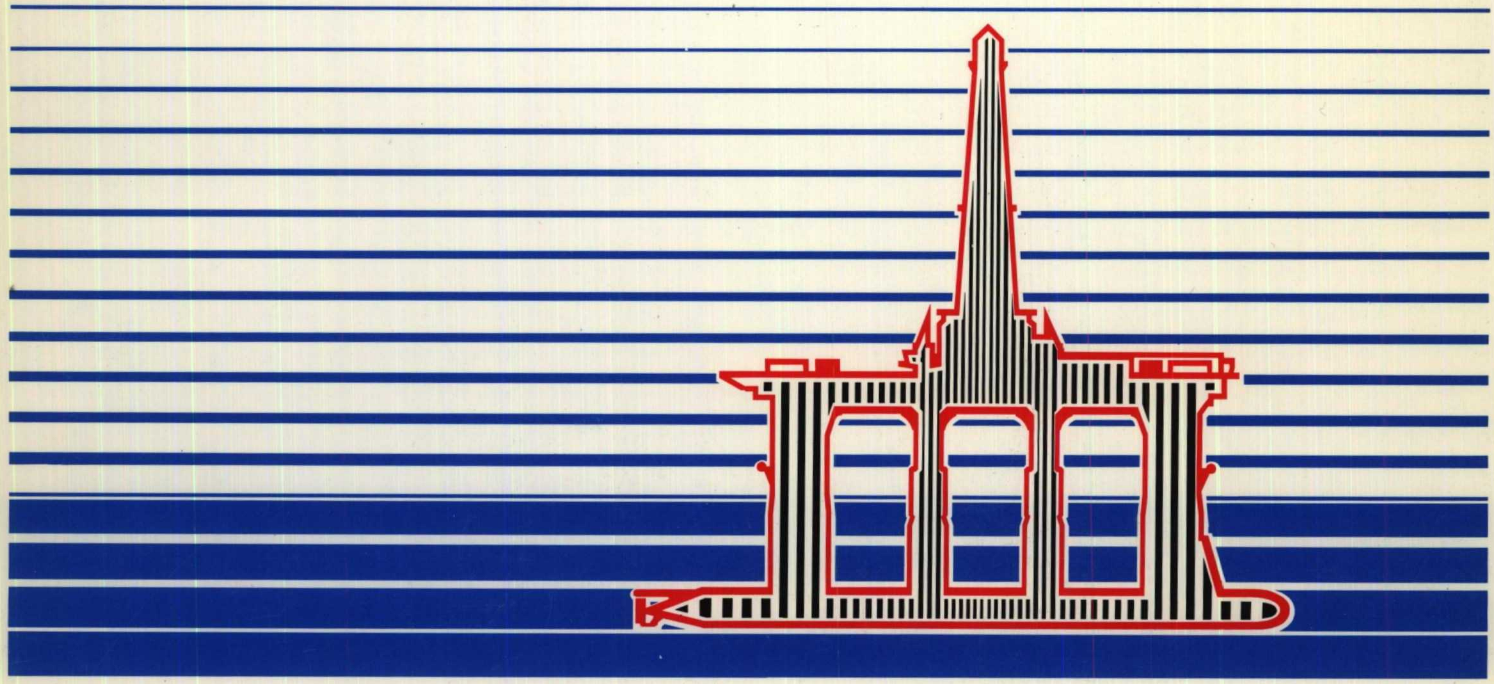
Royal Commission on the
Ocean Ranger Marine Disaster

Canada

Commission Royale sur le
Désastre Marin de l'*Ocean Ranger*

Newfoundland & Labrador



Report Two: Safety Offshore Eastern Canada

Conference Proceedings, 1984

The Royal Commission on the *Ocean Ranger*
Marine Disaster was jointly established and
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The two reports of the Royal Commission on the *Ocean Ranger* Marine Disaster consist of the following four volumes:

Volume 1	**Report One: The Loss of the Semisubmersible Drill Rig *Ocean Ranger* and its Crew**
Volume 2	**Report Two: Safety Offshore Eastern Canada**
Volume 3	**Report Two: Safety Offshore Eastern Canada** ***Summary of Studies & Seminars***
Volume 4	**Report Two: Safety Offshore Eastern Canada** ***Conference Proceedings, 1984***

Volume Four is the Proceedings of the International Conference on Safety Offshore Eastern Canada,
St John's, Newfoundland, August 21-23, 1984.

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PREFACE

In addressing the second part of its mandate, the Royal Commission followed a consultative process through which it sought opinions as well as factual information. A study program was undertaken, the purpose of which was to provide the Royal Commission with a concise but comprehensive review of the state-of-the-art in the main areas of concern. These studies, the various submissions received and the technical data gathered in the Part One Inquiry comprise the information base on which the Royal Commission prepared its second and final report.

The Conference on Safety Offshore Eastern Canada, held in St. John's Newfoundland, August 21-23, 1984 was organized by the Royal Commission in association with Memorial University of Newfoundland. It provided the first opportunity for public consultation on that information base and on the important issues that were being addressed. Summaries of most of the studies done for the Commission were distributed to participants before the Conference in the form of briefing papers. The main purpose of this Conference was to stimulate debate by experts on the basic issues and questions which the Royal Commission must address, and to illuminate possible new directions and opportunities for improvement. These proceedings incorporate the formal presentations made during the course of the Conference and summarize the discussion of those papers and commentaries. The editors have not attempted to conform the diverse styles of the papers presented at the conference, feeling that an accurate rendering of varied backgrounds and interests superseded the need for a uniform style of presentation. These papers provide a significant input to the Royal Commission in the preparation of the final report which will be submitted to the governments.

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INTRODUCTORY


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INTRODUCTORY

WELCOME TO MEMORIAL UNIVERSITY OF NEWFOUNDLAND

Dr. L. Harris
President
Memorial University of Newfoundland

It is an honour for Memorial University and a privilege to have among us so many distinguished Royal Commissioners, engineers, scientists, corporate executives and others who are concerned in a very real way with the matter at hand. I am particularly gratified to notice among the most distinguished participants some of those who have already honoured us by having accepted honourary degrees from this University. I am gratified as well to note that members of our faculties and, particularly, of Engineering and Medicine, are here and will participate in your deliberations.

Surely, in the context of incipient developments, there are few sets of deliberations that could have more consequence or more meaning than those with which we are now involved. The emergence of a major industrial activity in the harsh, Northern Atlantic environment certainly constitutes a major challenge to governments, to industry, to technical and scientific institutions and to all those who may be involved. It is a major challenge that principally revolves around the task of guaranteeing a measure of safety for those who exercise their business in such great waters.

I have a personal, though, precarious experience with those great waters that goes back for many, many years, since my family in its entirety wrested its livelihood from the waters of the Grand Banks. The names that were familiar in my mouth as household words in childhood were associated with the topography of the ocean floor lying on the Continental Shelf of North America, rather than with the land forms inward. I knew, as well, the perils of those regions, the dangers, the terrible fury of Atlantic storms, of seas, of gales, of fog, of drifting ice and of all the other associated hazards. In that environment I was continuously aware, as I now am, that the price of safety is eternal vigilance. More than that, it is eternal vigilance backed up by the very best systems and processes that the wizardry of our scientists and technicians can manage and that the wisdom of our political leaders can inform.

I am confident that this Conference will make a very significant contribution in this area and to the objectives that we all share. I am extremely happy to see that it is here on the campus of this University that the Conference is being held. I am happy that we have been able to have some small part in its organization and I am delighted, once again, to welcome you all most warmly and to wish very good luck as your discussions proceed.

OPENING REMARKS

Chief Justice
The Honourable T. Alexander Hickman
Commission Chairman

On behalf of the Royal Commission on the *Ocean Ranger* Marine Disaster, I welcome you all to St. John's and to the province of Newfoundland, Canada. We invited you to join us here, in the oldest city of North America, to take part in an unusual event. It is the first time a Canadian Royal Commission has ever sponsored an international conference. We regard the next three days as a crucial component of the public consultation process that we have embarked on in response to Part Two of our mandate. You have each been asked to participate because of your knowledge and experience in one or more of the key areas that affect safety offshore Eastern Canada.

There are many points of view represented at this gathering: those of people in governments both in Canada and in other countries; those of people in the industry: operators, drilling contractors, and service companies; and those of people from classification societies, consulting organizations, and educational institutions. There is assembled in this auditorium today a group eminently qualified to discuss the important issues that must be addressed by the Royal Commission. The issues at the heart of the challenging problem of improving safety embrace not only the relatively simple but most important questions of whether certain equipment is adequate and whether people are properly trained for the jobs they are doing, but require us to look for new insights into the complex relationships that govern these activities and for a fresh perspective on how effective they are likely to be over the next decade. This is essential if we are to ensure that an acceptable standard of safety is maintained in drilling operations off eastern Canada.

This Conference convenes with an acute consciousness that of recent years there has been a tremendous increase in the search for and exploitation of oil and gas reserves offshore throughout the world, which has resulted in a much more costly and hazardous operational challenge than is experienced by those working onshore in more favourable environments. Mankind has explored and exploited much of the world land mass in search of oil and gas; now emphasis is shifting to the remaining four-fifths of the earth's surface which is covered by water.

Those who work in the extractive industries, particularly offshore, recognize that there will always be an element of risk in their jobs. What they and their families want to be assured of is that every reasonable step has been taken to minimize that risk and to improve human safety. It is in pursuit of this attainable and desirable end that the Royal Commission looks to this Conference, composed of people who have had practical experience in offshore drilling operations in Canada and in other parts of the world, for expert opinion and guidance. There is no substitute for uninhibited dialogue between knowledgeable persons committed to the safety of those who work offshore in the hostile marine environment of the North Atlantic off eastern Canada.

Conferences are normally arranged for the benefit of the participants. This one is different. It has been arranged mainly for the benefit of this Royal Commission. That is why it has been structured as it has and why we have invited only a limited number of people to attend from among the many experts who could have helped us with our task. In order for this Conference to adhere fully to its intended purpose your discussions must be frank and open which I am certain will be the case. The Conference is not designed to be a formal Commission hearing but rather a forum for learned discussion with Commissioners and staff sitting among you as eager but silent listeners. In this way, we hope to make the best use of your combined talents and of the very short time that is available to us.

As you all know, we finished our Part One inquiry into the loss of the *Ocean Ranger* last March and our report was released a week ago by the Governments of Canada and Newfoundland. Its publication marks the end of the formal quasi-judicial phase of our work which was concerned with establishing the facts or, if that could not be done, with arriving at a credible basis for our conclusions. We have done our best to provide answers to the two questions put to us in our terms of reference: why was the *Ocean Ranger* lost, and why were none of her crew saved? It is our hope that the Conference will not take up its time with debating the merits or demerits of the findings and recommendations in our first report.

We invite you rather to concentrate on the third question with which we are faced by our mandate which is: how can we avoid another disaster of this kind? This requires us to turn our attention to the future and to seek opinions rather than facts. One of the best ways to test opinion is in discussion by knowledgeable people with their peers. This is why we decided to organize this Conference in association with Memorial University of Newfoundland.

My colleague, the Honourable Gordon Winter, Vice-Chairman of the Royal Commission, undertook the task of chairing the Conference Program Committee. I thank him for the able way in which he conducted the by no means simple process of determining the content and structure of this Conference. We are all grateful to the Committee as a whole for bringing it to this point.

The Royal Commission is fortunate to have Dr. Omond Solandt as its Senior Advisor. Most of you are, I am sure, familiar with his distinguished career in government, industry, and public service in Canada and abroad. He has undertaken the onerous role of general Conference Chairman and I shall leave it to him to explain to you how we shall be approaching the various sessions and what we expect to achieve over the next three days.

It is with great pleasure, tempered only with anticipatory excitement, that I declare open the Safety Offshore Eastern Canada Conference and invite Dr. Solandt to take over the meeting.

CONFERENCE INTRODUCTION

Dr. O.M. Solandt
Conference Chairman

My contribution to the Conference at this stage will be to elaborate on some of the points made by Chief Justice Hickman, then to introduce our keynote speaker and finally to turn the meeting over to Dean Ross Peters.

You have heard from the Chief Justice about the important role that this Conference will play in the Commission's accumulation of material for its Part Two Report. In planning the structure and content of the Conference, the Committee has had to be ruthlessly selective in order to fit it into three days.

This Conference is the apex of a fairly complex information gathering process. First a series of 24 review papers was commissioned. They are intended to cover the present state of knowledge in every aspect of safety in offshore oil exploration and development. Study of this material led to the identification of four areas in which it appeared that the main problems for the future would lie. They are the topics of the sessions in the Conference:

- Environment and Design
- Man/Machine Interface
- Emergencies
- Regulatory System

In each session there will be introductory papers followed by a few selected discussants followed by general discussion. We hope that you will not ramble into other fields unless you feel strongly that some very important topics have been missed. But do be sure to state your opinions concisely. As the Chief Justice has said, the purpose of the Conference is to let the Commissioners hear your views. Unfortunately, in a three-day Conference with such a long agenda it is very likely that some important things will remain unsaid. You are strongly urged to present them either personally or in writing to the Part Two Commission Hearings that will begin in October.

The novel idea of holding a Conference as a major element in the process of gathering evidence for the Part Two Report arose within the Royal Commission. The Royal Commission felt that all the major actors in the offshore scene should contribute to the planning of the Conference. A Conference Program Committee was appointed with the Honourable Gordon A. Winter as Chairman and Commissioners Mr. Jan Furst and Dr. M.O. Morgan as members. The Federal Government is represented by Dr. A.E. Collin, Associate Deputy Minister, Department of Energy, Mines and Resources; the Newfoundland Government by Mr. John Fitzgerald, Executive Director, Newfoundland and Labrador Petroleum Directorate; industry by Mr. Ken Oakley, Regional Director, Canadian Petroleum Association, Offshore Operators Division; and universities by Dr. G.R. Peters, Dean of Engineering and Applied Science, Memorial University of Newfoundland, who will soon appear as Vice-Chairman of the Conference.

Three members of the Commission staff are also members of the Committee: David Grenville, Secretary to the Commission who is the back stop for everything; Bevin LeDrew, Director of Studies, who commissioned and collected all the papers and will, with his staff, be acting as rapporteur for all the sessions; Neil Penney, the Conference Co-ordinator, and, finally, myself.

As the program took shape the Conference Committee saw that we needed someone to open the proceedings with a broad general look at the areas to be explored. Such a person should have a long and varied experience in industry, preferably including practical offshore experience in the most difficult environmental conditions. Because we were seeking the best in a very international field we knew that many of the candidates would not be Canadian but we all agreed that it would be nice if we could find a Canadian who could meet all the other requirements. The Committee feels that they have been doubly fortunate to have found a person who fully meets our exacting specifications and is a Canadian. Gordon Harrison is eminently qualified to give us his "Perspective on Safety" which will set the Conference on the right course for what I know will prove to be a very exciting and rewarding journey.

A PERSPECTIVE ON SAFETY

Gordon R. Harrison
Former President
Canadian Marine Drilling Limited

Safety is a serious issue in today's society, and it is a privilege for me to play a part in this international conference devoted to the safety of offshore drilling on Canada's East Coast.

We are here because of the tragic loss of the *Ocean Ranger*. Several official enquiries have already been made which have identified the causes of this mishap to be technical flaws in the ballast control system, the ballasting crew's ineptitude, and design deficiencies in the chain lockers and lower hulls of the vessel. I think we should be very careful in identifying cause. Personally, I see those factors cited as cause to be no more than part of a chain of events which made the vessel capsize and sink. They no more constitute the real cause than the final loss of buoyancy which at the end allowed gravity to pull the vessel to the sea bottom.

We need to examine the front end cause, the one that started this series of events. We need an understanding of what conditions exist in the drilling industry on the East Coast of Canada which could lead to the loss of a world class drilling vessel and her entire crew. We should also worry whether we are still courting disaster by the continuation of these drilling activities. If we are, we had better do something.

This Royal Commission has advised it is entering a new phase of its mandate in which it will be considering broad issues before making recommendations on public policy affecting safety of eastern Canada offshore drilling operations. In the course of its enquiry, the Commission will hear extensive representations of fact and judgement relative to safety issues. Before drawing on this material, the Commission advises it wishes to ensure what it hears is tested for correctness and credibility. Accordingly, we are being asked at this Conference not only to identify and critically examine matters affecting safety, but to subject these matters to discussion and debate. Obviously, we are fortunate the Commission has invited a prestigious group of international participants to bring expert knowledge on the matters set out in the conference program. In spite of the high qualifications of everyone here, it is my view it will be a difficult task to usefully impact safety of the offshore. What we are dealing with is a need for a new direction in the management of major projects of this nature. To do so will require change to the present order of things in society. There is nothing more difficult than that.

I must say I am encouraged by the atmosphere created here by the Royal Commission to examine the issues affecting risk and safety of the offshore drilling operations. We are told in our invitations to unshackle our thinking, to stimulate new ideas and to challenge each other's facts and opinions. It will, in my view, also be necessary to seriously challenge the conventional wisdom both of industry and of government. If we do these things and are outspoken and bold, hopefully we will not disappoint our host. It will be instructive for us to examine the safety issues of other sectors of society to see what we can learn which might apply to the offshore drilling sector. Certainly, we should stand back and adjust narrow focus away from the particular weaknesses of the *Ocean Ranger* and see whether by broader focus we identify a common characteristic of all man-made mishaps of this scale. The question I believe we must ask is whether there is a flaw in the way we do things in society which is the root cause of these costly and tragic events.

The outlook for safety in our society is not good. Ignoring, if you can, the ever present danger of annihilation by nuclear forces, we constantly face the prospect of calamities on the scale of the *Ocean Ranger*. Generally, these events occur with little bias towards the land or the sea. Many people are familiar with well-publicized mishaps such as the capsizing of the *Alexander Kielland* in 1980 with the loss of 123 people, the collapse of skywalks into a crowded dance party at the Kansas City Hyatt Hotel in 1981 killing 114 people, the Marine barracks massacre in Beirut, Lebanon in 1983 with a loss of 241 lives and the more recent sinking of the drill ship *Java Sea* with a loss of 81 lives. But it takes a browsing of the literature to be reminded of the astonishing frequency of less-noted breakdowns in safety which regularly occur in office towers, hotels, auditoriums, bridges, sports arenas, trains, mines, as well as offshore oil and gas structures.

We need a new and different approach. The steady repetition of mishaps makes clear we are vulnerable and nothing now points to a change which will diminish this exposure. The postmortems we conduct for each major mishap may help reduce the chances of that particular set of unfavourable circumstances from occurring again, but these investigations fail to identify the common denominator which haunts the background of all these tragedies.

My assignment today is to provide a "perspective on safety", which I interpret to mean to try to find and explain the nature of this common denominator. More specifically, I am asked to examine philosophically the relationship between safety and technical considerations. There is, of course, a direct and vital relationship between the final integrity of an operating system and technical parameters such as the state of knowledge about environmental factors, the selection of design criteria, the choice of design safety factors, the qualifications of the designers, practices used for material testing and job inspection, setting up operating procedures, job training and the like. It is my view that these factors, taken individually, are already within our control. Rarely can the source of today's major mishaps be attributed to shortages in knowledge or shortcomings in technology. As in the case of the sinking of the *Ocean Ranger*, it is not that we are operating beyond the state-of-the-art. We have the knowledge and the tools to avoid these major slips. The source of our problem is very basic: we are heavy on regulations and bureaucracy, light on creativity and management control – a serious source of imbalance in a society, like damage to the middle ear.

As one reads the investigative documents available on the circumstances surrounding the loss of the *Ocean Ranger* and the loss of her crew, one is repeatedly struck by the single notion of things not being right. I am referring to two rather curious matters. Firstly, the apparent absence of single management accountability for the safety of life in the operations of the *Ocean Ranger* and its extensive and numerous support systems. Secondly, the lack of focus or importance placed on this absence by the investigative documents themselves.

The *Ocean Ranger* was owned by ODECO, a U.S. Company, and was operating under a U.S. Flag, thereby coming under U.S. Coast Guard laws and regulations. She was designed by American engineers, built in Japan and classified by the American Bureau of Shipping. She was operating in international waters under the safety conventions of the International Maritime Organization but was under hire to drill exploratory permits issued to Mobil Oil and was therefore subject to regulations administered by COGLA and other agencies of the Canadian Government. Her major support systems, including supply boats, safety standby boats, helicopters and shore-base logistics were under the direction of Mobil through contracts with a number of third parties. She depended upon Mobil and Government Search and Rescue units for contingency planning for command of evacuation support equipment under emergency conditions. On board the *Ocean Ranger*, management and authority was shared in some manner by the ODECO toolpush, the ODECO ships' master and the Mobil drilling foreman. The ODECO toolpush and the Mobil drilling foreman reported to different company organizations on shore.

Let me say first, that this history and set of operating conditions I have just recited for the *Ocean Ranger* is not unusual. Indeed, it is conventional for the offshore drilling industry. Nonetheless, it is hard to escape the notion that, once drilling began on Canada Lands considerable ambiguity must have existed as to what management and regulatory authority dominated even for normal activities. For emergency operations there was room for even greater confusion. And prior to the start of drilling, if enquiry was made as to whether this would be a safe operation, who was one to ask? Was there a professional engineer who could certify that the vessel met critical design criteria for flotation stability and structural strength and that the sub-systems were also competent in terms of design, construction, licensing and operation? Was there a master mariner who could state with certitude that the vessel had adequate escape and survival systems? Could he provide assurance the crews were ready for emergencies? Were they familiar with the use and operation of the escape systems and had they practiced the complete evacuation with demonstrated skill and efficiency? Was there a suitable contingency plan for emergencies with all necessary support services and communications under a single command? Was there a senior officer of an operating company who could certify he had personally examined the professional engineer's work and was familiar with the critical environmental criteria and the safety factors used in the design? Was he personally satisfied that the engineer had properly conducted the design check and determined that the vessel's sub-systems were in good operating order and fully licensed? Had he similarly examined the master mariner and been satisfied with his assessments?

In other words, was there a senior officer of an operating company who had comprehensively examined all pertinent questions relating to the safety of the *Ocean Ranger* vessel and developed sufficient conviction about such matters that he would certify the vessel and all support systems were safe and ready for work? These are the questions that in my mind are important. But these are not the questions being asked. I think we should care less about compliance with the regulations of government and the codes of classification bodies and more about absolute accountability for safety. We should care whether there is a single responsible party who has done everything within reason to ensure that each drilling and support system operating on Canadian exploratory lands is safe against injury or loss of life.

The uncertainty about who is in charge and who is responsible is the common denominator to all large scale tragedies. When the 241 U.S. Marines were massacred while sleeping in a Beirut war zone, they had insufficient defence to stop a passenger car loaded with explosives from reaching and demolishing their barracks. It was reasonable to ask who was responsible and accountable for this lack of vigilance. It seems clear there was uncertainty as to whether this was a diplomatic or military mission. Consequently, it appears that neither the Department of Defense in the U.S. nor the Department of State was clearly given command and accountability for the safety of this outpost of young and vulnerable people. It resulted in tragic consequences.

Let's take another example. On July 17, 1981 there were 1500 people attending a party in the year-old Hyatt Regency Hotel in Kansas City. People were dancing in the large lobby and on two skywalks which spanned the lobby. Suddenly both skywalks collapsed and fell into the lobby killing 114 and seriously injuring another 216 people. It was the worst building failure in U.S. history. More than a dozen enquiries were conducted, including one by the National Bureau of Standards. The direct source of failure was apparently easy to determine. After construction was well underway, a design change was made through a telephone call between a consulting engineer and an engineer for the steel fabricator. After the accident, examination by the Bureau of Standards showed the redesigned skywalk was barely able to hold its own weight. Each engineer explained that he assumed after the phone discussion that it was the responsibility of the other to make the necessary calculations and neither did.

The cause of this calamity is also apparent. Seven major parties were involved in design and construction and all parties denied knowledge of who had overall responsibility. The architect who created the original design had little to do with job inspection as construction proceeded. Court documents show a construction job with a history of misunderstandings, oversights and safety problems. Mr. Edward Frang is Chief of the Structures Division for the National Bureau of Standards and has this to say in a quote from the New York Times: "Intuitively if you start seeing a history of management problems on a job, that's a building with a high probability of monumental failure." He goes on to say, ". . . there is a need for clear cut practices defining who is responsible for what in the construction process."

These examples and others demonstrate that safety, if put in proper perspective, will be seen as a management issue; lack of safety is a management problem. That, in my opinion, is all there is to it.

Listen to Eric Hoffer, a man who was first an uneducated longshoreman and then a social philosopher. "The only way to predict the future," he said, "is to have the power over the future." Now I think that is an awfully perceptive and important axiom which holds the crux of what we are dealing with here today. Let me illustrate. When President Kennedy announced in 1960 that the U.S. would have a man on the moon before the end of the decade, it was not that his gypsy fortune teller had that very morning read this event in his tea leaves. Rather the President intuitively sensed the project was an exciting goal which would raise the spirit of Americans and he was persuaded by the National Academy of Sciences that it was technically feasible and also would have enormous scientific and commercial spin-offs. He then charged the National Aeronautics and Space Administration (NASA) to perform the mission. NASA had single management authority for the program and, using 12,000 engineers, scientists, and technicians, was able to marshall scores of the best high-tech companies in the nation to serve under this authority. Nothing was left to chance and the best financed, best managed project in the history of the world, right on target, landed *Apollo II* on the moon surface on July 20, 1969. All of this was done with an incredibly good safety record. Yes, President Kennedy did predict the future, but only because he had power over the future. Moreover, when he delegated that power, he sensibly gave it to one single management authority.

"First we shape our structures," said Winston Churchill, "and afterwards they shape us." Quite so. On matters of safety our society is shaped by a complex structure of regulations and regulators embedded over the past century. By and large, this regulatory complex had been created in a manner which discourages or, at best is indifferent to, management responsiblity for safety. Indeed, incomprehensible as it may seem, we no longer seek to know who carried the responsibility, the authority and the accountability. Our system, by and large, leaves that matter to the lawyers and the courts.

The genesis of today's curious structure on safety may have occurred in Scotland about 100 years ago. In 1879, the Tay River Bridge, a vital railway link to the city of Dundee in Scotland, fell under the combined loads of a passenger train and furious gale-force winds. The bridge had been in operation for 18 months. It was the longest and considered the greatest bridge in the world and crossed the largest river in Great Britain. It was the dream, and briefly the crowning achievement of Sir Thomas Bouch, one of the great engineer-builders during a great bridge building era.

No one survived the accident. Seventy-five men, women and children died in this fall. It was human loss in scale about equal to that of the *Ocean Ranger* and other offshore drilling mishaps such as the *Alexander Kielland* and the *Java Sea*. Apparently, we have been packaging our man-made disasters in about this size for some time. A Court of Enquiry formed to examine the calamity delivered its findings to the British Houses of Parliament. Conclusions were the bridge was fatally flawed in its design, construction, and maintenance and that sooner or later was to be brought down by these inherent defects. Notably, the Board of Enquiry went beyond the question of cause and ruled on the matter of blame. They said Sir Thomas Bouch, the engineer-builder, was mainly to blame and specified further as follows:

- For the faults in design, he was entirely responsible.
- For the faults in construction, he was principally responsible.
- For the faults in maintenance, he was principally, if not entirely, responsible.

Sir Thomas Bouch, the Enquiry report went on to say, cannot escape his responsibilities. Indeed he did not. Several months before he had been knighted by the Queen for his triumphs as a bridge builder. Then, thoroughly discredited as an engineer, he went into seclusion to avoid the clamor for criminal proceedings against him. He died four months after he heard the censure from the Court of Enquiry.

I cite this bit of history because it seems this Tay Bridge disaster was pivotal in the setting of a course of events which brought us to where we are today. Several important points are worth noting.

It was a time in history when it was possible for a professional to have total technical control. Clearly Sir Thomas Bouch was a true bridge builder. He had the authority to control both the design and quality of the final operating product, starting at the drawing board and through to the quality control of the material and the workmanship. His responsibilities went beyond that. After construction was completed, he held authority for maintenance of the structure and control of the loadings placed on the structure during the operating stage.

Such a broad professional mandate in today's environment must be beyond the wildest dreams of Jerome Goldman, President of Friede and Goldman, and one of today's premier designers of world-class offshore mobile drilling units. Here are some excerpts from a speech given by Mr. Goldman in 1983, to the Symposium on the Safety of Life Offshore at Scripp's Institute of Oceanography: "When construction starts, the design has left the designer and becomes the responsibility of others." Mr. Goldman went on to discuss this lack of continuity in engineering responsibilities and he obviously harbors grave concerns about the consequences of this incongruity. "There is," Mr. Goldman says, "... no common ground for judging the quality of drilling units" nor for "... establishing and maintaining the quality of the drilling unit after it has left the yard." He goes on to say that as things stand today "... classification societies must bear the responsibility and the integrity to review the design of the unit and to maintain the quality of construction both during the shipbuilding stage and throughout the operational life of the rig."

Now obviously although broad and continuous professional responsibility existed at the time of the Tay River Bridge disaster, something very serious was also missing. Firstly, although up until the Tay Bridge Enquiry engineers had extensive professional responsibility, they did not have a commensurate degree of accountability to society for mistakes. Secondly, corporate accountability was totally absent. The National British Railway received little criticism or blame for the Tay Bridge collapse and the officers of this Railway received none at all.

Society could have at this point simply decided to demand both professional and corporate accountability. Regrettably, society instead began to seek compliance with codes and regulations. This fateful step had the following consequences:

- The engineering profession, considered at the time to be one of the wonders of the world, began a decline in prestige from which it has never recovered.
- Governments began their attempt to create safety by demanding compliance with regulations rather than through demands for accountability.
- Finally, the definition of who is responsible and accountable for safety in the areas of design, operation, and maintenance began to blur, until today it is virtually impossible to tie down.

We must, in my view, redress this unsatisfactory state of affairs we have inherited from the past. First, we must re-establish broad and continuous professional responsibility. Secondly, ultimate responsibility must be given to a sector of society which has two distinguishing characteristics:

- It must have a track record which proves it can meet the challenge of the assignment.
- It must play a role in society where the stakes are high; that is, someone who will gain measurably by success and suffer grievously from failure.

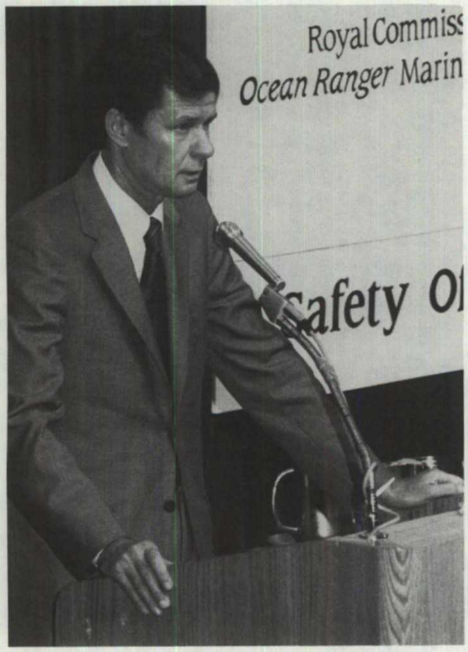
The obvious choice, and only choice in my view, is the private sector.

Ignor Ansoff in his book, *Strategic Management*, provides insight into the increasing difficulty for any function of society (such as safety) to hold its own in the fast moving world of today. He cites numerous studies made on the increasing speed of technological and social change. A common conclusion of these studies is that the time between emergence and the use of new technology is progressively shrinking. A companion aspect is that any particular social function benefits from this change only if it ties itself to one of today's fast moving commercial ventures. Safety, like everything in our society, is competing for talent.

Mr. Ansoff believes the key events in today's social and technological environment have become progressively 1) novel; 2) costlier to deal with; 3) faster; and 4) more difficult to anticipate. Given this environment, is there anyone who believes that the advances needed to assure safety in society should be placed in the hands of the classification societies and the regulating bodies of government?

One reply to this question is from the 1980 Burgoyne Committee Report which studied safety in the offshore United Kingdom. Regulations, the Report said, are "... slow to form and difficult to change; they are inappropriate in rapidly-changing technologies. What is needed for future projects is a more flexible system which can not only respond quickly to new problems, thereby generating improvements, but encourage a forward-looking attitude and put the responsibility for deciding what is safe where it belongs, with the Operator."

In my view, safety must stake its own claim to its fair share of the drive, the



Mr. Harrison graduated from the University of British Columbia in Mechanical Engineering in 1953 and has been in the oil industry ever since. In 1968, while with Mobil Oil Canada, he was responsible for drilling the first well on Sable Island, and in 1971 he established Mobil's first offshore drilling system for the Grand Banks. He also worked for a number of years with Dome Petroleum, and in 1976 as President of its subsidiary, Canadian Marine Drilling Ltd., he built and operated the first offshore drilling system in the Beaufort Sea. Mr. Harrison is presently located in Houston and is engaged in exploratory drilling and production on the U.S. Continental Shelf.

initiative, the creativity, and the success of the best in the private sector. It must clamor and fight for a position of top priority in the strategic plans of our successful corporations. Peter Drucker in his book, *Effective Management*, observes that the successful executive contrives to focus on the shortest possible list of priorities and the narrowest possible span of supervision. Safety must compete to become one of these areas of his focus. For society to achieve the best safety objectives, it is the energy of the senior executives of the best run companies that must be harnessed. Peter Drucker also says and I quote, "Whenever anything is being accomplished, it is being done, I have learned, by a monomaniac with a mission."

So let me say this in summary. Today I have offered the proposition that confusion as to management responsibility and apathy towards management accountability are the fundamental safety issues before this Royal Commission. I appreciate fully the usefulness of design codes and the value of regulations. I believe classification bodies are a progressive force in advancing vessel design and construction standards. I am concerned with the illusion that exists that compliance with regulations and the stamp of approval by classification bodies can in themselves provide offshore drilling systems with safe designs. I am for achieving safe performance through the dynamics of operator accountability rather than the passive compliance with safety standards. I am for continuity of professional responsibilities from the drawing board through construction monitoring and into the operating stage. I am for giving sole management authority to one entity for all aspects of offshore drilling projects in return for unambiguous accountability for safety.

What would it mean to offshore drilling on the East Coast of Canada if government authorities were to embrace the principles I describe? Firstly, responsibility and accountability would be vested in one single management with authority over the entire spectrum of design and operations for the offshore drilling systems applied to each exploratory permit issued by the government. The choice of this management authority would logically be the licensee/operator who would be accountable for the unsafe consequences of the entire operation.

As a first step, the Chief Executive Officer (or most senior operating officer) of the company would certify that he had engaged a professional engineer and was fully satisfied with the engineer's qualifications and experience. The professional engineer would be asked to provide a total design check and to certify that the drilling vessel met critical environmental design criteria for structural strength and flotation stability. Moreover, he would verifiy that all sub-systems of the vessel were competent in terms of design, construction, licensing, and operation. The C.E.O. would further certify that he had personally examined and was familiar with the critical environmental and safety factors used in the design check. He would state that based on his enquiry of the engineer, he was satisfied with the vessel's construction, that the vessel was in good operating order and was fully licensed. The C.E.O. would provide assurance that the crews were suitably trained and would be at all times ready for emergencies, that they were familiar with the escape systems and had practised complete evacuation with demonstrated skill and efficiency.

Now under today's conditions the C.E.O. would be faced with a fateful choice. Either he could state with certitude that the vessel had adequate escape and survival systems if the vessel needed to be evacuated, or he could call a spade a spade, and point out that the evacuation and survival systems specified by government code and regulations are useless in sea conditions relatively common to the East Coast of Canada. Obviously with today's state-of-the-art he would make the second choice. With this choice, he would set out a time schedule for the research, development, and demonstration of evacuation and lifeboat survival capabilities which meet the ocean conditions off the East Coast of Canada. The government, faced with this candor and commitment would undoubtedly grant the permit to begin drilling operations with the knowledge that:

- Accountability for safety of the entire operation of the exploratory permit was inescapably clear and that severe penalties could apply for non-performance.
- The serious gaps in the technology of escape and survival systems for all ocean vessels would rapidly disappear.

Over the last 20 years, the petroleum industry has progressively forecast that oil and gas will be found and produced in deeper and deeper waters under more and more severe ocean environments. Then, systematically using technology which competes in ingenuity with that of the NASA space program, this industry has advanced its operations from ten feet of water depth to five thousand feet, and from protected shoreline embayments to the most threatening ocean environments of the world. In short, it is an industry that has proven Eric Hoffer's intriguing thesis that with power over future events, one can predict future events.

These achievements by the petroleum industry have been obtained by management skills that can be applied equally well to one problem as another. Once clearly given the job to create a safe future for drilling on the East Coast of Canada, the industry will respond with unrelenting purpose, and once delegated the professional responsibilities to achieve this goal, I have absolute confidence that the creative talent and drive of the professional engineers, scientists, and architects engaged by our industry will once again prove that simple and powerful axiom: necessity is the mother of invention.

2

ENVIRONMENT AND DESIGN


Royal Commission on the
Ocean Ranger Marine Disaster
Canada
Commission Royale sur le
Désastre Marin de l'Ocean Ranger
Newfoundland Terre-Neuve
Safety Offshore Eastern Canada

ENVIRONMENT AND DESIGN

INTRODUCTION

The studies into the environment examined the physical environment of that part of the East Coast offshore where the offshore drilling operations take place. Emphasis was placed on the adequacy of available data and current data acquisition procedures and programs. Also examined were severe and limiting conditions, and their detection or prediction.

The studies into design aspects addressed the process of design conception, construction, classification, and certification of offshore structures and their ancillary equipment. The operational limitations and upkeep requirements of these structures and their equipment were also considered.

This Technical Session was chaired by Mr. R.A. Hemstock, an engineer with a lengthy and prominent career who is currently the President of the Canadian Council of Professional Engineers. Mr. Hemstock who holds an M.Sc. from the University of Alberta, worked with Imperial Oil Ltd. from 1948 to 1977; in those latter years he conducted research on the evaluation of engineering problems associated with the developments in the Canadian Arctic. From 1978 to 1983 he was Manager of the Environmental Division and Director of Hardy Associates and had primary responsibility for providing consulting services on environmental matters to the energy industry. Currently President of R.A. Hemstock Engineering Services Ltd., Mr. Hemstock has been a member of various advisory committees of the National Research Council, has represented the Canadian Petroleum Association on the Advisory Committee on Arctic Land Use Research, has represented Canada as a member of the Canadian technical exchange with the U.S.S.R., and was instrumental in the formation of the Arctic Petroleum Operators Association and is past Chairman of that organization.

Dr. W.L. Ford
Oceanographer

Dr. Ford holds degrees from the University of British Columbia, Northwestern University, the National Defence College, and honourary degrees from the University of New Brunswick and Dalhousie University. During his lengthy career, he had held positions with Dupont, Woods Hole Oceanographic Institute, and the Defence Research Board. In 1965 he was appointed Director of the Atlantic Oceanographic Laboratory at the Bedford Institute, a position he held until his retirement in 1978. Throughout his career, Dr. Ford has represented Canada on various international oceanographic committees, and he is a member of the Ocean Industry Advisory Committee and C-CORE's Research Advisory Committee. Since his retirement he has been an oceanographic consultant.

PAPER B1

Critical Environmental Factors off Eastern Canada

The goal of the Royal Commission in the Part Two Inquiry is to identify practical means of improving safety of our offshore drilling operations. To this end a number of studies were commissioned, six of which dealt with the physical environment under the headings: weather forecasting, ice, climatology, oceanography, wave climate, and seabed (1, 2, 3, 4, 5, 6). These six reports were subject to peer review and subsequently to vigorous comment at a recent workshop (9) attended by the authors, peer reviewers, and other specialists from the industry, the oceanographic and meteorological communities, and regulatory agencies. This paper presents the highlights from this process as I see them.

Offshore exploratory drilling got underway in our area in 1966; since then many rigs of various designs operating under a wide variety of conditions, some throughout the winter months, have drilled about 200 holes. There has been one tragedy, the loss of the *Ocean Ranger*. That incident has not been directly attributed (7, 8) to environmental factors, though they played a devastating role after things went wrong.

Notwithstanding the dark shadow thrown by this disaster, the overall impression is one of an industry actively concerned with those aspects of the physical environment bearing upon the safety of operations, including extensive contributions to the data.

Before getting into an examination of specific environmental issues, I want to make a general comment on the differences of opinion that are held concerning the adequacy, from a safety point of view, of our environmental knowledge. I suggest these differences fall into one or the other of two schools of thought. There are those who are of the opinion that the present levels of knowledge and of information services are quite adequate to run a safe exploratory operation. It follows therefore that purely on the grounds of safety, few if any, new initiatives vis à vis environmental factors need be undertaken. This is not to say that they are not wanted for reasons of improved efficiency. This school tends to treat good safety practices and sound economics as unrelated activities. The other school holds the view that good safety practice is good business, especially in the long run. For example, it would indeed be surprising if a substantial improvement in the reliability of weather forecasts, especially of severe events, leading to reductions in lost time in operations and hence increased efficiency, did not also contribute to the maintenance or improvement of safety. A reduction in the chances of being caught off-base by a sudden unsuspected change for the worse in the weather surely is a positive term in the safety equation.

Weather and sea state forecasts, first of the six studies, are very much an integral part of daily operations of the rigs, and of the supporting helicopters and supply vessels. There is a strong consensus for improvement in the precision of forecasts with the increased level of confidence in their validity that would ensue.[1]

Substantial improvement in these forecasts will not come easily. Although all rigs operating in our offshore are part of the observational network, the present real time coverage of weather and sea state in the area is far from adequate when compared to land based observational standards. Significant improvement in the quality of the marine forecast requires a marked increase in the real-time data base through, for example, the provision of many more observing points at sea, or greater use of satellite technologies. Beyond this, however, is the problem of mesoscale phenomena, like squalls and polar lows, capable of producing hurricane force winds. They are small enough to go undetected in the synoptic scale observing net as they are born, evolve and decay. Moreover the physics of these events is poorly understood, thus holding up the development of models capable of useful mesoscale forecasts even given the necessary data base.

This problem is not of course peculiar to the Eastern Canadian Offshore. It is receiving high profile attention worldwide. In Canada, following a mesoscale meteorology research planning workshop in January 1983, a meeting was held to examine the research requirement on the East Coast, specifically "user" and "provider" viewpoints. Detailed plans have been developed to investigate mesoscale processes within major Atlantic winter storms and have gone forward to the Office of Energy Research & Development for funding, strongly supported by proponents in industry, university, and government (15).

An experimental project to assess the feasibility of moored buoys as a means of improving the observing network was undertaken last winter jointly by Mobil Oil, Petro-Canada, Atmospheric Environment Service (AES), and Atlantic Oceanographic Laboratory/Bedford Institute of Oceanography (BIO). The buoys were moored at three sites, one buoy at each, along the southern flank of the Grand Banks. They transmitted atmospheric pressure and sea surface temperature via satellite to AES throughout the winter. An analytical study is now in progress at Dalhousie Univerity to determine whether the additional pressure measurements add significantly to the observing and forecasting of weather systems on the Grand Banks. If yes, an encouraging step will have been taken towards improving relatively soon and at reasonable cost the offshore real-time data base and hence the forecast.

Aside from advances in the basic product, better "packaging" and "delivery" can and should be provided by improved forecaster/client relations, verification procedures and training of personnel doing interpretation on site. Benefits should ensue in the short term from early implementation of these measures pending solution of the underlying problems of weather forecasting.

The second study deals with ice. The combination of icebergs and pack ice in eastern Canadian waters presents unique difficulties for exploratory drilling, let alone production. The industry has successfully addressed this challenge through the development of a system of ice management. The essence of the system is the avoidance of collision with ice. In ice infested waters such as the Labrador Shelf, the avoidance policy limits operations to the pack-ice free season and typically to dynamically positioned drilling vessels capable of a quick departure if threatened by an iceberg. Further south, in the Hibernia area, semisubmersible drilling units are in use year around. Their orderly withdrawal to avoid a developing ice threat requires a considerably longer time than with a dynamically positioned vessel. Without going into details, the system depends critically upon detection and tracking of any ice in the vicinity, plus the establishment of alert and safety zones appropriate to the type of rig on site. For example, disconnect procedures, both for drilling and anchors, are initiated when an iceberg comes within 40km of an anchored rig (2).

In the four to five years of all-season operations at Hibernia, only in the past two has ice made an appearance (2). Surveillance experience under winter ice conditions is therefore quite limited. Within the past year an important improvement was achieved by the establishment of coordinated industry-government surveillance serving a common operations centre and using every means of siting ice: visual and radar from aircraft, helicopters, and ships. Industry continues actively to promote improved detection and tracking of sea ice and bergs. The focus is upon developing better conventional marine radar and upon airborne imaging radar (9). Also an Environmental Studies Revolving Funds project is in progress, 1984, to conduct field investigations on the capability of synthetic aperture radar and side looking radar to detect icebergs, bergy bits and growlers under various conditions (10).

Detection and tracking is a particularly challenging problem under conditions of low visibility and heavy weather. At the Workshop (9) NORDCO presented some results of recent calculations on the ice detection capabilities of conventional marine radars as a function of sea state for an ice target of 20m length, 5m high, a large bergy bit. In sea state 0 to 1 the probability of detection is calculated to be 90% out to about 7km. As sea state increases, sea clutter also increases, downgrading detection in the near range. Thus at sea state 4, detection is less than 10% from 0 to 5km, rising to 25% at 7km, and then falling off rapidly. By sea state 6, clutter extends out far enough to reduce detection to virtually zero at any range.

Lever (11), reporting on a model study of behaviour of ice in a heavy sea, concludes that ice masses, which are small compared to the wave length, move as particles of water. Thus, for example, maximum full scale velocities of 4.5m/s would be possible for a 4,300 tonne bergy bit in a 14m, 12 sec. storm wave. Its kinetic energy would be equivalent to a 300,000 ton berg moving at 1 knot. Some people have expressed the opinion (9) that while such impact studies may be very important when considering production systems, they are not particularly relevant to safety in exploratory drilling because they do not contribute to the strategy of avoidance. Not everyone accepts this position. The probability of a piece of ice slipping through the surveillance net under conditions that could lead to a significant encounter, although generally believed to be remote, does not appear to have been quantitatively examined. However, Lever (9) in association with C-CORE, is planning to undertake the estimation of the joint probability of encounters. Such studies should be an important contribution to the assessment of the level of safety being achieved by the ice management system in the Hibernia area.

Icing, a term which includes accumulations on structures due to rime formation, as well as spray or precipitation freezing on contact, attracted attention in three of the studies (1, 2 & 3) and at the Workshop (9). On the basis of its operating experience to date, the industry considers (9) it is managing operations so that icing situations do not endanger the safety of rigs, supply vessels or helicopters.

From the point of view of the weather forecaster and climatologist, icing is regarded as a problem of considerable concern for safety offshore. The widely desired improvements in the precision of forecasts, discussed earlier, certainly apply to the specifics of icing forecasts, and therefore to icing sensitive operations like sea/air rescue and helicopter services. The state of knowledge about icing in the offshore is regarded by meteorologists as being very inadequate (2, 3) and in need of systematic long term investigation. For example, the present data base does not permit the description or the estimation of the probability of occurrence of extreme icing events. However, the studies have not revealed any reports of serious icing on any of the numerous rigs which have operated where and when icing is a distinct possibility. Although this suggests serious icing events may be uncommon, it is important to recognize there is no scientific basis available today on which a reliable estimate can be made of the probability of their occurrence.

Climatologists consider most aspects of the marine climate to be inadequately documented (3). The primary cause of this weakness is a general lack of base line data for *all* parameters, particularly in winter and in northern waters. Even for wind, the most important parameter, the data base is insufficient to define temporal and spatial variability, the effects of structures on the wind field or extreme values. Various approaches to estimating the 100-year return wind at Hibernia gave figures ranging from as low as 60 knots to as high as 140 knots (9). Such uncertainty leaves a designer or planner in the unsatisfactory position of probably having to overdesign while not necessarily contributing anything to safety.

The industry, working with the available climatology, has been able to develop operations over the past 18 years under a variety of severe conditions without a single serious accident directly attributable to a mis-judgement of a climate factor. The inference is that there is no requirement, from the operational viewpoint, for improved climatology strictly for purposes of enhancing the safety of operations. In the short term this may be evident, but is it so in the long run? Improvements in this field are inherently a long term process dependent upon development of not only the spatial aspect of its data base but, more importantly, the temporal aspect which cannot be hurried. Experience suggests improvements will be made and will be used in the industry for many purposes including higher standards of safety.

A word of clarification about oceanography is in order. Although wave climate is clearly an oceanographic matter, it was given a study of its own because of its outstanding importance as a limiting environmental factor. The oceanographic study, dealing with physical oceanography generally, excluding waves, concluded that the field is adequately developed for purposes of ensuring safety in exploratory and delineation drilling (4). Two matters did stand out, however. The first concerns iceberg trajectory prediction of an individual berg in a time frame of up to a few days. There have been a number of attempts to achieve useful predictions without much success. A new approach is underway by the Atlantic Oceanographic Laboratory at BIO using a recently developed acoustic current meter which permits the rapid determination of the current field surrounding a berg (15). The aim is to assess whether there is any real possibility in the foreseeable future of making trajectory predictions with sufficient accuracy to be useful in an ice management system.

The second, featured prominently in both the oceanographic and wave climate studies, is a requirement for the accumulation of a few series of simultaneous current, wind and wave measurements selected at rig sites offering a variety of environmental conditions. One purpose is to establish a relationship between current and the local wind and waves, thus permitting hindcasting of extreme currents which is now not possible. The other is to try to achieve a better understanding of wave/current interactions which have important implications in sea state forecasting, as well as wave climate.

Oceanographic matters of concern to the industry are being addressed on a continuing and cooperative basis by a joint committee made up of representatives from industry, universities, and government (17). Its principal focus is the physical oceanography of the Grand Banks as it relates to offshore development.

Waves are the most energetic environmental factors faced in offshore operations. One very important aspect of wave information has already been discussed as part of weather forecasting, i.e. the wave forecast, but now I want to touch upon outstanding issues in wave climatology. The wave climate study (5) reported on requirements of owner, design, classification, and regulatory organizations. These organizations are on record as wanting good data on wave climate generally, including spectral analyses and reliable estimates of extreme wave heights, periods, and crest heights. Such requirements are not, of course, exclusively related to safety.

Today there are still major gaps in our data base. The Labrador Shelf and northern waters are, for these purposes, in poor shape. The situation is much better in deep water of the southern areas; the data on Hibernia is generally agreed to be approaching a level where a reliable 100-year return wave height estimate can be made. However, moving into water shallow enough for bottom effects to play a major role, as around Sable Island, the state of the art leaves something to be desired. Much remains to be learned about the physics of the complex wave trains as they move into shallow water, often under the added effect of strong currents, before a reliable description can be provided of this special case of wave climate and its extremes.

The quality and precision required of environmental data, such as wave climate, for planning of production systems is of a higher order than that necessary for exploratory drilling. The wave climate in the shallow waters of the Venture site is a case in point and Mobil have investigations underway to support planning for the development of that field (13). As a spin-off, any resulting improvements in the knowledge of extreme events in the area will provide opportunities for additions to the safety margin in ongoing exploratory operations.

The Mobil studies are geared to producing results in a time frame of months and cannot be expected to dwell upon advancing the physics of wave behaviour. Scientists in Germany, Holland, and the United Kingdom have reported, recently, some success in modelling wave generation and propagation in shallow North Sea waters (12) and it is mentioned here as an indication of the growing attention being given to the subject. There is an evident need for ongoing, longer term research to resolve this scientifically difficult problem as it applies in our own waters. By its nature, it should be a joint undertaking of industry, university, and government to take full advantage of the independent and open appraisal of both project planning and project findings this approach offers. There are established precedents for this way of doing research business.

From the operating side, two requirements on wave climate were identified at the Workshop (9): one, the provision of more reliable estimates of the 100-year return wave in connection with proper deck clearance; the other, wave spectra for a possible role in that part of the spectra where the frequency of occurrence of wave impact on the structure may be strongly related to fatigue.

The Seabed study (6) concludes that geophysical surveys, and regional mapping do not provide, of themselves, sufficient information for siting drilling operations and that site specific geotechnical investigations are necessary. This is recognized in the industry and site specific surveys are standard practice.

The principal issue to emerge from the Seabed report (6) and ensuing discussions (9) was bore hole sampling as an essential element in determining the suitability of a site for positioning a jackup rig. Punch through is an important cause of failure in jackups (6). The probability of foundation failure in offshore units, though remote, is about ten times greater than on land (6). Geophysical and surficial geotechnical survey techniques cannot be relied upon, solely, to ascertain the presence or absence of potential punch through conditions (6). The addition of bore hole sample analyses provides for a more confident assessment. At the present time the use of bore holes is discretionary in surveys for siting jackups; a mandatory requirement is indicated as a contribution to safety.

To sum up: no inadequacies were identified in the state of knowledge about our marine environment so glaring as to constitute an imminent threat to safety in the offshore, given good operational safety practice. Nevertheless, it is evident there are many improvements to be made, generally incremental, which taken together, will give prudent management the opportunity to enhance safety on a broad front. Economical and timely realization of improvements would likely best be achieved by sustained joint research and development programs. Although there have been an encouraging number of cooperative arrangements put in place recently, greater reliance on this approach would surely be a sound investment in meeting the evolving research and development needs in respect of the physical environment that the industry will generate as it moves ahead in the decades to come in offshore eastern Canada.

[1] The weather forecast study by Seaconsult, Limited, (1) has been extended to permit evaluation of the operators' use of the forecasts and of what they see to be these needs. A report on this new work is not complete; it is therefore not reflected in this paper.

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Note: References 1 through 6 are reports submitted to the Royal Commission on the *Ocean Ranger* Marine Disaster.

COMMENTARY ON PAPER B1

L. Draper
Oceanographer
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Dr. Ford has comprehensively summarized the environmental factors in these waters and I thought that perhaps the most useful comments I could make would be to sound a word of caution on the accuracy of wave predictions. I am as guilty as anybody else in letting engineers get away with the thought that wave predictions are really precise; inadvertently we tend to give this kind of impression.

I have a number of questions about waves, to which I really do not know the answers, the simplest one perhaps is: "What do you mean by the crest of a wave?" It seems obvious, but it really is not. The distance between 100% water and 99% air is probably a couple of metres in a really severe storm. So, where is the crest? What do you mean by the crest? The apparent height on your recorder probably lies somewhere within this two metre range, but just where it does effectively lie is open to speculation. As a consequence, there is a large amount of water travelling horizontally above the level at which you think is the crest of the wave, and it is moving at 30 or 40 knots. So I do not really know where the crest is likely to be in any given sea.

Another thing I do not know is: "What is the actual distribution of crests?" If I use words which are not familiar to you, like Rayleigh distribution, don't worry, it is the conclusions which are important. It is tacitly assumed that wave height distribution is thought to be Rayleigh, and this is so in most conditions we can measure. It has not been proven to be so in extreme wave conditions where things go drastically non-linear. In fact, it is only strictly true for a narrow band spectrum in ordinary waves.

Another question is: "How accurate are our measurements?" Instruments are by no means perfect. Even if you have a calibration done to within a few percent over the whole frequency range of the instrument, you can not guarantee that all recorders respond instantly and exactly to the wave profile. We think of a wave record as being the history of the water surface through one vertical line with respect to time. The waverider which is much the most successful wave recorder in the world, goes round in something near to a circle, with a diameter equal to the wave height. It does not tell you what is happening at this particular point; it tells you what is happening here now, and 50 feet over there 5 seconds later. At the very least, it distorts phase relationships in the wave records.

What are the laws governing the distribution of wave height extremes? I also have to be careful with statisticians and not always believe everything they say. They recommend that you fit a thing called FT-1 distribution to the data. You have, say, 3,000 measurements of waves in a year on a typical station. So they say: "We have 3,000 samples; we can make beautiful predictions," and if you let the statisticians get away with it, they come along and at Seven Stones light vessel, which is still operating southwest of the U.K., they will give the following estimates of the height of the hundred-year wave:

FT-1 fit to Seven Stones data

Year	H_s, 100	95% Confidence Limits	
1962-63	15.79	15.73	15.86
1968	13.87	13.82	13.93
1969	13.39	13.34	13.44
1971-72	16.52	16.45	16.58
1972-73	14.61	14.55	14.67
1973-74	16.33	16.26	16.39
1975-76	13.71	13.66	13.77
1976-77	16.09	16.03	16.16
1982	16.84	16.88	17.01

In the first year of measurements, we had the prediction of 15.79. (In practice, we can completely ignore the second decimal figure of significant wave height.) It appears that we have a 95% confidence of it lying between 15.73 and 15.86. Marvellous! We have really arrived. The prudent, however, might say that perhaps the climate does change a bit, so let us try another year. It so happened that the next year's data for this particular location came up with 13.87 metres and you say, "Oh dear!" We then did this for 9 separate years of data, and in fact the 95% confidence limits do not even overlap! So, where do we go from there? In fact, the FT-1 is not really designed for that sort of thing, if you are honest about it, but what it is designed for is looking at individual maxima from each year. Then it has a sounder basis, with some theoretical justification, but this is a much weaker although more plausible assumption, and gives wider confidence limits.

Using the technique for which the FT-1 was designed on all the data from 9 years at Seven Stones, the 95% confidence limit lies between 90% and 132% of the value you have actually predicted. If you had been lucky enough to have 20 years worth of data, and you had predicted the same answer, the 95% confidence limit would then come down to between 92% and 115%. So, do not go home thinking that we can get it within half a metre, we can not.

Another nasty problem is: "How well do we sample the wave data?" We have a station, using a waverider, which is in waters comparable to Hibernia, but off the west coast of the Outer Hebrides where conditions are, in fact, more severe. One visiting scientist from New Zealand, B.R. Stanton, recently showed that waveriders preferentially lose the more severe wave records; the gaps are bigger in bad weather. That is not news to anybody, but what it does do, if you use standard techniques and ignore that fact, is underestimate the extreme condition. Mr. Stanton has shown that it would appear to be that the extreme conditions would have to be estimated to be at 16% more than the initially predicted value for this very severe location. Even now, we are still learning.

Wave conditions in Hibernia are about the same as in the northern North Sea, by and large; wave periods are probably somewhat longer because it is on the edge of an ocean which the North Sea really is not. Some of these problems are unquantifiable, although perhaps I could make a guess on the basis of our 20 years' experience in the North Sea; I do not know how many rig and platform years that is now, but it must be quite a large number. There has been no catastrophic incident ascribed to misunderstanding the waves in these 20 years. I could stick my neck out and say that the derived values, the ones which we have published, are probably within ±10% of the true value, if there is such a thing, for typical stations. Even so there is no evidence at all for overestimation of wave height. We have not so severely overcooked it that there are no accidents. We can not sit back and be complacent.

There are various other comments I could make about hindcasting, but the ultimate goal is to be able to hindcast rather than measure. It is not likely that this technique is going to become really reliable within the next ten years.

Just one thing I think I ought to say about the mention in Dr. Ford's paper about the Hermes data buoy, measuring, I think, atmospheric pressure and temperature over sea water. It does seem a pity to me that, if you are putting out a buoy, you do not go for the best which is available. In the U.K. we had DB-1 (Data Buoy 1) out in the Western Approaches for about three years and it performed exceptionally well; it really produced a lot of data. We have now gone to the next phase, to slightly smaller buoys called DB-2 and DB-3, and they are deployed southwest and northwest of the U.K. They cost a quarter of million pounds each, but they have a guaranteed data return, or severe financial penalty in lieu of 95% of the data. Everything is duplicated; the data are transmitted via METEOSAT every hour and a small amount every three minutes via ARGOS (the latter mainly for position fixing, but not entirely). Data are quality controlled to an IOS-agreed standard and data can be available within minutes of measurement, if you really need an instant response. It seems to me that a million dollars for the two buoys out in the water, upwind (or upwave), can not really be construed as being a luxury when you are concerned with the safety of a structure of the size of the *Ocean Ranger*. I think one ought to consider the possibility of spending a little bit more money in that direction.

My message is that we really ought to make a thoughtful assessment of everything concerned with the environment. As Mr. Harrison said, do not be complacent. Make somebody responsible for ensuring that all aspects are as reliable as can be achieved; in other words, absolutely everything must be checked in all aspects. Do not assume that because it is in print that it is actually gospel; it is not written on tablets of stone at all.

COMMENTARY ON PAPER B1

Dr. W. Speller
Supervisor, Offshore Assessment
Environmental Affairs, Petro-Canada

As a discussant of the environmental issues pertaining to the safety of offshore exploration operations, I have had the benefit of reviewing and responding to the six environmental reports prepared by the Commission, as well as the opportunity of attending the recent workshop on eastern Canada exploration and physical environment.

From my perspective, these activities have been both educational and surprising. Surprising, in that some government agencies and some consultants did not always appreciate or understand how environmental information is used to plan offshore drilling operations or support day-to-day activities. The workshop served a very educational role for all participants and the results have provided the Commission with a balanced perspective of the environmental issues affecting offshore hydrocarbon exploration.

With regard to the paper prepared by Dr. Ford, I concur with the contents, conclusions and tone of its various parts. It is a fair and balanced review of the papers, the physical environment workshop and ongoing physical environment research and development efforts in Canada. In my opinion, our discussions of the environmental issues today will centre not on what we should or should not be doing, but rather they will focus on the emphasis we should place in one direction or another to achieve our goals effectively and efficiently. With this in mind, I believe it is worthwhile summarizing several important basic points, which I believe will help to focus our discussions on the offshore physical environment.

The first point is that we do not have, nor can we be ever expected to achieve, consistency in the quality and quantity of environmental information available for different sectors of the Canadian East Coast, let alone other offshore regions of Canada. Where the search for offshore resources or the transportation of commerce at sea is carried out in new areas, there will always be minimal environmental information to work with. Only through technological developments, such weather satellites, and research will the level of baseline environmental knowledge improve for such new areas.

The issue we are really addressing here is the level of risk we are prepared to accept and how much environmental information is necessary to achieve the level of safety expected by our society. In this regard, standards of vessel design and operation procedures, government regulations and guidelines on operations planning, and management have been defined in order to reduce the risks to an acceptable level.

This leads me to my second point. In the East Coast offshore, world class units are used for year-round operations, and close attention is paid to environmental operating limits where ice conditions and severe weather increase the risk to equipment and activities. These units and the vessels and aircraft supporting them are selected on the basis of design and the extreme winds, waves, and currents which they can expect to encounter. Typically, estimates of 100 year extremes are provided to engineers for evaluation purposes. Confidence intervals are also provided around these data to indicate the quality of the data. Our experience in Canada has shown that the estimates provided for environmental extremes are reliable, and these estimates are successfully applied to the selection of offshore units, as well as to the planning of logistical support for their operation.

My third point is that day-to-day offshore exploration operations are designed to be conducted with nominal environmental information necessary for their support. Also, day-to-day management decisions are made to minimize risks to operations if environmental information received is erroneous in either degree or timing. Examples of this include management decisions to evacuate units in response to severe hurricanes tracking up the eastern seaboard. A decision to evacuate crews from the Grand Banks or Scotian Shelf requires 48 hours to implement. Clearly, our capability to forecast the tracks of hurricanes about the latitude of the Carolinas must advance by some quantum leap before rig superintendents will take the risks that these storms will not jeopardize the rig or its crew. The same analogy applies to tracking icebergs approaching anchored units on the Grand Banks. In raising these examples, I am not downgrading the need or value of continued R&D on these environmental problems; however, the level of forecasting ability necessary to manage the risk to offshore exploratory activities must be clearly appreciated with each and every study proposal.

Regarding our future efforts to improve environmental information in the offshore, it is both necessary and important to work together to focus our R&D and management efforts. Neither the time nor the resources are available for some of the individual approaches we have seen in the past. Concerning the direction and level of physical marine environmental R&D in Canada, it is obvious that the level of effort has increased significantly in recent years, primarily in response to offshore hydrocarbon production developments proposed for the Grand Banks and Scotian Shelf. Coordination between industry and government in this R&D has been greatly improved through the Environmental Studies Revolving Funds, the Office of Energy Research and Development and various government study groups. Canadian consultants and universities are also being involved both directly through contracts and indirectly through information exchange and advice. Our R&D efforts are world class, incorporating the latest advances in international technology and information processing and analysis. Also, our research objectives involve short, medium, and long term plans which are, by and large, strongly supported by the petroleum industry.

For my final point, I wish to draw your attention to the problems of how both industry and government will manage the physical environmental data, its processing, analysis, and communication resulting from all the R&D and data collection networks now being planned. At present, various government agencies are responsible for offshore environmental data management. Some of them are struggling to process and make accessible the data being collected. The same is true for other systems coming on stream over the next several years. The problems are related more to policy and financing, rather than to know-how in managing these data. If we are to properly manage the levels of real time environmental data needed to support our future offshore production and exploration activities, it is time to co-ordinate our efforts.

Earlier this year, at the Ocean Issues Conference, the CPA proposed that industry and government begin to address future environmental data communications and management by establishing a task force to address the many and varied problems. Also, solutions to these problems will require the participation of the environmental consultant industry to assure successful resolution. I believe I have highlighted the points which I think are important to our discussions and I appreciate the opportunity to have raised them here today.

Mr. C.A. Bainbridge
Senior Principal Surveyor
Lloyd's Register of Shipping

Mr. Bainbridge holds an M.Sc. in Aircraft Design and Structures and from 1956 to 1970 he worked in the aviation industry as a Structural Analyst in aircraft design. Since 1971 he has been with Lloyd's Register of Shipping, where he is currently Senior Principal Surveyor and Head of the Ocean Engineering Department. In that position he is responsible for structural analysis, plan approval, research and development, and computer analysis relating to all types of offshore structures. Mr. Bainbridge has presented numerous papers, worldwide, on structural analysis of offshore structures.

PAPER B2

Environmental Factors as an Input to Design

ABSTRACT

This paper outlines the role of environmental criteria in the structural design of semi-submersibles. The results of sensitivity studies on many recent units are presented and the effect of National and other code requirements discussed.

BACKGROUND

The forerunners of the present semi-submersibles were the bottom supported space frame structures of the early 1950's. To allow for uneven seabed conditions several of these designs tended towards multiple columns and individual bottom flotteurs. Water depths were of the order of 20 to 30m. These rigs were characterized by a very substantial beam, large freeboard and with limited structure in the maximum wave action area near sea level. In these water depths, the blow out preventers were placed just below the drilling floor and above sea level so all these units were designed with an open drilling slot over the whole depth of the structure at one end. The deck was connected to the matt type bottom structure by a number of columns, several of which, usually at the corners, were of a larger diameter, providing additional buoyancy during tow and deballasting during sit down on arrival on site. There were few or no diagonal bracing members and it is clear that many of these designs would have been suitable only for local tows and not ocean voyages.

The first true semi-submersible the *Bluewater 1* designed to drill in the floating mode began operation in the early 1960's. The majority still maintained the design requirement for the sit-on-bottom mode. These units would drill from about 20m of water in the bottom supported mode to above 100m in the floating mode. The upsurge in offshore exploration, still confined to a few areas of the world, led to a large number of semi-submersibles of different structural configurations becoming available.

Towards the end of the 1960's and early 1970's, the main advantage of the semi-submersible concept (a large stable floating platform) was being recognised and applied to other offshore operations not concerned with drilling at all. One of these first units was the *Santa Fe Choctaw I* an eight column, two pontoon vessel with multiple bracings, built in 1969 as a Crane Barge but soon converted to a Pipelay Barge.

Oil exploration was also now moving on a global scale and the original primary requirement of just moving into deeper waters was being amplified by the need to provide even larger deck load and bulk storage carrying capacity, significant reduction in mobilisation time and the ability to operate under more varied and harsher environmental conditions.

Semi-submersibles were also now being designed and built in a number of countries. Some of the original design criteria like the sit-on-bottom operation were discarded and others like mobilisation time and cost had grown in significance. The configuration reflected this change and generally narrowed down to the twin hull design with several columns and interconnecting tubular bracing members. Though the variations of structural configurations have been reduced semi-submersibles are being used for a larger number of specific offshore applications e.g. heavy lift, pile driving, firefighting, diving support, and early production platforms. For rapid mobilisation and location moves, some of these units are self-propelled for unassisted transit and to improve station keeping on location, others incorporate dynamic positioning.

INTRODUCTION

Against this background, the final design is a compromise based on the importance attached by the designer to the various conflicting criteria. Over the last few years, two additional factors have emerged, continual operation under extremely harsh environmental conditions, in some cases throughout the design life, and the introduction of National requirements incorporating design criteria. This paper outlines the basis of scantling design and the sensitivity of the critical internal stresses to varying environmental parameters e.g. wave heights, periods, directions etc., as well as, how this sensitivity can be influenced by National requirements or codes.

ANALYSIS SYSTEM

To evaluate the stress sensitivity of environmental factors, the "in-house" developed system LOADS (Reference 1) is used. This system (Figure 1) is based on an indirect dynamic analysis technique, in which rigid body velocities (whose structural effects are minimal) are neglected. The structure is considered to be accelerating in all six degrees of freedom from heave position, where the still water draft has been modified by its dynamic component for each wave condition and phase angle. All external applied forces (wave, current, wind, weight, buoyancy, mooring) are recomputed at this draft position and all remaining out-of-balance global loads (i.e. inertial loads) are balanced within the structure by applying linear and angular accelerations to an equivalent mass idealization of the unit, incorporating both inertial and damping effects.

A fundamental part of this system is to represent the structure as accurately as possible not only for determination of overall global stresses but also, and probably more important, to determine the stresses at the junctions of all the main structural components. A typical overall model is shown in Figure 2 and a close-up of the main joint in Figure 3. Finite element types in this model are as follows:

1. 'BAR' elements; six degree of freedom line elements carrying bending, torsion, shear and axial loads, representing all bracing members, and primary hull girders together with their associated effective width of plating.
2. 'ROD' elements; two degree of freedom line elements carrying torsion and axial load representing minor beams and groups of stiffeners on plated areas.
3. 'QDMEM 1' elements; three degree of freedom isoparametric quadrilateral membrane elements carrying in plane forces only, linearly varying direct forces in two perpendicular planes and shear forces representing the plated areas of the hulls, columns, upper deck box, and bulkheads.
4. 'TRIMEM' elements; three degree of freedom triangular membrane elements, again carrying in plane forces only, direct loads in two perpendicular directions and shear.
5. 'SHEAR' elements; quadrilateral elements carrying in plane shear only and are used as overlay elements representing the shear stiffness of internal plating and secondary structure.

The model shown contains 1010 node points, 405 bar elements, 1490 plate elements and 1420 rods, for comparative purposes, a stick model based on only bar elements is shown in Figure 4.

STATIC STRENGTH

Three main conditions are analysed for overall static strength each related to the particular draft:

1. Transit; at normal transit draft with a specified variable deck load and limited to sea conditions 8 to 12m wave heights or as stated in the operations manual before the unit is submerged to a column stabilized draft.
2. Operating; during the drilling phase and maximum semi-submerged draft with maximum variable load and drilling or crane lift loads, etc., to all sea conditions up to a maximum design specified limit. This limit is determined by the ability of the unit to drill, operate cranes or excessive motions limiting the use of machinery or equipment or airgap restrictions.

When used as an early production platform, the variable deck loads and distribution change and a range of drafts should be considered. Maximum wave heights in the range 14 to 20m are usually specified.

3. Extreme; an intermediate draft at a maximum allowable variable load condition in sea states between maximum operating and extreme design. For unrestricted worldwide use values of maximum wave heights up to 36m have been specified in design.

For each of the above global conditions, the limiting Design environmental criteria specified e.g. wave heights, wind, current, etc., are related directly to the vessel's draft. Over a three year period in the North Sea a drilling semi-submersible was at transit draft 3.4% of the time, 86.7% at operational draft and 9.9% at extreme storm draft. The multi-purpose support vessel *Uncle John*, on the other hand, will have the additional restriction of working close to a platform with no choice to either position or heading. "*Uncle John* normally moves away from its work site when the significant wave height exceeds 5m and there-after stands-by on the most comfortable heading in relation to the sea state", (Reference 2).

Government Regulations tend to focus on the extreme storm conditions while the other two, transit and operational being considered a measure of the efficiency of the unit.

In addition to the global design criteria, three other aspects must be considered for the structure:

1. Non-load related. There are minimum plate thicknesses and stiffener sizes which can be successfully built in any welded marine structure. These minima are specified in Classification Societies' Rules and are based on previous experience, there will be appropriate minima for main structure (pontoons, columns, and upper hull) and for secondary structure including internal frames and bulkheads etc. For structure below the deepest design waterline involving external surfaces, which would be protected by an approved cathodic protection system, the minimum scantlings above are increased, if an approved corrosion protection system is not fitted.

The steel grades are selected for particular areas of the unit with reference to structural importance, service temperature and plate thickness. A typical distribution is shown in Figure 5. The design service temperature is assumed to be the minimum average daily atmospheric temperature (Figure 6). In locations where the design air temperature is below -30°C the use of special low temperature steels at critical areas in the structure may have to be considered.

2. Load-related; 'other loads'. The sources include:

- Structure self-weight;
- Machinery and outfit equipment weights including seatings and foundations etc.;
- Dead loads of stores (bulk) wet and dry, provisions, crew and effects, cargo or other operating loads, which may be carried on the deck or in the tanks;
- Mooring loads, the unit must have sufficient strength to resist maximum pre-tension plus operational/survival surge loads in all lines and locally, each part of the mooring handling gear and foundations for loads up to the breaking strength of a mooring line;
- Towing loads, local back-up structure up to the maximum breaking strength of the specified tow line or towing bitts;
- Ice loadings, the dead loads of ice and snow on deck and sides of the upper structure, the forces on columns and lower hulls due to ice sheet crushing and impact from floes;
- Operational and equipment loads/forces including: drilling derrick crown block, rotary table, set-back, guide line and riser tensioners, service cranes, BOP transfer crane, diving bell transfer and main hoist, wire line D.P. reference, dragway winch, pipelay tensioners, side lay davits, stern latched ramp and stinger (for pipe laying) heavy lift cranes and derricks, fire monitor thrust, production riser loads, accommodation and emergency access bridge or gangway, tanker loading boom or crane and hose, launch and recovery gantry for submersibles etc.;
- Main propulsion thrust and steering nozzle or rudder forces, tunnel thruster forces, D.P. azimuthing thruster/propulsion unit force;
- Helicopter decks, the maximum design landing wheel loads for a particular helicopter over the landing area, manoeuvering wheel loads for the remaining deck area and crash loads for the main support beams and girders;

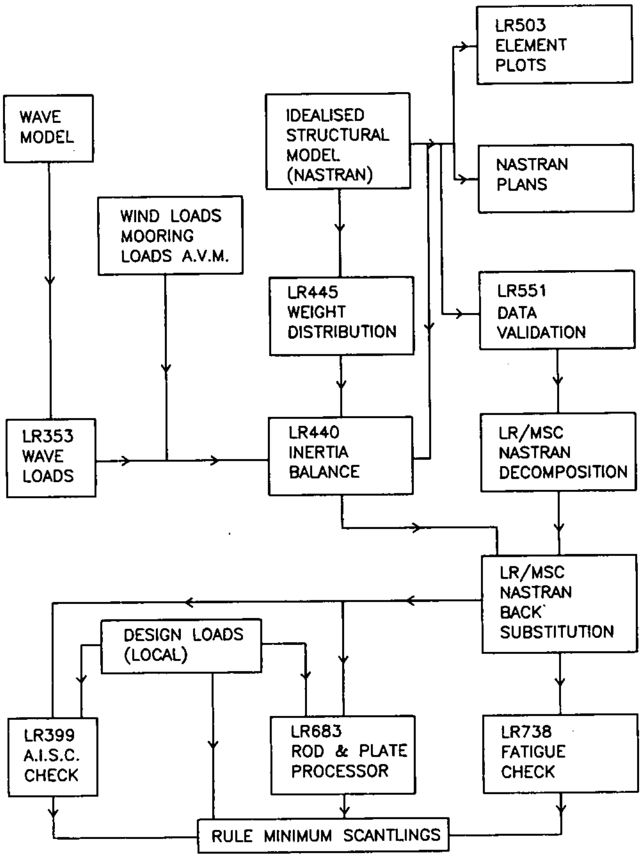

FIGURE 1 "LOADS". Structural Analysis System Flow Diagram

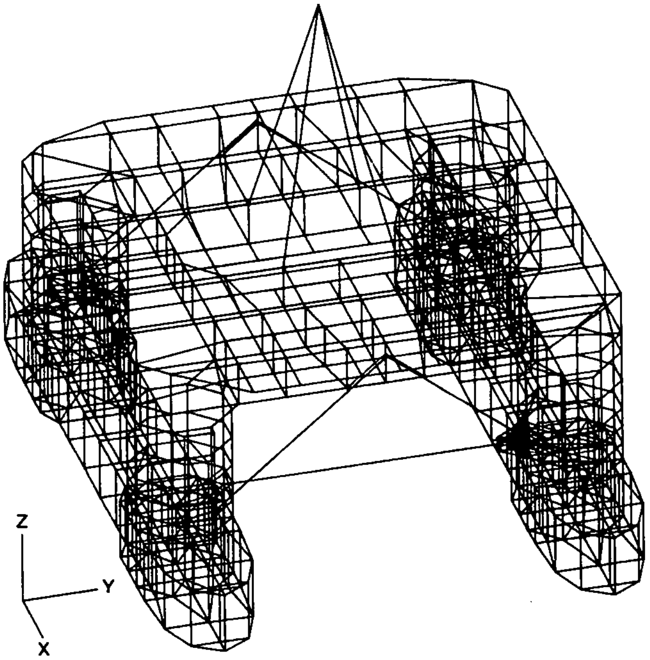

FIGURE 2 Typical global model

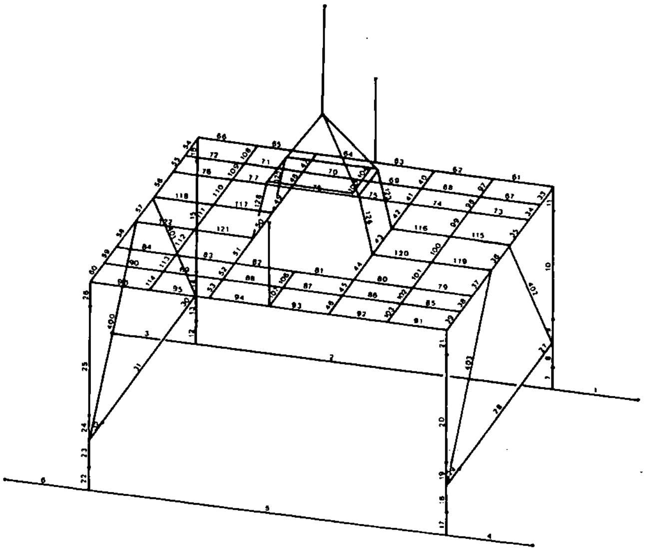

FIGURE 4 A typical stick model

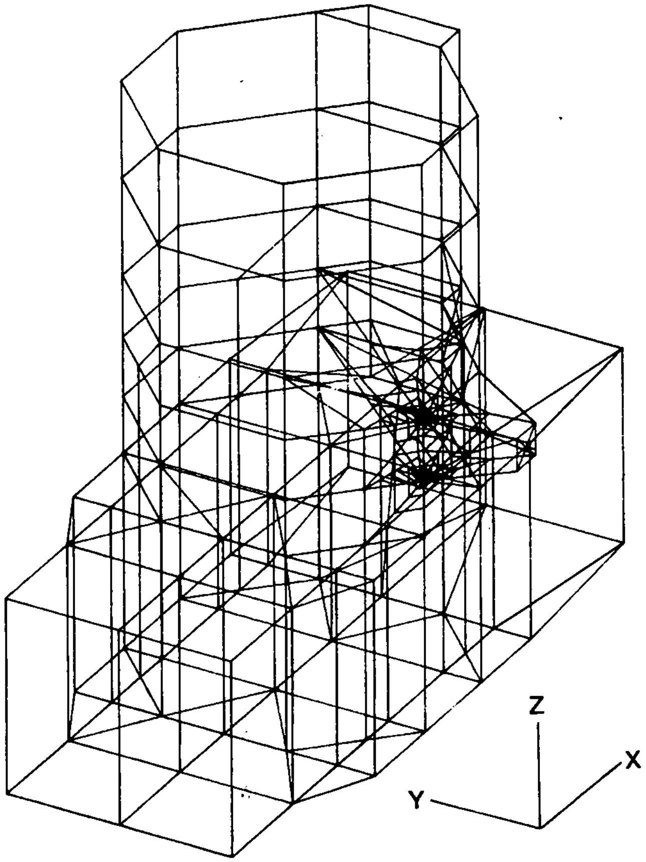

FIGURE 3 Main joint close-up

- Supply boat loads, forces of moored boats where mooring alongside is allowed. Generally for supply boats offloading, impact damage loads on columns and bracings is to be assessed including the effect on the overall structure;
- Deck loadings other than specified deck mounted items for example, crew spaces, walkways, work areas, weather decks, general storage areas have specified minimum pile requirements. Additionally maximum wheel loadings in any area where fork lift trucks or mobile cranes can operate;
- Inertial loadings superimposed on all structure, machinery, outfit, and dead loads based on the accelerations of the vessels' motions in a sea way (obtained from tank tests or equivalent prediction);
- Resonant vibration effects on support structure on certain machinery, propulsion, and operational equipment;
- Live loads from crane reactions, rolling loads etc.;
- Slamming loads and the subsequent vibration cycles on horizontal lower bracings.

3. Pressure-related design. In general, considerable areas of the lower hulls and columns are primarily designed by local scantling requirements of Classification Societies' Rules (Reference 3) due to hydrostatic head from tank overflow, maximum wave or damage water line. The lower hulls usually do not require any increase in scantlings to those designed by hydrostatic pressure except, in some cases, locally in way of the column connections.

Similarly the columns of most of the recent semi-submersible designs have small increases, in the order of a few millimetres over the hydrostatic head designed thicknesses. However, this depends on the relative size of the columns compared to the other rig proportions, if the columns are large like on the pipe-lay barges *Semac* and *Choctaw*, there will be no requirement to increase the basic scantlings while if the columns are small a greater proportion of the required thickness will need to be added by global framework stresses.

- The minimum scantlings of a tank boundary in any location in the vessel are determined by reference to the maximum pressure due to the load head to the overflow vent pipe. The proportion of this load head is determined in the same manner as those set for tank boundaries in the Ship Rules (Reference 4).
- The scantlings of the external boundaries of lower hulls and caissons/columns are not to be less than those for a tank boundary. The minimum head being not less than an equivalent hydrostatic head due to the sea at the maximum design wave crest elevation. In no case are scantlings to be less than those required for a watertight bulkhead as determined below.
- The scantlings of watertight bulkheads are to be determined using a minimum load head to the worst level of the applicable damage waterplane.
- The minimum scantlings for all areas of the unit subject to wave immersion is taken as the actual heads above, where applicable, but not less than 6.0m.

The strength criteria have been outlined above in some detail in order to illustrate that a large majority of the scantlings of a semi-submersible are set by basic considerations from Classification Rules. These can be overall global strength requirements or local design criteria or indeed particular stress cut-offs employed by individual designers, based on their own experience over and above any laid down requirements.

Complex fatigue analyses and spectral analyses procedures are being considered as check conditions for the original basic scantlings (Reference 5). National regulations are also being viewed in the same light as they generally give little or no guidance on acceptable basic scantlings, on the assumption that the unit will be classed.

MOORING

An increasing amount of attention is being paid to the design and analysis of positional mooring systems. As the mooring system loads are directly related to environmental conditions and vessel motions (which are also a function of the sea state) it is important that the basic design environmental criteria are realistically chosen. Of necessity, the design conditions are, in reality, envelopes of environmental criteria in association with operational limitations combined with acceptable Factors of Safety. Underestimation of the environment or particularly the way in which it combines, leads to excessive motions, inadequate safety factors and possible, costly failure, in addition to the general loss of operational time. Over-conservatism, on the other hand, adds weight and costs from larger and longer mooring lines, bigger winches etc. and perhaps reduced deck load carrying capacity. There are two main design conditions specified:

1. Survival represented by the 50-year storm. The vessel will be expected to remain on location, but with the drilling unit disconnected from the seafloor, large values of excursion can be tolerated. Design Criteria for this condition consist only of restriction of maximum tension in the mooring lines with a minimum factor of safety of 2.0 based on the breaking strength of the line. The maximum line tension is calculated for concurrent colinear combinations of design wind, design wave, design current in the most unfavourable heading and with the appropriate vessel motions and given water depth. Typical values in the North Sea are a sea state with a significant wave height 16m, 14 second period; maximum wave height 30m, 19 second period; a 1.5m/s current and a wind speed of 50m/s.

2. Maximum operating based on the combination of wind speed, wave height/period, current, at a water depth and offset limited to the value up to which the drilling unit can still sustain operations. In addition to heave the offset or total horizontal displacement from the well bore is another limiting factor in regulating operational activities, to prevent damage to the marine riser and BOP Stack. Operational criteria can vary with the characteristics of the unit and its equipment, however, typical values in the North Sea are a sea state with a significant wave height 7m, 9.5 second period; maximum wave height 13m, 12.0 second period; a 0.5m/s current and a wind speed of 20m/s at the specified water depth range and a maximum excursion up to 6.0% of the water depth. Sub cases may also be considered 'waiting on weather' with a larger offset and a harsher environmental combination. With the offset limitations above, a minimum safety factor of 3.0 must be achieved based on the maximum line tension against the breaking strength.

In the North Sea, the Norwegian Maritime Directorate has introduced "damaged" conditions, i.e. failure of a single line with both operating and survival above but associated with the reduced safety factors of 2.0 and 1.4 respectively. For semi-submersibles used as accommodation near fixed platforms, the latter safety factor is increased to 2.0 and applies specifically to the lines maintaining separation in the 'stand-off' position.

As stated previously, mooring line tensions and anchor loads are directly related to the motion characteristics of the vessel in a given sea state. The highest static loads occurring when the unit is at its greatest distance from its tensioned position. The pattern of motion comprises three separable effects:

1. A steady displacement from the origin to a mean position. This shift is caused by the wind, current, and mean wave drift forces.

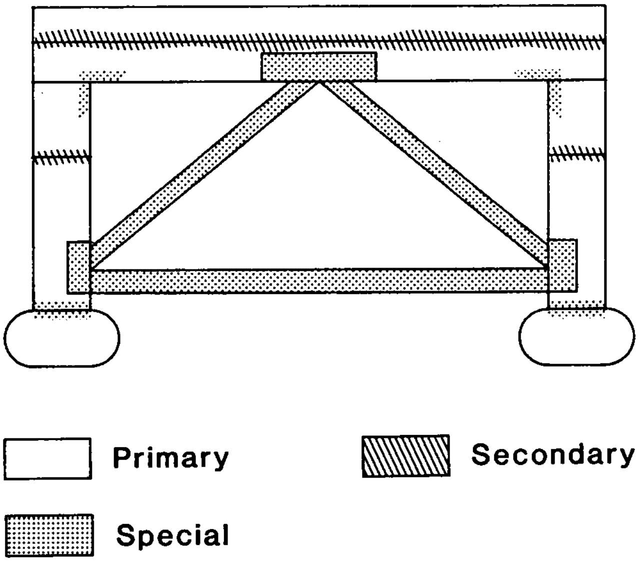

FIGURE 5 Typical steel categories

STRUCTURAL CATEGORY	REQUIRED STEEL GRADE	MAXIMUM THICKNESS (mm) FOR VARIOUS DESIGN TEMPERATURES 0 °C	−10 °C	−20 °C	−30 °C
SECONDARY	A	30	20	10	X
	B	40	30	20	10
	D	50	40	30	20
	E	50	50	50	50
	AH	40	30	20	10
	DH	50	50	45	35
	EH	50	50	50	50
PRIMARY	A	20	10	X	X
	B	25	20	10	X
	D	35	25	20	10
	E	50	50	50	40
	AH	25	20	10	X
	DH	45	40	30	20
	EH	50	50	50	40
SPECIAL	A	X	X	X	X
	B	15	X	X	X
	D	20	10	X	X
	E	50	45	35	25
	AH	15	X	X	X
	DH	30	20	10	X
	EH	50	45	35	25

FIGURE 6 Low temperature steel grades

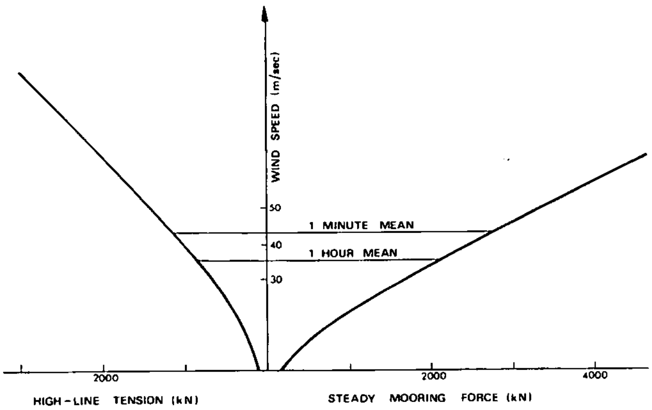

FIGURE 7 Effect of wind averaging speed

SEMI–SUBMERSIBLE

DESIGN CRITERIA WORLDWIDE
STATIC STRENGTH

DRAFT	WAVE HT(m)	ALLOWABLE STRESS
TRANSIT	8 – 12	0.6 Fy
SURVIVAL	30 – 36	0.8 Fy
OPERATIONAL	14 – 20	0.6 Fy

FATIGUE 20 YEARS MINIMUM

DRAFT	WAVE HT(m)
OPERATIONAL	2 – 12

WIND	UP TO 110 KNOTS
CURRENT	UP TO 2.5 KNOTS

FIGURE 8 Design criteria

2. A low frequency oscillation about this new mean position. This is the result of a slowly varying drift force, principally wave drift but with some wind influence.
3. Surge or sway oscillations at wave frequency. These, first order wave motions, have amplitudes which vary directly with wave amplitude.

This dependence on both environmental forces and the forced displacements makes sensitivity studies only relevant to a particular unit. Wind tunnel testing, wave tank models, and field investigations, analysing recorded mooring line tensions have been used for improving our knowledge of the individual parameters, and fully dynamic mooring analysis packages are being developed. The current state of the art analysis procedures, design envelope conditions, and factors of safety reflect operational experience. However, while there is some degree of standardisation of approach to the selection of the design envelope and to mooring line analysis procedures, there are anomalies. For example, the recently issued API RP 2P (Reference 6) recommends the one minute mean wind velocity as the basis for wind force calculation, whereas the Norwegian Maritime Directorate regulations (Reference 7) allow the use of the one hour mean wind speed. An illustration of the apparent differences, in mooring load and line tension, in the same environment, but with different wind averaging periods used, as the basis for calculations is shown in Figure 7. On this particular rig, as the one minute wind speed is some 17% higher, it generates 37% more wind force and adds 30% to the steady line tension.

It must be noted here that success of the mooring system depends not only on operation within the design envelope but also on the maintenance of the integrity and reliability of all the individual components.

A word of caution, introduction of new criteria, seemingly more onerous e.g. one line failure, leads to a more rigid mooring system. This trend increases the loads produced by currently considered "second order effects", such as slow drift oscillations. The long term possible fatigue problem has yet to be addressed.

STATIC STRENGTH SENSITIVITY STUDIES

All the results presented in this section have been obtained from the analysis of actual platforms satisfying the design criteria shown in Figure 8, and classed with the Society. Though there will be variations with different designs, the trends indicated are representative and have been confirmed by numerous analyses on several new semi-submersibles.

Wind

The structural implications of wind are not significant. For a typical vessel, wind forces lie within the range 250 to 500 tons for a velocity of 50m/s with head and beam on forces approximately equal.

Wave Height/Direction

The variation in nominal stress with wave height and direction for a transverse lower bracing member is shown in Figure 9. In each case a constant wave height/wave length ratio is maintained though the trend is similar for other ratios, the draft is kept constant at its operational value of 18m. The increase in member stress due to wave approach angle is clearly demonstrated. The nominal stress due to a 20m wave head on is roughly the same value produced by a 3m wave beam on, conversely there is a 46% increase in stress for a 20m wave from head on to a beam on approach. A diagonal lower bracing member shows different characteristics (Figure 10). In this case maximum nominal stress occurs for a wave approach angle near 45° and the stresses produced by a 20m wave from this direction are 65% greater than both beam and head on, which are roughly the same.

Wave Height/Period/Draft

In this investigation a transverse bracing in one of the newest semi-submersibles is considered. Only the critical beam on approach angle is used.

The maximum design wave height for transit draft is 10m, for operating draft 15m, and for survival draft 36m. With these imposed cut-offs the calculated nominal brace stresses at each of these drafts is shown in Figure 11. A wave height/wave length ratio of 1/10 has been used for wave heights up to about 24m varying to 1/14 for the maximum wave height of 36m. The maximum stresses produced at transit and operating draft are roughly the same and lower than that produced by a 20m wave at survival draft. In fact, normalizing these axial stresses with respect to wave height indicates similar curves for survival and operating conditions, as in both cases the brace is submerged. At transit draft higher levels of axial stress/wave height are produced. The brace is now exposed and there is a larger associated moment arm (Figure 12).

Some authorities allow increased stresses up to 0.8 x yield stress for all conditions involving environmental loads independent of draft. On this basis, it is obvious that the stresses at survival draft will be the critical design criteria for strength scantling assessment. On the other hand, it has always been our policy that stresses at transit and operational draft be restricted to the normal 0.6 x yield stress and the increased one and one-third factor only applicable to survival draft, consistent with the fact that a normal rig should only spend less than 10% of its life under extreme storm conditions at survival draft, the rig staying at operational draft as long as possible. Incorporating the increased allowable only for extreme storms at survival draft, the design criteria changes and strength scantlings will be determined by operational cases limited to 0.6 x yield stress. The dotted line in Figure 11, represents the survival condition reduced by 0.6/0.8 factor for comparison purposes.

It must be stated that the transit and to a lesser extent the survival conditions shown are conservative as one would expect the rig to be head on at the limiting wave conditions for each draft.

FATIGUE SENSITIVITY STUDIES

The fatigue life of welded steel structures is dependent solely on the applied stress range and the corresponding number of applications. For any point on the structure, the stress range will depend on draft, wave height, wave period, orientation, stress concentration factor. With a wave exceedence curve for the area of operation, a stress exceedence curve can be computed. The estimated fatigue life is then evaluated based on the Palmgren Miner cumulative damage law using an S-N curve appropriate to the weld detail. It is obvious that the environmental climate plays an important part in this assessment.

Wave Periods/ Direction

For a similar transverse bracing member as used previously, the stress ranges were evaluated for 5 wave heights, 2m, 4m, 6m, 8m, 12m with mean periods as shown in Figure 13 and a stress range exceedence curve computed (Figure 14). Again waves from head on having little effect. Using the U.K. Department of Energy S-N curves, the fatigue damage and fatigue life was estimated (Figure 15). The whole exercise was then repeated, this time assigning a range of periods to each wave height. The results in fatigue terms were similar, the mean period giving conservative lives. The convex shape of the stress range exceedence plot should also be emphasized.

In the conventional spectral analysis, the wave exceedences are computed from a Rayleigh distribution function. This leads to a linear variation of wave heights and excee-

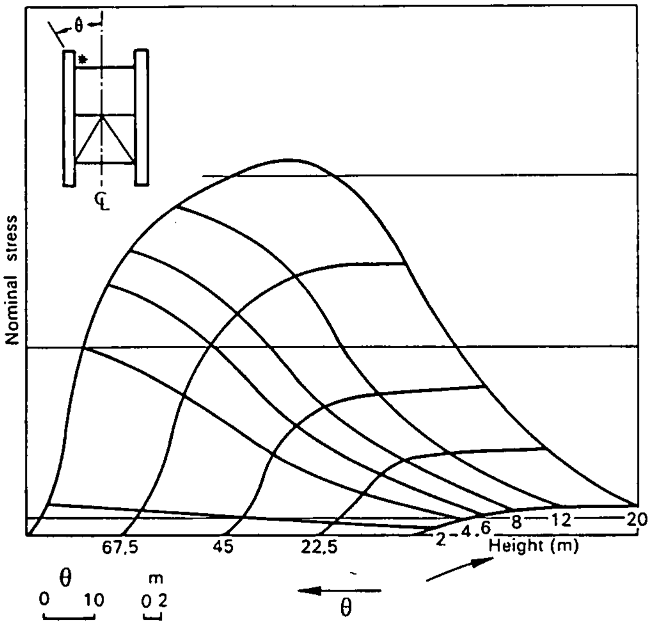

FIGURE 9 Nominal stress variation

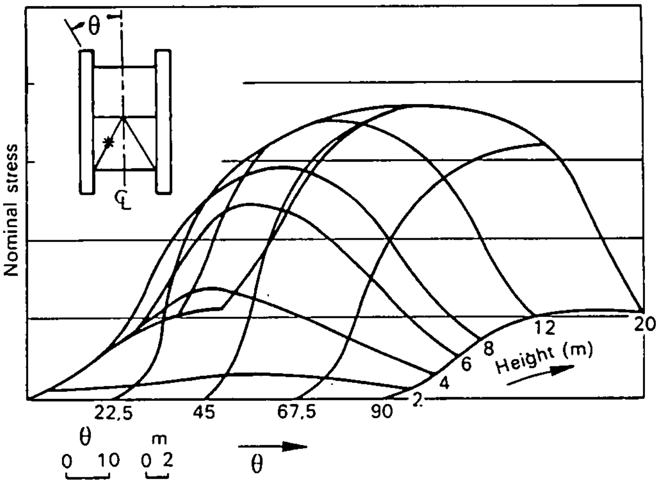

FIGURE 10 Nominal stress variation

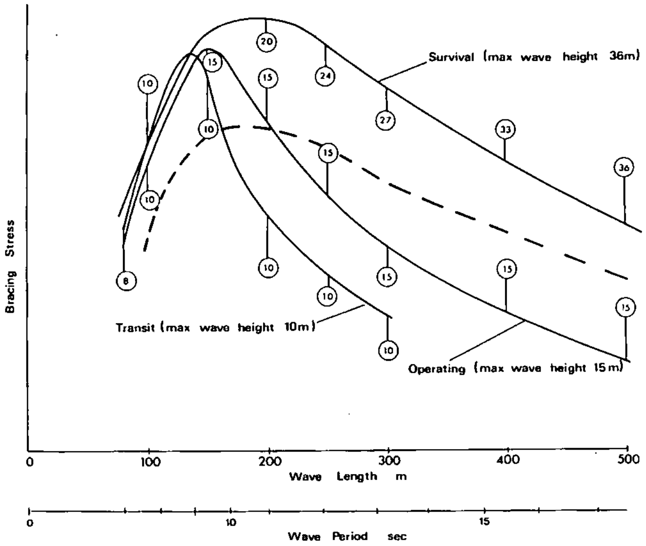

FIGURE 11 Maximum brace stresses

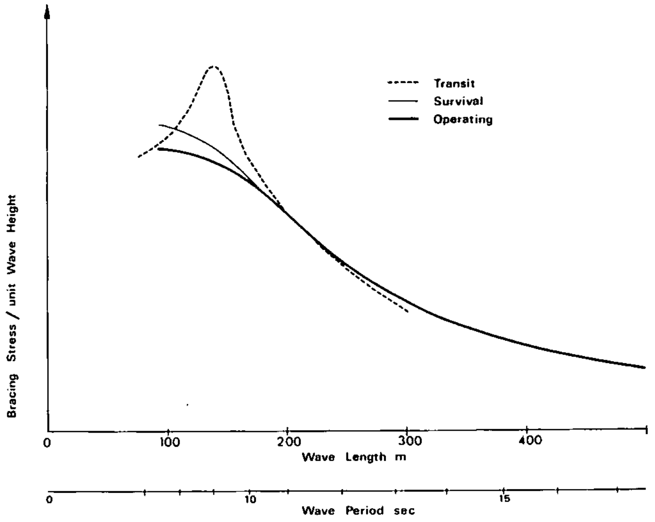

FIGURE 12 Normalized brace stresses

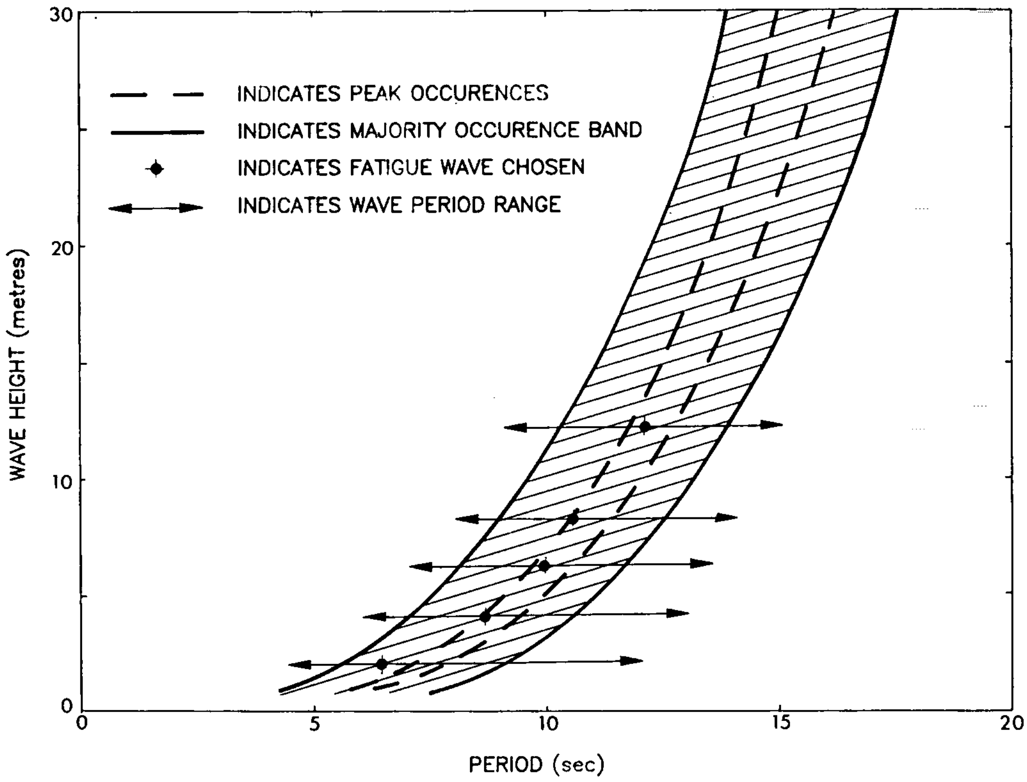

FIGURE 13 Wave height/period distribution

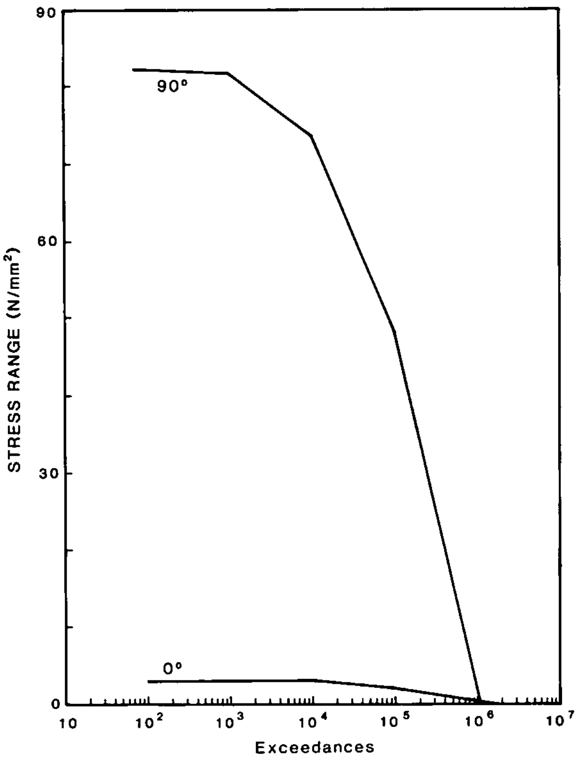

FIGURE 14 Typical stress range exceedence

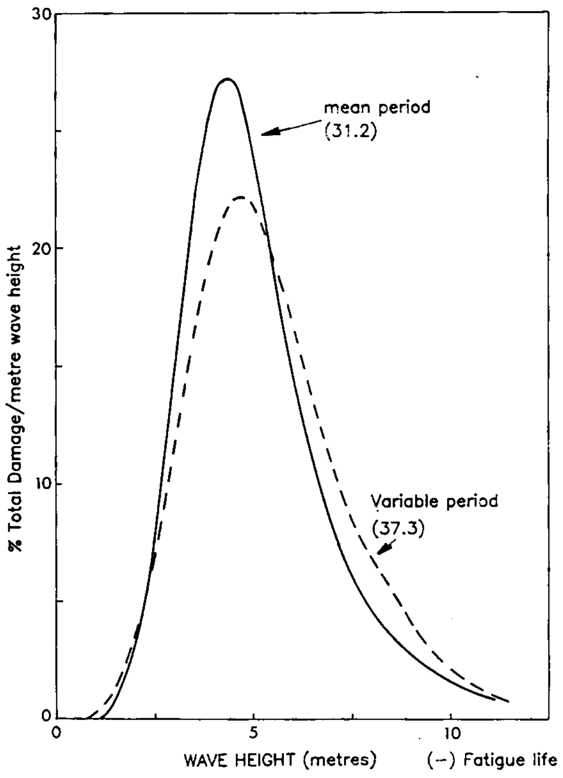

FIGURE 15 Fatigue damage

dences on a log-linear plot. With the further assumption of a linear relationship between wave height and stresses, the stress range exceedence plot will also be linear in contradiction to that evaluated previously. The method is used because of its computational simplicity but leads to inaccuracies if the stress and wave height relationship is not linear as is the case for semi-submersibles. The following procedure (Reference 8) is therefore used in evaluating the stress range exceedences (Figure 16). The sea states are defined by the scatter diagram of significant wave heights and zero crossing periods. An envelope of stress range transfer functions represented by stress range per unit wave height versus wave period, together with the relation between wave height and period given by the wave steepness are then used to compute the stress range spectra. The number of stress cycles corresponding to a given wave height are evaluated by summing the cycles from a Rayleigh distribution function of wave heights only. The stress levels and their occurrences are sorted to obtain the stress range occurrences summed to obtain the exceedence curve, which verifies the convex shape obtained in the deterministic method. This is an important point because the shape of this curve relative to the allowable S-N curve determines the sea states that cause most damage. A typical annual damage "scatter diagram" is shown in Figure 17, which indicates that the most damaging sea states for a semi-submersible are in the of region 6 to 10 seconds zero crossing periods and significant wave heights of 3 to 6 metres based on a North Sea scatter diagram. This includes the fact that the number of occurrences of these sea states in the wave scatter diagram have already been accounted for in the damage summation. It is also considered realistic to introduce a lower cut off level in the wave scatter diagram to about 2m wave height, as the characteristic dimensions of the structure are larger than the wave particle orbital path for small wave heights leading to inaccuracies in load estimation and the stress levels are very low.

S-N CURVES

Given the same stress range exceedence curve for a critical area in the semi-submersible the computed fatigue life and damage distribution can vary with published S-N curves, for example, the U.K. Department of Energy/B.S.5400 the Welding Institute (Reference 9) or American Welding Society (Reference 10) for the same welding detail.

The relative damage distributions for stress concentration factors of 1.0, 1.4, and 1.8 are shown in Figure 18 together with the calculated fatigue life. Based on the A.W.S. 'F' curve, no damage occurs with the three S.C.F.'s for all wave heights below 5m and the total damage is only a small fraction of the Department of Energy 'W' curve, where also upwards of 40% of the damage occurs below 5m wave heights.

Detail Design

Experience has shown that fatigue cracks start and propagate from areas of high concentration factors either at joints or along the bracings. Though it is preferable to avoid all unnecessary attachments, some are essential like butt welds, anode connections etc. The lower bracings of a semi-submersible are subjected to a complex stress range pattern due to overall racking, twisting, and splitting of the pontoons and columns caused by the passage of each wave. The maximum stress range for axial and bending loads along a 'clean' bracing for three different wave approach angles is shown in Figure 19. It can be seen that the quartering seas produce the maximum stress range over 30% of its length nearest each column, the central 40% being critical for beam on seas. Using stress concentration factors obtained from acrylic model tests for typical details (Figure 20), several parametric studies with different North Sea exceedence curves were conducted (Reference 11) and the results for acceptance of details along a brace are presented in Figure 21, including the effect of maximum design brace stress. Thus, for example, for a design nominal stress cut-off of 0.7 Fy in the brace, only a ground butt weld detail would be acceptable over the entire length, a smooth blended stiffener end detail would only be acceptable over the middle 80% of the bracing, all the other details would be unacceptable. At the other extreme, all the details would be acceptable if a limiting design brace stress of 0.4 Fy was used.

OPERATIONAL HISTORY

It can be seen that during the design phase, several assumptions have to be made about the environmental conditions a platform is likely to be subjected to during its life. This is further complicated by the number of different areas in which a platform is likely to operate. One of our classed rigs has already made over eight transatlantic crossings and more recently, the *Benreoch*, built in Korea, was towed to New Zealand for a short season of drilling after which, it will be dry towed to European waters for further operations.

To quantify actual operating conditions, the Masters' logs of several semi-submersibles are being continuously investigated (Reference 1). As an example, the first six years of records made every six hours on *Pentagone 84* is shown in Figure 22. Early calibration of the wave heights indicated a best fit of H (significant) = 0.7 H (visual) and this factor has been used throughout. A typical annual cumulative percentage rosette is shown in Figure 23. The significant wave height bands have been increased in 2m intervals from zero. Since the platform headings were also recorded, the right rosette shows the percentage occurrence of the sea states relative to the platform axis. In the example shown, *Pentagone 84* was operating in the Channel and the majority of the seas approached from the West. Since the Platform was also oriented towards the West during this period the sea states were predominantly head-on. From these rosettes, over the whole operational life, exceedence curves relative to the platform have been created, the wave data being grouped in terms of height, period, and direction.

For each wave height and direction category the percentage time of occurrence was then converted to numbers of waves and the ratios of numbers of waves in each height is shown for two directions relative to the Platform in Figure 24.

Percentage ratios for head on seas range from 17% for waves under 2m height to 40% for waves above 12m. These percentages and their subsequent structural effects would be vastly different under a different set of operational headings, bearing in mind, that beam on waves can be up to 30 times more fatigue damaging than the same waves head on for certain critical bracing members.

CONCLUSIONS

1. The fundamental design objective of a semi-submersible is to provide the offshore industry with a large stable, yet mobile, platform from which drilling and other operations can be safely, efficiently, and economically accomplished. As such, the final design must be a compromise to the various conflicting criteria, of which environmental climate is one.
2. Even under similar environmental conditions, the structural effects vary with operational procedures.
3. The calculated stress sensitivity of critical parts of the structure to particular aspects of the environment can also vary with National requirements and Codes of Practice.

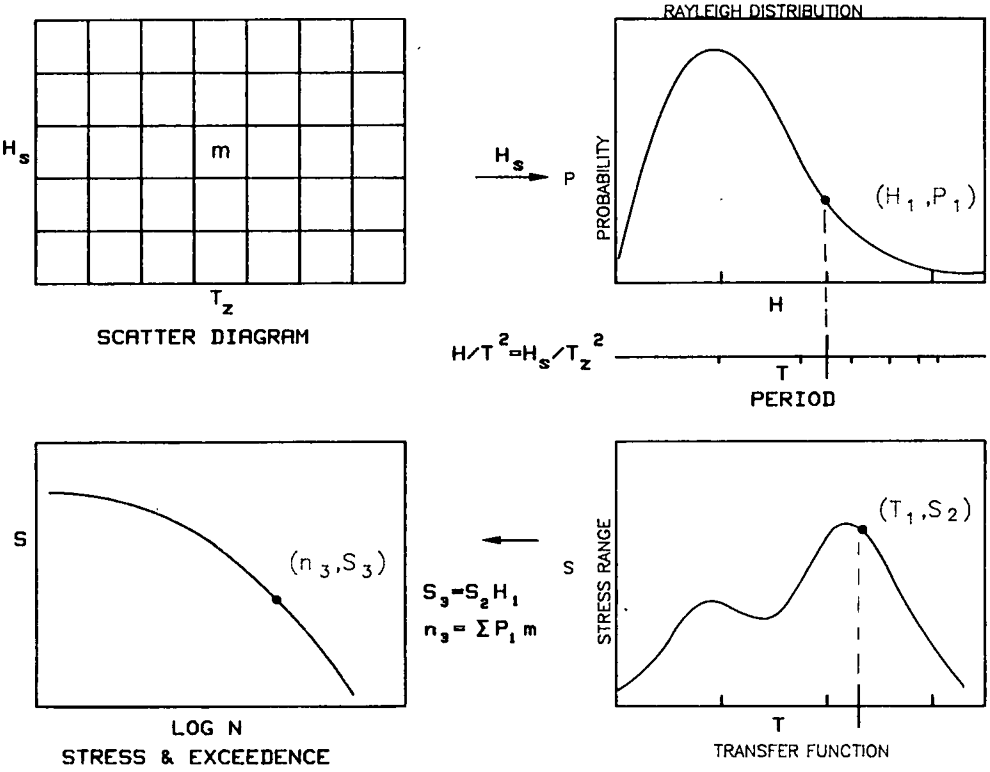

FIGURE 16 Modified spectral analysis

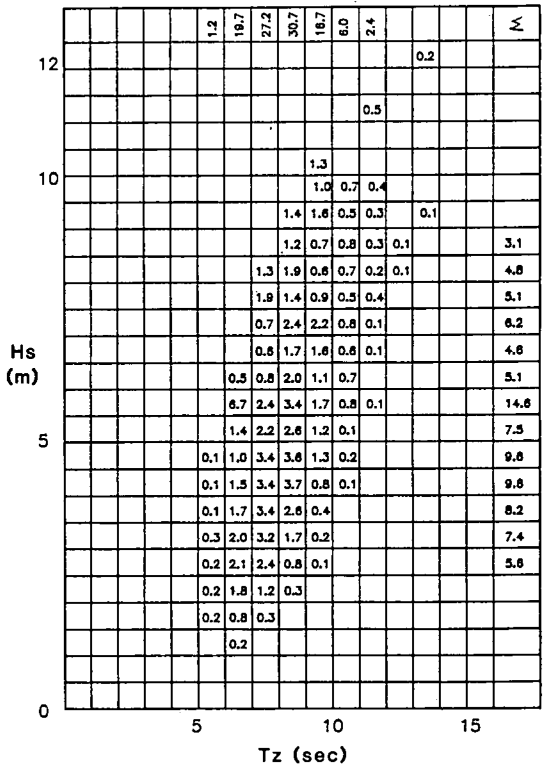

FIGURE 17 Annual damage scatter diagram

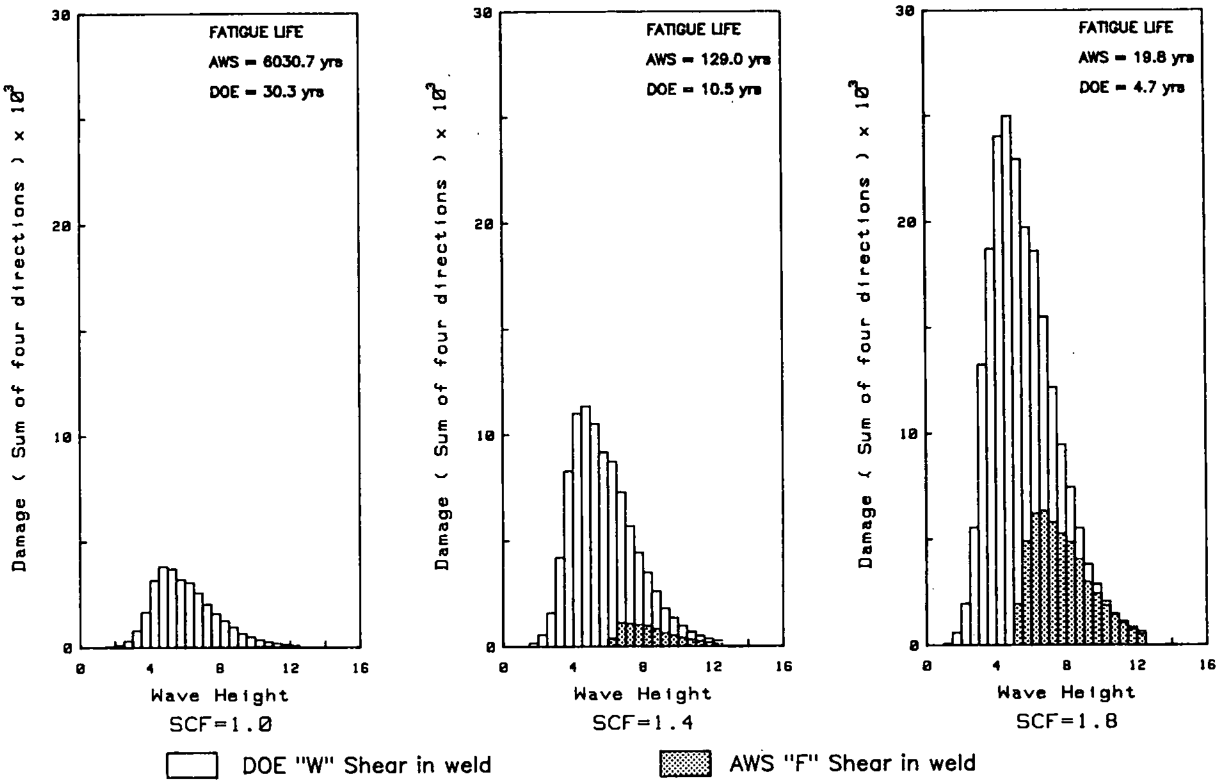

FIGURE 18 Fatigue damage distributions

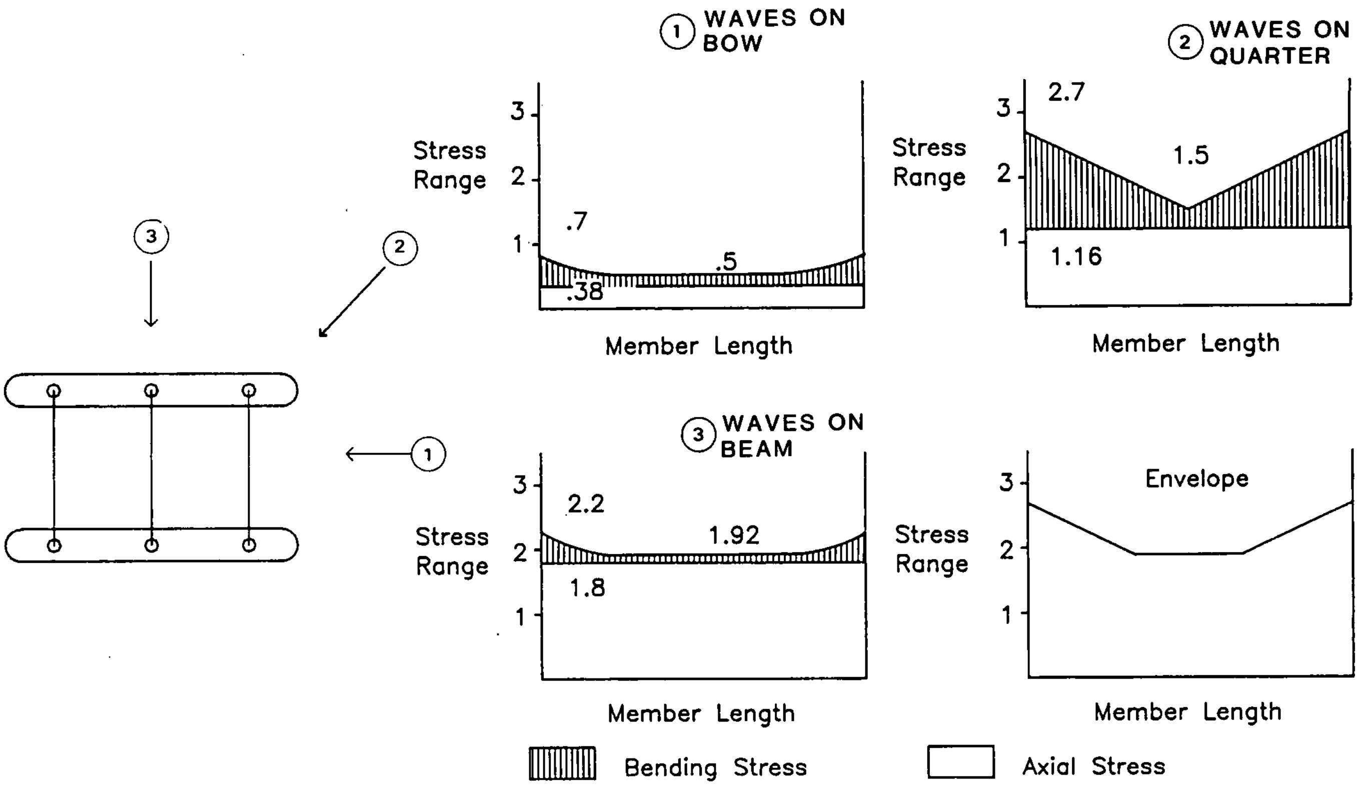

FIGURE 19 Stress range distribution

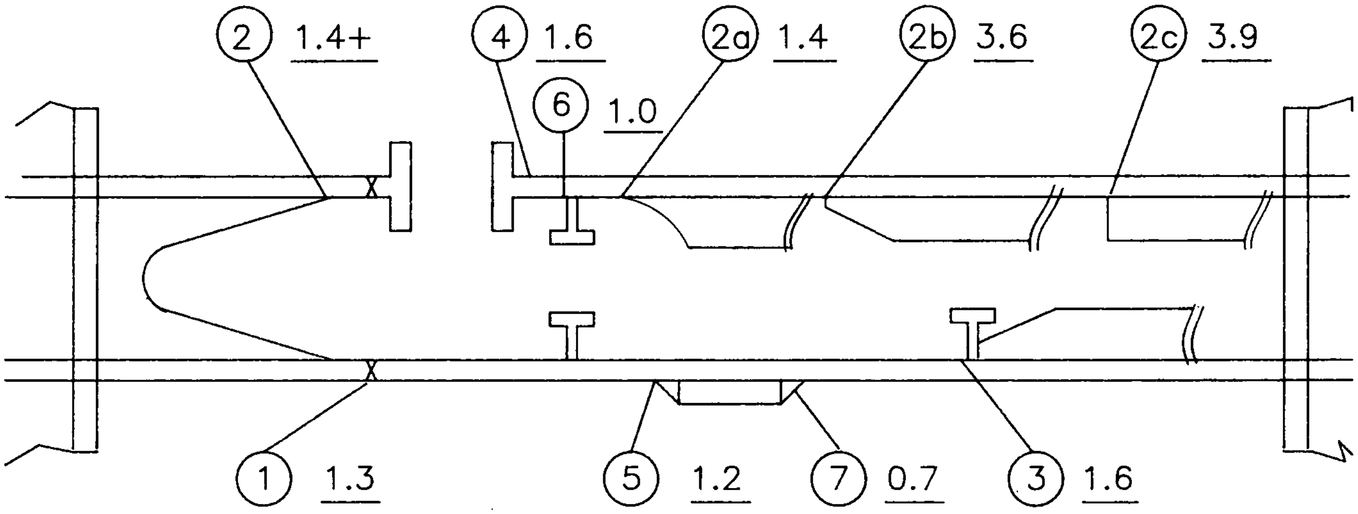

FIGURE 20 Stress concentration factors

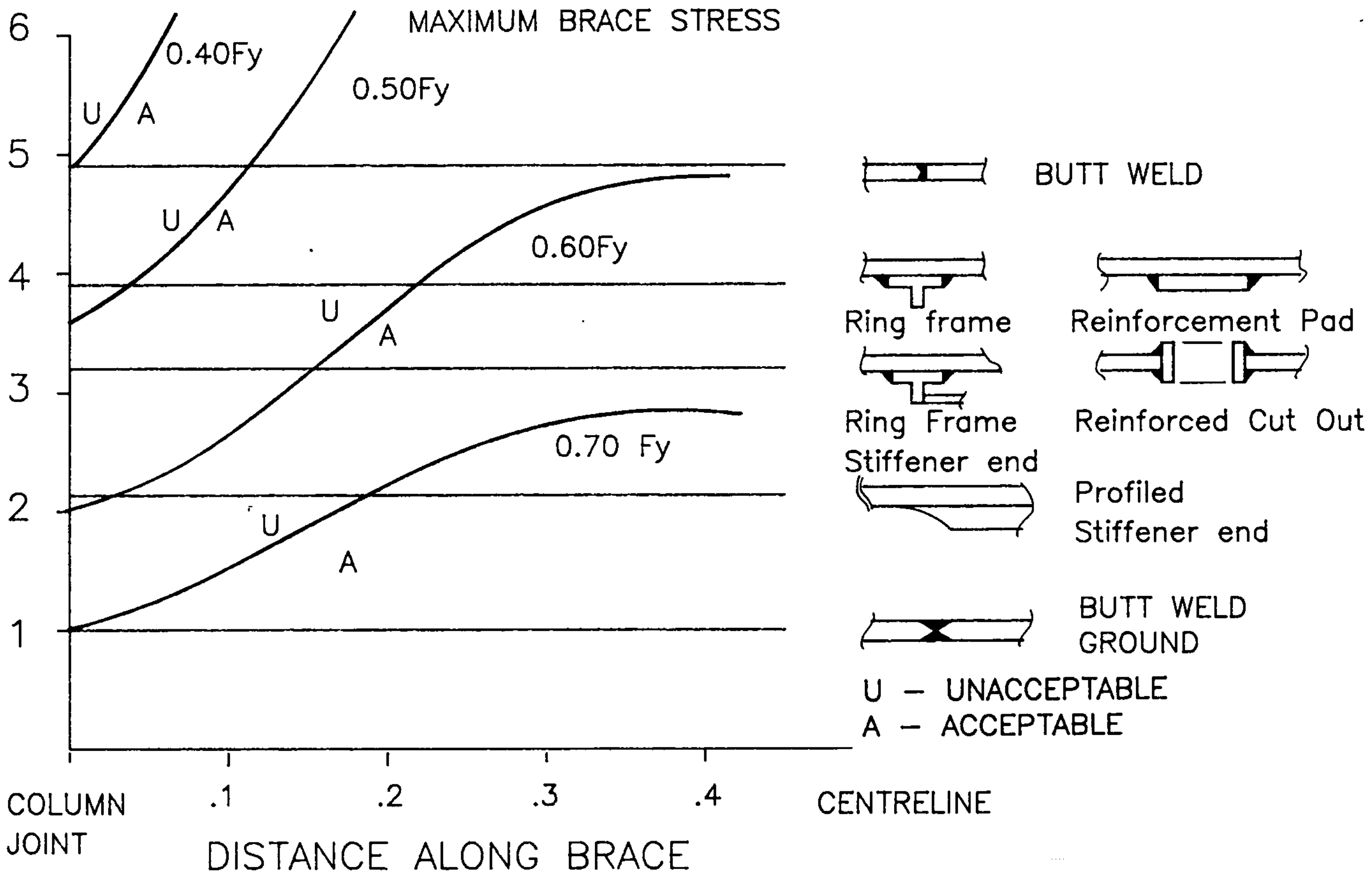

FIGURE 21 Detail acceptance

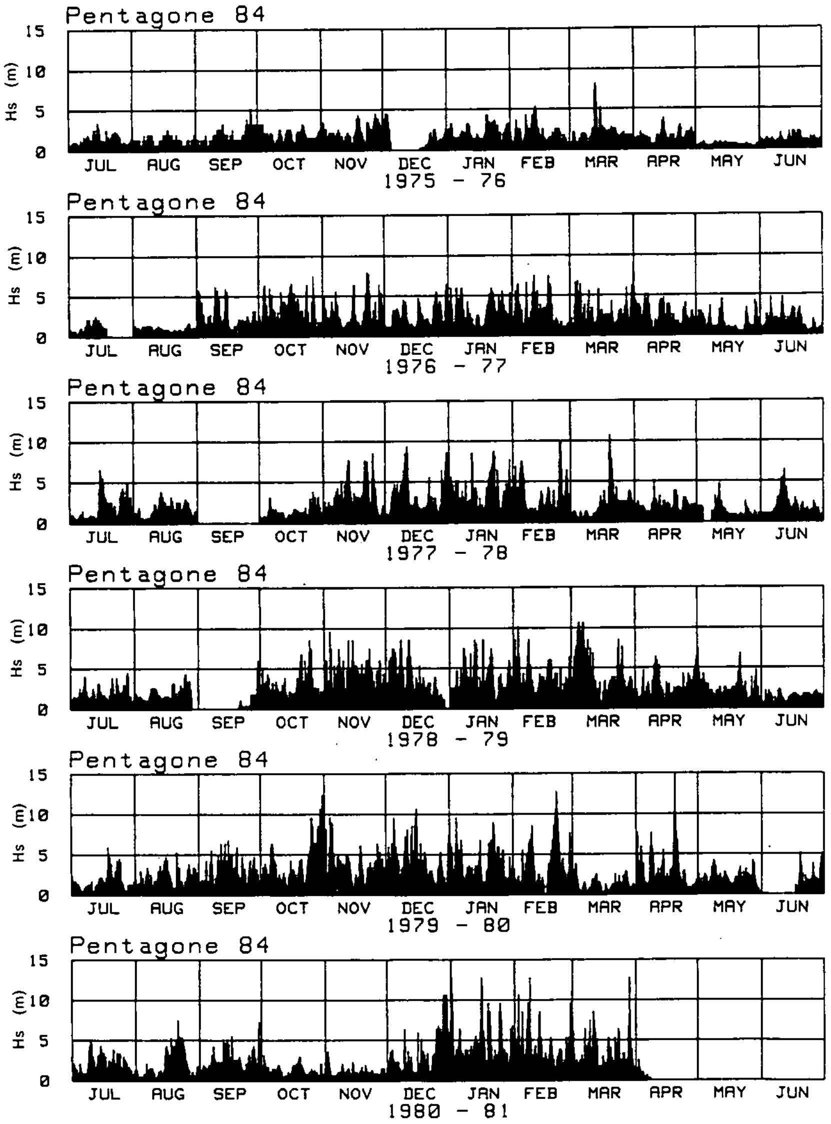

FIGURE 22 Seastate history

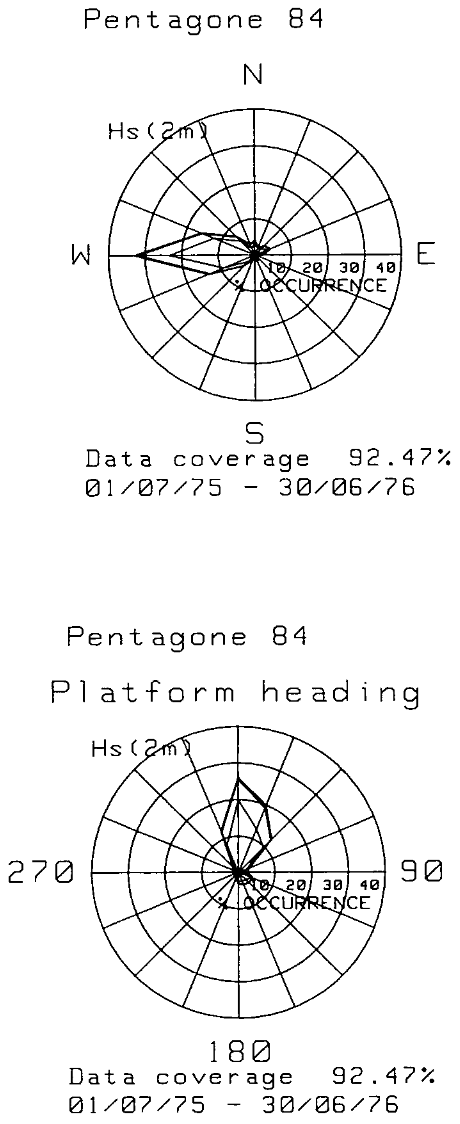

FIGURE 23 Annual rosettes

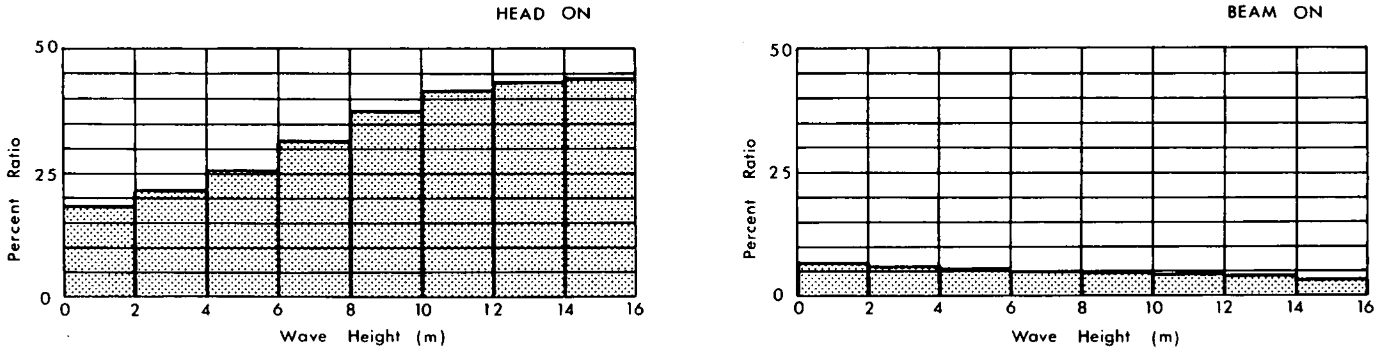

FIGURE 24 Wave directional distribution

ACKNOWLEDGEMENTS

The author is indebted to the Committee for permission to write this paper and to his colleagues for their help in its preparation.

The opinions expressed in this paper are the author's and are not necessarily the policy of Lloyd's Register of Shipping.

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COMMENTARY ON PAPER B2

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Noble, Denton & Associates

I wish to thank the Royal Commission and the author for providing me the opportunity to add any comment on this paper and the theme of Environmental Factors in Design.

The author is to be congratulated for compiling one of the most comprehensive and interesting papers on analysis of semisubmersibles and for identifying at least some of the conflicts facing designers of these complex structures.

There have been a lot of advances made in the last ten years in the analysis techniques of semisubmersibles; there is still a lot of progress, however, to be made. We have seen in this paper how computer programs can develop the motions of a semisubmersible and how you can use this to derive forces at the joints. Most of the available programs are based on the same hydrodynamic equations but the input of damping coefficients can change the results and thus you can get different answers. Most programs have been benchmarked against at least some model tests, but even these vary, depending on in which wave tank the model tests were performed. Some recent analysis done on semisubmersibles, using the Diffraction Theory as opposed to the Morrison Technique, has shown discrepencies of up to 20% in the forces. Wave induced heel is another area of some controversy which has shown up in model tests but so far very little evidence exists of its being a problem for full scale units (1). The observation to be made here is that this is the state of the art, and research and development is constantly revising the analytical tools we have available.

In 1972 I was on board one of the first semisubmersibles in the North Sea to suffer fatigue damage. The initiation point for the fatigue crack in that case was a poor detail on an access manhole into a bracing member. Industry response to this event, as is often the case in the offshore industry, was excellent, and as a result of this and one or two other incidents, we today have comprehensive means, as outlined by Mr. Bainbridge, of evaluating these fatigue effects. Ten to twelve years ago this was generally not done in the offshore environment, though some of the technology existed in the aircraft industry. Once this very sophisticated type of analysis and design check is complete, it is important to be aware that there are still problems in operating these units with respect to environment. Let me first say that perhaps the best way for owners, insurers, and government agencies to assure themselves of a quality design to good engineering standards is to have the design checked by a classification society and to have the unit built to a classification society standard.

Certain assumptions underlie any analysis, and it is necessary to make sure the assumptions remain valid at the operating location. Suppose we have a semisubmersible built to operate in the North Sea. As Mr. Bainbridge points out, we could be looking at 98 foot maximum waves in, say, a 19 second period. At a particular location in offshore Canada, a 105 foot wave with a 14 second period may be more appropriate. Since we have seen how wave height and period can vary the forces, we need to consider the effect of these changed environmental factors on the unit.

Mr. Bainbridge directed us to the wave height frequency scatter diagram used in evaluating the fatigue life of a semisubmersible. The distribution of wave heights does vary in different parts of the world. As Figure 1 indicates (2), a semisubmersible checked out by this method for the Gulf of Mexico would not necessarily have a suitable fatigue life in the North Sea or Canadian East Coast environment.

My main point is that when a rig designed on certain environmental assumptions moves to a new area of operation, it is necessary to check those assumptions against the conditions for which the calculations were done.

An example of this is when the first semisubmersible was towed to Hudson Bay. Elf Aquitaine chartered the semisubmersible platform *Pentagone 84*, owned and operated by Forex Neptune Drilling Company, to drill two wells in the summer of 1974. Prior to the tow from the North Sea, a study was carried out to determine the likely ice conditions to be met in the Hudson Strait when it was declared open for navigation. On the basis of this study, the five footing pontoons of the unit were reinforced at the waterline to withstand ice impact over an area of 120° each side of center line from forward. On the inward passage in June, seven-tenths multiyear ice cover was met in the Strait together with ice floes of an estimated 15,000 tonnes which were impacted at slow speed. On the return trip in October no ice was encountered.

Lest we spread too much alarm, let me assure you from all of the data I have seen to date, except for the iceberg problem, the environmental parameters for the North Sea and for the Canadian East Coast offshore are very similar and so the experience and technology developed for operating in the North Sea can be directly transferrable here.

The uncertainty over which of the analysis

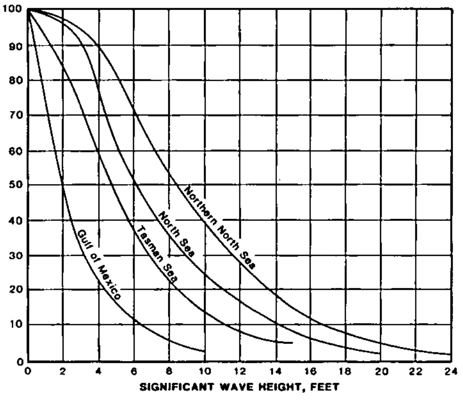

FIGURE 1 Wave height exceedance for four offshore areas

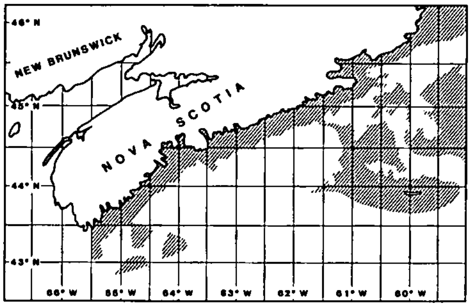

FIGURE 2 Possible area of jackup operations offshore Nova Scotia. Hatching indicates probable all-year operational feasibility against 100 year extremes subject to sea-bed conditions.
(Prepared by Noble, Denton and Associates)

methods and fatigue curves to choose, or which wave height distribution is appropriate boils down to the layman selecting a conservative approach and making sure detailed in-service inspections are carried out in a time frame indicated by the analysis methods.

What happens when we detect a fatigue crack? Do we weld it up and set the fatigue life back to zero and start again? The indication is that by grinding out a sufficient part of material on either side of the cracked area, we may indeed be able to set the fatigue life back to zero at that particular spot on the rig. The thing to be cautious about is the joint that was less critical the first time around may then be the next one to crack because its fatigue life was not set back to zero. Obviously I am simplifying the problem, but a great deal of research is going on at the moment by the Welding Institute in Abingdon, England, to find out which of the various repair techniques provides the most efficient way of obtaining useful extensions in the fatigue life of tubular joints. Their research also involves determining whether it is sufficient to repair only the cracked area of the joint or whether other areas which have accumulated fatigue damage without showing detectable cracking must be treated.

Subject then to the constraints that it is necessary to establish with a feasibility study, the limitations of the unit and its ability to work in a designated area, together with the constraint of a rigorous inspection program, what other environmental factors need to be considered? At any particular location we need to consider the ability of the anchors to hold the unit on location and thus we have to examine the sea bottom soil parameters. One needs to make sure that there are no submarine cables or buried pipelines that can be ruptured by dragging an anchor across them and it is necessary to confirm the absence of underwater obstructions or hazards which could endanger the mooring system of the unit. The calculations on moorings as outlined in the paper refer to the area from the anchor upwards. Obviously neither a designer nor the classification society, when looking at a unit, can tell you that the system will actually hold because this is dependent on the soil conditions at the specific location. We can recall the winter of 1973 when several units broke their moorings in the North Sea, and in 1982, in the North Sea, during the transient motion resulting from a double anchor line failure, a platform took with it the complete BOP and left the well open to the sea (3).

Selecting the anchors to be installed on these rigs represents, at best, a compromise, since it may be necessary to moor rigs in a variety of seabeds. It is always desirable to make sure that the bottom at the site where the unit is to be used is suitable for the anchors which are actually on the unit. In some circumstances, if the anchors will not bite in, it is necessary to switch anchors or to piggyback anchors to make sure the unit will stay on location in a reasonable storm condition.

There is no practical way of testing the anchor to its full capability. Pretensioning, which loads an anchor to somewhere around 60% of the load it expects to see in the most severe storm condition is usually carried out. This pretension is usually held for about an hour or so to prove the line. Whether the anchor will actually hold when it is needed depends on a variety of things, including the dynamic forces on the mooring lines, any chafing on the line at the seabed, and the general condition of the line. The analytical work is carried out assuming that all equipment is in new or like-new condition and has not been subjected to loadings in excess of its fatigue life.

Although there are sometimes problems with the analytical tools, the industry recognizes the shortcomings of the analysis methods and compensates for them with suitably conservative safety factors. Sometimes the safety factors may be too conservative. For instance, recent research on wind forces has indicated that the wind forces on semisubmersibles are generally overestimated. This is because many of the guidelines do not take the effect of shielding into account, nor do they take into account the lift forces, both above and below water. The present indications are that the wind forces may be less than the calculated ones, which means the safety is higher than we calculate. This also could mean that variable load weights could be increased may be by 400 to 500 tons on a typical semisubmersible without affecting its safety.

A great deal more research has to be done in the area of the effect of combined wind and wave effects on semisubmersibles. In Canada, the recently completed Boundary Layer Wind Tunnel at the University of Western Ontario under Dr. Alan Davenport's direction, offers a unique opportunity for research of this type.

THE ENVIRONMENT AND JACK-UP RIGS

Environmental factors are also an important consideration for jack-up drilling units. Several jack-ups are in use in offshore Nova Scotia and there is potential for use in other parts of the study area of the Royal Commission.

In Table 1 typical values for wind speed and wave height off the East Coast of

Typical Meteorological Data
(50 Year Return)

Extreme	Gulf of Mexico	North Sea	E. Coast Canada
Wave (feet)	52	60	95
Wind (knots)	131	80	88
Current (knots)	1.8	1.0	2.2

TABLE 1

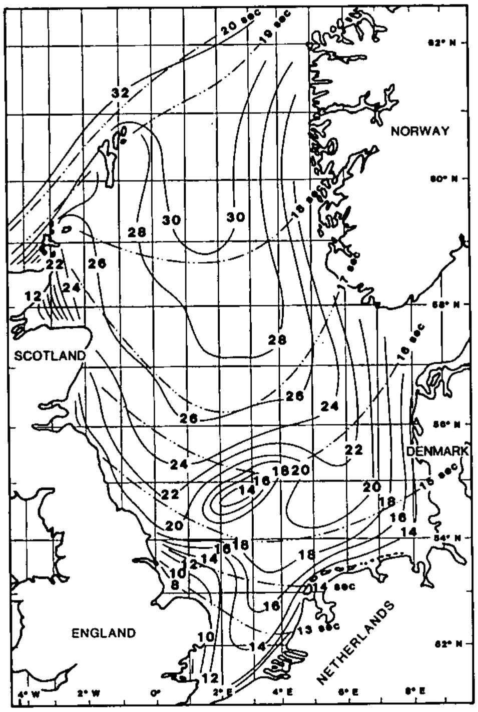

FIGURE 3 Fifty year extreme wave height (metres) and associated crest to crest period (seconds).
(Reproduced from North Sea Environmental Guide by kind permission of O.P.L.)

Canada are compared with conditions in the Gulf of Mexico and the North Sea. Since wave force is usually the largest contributor to overall forces on a unit at a particular location, it can be seen that the meteorological conditions offshore eastern Canada are probably more severe than anywhere that jack-up units have been used so far.

Quite clearly jack-up rigs built to date would not be able to withstand the force of an iceberg impact. In areas where there is a possibility of icebergs, the iceberg encounter probability should be calculated and shown to be below an acceptable risk level. The calculation should take in account weather conditions required for the unit to jack down and get out of the way of an iceberg on a collision path. Generally, for jacking up and down, a period must be available where wave heights do not exceed approximately five feet. There is at least one device, the SeaTek Slo-Roll System, which stabilizes the motion of a jack-up rig and can permit jacking into and out of the water in up to 15 foot waves. One of these devices is fitted to the *Glomar Labrador I* jack-up currently operating off Nova Scotia.

For environmental input to the jack-up design, a designer would typically select one or two water depths, one or two wave heights, and one wind speed distribution. It would be impossible for a jack-up rig designer to consider all the areas of the world and all the locations a rig is likely to drill in its lifetime. A unit may drill in Alaska one year, Canada the next, Africa the next, and so on. In each of these areas there may be specific environmental problems: high waves, strong currents, and a variety of seabeds. The number of variables would be too large to contain in an operational manual and the cost prohibitive.

Consequently, for a jack-up rig it is necessary to check that the site specific data on a location is compatible with the environmental parameters set by the designers. This can be done by obtaining data on the extremes of wind, wave, and current based on the COGLA requirement of 100-year return data from a reputable meteorological consultant. Regretfully, not all experts with the same data will draw the extrapolation lines the same way, so one often gets conflicting data for the same site. This can lead to undesirable competition for the lowest meteorological data.

In establishing the environmental extremes it is desirable to construct a set of maps showing the contours of extremes for the whole area as a benchmark for all site specific studies. These maps should, if possible, be endorsed by a government regulatory authority. Figure 3 shows the 50-year extreme waves offshore North Sea; these were derived by the author's company (5).

Although such maps are in existence for generalized wave climate offshore Canada, they are not yet publicly available. Since the design of a jack-up rig is directly dependent on wave height, it is very important to establish this benchmark so that meteorological consultants are not competing for the lowest wave at a specific site, since this infringes on the safety of the rig.

CONCLUSION

Clearly, environmental factors are of paramount importance as an input to design, and environmental parameters at the operating location must be compared to those used in the design to result in a safe operation for either semisubmersibles or jack-ups.

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COMMENTARY ON PAPER B2

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Mobil Oil Canada Ltd.

INTRODUCTION

Mr. Bainbridge has made an excellent presentation of some of the effects the environment can have on a semisubmersible. He has also pointed out some of the inconsistencies between classification societies of different nations and the anomalies that may occur if one is not careful in examining all the variations and combinations of environmental loadings. If there is a shortcoming of the paper, it is one that is characteristic of classification society publications; that is, he does not explain the rationale used in selecting basic criteria, safety factors, and the basic loading algorithms. In addition, and of particular importance in the area of the northern Grand Banks, he includes ice loading as a section of "other loads" but does not describe how the classification societies would expect a designer to calculate these loads, and allow for them in the scantling design.

DISCUSSION

In order to elaborate on the paragraph above, I will make my comments in the order the topics appear in Mr. Bainbridge's paper.

In the analysis section, the author describes in general terms the algorithm (LOADS) that is used to determine the environmental loads on a semisubmersible due to wind, waves and currents. Unfortunately, he does not discuss the basic equations or physical relations that are used to convert the environment to loads. It is one thing to go to a classification society's "rules" and another to understand the basis from which these rules were derived. With his experience and expertise, Mr. Bainbridge could have done the designers and the Commission a great service if he would have related the basic physical relations to the predicted loads on the structure. In this manner, he could have provided insight on what effect errors in drag coefficients, inertial coefficients, wave lengths, and wave periods would have on the loadings.

In the section on "other loads", Mr. Bainbridge delineates some of the other loads that must be taken into consideration. Of particular interest are the environmental loadings due to icing and ice which are highly relevant in the Grand Banks area. It would be significant if a relationship to specific ice conditions, such as solid ice, broken ice, and load could be provided. Guidance on icing loads, their rate of accumulation, the maximum allowable accumulation, and the location of accumulation would be very useful.

The author points out that National Regulations generally give little or no guidance on acceptable basic scantlings on the assumption that the unit will be classed by a recognized classification society. This is an important point in a country just establishing its regulatory posture. He also points out that the design conditions are, in reality, envelopes of environmental criteria associated with operation limitations, combined with acceptable factors of safety. In other words, a good deal of engineering judgement is involved.

The author describes two design conditions the survival condition and the operating condition. He indicates that the survival condition is based on the 50-year storm. It would be of interest to know the rationale Lloyd's has used to arrive at the 50-year storm and not a 100-year storm, and whether the 50-year storm is equivalent to the 50-year wave, or the 50-year current. It is my understanding the other classification societies use a longer return period criteria. It also would be of interest to understand why the mooring system has to be designed to the concurrent maximums of wind, wave and current in the most unfavourable heading, rather than some joint probability of these occurrences.

The author points out the conflict between the API RP 2P recommendation of the use of a one minute wind and the DNV recommendation of the use of a one hour wind, the difference resulting in a 30% decrease in the steady line tension. Can the author provide any guidance on which to use and why?

The information presented by the author on the sensitivity studies related to stress variation with wave height and direction are enlightening. Figure 9 shows an apparent significant increase in stress in transverse members with a beam on sea. Does this mean a symmetrical semisubmersible will be more efficient than a rectangular semi because of a more even distribution of stress due to changes in wind direction?

The author points out in Figure 11 that, under Lloyd's rules, the maximum bracing stress occurs in the survival conditions; however, it is not clear that the maximum stress occurs at a wave height less than the maximum wave height. If this is so, could the author explain why this would occur in the survival condition, and not in the operational or transit condition? It is of interest to note that, if one permits a different allowable stress for different drafts, one can interpret Figure 11 as indicating that the maximum stresses are experienced at the operational conditions, NOT in the survival conditions.

It is enlightening to see from Figure 17 that a majority of the fatigue damage is accounted for by relative low wave heights (3 to 6m) between the 6 to 10 second zero crossing periods, but could the author explain the meaning of the number in the squares of the scatter diagram?

Another anomaly pointed out by the author is the difference in the American Welding Society and U.K. Department of Energy welding standards and the effect it has on the interpretation of the amount of damage that could occur. Could the author comment on such differences, particularly in light of the Commission's charge to make recommendations as to guidelines and criteria?

In summary and conclusion, the author did a fine job in explaining what environmental loads should be considered in analyzing a semi, but did not explain how the environment factors could be translated to design criteria. He provided considerable insight into the sensitivity of environmental loads to wave height, period and direction, and last but not least, he pointed out the various inconsistencies among the various world standards and guidelines.

Summary of General Discussion Following Papers B1 and B2

Session Chairman R.A. Hemstock opened the discussion period with a written question from G.L. Hargreaves (Consultant, U.K.) regarding the application by engineers of the U.K. Dept. of Energy's published S/N (nominal stress) curves in taking into account the problem of "fatigue life" in the design process. Mr. C.A. Bainbridge (Lloyd's Register of Shipping) responded by saying that there are problems with the interpretation of the curves as they exist, particularly when applied to offshore structures where loads are from waves rather than from repeated "known loads". Mr. Ray Street (Hollobone, Hibbert) inquired whether current U.K. research on fatigue and fatigue curves is being effective, in view of the financial support provided. Mr. Bainbridge replied that new curves are being introduced, but only for tubular joints.

Dr. R.B. Wardlaw (NRC) referred to the importance of wind loads in structural design, since they affect mooring loads and the natural frequencies of rig motions. He also emphasized the importance of a correct interpretation of the 100-year return wind (or wave): that it means a one in one hundred probability of such a wind (or wave) occurring in any given year.

Dr. B.P.M. Sharples (Noble, Denton) agreed that consideration of wind loads is indeed important and that the variability of the wind creates loads which can produce a fatigue effect on a structure. There is ongoing research by the Society of Naval Architects and Marine Engineers (SNAME) in this direction, particularly as it affects semisubmersibles. He pointed out, however, that care should be taken to ensure that new wind load data do not offset current practices in other areas of structural design.

Dr. G.P. Vance (Mobil Oil Canada) asked Mr. Bainbridge whether a symmetrically-shaped semisubmersible with a box girder, as opposed to two pontoons, would be more structurally efficient. Mr. Bainbridge replied that it has been shown that such a non-square configuration displays better motion characteristics and less resistance during towing.

Mr. F. Dello Stritto (Mobil Oil Canada) asserted that the skeptical attitude towards environmental data (particularly wave heights) on the part of oceanographers, ocean engineers, structural engineers, and designers is healthy, as it results in an intrinsic review system throughout the design process. It also results in these specialists becoming more adept at discussing that data in a critical way, and being conservative in their estimates of wave loads, current loads, and icing loads. The people using the data are aware of the inadequacies of the data acquisition and analysis methods and are therefore cautious in use of them in the design process. Dr. Sharples agreed with Mr. Dello Stritto that wave height data do present problems, particularly when approval of a unit for a specific site is sought from regulatory authorities who must also interpret the data.

In relation to the inadequacies of weather forecasting methods, Mr. Dello Stritto noted that the present inability to forecast mesoscale storms can have disastrous effects on vessels and structures offshore. He pointed out that the use by Dr. Ford of the 60 to 140 knot range in estimate of the 100-year wind at Hibernia gives an inaccurate impression because available methods can provide a much smaller range of predictions. Mr. V. Swail (Atmospheric Environment Service, Environment Canada) said that the climate study of which he was an author cited the 60 to 140 knot range on the basis that available published literature provides values throughout that range. He agreed that the range would be less if current knowledge and methods were used, but would probably not be reduced by more than one-half.

Mr. Dello Stritto also criticized the lack of any Canadian regulation requiring operators who intend to use a jack-up platform to submit borehole data for the site selected. He emphasized that most companies do, in fact, obtain borehole samples of a selected site, despite the lack of such a regulation. Although stating that such a regulation was in order, he cautioned that such a requirement would also result in a decrease of incentive on the part of the operator. Mr. L. Brandon (COGLA) pointed out that a guideline, not a regulation, does exist which requires that the geotechnical engineer employed by the operator submit a report to COGLA on the seabed in question and that the engineer also be present during the jacking up operation. Mr. Brandon also pointed out that this form of regulatory procedure places the onus of responsibility on the industry, a process which was encouraged by Mr. G.R. Harrison in his introductory address.

Mr. W.H. Michel (Friede & Goldman) added that designers have additional problems of definition of wave height data: is wave height measured from crest to trough of the highest wave; or, is it the double amplitude of a crest? Mr. L. Draper (Institute of Oceanographic Sciences, U.K.) disagreed with Mr. Michel's second definition, saying that oceanographers deal only with crest-to-trough wave heights. Mr. Michel, however, insisted that designers are faced with this dilemma and he emphasized that it is the amplitude of waves that causes the force and motion characteristics which are necessary considerations in design.

Mr. Swail enlarged on the consideration of wind loads, and expressed concern that these loads were being downplayed. He referred to current research in the wind tunnel at the University of Western Ontario, where tests are showing that wind loads are, under certain conditions, potentially as high as wave loads. Mr. Sharples agreed that the effects of combined wind and wave loads on semisubmersibles are still unknown and certainly warrant investigation. Dr. Wardlaw pointed out that NRC is also aware of the effects of wind loads and is therefore active in pursuing the idea of simultaneous modelling of wind, waves, and current. The National Research Council would welcome comments or suggestions on this research topic.

Another area of concern identified by Mr. Swail was the effect of ice accumulation, particularly when combined with wind and/or wave loads. These combined loads could have significant impact on safety, both for the individuals on deck, as well as for the entire rig.

Mr. J. Benoit (Mobil Oil Canada) addressed Dr. Ford's concern with bergy bits and growlers, and the difficulty of using radar to track them. He said that industry, along with the International Ice Patrol, has found that these smaller pieces of ice, which tend to deteriorate as rapidly as within one day due to water temperature and wave action, are not randomly distributed but are nearly always clustered in the general area of a larger berg (from which they have calved). This means that bergy bits can be more readily tracked. Studies conducted under the Environmental Studies Revolving Fund are aimed at improving detection techniques for both the large bergs and the smaller pieces of ice. Dr. Ford pointed out that radar detection ranges for icebergs are based on theoretical calculations which need field verification provided through the current research.

Mr. W. Michel
Vice-President
Friede & Goldman Limited

Mr. Michel is a Naval Architect with extensive experience in design engineering and construction. He has been with Friede & Goldman Ltd. for 23 years with responsibilities for research and development of all types of marine vessels. He is also engaged in detailed structural and hydrodynamic studies for new types of vessels and the development of new features. His specialties include ship resistance and propulsion, sea behaviour, and advanced hydrodynamic and structural analysis. Mr. Michel is a member of SNAME and has served on a number of its committees; he is presently a member of the ABS Rules Committee on Mobile Offshore Units.

PAPER C1

Design Principles and Process for Safe Operations Offshore

INTRODUCTION

In order to address the subject of design principles for safe operations offshore, it is necessary to refer back to practices that have existed for the last two decades, some of which have been established as sound in judgement and execution and some of which remain suspect, though expeditious and presumably attractive. We must begin with the observation that the first rules and regulations for mobile offshore drilling units were established by the offshore industry itself – a set of principles and formulations proffered by the collective action of designers, owners, and operators of offshore drilling units to the American Bureau of Shipping, for administration and certification purposes. That agency's first set of rules for MODU's was established in 1968 and has formed the basis for all worldwide regulations that have since been promulgated.

In following years, there have been a number of rule modifications and clarifications resulting from further experience and deeper consideration of basic requirements. However, not all major considerations of structure and stability are sufficiently addressed, and research has been sporadic. Only since the several major catastrophes which have most recently occurred, has there been any concerted effort to re-examine the principles and processes for proper design of mobile offshore units.

This paper will present a number of design features and practices for semi-submersible and jack-up units that we have developed over several decades of experience in this field, toward the end of establishing a sound structure capable of sustaining the environment that confronts it. As such, it may be considered as a follow-up on paper No. 14 of the Design-Inspection-Redundancy Symposium, given at Williamsburg, Virginia in November, 1983, which stressed the need for further research on structures and stability, control of construction and inspection, and re-examination of certain vital design formulations.

For purposes of immediate referral to the intent of the present paper, we will restate the summary and conclusions from that previous paper (Reference 1). A broad view of major problem areas in considerations of design inspection, and redundancy has been presented, with emphasis on those aspects to which early attention should be directed. Proper treatment ranges from simple "cleaning house" exercises, which must first be attended to, to in-depth analysis and research for those matters not yet fully within grasp. The following should be considered:

1. Resolution should be made of such issues as the need for more unified and proper formulations for deep tank scantlings for semi-submersibles, and the need for more rigorous inspection during construction.
2. Hull girder requirements need to be reanalyzed in depth, particularly in regard to structural stability for the lightly-scantlinged upper hulls, and in the presence of multiple cut-outs.
3. Research is imperative on high cycle fatigue, particularly in regard to the development of proper S-N relationships for the particular types of fabrication details utilized in floating platforms.
4. Continued development of fracture mechanics methods should be maintained, toward prediction of low cycle fatigue. It is recommended that statistical studies be made of the size and character of flaws likely to be undetected during construction inspection, as discovered in later surveys.
5. Further testing and analysis is indicated for resolving wind effects on semi-submersibles, and with the ultimate necessity for conducting research on the combined wind and wave effects to establish proper criteria.
6. Development of a more precise methodology is necessary for wave loadings and their structural consequences, for jack-up units under severe environment in deeper waters. Model tests of jack-ups in elevated positions to establish parameters of damping, amplification, and ultimate spectral analysis approach are considered essential.
7. A comprehensive study using risk analysis techniques is needed to establish justification for redundancy requirements in regard to loss of major components, such as a complete jack-up leg, a semi-sub caisson or hull, etc.

SEMI-SUBMERSIBLES

General Structural Considerations

A typical twin hull, semi configuration is shown in Figure 1, which depicts the "Pacesetter" class developed by our firm, of which more than twenty units have been built since the first one completed for the Western Company in 1972. It shows three caissons on each hull, with a full set of horizontal and diagonal bracings, supporting a grid beam type of platform deck. Some designs of other firms have employed four caissons per side, and some (with a full topside hull structure) only two per side.

Our basic philosophy has been to triangulate the structure to minimize rotational moments at critical structural joints, such as develop with portal frames and Vierendeel trusses, particularly under lateral loads. In some cases, where we have employed full box hulls as the top side structure, the diagonal braces in the fore and aft direction have been eliminated, but only after detailed examination of probable stress levels under extreme environmental loads. In this latter regard, it may be noted that for the pipelayer *Castoro 6*, which has a complete upper hull, and lower hulls with five caissons per side (almost two Pacesetters, end to end), it was considered necessary to brace every longitudinal bay to minimize bending stresses that would otherwise develop under the classical longitudinal ship bending loading. In any event, in consideration of the high lateral load that can occur on a semi-submersible under severe environment, we believe that properly oriented diagonal bracing is essential to insure against inordinate bending stresses being developed in critical areas. We do not have the temerity to eliminate them entirely.

In determining the wave loadings to be used in the space frame structural analysis we rely to a large degree on model tests, not only to establish motions, but for direct read-out of forces and moments on the structural elements under maximum sea conditions at survival draft, as well as specified sea conditions for transit and drilling modes. For any significant change in dimensions, although the general configuration may be the same, we will conduct new tests to confirm any analytical projection that may have been made for preliminary evaluation. With this information as input, along with service and operational loadings, about twenty different combined load conditions are analyzed, covering the gamut of all anticipated situations, to establish the validity of the overall structure.

Lower Hulls and Caissons

Typically, the shell and bulkhead plating and framing of the lower hulls and caissons of a semi-submersible are sized on the basis of deep tank formations. In general, the resulting scantlings are sufficient to enable these members to act effectively as space frame elements, at nominal stress levels within allowables (except in the highly loaded areas of hull/caisson bracing intersections, where reinforcement is usually required).

In our practice, we establish these scantlings on the basis of the full head to the top of the overflow (plus friction head), rather than the normally accepted two-thirds height as applied in surface ships, in consideration of the fact that semi deep tanks are pressure-filled at a high flow rate and resulting overflow in service is not uncommon. Further, we view the margin normally applied to the scantlings to be more an experience factor than a corrosion allowance, and we do not reduce scantlings even though all surfaces are corrosion protected. Even more, the thickness of the external shell plating is further increased to minimize the possibility of rupture under damage, which would be difficult to repair for such areas that are inaccessible.

In further consideration of the importance of maintaining the integrity of all compartments in the hulls and caissons, from both a structural and stability standpoint, our specifications require that all tanks be tested to the full overflow height, to insure sound construction as well as adequate design.

Horizontal Bracings

These are the most critical structural members of the semi-submersibles, providing the means of holding the lower hulls and caissons together. Essentially, they are tension members under the direct loading of top side weight and service loads, accentuated by mooring and wave spreading forces on the caissons and lower hulls. While these latter loadings are cyclic and influence fatigue life, the ultimate failure mode is nevertheless that of tension, and special attention must be given to the structural arrangement of these members, both in design and construction, to minimize the possibility of catastrophic parting of the bracing. To this end, the structural design of the horizontal bracings, as employed by this firm, may be delineated as follows:

1. The bracings are completely watertight, with access openings from within the caissons to allow for dry inspection of the inner structure, without the need for raising the unit.
2. Monitoring devices are installed to allow remote checking of the internal volume of the bracing, to detect possible water leakage from structural cracks.
3. A number of heavy T-beam longitudinal stringers are installed internally around the periphery of the cylindrical shell of the bracing, extending continuously between end attachments, Figure 2. These, in association with the ring frames needed to prevent shell collapse under water pressure forces, form a highly resistful structural grid to minimize local damage due to wave impact and/or collision (particularly during the transit mode). Of further and critical importance is the redundancy provided by these stringers, toward restraining the propogation of shell cracks that may develop under a fatigue or damage situation. In this latter regard, we further specify that the butt weld attachments of the stringers be offset sufficiently from the butt welds of the tubular shell.
4. Finally, in way of critical joints, the bracing shell plate is increased in thickness and the longitudinal stiffeners are faired into heavy internal diaphragm plates that continue directly through the joint as part of the adjacent caisson/hull structure, Figure 3. These joint scantlings are so determined that the nominal stress level is approximately one-half that allowable under the maximum conditions of loading. Detailed finite element analysis of the resulting joint structure indicates that the maximum local stress intensity would not exceed the full allowable and, thereby, for considerations of fatigue, the only stress concentration factors that need to be considered would be those of welding and fabrication which are reasonably well assessed from established codes.

Vertical Diagonal Bracings

Similar consideration and treatment are given to the bracings that support the upper structure, with the one exception that longitudinal stiffeners along the bracings are omitted. In this case, the bracings are essentially compression members and the need for redundant internal elements is not mandated. Further, the intensity of wave impact loadings is significantly less, and while the possibility of local damage due to support vessels while in operating condition is fairly likely (and occurs frequently enough), the risk of calamity is minimal insofar as those peripheral braces are not in a high stress condition under these operations, and any damage of consequence is readily observed and repaired.

In any event, it may be noted that the Pacesetter bracing system has the built-in redundancy that is now becoming a requirement of several regulatory bodies, wherein the loss of any one bracing will not cause collapse of the overall structure. What is not addressed by most regulatory and classification bodies is the detailed design requirements for the individual bracings themselves, such as outlined above, in regard to inspectability, redundancy within tension members, etc. Attention should be given to these considerations to minimize the possibility that a bracing loss will occur.

Upper Platform Structure

From a purely structural standpoint, our favorite type of upper structure has been the open grid beam configuration, on which platform decks, deck houses, sub-structures, pipe racks, etc., are constructed as

FIGURE 1

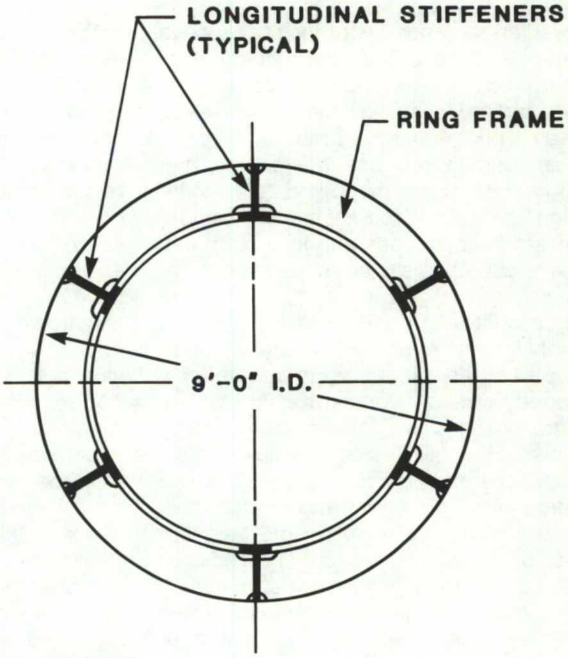

FIGURE 2

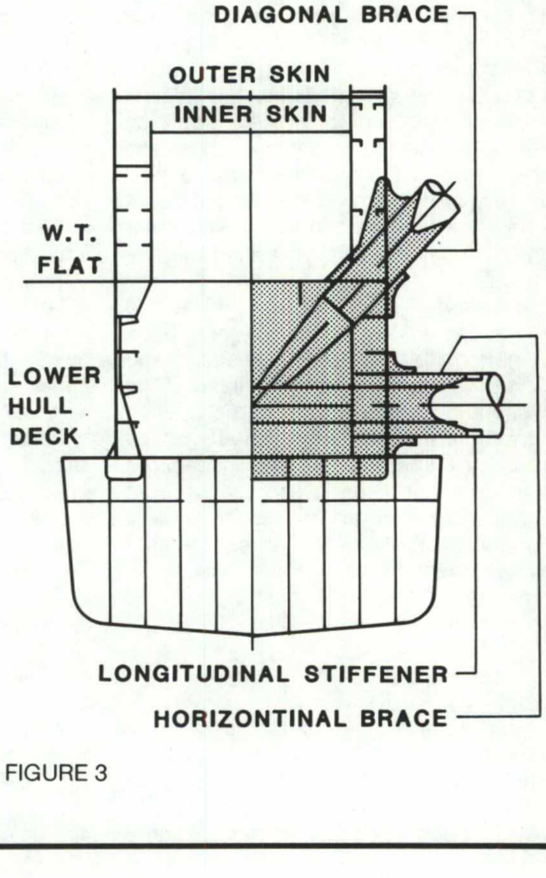

FIGURE 3

the need and arrangement require. We have confidence in the design methodology dictated from civil codes and practices of long years standing, for such similar structures as highway bridge and building girders, wherein loading patterns are similar and structural details are mandated to account for high shear and moment transfers under significant bearing loads and joint supports. We have used this system on a majority of our units.

The present vogue is to utilize a full box upper hull, with most of the power equipment, drilling and ship service installations, and quarters neatly compartmented within. Its attractiveness lies in a more uniformly available upper deck space for drilling storage and operations, and a generally more sheltered area for systems and for habitability against wind and cold (in the Northern climes, of course; not so advantageous in the Gulf of Mexico or similar hot environs).

Its main purpose, nevertheless, is to more easily meet the flotation requirements for the latest damage stability regulations of several European authorities.

Structurally, however, the full box upper hull is suspect as to its adequacy to meet the service and environmental loads to which it is subject. It is stiff beyond a doubt, which tempts many designers to eliminate bracings, but which can cause high local stressing (and straining) at important connection areas. There is no basic experience factor for very thin skinned boxes subject to high local bearing and support loadings, of the proportions indicated for the typical semi-submersible. Finite element analyses are the only expedient and these can lead to complacent conclusions, wherein one may not have modeled a major deck hatch opening or a large access opening in a vital bulkhead, or whatever similar omission that may be critical.

Nevertheless, the box upper hull is here to stay. For our units so built, we establish a grid pattern of major bulkheads and associated deck and bottom "flanges" of high strength plating to simulate the open grid structure that we favor. We attempt to establish (by specification and inspection) that these areas remain sacrosanct from unauthorized penetrations or those without reinforcement. We view this procedure as a measure of redundancy against any possible fracture or failure of the "stressed-skin" of the box hull.

Stability Considerations

Since the development of the first set of requirements for mobile unit stability, issued by the American Bureau of Shipping in 1968, our organization has been trying to interest any and all concerned with offshore activities in developing requirements that more rationally and accurately take into account the effects of all of the environment – wind, sea and current – rather than continue with belaboring a wind only criterion that uses arbitrary and uncorroborated factors. Aside from the one research effort conducted in the early 70's (Reference 2), and which produced definite results sufficient to encourage futher investigation, there has been little support shown for additional research throughout the industry. It would appear to us that from the standpoint of safety at sea, governmental regulatory bodies and classification agencies, if no one else, need to have established a proper set of criteria. We will keep trying.

On the matter of new regulations and proposals concerning damage stability, we endorse the requirement that under one (realistically two) compartment damage, the unit shall not heel beyond 15 degrees and all major survival systems shall remain operative and effective, including ballast. This is a proper restriction and parallels that of long standing and experience for passenger ships, wherein 15 degrees is considered a limiting angle for emergency operations and personnel safety.

However, we fail to see the validity or to understand the rationale for the proposal that under a calamitous loss of buoyancy (typically the loss of a caisson) the unit shall survive a heel of 35 degrees (magic number) and that measures are provided aboard to restore it to some more amenable position. From units that have already met such requirements, or presumably so, we have seen that some of the necessary provisions occasion greater casualty risk under more probable circumstances; for example, the restriction of normal escape routes (the only acceptable one being toward the well center – the well center?).

We have had to address these later requirements in several instances where rig owners have specified their need to operate under such regulations. We have done so with misgivings, but to the best of our ability to accomplish the purpose without undue sacrifice of the features that make the unit effective, efficient and safe under more probable circumstances. We continue to maintain our objection.

JACK-UPS (SELF-ELEVATING UNITS)

General Considerations

The operating modes under which different types of structural analysis must be performed for jack-up units may be presented in chronological order:

1. The unit is in transit from some previous station to the desired site, typically afloat on its own hull with its legs fully raised.
2. On location, it lowers its legs until positive touchdown to the sea floor and then jacks up the hull to a point where pre-loading can be accomplished to prove out the bearing capability of the soil, and then finally it jacks up to a designated height above sea level where the hull is secured for drilling operations.
3. In its final elevated position for drilling operations, the unit must sustain its structural integrity under the various combinations of operating load and environment (sea, current, and wind) as specified for the particular location.

It is of definite interest to note that the severest casualties, experienced over the 25 years or so of jack-up operation, occurred in the same descending order. Most casualties that have resulted in loss of life, as well as the unit itself, have occurred while in transit; to a less severe degree (although more numerous regarding leg damage) when lowering and raising the unit; and virtually nothing when in the jacked-up position under the prescribed environment. Despite this, design emphasis has been in the opposite order for the very significant reason that the unit is to be built for the purpose intended, drilling while in the elevated position, and all other situations are necessarily given secondary consideration.

The basic principles on which the structural design should be based are covered in excellent fashion in the classification note on self-elevating units issued by Det norske Veritas (Reference 3). It is intended here to present some of the detail structural considerations to satisfy such principles under maximum design conditions for the various modes of operation that the jack-up is subjected to. Such information is based on the particular type of unit that we have developed; the three-legged jack-up, wherein each leg is truss type with three chords and independent footings, and where elevating means is by rack and pinion. Figure 4 shows the typical configuration of our design designated as the L-780 series, of which more than twenty-five units have been built since 1980.

Unit in Elevated Position

With the unit in fully elevated position, the main structural consideration is that to withstand the horizontal forces of wind, wave, and current while supporting the topside weight of hull, equipment, and supplies. The overall configuration may be visualized as a portal frame supported at the ocean floor, and requiring some rigidification at the leg/hull connections to maintain structural stability, Figure 5.

Regarding the development of the horizontal forces for a specified set of environmental factors, it may first be noted that computational methods for determining wind forces have been reasonably confirmed by wind tunnel tests on components of hull and legs, as well as the entire assembly, to where there is little room for controversy or misguidance. However, such is not the case for wave and current forces, whose combined effects become the over-riding force consideration for more severe sea conditions and in deeper water.

The generally required theory for wave, plus current forces, has been that of shallow water, finite height, regular two-dimensional waves of Stokes' 5th or Stream Function type, to establish wave particle velocities to which the current velocity (anybody's guess) is added, and the forces on the legs determined as a function of the combined velocity and "suitably established" drag coefficients for the leg components. Insofar as the early jack-up developments were in fairly shallow water with significant wave steepness and storm tide surges, this was the only reasonable approach. The practice has been carried forward to where it is still applied for water depths of 300 feet and more, but where its use is highly questionable as an accurate representation.

Whether because of its conservatism, or whether all of the design environmental factors were never collectively experienced, the fact that there has been minimal evidence of casualty in this attitude has lead to some relaxation of requirements by several agencies. For example, when using this theory, one agency will allow a lower leg drag coefficient and another will allow calculated leg stresses to approach the yield strength of the material. We satisfy ourselves with the view that our drag coefficients and our calculated stresses are of the right order and take the conservatism as a margin against untoward events or undetected construction errors.

However, when considering water depths over 300 feet, the need for a more realistic appraisal of wave plus current effects becomes necessary. With longer leg lengths, the natural oscillation period of the unit approaches the range of harmony with the periods of the sea waves, and the sea itself is more characteristic of irregular deep water behavior. Such considerations need to be evaluated on their own merits and not on past acceptance practices.

This is somewhat virgin territory and the need for research and well-modeled tank testing of units jacked up in water depths exceeding 300 feet, and in the presence of realistic seas, is essential toward a proper determination of the loadings imposed on the unit.

Returning to the structure itself, it is seen that the most critical and highly loaded area is that of the leg/hull connection, wherein moments of high magnitude must be absorbed over a relatively short distance. Thus, for most types of units, with the vertical load being supported by the jacking pinions, the joint moments are taken in high horizontal reactions at leg guides in the vicinity of the bottom and the main deck of the hull. These reactions produce high axial loads in the leg bracing within the support area, along with possible leg chord distortions and leg joint rotations, Figure 6.

For the independent leg type of jack-up, in different depths of water and/or different leg penetrations in different soils, practically all bracings may be subject to these high joint loadings, at one time or another, and thereby must all be sized to suit such maximum loading.

To minimize this excess use of steel, with its resulting greater leg weight, our firm developed the "Rack Chock" system of leg/hull attachment, wherein almost the entire moment reaction loading is taken vertically through the leg chords, supported at the hull bulkheads of the leg wells, with a minimum horizontal reaction, except for the shear loading of the wind force alone. Further, there is no "joint rotation" due to gear and pinion clearances when supported by the jacking system, and thus the sidesway under environmental load is minimized, as is the resulting secondary bending of the legs.

A further feature of our leg design may be noted. As shown in Figure 6, we utilize the overlapped bracing joint, both at the "K" and at the chord intersection. This is more costly construction and requires greater care in fitting up and welding, when compared to the typical open joint with or without bracket attachments, but its high strength and minimum stress concentrations make it highly desirable.

A more detailed description of our considerations of leg design and hull support has been given in the paper presented before the Memorial University of Newfoundland's seminar on Safety Management for Offshore Operations on the Canadian East Coast, in Calgary, during June, 1983 (Reference 4).

Considerations of structural requirements for the hull involve the same concern as indicated above for the upper box hull of a semi-submersible. Being the top girder of a portal frame, with high end loadings and moments, the hull scantlings cannot simply be determined in the classical ship bending manner, but full account of all specific loadings must be made, utilizing a detailed finite element approach. Particular attention must be given to the highly loaded leg support areas, in full consideration of stress concentrations and fatigue assessment (in transit mode, as well as in elevated mode).

In addition, the strength of the hull girder in transmitting loadings between legs must be viewed carefully to insure that its continuity is not sacrificed to the need (or convenience) for hatches, vents, and archways that seem to proliferate during construction and also while in service. Thus, we may see from the simplified plan, Figure 7, that the main load path tends to be along the longitudinal bulkheads that support the cantilever drilling load, but which area is prone to those numerous deck and bulkhead cutouts. We therefore run finite element analyses for two different structural situations; first, full intact structure, including major designated openings to determine the probable (or at least initial) load path and stress; and second, with the main longitudinal bulkheads made discontinuous (eliminating one bay each) so that the main load path is around the periphery of the unit, which areas are wing tanks not subject to large openings and thus considered intact.

Touchdown and Preload Conditions

Most of the accidental damage to a jack-up unit occurs during the operation of getting on location (and also getting off), from the point of leg touchdown to the jacked-up position to conduct pre-loading (and also when attempting to raise embedded legs, while the hull is afloat).

Touchdown is a fairly uncontrollable situation in any sizable sea. The motions of the unit afloat on the hull can cause leg and leg support damage due to a scraping-upon-ground contact (roll and pitch) and/or high impact (heave, with roll or pitch). Measures to alleviate such problems have been proposed, such as the "Slo-Rol" installations, for minimizing roll and pitch, and the resilient shock absorbers that we have developed to reduce heave impact. However, there has been little enthusiasm shown amongst the operators for incorporating such features, for whatever economic or operational reasons, and the tendency remains to look for the weather window under which such operations can safely be made with units as now configured. Typically, it remains a factor of experience and luck, as to whether damage will or will not occur. General instructions for conducting such operations includes the recommendation that seas should not be over about six feet high (no guarantees).

Pre-loading is conducted with the hull a minimum distance above wave disturbance, and with all ballast tanks filled, to pressure the soil to a load-carrying capacity equivalent to the maximum that can be anticipated

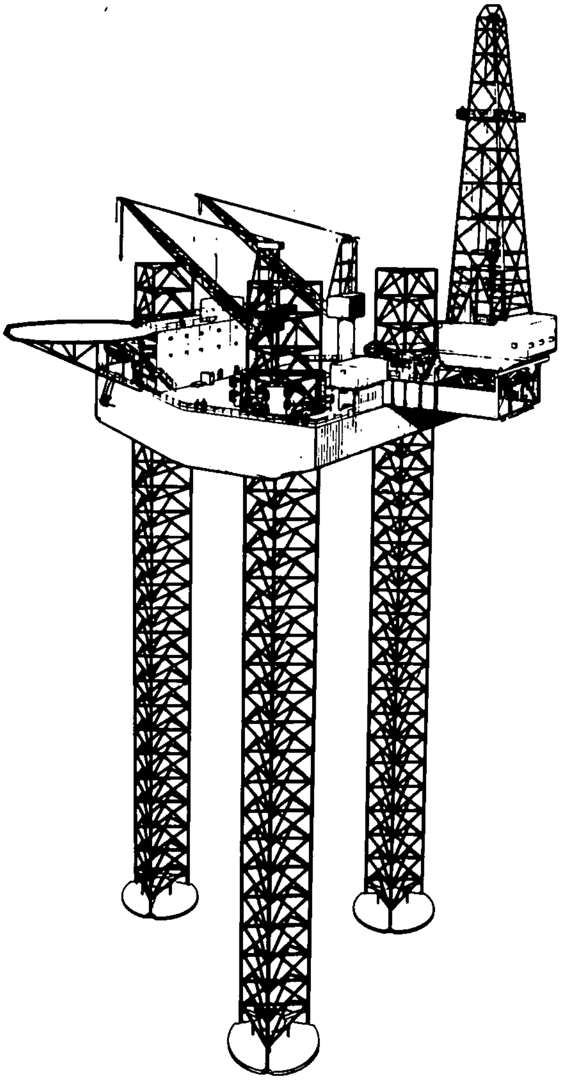

FIGURE 4

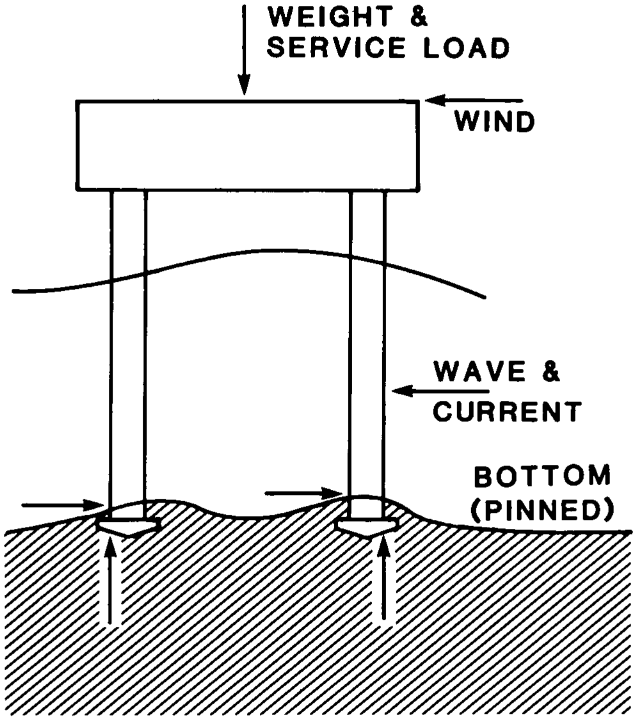

FIGURE 5

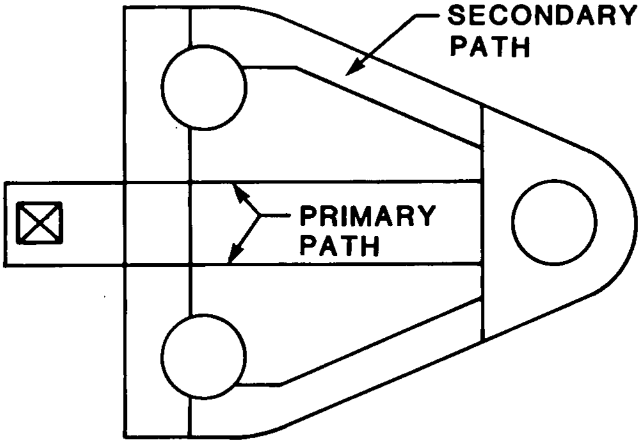

FIGURE 7

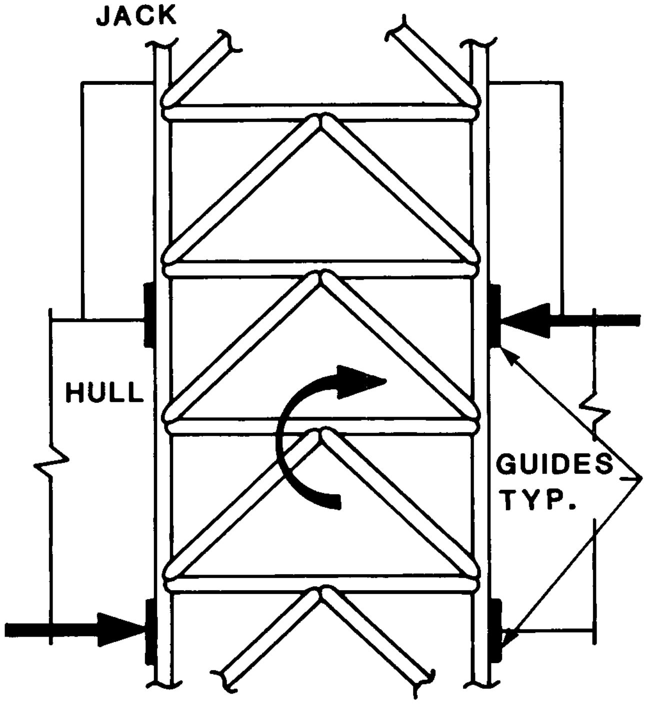

FIGURE 6

under the prescribed environmental loadings. Frequently, it is found that the soil is insufficient, and bearing is lost to where the unit lists and leg damage occurs. A method to evaluate the potential for leg damage under different assumptions of punch-through penetration, water depth, etc., has been developed (Reference 5).

Getting off location presents another hazard, whereby the hull is lowered to the afloat position and leg retraction is attempted. Under conditions where the legs are deeply imbedded, such operations may consume time, and if the wave and current forces cause considerable sway of the hull, leg damage can result.

All of these damage situations remain prevalent, to where experienced judgment may be overridden by the element of chance. Fortunately, the damage that may occur is to structural elements (principally in the legs) that are reasonably capable of being repaired, and injury or loss of life under these circumstances is a not probable consequence.

It may be noted that, for the several incidents of leg damage, the overlapped joint employed for leg bracings in our design has not failed or even cracked, despite brace buckling or fracture, which helps to affirm our belief in its superiority.

Transit

The most significant casualties, wherein both loss of life and loss of unit resulted, have occurred when in the transit condition, afloat on the hulls with legs in the elevated (or partly elevated) condition. Some of the earliest experiences may have been due to an absence of basic stability, a cracking of hull structure at the leg support area (and where flooding of adjacent spaces was uncontrolled) or unsatisfactory securing of legs leading to leg failure. Many of those situations have since been addressed by regulation and voyage survey requirements, but the situation remains precarious in regard to high leg bending and leg support loadings when in seas that may cause untoward roll/pitch motions.

Model tests conducted on our L-780 units afloat, with legs fully raised and in a range of severe irregular seas, indicate that the maximum forces and moments recorded at the leg/hull attachment closely approximate the ABS criteria of 15 degrees, 10-second roll/pitch acceleration (correspondingly less than the 20 degrees, 10-second criteria of Noble, Denton). Further analysis is required to establish whether limitations on leg length and/or voyage routes would be necessary due to considerations of low cycle, high stress fatigue, which can cause leg failure or hull cracking. Several of the principal regulatory agencies are starting to address this situation, but no definitive methodology has yet been established.

It may be noted that most long voyages today are made by "dry tow", wherein the jack-up unit is carried aboard a special ship or ship-shaped barge, to minimize time at sea. Similar roll/pitch considerations exist, depending on the ship characteristics, as well as provision of adequate dunnage and chocks to minimize hull damage under extreme sea conditions. It is beyond the rig designer's control to regulate these operations, and beyond the scope of this paper to go into details concerning this mode. In any event, sooner or later, the unit must float alone and be subject to the exigencies described above (and as follows).

Seakeeping and Stability, Afloat

While the criteria for leg strength are fairly well defined for transit conditions, afloat on the hull in severe environment, there is apparently little recognition or provision amongst the numerous regulatory agencies that the jack-up unit afloat is a poor seakeeping vessel and prone to damage conditions that may cause casualty to a greater prevalence than leg failure.

With its high vertical extent of weighty legs (whether raised or lowered) the unit has a large mass moment of inertia to where it responds sluggishly to the oncoming waves, resulting in green seas of sizable magnitude mounting over the deck. This has been experienced frequently with units in service, and is dramatically evident in model tests under severe environment. It is questionable whether the standard requirements for plating and stiffeners of barge deck house fronts are adequate and properly disposed to withstand the high impact pressures that are likely to develop.

In addition, more careful attention must be given to the strength, height, and locations of vents and overflows from spaces below deck, not only to withstand the forces imposed but to insure against down-flooding. In this regard, the normally considered stability requirements (whether intact or damaged) which presume a wind overturning factor inclining the unit in still water does not cover the situation of green seas running across the deck.

OFFSHORE DESIGN AS INFLUENCED BY RISK/SAFETY CONSIDERATIONS

It should come as no surprise that we do not use formal risk analysis in the development of our offshore designs nor to establish justification for their acceptance. We do not attempt to assign probability factors for environment, operations, or accidents or to develop confidence levels for material and welding strength and behavior, or, finally, to reflect some industrial index for acceptable loss of life and/or property. This is not our province, our responsibility, or our right.

It is the regulatory bodies that must establish these criteria, codes, and judgements on which we must produce our designs and verify their validity. Whether it be governmental agencies, classification bureaus or insurance underwriters, and however they establish their requirements, it is then the necessary obligation of the designer to satisfy them in a deterministic manner.

We do, of course, address and always have addressed the question of risk and safety in our designs. However, ours has been a qualitative assessment based on our marine experience accumulated over the years and our knowledge of offshore drilling operations. Our resultant practices in this regard, along with those of other responsible designers and rig owners and operators, are represented to a large extent in the rules and regulations that exist today throughout the world, and we continue to provide vital input toward future considerations, as members of committees and advisory boards, to the various regulatory bodies.

It may be noted in this regard that not all of the design practices we endorse have been accepted as necessary requirements by the regulatory bodies, nor conversely that those requirements we feel need revision are being acted upon, as may be construed from our presentation in the earlier portions of this paper.

Our approach to the matter of risk and safety is rather simplistic. We ask ourselves the question: "What could happen if. . .?" where "if" is the important word. If an unintended event were plausible, and if it could result in a precarious situation, we then look to answer the further question: "What can be done to prevent a major casualty?" A few examples may illustrate:

1. "If a supply vessel or other object were to strike and damage a caisson of a semi-submersible" this is plausible and happens frequently enough, and could cause unrestrained flooding and loss of stability. What is done is to require compartmentation to limit the flooding and maintain stability under some acceptable heel angle, from which measures can readily be adopted to restore the unit to its original state. It may be noted that this was one of the early safety considerations incorporated into the 1968 ABS Rules, and represented the first damage stability requirement for any vessel other than passenger ships.
2. "If a caisson of a semi-submersible completely lost all of its buoyancy" we stop with

the "if"; there is no plausibility in considering that any vessel (or iceberg?) could neatly sever a caisson, leaving everything else buoyant and intact, nor is there any other eventuality that we can conjure in this regard. There have been losses of caissons in several disasters, but these have been due to structural failures of supporting members, which has been addressed under other "if's".

3. "If a supply vessel or other object were to strike and damage the leg of a jack-up" this is plausible and has occurred, but not so frequently since boat operators have learned to avoid such confrontation at all costs (to themselves). In any event, it is plausible enough to require consideration for strength in the individual chord and bracing elements to sustain leg integrity under an incident of this type.

4. "If a large vessel (or iceberg?) were to strike and collapse a leg of a jack-up unit" this is plausible, if extremely unlikely (and has never occurred), but which would collapse the entire unit. There is no solution for any of the three (or four) independent leg units existing today.

Simplistic as this approach may be, there is little more that we can apply at present. Only when we have enough statistics on enough casualties of the same type on similar units in similar situations, can we begin to establish a reliable risk analysis methodology. With the help of divine Providence, may we increase our knowledge and wisdom, to produce offshore units of greater safety and reliability, to where such accumulation of casualty statistics may never be attained.

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COMMENTARY ON PAPER C1

T. Haavie
Managing Director
Submarine Engineering

Mr. Michel has presented a very interesting paper. In his treatment of a number of important design issues, I recognize the same situations of decision making as I have found myself in over the years. In most cases I agree with the reasoning. My contribution would be of little value, however, if I were to go through Mr. Michel's paper and, point by point, agree with him. Therefore, I shall try to express some different views on some issues, and make some additional points within the minutes I have at my disposal.

GENERAL STRUCTURAL CONSIDERATIONS (SEMISUBMERSIBLES)

I would like to present some alternative reasoning with regard to the global configuration of semisubmersibles; since the early days of semisubmersible design, units with two pontoons and four, six, or eight columns have been presented and built. It appears to me that one could argue as follows:

1. The larger the requirement for deck carrying capacity, the larger the units become.
2. The larger the units become, the more support points for the decks and superstructures will be required to keep the weight of the deck structure as low as possible.
3. Support points can be provided by columns and/or by trusses in vertical planes.
4. Trusses in the vertical planes are collision-prone items, and they do not provide any significant contribution to vessel stability. On the other hand, they are low in weight and effective frame stiffening members.
5. Connection between trusses, and between trusses and columns are well known "trouble areas" on semisubmersibles.
6. Trusses in the horizontal planes are basically tying the column footings or pontoons together to form closed frames. Their presence reduces bending moments in the deck structure. Such transverse trusses have low positions of centre of gravity, and their presence generally allows for a lighter deck structure than if they were not incorporated. In my opinion they represent well-spent material. They are, of course, of some magnitude and liable to dynamic loadings and possibly local slamming during transit in waves. Diagonal trusses in horizontal planes are generally incorporated to resist longitudinal misalignment between the pontoons. They are often termed "shear trusses", and as such take shear which would otherwise have been taken up in the deck structure. If the semisubmersible is relatively large, and particularly if the deck structure is "skinny", I consider such trusses as material well-spent.
7. A full deck box design, if sensibly composed, represents a strong bridge structure between the column tops. It is possible, and essential, that the column tops are given a good connection to the bulkhead and girder system in the deck box. A full watertight deck box design will have the following advantages:

- It provides valuable buoyancy in the case of damage.
- Its presence, with its inherent shear and bending strength, has justified the absence of vertical diagonals in longitudinal planes.

In the case of small semisubmersibles, this means the removal of the horizontal diagonal shear trusses near pontoon level, and in some cases of large semisubmersibles, the removal of the vertical plane diagonal trusses in the transverse plane. In other words, the designer may have an opportunity to compose a weight efficient semisubmersible with a minimum of collision-prone items passing through the air/water interface.

The watertight deck box, in our opinion, represents a valuable life assurance against capsize and sinkage.

STABILITY CONSIDERATIONS (SEMISUBMERSIBLES)

Again, one may return to the basic choice of vessel geometry. Watertight deck box or not, the damage stability property of the semisubmersible is very dependent upon the number of columns chosen. Let us take the example of the loss of buoyancy of one column at the maximum operational draught of three different semisubmersibles, and see how each unit reacts. Before we start, it may be useful to have in mind that if one considers one column to be flooded on three different semisubmersibles of the same weight, weight distribution, displacement and column heights; one with eight columns, one with six columns and one with four columns, then the resulting equilibrium angle would be largest on the four column unit and smallest on the eight column unit. By adjusting column heights, (assuming all the vessels to have a watertight deck box configuration), the result can, however, be influenced considerably:

1. P099 Drilling Unit, 8 Columns. One column flooded when at operation draught. Angle of heel/trim: approximately 20 degrees.
2. MSV Stadive, 6 Columns. One column flooded when at operation draught. Angle of heel/trim: approximately 18 degrees.
3. P007 Design, 4 Columns. One column flooded when at operation draught. Angle of heel/trim: approximately 16 degrees.

As can be seen, the watertight deck box and the harmonization of column heights give reasonably small angles of heel/trim even in the case of extreme damage to any column of a four column unit. Even lifeboats can be launched, provided the wave conditions are not too extreme. However, if the vessels become large, then four column units will readily experience combined angles of heel and trim, subsequent to such damage, in the order of 27 to 35 degrees.

METACENTRIC HEIGHTS (SEMISUBMERSIBLES)

In our opinion the minimum GM values presently proposed by regulatory bodies are far too lenient. Here are some reasons why we believe that the calculated GM values of a semisubmersible, in any condition, should be greater than 1.5 metres: it is well known that "ghost loads" of 200 to 400 tonnes are sometimes noted onboard semisubmersibles. Speculation as to the source of this unaccountable weight difference between displacement, arrived at by calculation of lightship, deckload, ballast water, fuel oil, consumables, etc., and displacement deduced from hydrostatics based on draught mark readings, has centred on weight growth and unidentified items onboard. Such loads are undoubtedly part of the "ghost load", but other factors could be equally important.

1. The compression of the lower hulls with increase in draught (resulting in less buoyancy, and therefore a deceptive impression of the ballast water needed to achieve a given draught; that is to a false impression of a lower KG value than the actual, and also to a higher GM value), calculations of the lower hull compression effect showed that plate field deflections (midfield) in the pontoons were in the order of 1mm on the *Ocean Ranger*, and panel deflections in the pontoons, between webs of the order 0.2mm (both values referred to hydrostatic pressure at about 20 metres water depth). It was estimated that this effect together with the welding effect (hungry horse effect) could account for a shrinkage in the order of 40 to 50 tonnes at the deepest draught. For a vessel of the size of the *Ocean Ranger* this shrinkage would have only a marginal influence on the GM value. However, for smaller semisubmersibles with thinner plates, but approximately the same frame spacings and the same draughts, the effect could be more radical, and could possibly become significant. This is therefore an item which should be borne in mind as requiring a margin when stipulating minimum calculated GM values for semisubmersibles.
2. The inaccuracy of tank soundings even in calm water conditions when the tanks are either thought to be empty or full. It is felt that the inaccuracy of tank sounding also may have a significant influence on the accuracy of the results from inclining experiments. Bearing in mind that a five percent overestimation or underestimation of the content of each full tank in the *Ocean Ranger* could represent a weight difference of the order 600 tonnes, this may be appreciated. In order to control such errors in a better way and hopefully be able to reduce them, it is proposed to carry out inclining experiments on at least two different draughts (with radically different tank contents), and also an additional displacement/draught test on a pontoon draught. The above effects could, even before delivery of the vessel, lead to an erratic basis for future assessments of KG or GM values.

During operations further errors will inevitably occur which would justify reasonable GM margins:

1. The uncertainty of any deckload weight assessment onboard a semisubmersible unit in operation;
2. The inaccuracy of tank soundings, particularly in a seaway with the vessel normally in a slightly heeled or trimmed condition;
3. The fact that many ballast control room operators do not like to "press up" tanks, and a full tank to the operator is usually a tank which is gauged "full", considerable volumes are often left as air pockets. The significance of this can best be illustrated by the underestimates of the tank content in a tank 10 metres x 14 metres. If 0.3 metres between liquid level and tank top is not filled, this is equivalent to approximately 45 tonnes underestimation if the tank is assumed full. This could be approximately four percent of a tank volume. The fact that a tank sounding of a "full tank" is usually different after some minutes (settling effect) also adds to the uncertainty.

Therefore, if the calculated GM value of a semisubmersible is, say, 1.5 metres, then it may well be that a unit actually only has a GM value of 0.5 to 1.0 metres. The dangers of such low GM values are now well known, and apart from the vessel's failure to actually meet the present rules, the following effects could endanger the vessel:

1. The wave induced tilt phenomena which are most pronounced at low GM values, and can cause substantial angles of heel;
2. The possibility of experiencing a reduced static GM value due to dynamic effects;
3. The variation in wind heeling moment effects causing frequent use of the ballast system for changes in the wind speed and direction.

CLOSING REMARKS

It could be said that the NMD damage stability requirement pertaining to the loss of buoyancy of one complete column is as unreasonable as asking an aircraft designer to design a fixed wing aircraft which shall be able to fly even when it loses one of its wings. It is, however, our opinion that the basic idea of a requirement for reserve buoyancy is a sensible one, but care should be taken not to attempt to link such a criterion to any form of realistic "high energy impact" damage. If this is done, energy considerations may lead to far too complex, selective and unrealistic calculations.

The criterion of reserve buoyancy should remain a "reserve buoyancy" criterion and be incorporated in any design as an extra safety against unlikely damages resulting from acts of God, collision with rocks, reefs, other large floating or fixed units. Such damages are usually considered as so unlikely that they will not occur. It is possibly appropriate to compare this with the improbability of collision between two aircraft, and also in this connection, to remember the fatal collision between two aircrafts on the ground in Tenerife some years ago.

The specified "volume of one column from lower deck level to top of pontoon level" also seems to give a sensible measure for reserve buoyancy. The advantage of stipulating the reserve buoyancy in terms of volume of one column instead of, for example, as a percentage of the total displacement volume are:

1. It prevents designers from designing semisubmersibles with four columns (or less) unless they take comprehensive measures to reduce the consequence of losing *one* of the few "stability" – and "structural" – main "supports". Vessels with six or more columns have a distinct advantage with respect to compliance with the rule. This seems to be a justified advantage, since the consequence of serious damage to the most damage prone items of a semisubmersible (the columns and vertical braces) is reduced with an increase in number of elements.
2. The location of corner columns is the most unfavourable part to lose buoyancy on a semisubmersible unit. The "one-column-flooded" criterion does therefore also provide a suitable moment imbalance for the buoyancy to counteract.
3. The definition of the reserve buoyancy as equivalent to the volume of one column from the lower deck level to the top-of-pontoon level provides a simple, clear, and undisputable criterion which cannot be misinterpreted. It has also been shown that most semisubmersible configurations, by sensible design, can be made compliant with such a criterion.

However, I also question, as Mr. Michel does, the "magic number" of 35 degrees.

COMMENTARY ON PAPER C1

W. Martinovich
Executive Vice-President
Earl & Wright

Mr. Michel's paper provides an excellent overview of design principles and processes for safe operations offshore as practised by the firm of Friede and Goldman. In general, I agree with most of this paper. The main feature, in my view, is the consistency in approach developed over the years and the application of this approach in a professional manner to the design of MODUs.

There are a number of points on which I do not agree with the author, but for the most part, they represent professional differences of opinion which in the end, whether practised consistently by his firm or mine, would result in a safe design.

I would like to make some remarks on a number of points which were either not fully discussed because the scope of the paper was rather large or about which I am particularly concerned and to which I wish to expose this conference.

SEMISUBMERSIBLES

Intact Stability

The present method of calculating intact stability is ridiculous. Considering that we are in a highly technological era of the late 20th century, what is in current regulations is a joke. We continue to try and accurately calculate wind overturning moments under the unrealistic condition of a flat ocean and an unmoored unit, when we know that motions are caused by waves, not wind, and that an intact semisubmersible of the type in use today cannot be capsized.

Other serious flaws in current rules are the definition of downflooding and the use of deck buoyancy to meet stability requirements. Most buoyant upper hulls are watertight in theory but not in practice, prime examples being the *Ocean Ranger* and the *Alexander Kielland*. When used to satisfy stability requirements, upper hulls generally are not designed to resist local forces due to waves, and that includes slamming.

In summary on this point, I believe a rational intact stability rule, as suggested in a statement (which follows this commentary) adopted by SNAME Panel MS-3 on May 7, 1984, along with explicit requirements for water and weathertightness and realistic structural requirements for buoyant upper hulls, is required.

Damage Stability

Damage stability is a real problem with respect to defining a credible event causing loss of buoyancy. Since the issue is primarily subjective, there can be as many different criteria as there are regulatory organizations. I look forward to the day when there is a reasonable, worldwide consensus of agreement on damage stability requirements. The limiting angle of 15 degrees mentioned in Mr. Michel's paper may not be a reasonable requirement. At Earl and Wright we believe a unit that relies on meeting the damage stability requirement by providing a generous gap between the operating waterline and the deck and lists slightly more than 15 degrees is inherently safer than a unit which has minimum gap and relies on an upper hull of questionable watertightness and strength to limit its angle of list. As with intact stability rules, we question the use of wind overturning after damage in defining limits of submergence. We believe that providing some freeboard, or allowing some angular motion, or an error in GM to determine an allowable final waterline below downflooding after damage would be more rational. We agree with Mr. Michel and totally reject as a reasonable criterion the loss of buoyancy of a column as required by Norwegian regulations. The clever designers are meeting this requirement by providing deck buoyancy through an upper hull which can be made watertight in theory, but not in practice, and which is not designed to withstand wave forces. The end result is a false sense of security.

JACK-UP UNITS

With respect to the jack-up type of unit, I believe the concerns expressed in the paper about extending the experience beyond a 300 foot water depth are very real. In fact, I am surprised that there have not been more incidents of fatigue failures in deep water units that have been designed without considering dynamic amplification of motions and with questionable fatigue criteria.

RISK ANALYSIS

On risk analysis, I wholeheartedly endorse the position of Mr. Michel's paper on the subject and recommend that conference participants who are interested in the subject, study the Part Two Studies paper by Ian Burton on the subject.

INTACT STABILITY ON SEMISUBMERSIBLES

A Statement Adopted by SNAME Panel MS-3
Mobile Ocean Platforms
May 7, 1984

The SNAME Panel MS-3 (Mobile Ocean Platforms) takes interest in the several ongoing investigations into the above subject and wishes to make several observations and comments. It is hoped these comments will be considered when deciding the scope or direction of research and when drawing conclusions. They are offered in a constructive light, and represent the opinion of a cross section of designers, operators, owners, regulators and builders of semisubmersible vessels.

1. The present intact stability criteria for semisubmersibles which have been adopted by regulatory bodies worldwide are empirical. They are adapted from criteria developed for ship-shape vessels. At sea, experience has cast doubt on the absolute validity or applicability of the criteria. This situation is now being addressed; there is tremendous interest in developing meaningful, rational, and practical criteria.
2. A large amount of evidence is available from which assessments of intact stability of semisubmersibles can be made. This consists of about 20 years of operating experience, model tests and analytical work. If no damage, flooding or internal weight shift occurs, the records shows no stability casualties, and model tests have not been able to cause capsize, to the best knowledge of the panel. This is considered as ample evidence that the intact stability of contemporary semisubmersibles exceeds that necessary for safe operations.
3. This observation leads the panel to conclude that for contemporary semisubmersibles, it is likely that no intact stability criteria are necessary other than a minimum practical metacentric height. This is to say that, were a rational criteria written and applied, it should be satisfied by any contemporary semisubmersible with specified minimum practical GM.
4. The panel anticipates that current research efforts will culminate in conclusions similar to the above. If so, the task of setting down criteria reduces to one of defining limiting proportions for semisubmersibles of "normal forms" and "normal righting arm features" for which no criteria other than a minimum practical GM are necessary.

It is hoped that those engaged in stability research for semisubmersibles will allow for the possibility that their work may culminate in no criteria, rather than new criteria. A preconception that some criteria are necessary (other than minimum practical GM) should be avoided.

Mr. A. Broussard
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Sonat Offshore Drilling

Paper C2 was written by A.M. Koehler, D.R. Ray, and A.A. Broussard. Mr. Broussard, who presented Paper C2 on behalf of its three authors, holds a Master's degree in Civil Engineering and has worked with Sonat Offshore since 1975. After serving as Manager of a number of Sonat's divisions, he was appointed in 1984 as Manager of the Research and Development Division. Mr. Broussard is a member of the ABS Special Committee on MODUs and the DnV Advisory Committee on Offshore Technology.

PAPER C2

Critical Systems and Continuity of Engineering Responsibility

This paper will consider the design of critical subsystems and the extent to which human engineering considerations are among the design criteria applied; and the importance of ensuring the continuity of engineering responsibility through the successive phases of rig design, construction, licensing, and operation. These two areas will first be addressed separately. Then the important feedback contribution to critical system designs due to engineering continuity will be highlighted.

Sonat Offshore Drilling, formerly The Offshore Company, has been involved in the design, construction and operation of mobile offshore drilling units since 1954. During this 30 year period, Sonat has designed and operated jackups, drillships, and semisubmersibles, participating in and contributing to the design evolution of the industry. This participation has included development of criteria and requirements for operating in deeper water and more remote, hostile areas. We are currently in the final stages of design of two fourth generation winterized semisubmersibles. The concepts discussed in this paper are drawn from these years of experience in the design and operation of MODUs, as well as from the background technical reports which have been prepared for the Royal Commission.

DESIGN OF CRITICAL SYSTEMS

"Critical systems" are those systems whose failure to function totally or in part could lead to the loss of the MODU or endanger the lives of those on the unit in credible adverse circumstances. This definition is the study basis used by Det norske Veritas (Canada) Ltd., in a report prepared for the Royal Commission which identified three of the systems most critical to the safe operation of MODUs. The selection of these most critical systems was based on DnV's assessment of the accident history of the mobile drilling industry, combined with the judgements of knowledgeable industry experts. According to this report, the most critical systems are:

- Stability/ballast systems of semisubmersibles
- Towing/transit systems of jackups
- Well control systems

Human engineering considerations are taken to mean the conditions, controls, limitations, etc., imposed on the configuration and functioning of a system by the fact that the system will be operated by men. Most human engineering considerations are universal, regardless of the purpose of the system. Therefore, for illustration purposes, these concepts will be discussed as they apply to the ballast system of a semisubmersible.

For critical systems, human engineering considerations must include the condition of the unit or system after the occurrence of a postulated incident. This may be a collision, fire, structural failure, or blackout. The incident may result in extreme inclination of the vessel, the presence of smoke or gas, flooded compartments, or power failure. The design criteria for the critical system must include redundancy, accessibility, ease of operation, minimum use of ancillary equipment, and self-diagnostics. Components of critical systems must be failsafe, foolproof, and field proven.

A fundamental design requirement from the standpoint of human engineering is that a critical system be configured for ease of access, inspection, testing, and in-service maintenance. Routine inspection, testing, and maintenance must be possible without interrupting the normal operation of the unit. This requires that the system be redundant so that individual functions can be performed with certain components out of service. The system must be subdivided so that malfunction in one area does not cause failure of the entire system. It must be possible to isolate subsystems or individual components for maintenance, testing, or repair without disabling the entire system.

If access is required to activate an emergency back-up function, then access must be humanly possible and reasonable after the occurrence of the postulated emergency. Further, to be meaningful, the access must be within a reasonable time frame. For ballast control, this requires that if certain ballast tank valves are designed to be manually operated as an emergency backup, then these valves must be within easy reach (not located under floor grating) and operable. It must be possible within human capabilities (physical and psychological) for a crew member to move down the column and into a pump room to easily reach the specific valve with the proper tools and equipment to operate that valve. In addition, there must be a positive indication on that valve of the position of the valve.

The controls of a critical subsystem such as the ballast system must be designed and configured to allow in-service troubleshooting. A malfunction in the system must not disable the entire system, and alarms and indicators must be provided to allow the fault to be located and remedied in a reasonable time frame. To minimize distraction of the ballast control operator's concentration when responding to an alarm condition, the alarm system should have an effective alarm silencer. When the audible signal is silenced, the indicator for the source of the alarm should go from continuously lit to flashing. Any additional alarm after the alarm silence is activated must retrigger the audible signal.

For a system to be in good working order and available for activation in an emergency or critical situation, it must be routinely maintained and tested. Hence, its access must be convenient and designed to minimize the effort required for inspection and testing. It is an established requirement in the industry, for example, that all void areas on a semisubmersible be inspected monthly. However, on some existing designs, it may take several days and many manhours to perform such an inspection. The more difficult and time-consuming the inspection, the more likely that in operation the inspection will be delayed or cut short. Therefore, one of the prime considerations in the design of any subsystem is ease of inspection and maintenance.

It is desirable that any equipment required for response to an emergency situation be used during normal routine operation as well. This will maximize the potential for the equipment to be in good working order if an emergency occurs. If it is necessary to use a specific ballast pump to compensate for accidental flooding or damage, then this pump should be used for the same tank action in the normal operation of the vessel. If certain tanks of a vessel are configured so that a submersible pump would be used to empty that tank during damaged situations, then that submersible pump should be used routinely to ensure that it is in good working order and available for such service. A unique emergency response system to provide redundancy and backup for the primary system is also necessary. This system should be routinely tested and maintained.

In general, all critical systems should be designed and configured to allow routine maintenance without interrupting the normal operation of the unit. Procedures that require shutdown of drilling operations may be put off to minimize the impact on the operation, causing an adverse effect on the overall safety level of the unit.

CONTINUITY OF RESPONSIBILITY

Responsibility for human safety in offshore drilling activities extends from the host government that utilizes these services for resource development to the individual worker on the rig. Each of these several contributors, which include government authorities, operators, owners, classification societies, insurance surveyors, industry associations, joint governmental agencies, and crew members have the potential to support engineering continuity. This support can range from governmental rule making, to industry technical advances, to beneficial design feedback by a well trained crew. Through cooperative effort, the industry can safeguard its most valuable resource, its workers. As a preamble to the discussion of assuring continuity of engineering responsibility, the major contributors are acknowledged:

1. Government. Laws, rules, regulations, and standards established by governments to control the offshore operations in their country must be based on the principle of safety. These controls must not place the safety of the operation in jeopardy. As an example, the establishment of a quota on national crew members must also require a minimum level of training of these persons. Assurance of fully qualified nationals is the government's responsibility.
2. Operator. Operators should be required to conduct their operations in a manner consistent with the philosophy defined by the rules, regulations, and laws of the government. This means they must be responsible to select a rig and contractor which satisfy all the safety requirements; rig selection can not be based just on the lowest day rate. Operators must not compromise safety for the sake of money and should not contract a rig that is unable to safely conduct the operation.
3. Owner. The owner should never offer a rig for a job unless he is certain that the unit can safely conduct the operation from the point of view of the design of the unit and the qualifications of the crew. The owner is responsible for ensuring that the crew members are well trained, know what they are supposed to do, and are capable of doing their job. The owner is responsible for ensuring that subsequent changes and modifications to the unit and methods of operation after it goes into service do not result in a reduction in safety.
4. Classification Society. The classification society is responsible for seeing that a unit is designed, built, and maintained in accordance with latest rules. Since rules are periodically revised to improve the safety of the unit and could change during construction, the design and construction of the unit should be changed to comply with the revised rules. The society should ensure the use of good engineering practices in all aspects of design and construction. Problem areas not specifically covered by the rules should not be ignored.

   Since the society is paid indirectly by the owner through the builder, conflicts of interest may occur. The societies should be more definitive about what is included in class in terms of the work they provide. Owners should realize that the society's representatives are surveyors, not inspectors. These surveyors are basically making spot checks to ensure that the manufacturers apply proper quality control, and do not necessarily continuously monitor the manufacture of components such as chain nor the construction of the unit. Wide variation of services provided by the different societies may exist.
5. Insurance Surveyors. Insurance surveyors are responsible for ensuring that the criteria applied in evaluating the suitability of a unit to work on a given location are safe and consistent from unit to unit. They usually have very little impact on original design.
6. Industry Associations. Industry associations such as API, ASME, and others are responsible for assuring the standards of quality and workmanship implied by their monograms. Manufacturers and suppliers should be routinely monitored and audited.

   Associations such as IADC should be supported in their efforts to provide an effective forum for the exchange of ideas and the development of training standards.

Continuity of engineering responsibility through the successive phases of rig design, construction, licensing, and operation is fundamental and essential. It is generally accepted that the owner is responsible for licensing and operating a rig. He must also be fully accountable for the design and construction, although he may delegate all or portions of these responsibilities to qualified designers, builders, and classification societies. Continuity through all of these phases can be guaranteed only by the owner and is therefore the owner's unique responsibility.

Engineering responsibility from concept throughout the life of a mobile drilling unit can vary widely depending on the history of the particular unit. In the simplest case, a unit is conceived, designed, constructed, licensed, operated, modified, and maintained under the control of a single entity. An example of this is the drilling contractor who provides a full range of mobile drilling unit development and use. At the other extreme is the complex case where the designer, the constructor, the operator may be different entities. In addition, the unit may be operated by several different companies throughout its life. In the simplest case, engineering continuity is ensured and rests with the owner of the unit. In the extreme case, with responsibility divided into various segments and among various entities, the assurance of engineering continuity is much more difficult.

In either case, a primary role in the successful life of a mobile drilling unit is played by the classification society. Only the classification society is assured of significant involvement in a drilling unit's development and application. This is an obligation to which the classification societies have responded effectively. However, there are certain weaknesses in this system that the industry must be aware of and respond to appropriately.

In general, classification societies have become involved in the mobile drilling unit business in response to the interest and need of the industry to have a set of uniform rules prescribing design procedures and operational guidelines. To a large extent, these classification rules have been developed by the joint efforts of representatives of the drilling industry acting with the society. This group, developing the rules in association with the classification societies, is represented by the designers, the constructors, the operators, representatives of national authorities, and many of the significant equipment vendors. Classification societies are self-governing bodies with rules developed through an interactive process with important input from all of the participants. This input results in a negotiated rule development process. The groups have generally tried to obtain a responsible balance between the vested interest of the various groups.

Unfortunately, classification is a competitive business. This competition for class services among societies somewhat weakens their position in developing and enforcing tougher rules. They must be responsive to the interested groups that not only help develop their rules but are the primary clients for use of their rules and services. It is essential that classification societies develop rules based on their specialized technical knowledge and experience in the field of drilling unit design and that these rules be applied uniformly and fairly over the whole class of worldwide drilling units. The lobbying efforts of various special interest groups must be judiciously weighed against the necessity for providing a safe and reliable product.

Additionally, the various classification societies at present have somewhat different requirements, and perhaps more significantly, a somewhat different approach to the task. It thus becomes an important responsibility for the owner to judiciously evaluate the choice of classification society on the basis of its requirements, procedures, and knowledge available. For the owner to choose a society on the basis of the lowest bid is as unacceptable as it is for an oil company to choose a rig on the basis of the lowest day rate.

Whereas a class society may review the design of a specific unit to a given design criteria, they do not have any input into the site-specific use of such a unit. That is, a unit may be classed by the society for a design criterion that may or may not meet the requirements for operation in a specific location. The actual application of a unit on site-specific basis has generally been left to the owner's discretion. To accomplish this, the owner uses the services of a marine surveyor. The marine surveyor must provide the basis and review on which the unit is insured for a specific location. There may be a significant difference between the opinions of the various marine surveyors as to suitability of a unit for application on the specific site. The marine surveyors must necessarily use the services of experts in the fields of meteorology and oceanography to establish the design recurrence storm levels for a specific site. Once the site-specific criteria are provided, the marine surveyor must verify the structural and operational adequacy of a unit. The evaluation of structural adequacy must be based on methods consistent with the original design approach for the unit.

One of the problem areas in the industry is the difference of opinions of the experts in developing the meteorological extremes for a given location, and significant variation can occur. It thus results that a given drilling unit design may be approved for a specific location by one marine surveyor based on the environmental criteria developed by one expert, whereas an identical unit would not be approved for the same location based on a survey by a different marine surveyor using the services of a different expert. Determining the appropriate environmental criteria on a site-specific basis has and continues to generate concern and confusion among drilling unit owners.

During the classification society's design approval and its subsequent engagement, the society gains a unique knowledge of the qualities of the unit. This knowledge is, however, not fully available to and sometimes not even within the area of competence of the marine surveyor. There is thus reason to investigate whether a redefinition of the areas of responsibility of the parties and a change of their modes of cooperation would make it possible to improve the very important task of approving a unit for a specific location.

There can be no uniform assessment of risk for a mobile drilling unit operating in a specific area until there is uniformity in the environmental criteria. This difficulty in locating drilling units in site-specific areas is especially troublesome for the jackup drilling unit. However, it appears that the least uniformity of site-specific environmental criteria exists in those areas. To the owner and designer of a mobile drilling unit, this creates a very perplexing problem in which it is very difficult to determine what environmental criteria should be selected for the design of a unit that will give it the greatest marketability and yet allow economic and region-specific design application. One approach which has been taken in the North Sea is that the regulatory body specifies the environmental criteria to be applied for certain areas of operation. In this case, a given drilling unit design can be evaluated against known criteria, and a level of risk can then uniformly be applied to all units considered for operation in that area.

As the industry moves into frontier operating areas such as Canada, it is essential that the industry develop some method of establishing uniform environmental design criteria that can be made available to designers, owners, and operators of drilling units so that the units can be economically configured and built for efficient, safe operation.

In general, rules and regulations are developed based on advances in technology, improved analytical techniques, or as in the case of the *Ocean Ranger*, in response to significant failures of concepts, equipment performance, or crew response. In each case, the intent of revision of the regulation is to provide safeguards against accidents or failures that endanger human life and the environment. They are generally developed by collective engineering judgement and often in response to industry-wide experience. As such, they expand the awareness of the individual designers and owners and thus represent an element of universal continuity of engineering responsibility.

Unfortunately, there exists a significant short circuit in this evolving process and that is the concept of "grandfathering." In principle, the practice of "grandfathering" is to minimize the sudden economic impact on the industry and, specifically, on individual owners and contractors, of restricting or denying operation of their units in specific areas. However, the result is that in a given operational area, there may be two rigs operating: one that has been designed to the improved expanded regulations and one that is allowed to continue to operate with some exemptions from full compliance with these regulations. It must be that the level of risk associated with each operation is different and in extreme cases can be extremely different. Therefore, the industry must question the concept of "grandfathering", unless it mandates a specific deadline for bringing an existing unit into full compliance with the new regulations.

This is a controversial issue; the designers and owners of an existing unit will generally take the stand that their unit's design has been safe enough and that the regulations have been drawn up out of an overreaction to a specific occurrence or set of circumstances. It is argued that such an occurrence in isolation does not justify the regulations. However, the argument can be made on the other hand that while it is human to make an error or to be less than perfect in the evolution of an industry or design concept, it is negligent not to respond to the lesson that operating experiences teach. It is recommended that "grandfathering" be allowed only on a very limited basis and that a definite time frame be specified for existing units to be brought in full compliance with the new regulations.

Engineering design is an iterative process, progressing in stages of evaluation and revision. The refinement of each successive stage depends on the assessment of the previous stage. The process continues until the resulting system performs to a chosen standard of safety and reliability. The parties involved in offshore drilling from government to worker are interdependent and must rely heavily on each other for valuable input and feedback to refine system design and performance requirements. Each party is responsible for obtaining such input and providing necessary feedback.

The designer of a semisubmersible is responsible for the design of critical subsystems such as the ballast system. This responsibility does not end with the design but extends through construction and operation. The owner is responsible for the operation of the ballast system and the training of the ballast control crew; however, the designer must remain involved, giving procedural input and receiving performance feedback. Only through an assessment of operability and performance in practice can the design be evaluated and refined to provide greater safety and reliability.

The contribution of the government of Canada through this Royal Commission Conference in providing a forum for the exchange of ideas among the responsible parties is applauded. This will certainly promote a clearer understanding of the necessity of, as well as the difficulties involved in ensuring continuity of engineering responsibility through the successive phases of rig design, construction, licensing, and operation. We appreciate the opportunity to participate in this conference.

COMMENTARY ON PAPER C2

F. Atkinson
Senior Principal Surveyor
Lloyd's Register of Shipping

Dr. Koehler has enhanced the proceedings of this Seminar with a paper which covers a wide range of activity, examining the engineering responsibility of a number of large organizations concerned with the design, construction and ongoing operation of an offshore mobile unit. It is unfortunate, but true, that most advances in safety connected with the marine industry are the result of a tragic accident, and I have no doubt that, just as the *Alexander Kielland* contributed to enhanced safety, so the loss of the *Ocean Ranger* will improve the lot of the mariner involved with offshore activity.

It is impossible to look at any one organization and say with absolute certainty that any activity is entirely its responsibility. Design and construction of a mobile unit are governed by the wishes of an owner and the ability of the designer to respond to those requirements while at the same time producing a design which can be efficiently constructed by the builder. In turn, these three bodies must ensure compliance with the requirements of the classification society, the national government or flag state, international standards and a multitude of codes to bring about a successful unit.

Unlike conventional ships, where international regulations are paramount, mobile units must be primarily designed to the wishes of the government upon whose continental shelf the rig is to operate. Although various national regulations may be common in intent, there are a variety of differences which make truly international operation difficult. For instance, one only has to compare the requirements of the governments of Canada, the U.K., U.S.A., and Norway to highlight a number of differences, most of which are connected with the standard of damage stability. The way in which the rules are interpreted with regard to structural redundancy and boat impact damage emphasizes this point.

Although the environmental factor is part of the equation when the structural analysis is examined by the classification societies, I would suggest the setting of extreme conditions must rest with the government of the continental shelf state. Dr. Koehler tends to suggest that the classification societies do not have any input into the site location of a mobile unit, but this is not strictly correct. If a unit operates at a location where the environment, for either transit, operational, or survival modes, is outside of the prescribed conditions, then it is out of class.

In addition, if we, as a classification society, are acting as a certifying/verification agency, then the *Certificate of Fitness* applies specifically to a chosen area. Having said this, I would suggest that I would question Dr. Koehler's remark that once an area is chosen, the marine surveyor can verify the structural and operational adequacy of the unit. This can only be done by having an intimate knowledge of the unit.

As Dr. Koehler had indicated, it is unfortunate, but true, that the main factors concerned with the *Ocean Ranger* casualty would appear to be connected with the ballast system, the control mechanism to that system and the ability of the crew to operate it. This highlights the duplicity of control exercised over offshore operations and emphasizes perhaps the need to have more stringent international, or at least national, statutory requirements.

The human activity that takes place on an offshore unit is considerably varied, depending on its mode of operation. Such a variety of interests and disciplines must lead to a dichotomy of responsibility and emphasizes the need to have a fully trained and competent crew with someone in absolute authority at its head.

Although mentioned by Dr. Koehler, I do not think that significant emphasis has been given to crew training and it is a point this symposium may wish to discuss further – training in association with assessed and agreed levels of competency.

If one looks at any offshore unit, it can be seen that the end result is an amalgam of design aspirations, constructional limitations, stability criteria, inspection methods fraught with human fallibility, and the relatively limited requirements of certification, classification and quality assurance. These are further confused by the necessity of crewing such a unit and providing them with adequate lifesaving appliances, which will only be required under extremely harsh environmental conditions and at times of considerable stress and confusion.

I will turn now to the second part of the paper dealing with the continuity of responsibility, particularly as experienced during the life of a MODU. Historically, unlike normal marine activities, it is more common for designers to be involved with the eventual operation of a mobile unit. This pattern is slowly changing whereby the shipyards are now responsible for their own design, with the vessel being operated by a company detached from the designer. This trend breaks down the traditional continuity from the designer to drilling contractor, and with the influence of port state authority being exercised only over limited periods, I would suggest, in agreement with the author, that the classification societies are the organizations involved with a particular unit over the longest period of time. However, it should be appreciated that, whereas the societies take a considerable interest in structural aspects and are tending to be more involved with stability, they cannot and should not be involved with crew competency. This is entirely a matter for the country of registration and the continental shelf state concerned.

In discussing the role of the classification societies, Dr. Koehler has raised three items worthy of discussion.

1. He suggests that rule changes which occur during the construction of a unit should apply immediately. This is contrary to all of our normal marine approach where rules only apply six months after acceptance and then only to designs introduced after that date. To accept the authors' proposal would introduce considerable contractual difficulties and would be completely unacceptable to the builder.
2. I would agree with the authors' suggestion that a grandfather clause should only be introduced on a very limited basis and then within an adequate time frame. Grandfathering has only been done on very, very rare occasions and I would suggest this is mainly the prerogative of governments, not Classification Societies, and even then on a gently, gently basis. It can be done, of course, and the audience's views on this would be welcome, but the considerable financial ramifications, although outside the classification process, should not be forgotten.
3. Dr. Koehler indicates that an owner may delegate all or part of his responsibilities. I would suggest that no owner can ever delegate all his responsibilities and, indeed, at the end of the day, he has ultimate responsibility, even though it may be shared with other bodies. I note the authors' remark on competition between the classification societies, but can not entirely agree with the implication that business may be bought at the expense of safety. I do feel, however, that all societies should be divorced from governmental authority, and protectionism should be deprecated.

I think that both this Conference and Dr. Koehler's paper have indicated a need for a stricter control over the design and operation of mobile units. Whatever changes are made, however, should be technically justified and not the result of emotive changes to satisfy public conscience. I would suggest to this audience that it is not the great momentous changes which will influence the future safety of mobile rigs but greater attention to detail, during both the design and construction of future rigs.

I would like to thank the Royal Commission for the opportunity to expound these views, all of which may not directly relate to Dr. Koehler's paper but which are complementary to them and should ensure a wide ranging discussion aimed at enhancing the safety of offshore mobile units.

COMMENTARY ON PAPER C2

M. Vermij
Engineering Specialist
ASE, Transport Canada

Since my background is not directly related to marine safety, but rather to aviation safety, I will restrict my comments to the experience I had with the *Ocean Ranger* accident investigation and the wreck's safety analysis issues.

First of all, I would like to have a look at the definition of critical systems, as it was described in Mr. Broussard's paper, and I would like to make an addition to that. The paper stated that critical systems are those systems whose failure or function in part or totally may lead to a loss of the rig and endanger the lives of those on the unit in credible, adverse circumstances. I would like to add that it is also the improper operation of a critical system, as is evidenced in the analysis of the *Ocean Ranger*, which may lead to a loss. Also, the words "credible, adverse circumstances," from a safety point of view are really not necessary. The definition of engineering continuity I could not find in the paper, and I made up my own. I would like to submit it for discussion and see if it is a correct or a desirable definition: "the creation and maintenance of an operational line of communications, mostly to the crew, reaching sure, proper and safe operation, monitoring and maintenance of the rig's critical systems in all possible conditions throughout the service life of the unit."

A	B	C	D	CAUSAL FACTORS (*Ocean Ranger* Disaster)
■				1. Severe Storm
■				2. Wave and Wind Direction
	■			3. Location of Ballast Control Room
	■			4. Portlight Strength
			■	5. Position of Deadlight
	■			6. Water Resistance of Switches
	■			7. Electrical Control of Pneumatic Valves
		■		8. Independent Valve Status Panel*
	■		■	9. Switches Failsafe Wiring
	■			10. 24 and 115 Volt System Proximity
			■	11. Panel System Intervention by Crew
	■		■	12. Tank Level Monitoring System
			■	13. Manual Valve Operation by Crew
	■			14. Draft Monitoring System
	■			15. Ballast Pump Location
	■			16. Tank Piping System
		■		17. Chainlocker Deckholes
		■		18. Chainlocker Drainage
		■		19. Vent and Stairwell Deck Holes
			■	20. Evacuation Timing
	■			21. Evacuation System
■				22. Low Temperatures
	■			23. Protective Gear

A Environmental Factor
B Critical System Failure
C 'Non' Critical System Failure
D Engineering Discontinuity

*The lack of an independent valve status panel cannot be considered a causal factor.

From being involved in the *Ocean Ranger* disaster analysis and reading through the Part One Report, I added something like twenty-two causal factors that led to the sinking of the rig and the loss of the lives of the crew. Seventeen of these causal factors caused the sinking of the rig and if any one of these factors were changed, the disaster would probably not have occurred. As you can see, six of these factors are directly caused by engineering discontinuity and twelve are directly related critical systems failures. This display has the purpose of giving some meaning to the concepts of critical systems and engineering continuity. As a lesson from the *Ocean Ranger*, I would consider it an important design principle to include detailed fault tree analysis as a design and safety tool, preferably performed by an independent facility and maybe be presented to the designers on a quasi-adversary basis.

There are two points in Mr. Broussard's paper with which I did not quite agree. One is where it was stated that, "if the engineering responsiblity was solely due to the simple case of where the design, construction, operation and modification and control came from a single unit, then the engineering continuity is ensured and rests with the owner of the unit." I do not quite agree with that. I think the responsibility in this case is quite clear, but engineering continuity is certainly not ensured just because there is a single owner and designer. The engineering continuity requires a continuous effort by the parties concerned to maintain it and to keep the crew, etc. properly trained to manage the ship properly.

The other point I would like to make relates to the comment that, "The establishment of a quota on national crew members must also require a minimal level of training of these persons and assurance of fully qualified nationals is the government's responsibility." I do not think that just because the operator has an agreement with a particular government that he can transfer the responsibility of crew training.

That is about all the comment I have. I thought it was an excellent paper and I had great difficulty in finding any discrepancies. Thank you very much.

Summary of General Discussion Following Papers C1 and C2

There was considerable debate throughout the discussion period on the matter of classification society design rules for MODUs, how they are compiled and then applied, and the effect of rule changes on existing and in-progress units. Mr. R.E. Johnson (NTSB) criticized the lumping together of stability requirements for semisubmersibles, jack-ups, and drill ships, as the forces and responses affecting each type are significantly different. He felt that most research to date on the damage stability question has been concentrated on the semisubmersible type of unit. Although Mr. Johnson agreed that model testing could be a useful tool, he outlined the problems of accurately modelling the effects of green water on decks, of wave impact on deck structures, and of selecting appropriate wave spectra. He was also wary of the problems associated with translating test results into information which is relevant to the end user onboard a ship or rig. Mr. E. Dudgeon (NRC) advocated the use of simulations to ensure the accuracy of tests results.

With regard to the selection of appropriate wave spectra, Mr. L. Draper (Institute of Oceanographic Sciences, U.K.) responded that it is not possible to apply one standard wave spectrum in all model tests because each geographical region has its own distinctive energy spectrum.

Mr. W.H. Michel (Friede & Goldman) responded to Mr. Johnson's concern about stability requirements by re-affirming his contention that it is necessary to consider both wind and waves in establishing and applying stability criteria, and that designers should incorporate both model test results and theoretical calculations intelligently, in designing to compliance with stability rules.

Mr. Johnson disagreed with Mr. T. Haavie (Submarine Engineering) that a number of inclining tests should be carried out on any one rig design-type while it is still new, but Mr. Haavie emphasized the importance of obtaining accurate results and this, he felt, justified his argument that more than one inclining test be required, despite the high cost.

Dr. J. Pawlowski (NRC) addressed the need for research on stability, and endeavoured to place the issue in a broad perspective. The current design emphasis is on structural features. On the other hand, the loss of a vessel is always related to a loss of stability and flotation. Dr. Pawlowski emphasized the role of research as a forerunner to design in the building process, and it is the evaluation of the performance of the resulting design which confirms that the research process has been effective. Because a well co-ordinated research effort in this area does not yet exist, he urged research and regulatory institutions to combine their efforts towards a better understanding of the stability of floating structures and so provide designers with significantly more reliable guidance.

Mr. V. Greif (SEDCO, Inc.) commented on two aspects of Mr. Broussard's paper: 1) the responsibilities of training personnel in regions which have local hiring policies; and, 2) the revision of design rules and regulations and the potential effect of "grandfathering" units. He submitted that it is the role of industry, not government, to hire and train local labour, with the proviso that imposed quotas should not create unreasonable pressures on the training effort. Mr. T.S. McIntosh (IADC) added that, where quotas are set without consideration of the availability of qualified workers and the requirements in the training of unskilled workers, the government setting the quotas assumes a portion of the responsibility of providing training, even though that responsibility may be delegated to industry.

Mr. Greif then spoke with reference to upgrading existing units as rules and regulations evolve by pointing out that most units have operated successfully over many years without accidents and without the incorporation of major changes, so there is no justification for the automatic retiring of those units which do not comply with the most recent rules. He said that, in most cases, prudent owners do upgrade their rigs when rule changes are critical and when the changes are deemed beneficial. This, of course, assumes that the change is both feasible, and, as well, that it does not adversely affect other aspects of the unit. Mr. McIntosh added that Zapata Corporation does incorporate any rule changes during the design and construction phases of a unit, which are justified to increase the unit's reliability or level of safety.

Mr. F. Atkinson (Lloyd's Register of Shipping) pointed out that not all rule changes are of equal significance or of fundamental importance to rig safety, and therefore it is important to evaluate carefully the changes before creating contractual and financial difficulties by requiring changes in a unit already under construction. Mr. Broussard (Sonat Offshore Drilling) disagreed that not all rules should be incorporated, even if a unit is in midstream, because owners usually demand that new units comply with all the most current rules, not just those selected as most relevant to that particular design.

Mr. J. Hornsby (CCG Ship Safety Branch) then referred to the matter of responsibility for ensuring that a rig is appropriate and safe for a particular function, regardless of its compliance with rules. He maintained that the flag state, because it administers the licencing of rigs operating in its jurisdiction, assumes responsibility for ensuring the adequacy of a unit. This is especially true because the classification societies maintain a waiver of responsibility in their rules. Mr. Hornsby then promoted the idea of working through the International Maritime Organization to establish international standards for MODUs, and Mr. I. Manum (Norwegian Maritime Directorate) agreed that such an approach would be most appropriate.

Mr. Dudgeon suggested that if a MODU is viewed as a complex, industrial system, then its operating behaviour must also be treated as a system. He pointed to the use of models and simulations, both physical and computerized, as aids to systems analyses and design, and to simulations being particularly effective as training tools and in examining "what-would-happen-if" scenarios.

Mr. Nigel Hendy (Burness, Corlett & Partners) explained that model tests were used extensively in the course of the *Ocean Ranger* investigations, and that the tests at both NRC and NHL used a combination of wind and wave loadings, as well as wind gusts. It was found that although wave forces predominated in the moored condition in shallow waters, the effects of wind loads can become more prominent with a change in water depth or changes in the condition or type of mooring system. Mr. Hendy, in closing, agreed with Mr. Haavie's comment that portholes, if unsatisfactorily designed and operated, can place a unit at risk in cases of extreme listing.

Mr. Ray Street (Hollobone, Hibbert) questioned the thrust of research into the analysis of structures and their stability in light of accident statistics which indicate that none resulted from a failure of static stability. It seems more appropriate to expend greater efforts in examining and ensuring the reliability of systems, the failure of which seems to contribute more often to accidents.

Mr. Michel defended the present concentration on stability research and said that it is necessary to establish proper stability criteria and to know their influence in maximum environmental conditions. Mr. Manum also supported the importance of being able to establish damage stability criteria, the knowledge of which could prevent capsizing and increase survivability. He felt that damage stability was an especially important consideration in providing sufficient time, when an accident occurs, to permit a unit's crew to mobilize the lifesaving appliances available to them. Without stability in a damaged condition, capsizing would probably occur before the crew could be evacuated safely.

Mr. G.L. Hargreaves (Consultant, U.K.) referred to certification, as opposed to classification, practices in the U.K. The sole authority for allowing exceptions to the rules is vested in the Secretary of State, and exemptions are approved only after consultation with the certifying authority and its advisors. In Mr. Hargreaves' experience an exemption is granted only with some compensating condition imposed to ensure safety of life. Mr. Manum said that in Norway the certifying authority is the Norwegian Maritime Directorate which is very concerned with damage stability criteria and works closely with the classification societies and their criteria.