CHAPTER 341

DESIGN CONSIDERATIONS FOR COASTAL PROJECTS IN COLD REGIONS

Craig B. Leidersdorf, M. ASCE[1]
Peter E. Gadd, M. ASCE[1]
Kennon D. Vaudrey, M. ASCE[2]

ABSTRACT

Design considerations for coastal projects in cold regions include not only the oceanographic factors that tend to assume primary importance in temperate climates, but also ice and thermal factors. This paper reviews the current understanding of each of these three types of design considerations, with emphasis on the lessons learned from recent project experience in the Alaskan Beaufort Sea. It is concluded that the environmental influences unique to cold regions introduce both increased complexities and increased uncertainties into the design process for coastal structures. In consequence, a conservative approach that incorporates damage-tolerant components and non-catastrophic failure modes is recommended for the design of sensitive facilities.

INTRODUCTION

During the past two decades, the number of coastal and nearshore projects constructed in cold regions has increased significantly. The primary motivation for these projects has been petroleum-related activities, which have resulted in the installation of more than 50 artificial islands, causeways, and coastal pads off the Arctic coasts of Alaska and Canada. Public works projects also have been undertaken by communities such as Barrow, Alaska, where bluff stabilization and beach nourishment programs have been carried out in recent years (Wiegel, 1995).

For purposes of this paper, a "cold region" is defined as an area in which the sea surface remains ice-covered for a significant portion of each year. Important

---

[1] Principal, Coastal Frontiers Corp., 9420 Topanga Canyon Blvd., Ste. 101, Chatsworth, CA 91311
[2] President, Vaudrey & Associates, Inc., 1540 Marsh Street, Ste. 105, San Luis Obispo, CA 93401

design considerations for coastal projects in cold regions include not only the oceanographic factors that tend to assume primary importance in temperate climates, but also ice and thermal factors.

The objective of this paper is to review the current understanding of ice, oceanographic, and thermal design considerations for coastal projects in cold regions. Particular emphasis will be placed on recounting the lessons learned from recent project experience in the Alaskan Beaufort Sea.

ICE DESIGN CONSIDERATIONS

Ice-related factors that may warrant consideration in the design of coastal and nearshore facilities include horizontal loads, encroachment onto the structure work surface, gouging of the sea floor by ice floe keels, and "strudel scouring" of the sea bottom by the drainage of river outflow through holes in the ice. The first two factors, horizontal loads and encroachment, can exert a major influence on structures that extend above the sea surface, such as islands, causeways, and coastal pads. The last two factors, ice gouging and strudel scouring, are particularly relevant to engineering works constructed on the sea floor, such as pipelines and toe protection.

Horizontal Ice Loads

The horizontal loads that result from ice movement can be segregated into two categories: global ice loads, which act on large structures such as gravel islands, and local ice loads, which act on small structural elements such as sheet pile walls and caissons. Global ice loads vary with the ice thickness, strength, and mode of failure. In turn, the failure mode depends on the type of ice feature impacting the structure. For exposed locations in the Beaufort Sea in water depths of 10 to 15 m, the governing global ice load is likely to be produced by encounters with multiyear floes (floes that have survived at least one open-water season). For protected locations between the shoreline and the 10-m isobath, the design global ice load results from first-year sheet ice. Such loads can be calculated probabilistically or deterministically, with the methodology for each presented in the American Petroleum Institute Recommended Practice 2N (API RP2N; 1995), and in Sanderson (1988).

In the case of exposed structures such as man-made islands, it is assumed that the kinetic energy of the moving multiyear floe is totally dissipated in ice crushing as the floe either comes to rest against the island or continues moving past while developing a maximum contact width equal to the maximum waterline dimension of the island. If a floe of mass m is traveling at velocity v, it will come to rest after a total penetration X, when:

$$\tfrac{1}{2}mv^2 = \int_0^X P(x)dx \qquad (1)$$

where $P(x)$ is the total force exerted when the floe has moved a distance x after initial contact. The load $P(x)$ may be expressed as:

$$P(x) = \sigma(A)\ A(x) \qquad (2)$$

where the contact area $A(x)$ varies with the penetration distance and $\sigma(A)$ is the average ice failure pressure associated with this contact area. It is assumed that the largest global ice load for any multiyear floe impact will occur at the point of maximum penetration. In order to solve Equations (1) and (2), values are required for the ice floe mass m, the initial velocity v, and the failure pressure $\sigma(A)$. The contact area $A(x)$ is determined from the interaction geometry of the floe and the structure.

Using the above ice loading scenario and Equations (1) and (2), global ice loads can be computed probabilistically by considering the input parameters as random variables. Independent distribution functions are required for the multiyear floe thickness, the floe diameter, the floe velocity, and the ice failure pressure to determine the annual probability distribution of the total ice load P acting against the structure. The maximum annual load developed from an appropriate random sampling of the four input parameters is assumed to approximate an extreme value (e.g., Type I or Gumbel) distribution, from which a design value can be determined. In the Alaskan Beaufort Sea, representative design global ice loads associated with multiyear floe impacts range from 5 to 6 MN per meter of island exposure width for a return period of 100 years.

In the case of protected sites such as coastal pads, the maximum global load P exerted by sheet ice can be estimated on the basis of an ice crushing failure using a modified version of the Korzhavin equation (API, 1995):

$$P/D = p\,t \qquad (3)$$

where P represents the total horizontal ice force acting against the maximum exposure width D of the structure, t represents the ice thickness, and p represents the effective ice crushing or failure pressure (which varies with the ice type, temperature, movement rate, and contact area).

The maximum annual load usually will occur in late winter, when the ice temperature and thickness produce the strongest ice. Values ranging from 1 to 1.5 MPa for the effective ice failure pressure p and 0.5 to 2 m for the ice thickness t are representative of the nearshore first-year ice conditions utilized for design purposes in the Alaskan Beaufort Sea. The resulting global ice loads range from 0.5 to 3 MN per meter of exposure width for a return period of 100 years.

Small structural elements such as sheet pile walls and caissons must be designed to withstand ice pressures exerted over areas of several square meters. These local ice failure pressures can be much larger that the uniaxial compressive ice strength because of the confinement provided by the surrounding ice. In consequence, the design local ice loads on small structural elements always exceed the global loads exerted by the same ice conditions on large structures.

As suggested by Figure 1, local ice pressures increase with decreasing contact areas. The two curves in Figure 1 represent recommended upper and lower bounds derived from an empirical local ice pressure-area relationship set forth in the API RP2N (1995). The lower bound is based upon the mean plus two standard deviations ("M+2SD"), while the upper bound is based upon the mean plus three standard deviations ("M+3SD"). Because these curves were developed from measurements acquired throughout the Arctic, site-specific experience should be taken into consideration when they are applied to specific projects. In addition, the curves should be utilized only for contact areas less than 10 m^2; the product of the local ice pressure and the contact area always should exceed the global ice load calculated according to the appropriate method described above; and the local ice pressure should be regarded as acting normal to the exposed face of the structure.

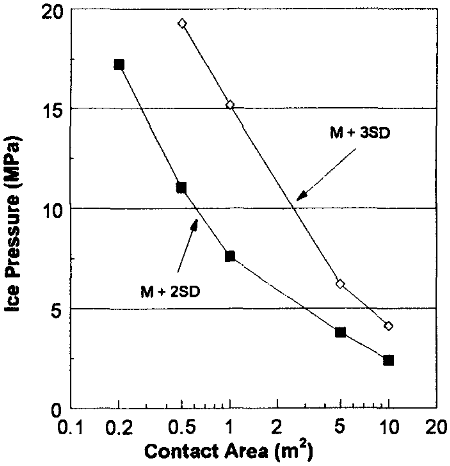

Figure 1. Pressure-Area Curves for Small Structural Elements

Ice Encroachment

In the context of this paper, encroachment refers to the movement of an ice sheet or individual ice blocks onto the work surface of a man-made island or coastal pad (Plate 1). If the sheet ice is driven up the side slope intact by a storm wind, the phenomenon is considered ice "ride-up". If the ice fails in buckling or bending and breaks up into individual blocks, an ice "pile-up" is formed on the side slope. In the Beaufort Sea, ride-up and pile-up events can occur during both freeze-up (early October through mid-December) and break-up (early June through mid-July).

Plate 1. Ice Encroachment on Endeavor Island, Alaska (1982)

A number of factors influence the susceptibility of a given location to ice ride-up, pile-up, and possible encroachment. Although ice movement results from wind stress, the single most important factor in initiating a ride-up or pile-up event is the loss of confinement of the ice sheet. Reversal of the wind direction is the usual cause of confinement loss, due to the formation of cracks or small leads in the nearshore ice. An easterly wind may produce the cracks or leads in the ice, for example, after which a westerly wind can drive the relatively unconfined ice up the slope of a pad or island.

While loss of confinement represents the dominant influence on ice ride-up and pile-up events, the ice thickness and the intensity and duration of storms constitute important secondary influences. The greater the ice thickness, the larger the driving force that will be required to initiate motion. Once the ice begins to move, severe storms of long-duration will maintain sufficient driving force to keep the ice in motion. The ice typically moves at a rate of 100 to 200 m/hr during the formation of a shoreline ice pile-up. Motion ceases when the driving force is balanced by the resistance of an "infinitely" wide obstruction, such as a shoreline.

The most common encroachment event, a combination of ride-up and pile-up, occurs when the sheet ice rides up the structure slope until increasing frictional resistance or a change in slope causes the ice to rubble and form a pile-up. If the pile-up attains sufficient height, ice blocks at the top of the pile can tumble down onto the work surface. Such an event occurred in October 1982 on Endeavor Island, which is located in a water depth of 3.7 m in the Alaskan Beaufort Sea. As is evident in Plate 1, a southwesterly storm with wind speeds of 15-20 m/s created a 7.6 m high pile-up and caused 20-cm thick ice blocks to encroach up to 5 m onto the island work surface (Vaudrey, 1983).

Because our present understanding of pile-up mechanics is limited, encroachment estimates must be based upon statistical extrapolations of pile-up characteristics observed in the general project area. The method involves four primary steps: (1) compiling a database of historical pile-up events; (2) performing an extremal analysis to estimate the pile-up height associated with the desired return period; (3) estimating the pile-up geometry; and (4) computing the encroachment distance based on the structure geometry (Figure 2). A conservative lower bound of 30° is recommended for the slope angle β of the landward side of the pile-up. This value is based on shoreline pile-ups observed on the Alaskan Beaufort Sea coast and on the west coast of Banks Island, Canada, by Kovacs and Sodhi (1980). In the Alaskan Beaufort Sea, the predicted 100-year return period ice encroachment distances typically range from 8 to 16 m for work surface elevations of 3 to 6 m above mean sea level. A buffer zone exceeding the predicted encroachment distance can be maintained around the perimeter of the work surface to insure that sensitive facilities are not impacted.

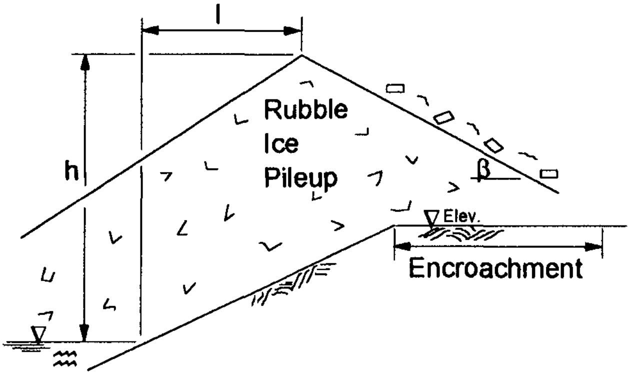

Figure 2. Ice Encroachment Geometry

Ice Gouging

The term "ice gouging" refers to the distinctive furrowing of the sea floor that results from the plowing action of ice keels. A representative example is provided in Figure 3, which displays a multi-beam sonar image of several gouges detected off the Alaskan Beaufort Sea coast in a water depth of 11 m. The single gouges were formed by individual ice keels, while the "gouge multiplet" is believed to have been caused by a multi-keeled ice feature.

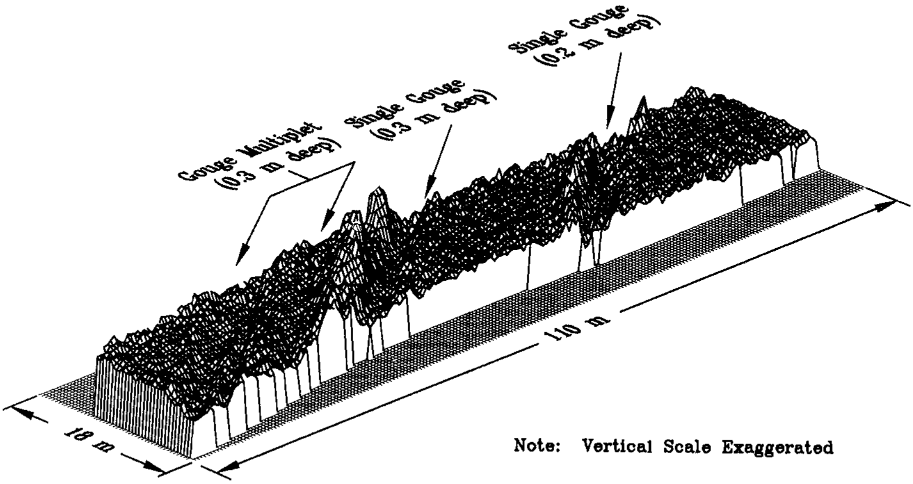

Figure 3. Multi-Beam Sonar Image of Ice Gouges in the Alaskan Beaufort Sea

The frequency and severity of gouging depend upon complex interactions between the dynamic ice environment and the sea floor sediments. Although our knowledge of the process is far from complete, key parameters appear to include the ice movement characteristics, the soil characteristics, the sea floor slope, and the water depth. From a study of ice keel structure and available driving forces, Kovacs and Mellor (1974) concluded that virtually all ice keels possess sufficient strength for gouging.

Extensive ice gouge measurement programs were conducted in the Alaskan Beaufort Sea from 1970 to the mid-1980's by the U.S. Geological Survey (USGS). Based on an analysis of more than 100,000 gouges, Barnes, *et al.* (1984), reported an average gouge density of $70/km^2$ and a maximum density of $490/km^2$. The mean incision depth for individual gouges was 0.56 m (measured below the original sea floor), while the maximum measured value was 4.0 m. The dominant gouge orientation was found to be slightly onshore of contour-parallel. Additional findings from the USGS programs of potential relevance to engineering projects such as subsea pipelines include the following: (1) gouge characteristics (density, depth, and width) attain their maximum values in the zone of active ice rubble formation known as the "stamukhi zone"; (2) sea floor morphology influences the intensity of gouging, with shallower gouges typically occurring in areas protected by offshore shoals; (3) gouge frequency and size are extremely variable from year to year in any one area, and from area to area in any one year (Rearic, 1986; Rearic and Ticken, 1988).

In view of the spatial and temporal variability inherent the gouging process, repeated annual surveys are advisable to obtain an accurate statistical characterization of the gouge population at a particular project site. Multi-beam sonar, when used in conjunction with differentially-corrected Global Positioning System (GPS) position data, has proven to be a valuable tool for such surveys. Based on two successive field programs performed in support of a planned pipeline project near Prudhoe Bay, Alaska, multi-beam sonar is capable of mapping gouge features with a resolution of less than 0.1 m.

Strudel Scour

Strudel scour depressions in the sea floor are formed in the spring, when the breakup of river ice precedes the breakup of ice in the nearshore zone. If the sea ice in the river deltas is frozen to the sea floor (as occurs in the Alaskan Beaufort Sea to a depth of 2 m), this "bottomfast" ice forms a dam that causes overflooding of the river water. The overflood water, typically 0.5 to 1.5 m deep, spreads offshore and drains through discontinuities in the ice sheet caused by tidal cracks, thermal cracks, and seal breathing holes. Such "strudel zones" usually are located immediately offshore of the river deltas, in water depths of 2 to 9 m.

In those instances where the overflood rate is high, the drainage holes become enlarged and powerful strudel jets develop. Sizable scour depressions in the sea floor can result, particularly in the area immediately seaward of the bottom fast ice where the attenuating effect of the water column on the strudel jet is minimal. Although the depressions tend to be circular in plan form, clustered scours and extended linear scours also have been detected. The probable cause of these multiple and extended scours is drainage through linear fractures in the ice sheet, such as tidal cracks.

Measurements of strudel scour characteristics, unlike those of ice gouges, have been extremely sparse. Studies conducted by the USGS in 1972 (Reimnitz, *et al.*, 1974), and 1978-80 (Reimnitz and Kempema, 1982) documented three scour depressions in the vicinity of Prudhoe Bay in water depths of 3.0 to 3.5 m. The scour depths ranged from 1.2 to 4.3 m below the original sea floor, while the maximum horizontal dimensions ranged from 12 to 25 m. Of interest for the design of nearshore structures is the data set acquired by BP Exploration (Alaska) Inc. in the vicinity of Resolution Island, which is located in 2.3 m of water off Alaska's Sagavanirktok River. Annual bathymetric surveys conducted from 1985 through 1995 revealed the formation of seven strudel scours in proximity to the island toe (Coastal Frontiers, 1996). The deepest, 2.8 m below the sea floor, re-filled with sediment to the point that it was no longer detectable five years after its discovery. A probable explanation for the high frequency of strudel scouring at this location is the tendency for the island to induce cracks in the surrounding ice sheet. The primary implication for coastal projects is that the lower slope and toe of a nearshore structure may require additional protection to withstand the strudel jets caused by the presence of that structure.

OCEANOGRAPHIC DESIGN CONSIDERATIONS

Oceanographic design considerations in cold regions are analogous to those in temperate climates, with water levels, waves, and currents often constituting the key parameters. Complications can arise, however, from factors that include a paucity of measured data and exceptionally large storm surges.

Due to low population densities, low volumes of vessel traffic, and the difficulties associated with obtaining measurements in ice-infested waters, oceanographic data tend to be sparse or non-existent in many cold regions. Of particular concern is the situation that arises in areas like the Beaufort Sea, where the most severe storm events of the open-water season often occur just prior to freeze-up. If bottom-mounted instruments such as wave gauges or current meters are removed in advance of this period, the data may be skewed toward milder conditions. Conversely, if the instruments are allowed to remain in place until after freeze-up and then recovered through the ice, the probability of damage or loss from ice keel impacts increases substantially.

In the absence of reliable measurements, the database needed to estimate extreme events at coastal project sites must be derived from hindcast analyses. Difficulties may be encountered in a number of areas, beginning with a lack of meteorological data from which to specify the wind fields. Also problematic is the influence of sea ice, whose damping effect on wave generation and propagation is not fully understood. Specification of the fetch for wave generation is further complicated by the mobility of the ice edge during storm events.

Despite these difficulties, the hindcast approach has proven to be both reliable and cost-effective in the Alaskan Beaufort Sea, where storm surge and wave models were used to hindcast the 16 most severe storms occurring between 1949 and 1980 (Oceanweather, 1982). Initially, the models were implemented for the entire region, with the surge model utilizing a grid spacing of 4.6 km (2.5 nautical miles) and the wave model a grid spacing of 37 km (20 nautical miles). Subsequently, nested grids have been used to predict extreme conditions at numerous individual project sites.

Because Coriolis force increases with the sine of the latitude, coast-parallel winds at high latitude produce storm surges and setdowns of greater magnitude than would occur under similar conditions at low latitude. One obvious implication is that flooding constitutes a major design consideration for many coastal projects in cold regions. In the Beaufort Sea, for example, the predicted 100-year surge heights are typically on the order of 2 m, and driftwood strand lines have been observed as high as 3.4 m above mean sea level (Reimnitz and Maurer, 1979).

Surge-altered water levels are important not only for their direct impact on coastal flooding, but also for their indirect influence on wave and current conditions. In those areas where the wave heights are depth-limited, the elevated water levels that result from storm surge can cause substantial increases in design wave heights. To properly account for this phenomenon in hindcast analyses, a time-series history of water levels should be developed for each historical storm and then utilized when modeling the wave conditions for that event.

The pronounced surge and setdown events that occur at high latitude can induce accelerated coastal boundary currents. As water either builds up or draws down at the coastline, a sloping sea surface is created in the shore-perpendicular direction. The resulting pressure gradient couples geostrophically with Coriolis force to produce a strong shore-parallel flow known as a barotropic coastal jet (Csanady, 1982). Indirect evidence supporting the existence of such currents is provided by ice floe velocities recorded in the Alaskan Beaufort Sea during the 1984 open-water season (Tekmarine, *et al.*, 1985). The floe velocities measured landward of the 30-m isobath during periods of accelerating winds averaged approximately 5% of the wind speed, which is substantially higher than the value of 2 to 3% that might be expected in deep water. The implications of these accelerated currents for the design of nearshore structures include higher velocities for ice floe impacts during periods of open water, and an increased potential for current-induced scour.

THERMAL DESIGN CONSIDERATIONS

Of the many thermal design considerations unique to cold regions, those of particular importance to coastal projects include thermal erosion of ice-bonded bluff sediments, and low-temperature effects on construction materials. In the case of thermally-induced erosion, bluff retreat can result not only from sea water thawing the base of the bluff (Kobayashi and Reimnitz, 1988), but also from elevated air temperatures thawing ice lenses embedded in the bluff face.

Insight into the process of thermal erosion has been provided by an on-going monitoring program at Heald Point Peninsula, which constitutes the northeast boundary of Prudhoe Bay, Alaska. From an analysis of aerial photographs obtained periodically between 1949 and 1988, and survey data acquired annually between 1989 and 1994, it was determined that the central portion of the 5-m high western bluff was retreating at an average rate of 1.6 m/yr. The adjacent bluff areas, by comparison, were retreating at less than 0.5 m/yr (Figure 4). Annual inspections revealed the cause of the accelerated erosion to be the melting of a 2-m thick ice lens embedded in the bluff face near the top of the bluff (Plate 2). Notwithstanding the importance of factors such as wave-induced erosion of the bluff toe and the degree of soil cover on the ice lens, the dominant influence over the annual retreat rate was found to be the summer air temperature. In 1989, for example, when exceptionally high mean monthly temperatures were recorded during the summer season, the bluff edge in the area occupied by the ice lens retreated by up to 7.2 m.

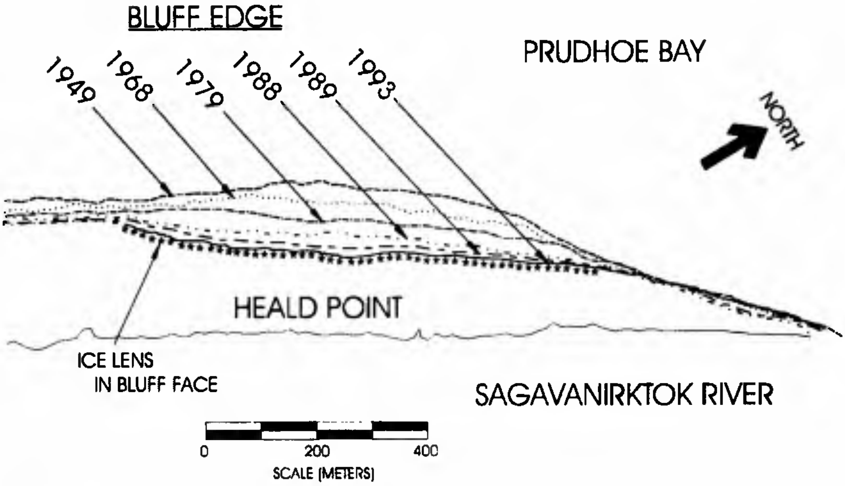

Figure 4. Historical Bluff Edge Retreat at Heald Point, Alaska

Plate 2. Thermal Erosion of Ice Lens in Heald Point Bluff Face (1993)

A particular concern with subaerial melting is that erosion can occur even in the absence of severe oceanographic events. Fortunately, however, the experience acquired with a gravel pad constructed on Heald Point suggests that the problem can be addressed by insulating the bluff face with granular fill material. Since 1993, when gravel was installed from the blufftop to the waterline at a slope of 7(H):1(V), thermal erosion of the western bluff edge has been negligible.

Among the low temperature effects on construction materials encountered in cold regions, freeze-thaw stressing and brittle failure often assume importance for the design of coastal structures. Prior to freeze-up, when air temperatures are sub-freezing but the sea remains unfrozen, materials in the splash zone can be subjected to repeated freeze-thaw cycles. To minimize the impact on concrete structures or armor units, the concrete should be made as impermeable as possible through the use of a high cement factor, a low water-cement ratio, and pozzolan or silica fume (Leidersdorf, *et al.*, 1982). Air entrainment of 6% to 9% is recommended to limit cracking. In addition, sufficient reinforcing steel must be provided to insure that the cracks which do occur will not progressively widen.

Steel components that will be subject to impact or vibration, such as lifting eyes, should remain ductile at the lowest temperatures anticipated. Although corrosion losses over the design life must be taken into consideration, data obtained on Resolution Island suggest that corrosion rates in the Alaskan Beaufort Sea are modest. During a 4-year period in which exposed carbon steel rebar was monitored in the splash zone, corrosion rates were found to be less than 0.05 mm/yr.

CONCLUSIONS

The design of coastal projects in cold regions often is complicated by the need to consider ice and thermal factors as well as oceanographic factors. In some cases, the design process involves identifying a single governing influence; in others, the potential interactions between factors must be taken into account. A representative example of the former situation arises in determining an appropriate work surface elevation for a coastal facility. Two distinctly different phenomena, wave overtopping and ice encroachment, must be evaluated independently before selecting an appropriate minimum value. A situation where interactive environmental factors assume primary importance is in designing a slope protection system that must withstand wave and ice attack. Prototype observations have indicated that ice impacts can predispose the armor to damage under wave conditions that otherwise would be considered benign (Gadd and Leidersdorf, 1990; Leidersdorf, *et al.*, 1990).

In addition to increased complexities, the environmental influences unique to cold regions often introduce increased uncertainties into the design process. At the present level of understanding, quantitative predictions of phenomena that include ice gouging, strudel scouring, and thermal erosion can be derived only from statistical treatments of limited historical databases. In consequence, a conservative approach that incorporates damage-tolerant components and non-catastrophic failure modes is recommended for the design of sensitive facilities.

REFERENCES

American Petroleum Institute, (1995), *Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions* (API RP2N), Dallas, TX.

Barnes, P.W., D.M. Rearic, and E. Reimnitz, 1984, "Ice Gouging Characteristics and Processes", in Barnes, P.W., D.M. Schell and E. Reimnitz, *The Alaskan Beaufort Sea: Ecosystems and Environments*, Academic Press, Orlando, FL, p. 185-214.

Coastal Frontiers Corporation, 1996, "1995 Resolution Island Inspection Program", Chatsworth, CA, 51 pp. + appen.

Csanady, G.P., 1982: *Circulation in the Coastal Ocean*, D. Riedel Publishing Co., Boston, MA, 279 pp.

Gadd, P.E., and C.B. Leidersdorf, 1990, "Recent Performance of Linked Concrete Mat Armor Under Wave and Ice Impact", in Edge, B.L., ed., *Proc. 22nd Coastal Engineering Conference*, ASCE, New York, NY, p. 2768-2781.

Kobayashi, N, and E. Reimnitz, 1988, "Thermal and Mechanical Erosion of Slopes and Beaches", in Chen, A.T. and C.B. Leidersdorf, eds., *Arctic Coastal Processes and Slope Protection Design*, ASCE, New York, NY, p. 46-62.

Kovacs, A. and M. Mellor, 1974, "Sea Ice Morphology and Ice as a Geologic Agent in the Southern Beaufort Sea", in J. Reed and J. Sater, *The Coast and Shelf of the Beaufort Sea*, Arctic Institute of North America, Arlington, VA, p. 113-161.

Kovacs, A. and D. Sodhi, 1980, "Shore Ice Pileup and Rideup", *Cold Regions Science and Technology*, v. 2, p. 209-288.

Leidersdorf, C.B., P.E. Gadd, and W.G. McDougal, 1990, "Arctic Slope Protection Methods, in Edge, B.L., ed., *Proc. 22nd Coastal Engineering Conference*, ASCE, New York, NY, p. 1687-1701.

Leidersdorf, C.B., R.E. Potter, B.C. Gerwick, Jr., and Y.Y. Hsu, 1982, "Modular Slope Protection for the Arctic Environment", in *Proc 14th Offshore Technology Conference*, Houston, TX, p. 689-704.

Oceanweather, Inc., 1992, "Beaufort Sea Wave Hindcast Study: Prudhoe Bay/Sag Delta and Harrison Bay", White Plains, NY, 103 pp. + appen.

Rearic, D.M., 1986, "Temporal and Spatial Character of Newly Formed Ice Gouges in Eastern Harrison Bay, Alaska, 1977-1982", Open-File Report 86-391, U.S. Geological Survey, Menlo Park, CA, 52 pp.

Rearic, D.M., and E.J. Ticken, 1988, "Ice Gouge Processes in the Alaskan Beaufort Sea", in Chen, A.C.T., and C.B. Leidersdorf, eds., *Arctic Coastal Processes and Slope Protection Design*, ASCE, New York, NY, p. 85-107.

Reimnitz, E., and E. Kempema, 1982, "High Rates of Bedload Transport Measured from Infilling Rate of Large Strudel Scour Craters in the Beaufort Sea", *Continental Shelf Research*, v. 1, n. 4, p. 237-252.

Reimnitz, E., and D.K. Maurer, 1979, "Effects of Storm Surges on the Beaufort Sea Coast, Northern Alaska", *Arctic*, v. 32, n. 4, p. 329-344.

Reimnitz, E., C. Roderick, and S. Wolf, 1974, "Strudel Scour: A Unique Arctic Marine Geologic Phenomenon", *Journal of Sedimentary Petrology*, v. 44, n. 2, p. 409-420.

Tekmarine, Inc., Polar Alpine, Inc., and Offshore and Coastal Technologies, Inc., 1985, "1984 Beaufort Sea Multiyear Ice Floe Tracking Study", AOGA Project No. 280, Sierra Madre, CA 233 pp. + appen.

Sanderson, T. 1988, *Ice Mechanics: Risks to Offshore Structures*, Graham & Trotman, London, UK.

Vaudrey, K., 1983, "1982 Freezeup Study of the Barrier Island Chain and Harrison Bay", AOGA Project No. 200, Vaudrey & Associates, Inc., San Luis Obispo, CA..

Wiegel, R.L., 1995, "Shore & Beach Observations, Alaska", *Shore & Beach*, v. 63, n. 2, p. 2, 37.