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Construction in Arctic and Sub-Arctic Environments
Construction dans des environnements arctiques et subarctiques
Konstruktion in arktischer und subarktischer Umwelt

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SUMMARY
Marine construction in the Arctic and sub-Arctic must address the special problems raised by the unique physical and ecological environment. Of special concern are the perceived hazards of noise and construction activity on caribou, sea mammals, and nesting waterfowl. The impacts of near-shore and on-shore support for marine operations must be addressed, especially roads, gravel removal and embankments, ice jams, waste disposal, coastal erosion and air pollution. Dominating all is the potential for oil spills in wetlands and in the sea ice.

Construction dans des environnements arctiques et subarctiques

Résumé

Les constructions marines dans les régions arctiques et subarctiques doivent prendre en compte les problèmes spéciaux soulevés par cet environnement physique et écologique unique. Les problèmes particuliers concernent les dangers du bruit et des activités de construction sur la flore et la faune côtières. L'influence des installations proches de la côte et en mer doit être prise en compte, en particulier les routes, les gravières et les digues, les blocs de glace, les déchets, l'érosion côtière et la pollution de l'air. Le danger potentiel principal reste la pollution pétrolière dans les zones de marais et dans la glace.

Konstruktion in arktischer und subarktischer Umwelt

Zusammenfassung
Küstenbau in der Arktis und Subarktis muss die speziellen Probleme berücksichtigen, die sich durch die einzigartige klimatische und ökologische Umwelt ergeben, berücksichtigen. Von speziellem Belang sind die spürbaren Gefahren durch Geräusche und Bautätigkeit für Karibus, Meersäugetiere, und nistende Wasservögel. Zu beobachten sind die Auswirkungen von Infrastruktureinrichtungen für maritime Operationen in Küstennähe und an der Küste, insbesondere Strassen, Planierungen und Aufschüttungen, Eisstaus, Abfallbeseitigung, Küstenerosion und Luftverschmutzung. Besonders gravierend ist die Gefährdung durch auslaufendes Oel in Feuchtgebieten und im Meereis.

INTRODUCTION

Major marine activity in the Arctic and sub-Arctic regions has accelerated in recent years due to the discovery of large petroleum resources. This activity has included the construction of docks and causeways along the coasts, pipelines bringing water and oil to shore, artificial islands, shipping terminals, and offshore platforms.

The ambient environment in which these activities are being carried out is unique. It has often been characterized as fragile, although that word is mainly a representation of the slow progress of many natural processes as compared to those in warmer regions of the world.

Low temperatures, down to -50°C, persist for many months of the year. Long dark winters contrast with days of 24 hours of continuous sunlight during the summer. The air is calm during much of the year, punctuated by relatively violent local storms, the "polar lows." Haze and smoke hang low in the air during the winter.

The Arctic itself is dominated by the Polar Ice Cap 3 to 4 m. thick and 1500 km in diameter, slowly revolving counter clockwise. Along the coasts, annual ice forms, much of it anchored to the shore and thus designated as "fast ice." Between the polar ice cap and the fast ice lies the shear zone, a dynamic area of movement. When the annual ice is gone, the shear zone may be dominated with intermittent ice floes, driven through the sea by current and winds.

Glaciers reach down to the sea from the mountainous areas, along the coasts, terminating in ice shelves that spall off icebergs. In the true Arctic, these become captured by the ice sheet and circulate around the pole as "ice islands" for several years before breaking up.

The Arctic waters are typically cold, about -2°C, although in late summer, shallow coastal waters may warm up to + 8°C. Their oxygen rich waters are extremely productive biologically, with rapid plankton growth as the sunlight strikes open water. This in turn starts the spectacular migrant food chain of pelagic and anadromous fish, marine mammals, such as seals and whales, hordes of geese and ducks, and land predators, such as polar bears.

The mammal "Man" has inhabited the circumpolar regions for 12,000 to 15,000 years. The Inuit, apparently originating in northeastern Asia, spread their unique culture around the top of the world as the last ice age retreated. Their ability to survive has only been seriously challenged by the diseases brought by men from the south in the last century, and by the cultural changes imposed by Western Civilization in this century.

The Inuit peoples have become politically active in recent years, uniting across national borders, and making the world aware of their demands that their historical identity be preserved.

The Inuit are marine - oriented peoples, living by and on the sea. Their villages have survived through their unique capabilities and traditions. This culture spreads around the pole, across Arctic land claimed by 5 countries, yet through today's communications the Inuit are becoming aware of their common heritage and destiny.

The coasts themselves are maintained in relative stability by being permanently frozen. Permafrost often lies but a half meter or less beneath the surface. That surface is in turn protected by an insulating blanket of tundra, a collection of lichens, moss, ferns, and grasses.

The near-shore bottom of the seas is most often silt, loose on top,

but often overconsolidated at a depth of a few meters. These bottom soils out to a depth of 50 m are continuously plowed by the keels of ice ridges.

The world has lately recognized the importance of these Arctic and sub-Arctic regions to the world's ecosystem, and governments have initiated regulatory and educational institutions to preserve it.

These Arctic regions also offer unique scientific opportunities to the world. Currently an international consortium of national scientific organizations is being formed, to join in cooperative and collective effort in carrying our investigations and improving our understanding of physical and biological processes in the northern polar regions.

Until the 20th century, the only intruders to this pristine environment were the explorers, the fur traders, the fishermen, and the whalers. Although their depradations were serious - measles, the near-extinction of the sea otter and the bowhead whale, the Arctic showed amazing recuperative ability.

Into this precarious, but quasi-stable environment, modern construction activity is being thrust, as a result of the insatiable demand of Western Civilization for minerals, principally oil, but also including gas, zinc, lead, tin and gold. The distinguishing element of these modern day invasions is their scale: they are characterized by large-scale activity on-shore, along-shore and off-shore. Their potential for major damage to the environment is thus multiplied by several degrees of magnitude over that of previous activities.

Concurrently, awareness of the global environment has become a politically important force in the Western World. Thus, we are currently faced with a conflict between the insatiable demand for resources and the highly vocal and articulate demands for preservation of this remote part of the globe in its original pristine state.

SPECIFIC PROBLEM AREAS

Freed from the hysteria which surrounds most large-scale proposed developments in the Arctic and sub-Arctic, specific concerns and problem areas emerge. Some are local, some global.

Ecology

Waterfowl, from terns to geese to ducks, nest by the millions on the Arctic coastal plains, feeding in the rich tundra and shallow water lakes.

Caribou are a herd animal, often grouping in bands of 1000 or more. They are migrant, sometime following fixed routes, other times driven by severe climates and predators to new areas.

Offshore, the seals are the dominate marine animal, food for polar bears and man. Whales of several species mate and rear their offspring in the Arctic. Walruses plow the mud bottom and sea otters search for clams on the seafloor of sub-Arctic areas.

The Arctic is famous for its huge stocks of fish. The Bering and the Barents Sea are the most protein-productive regions of the Northern Hemisphere.

Predators exist in a dynamic state of balance: Polar Bears, whose primary food is seals; wolves, who stalk the sick and crippled and aged caribou; foxes creeping towards the waterfowl.

Predators and hunted undergo cyclic patterns, slightly offset from each other. The result may be yearly populations that vary

dramatically, sometimes by a factor of 10.

Environmentalists are properly concerned about any major disruption to this semi-balanced ecology, especially as there is still so little understood about the cyclic variations in populations. For example, even the killing of a relatively small member of female seals in a populous year has resulted in endangerment of the herd in a subsequent year of low reproduction.

The effect of an oil spill on these Arctic waters is certainly by far the most politically dramatic concern. The world-wide public views an oil spill as prima facie evidence of unbelievably disastrous environmental damage, despite considerable evidence to the contrary.

For example, the year following the large oil spill in Prince William Sound in Valdez, Alaska, was the most productive salmon fishing in history. It was exceeded only by the following year, 1990. It is probable that the most important effect of the oil spill as far as salmon were concerned was to reduce offshore catches due to the closing of the coastal waters for fear of contamination, allowing the fish to proceed to the estuaries and rivers. But even that does not explain the cyclic phenomena so characteristics of Arctic species.

Regardless of the factual and rational aspects, oil spills of any quantity are viewed by the public and the governments as totally unacceptable. As far as the engineering construction industry is concerned, they have the same status as loss of life: only zero is an acceptable amount.

Therefore, extreme care had to be taken with all construction activities to prevent any waste oil or oil drips from entering water. Oil on streams will flow to the sea. A small amount of oil on the sea will spread out in a sheen that is visible for many miles.

Of special concern are provisions for clean-up after an oil spill. These must be available for containment and clean-up under all circumstances: waves, broken sea ice, full ice cover.

Waves will disperse and break-up oil concentrations quite effectively. Conversely, they render booms and skimming devices ineffective.

Freed from all irrationalities, the most critical areas for oil spill are the marshes and low-lying tundra; the "wetlands." Here the natural degradation of oil as a result of sunlight and oxygen and bacteria takes much longer, and the effect on the animal and plant life is direct and persistent. It was the fishermens' quick response to the Valdez disaster that saved their rivers and streams, the salmons' breeding grounds. The fishermen fixed log and fabric booms across the rivers' mouths.

Grayling and salmon must find their breeding grounds in the gravelly stream beds. They can swim up streams that in places are only 50 mm deep, but they cannot cross a 50 mm high dam of gravel.

A simple solution for gravel reclamation in Arctic streams is to drag the bucket lengthwise, creating longitudinal furrows, instead of across the stream.

These anadromous fish, as they approach their breeding streams, swim close to the shore, in shallow water. Obviously causeways disrupt their passage. Openings in the causeways, bridged over, appear to be a logical answer, except that salmon are reluctant to swim under a shadow! Perhaps this is a genetically-transferred reaction to the shadow of the Alaskan brown bear which scoops out the fish with its giant claws.

More research on this phenomenon and means to overcome it is being carried out at present.

Although environmental groups have expressed concern over dredging and filling and the consequent plumes of silt-laden water, it must be recognized that Arctic rivers such as the Mackenzie, Yukon, Kuskokwim and their counterparts in Siberia, deliver enormous quantities of glacial silt and clays to the Arctic Ocean. Thus, the adverse effects of dredging, if any, will be limited to a small local region such as a harbor.

Noise has an adverse effect on many of the higher organisms, including man. It reportedly confuses whales, who communicate and navigate by sonics. It disturbs geese and ducks. Strangely, many animals become used to it: caribou no longer raise their heads as a helicopter buzzes overhead.

Adverse construction noise arises from a variety of operations.

Dredging creates water-borne low frequency noises as the rocks and gravel pass through the discharge line. Drilling similarly creates low frequency noises. These noises travel long distances through the water. The sounds are unfortunately in the range used for communication and navigation by the bowhead whale, a mammal believed extinct in the eastern Arctic and threatened in the Beaufort Sea.

Piledriving undoubtedly is as bad or worse, especially when driving the steel tubular piles typically employed in modern Arctic marine structures.

Waterborne noise can be attenuated and dissipated by air bubble curtains.

Another source of noise are power-driven boats and propellor-driven ships. Although the native population regularly use "skidoos" which create very loud air-borne noises, highly objectionable to man's ears, they claim that propellor noises, being in lower frequencies and waterborne, have greater adverse effect on fish and marine mammals. The natives claim, with some substantiation, that the whales are moving further offshore in their migration routes with each passing year, due to near-shore construction noise and activity.

Low flying aircraft can be very disturbing to nesting geese. Various operational restrictions have therefore been imposed by local authorities.

In an effort to prevent the adverse effects on the Bowhead Whale, which is designated as a threatened species, many construction and drilling operations are limited as to the times of year when they may be carried out. It is generally agreed by all that these noise-producing activities must be suspended as the semi-annual migrations pass.

Waste disposal in the Arctic is a difficult matter. The permanently frozen soils, permafrost, located only a half meter or so below the surface prevent dissipation and digestion in the soils. All surface effluents run off to the lakes, rivers and ocean. Only carefully planned and implemented chemical treatment, involving heat, chemicals, and bacteria, can convert the wastes of man, garbage and sewage, into environmentally acceptable effluents.

Similarly, solid waste is a much greater problem in the Arctic than in temperate climates. Low temperatures minimize corrosion and degradation. As a result, garbage becomes an attraction for Polar Bears, always a threat to a human community, since their natural food

includes seals and man. Landfill disposal is impossible with permafrost. Even where unfrozen soil makes landfill feasible, the bears will dig it up, as demonstrated at Point Barrow. Today, some major oil centers in the Arctic are shipping their solid waste back to temperate climates on the return trips of the barges and ships that bring in their supplies.

COASTAL STABILTIY

As noted earlier, the coasts, largely dunes of sand and silts, are stabilized by being permanently frozen, insulated from summer warming by a thick coat of tundra. Any disturbance of this state of balance. which depends on only a few degrees of temperature disturbance, can lead to substantial slides and erosion.

Thermal disruption can arise from a variety of construction operations. Bulldozer tracks crush the tundra and expose the black earth beneath, which then absorbs the sun's radiation. A black pipeline laid on the soil can cause similar local thawing. Trenching and excavation of course disturb the thermal regime, which will be re-established with new boundaries. Removal of vegetation and clearing of snow will allow the soil to freeze more deeply, leading to formation of an ice dam during Spring run-off, with consequent local flooding.

A special problem along many of the Arctic shores is that they are comprised of frozen silt, with a high water content. Once thawed, they turn to muddy water, of little or no shear strength.

Water flowing over ice dams, or through culverts, will quickly thaw the soil. Drainage water from waste disposal can create a major gully.

Offshore much of the Arctic coastline are barrier islands: migratory sand bars, with the added factor of having a frozen core. These protect the shore from direct onslaught by waves and ice. In summer, sand thaws and erodes on the up-current end of the island, extending it on the downstream end. When construction and drilling operations stabilize these islands by building fixed structures, downstream erosion results just as in temperate climates. So far these effects have been accepted because they have not interferred with native offshore hunting and fishing to any degree.

Ice jams during Spring break-up can be caused by the contractor, as a result of constructing a winter road crossing of the river. They can also be caused by construction in the river such as trestles and bridges.

Embankments of gravel are an especial source of serious slumping. They may contain ice particles, which compact like rock in below-zero weather, yet on thawing create a high percentage of voids. A potential critical condition can arise when gravel, at -30°C is dumped into shallow water at -2°C, creating ice within its interstices. Later operations, such as drilling and production of hot oil, can lead to slumping.

Much has been written about the problems of construction roads in the Arctic: the need to insulate the road from the permafrost, and the need to provide proper drainage in order to prevent freeze-thaw phenomena. These problems are not peculiar to the coast, but dominate the construction planning in all Arctic operations.

Air quality requires special attention in Arctic operations. During

low temperatures in the winter, particulate matter hangs in the heavy air, serving as nuclei to coalesce fog particles, which freeze. The result is an intensification of the naturally occurring Arctic haze and white-out, in which visibility is reduced to zero and all visual reference frames disappear.

While these atmospheric problems are widespread, they can be intensified in the vicinity of construction operations if care is not exercised to prevent or minimize discharge of diesel smoke and burning wood.

CURRENT TRENDS

Recent experience with oil and mineral related developments on the Arctic Ocean coasts of Alaska and Canada have shown that when early recognition has been given to potentially adverse impacts and appropriate measures have been taken, construction operations can be carried out within acceptable levels of temporary damage and indeed, in many cases, offsetting positive benefits can be achieved.

Lt. Gen. O. Hatch of the US Corps of Engineers, the organization in the United States charged as the lead agency to monitor and control environmental impacts, has stated that: "The emphasis is today shifting from mitigation of adverse impacts to integration of environmental objectives into the development process, a subtle, but all-important distinction."

The U.S. Arctic Research Commission has recommended research that will enable the development of the Arctic to be carried forward in an environmentally-safe manner. Among the specific research goals, given priority by the Commission, are "oil spill prevention technology, including clean-up of oil spills in broken ice," "waste disposal," "the improvement of technology for Arctic construction so as to reduce the high costs, while improving performance," and "the development of transportation systems for Arctic conditions."

Many papers have been presented at recent conferences dealing with the probable effects of global warming. Should this occur, Arctic coasts would see the earliest and greatest changes, with sea level rise, warmer air temperature, especially in winter, leading to thawing of near-surface permafrost, and probably more dynamic seas. These changes would pose major challenges and opportunities for marine construction in the Arctic.

CONCLUSION

The Arctic regions pose severe environmental constraints on construction activity. This paper has identified oil spills, gravel mining, causeways, noise, waste disposal, coastal erosion, and air pollution as the major sources of concern which are related to construction operations.

The Arctic and sub-Arctic are extremely important regions for biological productivity. Their ecology is in a delicate state of balance with the overall environment. Hence, disruptions by man's activities can have widespread disastrous results.

Although the Arctic is geographically remote from populous centers, it has attracted much attention politically. Not the least of the political forces to be concerned with are the native Inuits and their desires to continue their historical way of life even while benefitting from the positive elements of Western civilization.

This conflict can and has been successfully resolved in many large-scale construction operations. This paper suggest a few such solutions, but more are to be found in recent publications dealing with the Arctic.

When these concerns are neglected and ignored, the results, politically and economically, have often been severe or even catastrophic, damaging not only the Constructor's success and profitability, but also those of his Client.

Thus, the Arctic Constructor must address environmental mitigation with the same attention and intensity as he addresses the regions unique climatic, geotechnical, and ice phenomena. They are all integral problems inherent in the carrying out of construction operations in the Arctic.

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