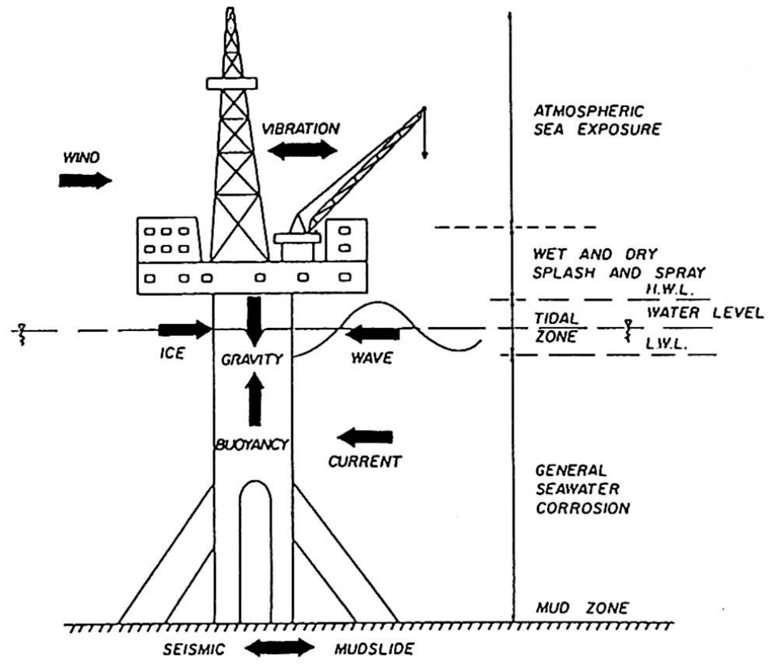

Fig. 2 Major platform loads and corrosion zones.

2. REVIEW OF STEEL, CONCRETE, COMPLIANT AND ARCTIC STRUCTURES

Steel Structures: The installation of the first template or jacket type steel structure in the Gulf of Mexico, off the Louisiana coast in 1947 at a water depth of 6 m, marked the first use of welded tubular offshore platform. Since then the offshore industry has seen the evolution of many platform designs (Fig. 3). Presently, over 3,700 offshore steel platforms are operational worldwide with the predominant locations being the Gulf of Mexico, the North Sea, and the Arctic. The majority of offshore structures are steel structures consisting of welded tubular members welded together. The reason for their popularity is due to the fact, that they posses excellent strength properties and offer minimum exposed area to wind and wave forces. They also exhibit omni-directional strength with design flexibility, greater economy in mass and possess better hydrodynamic properties. The world's tallest steel platform at present is the Bullwinkle platform (Fig. 3), installed in the Gulf of Mexico in 1988. It has a height of 492 m and weighs more than 71,000t and has a base measuring 122 by 146 m /3/.

Concrete Structures: During the 1970s, a second generation of offshore structures have been evolved. The North Sea oil exploration sparked the idea for concrete deepwater platforms (CONDEEPS) /Fig. 1, c & e/. These concrete gravity structures rest directly on the ocean floor by virtue of their own massive weight. In the early stages, they are constructed onshore or in sheltered waters, then towed in semisubmerged position to the site and installed in position by ballasting. The size of the concrete structure vary depending on the design. The base diameter range from 52 m to 169 m, while the column diameter may vary from 15 - 30 m. Since the first Ekofisk platform installation in 1973 at a water depth of 70 m, more than 20 concrete platforms have been installed in the North Sea. The recent tallest concrete platform to be installed in the North Sea in 1990s is the concrete tripod platform (Fig. 3) for the Troll field at a water depth of 335 m. It requires about 750,000t of concrete and has a payload capacity of 60,000t /5/. Apart from the North Sea concrete structures, is the Hibernia concrete gravity based structure (GBS) planned for offshore Newfoundland for a water depth of 80 m. This GBS platform will have a diameter of 105 m and a height of 148 m (Fig. 1k), with a concrete volume of 60,000 cu.m. and steel weight of 59,400t. The total weight of the structure when completed will be 1,025,000t. This massive structure is designed to resist the impact exerted by the moving icebergs with an average mass in the range of 30,000 to 60,000t /6/.

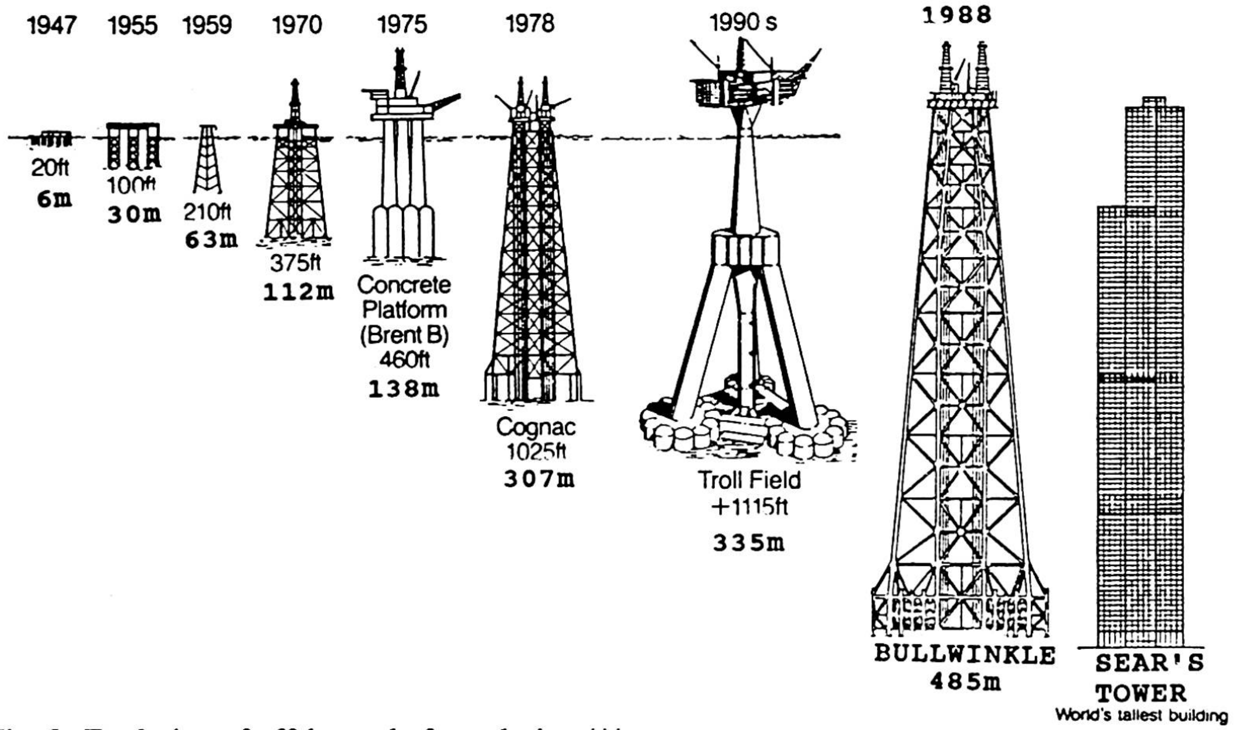

Fig. 3 Evolution of offshore platform design /4/.

<u>Compliant Platforms</u>: As the water depth increases, the use of jacket-type and concrete platforms becomes unacceptable because of high increase in weight and costs. In such situations, a new class of structures, namely the "compliant platforms" (Fig. 1 b, h & i), is likely to become increasingly important. Prominent new examples of this type of structures are the tension leg platform (TLP), articulated column, the guyed tower, and the semi-submersible. The principal characteristic of these structures that distinguishes them from the more traditional fixed jacket-type structure is that they more or less ride with the waves rather than resist them. Hence, the name compliant. The advantages of these compliant structures is that they can have excursions with extreme values of the order of several meters. In addition, as the water depth increases, the traditional fixed jacket-type structures become extremely costly as can be seen in Fig. 4 /8/, while tension leg platforms offer many advantages with regard to safety and cost reduction. For example, the tension leg well platform (TLWP) requires only 5,000t of steel compared with 50,000t for a fixed platform for a water depth of 533 m. The TLWP carries only wellheads and related equipment, while process equipment and accommodation would be on a tanker moored permanently few kilometers away from the structure /4/.

<u>Arctic Structures</u>: The new discoveries of vast reserves of oil and gas in the ice-infested waters of Alaska and the Canadian Beaufort Seas in the late 1960's and early 1970's, led to the development of new generations of arctic structures for these areas /Fig. 1(m - r)/. Offshore exploration and production structures for the high arctic can be divided into two categories: bottom-founded and floating. The bottom-founded structures can be further divided into five types, namely, 1) artificial "fill" islands, 2) caisson retained islands, 3) caissons, 4) cones and monocones, and 5) monopods and monoleg jackups. These shallow water arctic structures (20 - 45 m) must be designed to operate safely under design requirements (winter and open water seasons) and survive extreme conditions without catastrophic consequences. They have to operate at temperatures as low as - 50 °C, and with a 95 kph wind chill factor it can drop to -110 °C. In addition, the structures have to resist ice forces from multi-year ice with thicknesses ranging from 5 to 7 m. The operating costs of arctic structures are believed to exceed $600,000 per day /9/.

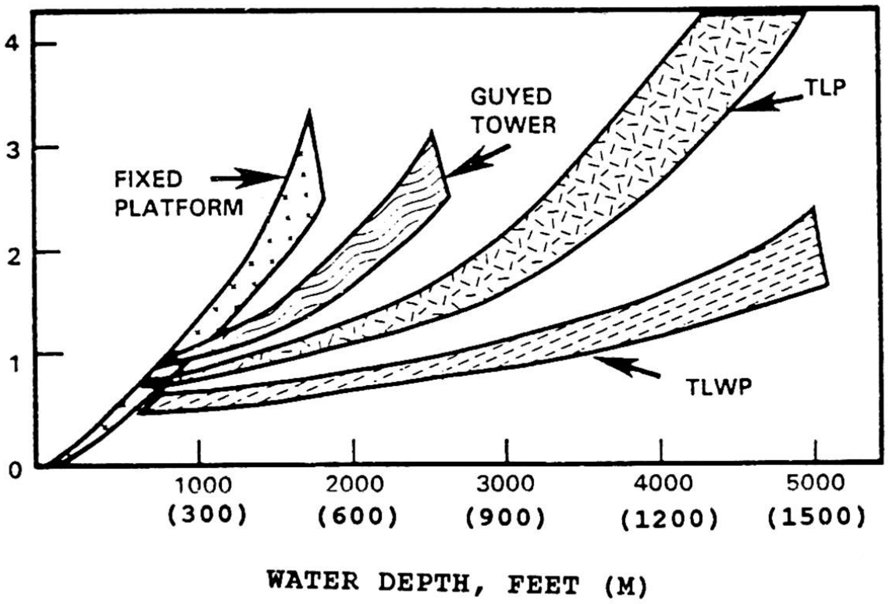

Fig. 4 Relative cost for field development (Gulf of Mexico) /8/.

3. APPLICATION OF NEW MATERIALS

Offshore structures are subjected to cold temperatures, ice forces, strong winds, high waves and extremely corrosive conditions than in the case of land based structures. Because of the low performance of traditional steel and concrete material in extreme offshore conditions, a number of so-called new uncommon materials are emerging in the offshore industry. These include, high alloy stainless steel, high-strength steel, high-strength concrete, light-weight concrete, aluminum, fiber reinforced superalloy composite materials,new coating materials etc. These new materials have the vast potential for weight and cost savings. According to Alcan Offshore Co., the use of aluminum rather than steel in accommodation modules, helidecks and other units of offshore structures can offer up to 40 - 70 % weight savings.

Higher strength steels(HSS) are currently finding increasing demand because of improved welding procedures. HSS having tensile strength in the range of 550 - 785 N/mm2 (Y.S. = 460 N/mm^2) and higher are replacing the traditional steel having T.S. 490 - 640 N/mm^2 (Y.S. 355 N/mm^2).

New polyethylene and polyurethane coating materials for steel piles and pipes are finding increasing use in marine applications. They are used to protect against corrosion, wear and adfreezing effects. The technical and economical advantages of composite materials made of epoxy and glass-fiber for pipes and other subsea offshore systems are on the increasing demand in recent years.

The use of high-strength light-weight aggregate concrete in marine structures is highly attractive because of many advantages. Programs to develop light-weight concrete having compressive (cylinder) strength ranging from 50 - 60 MPa, with densities 1920-2080 kg/cu.m. are under progress. The better quality high-strength concrete having compressive strength more than 100 MPa for cold region applications are also under development in many countries.

In the case of arctic and massive gravity-based structures, the use of sandwich steel/concrete composite construction has a potential for cost savings. The basic composite system consists of two thin continuous steel plates, placed concentrically with a filler material such as concrete between them. Composite members exhibit high flexural and shear capacity with very ductile failure and a large capacity to absorb energy. To further increase the load carrying capacity of composite structures, different materials, such as steel studs, steel fibres, bar shear reinforcements and high-strength steel and stainless steel are used. Some experimental tests on 18 such steel/concrete composite structures have been carried out at VTT and a significant difference in load carrying capacity was noticed among different specimens. Fig. 5 shows the load-deformation behaviour of composite members with some different combination of materials.

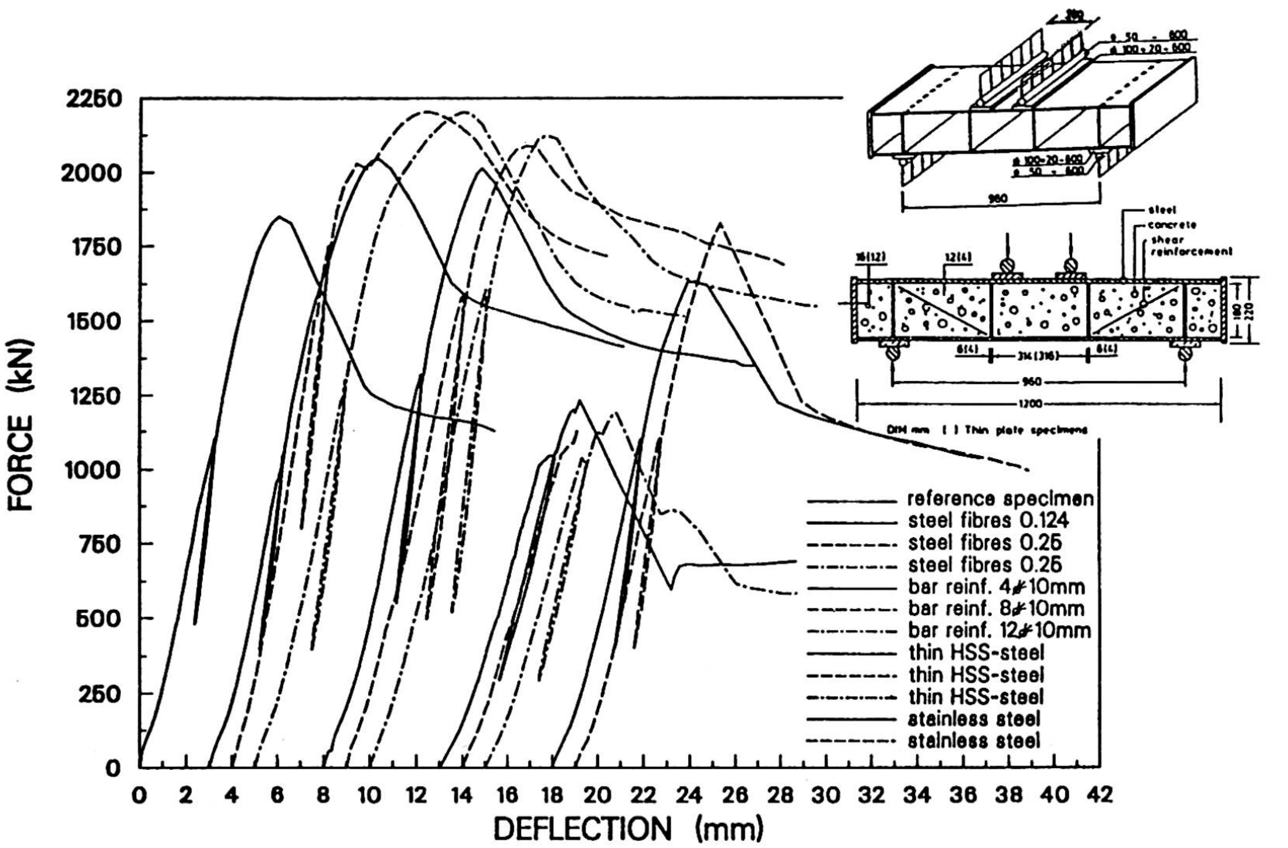

Fig. 5 Load-deformation behaviour of some different steel/concrete composite specimens.

5. CONCLUDING REMARKS

The ever increasing demands of oil and gas and the involvement of the offshore industry, contributed to many outstanding achievements and technical breakthroughs in the field of offshore engineering. Despite the current economic uncertainties, the development outlook for offshore, the arctic and sub-arctic regions will probably continue, but with a slower steps than planned. New generation of production structures for water depths deeper than 1000 m and for the high arctic regions are still technological challenges facing the engineers. In this regard, the new technologies and the development of new materials, material combinations and structural systems for offshore applications will play an important role in the future.

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