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Publisher’s version / Version de l'éditeur:

Proceedings of the 17 International Conference onthPort and Ocean Engineering under Arctic Conditions POAC'03, 2, pp. 797-806, 2003-06-16

Proceedings of the 17th International Conference on
Port and Ocean Engineering under Arctic Conditions
POAC'03
Vol. 2, pp 797-806
Trondheim, Norway, June 16-19, 2003

ICE DAMAGE ZONE AROUND CONICAL STRUCTURES: IMPLICATIONS FOR EVACUATION

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ABSTRACT

The size of the ice damage zone around conical structures was characterized by analyzing the results of physical model tests, numerical modeling and full-scale field observations. It is found that the size of the damage zone increases with increasing ice thickness and is a strong function of the ice morphology. The results are discussed in terms of the safe evacuation from an offshore conical structure in ice-covered waters.

INTRODUCTION

Since the loss of the Piper Alpha platform in July 1988, extensive work has been undertaken on upgrading escape, evacuation and rescue (EER) capabilities for offshore installations in open water. However, comparatively little effort has been expended to date on developing EER equipment and techniques for waters where sea ice is present for at least a portion of the year. Rather, the current state of EER equipment and procedures for offshore petroleum operations in ice covered waters depends primarily on adaptations of existing equipment and methods now employed in the offshore industry. This is partly attributed to the fact that most offshore petroleum exploration operations have been carried out either during the open water season or in mid- to late winter, after formation of a stable ice cover. Until recently, production facilities (e.g. Endicott and Pt. McIntyre) in the North American Arctic have been located in relatively shallow waters linked to shore via a causeway. With the development of prospects in deeper waters or where a direct link to shore is not practical (e.g. Beaufort Sea, North Caspian Sea and Sea of Okhotsk offshore Sakhalin Island), the need for effective platform-based evacuation systems designed for ice has intensified.

As defined in Cullen (1990), the term evacuation refers to the planned method of leaving the installation without directly entering the sea. Successful evacuation results in those on board the installation being transferred to an onshore location or to a safe offshore location or vessel. Evacuation methods and techniques used during drilling operations in a stable, non-moving ice regime have generally been similar to those employed on land-based drilling units. For operations in the subarctic where extensive periods of open water occur, drilling operations have generally been carried out during the summer months, relying on conventional marine approaches. In the case of Alaskan Cook Inlet platforms (where sea ice approaching up to 1 m thick can be present for 3 to 4 months each year), emergency response plans deal primarily with the open water season.

The present study was undertaken to ascertain whether during a platform emergency, personnel could be safely evacuated to a solid ice cover (or to a partial ice cover). To have confidence in developing this system, information was required on the dimensions of the zone of broken ice along the sides of the structure, in the direction perpendicular to the ice movement. In this paper the offshore ice environment is characterized in the vicinity of sloping structures deployed in water depths where grounded rubble is not expected to form. This information is applicable to many arctic and subarctic regions of the world such as the Russian and North American Arctic and subarctic as well as more southerly seas where sea ice may impact hydrocarbon development activities, e.g., northern Caspian Sea, Sea of Okhotsk, and Bohai Bay (Wang et al., 1993).

BACKGROUND

To gain insight into the width characteristics of broken ice along the sides of a conical structure, ExxonMobil commissioned the Canadian Hydraulics Centre (CHC) of the National Research Council of Canada (Timco and Morin, 1996), and the US Army Corps of Engineers Cold Regions Research and Engineering Laboratory, CRREL (Sodhi, 1996) to analyze non-proprietary information on ice around conical structures. The work collects information from physical model tests, numerical model results, and field observations with conical-shaped structures.

Dynamic ice conditions adjacent to a sloping structure can be highly variable and safe approaches for evacuation must satisfy criteria experienced over a range of ice conditions. As illustrated in Figure 1, there are in general terms, three basic ice zones around a structure: 1) the **updrift** direction, 2) the **longside** direction and 3) the **downdrift** direction. The updrift side of the structure is the area where dynamic ice and active failure processes are usually observed. Significant ice rubble and pile up can occur updrift of the structure. Therefore, under most scenarios, this side of the structure is assumed to be inaccessible when developing the evacuation strategy. Ice clearing around the sides of the structure can also be quite dynamic. The width of this broken ice zone is a function of the ice thickness and failure mode. Evacuation from the longside region of the structure could be accomplished by bridging the broken ice zone. Depending on ice drift characteristics, one side of the structure may be preferred over the other. Finally, the downdrift direction may at times exhibit either an open water wake or a broken ice area that fills with brash ice created from the ice-structure interaction and thus may be safe for evacuation from an ice standpoint. However, because the downdrift area is typically located in the down wind direction, it is expected to be inaccessible during most of the major platform emergency incidents (e.g. fires and unignited gas blowouts).

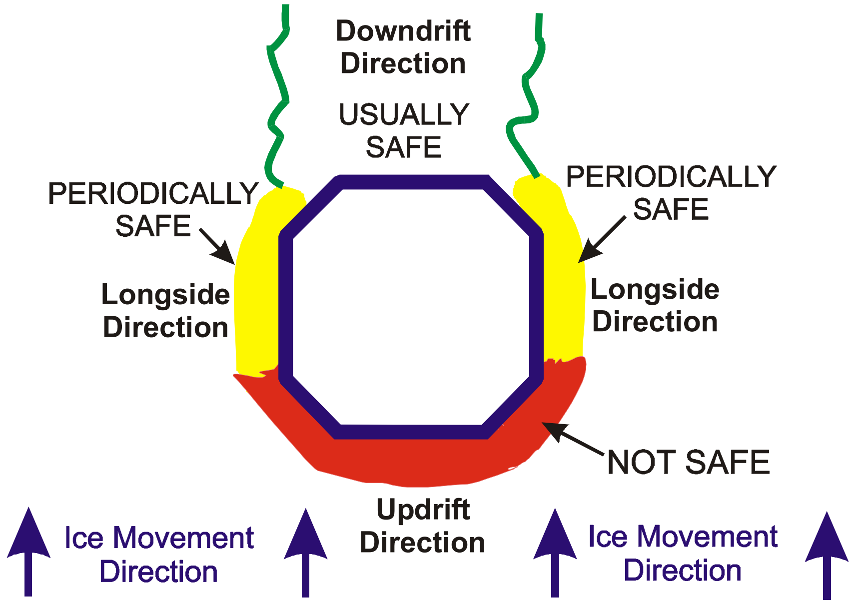

Figure 1. Anticipated evacuation directions from a structure in ice

The objective of this assessment was to characterize the extent of the zone of deformation of both a first-year ice sheet and rubble/ridges during their interaction with a sloping structure. Figure 2 illustrates the definition of terms used in the analysis. In this case, the "**Maximum Damage Distance**" from the edge of the cone at the waterline to the farthest point of broken ice (i.e., perpendicular to the ice movement direction) was quantified. Available information was analyzed to provide quantitative information on the size of the damage zone. The lateral damage distance was calculated from the path width and water-line diameter. The resulting data were subsequently used by ExxonMobil to support development of an EER strategy. Specifically, the data were used to assess the feasibility of evacuating personnel in response to an onboard emergency from the longside direction of a sloping structure onto an ice cover.

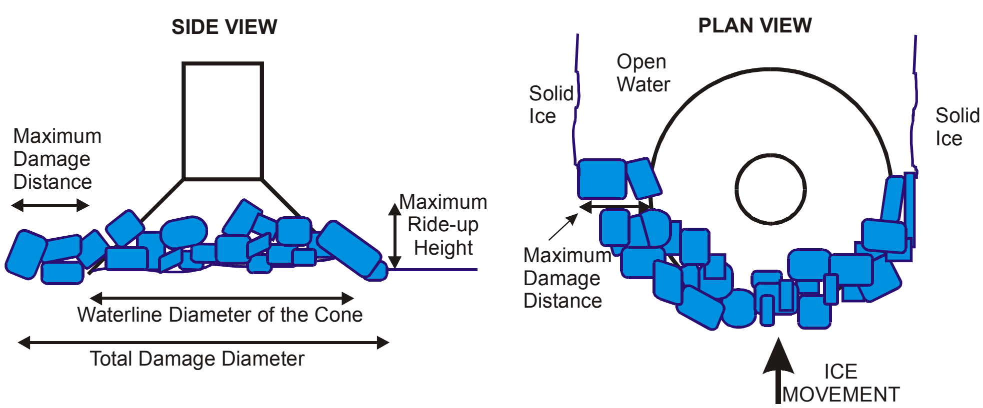

Figure 2. Ice-structure interaction details and the definition of the maximum damage distance

PHYSICAL MODEL TESTS

Whereas many small-scale studies reported the size broken ice blocks and the manner in which an ice sheet cracks when interacting with a structure, few provide information on the width of the track created by the structure in an ice cover and the extent of its lateral ice deformation. This type of information is needed to develop a methodology as well as the systems required for evacuation of personnel off a structure in a direction perpendicular to ice movement (i.e. the longside direction). Information for the present study was collected for both level ice and ridge loading on a cone.

Information on the width of the broken ice along the sides of the model was provided by an analysis of videos and/or photographs taken during the model tests. In most cases, cameras were fixed to a carriage moving with and/or in front of the structure. This video image provided a means of determining the width of the broken ice zone using a scale. In performing the measurements, the video display screen was calibrated, based on the known dimensions of the model structure. This calibration gave a ratio between the screen image and the model dimensions which in turn was used to calculate the lateral distance of the damaged ice zone. With this technique, the accuracy of the measurements depends upon the angle of the camera relative to the structure. Since the angle was set to be relatively low, this approach was deemed to provide reliable results. This information was subsequently scaled to representative full-scale conditions using conventional Froude scaling laws (see e.g. Timco, 1984).

Four model test programs were analyzed to collect information on ice loading on cones:

CHC Multi-faceted Cone - The CHC investigated the loads from both level ice and ridges on a multi-faceted cone (Irani and Timco, 1993). Tests were performed over a wide range of ice strength and thickness.

CHC PEI Pier - The CHC investigated the ice loads on the design of PEI bridge piers for both level ice and ridge loading (Timco and Cornett, 1995: Timco et al., 1996). Piers were columnar in shape, but they contain a 52° slope conical icebreaking collar at the waterline. Model tests were performed at a geometrically scaled 1:30 representation of a full-scale pier.

CRREL Tests - Sodhi (1996) assessed the ice damage zone using videos and photographs from model tests evaluating first-year level ice forces on three different types of sloping structures. The model scale of the tests ranged from 1:16 to 1:50. The small-scale model tests revealed that the ice sheet was lifted up or down by the structure's sloping surface and broke non-simultaneously around the structure into crescent-shaped ice blocks. This resulted in a wavy edge to the track in the ice sheet that was attributed by Sodhi as being due to randomly located contact points between the advancing ice sheet and the sloping sided structure. The ice damage zone width was conservatively estimated as about five times the level ice thickness.

Arctec Cone - A model test program performed at Arctec Inc. (Edwards and Abdelnour, 1975) provided information on loading from ice ridges. This study used synthetic model ice modeling multi-year ridges.

Level Ice

Analyses of level ice loading a cone revealed that the ice failed as it encountered the cone, rode up the face of the cone, and then rolled back and fell to the side or in front of the cone on the advancing ice sheet. In some cases, the ice rode up to the top of the model structure. The broken ice usually cleared around the structure, but it was observed that clearing was a function of the ice strength and thickness (Izumiyama et al., 1994).

Figure 3 is a plot of the maximum damage distance versus the ice thickness, extrapolated to full-scale conditions for loading with level ice. There is good agreement between the data extracted from the CHC multi-faceted cone tests and the CHC/PEI pier tests. Although there is scatter in the data, a general trend of increasing damage distance with increasing ice thickness is apparent. A best-fit power law of the form $D_{max} = m\,h_i^b$ was chosen to characterize the data. In this equation, D_{max} is the maximum measured damage distance in the longside direction, h_i is the ice sheet thickness and m and b are constants. For level ice, the best-fit equation ($r^2 = 0.87$) was $D_{max} = 3.57 h_i^{0.64}$.

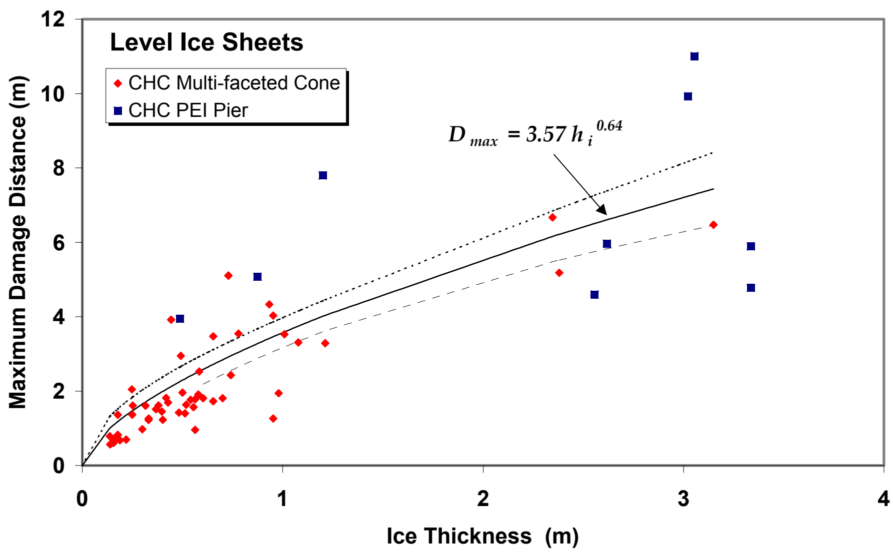

Figure 3. Maximum damage distance versus level ice thickness, extrapolated to full-scale conditions for the multi-faceted cone and PEI model test programs. Dashed lines indicate the 95% confidence limits

Ridges

During ridge interaction with the cone, the ridge usually cracked in a number of different locations resulting in break-up into several large pieces. In this case, the distance to the furthest crack was defined to be the Maximum Damage Distance. The ridge typically failed with a progressive series of cracks. The ridge first cracked across its width at a point initiated by the model. This was followed by secondary cracks further out along the ridge. Depending upon the model test conditions, there could be a wide range of sizes for the ridge pieces after the interaction process. Five failure modes were observed: 1) large-scale lifting of the ridge, 2) ridge splitting, 3) circumferential cusp failure, 4) ploughing failure, and 5) ridge breaking apart into several pieces. For nearly all of the interaction events, there was a combination of more than one of these failure modes. In general, the failure of the ridge started with an uplift of the ridge followed by either a splitting or a cusp failure. The level ice played a role in defining the failure pattern of the ridge. When the level ice behind the ridge was relatively thin and weak, the ridge was more likely to fail by splitting whereas when the level ice provided support for the ridge, the ridge failures tended to be more localized around the structure. Although the failure behavior was complex, the size of the broken ice pieces, as well as the extent of the failure pattern, tended to be much smaller with the weaker ice.

Figure 4 shows the Maximum Damage Distance versus the thickness of the consolidated layer of the ridge from the physical model tests. There is good agreement between three of the data sets, with a definite trend of increasing damage length with increasing thickness of the consolidated layer. Similar to the level-ice tests, a best-fit power law (r^2 = 0.91) for these tests was determined for these data where h_{con} is the average thickness of the consolidated layer of the ridge. This analysis gave $D_{\max} = 13.6\, h_{con}^{0.97}$. Thus, in this case there is an almost linear relationship between the damage distance and the thickness of the consolidated layer. Note that in the case where the ridge failure mode was by the ridge breaking apart, the damage zone was smaller and relatively independent of ice thickness.

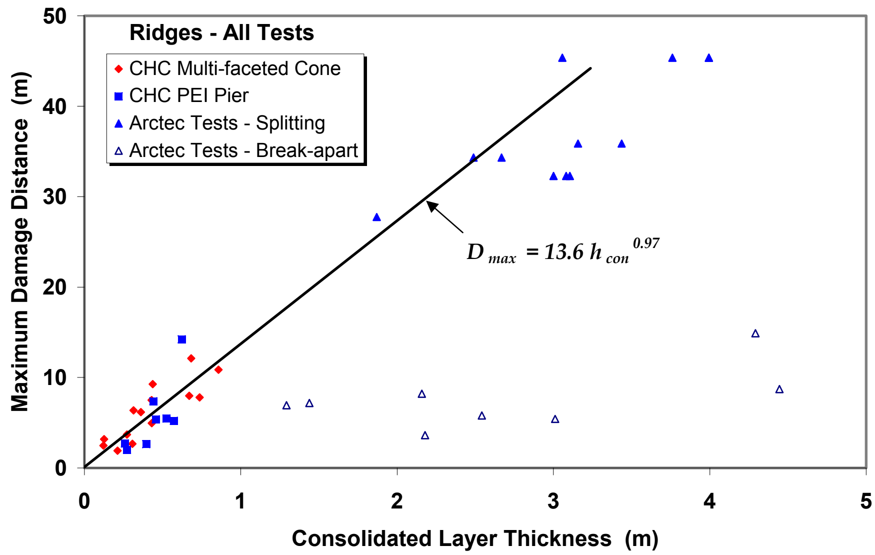

Figure 4. Maximum damage distance versus consolidated layer thickness for ridges extrapolated to full-scale conditions

NUMERICAL MODELING

Recently, Barker and Timco (2003) used an implicit particle-in-cell numerical model to investigate the influence of the structure shape on the size and extent of the ice damage zone around an offshore structure. A conical-shaped structure was used in the analysis with a Maximum Damage Distance of 3 m for an ice thickness of 1 m. The paper by Barker and Timco (2003) should be consulted for full details.

FIELD OBSERVATIONS

To collect information on the damage zone around conical structures in the field, two different structures were investigated:

1. Photographs and videos of the ice interaction with three conical light piers (Curve 1, Curve 3, Yamachiche) that are in the St. Lawrence River in Canada.
2. Photographs showing the ice interaction with the conical piers of the Confederation Bridge in Canada. These observations were made during the construction of the bridge.

The observations showed a range of scatter with damage zones ranging from 2 to 8 m for ice with a thickness of 0.3 to 0.6 m.

COMPARISON OF RESULTS

Figure 5 shows a compilation of all of the results of this study. The results show that the Maximum Damage Distance in the longside direction is a function of ice thickness and the morphology of the ice. The results show that the damage distance can range up to 15 m for a 1 m ice thickness.

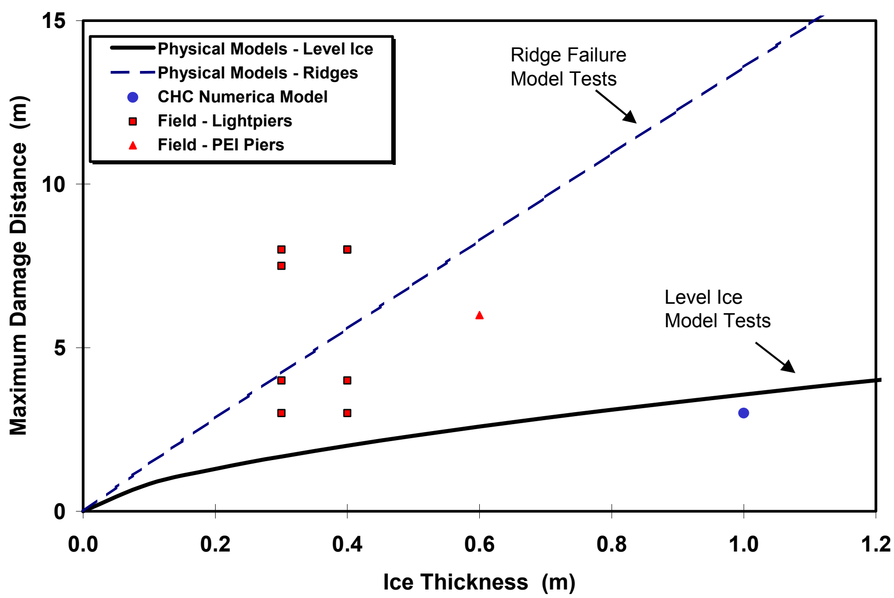

Figure 5: Comparison of extrapolated results from physical model tests, numerical models, and field observations

IMPLICATIONS FOR EVACUATION

The evacuation strategy amidst dynamic ice conditions needs to be given more consideration. Two important issues requiring resolution are:

1. What environmental conditions are likely to exist during evacuations?
2. What specific emergency responses are appropriate over the full range of environmental conditions anticipated?

Evacuation Environments

Sea ice is an extremely important factor to consider when devising an EER strategy for ice covered waters. Scenarios based on environmental conditions that might be present when abandoning a platform in a sea that contains sea ice for a portion of the year include:

- Abandonment to open water with little or no ice present
- Abandonment to a solid, non-moving ice cover
- Abandonment to a newly-formed ice cover, and
- Abandonment to a sea with a partial ice cover

Evacuation methods during the open water season with little or no ice present can utilize conventional marine means such as those employed for the North Sea and other cold water areas. During periods with higher sea ice concentrations, additional factors must be considered. For example, the fire protection system of a TEMPSC deployed on ice may be rendered inoperable. Abandonment onto a solid, stable, non-moving ice cover (e.g. landfast ice) is similar to abandoning a land-based drilling unit. However, unlike a land-based operation, escape routes to and across the ice must be provided. Additionally, personnel involved in the abandonment must be supplied with suitable gear to survive the arctic environment. It is not uncommon for unstable rubble fields or collars to form around offshore structures. Because of its roughness and inherent instability, ice rubble is difficult to traverse by foot and would be especially so under duress caused by the emergency. Therefore, a means of abandonment that accounts for bridging the ice rubble would be desirable. Due to weight, space, maintenance, training and cost implications, a system that could offer year-round evacuation capability would be preferred.

Abandonment to a newly formed ice cover presents a more formidable challenge. This is because nilas or new ice may not be capable of supporting the weight of a person and may impede or prevent a totally enclosed motor propelled survival craft (TEMPSC or lifeboat) from maneuvering. This ice condition would make it difficult to abandon an offshore installation without outside support and as such may present one of the most difficult environments in which to evacuate. However, if the current is fast enough, a strategy that relies on the TEMPSC to drift away from the structure upon launch may be feasible.

Abandonment into a sea with a partial ice cover may be necessary at various times during winter and during the spring melt season. This type of condition ranges from open water to about nine-tenths ice cover with ice generally sufficiently thick to be able to support both people and equipment. The ice would most likely be drifting past the offshore installation, but could be potentially from any direction. In lower ice concentrations, abandonment in this type of ice condition may allow lifeboats to be lowered into open water and to be maneuvered away from the platform. At higher concentrations, the ice may drift past the installation in one or two preferred directions, but could, depending on the tidal cycle move in any direction and/or temporarily linger in one position.

Potential Evacuation Approaches for Ice Covered Seas

The preferred way to resolve current issues associated with evacuation in ice from sloping structures would be to provide a means that is the same regardless of the conditions encountered. Potential EER systems for ice-covered waters are discussed in Poplin et al. (1998) and Wright et al. (2002). Helicopters or transfer directly to a vessel are the preferred means when environmental conditions and the nature of the incident allow. Direct transfer to the deck of a standby ice management icebreaker (as currently planned by Exxon Neftegas Limited for offshore Sakhalin) is an acceptable, but costly approach in the long-term. Unfortunately, at present, there is no proven, lower cost technology that can be readily used under all environmental conditions. However, there is emerging technology that might help fill the gap in evacuation procedures in the arctic and subarctic offshore.

For installations in dynamic sea ice where sour gas is not present (e.g. offshore Sakhalin, Beaufort Sea, etc.), methods that can bridge the ice damage zone and place an evacuation craft either onto a drifting ice cover or into the sea in a partial ice cover, are preferred. Marine survival craft potentially including winterized and ice-enhanced TEMPSC could be lowered beyond the ice damage zone via conventional davits if the platform deck overhang is sufficient to span the ice damage zone. Evacuation craft could also be lowered conventionally to the moving ice via a cantilever if the overhang distance is not sufficient to span the ice damage zone. Alternatively, articulated systems currently being developed by others show promise in being capable of placing an evacuation craft beyond the ice damage zone.

Bridging the damage zone in dynamic level ice is not expected to be major design issue. On the other hand, spanning the damage distance for ridges in a dynamic ice pack could pose a major challenge to the aforementioned concepts. From the standpoint of evacuation, this maximum damage distance is considered to be conservative. For example, it may be possible to launch a marine survival craft onto a smaller, partially deformed ridge fragment (or into the sea in a partial ice cover) that is closer to the structure without compromising the safety of those on board. However, additional analysis is warranted to determine the minimum evacuation distance required for design. In addition, it is necessary to account for the ice characteristics, the hull shape, the size and weight of the craft, and its resistance to ice forces and abrasion.

When the structure concept is selected, the type of ice-structure interaction anticipated needs to be assessed to ascertain the nature and extent of ice pile-up, ride-up, and rubble field formation around the structure. Then, a determination can be made as to the best methods of escape and evacuation either onto the ice or into the water and the best location for placement of the lifesaving equipment.

CONCLUSIONS

An analysis was made of the size of the damage zone around conical-shaped structures in ice-covered waters. Based on an analysis of physical model test results, numerical modeling and full-scale field observations, it was found that the size of the damage zone increases with increasing ice thickness and is a strong function of the ice morphology. These data were used to evaluate the feasibility of a platform abandonment approach that bridges the maximum damage distance in placement of the evacuation craft.

REFERENCES

Barker, A. and G. Timco, (2003). The Effect of Structure Shape on the Broken Ice Zone Surrounding Offshore Structures. Proceedings POAC'03 (this volume). Trondheim, Norway.

Cullen, W. D., (1990). The Public Inquiry into the Piper Alpha Disaster, Vols. I & II. Presented to Parliament by the Secretary of State for Energy by Command of Her Majesty. November 1990.

Edwards, R. and R. Abdelnour, (1975). Preliminary Modeling of the Process of Penetration of Pressure Ridges by Conical Structures. Arctec Report 62C-2, Montreal, Canada (APOA 86).

Irani, M. B. and G. W. Timco, (1993). Ice Loading on a Multifaceted Conical Structure. International Journal of Offshore and Polar Engineering 3, No. 4. pp. 313-321.

Izumiyama, K., M. B. Irani and G. W. Timco, (1994). Influence of a Rubble Field in Front of a Conical Structure. Proceedings 4th ISOPE Conference, ISOPE'94, Vol. II, Osaka, Japan. pp 553-558.

Poplin, J. P., A. T. Wang and W. St. Lawrence, (1998). Escape, Evacuation and Rescue Systems for Offshore Installations in Ice-Covered Waters. Int. Conference on Marine Disaster: Forecast and Reduction, Nov. 2-5, 1998, Beijing, China. pp. 338-350.

Sodhi, D. S., (1996). Ice Deformation in the Vicinity of Sloping Structures. US Army CRREL Report for Exxon Production Research, Hanover, N.H., USA. 22p.

Timco, G. W., (1984). Ice Forces on Structures: Physical Modeling Techniques. In 2nd IAHR State-of-the-Art Report on Ice Forces on Structures, Proceedings 7th IAHR Symposium on Ice, Vol. IV, Hamburg, Germany. pp. 117-150.

Timco, G. W. and A. M. Cornett, (1995). Model Tests of Ridge Interaction with a Bridge Pier for the Northumberland Strait Crossing. NRC Report TR-1995-02, Ottawa, Ont., Canada. (Controlled).

Timco, G. W., A. M. Cornett and R. Frederking, (1996). Model Tests of Ice Interaction with the Ship Protection Collar on the PEI Bridge Piers. NRC Report HYD-CTR-011, Ottawa, Ont., Canada. (Controlled).

Timco, G. W. and I. Morin, (1996). Ice Damage Zone Around Conical Structures. Canadian Hydraulics Centre Controlled Technical Report HYD-CTR-027, Ottawa, Ont., Canada. 58p.

Wang, A. T., J. P. Poplin and C. E. Heuer, (1993). Hydrocarbon Production Concepts for Dynamic Annual Sea Ice Regimes. First Int'l. Conf. on Russian Arctic Offshore, St. Petersburg, Russia.

Wright, B. D., G. W. Timco, P. Dunderdale and M. Smith, (2002). Evaluation of Emergency Evacuation Systems in Ice-Covered Waters. PERD/CHC Report 11-39, Canmore, Alberta, Canada.