Proceedings of the

THIRD INTERNATIONAL OFFSHORE MECHANICS AND ARCTIC ENGINEERING SYMPOSIUM

VOLUME I

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DEEPWATER PLATFORMS
MARINE RISERS
SUBMARINE PIPELINES
EARTHQUAKE ENGINEERING
VORTEX SHEDDING VIBRATIONS
FLUID-SOLID INTERACTIONS
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OFFSHORE MECHANICS I

OCEAN AND ARCTIC ENGINEERING:
RISK AND THE ECONOMIC, SOCIAL, LEGAL CONTEXT

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ABSTRACT

Ocean and arctic engineers typically play three roles. Through research, they contribute new understandings of basic scientific principles applied in a strenuous and hostile environment. Through design, they apply that knowledge to such crucial functions as construction, transportation, communication, extraction of natural resources, and environmental conservancy. Through serving as a systems analyst or administrator, they are concerned with both the industrial management of marine technology and with its social management. In this latter concept, ocean and arctic engineers bond their technical talents with deeper perceptions of their client's dilemmas in a concern for ends as well as means. This exercise is the least familiar to the engineering professional, yet it entails the most trenchant contribution that engineers make to human affairs and thus the noblest expression of social responsibility.

This paper traces the connections of ocean and arctic engineering to their broadest context--the economic, social, legal, cultural and political ramifications that increasingly season intrinsic elements of research, design and application. With a series of historical and anecdotal vignettes, this theme is elaborated to dramatize the sharp changes that have accompanied the interaction of technology and society generally in the last four decades. Moving from examples of the excitment of personal enlightment through discovery to the satisfaction of successful operating performance, this review concludes with four evolving challenges: updating tools of practice to incorporate notions of risk assessment and social impact; major reforms in engineering education to emphasize breadth instead of specialization; active engagement in technology-policy analysis to facilitate citizen enlightenment and foresight; and recognition that engineering ethics must parallel technical proficiency and virtuosity in carrying to the future the unique torch of <u>noblesse oblige</u>.

INTRODUCTION

Every speaker must acknowledge a special challenge and a special responsibility in a keynote address. With this Third International Symposium on Offshore Mechanics and Arctic Engineering, for example, some 200 papers will be delivered in 20 technical fields, and with participants from perhaps 25 nations. One obvious requirement is to identify a unifying theme. That is necessary but hardly sufficient. A stage should also be set to establish perspective for more specialized contributions that follow. Finally, the audience should expect that ideas advanced be sufficiently fresh and robust to stimulate professional thought long after the address.

In that spirit, I have chosen as an assignment the question of connections between ocean and arctic engineering and human affairs. To avoid glittering but unproductive abstractions, I shall focus explicitly on risk, on the subtle yet poignant elements of uncertainty that attend technological enterprises and underpin social responsibility in all engineering practice.

This theme will be developed in five steps: (1) key features that characterize the interaction of technology and society; (2) circumstances that establish ocean and arctic engineering as frontiers deserving of the type of inquiry that attended both nuclear and space engineering in their infancies;

(3) definitions of risk and its crucial role in relating technological performance to human values, needs and wants; (4) the role of government as steward of the public interest and thus of public policy in risk abatement; and (5) a few words about the power of technology assessment to meet needs of engineering practice, but with some unorthodox notions of breadth in engineering education and of public participation.

With that mix of technical and social elements, it should be evident that value preferences of the author play a significant role in analysis that follows. Perhaps these can be defined by a brief reminiscence of three life experiences.

My initial ocean engineering exposure was in the static and dynamic strength of ship structures, then in the generation of new design criteria for submarine pressure hulls. Apart from recourse to mathematical theory of thin elastic shells, and experimental stress analysis, that position carried an obligation to serve as test pilot on the first dive of each new class of vessel--- a powerful technique, incidentally, of making sure your sums are correct. There I learned first hand about the trenchant meaning of the safety margin, and the delicate tradeoffs required between high performance and risk in choosing that number.

Next, it was my fate to serve as a technical advisor to three U.S. presidents, and to the U.S. Congress. Here, I observed that affairs of government were becoming more technological and, conversely, that technology was becoming more political. One the one hand, government was involved with technology in four separate ways: to stimulate innovation and entrepreneurship in private enterprise; as a customer of (military) technology; as a source of funds for research and development; and as a regulator of activities involving technologically induced risk. On the other hand, most of the key decisions involving science and technology were not being made by scientists and engineers. They were being made by political leaders-- interpreting and representing the public interest, establishing goals to which technology was addressed, investing public resources for their achievement, and selecting both benefits and beneficiaries.

This fourth role of government emerged from a property of technology that I was unprepared for; namely the power of all technologies to generate side effects. Many of these were unforeseen, capricious, often hibernating to explode as surprises in the future, in some remote district. Many were unwanted, and of special concern because of adverse effects on innocent bystanders. Nuclear power as an economically attractive alternative to fossil fuel revealed hidden problems of cost, waste disposal and safety. Pesticides to enhance food production could cause cancer. Computers threatened to violate privacy and were vulnerable to criminal intervention. Practically every technology sought for its benign contribution to the quality of life emerged as a two-edged sword.

In wrestling with this paradox, it became clear that the answers could not be cast as with engineering as either right or wrong. Amidst complexity and ambiguity, it was not even easy to frame the right questions. Indeed, here was a whole class of questions with which I was unfamiliar--ill-structured socio-technical problems in which the value ingredients were of comparable importance to the technical aspects, where there was a low degree of certainty in the methodology of solution, and where it was important to ask not only "what might happen, if?" but also, "to whom?"

Risk as I then grew to perceive it could no longer be expressed simply in terms of a factor of safety as with a submarine pressure hull, or only in terms of directly affected parties as clearly as with the submarine's crew. The notion of risk became messy. It was during this interval that, along with colleagues, I tripped over the notion of technology assessment as an aid to decision-making with those risk-laden issues that were proliferating, a matter we return to subsequently.

My most recent experience as teacher introduced a third element. In being with the young, I felt obliged to think with them about the future, their future. I began to recognize that tomorrow's risks frequently arise from today's choices; and that almost all of the institutions of our society were neglecting the future dimension in their decision-making. Politicians were mainly worried about how their votes might influence the outcome the next election, not the impacts five or ten years hence. Business leaders were concerned about short run initiatives that would produce fast profits, overlooking the longer term effects of choice on the success of their own organization, but also overlooking externalities, the effects of their actions on people and institutions outside of the transaction. Examples abound of this pathology of the short run, including the failure to perceive as long ago as 1970 the energy crisis that was approaching, and in which we are still embedded. Or the leapfrog of foreign competition and its eventual economic shock to the technological prowess of the United States resulting from short sighted decisions of industrial managers.

Coming as I do from the State of Washington, I may be especially sensitive to defects in foresight. This is the state that hosts the crisis over WPPSS, the Washington Public Power Supply System. As almost everyone knows, that organization is in a desperate situation. It chose to build five nuclear plants simultaneously, without even the experience of building one. It was exploited by the bond merchants, the lawyers, Bonneville Power Authority, the contractors, subcontractors and unions. It has suffered from progressive changes in safety requirements in the aftermath of Three Mile Island. And it was undermined by its own naivite and lack of objectivity, especially in projecting a power demand that never materialized. Now the system is in default on its bonds, and at best will complete only two of the five plants.

There is enough blame in this catastrophe to charge all parties with negligence. But what we should recognize is that from the outset, the fundamental deficieny was failure of civilian nuclear power advocates to approach the problem as technological, not just as engineering. By that is meant that human systems components were neglected. Only with hindsight were adequate questions raised about risks, uncertainties in forecasts, in interest charges, the burden of delay and possible consequences of amateur management; even about the definition of risk. People then got into the debate, organizations that were violently and hysterically anti nuclear, but also ratepayers who have to foot the exorbitant bills and who were not consulted by the PUD members of WPPSS. Most of the nuclear engineers didn't understand what was happening, were unprepared to deal with this dimension of their practice, were quick to develop their own emotional attitudes toward skeptics, and an intolerance for dissent.

SHIFTS IN TECHNOLOGY/SOCIETY RELATIONSHIPS

What is suggested here is that the context for the practice of engineering has markedly changed over the past three decades. During and after World War II, there was a certain magic to both science and engineering. The prevailing attitude of uncritical support reflected appreciation of technology in helping the Allies win a war that was begun when the Axis powers chose to employ technology as an instrument of their foreign policy. For our side, not only was there victory as a consequence of technological feats such as radar, the proximity fuse, and the atom bomb. There was victory with a relatively limited loss in human lives. The Soviet space surprise of October 4, 1957 only reinforced a spirit that was already manifest and eligible for ignition. Through the early 1960's, the nation was equating technology to progress; and it was asking about technology, "Can we do it?" One reply was a manned lunar landing.

During the late 1960's however, another cultural tide was at work. Many social critics saw a connection between technology and phenomena that they felt were detrimental to human progress. Along with a counter-culture rebellion there was a call to turn technology off. More significant, however, was a growing litany of the unwanted side effects referred to earlier, epitomized for the environment by Rachel Carson's SILENT SPRING. Now people began to ask a different question, "Should we do it?" That era, incidentally, was marked by the translation of that cultural tide into landmark legislation, the National Environmental Policy Act.

In the 1980's, a new issue is emerging, along with the emotional rhetoric to "get government off our backs". More to the point of the interaction of technology and society is the question, "Can we manage it?"

It is here that we should recognize that the concept of management extends far beyond the boundaries of "industrial management". That field deals with decision making in the direct oversight of technological enterprise, primarily to assure efficiency. Now the problem is one of social management of technology, the entire repertoire of social and policy processes by which socially satisfactory outcomes, in the long as well as short run, can be assured. And that means coping with risk.

Such an approach is especially important with frontier technologies where rapid development such as with space and nuclear enterprises lacks the luxury of hindsight and usually outpaces slower social institutions. Ocean and arctic engineering fall into this category, thus motivating a search for their connections to public policy and risk.

FRONTIERS IN OCEAN AND ARCTIC ENGINEERING

The sea has always been a vital component of social history of the human race. It has served as a source of food for coastal communities. It functioned as a protective moat, isolating peoples from each other. But it also provided an inviting, mystical attraction for the bold and imaginative, to foster transport and trade, and eventually as the route to empire. In modern times, the sea acquired four other attributes: as a source of energy and minerals, a depository for industrial and human waste, as a locale for recreation and spiritual refreshment, and, at the coastal margin, as the magnet for urban populations. Indeed, recognition of the emerging importance of the sea was reflected at the highest policy level in the United States beginning in 1959. A flurry of congressional proposals elevated marine related endeavors to a level of visibility and national initiative equal to the fledgling space program. Most of these initiatives failed, but in 1966, a new law was enacted, the Marine Resources and Engineering Development Act, P.L. 89-454.

This new legislation, for the first time in American history, proclaimed the importance of the oceans to national interests and asserted a mandate for planning, research and for action that would enliven an otherwise neglected enterprise. Unnoticed but of enormous significance was evolution of that policy from its original introduction in 1964 as the National Oceanographic Act. This title reflected an appreciation for the use of the sea, not simply its study. Paradoxically, this broader concept came not from the usual stimuli of crisis or special interest pressure, but entirely from the policy analysts. While the scientific community had been a powerful lobby to ignite action, it mainly sought to correct inadequate funding for research, facilities and ships. The engineering community almost completely ignored this theatre of action, as had been their self-imposed practice for so long of nervous isolation of engineering from politics. The aerospace community, however, was a vigorous advocate in the belief that the marine field might supplement the space program whose funding under budget pressures of the Viet Nam war was already drooping, but it had no marine policy credibility and was patently self-serving. The maritime community, however, offshore oil, minerals, transport and fishing, also ignored this rare opportunity for engagement of national policy at the highest level, out of parochial habits of dealing only with sectoral issues and not the national interest.

What happened subsequently with implementation is a fascinating story of unprecedented advocacy by both President Johnson and Vice President Humphrey, but it is beyond the scope of this paper. What is relevant, however, arises from the reality of the continued presence of that legislation and its neglect by recent administrations and the Congress, a matter treated later.

But to return to the legislative history--in the 1950's, five unrelated circumstances converged to set the stage for unprecedented policy-level attention. First, scientific oceanography began to generate deeper comprehension of what is in and under the sea, and the dynamics of marine ecology. Second, world populations outracing their food supply, energy and minerals, began to examine more seriously resources that lay relatively untapped beyond the coastline. Third, as these populations grew, they concentrated along the coasts, following industries located there by the compelling economics of low cost maritime transport as well as the salubrious environment for housing and leisure. Fourth, as international tensions grew, recognition increased that the oceans might either become a theatre for new levels of conflict or an arena for peaceful cooperation. Indeed, by the late 1960's, the same type of attention accorded marine affairs by the United States was now on the agenda of the United Nations, and perforce the policy leaders of most of its members.

Fifth, and to the point of this paper, there was growing recognition that through new engineering developments, man could engage activities on, in, and under the sea that were historically thwarted by the hostile and strenuous marine environment.

These five conditions led to informed speculation that during the next few decades, sharp growth could be expected in extraction of offshore oil and gas, ocean shipping, arctic development, growth of coastal communities and associated conflicts in shoreline use, in commercial fishing and water recreation. Indeed, it was estimated that all of these enterprises would expand at rates exceeding the GNP. This opportunity waiting to happen was one of the motivations for signalling a new era in the technological identity of the legislation.

To be sure, there was a long history of successful ocean engineering in naval architecture, undersea cables and tunnels, coastal protection and shallow, offshore petroleum operations. All evolved from classical engineering disciplines, using basic principles concerning mechanics, propulsion, materials, structures, energy, communications, further shaped by considerations of cost, reliability, and safety. Nevertheless, there was growing recognition of the special demands of the marine, and later, arctic environment: sea-surface motion, tides, currents, wind and wave forces, hydrostatic pressure at depth, ice loading, opacity of sea water to electromagnetic energy, high attenuation and scattering of light, high conductivity of sounds, lack of gaseous oxygen to sustain man, problems of the interface, of corrosion and fouling. These were now gaining attention as topics both in research and in practice. And it is these achievements that constitute the bulk of progress being reported at this symposium.

This progress can be dramatized by the swift evolution of offshore oil and gas development made possible by precocious platform engineering. From 1970 until 1983, the number of offshore rigs increased from 200 to 700. Size increased from 3,000 to 60,000 tons. Depth of water drilling increased from 340 feet to 1025. Worldwide, drilling from various types of platform advanced in water depth from 1500 feet to 5624. Off U.S. shores with 4 billion barrels of oil produced since 1970, only 800 barrels were lost in blowouts.

These statistics confirm our technological prowess and progress. Yet, as this body of knowledge and practice advances, gaps remain: in particular, the connection of ocean and arctic engineering to human affairs.

RISK AND ITS TECHNICAL MANAGEMENT

So far, we have avoided a pedantic negotiation of basic definitions. But we cannot delay that requirement indefinitely. Three term deserve elaboration because they are both familiar and misunderstood: technology, safety and risk.

Technology, as with Webster, represents the totality of specialized means employed to provide objects or services necessary for human sustenance and comfort. Technology, therefor, is more than technique. Most importantly, it is more than engineering. It is a social process, and has been a fundamental component of progress throughout human history. (Indeed, sometimes all we know of that history is what can be deduced from technological artifacts that are left behind). We know that technology has profoundly altered human affairs-- material comfort, life styles, values and institutions. In turn, technology has been influenced by the social setting, institutional structure and decision systems. Thus, while technology is said to impact society, the reverse is also true.

If there is any quantum change from the past, it is that we no longer simply use technology; as Langdon Winner has said, we live it. Perhaps this broadening concept of technology can better be expressed through the notion of a technological delivery system--that combination of institutions, information networks, social, economic, legal and political processes by which technical knowledge, combined with fiscal, natural, human and management resources, is converted to some selected output. As a footnote, we recall an earlier observation regarding side effects, so that in modelling any particular delivery system (for oil production, maritime shipping, fishery enhancement, etc.) it is necessary to include the unintended outputs as well as the intended.

As to the term safety, this characteristic cannot be derived on an absolute scale or stated rigorously as a specified condition depending on the physical parameters of the system under study. Rather, safety must be defined as a socially acceptable state of risk. Thus, perceptions as to what is acceptable vary among different groups in our society, and at different times. We have witnessed a sharply reduced public tolerance for maritime pollution following the TORREY CANYON incident, for location of nuclear power plants following Three-mile island, now even for deaths on the highway from alcoholics. Most important, there is a heightened sensitivity by the general public to technologically induced threats, particularly to innocent bystanders.

Scholars of risk analysis contend also that there are two conspicuously different states of acceptable risk, depending on whether it is voluntary (as with mariners) or involuntary (as with passengers on ferries regulated as common carriers). It must also be noted that neither the exact state of safety nor predictions of trends can be based entirely on historical casualty data, especially when appraising the low probability, high consequence event. There are many techniques available for risk assessment, but what follows deals more with management than with method.

By no means has this element of engineering been neglected. On the contrary, over the last 150 years or so risk and its mitigation have been the subject of research and of systematic practice through introduction of the safety margin. As we all know, the safety margin is an act of social responsibility by engineers to protect user and the general public from bodily harm, functional inconvenience, and from economic loss. By this technique, there can be accomodated uncertainties: uncertainties in environmental exposure, in loading, in properties of materials, in quality control of fabrication, in maintenance and effects of aging. The safety margin compensates for ignorance and fallibility because of inadequate knowledge in the application of engineering principles, or of behaviour of the system never before built to that scale. Finally, the margin may accomodate risks of human error, abuse, idiocy, blunder and mischief.

While all engineers would agree on this practice, that consensus falls apart when the question is posed as to how large the margin should be or how to derive it rationally. Experience with casualties is a powerful learning aid, and much was learned about the pressure vessel strength of steamboat boilers after an epidemic of explosions. Many rules for ship design were laid down by the rule making authorities from analyzing losses. Yet, we know from recent experience that even familiar structures such as bridges and buildings are not immune today from loss, and the courts are loaded with lawsuits after almost every aircraft fatality.

Most shocking, perhaps, is the continued rate of maritime transportation casualties. Examination of records over the past 10 years reveals that in U.S. waters, and worldwide, the rate of accidents has not diminished, notwithstanding the introduction of many high-tech aids to navigation. Indeed, the paradox of continued high accident rates has led to identification of the "radar-assisted collision". The nub of the problem lies in human error being the cause of casualty in anywhere from 65 to 80% of the cases.

Last winter, I completed a study of maritime safety in Puget Sound that reinforced general impressions about vulnerability of human systems to human frailty. Pinpointed was the role of information required by the ship operator for collision avoidance, and the requisite competence for its use. Six major recommendations at relatively low cost were recommended to the U.S. Coast Guard. One year later, the agency responsible for marine safety had not even responded to Congressional requests for evaluation of these proposals, even though they have been supported by the National Transportation Safety Board, and endorsed by 52 ferry skippers in Puget Sound.

Now, we begin to recognize that questions of safety extend beyond the conventional reach of the engineer, to include elements of both human and institutional behavior that are relatively unfamiliar to the engineer.

RISK AND ITS SOCIAL MANAGEMENT

Thus, we cannot duck the issue of preparation by engineers to deal with risk management. First, although engineers introduce a margin of safety to deal with uncertainty, this process only treats steps to guarantee technical integrity of the engineered product. That step does little to deal with uncertainties associated with social values. Here, we find a widely recognized gap. As C.P. Snow wrote, engineers are people who make the hardware, who use existing knowledge to make something go, but conservative in politics and accepting of any social environment in which they find themselves if they are permitted freedom to pursue their craft, indifferent to human relations, far less sensitive to social than to technical issues. Put another way, most technical experts view technology as a physical entity, as hardware, where risks can be distilled simply by analysis and then "controlled". Non-technical issues are then dismissed as spurious if not irrational, especially if they are loaded with ambiguity (as they usually are) and not subject to control.

Put another way, engineers would be comfortable in dealing with socio-technical risks if they could apply Newtonian rationality and solve or optimize the problem, if it were quantifiable, reproducable and subject to experimental proof, and if time and values were constant for all parties. Instead, we have issues clouded by ambiguity, with imperfect information mostly qualitative, incoherence because of social diversity that engenders dialectical intercourse, and distributed decision-making rather than centralized.

The social dimensions of technology, involving institutions and individuals, their behaviour, communication channels and relationships are the key to harmonious introduction today of any new technology. Yet this notion is often rejected even though resulting isolation of the technical components of technology flies in the face of reality.

Indeed, engineers typically would prefer to deal with machines rather than people. Moreover, the engineer undervalues inputs of non-technical individuals who are most likely to be affected by the social uncertainties involved. These uncertainties constitute the major battlegrounds on which technological risks are debated, the social, economic, political and legal uncertainties that feed the conflicts and which cannot be resolved simply by another layer of computer assisted analysis. Engineers tend to ignore the fact that attitudes toward risk of the expert and the non-expert differ radically, especially where the expert has such confidence in the available numerics and the non-expert trusts only common sense. This is why stake-holders need to participate in the problem-solving process. But that notion of public participation engenders fear and anger because the engineer and entrepreneur-innovator regard involvement of the public who are consumers of the intended technology as either an additional cost or an additional risk, or both!

Admittedly, this notion of involving stakeholders in the risk analysis process is pure heresy. Yet, there are both ethical and epistemic grounds for including others when trying to determine what is a socially acceptable level of risk. It does not suffice for the engineer to simply assume that their values represent the average citizen. Brian Wynne has put it this way. "Anthropologists have demonstrated to legions of experts in developing countries the solid rationality of peasants who refuse alien and for them uncertain risks offered by the moderniser. These peasants are not pathological or naive devotees of an illusory freedom from risk. But they have means for choosing them which do not include unpredictable social and cultural changes combined with deposition of their fate into the hands of a group whose values and guiding interests they do not understand, let alone trust, There is a moral in this for our own decision-making elites."

How to involve the stakeholder effectively is a major enigma.

TECHNOLOGY, RISK, POLITICS AND PUBLIC POLICY

As mentioned earlier, public safety has become a matter of government stewardship over the last century or so, now embodied in an enormous number of engineering codes. These relate to almost every major artifact employed by our society--dams, buildings, pressure vessels, ships, aircraft, now automobiles, etc. and to air, water, food and drugs. But beginning in the 1960's when the "ought we?" question was raised, an entirely different process was conjured up, of legislatively-based administrative rules. These were required for engineering systems having potential for simultaneous hazards to large numbers of people, (1) where a fault could endanger all users, (2) where interaction of different users can endanger many lives, or (3) where systems utilized such large concentrations of energy with the potential for either sudden or long-term release that again many people would be endangered.

It is in these cases that the public interest was felt represented only through public policy. The product of that change has been ubiquitous legislation: the National Environmental Policy Act, Consumer Safety Act,Occupational Safety and Health Act, and many more.

Even politicians would agree that the formulation of such public policy is a fuzzy and often arcane process, made all the more difficult in the case of policies that are science and technology intensive. These policies are different because:

- Scientific fact plays a crucial role in the substance of these issues, and cannot be negotiated by the usual political bargaining;
- The base of fact may be in a constant state of flux; indeed, technological change may exceed the pace of