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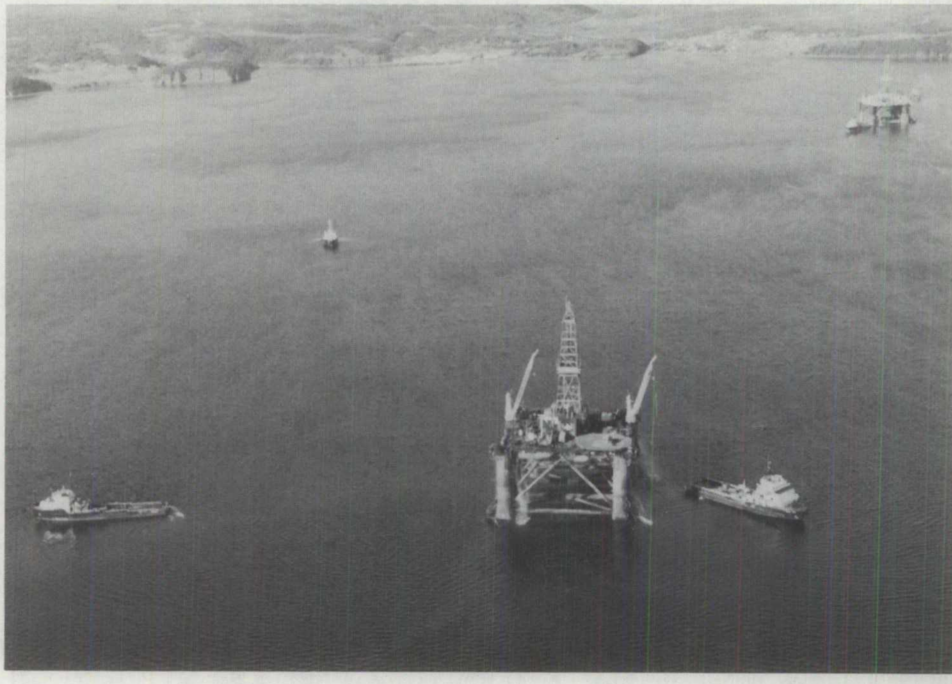
DESIGN AND CONSTRUCTION

CHAPTER FOUR DESIGN AND CONSTRUCTION

The design of a mobile offshore drilling unit is intended to create a functioning machine which as closely as possible can meet the requirements of the owner for efficient drilling under specified environmental conditions within the framework of relevant regulations and classification society rules. The development of drilling units has depended upon and pressed forward the "state-of-the-art" of many engineering, industrial and marine disciplines. The rapid growth in the scale of operations and the parallel evolution of designs to cope with increasingly remote and demanding environments have challenged the ingenuity of all those who participate in and regulate the offshore industry. To assess the suitability of a rig for these environments, it must be determined whether the methods and principles applied in MODU design establish an adequate level of safety, whether MODUs are built to an acceptable standard and whether they can be operated safely under adverse conditions. An analysis of the procedures followed in building rigs reveals the potential for the wide variations in quality that are to be expected in a rapidly evolving international industry operating under a number of different regulatory regimes.

In light of past tragedies and of increased drilling activity in offshore environments which are not fully understood nor well characterized, a basic practical issue is the suitability of MODUs to operate on the Canadian Continental Shelf. As these rigs arrive in our waters with widely varied design, construction and operating histories, it is imperative that the principles and regulation of their design and construction be examined and that it be determined to what extent the Canadian regulatory agency can rely on international practice in establishing adequate standards of safety. After that examination, it is then necessary to decide the extent to which, and the methods by which, an adequate standard of safety is assured and is maintained on all rigs under Canadian jurisdiction. The physical environment off eastern Canada tests structures and systems severely; if their quality and suitability for operation in that environment cannot be assured by international practices, then the regulatory authority of the Coastal State must obtain that assurance through the most appropriate means.

Both fixed and floating MODUs have operated successfully in eastern Canadian waters. Drill ships have been used in the Davis Strait, in the Labrador Sea and on the Grand Banks; jack-ups are employed on the Scotian Shelf, and semisubmersibles remain the most widely used rigs for exploratory drilling offshore Nova Scotia and Newfoundland. Floating MODUs are expected to function safely and efficiently in this hostile Northwest Atlantic climate, to maintain their position within a few metres relative to a wellhead with a minimum of motion during drilling and to accommodate the loading and movement of materials while maintaining their draft and trim. Jack-up rigs must stand firm against the forces of wind, wave and current



4.1 Of the twelve MODUs drilling off Canada's East Coast in May, 1985, seven were semisubmersibles and five were jack-ups; there were no drill ships operating in the area at that time. Submersibles have never been employed on the East Coast, although ice-reinforced submersibles have been used successfully in the relatively shallow waters of the Beaufort Sea.

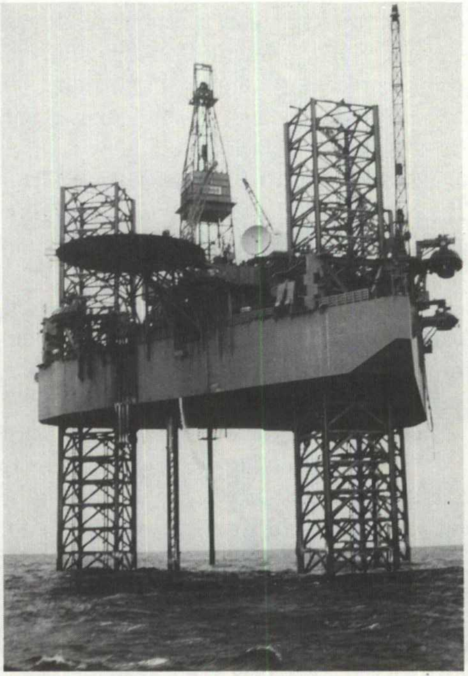
while drilling, and yet make a safe transition to a free-floating state in order to change drilling locations.

A MODU design will be replicated only a limited number of times, usually by a number of different builders, and even units built to the same overall design will vary significantly in detail in order to take advantage of new technology and to meet the requirements of regulators and individual owners. It is the rig owner who must ultimately assume full responsibility for the quality and safety of the MODU that he owns and operates. Nevertheless, the ultimate level of safety is also dependent upon contributions made by others, including those involved in its design and construction, and in its inspection and certification. One factor upon which these contributions are significantly dependent is the extent to which each party communicates with the others and participates in the planning, development and operation of a MODU.

The working arrangements among those who design rigs, those who build them, and those who ultimately own and operate them are varied. The designer may be part of the organization of a rig owner, he may work with a shipyard or rig builder or he may operate independently. The extent and quality of the communication between the designer of the rig, the shipyard that builds it, and the owner who operates it will vary for virtually every project. In many instances the designer will participate in modifying the design to meet the owner's requirements and the constraints of construction, and in assisting the owner in supervision and inspection; the designer's involvement may, however, terminate with the sale of the design to an owner or builder (Appendix C, Item 1).

Normally, a rig owner with a design capability in his own organization will first prepare a set of specifications, based on anticipated developments in market conditions, including a description of the rig's proposed operational capabilities and of the environments in which it may be required to operate. In many instances these requirements can best be met by adapting an existing design with a proven record of operations. Otherwise the more lengthy and expensive process for a new design will be initiated.

Independent designers and those who work for rig builders usually develop a conceptual design to meet the general requirements of owners working worldwide in diverse offshore areas, and modify the plans as necessary so that it can be built effi-



4.2 Of the 773 MODUs working, under construction or planned in September, 1984, there were 463 jack-ups, 180 semi-submersibles, 91 drill ships/barges and 39 submersibles. The largest concentration of MODUs at that time was in the Gulf of Mexico, where 199 rigs were in operation.

ciently in shipyards with different capabilities and equipment. The design concepts are marketed to prospective clients on the basis of inherent competitive advantages and their adaptability to particular needs and requirements.

Whatever may be the designer's arrangement with the builder and owner, it will rarely be known with certainty where the rig will drill for more than the first few years of its active life or the manner in which it will be operated and maintained. He therefore designs a rig that is capable of operating safely and efficiently in the most extreme environments which the owner may specify, that can be built at a competitive cost, that meets all requirements of the selected classification society, and that meets the requirements of the Flag State and of as many Coastal States as practical. Between the often conflicting requirements for operational flexibility, cost and regulatory compliance, there are trade-offs in which potential theatres of operation may be sacrificed to enhance competitive advantage in more certain markets.

The design process for a rig is, like most engineering design processes, an elaborate iterative one in which many variations of structural arrangements and configurations may be explored. The operating capabilities of the MODU are first clearly defined and a conceptual design is accordingly formulated. The concept becomes the subject of extensive analysis, as the designer combines personal judgment and past experience with mathematical and physical modelling techniques in an effort to reach an optimum design. Structural strength and stability are examined to ensure both the integrity of the rig under various loading and environmental conditions, and its compliance with relevant national regulations and classification rules. Motion characteristics are estimated and compared with the operational criteria, towing resistance and propulsion requirements studied, and modifications to the concept analysed to determine their overall effect on performance and cost. When the conceptual design has been accepted, a preliminary design is developed by naval architects, structural engineers, mechanical and electrical machinery specialists, and experienced operational personnel. A classification society is generally consulted during this stage or even earlier, and, as the design becomes more definite, approval in principle is sought from the appropriate bodies involved in the regulation of the drilling rig, in its classification, and in its operation. Finally, the designer will prepare a set of engineering drawings and written specifications to enable the owner to call tenders for the rig's construction. Although this may represent the end of the original designer's involvement, it is important to realize that it does not mark the end of the design process. A significant portion of the design is, in fact, carried out by the builder and by the owner. The builder is usually responsible for developing all the working drawings and detailed design work necessary for construction, and may carry out this work with little or no guidance from the original designer. The owner, through the provision of "owner-furnished equipment", actually influences the design of large portions of the rig. The entire drilling and well control systems, for example, are usually owner-furnished.

During the design and construction of a rig the society selected by the owner to class the rig assumes increasing involvement as an independent inspector. During the preliminary design phase, the classification society will have analysed the design and issued an approval in principle. After a contract for construction has been let, the society, under contract to the builder,[1] will approve the method of construction and the working drawings developed from the original design and, in consultation with the builder, establish an inspection and testing plan for approval by the owner. Based on statistical data from new constructions and annual surveys, a sampling of welds will be selected for non-destructive testing. Elements and connections which are critical to the structural integrity of the rig will be singled out for testing in excess of that proposed for sections of lesser importance.

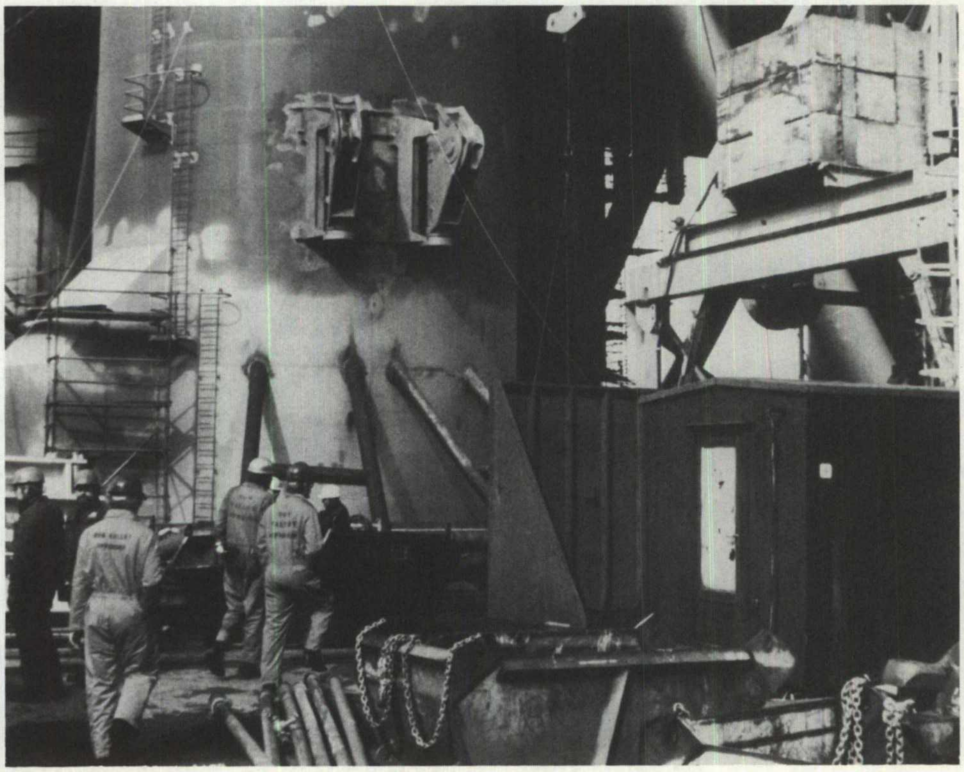
The classification society carries out its inspection and approval role only to the extent necessary to ensure compliance with its rules. What the owner may request, in addition to this inspection and the quality control practised by the builder, is entirely a matter of choice. The level and extent of the involvement of owners in supervision, inspection, and quality assurance during construction varies widely, ranging from those who will commit significant resources to the task to those who will essentially delegate all responsibility to the shipyard and the classification society.

During construction the detailed design of the MODU will continue to evolve as day-to-day decisions are made to improve construction scheduling and efficiency, reduce cost and enhance the safety and performance of the final product. All changes which affect the items covered by classification will normally be referred to the society's representative at the site, and all changes are subject to the approval of the owner. In many cases, changes will be the subject of negotiation between the builder, the owner's representative and the classification society's inspectors. Even after the rig has been subjected to an inclining test, dock and sea trials and has been approved by the classification society and appropriate national regulatory bodies, outfitting may remain to be completed and minor changes may still be underway when the rig arrives at its first drilling location.

A number of documents will be prepared to assist the owner in the safe and efficient operation of the rig. Although the classification and regulatory requirements for the extent, quality and approval of these documents varies, an operating manual and construction portfolio constitute the essential minimum to be provided. The operating manual should outline the operating limitations of the rig implicit in its design criteria, the operating procedures necessary for its safe operation and all other relevant information. The construction portfolio should contain a complete set of "as-built" drawings together with directions for the frequency, location and extent of the inspections necessary to confirm the rig's structural integrity throughout its active life.

The new MODU joins a world fleet of nearly 800 others. Many of the rigs now being designed and built are specifically intended for drilling in harsh environments, cold weather and deep water; some may eventually drill in Canadian waters, as may

[1]Although the classification society is selected by the owner on a competitive basis, the society is generally retained and paid by the builder. The approval of the finished unit by the selected society is a condition of the contract between the owner and the builder.

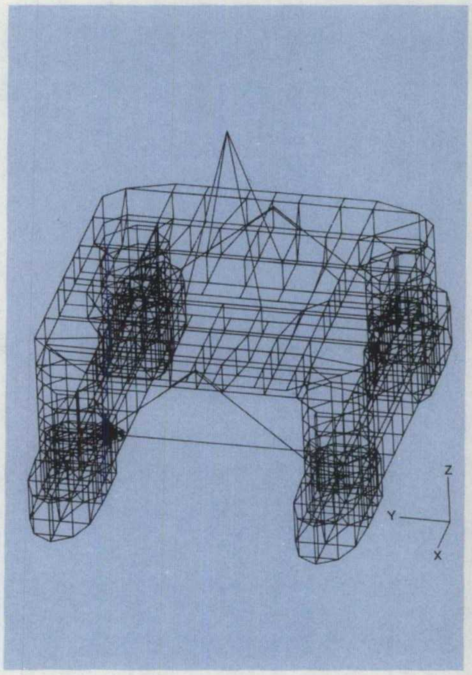


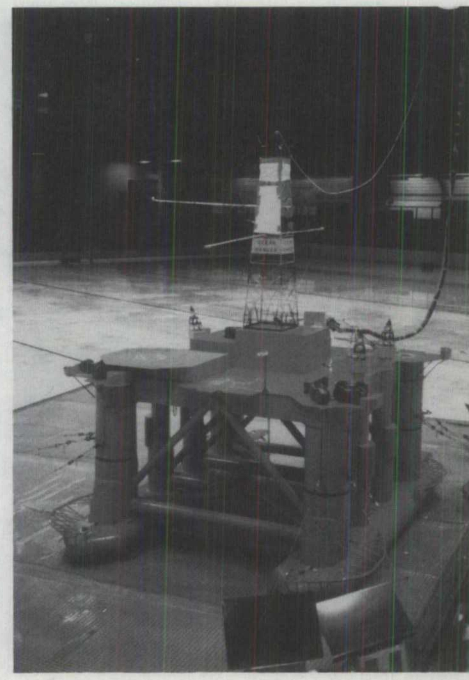
4.3 The construction of a new MODU is a complex operation involving hundreds of skilled tradesmen. A high standard of quality assurance is necessary during the construction process to achieve an acceptable level of safety.

other older rigs from the existing fleet. Their ability to operate safely is contingent largely upon the success of the design and construction process through which they have been created.

Designers, and the classification societies which approve their work, are faced with many uncertainties in predicting the strength and behaviour of the finished unit from the detailed analysis of the design. The limitations of existing analytical techniques, the inherent uncertainties in the conversion of environmental forces to loads and stresses in the structure, the potential for flaws in materials and construction techniques and, ultimately, the limitations of those who will operate the rig, must all be addressed. Most of these difficulties are counteracted by the use of adequate safety factors for the structural members and connections that are critical to the rig's integrity, and by incorporating a level of redundancy in the structure which, in the event of a failure, will allow loads to be carried through alternative components. Safety factors must be recognized as a means of reducing risk where uncertainty exists and as a legitimate method of compensating with subjective experience for shortcomings in analysis and in construction.

The rules of classification societies and, often, the regulations of Flag and Coastal States require that a design be capable of withstanding a specified set of environmental conditions. The prospective owner may, for a variety of reasons, stipulate more rigorous conditions. To develop a design that meets these requirements, the designer will employ a variety of analytical and design methods, some explicitly suggested or required by regulatory bodies or by classification societies, some a matter of the designer's choice. Individual designers will, through experience, have greater confidence in some techniques or procedures than in others. The analytical or experimental techniques, however, by which environmental conditions are converted to loads or forces on the rig, involve simplifying assumptions that make possible the analysis but also introduce uncertainties in the results that they yield. Furthermore, it is often difficult to determine the vulnerability of a design to a combination of conditions, each less severe than the specified extremes. The extreme forces may not be





4.4 Mathematical and physical modelling techniques continue to evolve with improvements in computer technology and in the understanding of the behaviour of full-scale structures. Nevertheless, both methods involve uncertainties which can affect the overall safety of a rig's design.

those that have the greatest effect on the structure. Jack-up rigs have suffered fatigue damage in their legs, and semisubmersibles in their trusses, in wave conditions far less severe than the extremes for which they were designed. Both designer and classification society need to agree on a number of load cases that are representative of the worst loadings to which the unit will be exposed in actual operation. It is recognized that it will not be possible or necessary to analyse every conceivable load case.

Physical model tests can provide important information on the strength, behaviour and stability of a structure and supplement or complement the results of other purely analytical techniques. Physical model tests, however, as do the analytical approaches, involve many simplifying assumptions and limitations. While they are intended to reproduce real operating conditions and appropriately scaled physical members of the rig, they cannot reproduce all the complexities of the full-scale structure, the environments in which the rig will operate, or the combinations of conditions to which it may be exposed. Many difficulties are encountered in establishing the scaling factors necessary for adequate simulation. The differences between model tests, mathematical modelling and real-life behaviour will be better understood and the predictability of behaviour improved when more attention has been given to full-scale, real-time instrumentation, monitoring and testing of operating MODUs for which model-testing data are available (Appendix C, Items 2, and 6).

Simplified procedures and general yardsticks have been adopted in certain areas where the theoretical basis for assessing a MODU's behaviour is either inadequate or so complex that it is of little practical use. This has been done in the determination of the wind-related forces and of the resultant heeling of semisubmersibles. Experience has shown that this simplified approach provides a reasonable factor of safety, and comparisons of the forces calculated using this empirical method with model-testing data have indicated the approach to be somewhat conservative. There is, however, a lack of a firm and rational basis for these empirical yardsticks, and a lack of agreement regarding theoretical approaches to the problem.

With the increasing use of higher strength steels, and with more sophisticated and apparently accurate methods of structural analysis, the designer today can significantly reduce the weight of the rig, and increase its operational efficiency with attendant commercial advantages. High strength steels, however, call for more sophisticated welding methods and materials, more accurate lineup and fitting, and better control and inspection than conventional steels. While the newer methods of analysis may be more accurate and permit more efficient designs, the level of quality assurance must be more stringent in order to maintain acceptable standards of safety. None of the methods available can give assurance that all loadings to which a MODU may be subjected can be accounted for analytically in the design process. Nevertheless, these analytical tools do allow the identification of critical elements in the design and of the areas requiring intensive inspection.

The development of new concepts and techniques in design and in their supporting analyses, which are almost invariably computer-based, enables the designer to explore quickly the effect of changes in his design and in the magnitude and frequency of applied loads. These new techniques provide a capability to reduce some of the uncertainties in earlier designs and to achieve a reduction of weight and cost while enhancing the potential performance of a design. Similarly, the application of these techniques may allow designers to accommodate fully new and more severe code requirements with little, if any, change to the design and thereby to avoid increased costs. Only with time, experience and the careful monitoring of operating rigs, however, will justifiable levels of confidence in new concepts and techniques emerge.

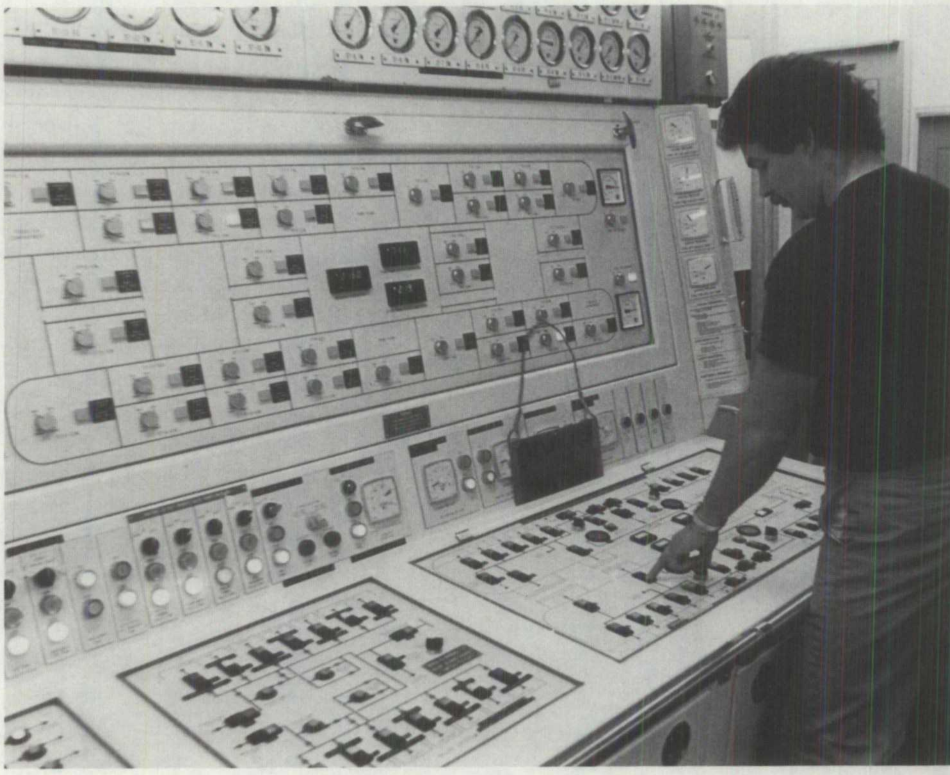
Whatever the type of analysis that is employed, it is significant that some of the assumptions made by the designer in order to carry out the analysis may pass through the approval process without being challenged. The result has proven disastrous on a number of occasions. The sinking of the semisubmersible *Transocean III* in the United Kingdom sector of the North Sea in 1974 was directly attributed to an erroneous assumption regarding the transmission of loads from the legs to the main structure. No lives were lost in that incident, as the crew were evacuated six hours before the rig capsized. The loss of the semisubmersible *Alexander L. Kielland* in the Norwegian sector of the North Sea in 1980 was attributed to the failure to identify, in the structural analysis or during construction, the stress concentration that was caused by a hydrophone support opening in a primary bracing member; the result was the failure of the bracing member under conditions that were within the rig's design limitations, the subsequent separation of an entire column and the loss of 123 lives. These two examples indicate the serious results of human shortcomings that may be present and the need to ensure that the assumptions made in the design and construction process are independently challenged and subjected to intense scrutiny. It is a sobering reminder that both the *Transocean III* and the *Alexander L. Kielland* were in class, had been approved by their respective Flag States and had been inspected by the Coastal States under whose jurisdiction they were operating.

"Certifying Authorities should be reminded of their obligations to make a critical scrutiny of all design details and, in particular, to question and verify the applicablity of all assumptions made in the course of design – this is of particular importance where designs or design details involve unusual or novel conceptions."

Recommendation from the Report on the Loss of the Drilling Barge Transocean III. UK Department of Energy, Petroleum Production Inspectorate. 1975

With the selection of the design, the owner fundamentally assumes the responsibility for establishing the quality of the rig, its safety and its efficiency in operation. His selection of the yard in which to build the rig, the extent of his involvement in supervision and inspection and the level of supervision during construction have a great influence on the quality of the constructed unit. In many cases the designer retains little, if any, control over the detailed design carried out by the builder, or over the selection and integration of owner-furnished equipment. The extent to which these design and outfitting processes are analysed to ensure overall compatibility varies widely; isolated acts by the builder or owner, which when taken individually appear inconsequential, may produce unexpected vulnerabilities in the overall design.

An illustration of the importance of the owner's and builder's influence on design can be taken from the investigation of the loss of the *Ocean Ranger*. The design specifications for the rig described a ballast control panel with simple manually operated pneumatic valves. The builder subcontracted the detailed design and assembly of the panel to an outside firm which proposed the addition of an electrical



4.5 The complex interaction between human operators and the systems under their control requires careful consideration during the design process. Schematic control panels, such as the ballast control panel illustrated, have been replaced by computer control systems and video display terminals on some new rigs. Some of the factors affecting the "man-machine interface" are addressed in Appendix C, Item 3.

control system to operate the pneumatic valves. This design was accepted by the owner as being equivalent to that described in the specification, even though the less complex manual valve panel had been installed on the owner's earlier rigs and had performed well in operation. The vulnerability of the *Ocean Ranger*'s electrical control system to flooding was a major factor which contributed to the loss of the rig. Whether the same outcome would have resulted if the design specification had been met and a pneumatic panel installed, was answered in February, 1984 when a second ODECO semisubmersible, the *Ocean Victory*, sustained wave damage which ruptured a portlight and deadlight assembly in the ballast control room and resulted in the ingress of water. A United Kingdom Department of Energy memorandum on the event concluded that "it was fortunate that in the case of *Ocean Victory* the ballast controls were pneumatic and therefore not affected."

An examination of the roles of the designer, owner and builder in their search for more reliable, more efficient and cost-effective structures has revealed extensive evidence of vulnerabilities produced by a lack of attention to the human element of MODU operations. The level of safety achieved by concentration on the rig's structural integrity may be substantially eroded if control systems and equipment are not designed with consideration for the way in which the operating personnel receive and respond to information, the manner in which the information is processed and used and the factors which modify or alter the response of individuals to the critical processes under their control. This "man-machine interface" is often compromised by equipment design and layout based solely on engineering requirements; features of the detailed design of systems critical to the MODU's safety may limit or preclude their operation under foreseeable adverse circumstances. Many of these limiting features were discovered during the inquiry into the loss of the *Ocean Ranger*. There should be no ambiguity for an operator about the status of a critical valve, its location or how to operate it manually, if the need to do so should arise. Furthermore, in the event that the rig is damaged and listing, the limited ability of anyone to perform tasks on a tilted surface which is in constant motion, should be recognized and should govern the design, location and orientation of critical controls and equipment with which the operator must work. Expertise in this field of "human factors" has been readily available for many years, but its application in MODU design is not yet a common practice.

The role of the builder in determining the level of quality and thus the ultimate safety of the rig cannot be overemphasized. Even though during construction the rig is inspected by a classification society and often by the owner, in the final analysis the effectiveness of this process will depend to a great extent on the builder's own quality assurance program, on the skill of the design staff and on the competence of the workers. As many MODU designs differ radically from conventional vessels in the materials, methods and complexity of construction, the builder's previous experience with MODUs is crucial. The contemporary use of higher strength steels has been accompanied by advances in welding techniques, materials handling and alignment tools; nevertheless, stresses in the structure induced during construction and flaws in materials and welds that may have been present in earlier units may not be as easily forgiven by nature in new and leaner rigs destined to operate closer to their design limitations in severe environments. Even the best designs can be compromised in construction.

A rig is designed and constructed in accordance with the rules of the classification societies, international conventions and the regulatory requirements of the Flag State. Although they differ in some respects, the major classification societies are generally similar in their function and in the responsibilities that they assume. They, on behalf of rig owners and associated interests such as insurers, machinery suppliers and steel makers, establish rules relating to design, construction and materials for different classes of vessels and carry out analyses of designs and inspections of new construction, modifications, maintenance and repair to assess compliance with these rules. In the formulation of their rules and in their inspection procedures, they draw upon long experience, a large pool of statistical data, and extensive research and development capability.

Meeting and maintaining compliance with class rules is usually a requirement of the owner, the insurance underwriter and often of the Flag State.[2] It signifies that the vessel complies with a standard of construction which assures structural strength for the conditions for which it was designed; that particular electrical and mechanical systems comply with the rules and are installed properly; that the vessel is maintained by its owner to the extent that it does not lose its classification, and that all major repairs or structural changes on the vessel are carried out in accordance with the rules of the classification society.

Classification assures that the design and integrity of the main structure and certain of the systems of a MODU are adequate according to the societies' rules, but the classification process does not address many of the systems upon which the safety of the rig may depend. Mooring systems, for instance, which are of critical importance in station keeping and may have to be rapidly disconnected for ice avoidance in eastern Canadian waters, may not always be subject to classification. Communications and evacuation systems, which may spell the difference between life and death during emergencies, are also outside the societies' ambit, as are the drilling and well control equipment, the failure of which may give rise to disaster. Classification rules are primarily oriented toward the MODU's structure and hardware. The overall tendency of the rules regarding equipment is to concentrate on the mechanical and electrical suitability of individual components, and not sufficiently on their integration into reliable and operable systems.

[2]For instance, the Canadian *Interim Standards Respecting Mobile Offshore Drilling Units*, to which all Canadian-registered MODUs must comply, allow the acceptance of the construction standards published by Lloyd's Register of Shipping, the American Bureau of Shipping, Bureau Veritas, and Det norske Veritas, four of the major classification societies.

The choice of Flag State under whose regulations the vessel will be built is normally made before construction begins. Individual Flag States exercise varying degrees of regulatory control over the design and construction of MODUs under their registry. Although stability rules have traditionally been the responsibility of the Flag State, many countries require only that the rig meet the stability criteria of the society under which it is classed, and the issuance of the certificate of registry is often delegated to the classification society. Classification and compliance with the *International Convention on Load Lines* and the *Safety of Life at Sea (SOLAS) Convention* may be the sole requirements for registry. It is significant that both Conventions were developed for international application to conventional vessels, and do not adequately address the requirements of MODUs. The *International Convention on Load Lines*, while applicable to drill ships and transiting jack-ups, cannot be applied logically to semisubmersibles because of their structural configuration. The *SOLAS Convention* deals with the design of a vessel as it affects the safety of life, including communications equipment and lifesaving appliances. That even those MODUs outfitted far in excess of the SOLAS requirements do not provide the means for successful evacuation in foreseeable emergencies is evident from historical record.

Many Flag States require that the standards of the *International Maritime Organization (IMO) Mobile Offshore Drilling Unit Code*, adopted in 1980, be met. Some countries have supplemented the requirements of the *Code*, as Canada has done, while others have introduced requirements that depart sufficiently from the *Code* to establish, in effect, a new regulatory regime; Norway moved in this direction when she introduced, as a result of the loss of the *Alexander L. Kielland*, among other requirements, the provision that a semisubmersible be able to survive the loss of buoyancy equivalent to that of a main column. Many dispute the current approach of relying on the buoyancy of the deck structure to comply with Norwegian requirements in that the watertightness of the deck relies heavily on efficient closing appliances and on absolute adherence by the crew to operating procedures. Both of these assumptions have proven fallible in the past. The design requirements for a watertight deck may also limit the number and location of emergency escape routes which can be provided to the perimeter of the unit. In the opinion of many, these dramatic departures from the established principles of the *IMO MODU Code* may not necessarily contribute to the overall safety of those involved in offshore operations.

"Realization of realistic criteria for leak [sic.] stability for some types of platforms will lead to requirements for making some parts of the deck structure buoyant. . . . To use (part of) the deck of conventional platforms as buoyant elements in a leak or damage condition, is. . .to a great extent to be considered as a new principle. Introduction of new types of platform may also represent changes of the conditions of operation."

The Alexander L. Kielland Accident. Norwegian Public Reports. March 1981

Although no losses of semisubmersibles have been attributed to inadequate intact stability rules, the differences in the rules are evident from the tables in Appendix C, Item 4. An example where agreement among regulatory agencies is desirable is the calculation of the effects of wind forces on MODUs. The methods vary considerably, although the procedures for calculating wind heeling moments contained in the most specifically formulated rules are said to be adequate and conservative. There is no uniformity in the requirements for the minimum metacentric height (GM) and not all regulatory agencies limit the maximum static angle of heel in wind. All the individual intact stability requirements combined are necessary to provide a reasonable safety factor for the stability of a drilling rig; GM is directly related to the forces that act to restore a heeled MODU to its level position, and is determined by the shape of the submerged parts of the rig and by its centre of gravity in a given operating condition. An increase in the minimum required GM, which may result from changes to one or more of the existing intact stability requirements, will reduce the carrying capacity of a MODU at a given draft with a consequent need for more frequent resupply.

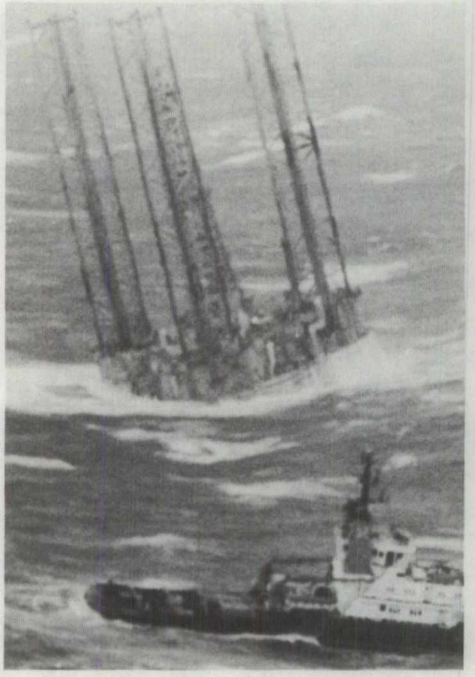
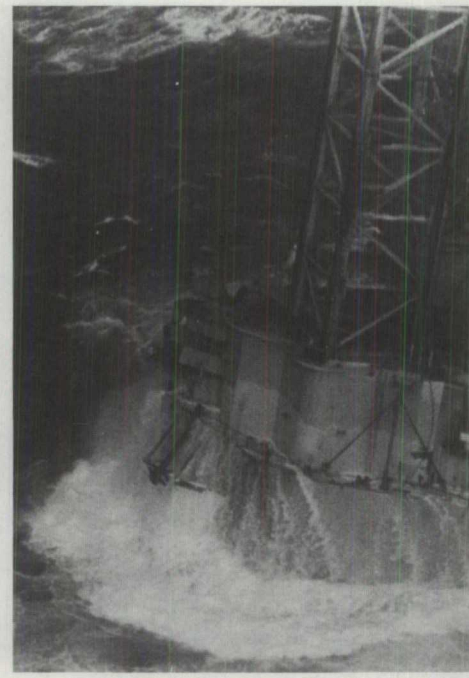
The existing rules worldwide, regarding the ability of a semisubmersible to remain stable and afloat after sustaining damage and flooding of watertight compartments also show differing opinions, primarily in the assessment of the extent of damage for which allowance must be given and in the establishment of the maximum

4.6 Numerous collisions have been reported between drilling rigs and supply vessels on Canada's East Coast. Supply vessels must manoeuvre in close proximity to the outer periphery of a rig during cargo transfer and anchor-handling operations. Many rigs are equipped with fenders to limit impact damage. This photograph of the *Ocean Ranger* at transit draft shows the fenders high above the waterline.

angle of inclination which may result from that damage. Most authorities have based the extent of damage to be considered on the credible consequence of impact with a supply vessel, as this represents its most likely source. As supply vessels operate near the outer perimeter of the rig, only those watertight compartments on the outside of pontoons and columns are considered; no provision is made for protection against the impact of ice, which may occur on the inner periphery of pontoons and columns. This problem requires early consideration for units operating in ice-frequented waters. Although the *IMO MODU Code* does not define a specific angle of inclination which may result from the assumed extent of damage, the Canadian *Interim Standards Respecting Mobile Offshore Drilling Units* limit the allowable angle to 15 degrees.

A further difficulty in most current damage stability regulations is that they assess downflooding only on the basis of the static inclination caused by the damage and a specified wind force. They do not take into account the motions of the semi-submersible and the action of waves on it. Stability rules currently require a MODU to be designed so that, under the specified extent of damage and wind conditions, it will not list beyond the angle of downflooding, which by definition is the angle at which an unprotected opening in the structure reaches the mean sea level. Because rig motion and wave action may cause downflooding long before that point is reached, codes should include provision for freeboard to potential downflooding points, or for reliable weathertight closures to protect openings that may be immersed.

Jack-up rigs are particularly vulnerable during long tows since they are not always able to avoid severe storm conditions. Their freeboards are normally quite low and because of their typically short and blunt hull shapes, their motions in rough seas are large. Considerable green water can be shipped over the deck in a storm, with the potential of causing damage to deck fixtures, or shifting of cargo with resultant damage and downflooding. While there is a growing trend to transporting jack-ups to new locations aboard barges, more attention should nevertheless be given to the weather- and watertight integrity of these rigs.

4.7 The jack-up drilling rig *Dan Prince*, 600 nautical miles south of Alaska while under tow to West Africa in October, 1980. Hurricane-force winds and high seas battered the rig for six days before it eventually capsized and sank. The sinking was attributed to flooding caused by structural damage and by the shifting of deck equipment and cargo.

MODUs designed and constructed as discussed above, are governed by international conventions, the rules of classification societies and the requirements of their Flag State. The fundamental question for the Coastal State, upon whose continental shelf they are intended to operate, is whether a particular rig is suitable for operating under the environmental conditions prevailing there. The Coastal States under comparative review have each answered this question in a different way.

In the United States, the approval of MODUs is regulated by two agencies, the United States Coast Guard and the Geological Survey. The Coast Guard carries out inspections to assess the rig's structural integrity, stability and compliance with rules which incorporate the standards of the American Bureau of Shipping (ABS), the American National Standards Institute, the American Petroleum Institute and others. Certain assessment and inspection activities may be delegated to ABS for any United States-registered rig that it has classed. Foreign flag rigs are required either to possess a valid certificate of compliance with the *IMO MODU Code*, or to submit to Coast Guard inspection for the issuance of a letter of compliance which indicates that an equivalent level of safety has been established. The Geological Survey has additional requirements to establish the fitness of a MODU to withstand oceanographic, meteorological and seabed conditions.

In Norway, the Norwegian Maritime Directorate or a delegated body such as Det norske Veritas, conducts an assessment of any existing rig, or rig under construction, which is proposed for operation in Norwegian waters. The survey is conducted to assess compliance with the *Mobile Drilling Platform Regulations*. After the rig has been accepted, intermediate surveys are carried out annually in addition to an extensive review and inspection every four years.

The United Kingdom has instituted a process for the approval of MODUs to ensure that all aspects of the design and construction processes are subjected to critical scrutiny by an independent body, after which a *Certificate of Fitness* is issued for the intended area of operation. The regulatory authority has approved six certifying authorities to carry out the survey, five of which are classification societies. To date, only the classification societies have issued certificates, and, in most cases, the society doing so had already classed the rig. The certification process is carried out to assess compliance with an extensive set of performance standards entitled *Offshore*

Installations: Guidance on Design and Construction and generally referred to as the "Blue Book".

The Canadian approval process for MODUs has changed significantly since the loss of the *Ocean Ranger*, just as the Norwegian process was altered after the loss of the *Alexander L. Kielland*. When the *Ocean Ranger* was proposed to operate on Canada's East Coast in March, 1980, the Canada Oil and Gas Lands Administration (COGLA) accepted the rig on the basis of its classification certificate, *SOLAS* and *International Load Line* certificates and its *Certificate of Registry* as a United States vessel. No surveys were conducted by a Canadian regulatory authority to ensure that the rig was suitable, in an overall sense, to carry out operations on Canada's Continental Shelf. COGLA performed inspections only to the extent necessary to confirm that the drilling program itself was carried out in a safe manner conforming to good oilfield practice.

Since the loss of the *Ocean Ranger*, COGLA has required that all MODUs intended for operation in Canadian waters comply with the *Interim Standards* and, through a Memorandum of Understanding, has given authority to the Canadian Coast Guard to inspect rigs for compliance with these standards. The standards essentially embody the requirements of the *IMO MODU Code*, with the addition of more stringent requirements for stability and ballast control in reaction to the loss of the *Ocean Ranger*. Canadian-registered rigs must also comply with the requirements of the *Canada Shipping Act*, and all rigs must comply with the requirements of the *Canada Oil and Gas Drilling Regulations* and their accompanying guidelines.

The central focus of the present certification process in all four jurisdictions is the structural integrity and stability of the rig. The assessment also includes such items as emergency power, fire protection, communication, lifesaving equipment, and maintenance of equipment. But the safety and hence the suitability of a rig for operations on the Canadian Continental Shelf will depend not only upon the physical integrity of the rig and its equipment but also upon its critical systems and upon its management and crew. To this end, what is necessary is a three-phase safety audit or approval process; one for each of the essential criteria of suitability. The first phase should consist of an assessment of the physical integrity and the stability of the rig; the second should be an evaluation of the operability and integration of its critical systems; the third should constitute an assessment of the qualifications and competence of its management and crew.

Before the first phase can begin, a comprehensive body of regulations and guidance notes needs to be developed against which a rig is to be assessed. The Blue Book in the United Kingdom and the *Mobile Drilling Platform Regulations* in Norway provide a broad scope of requirements, which make clear, both to the inspection agency and to the owner of the rig, what is required for approval. Canadian requirements are less developed and less comprehensive than those of the other jurisdictions examined and they need to be reviewed and in many cases amplified with particular attention to design; standards of material and of construction; hazards from environmental conditions, especially ice and icing; evacuation and lifesaving systems; station-keeping and mooring systems; and preventive maintenance. Of particular concern is the fatigue strength of certain structural members exposed to vibrations, the effect of which it is difficult to predict. Welded connections between struts and columns are especially vulnerable and closer inspections of them would be advisable. It is interesting to note that, in 1982, the Newfoundland and Labrador Petroleum Directorate developed design and construction regulations, that drew upon those of other jurisdictions under review but supplemented them in such areas as drilling equipment, mooring systems and environmental conditions, particularly ice. In the formulation of the needed comprehensive body of requirements to assure the physical integrity and the stability of the rig, the Canadian regulatory authority should draw upon the expert advice available in other government departments and agencies, consult closely with industry and adapt to its special needs the knowledge and experience of other nations.

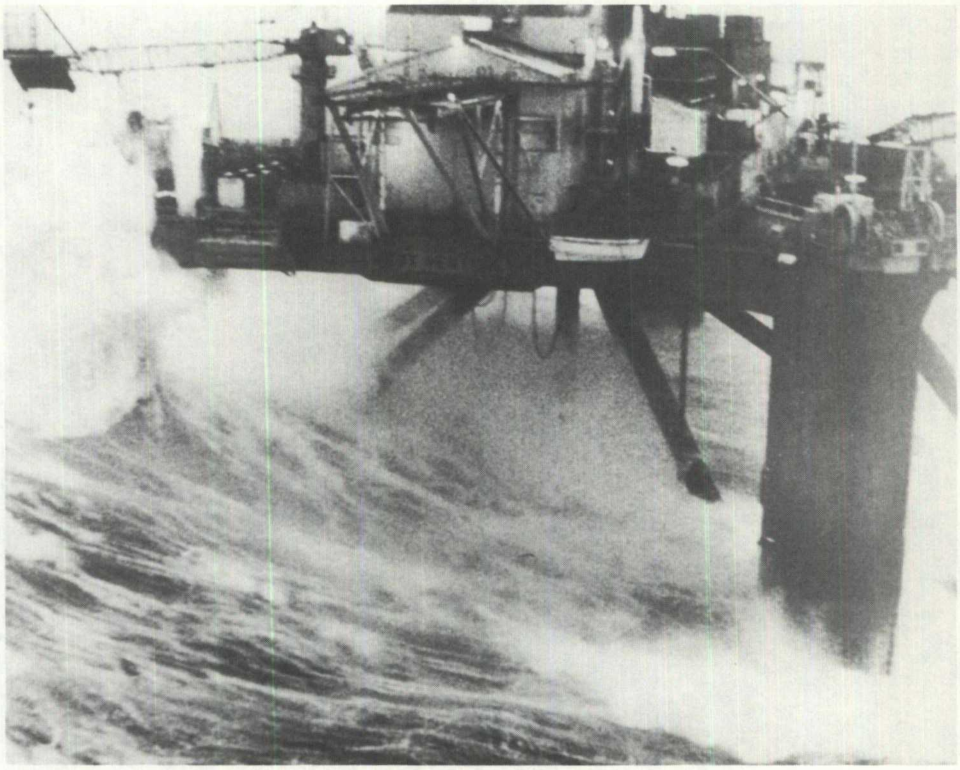
The assessment of a rig to determine its compliance with requirements and guidelines is often delegated, in whole or in part, to classification societies, in Norway to Det norske Veritas, and in the United States to the American Bureau of Shipping. In the United Kingdom, as stated above, classification societies have been used to certify the rigs proposed for use on its continental shelf. The logic of the British approach is that technologies of MODU design and construction are rapidly evolving and their scrutiny needs experienced practising professionals supported by multidisciplinary resources of personnel and testing facilities. Since external agencies possessed these resources, the decision was taken not to develop the capability within government. In Canada, there has been no delegation to external agencies and rigs have been assessed by the Ship Safety Branch of the Canadian Coast Guard. With the introduction of more detailed and broader requirements, it would appear advisable to utilize the classification societies with their long experience, their reservoir of statistical data and their extensive investigative resources rather than to attempt to develop an in-house capability to determine whether a rig complies with the requirements which govern its structural integrity and its stability. The classification society would certify to the regulatory authority that all regulations have been met and all guidance notes followed. This assurance of compliance would constitute the completion of the first phase of the safety audit or approval process.

The second phase of the safety audit or approval process should be an evaluation of the systems identified as being critical to the safety of the rig, of the interrelationships and interactions among these systems, and of the procedures governing their operations against the environmental conditions of the proposed drilling site. These systems should be subjected to a level of analysis consistent with their potential impact on safety. Before an evaluation can be undertaken, there is need of a clear, comprehensive set of performance standards and criteria, drawn up by the regulatory agency in consultation and collaboration with industry, against which an evaluation can be made.

Because the nature of the assignment is quite different from that of the classification societies, it is not recommended that the second phase of the safety audit be performed by them. This second phase of the approval process should be carried out by a safety audit team appointed by the rig owner, subject to the approval of the regulatory authority. It should consist of persons whose personal judgment is supported by extensive experience, who have demonstrated knowledge of offshore operations, systems reliability and risk analysis, and who are well grounded in all aspects of safety management. The function of the safety audit should be one of seeking improvements rather than of laying blame, of assessing the consequences of inadequacies, and of evaluating remedial measures necessary to improve the safety of operations. This objective can be fully achieved only when the owner incorporates it as part of his own program for quality assurance and safety. The appointment of the auditors by the owner should assist in the attainment of that goal.

All drilling units operating or intended for operation on Canada's Continental Shelf, whether existing or new construction, built in Canada or abroad, should be audited for safety. The rigs to be audited will generally be those already in existence and intended for operation in Canada. Since it would be neither fair nor practicable to have the owner bring a rig into Canada, only to have it subsequently rejected, the major portion of the safety audit should be done within the six-month period before its intended arrival in Canadian waters. It is recognized that special consideration may have to be extended to rigs which have already been approved and are operating on the continental shelf but "grandfathering" should be kept to a minimum.

The second phase of the safety audit or approval process should not duplicate the assessment of the structural integrity and stability of the rig that was completed

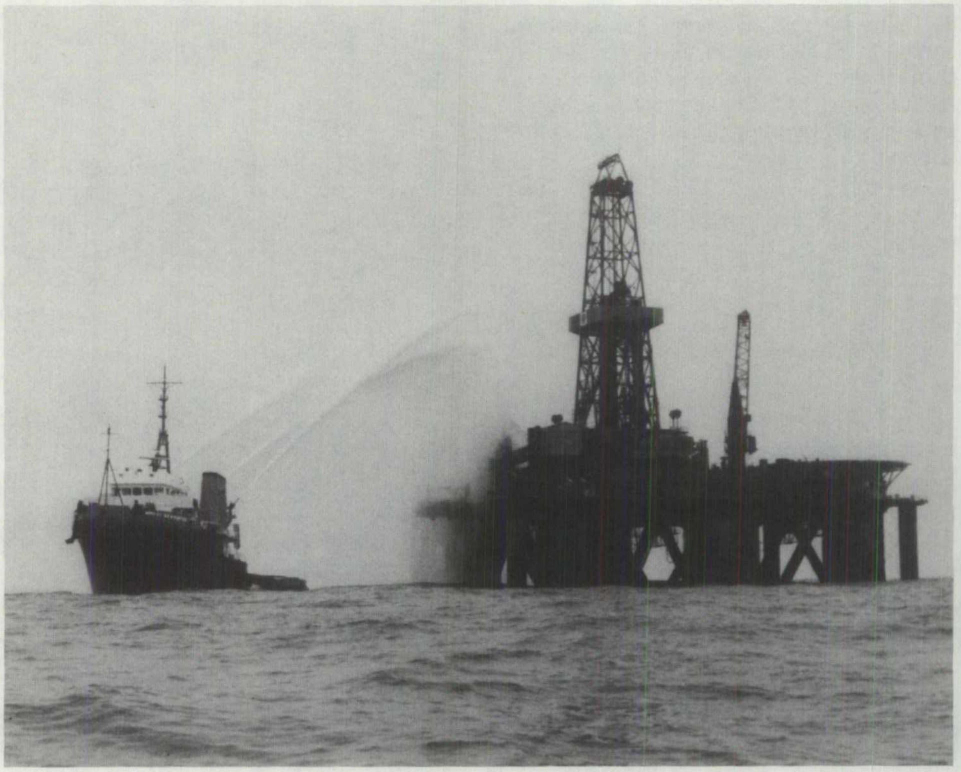


4.8 The extreme environmental conditions encountered off Canada's East Coast demand that particular attention be paid to the adequacy of the critical systems, personnel, and operating procedures of each drilling rig.

during phase one. The safety auditors, nevertheless, would be expected to discuss with the appropriate representatives, any matters of concern which might arise out of the review of the documentation. The first task of the safety auditors would be the gathering and assimilating of information with respect to the rig. This documentation should include all available information about the rig, its design and construction, its critical systems, its management and crew. It should also include a critical review of, *inter alia*, all certificates issued under phase one of the approval process and other documentation required in order to enable it to operate; the operating and emergency procedures manuals, the operational history of inspections and modifications, preventative maintenance logs, the crew training program, personnel qualification requirements, and administrative procedures. The audit team would also be provided with all documentation pertaining to the assessment of the physical integrity of the rig carried out in phase one of the approval process. Should their examination of this documentation or other evidence reveal inadequacies, independent analyses as well as thorough inspections and assessments of the structure and equipment could be required.

The review of documentation should be followed by an inspection of the rig. In addition to the inspection of equipment and systems and the assessment of their functional performance, the auditors should assess the extent to which actual operating procedures comply with those intended by management. When deficiencies are identified and recommendations for improvement considered, the safety auditors should discuss with the owner, the operator and the regulator how the deficiencies can be addressed, the urgency of doing so, a schedule for any agreed remedial steps, and restrictions that may be imposed during the intervening period.

The report on the second phase of the safety audit or approval process should identify any feature of the rig that would preclude or unduly inhibit its safe operation under foreseeable circumstances on the Canadian Continental Shelf. The report should be submitted to the rig owner, the operator and the regulator. The report may unconditionally certify compliance of the unit, categorically reject it, or conditionally



4.9 Recent blowouts on the Scotian Shelf, on the semisubmersible *Vinland* and the jack-up *Zapata Scotian*, were attributed to a combination of mechanical failures and human errors in the operation of well control systems. Both incidents illustrate the need for a closer examination of the design and operability of the critical systems used on MODUs.

certify compliance, recommending that the issuing of permits or permission to proceed beyond certain defined milestones or dates be dependent upon the completion of specified modifications, or upon the institution of changed operating procedures. Upon receipt of a satisfactory report, the regulatory authority should issue a conditional approval. The owner will have assurance that the rig will be permitted to operate when it arrives in Canada or, alternatively, he will have the option of not bringing it to Canada, if he is not prepared to correct those deficiencies identified by the safety auditors.

The third phase of the safety audit or approval process should be carried out by the safety audit team after the rig is in operation in Canadian waters. It should be directed towards confirming that any deficiencies or vulnerabilities noted in the safety auditors' report and required by the regulatory authority to be rectified or remedied have been satisfactorily attended to. It should then be directed to an assurance that the approved operating procedures for the safe operation of the rig are being followed by a competent and qualified crew. This review should include an assessment of the training, knowledge and qualifications of those involved in the control and operation of critical systems and the effectiveness of these individuals in performing both routine tasks and emergency drills. This assurance is necessary because of the common practice of making significant crew changes when a rig moves from one jurisdiction to another. Upon receipt of a favourable audit report, the regulatory authority should issue an unconditional Certificate of Approval.

Other audits may be deemed necessary, whether after a fixed number of years or upon a proposed move to a location of greater environmental hazards. The need may, indeed, be dependent upon the outcome of the initial safety audit or may arise from the operating experience and the occurrence of "significant events". The scope of these audits should be determined after full consultation with the owner and with the operator.

The importance of establishing a clear understanding of the responsibility and accountability of each of the parties involved in offshore petroleum activity under

Canadian jurisdiction cannot be overestimated. The increasing complexity of the industry has led to contractual and organizational arrangements within which dilution and diffusion of responsibility and of accountability for safety can readily occur. There should be no confusion regarding the responsibility and the accountability of the rig owner and of the operator.

The rig owner should unequivocally be responsible for the integrity of the rig and accountable for its safe operation. This responsibility requires that he be satisfied with the quality of construction and that all reasonable steps be taken to identify construction flaws that may adversely affect the safety of the rig; to ensure that the rig complies with the design principles, performance standards and criteria set out by the regulatory authority; to arrange for audits as required by the regulatory authority to establish compliance with its standards and criteria; and to report to the regulatory authority, as required, those incidents that may have endangered equipment or personnel, or revealed a need for change in equipment or operating procedures.

The operator is legally accountable for all aspects of the operations under his permit. It is he who hires the MODU and, from that fact, he cannot escape responsibility for its quality and its performance. Ultimately he has the power, through the contractual arrangements into which he enters, to influence the safety consciousness and performance of the contractors whom he retains. It is the rig owner who should be clearly responsible for the fitness and safety of his drilling rig, and his contract with the operator must reflect his responsibility to manage and maintain it in an acceptably safe condition that complies with the requirements of the regulatory authority.

The knowledge, capabilities and commitment to safety of all those involved in the many diverse functions required to operate a drilling program offshore eastern Canada will, in the final analysis, determine the safety of the drilling rig and its crew. No equipment, however well designed and built, subjected to the demands of these offshore marine environments, can be made impervious to human error or fallibility. Ultimately, safety depends as much on people as on the soundness of the equipment.