PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

FIXED OFFSHORE PLATFORMS IN THE ARCTIC OCEAN

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INTRODUCTION

Due to the current surge of interest in the development of hydrocarbon reserves on the North Slope of Alaska, and in the McKenzie Delta and Arctic Islands area of Canada, it is evident that a need exists, and will become more pressing in the future, for buildable designs which are not prohibitively expensive for fixed structures to support drilling and production operations in the hostile environment of the Arctic ice pack.

If the Trans-Alaska and/or the Trans-Canada pipelines are prohibited, or rendered uneconomical by stipulations or restrictions of the governmental agencies having jurisdiction, then berthing and product transfer facilities for submarine or surface tankers may also be required in the Beaufort Sea or the Chukchi Sea.

Given the need for fixed offshore Arctic platforms to support various operations, the principal problems are rather quickly resolved to be definition of design risk level, derivation of loadings suitable to that risk level, and development of structural configurations which will resist those loadings and provide satisfactory operational characteristics.

CONCEPTUAL DESIGN CONSIDERATIONS

There are myriad considerations which contribute to a structural configuration in any part of the world. Many of these considerations are identical, or at least similar, whether the structures are in the Beaufort Sea or the Persian Gulf. For Arctic offshore structures, however, there are several areas of influence which are either singular to the Arctic, or are so changed in scope as to demand particular consideration.

Loadings - One generally thinks of structures sufficiently close inshore to lie within the bounds of shore fast ice as essentially static structures subjected only to loadings induced by thermal expansion and contraction of the ice. In such a location, however, the primary design consideration may well be wave action during the ice free season or ice forces during heavy weather conditions before the ice mass becomes fast to the bottom or after spring breakup starts.

In locations further offshore, the problem becomes compounded. Wave action is still a significant consideration, both as a possible maximum loading, and as an influence on installation procedures for the structure. Probable sea states at the planned location will affect the installation and could have a profound effect on the design of the structure. The primary lateral loading, however, will likely be imposed by ice in its various forms; pack ice with the attendant folds and pressure ridges, and, in some locations, ice islands and bergs. In some areas of the Arctic, loadings in response to seismic activity must be considered.

It has long been the practice in the petroleum industry to stipulate as the design condition for a platform the worst loading event or summation of events which could possibly take place, with insufficient regard to probability of occurrence in comparison with the useful life of the structure. This practice has been justifiable in many instances in the past. In hurricane influenced areas, for instance, the change from a 25-year recurrence interval design wave to a 100-year design wave produces a heavier, higher and more expensive structure, but the extra expense is generally small enough to justify the increased safety factor. In the Arctic offshore however, with much more severe conditions, this practice may well lead to prohibitive costs. It will be necessary to carefully assess the probability of occurrence of loading mechanisms and their intensities for each given location. Pack ice conditions which would produce a very expensive structure in one location may not exist with significant probability in another location. One would not expect, for instance, an economical design destined for operation in many locations in the Canadian arctic archipelago to necessarily withstand loadings imposed by the main mass of the pack offshore Barrow. The final selection of design conditions should be made in light of the economic significance and desired life span of the structure.

Materials - Steel has long proved to be the most appropriate material for offshore structures in many areas of the world. This has been primarily because steel afforded the high strength to weight ratio and ductility required of a space frame structure designed to resist wave and seismic loadings, and which was to be fabricated onshore, transported to its intended location, and then installed with the aid of floating lift equipment. When the petroleum industry moved into Cook Inlet, steel remained the most logical material for structures, with a shift to the low temperature notch tough steels. Steel remained logical since a high strength to weight ratio, ductility and abrasion resistance were desirable material properties for the Inlet structures. In these structures, local shell rigidity to resist ice impace was provided by the cellular, steel-grout sandwich make-up of the tubular legs.

In the Arctic, the same material properties are still desirable. One would desire a material which provides a high resistance to ice abrasion, low temperature ductility, and a high strength to weight ratio. The strength to weight ratio may not be, in the Arctic structure, so important to operational performance, but is vitally important to transportation, installation, and possible salvage at the end of its economic life 15 or 20 years hence.

Steel will, therefore, probably prove to be the most economical material for Arctic structures, with substructures having grout filled steel cellular exterior hulls to provide local rigidity to ice forces. An alternate substructure material may be prestressed concrete with a steel abrasion face. A prestressed concrete substructure would, however, be heavier than one of steel and may require a longer transportation time due to the resulting less favorable tow characteristics. A self buoyant concrete structure would certainly have draft limitations during transportation and installation which would be more severe than that of a steel structure.

Foundations - The Arctic sea floor, within depth limitations of fixed structures, ranges from coarse granular materials of various densities to silts and clays in all stages of consolidation. Many of these materials are incompetent to support heavy surface loadings, and most will be to some extent susceptible to scour, particularly in locally accentuated currents around a structure. For any transportable structure of reasonable size and mass, the foundation will be required to resist not only bearing loads, but also uplift from the lateral load overturning moment. The foundation must resist lateral movements to within the limitations imposed by well casing and product flowline flexibilities.

Mat foundations, such as those used to support many massive conical lighthouse structures, do not possess the capability to resist overturning uplift. That resistance must come from the mass of the structure. Except in favorable subsurface conditions, mat foundations will not provide bearing capacities in the order of magnitude likely under Arctic structures without pile support. Certainly, there is no assurance that with a mat foundation the gradual accumulation of lateral deflections under transient and vibratory ice loading would not exceed the flexibility limitations of well casings and flowlines, even for the most massive of structures.

It seems inevitable, then, that pile foundations will prove to be necessary as a general rule to support Arctic structures, particularly in deeper water. Pile foundations can be designed to resist overturning couples and lateral shears even in the worst of subsurface conditions.

The drawback which some investigators feel is fatal to pile foundations under Arctic drilling and production platforms is that piles will in many locations extend into permafrost. This is the permafrost zone which has been encountered at varying depths below the sea floor for considerable distances offshore the Beaufort Sea coast, probably the fossil residual from the rapidly receeding shore. These investigators fear that the pile will act as a thawing mechanism in the permafrost. The problem is intensified by the probable use of at least some of the piles as well conductors. Permafrost thaw is a very real problem, but is soluable through the proper application of insulation and refrigerants in the pile-well casing annulus.

<u>Installation</u> - Structures destined for any area of the world must be designed to an installation procedure utilizing the floating equipment available and recognizing the limitations imposed by prevailing sea states and logistics. In the Arctic, this is particularly so. Failure to design for minimization of installation time and equipment will likely cost more than inattention to any other consideration. For installations in those locations requiring floating equipment to transit Point Barrow in the short passage season, time is of particular importance. The successful design would, then, provide good towing characteristics to minimize travel time. For self buoyant structures, this requires a small draft, implying a low mass to volume ratio, and sufficient stability to withstand, with a margin

of safety, sea states likely to occur between the fabrication site and the erection site. Structures not providing their own buoyancy must be capable of load out onto, and launch from, a cargo barge. Within size limitations imposed by cargo barge stability, a barge transported structure would provide better tow characteristics than a self buoyant structure.

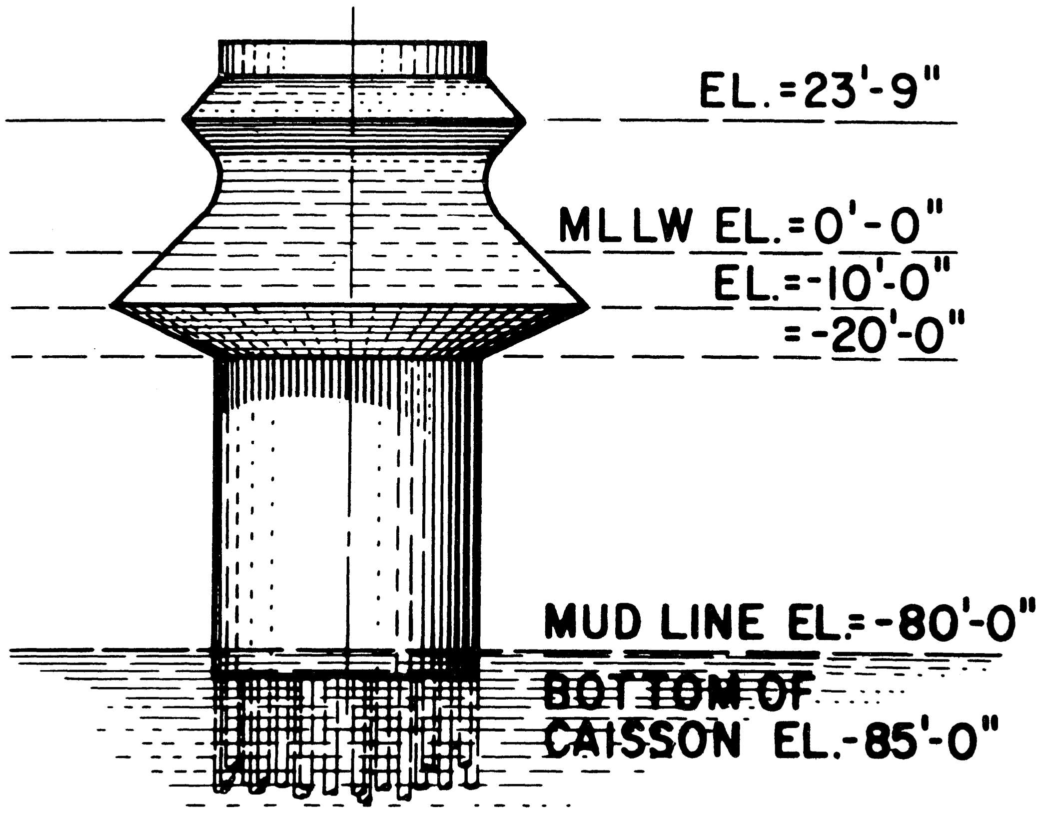
The procedure for installation of deck modules and piling must be as independent as possible of floating lift equipment. Deck modules, including operational and construction equipment, should be installed on the erected substructure after a minimum number of piling are installed to support temporarily the gravity loading imposed by the remaining erection sequence. The derrick barge could then be released and the remaining piles installed from the platform, possibly being drilled in with the platform rig. While such a procedure might require the retention of a cargo barge and tug for a long period, the expensive derrick barge spread could be released for another job, or for return to ice free water, in a relatively short time.

The optimum design would be the structural configuration which could provide sufficient buoyant stability to undergo tow and sinking on location with all deck units and operational equipment on board. Such a structure would provide for a self-contained pile installation program with construction period foundation loads controlled by partial ballasting of the structure.

ARCTIC DESIGNS

It is obvious that structural concepts which would be successful in one area of the Arctic offshore would yield to other configurations in other locations and loading environments. It is of interest, however, to examine one design which was proposed for a location in the Beaufort Sea and a possible configuration for a drilling and production platform in a similar location.

Beaufort Sea Test Module - This structure, shown in Figure 1, was proposed by J. Ray McDermott & Co., Inc. as a test module to assist in the accumulation of data on pack ice characteristics and forces. The client's specifications were intended to produce a relatively inexpensive structure to support a sloped icebreaking face and having a required life span of only several seasons. Further, the proposal tender was timed to require several compromises to optimum design to insure a completed structure for the desired ice season.



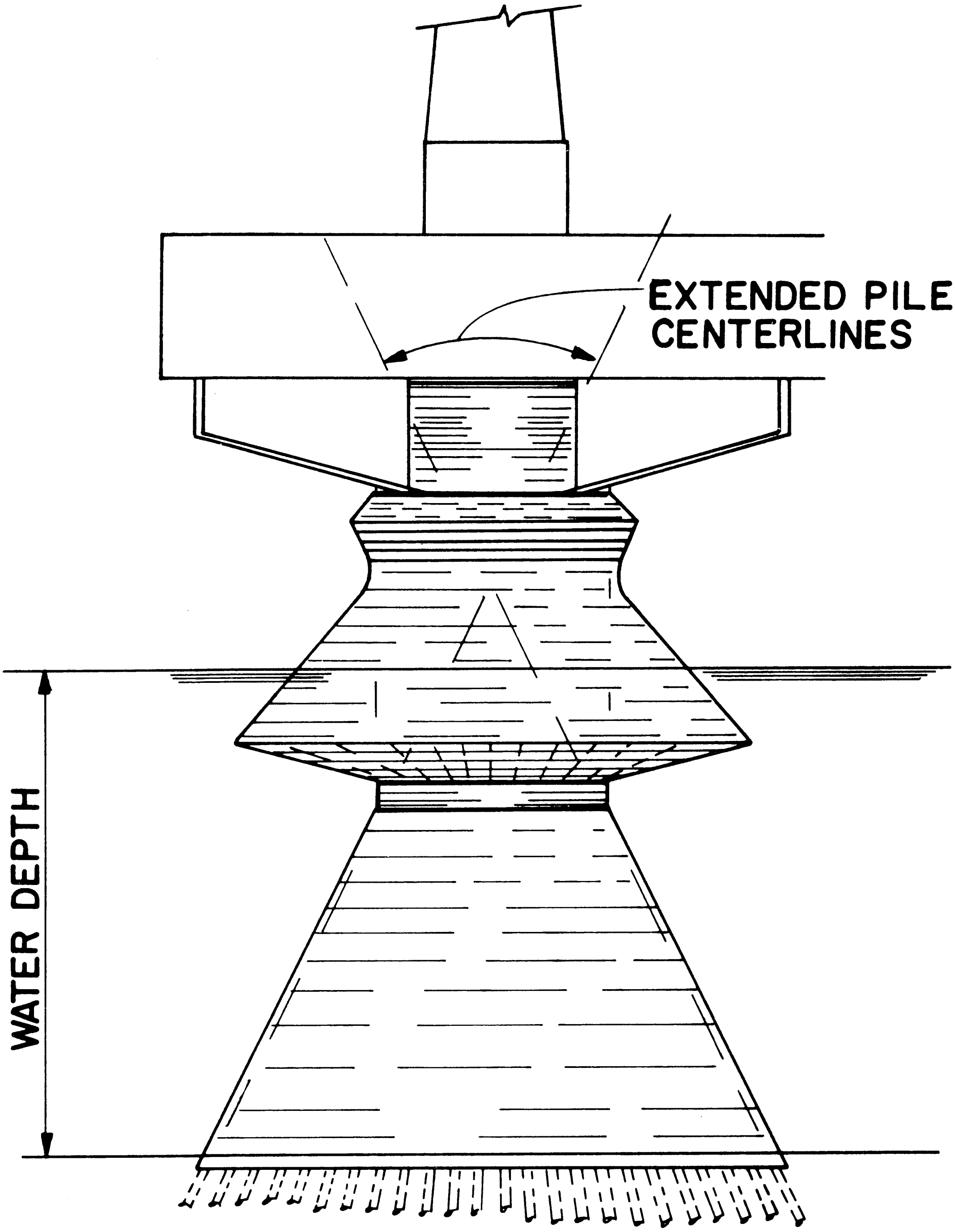
ESSO BEAUFORT
SEA TEST MODULE

FIGURE 1

The structure was proposed to be a 50 foot diameter steel caisson of cellular hull construction with a slip-over ice breaker having a water line dimension of 80 feet. The icebreaker position was to be field adjusted to provide an 80 foot dimension at the water line regardless of depth, for depths equal to or less than design. The structure was to be supported by forty pipe piles having a mudline section 38 inches in diameter with 2.5 inches wall thickness. The pile section could have been reduced considerably if the lower portion of the caisson could have been belled to permit installation of the piles on a batter. A constant diameter caisson was required, however, to permit the icebreaker to be positioned at any height on the caisson. The structure was designed to be towed to location on a cargo barge, launched, and erected using controlled flooding. Once in position, a sufficient number of piles to support the remaining erection loads were to be driven. A small drilling rig and a crawler crane were then to be off loaded onto the upper deck of the caisson to complete the pile installation by drilling and grouting to the formation and the structure. The floating equipment, except for a cargo barge for piling, was thus free after a short time to move back around Barrow should it appear that the pack was likely to close in at the Point.

Drilling and Production Platform - It is probable that the best configuration for a production platform substructure in a location similar to the Esso test module would be a conical form similar to many lighthouse structures, and supported by a batter pile foundation.

For somewhat deeper water, however, the volume and surface area of a conical structure becomes extremely large. With large radii, hull stiffness becomes difficult to maintain, even with cellular construction, and unnecessarily large areas are presented to pick up force from pressure ridge ice below the waterline. In such a case, a stepped hull form such as that indicated in Figure 2 would provide improved characteristics. The step, or return, in the upper cone provides the possibility of objectionable uplift due to ice pressures on the lower face. The uplift can be minimized, however, by judicious choice of return slope. Using this technique, it is possible to improve overall pile loads in spite of the added uplift.



DRILLING AND PRODUCTION PLATFORM

FIGURE 2

SUMMARY

The economic success of Arctic offshore structures depends on definition of loadings appropriate to a realistic risk level, recognition of the hazard of construction in ice susceptible areas, the limitations of short construction season and difficult logistics, and, in the author's opinion, a dramatic increase in the price of crude oil. Given these stipulations, it is possible to design platforms to successfully resist Arctic ice loadings. To predict structural configurations without aiming toward a particular set of criteria is valueless, as in the Arctic, more than any other area of petroleum operations, the structural concept will be determined by local probable conditions at the proposed structure's location.