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Anne Barker, Garry Timco and Brian Wright

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CHC-TR-049

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Guidelines for Using Evacuation Shelters as a Part of Beaufort Sea EER Strategies

Anne Barker[1], Garry Timco[1] and Brian Wright[2]
[1]Canadian Hydraulics Centre
National Research Council of Canada
M-32, 1200 Montreal Road,
Ottawa, ON K1A 0R6
Canada

[2]B. Wright and Associates Ltd.,
212 Sir Charles Carey Street,
Canmore, AB, T1W 2R6
Canada

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ABSTRACT

With offshore exploration activity and the potential development of production platforms for offshore gas in the Canadian Beaufort Sea, issues related to proper Escape, Evacuation and Rescue (EER) systems are critical. Structures in the Beaufort Sea have unique requirements with respect to EER design and operation. The considerations for establishing an Evacuation Shelter (ES) on stable ice and the effects of the shoulder seasons on suitable EER systems in the Arctic may have a significant impact on receiving regulatory approval for operations. This area of study has been largely neglected in the past but it should be at the forefront of concerns for resource development in frontier regions.

This report develops guidelines for establishing ES in the Canadian Beaufort Sea region of the Arctic. The authors have developed two decision-making flowcharts. The first helps decision-makers evaluate whether an ES may be part of an overall EER strategy for a particular platform. The second flowchart aids in establishing the timing and siting of an ES in the Beaufort Sea. The report also presents the potential impact of personnel traveling over an ice surface under a range of conditions, and the costs of establishing an ES, including labour, equipment and financial concerns are estimated to provide guidelines for operators.

The information concerning ES viability is presented in order to provide guidelines for safe evacuation to an ES on stable ice. Doing so provides industry with concrete tools that may be included in future EER procedures and will provide regulatory agencies with guidelines that may be integrated into Arctic code development. Demonstrating the viability of ES(s) provides information on one part of year-round EER methods, which will remove a significant barrier for production in the frontier gas region.

RÉSUMÉ

Les travaux d'exploration pour le gaz naturel dans la mer de Beaufort au large des côtes canadiennes, et la construction éventuelle de plateformes de production, mettent en relief l'importance d'un système fiable en ce qui a trait à l'évacuation et le sauvetage du personnel. Or les ouvrages côtiers dans cette région ont des exigences particulières en ce qui concerne la conception et la mise en œuvre d'un tel système. L'approbation des organismes de réglementation pour le lancement des travaux pourrait dépendre des éléments dont il faut tenir compte dans l'établissement d'un abri de secours sur une surface de glace stable, et de la conjoncture en automne et au printemps touchant la mise en œuvre de ce système dans l'Arctique. Il s'agit d'une question qui, à ce jour, a été largement négligée et qui devrait constituer un priorité pour l'exploitation des ressources en régions éloignées.

Dans ce rapport, on présente des lignes directrices pour la conception et l'utilisation d'abris de secours en mer de Beaufort, dans l'Arctique canadien. On met de l'avant deux organigrammes servant à guider le processus décisionnel. Le premier permet d'évaluer si le recours à ces abris cadre bien dans une stratégie globale d'évacuation et de sauvetage pour une plateforme donnée. Le second sert à guider l'exploitant dans le choix d'un site et d'une période de l'année pour l'établissement d'un abri de secours en mer de Beaufort. Ce rapport s'attarde également aux risques que comporte l'accès du personnel à la couverture de glace sous différentes conditions. De plus, on aborde les coûts reliés à l'établissement d'abris de secours, incluant main-d'œuvre, équipement et autres considérations d'ordre financier.

Cette étude sur la viabilité du concept des abris de secours vise à guider l'élaboration d'un plan d'évacuation sécuritaire vers ces installations sur de la glace stable. Elle présente donc des outils

que les intervenants du secteur privé pourront inclure dans des procédures éventuelles d'évacuation et de sauvetage et qui serviront de guide aux organismes de réglementation dans la formulation de leurs directives. La viabilité de ce concept fait partie intégrante d'un système d'évacuation et de sauvetage mis en place au cours d'une année, et permettra de surmonter un obstacle important à l'exploitation des ressources de gaz naturel en régions éloignées.

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1. INTRODUCTION

With the development of exploration platforms and potential deployment of production platforms in the Canadian Beaufort Sea, numerous challenges arise concerning evacuation and rescue procedures in ice-covered waters. The ISO Code for emergency Escape, Evacuation, and Rescue (EER) from arctic structures, which is currently being developed, is based on an integrated system of risk, environment, hardware integrity, personnel competence, and procedures and controls. These must be balanced to ensure that the safety level remains the same throughout the year. For a production platform in open water conditions, this is usually achievable with systems that are developed for year-round similar conditions. For a structure in the Arctic, however, this is not the case and the Health, Safety and the Environment (HSE) Management System must consider a wider variety of options. Some of these options may only be appropriate for specific times of the year.

During the summer months, in open-water conditions, personnel may be evacuated using conventional methods, such as helicopters, loading to vessels and emergency craft such as TEMPSC. In the remaining months, if a preferred means of evacuation such as a helicopter is not available, the options for evacuation may narrow considerably. Additionally, platforms require primary and secondary means of evacuation. In the autumn, ice formation begins and conventional TEMPSC systems may incur damage from moving ice. Further, station keeping of supply vessels becomes difficult due to the increasingly severe ice conditions. Icebreaking vessels would be required to possibly clear away any accumulated rubble around the structure for station keeping purposes. During the winter months, when a structure may be surrounded by landfast ice and/or a stable, grounded rubble field, icebreaking vessels are not feasible, and without means of self-propulsion over the ice, conventional TEMPSC could only be lowered onto the ice as shelters. Tracked or amphibious vehicles may be more suitable for this time of year, although they too may have limitations traversing a typical rubble field or large ridges, if navigation around such features is not possible. However, it can be feasible to establish an evacuation shelter (ES) on the ice that surrounds the platform. An ES could range from an inflatable raft housed until needed in a canister to a semi-permanent shelter that remains set-up throughout its period of use. Regardless of the physical type of shelter, it should be capable of providing protection for personnel for a certain amount of time (generally days) from the hazard, the environment and bears, and be equipped with sufficient provisions, heating and so on for survival until rescue can be completed. Such a structure has flexibility in the location of the shelter(s) on the ice, and takes advantage of the presence of ice. Naturally, in the spring, similar issues to the autumn may exist and during break-up an ES cannot be used; other systems must again be deployed. Clearly, there are major challenges to safe EER procedures in ice-covered waters.

If an ES is established, and a large, grounded rubble field surrounds the exploration or production platform, the field would need to be traversed in order for personnel to reach this safe haven. A variety of possibilities exist for establishing a route through the rubble to the ES, by bulldozing, creating a spray ice road or by “simply” traversing the field. This report examines the viability of establishing a route and shelter, presenting two decision-making guides: one for determining whether or not an ES is an appropriate strategy for a given platform and if so, where and when such a structure may be sited. Additionally, the associated risks, costs, maintenance and physical requirements necessary to keep such a route open are examined. For example, the number of ES necessary for different scenarios is researched. Would one ES suffice? What would happen if the ES was located down-wind, in the event of an explosion or fire? Should another ES be established at the opposite side of the structure? But this possibility may be limited by the size, extent and anisotropy of a typical rubble field. A report and paper (Barker and Timco 2006; Barker et al. 2006a) examined the characteristics of grounded rubble fields, and provides input into this aspect of the study. Aspects relating to moving pack ice and winter evacuation conditions have been researched by Timco and Dickins (2005), Timco et al. (2006), Wright et al. (2003) and Simões Ré et al. (2003), for example. However, most of these studies addressed neither the potential combination of rubble and pack ice, nor the logistics involved in ES use.

This project has a novel aspect not previously examined in a Canadian context, as it incorporates the first systematic investigation of the issue of traversing rubble fields and in applying ice engineering technology (spray ice and ice management) to the EER process. During the course of this four-year project, the Arctic exploration platform at Paktoa C-60 was established. Discussions with the authors, industry and regulators led to the deployment of an ES at this site by Devon Canada. This report documents that deployment of the Paktoa C-60 ES, including the procedures used to do so. The considerations for establishing ES on ice in the Arctic may have a significant impact on receiving regulatory approval for operations. This area of study has been largely neglected in the past but it should be at the forefront of concerns for resource development in frontier regions. The data obtained from this project is interpreted to provide guidelines for safe evacuation to an ES. This will provide industry with concrete tools that may be included in future EER procedures and will provide regulatory agencies with guidelines that may be integrated into Arctic code development.

2. DECISION-MAKING PROCESS FOR CONSIDERING AND ESTABLISHING AN EVACUATION SHELTER

2.1 General

There are a number of factors that must be recognized when considering the deployment of an ES on the ice cover around Beaufort Sea structures. The first and most obvious factor is the stability of the ice that is adjacent to the structure. Clearly, the structure must be located within the landfast ice zone and/or surrounded by a grounded ice rubble field that is both stable and sizable, for an on-ice ES to be feasible.

This section of the report identifies the range of factors that should be accounted for when deciding whether an ES may be part of a platform's EER strategy and when selecting an appropriate ES location on the ice adjacent to a structure. It also provides some representative examples of full scale data, to illustrate key points about the "do-ability" of on-ice ES deployments, on a scenario basis, as a function of water depth.

2.2 Key Considerations

The main topic areas that should be addressed when evaluating the option of placing an ES on the ice around a Beaufort Sea structure are apparent, and include:

- the type of Beaufort Sea structure
- the type of ice regime in which it is deployed
- the type and extent of the ice rubble that may form around the structure

Once the decision to proceed with using an ES has been made, additional topics to be considered include:

- the time dependent nature of the ice regime and ice rubble around the structure
- the preferred location of the ES (s) in relation to the structure
- the preferred location of an ES (s) in relation to the hazards that may occur
- the type and number of on-ice routes to the ES (s) placed around the structure

The type of platform that is under consideration and its function are obvious factors of importance and are also intertwined with considerations of water depth. In this regard, the only Beaufort structures for which the deployment of an on-ice ES is possible are ones that are located in landfast ice or situated in deeper water pack ice areas (i.e. in the transition zone) which will "capture" stable grounded ice rubble fields around them. Also, the function of the structure, as either an exploration or production platform, has a relationship to the range of hazards that may occur and the number of onboard personnel that may have to be evacuated.

The type of ice regime in which the structure is located is of patent importance, as noted above. The structure must be located within the landfast ice zone and/or surrounded by a grounded ice rubble field that is both stable and sizable, for an on-ice ES to be feasible. In the Beaufort Sea, the landfast ice zone is the most quiescent, and should be favoured for the on-ice deployment of an ES. However, ES placements in grounded rubble fields around structures in the pack ice zone are also worthy of consideration. A diagram of the typical ice regimes of the Beaufort Sea region is shown in Figure 1. A discussion regarding the extent and thickness of seasonal pack ice may also be found in Melling et al. (2005).

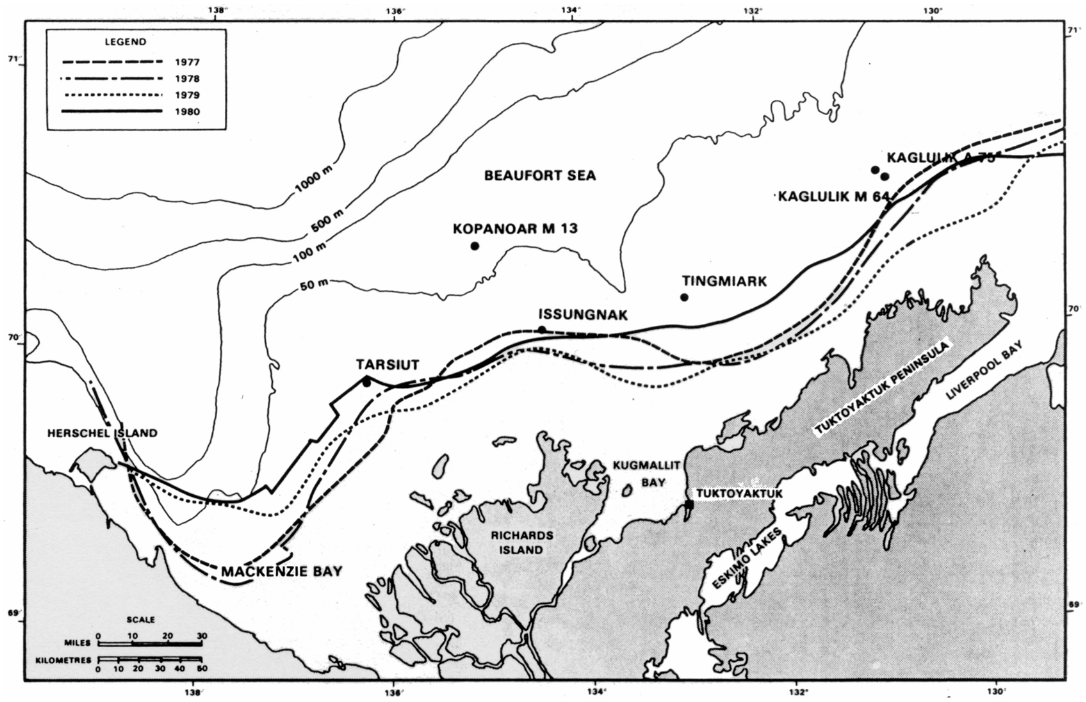

Figure 1 Diagram showing maximum extent of Beaufort Sea landfast ice edge from 1977-1980 (Dome Petroleum Ltd. et al., 1982).

The type and extent of the ice rubble that may form around the structure was extensively examined in Canatec Consultants Ltd. (1994) and Spedding (1987), while Barker and Timco (2006) examined rubble field dimensions and timing specifically in the context of EER procedures. There were three key results of the latter report with respect to ES considerations:

- The anisotropy of a rubble field will play a large role in the location of an ES, as fields are rarely a uniform shape around a structure. In some cases, little or no rubble may be present at one side of a structure, for example, while in other cases, an extensive rubble field may completely surround the structure.
- The definition of the stability of a rubble field needs to be clarified with respect to EER strategies. For example, whether a rubble field is safe for personnel versus whether it is stable may have different definitions depending upon the level of safety required by regulators, calculation methods (grounding resistance, presence of landfast ice, percentage of grounding), time of year and so on.
- The third key result ties into the time-dependent nature of the ice regime and ice rubble formation. Four seasons with respect to evacuation were described in the report: open water, pack ice, quasi-stable rubble and stable rubble/ice. At any given location, and often changing each year, an offshore structure in the Arctic will encounter two or more of these seasons. The latter two seasons, quasi-stable rubble and stable rubble/ice, are those that may be considered as potentially suitable for an ES. For the rubble fields that were examined in that report, these rubble features (whether floating or grounded) were present for a large period of the year. This could be an advantage for ES applications. The timing of the development, stabilization and decay of the ice at a site is of prime importance regarding the placement of an ES, and needs to be revisited throughout a drilling program, as this will impact the initiation and implementation of any ES strategy.

Figure 2 outlines the decision-making process for determining whether an ES may be a viable part of an HSE Management Plan.

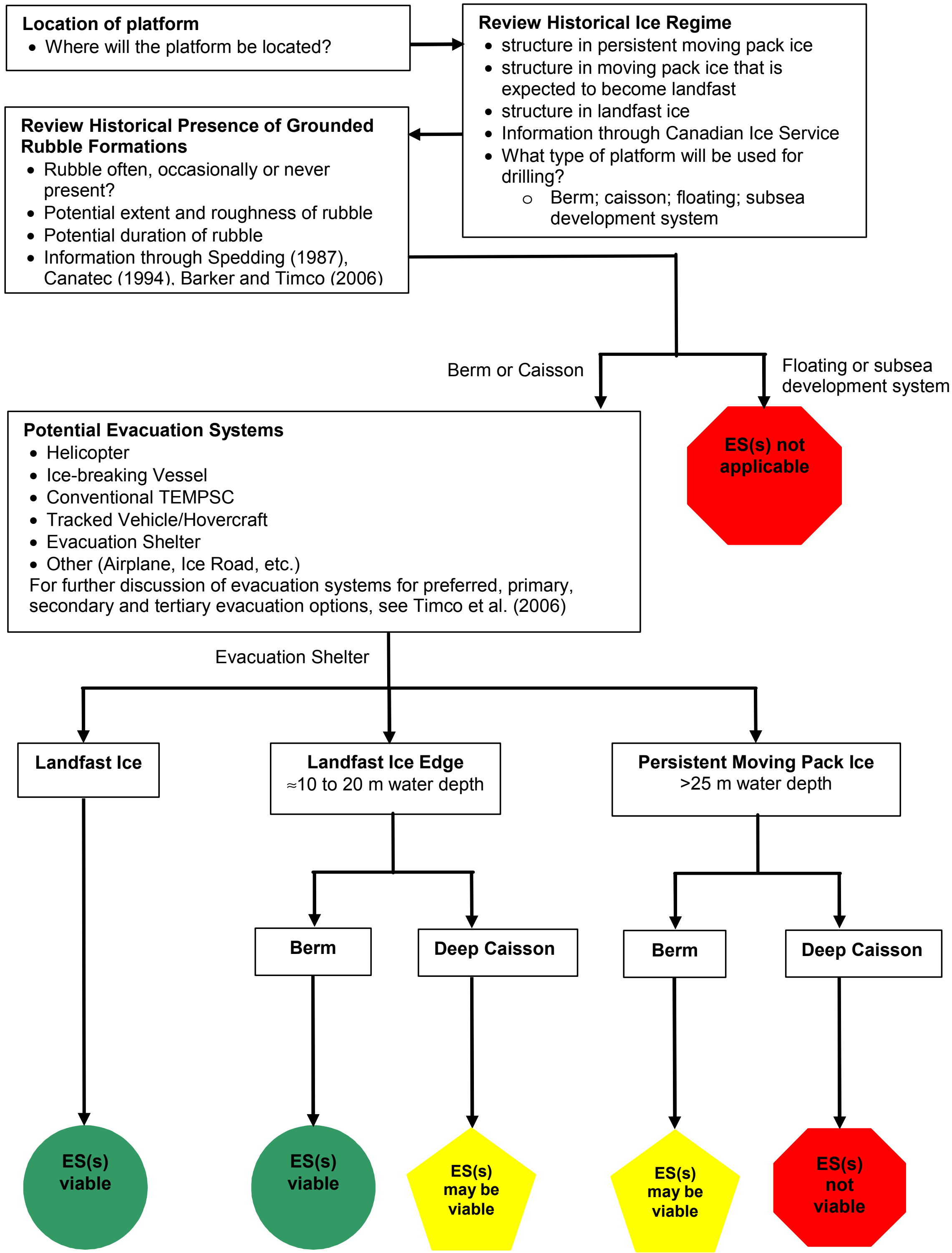

Figure 2 Decision-making process for determining whether an ES may be part of the HSE Management Plan.

Once it has been decided that an ES is a viable part of an HSE Management plan, the remaining topics of consideration may be evaluated. The preferred location of the ES(s) in relation to the structure, the preferred location of an ES(s) in relation to the hazards that may occur and the type and number of on-ice routes to the ES(s) placed around the structure may all be specific requirements as outlined by regulator or operator guidelines. However, some general considerations include locating the ES sufficiently far away from the structure that personnel will be at a safe distance from a hazard, but also such that the ES is not so close to an active edge of the rubble field that personnel become at risk from failing ice. The number of ESs required may be based upon the nature of the ice surrounding the structure (e.g. if there is only a marginal rubble field and no landfast ice, there may be no room for an ES and it may be unsafe to place such a shelter on the ice), the nature of any hazards that may occur, the geographical location of the structure (e.g. a location with two prominent wind directions) and the level of evacuation for which the ES is designed (e.g. secondary or tertiary).

A logic diagram for the selection of an ES site(s) is given in Figure 3. The issues that are identified in this methodology, and the logic flow for related decision- making, should be clear. Key considerations range from ice-related factors affecting the strategic placement of an ES, to considerations regarding the avoidance of the effects of any "fall-out" from the on-board problem.

The detailed planning process, as shown in Figure 3, encompasses a number of considerations. Given suitable ice conditions around a platform for the deployment of an ES(s), namely the presence of a stable ice rubble formation and/or landfast ice, the following questions are of practical importance for any evacuation plan.

- When should this type of evacuation option be adopted as being a viable option after freeze-up, and when should it be abandoned in spring?
- How to get down off the platform and onto the ice, and at how many locations to allow flexibility?
- Should one or more egress pathways be "cleared" on the surrounding ice, to allow easy access to ES(s) that have been deployed?
- How is this best done given the range of ice conditions that may be experienced?
- How should these access routes to an ES (s) be maintained?

The first point is discussed in this section, while the second point is not discussed, due to its dependence upon the type of platform. The third point and the implications of the type of over-ice route are addressed in Section 3. The fourth and fifth points are addressed in Section 4.

More specific yet ancillary issues include:

- The ability for on-board personnel to move down and off the platform, through a prepared route to an ES, the clothing they should wear, and the training they should have.
- The types of emergency supplies that should be housed in the ES(s), and related "durations", which will depend on likely rescue time frames (i.e.: hours versus days) for the evacuated personnel.

These two points are discussed in Section 5.

Barker et al. (2007) also summarizes the decision-making process, and a copy of this article may be found in Appendix A.

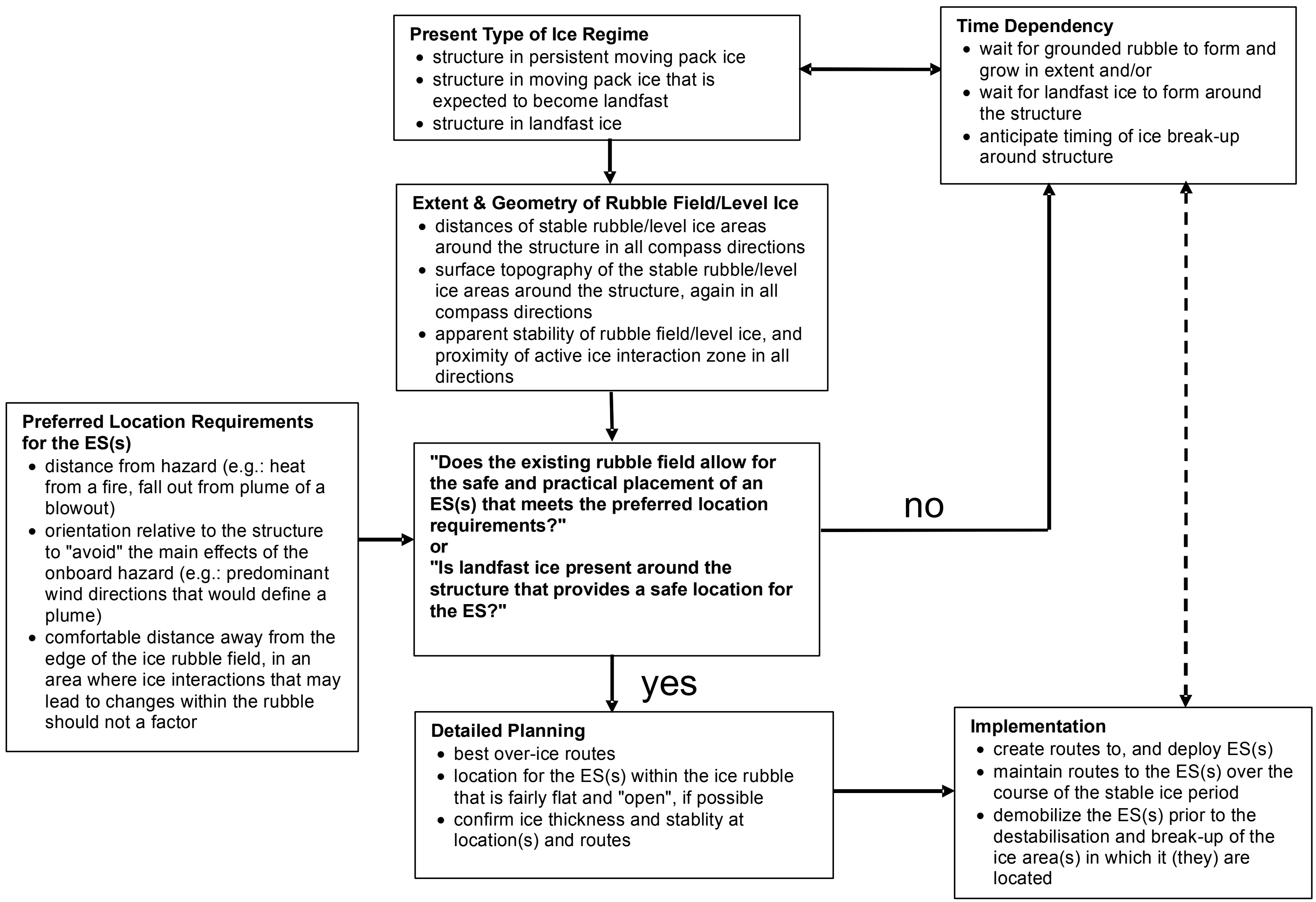

Figure 3 Evacuation Shelter site selection decision-making flowchart.

2.3 Ice Bearing Capacity and Stability Assessment

Before any shelter may be placed on the ice, it is of paramount importance that the bearing capacity and stability of the ice are ascertained. It is essential that when carrying out any work or placing of personnel on the ice, bearing capacity and stability are considered in tandem. The procedure to do so may be carried out differently depending upon the ice conditions and location of a site, however there are some common elements of consideration.

Ice bearing capacity may be defined as the amount of weight the ice can support, calculated by estimating the strength of the ice, its allowable deflection and the weight it must carry. Ice bearing capacity has been studied extensively over the years in a variety of contexts – including crowds of people on ice, ice platforms, airstrips and ice roads (e.g. Nevel and Assur, 1968; Gold, 1971; Baudais et al., 1974; Frederking and Gold, 1976). In order to ascertain if the bearing capacity of level ice or ice rubble is sufficient for personnel, a number of techniques may be employed, including ice thickness determination, observation of ice type and deformation, environmental monitoring, ice resistance calculations and use of existing charts and equations for ice thickness and bearing capacity.

For ice rubble, the bearing capacity is largely due to the strength of the rubble, which in turn is strongly related to the consolidation of the rubble field (Roth and Marcellus, 1986). As discussed in Høyland and Liferov (2005) and Timco et al. (1987), for example, the thicker the consolidated area, the stronger the ice. In these papers, the consolidation rate is linked to initial ice temperature, time available for consolidation, keel depth, oceanic flux, and so on. Timco et al. (1987) found that the consolidation depth was found to be linearly related to the square root of the product of the temperature of the ice surface and the freezing time in hours. The importance of the initial ice temperature and freezing time was confirmed in Høyland and Liferov (2005). Those authors also found that the cohesive strength of the rubble was linked to the freeze bonds that formed between ice blocks, such that the strength of the rubble increased in the initial phase of consolidation, but decreased thereafter. Roth and Marcellus (1986) summarized reports describing how the strength of the ice rubble is also related to parent ice sheet properties, confinement, porosity, temperature, loading rate and, for grounded rubble, the degree of grounding and seabed strength. They discuss that for unconsolidated broken ice, the bearing capacity will be equal to the sum of the buoyant inertial and drag forces, as a lower boundary condition. For totally consolidated broken ice, Roth and Marcellus point out that by making some assumptions, the bearing capacity for totally consolidated broken ice may be calculated as if for a level ice sheet. This calculation would give an upper boundary condition for ice rubble.

An example of the importance of determining the bearing capacity of rubble and how it may change is illustrated by way of an occurrence at the Tarsiut N-44 drilling site. At that site, during the 1981-1982 exploration drilling program, rubble was moved from one location on the site to another, to help to create a spray ice relief well pad. Where the rubble was removed, the rubble at that site, initially grounded, became floating. It was subsequently pushed away by moving ice, carrying away drilling supplies that had been placed on the ice surface. Additionally, the rubble in areas where supply vessel access had been maintained through early December did not ground.

The stability of ice may generally be described as the ability of ice to resist movement. The greater the stability, the less likely the ice is to move due to environmental forcing. For level ice, stability will largely be a factor of whether the surrounding ice is landfast, and how imbedded within the landfast ice zone a structure may be, if so. The stability of landfast ice is generally determined based upon weather conditions, air temperature, ice thickness, the presence of grounded ice features in the vicinity of the structure, and the judgment of the individual(s) responsible for this assessment, as well as the possible consequences of being wrong, should the ice become unstable. This latter may be a minor effect, for example, the ES location moves some distance from the structure but may be readily retrieved, or it could be potentially serious, such as the opening of water close to egress points off of the platform, for example.

The determination of the stability of grounded, rubble ice is not clearly defined. Resistance calculations, drilling profiles to determine degree of grounding, satellite imaging and sail height to water depth ratios are some means of stability determination that have been used to make this assessment in the past. The consolidation of ice rubble is another stability consideration, as described previously. Most of these stability issues are addressed in the initial decision-making process, as shown in Figure 3 and are further discussed in Barker and Timco (2006). Additional factors may also be considered when grounded spray ice pads, for example, are used for a base. Many times, the final decision rests upon engineering judgment.

The timing of the deployment of an ES will depend upon the type of the ice that surrounds a structure. For level ice, once the ice is strong enough and landfast, an ES is, essentially, immediately viable. When a platform is surrounded by grounded rubble, the deployment possibilities may not be so clear. As previously indicated, if the rubble field is not surrounded by landfast ice, the stability may be more difficult to ascertain. In the autumn, the rubble field may form quickly, but may be constantly changed by moving ice. In the spring, after the landfast ice has broken up, decay of the field may occur rapidly, with melt ponds forming on the surface of the field. It is likely that once the landfast ice has broken up, and decay of the field is visibly underway, an ES may not be viable, due to safety concerns for travelling over decaying ice.

The Paktoa C-60 site is used as an example of the determination of ice thickness and stability. At this site, landfast ice conditions were presumed to exist by early January. At that point, the ice was deemed safe enough to walk on by observing the ice deformation, ice type (nilas, gray, etc.), tracking the ice growth near the platform, monitoring air temperature and using Zubov's formula relating ice thickness to frost degree days. As an additional precaution, the SDC crane with a personnel basket attached was used for preliminary augering for the first time on the ice in late December. In mid-January, radar reflectors and route markers were set out along two potential routes and ES locations that were located on large, undeformed floes. The ice thickness along the routes averaged 0.67 m. However, by January 25, a movement of what had been thought to be stable, landfast ice occurred, moving the reflectors and route markers a sizeable distance from the SDC, which had to be retrieved. After that event, extensive, grounded ridges formed in the vicinity of the SDC helped to stabilize the now-landfast ice, such that a new route to a proposed evacuation shelter location could be established.

For on-ice work with heavy machinery, the general rule was to wait until the ice was over 0.6 m. Once personnel could be placed on the ice with light machinery, profiling of the ice route was able to begin, using ground penetrating radar (Figure 4) and a four-inch auger (Figure 5). Results of that survey determined that the ice was thick enough for heavier machinery and for work on the ES to begin.

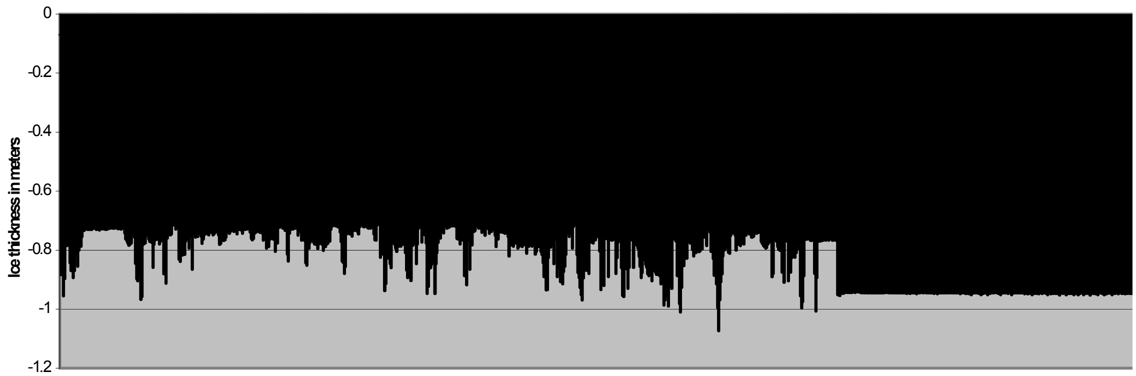

Figure 4 Results of the ground penetrating radar plotted in Excel. X-axis shows distance along the taxiway and Y-axis is ice thickness in metres (Image courtesy of Horizon Ice Inc.).

Figure 5 Manually profiling with an auger (Photograph courtesy of Horizon Ice Inc.).

2.4 Decision-Making Approach for ES Site Selection

The approach to the decision-making chart will be illustrated. For the purposes of this work, three different scenarios have been considered in terms of an appropriate “onto-ice evacuation method”, from a Beaufort platform to a surrounding stable ice rubble field, or beyond. To represent these scenarios, three case histories from previous structures used in the Beaufort Sea have been selected. The scenarios and case histories include:

- a platform located in shallow water (5m to 10m), which is surrounded by a small ice rubble field, and lies in the landfast ice regime: artificial island at Netserk F-40, in 8m of water

- a platform located in intermediate water depths (15m to 20m), which is surrounded by a sizable grounded ice rubble field, and lies in the landfast ice regime over most of the ice-covered season: Tarsiut N-44, CRI in 19m of water
- a deeper water platform (25m or more) which is surrounded by a heavily grounded ice rubble field, but is located in moving pack ice throughout the winter period: the Molikpaq (on a large berm) at Amauligak F-24 in 32m of water

The platform in intermediate water is examined in detail first. The others are then studied, to see how they may differ from this initial scenario. Aerial photographs of the ice conditions and rubble formations were acquired while these Beaufort structures were operating, along with on-ice observations. This data has been used as a basis for the “evacuation do-ability” considerations that are outlined below, on a scenario basis. For this exercise, available data included wind data for the site, rubble maps and progressive topographies throughout the winter and so on. Obviously, such site-specific data is not available for an EER system designer in advance. However, knowing expected environmental conditions for a given location (e.g. wind speed, typical ice regime, water depth), hazard distances and preferred number of routes in advance, a number of methods exist to estimate some of the required parameters such as the main effects of the onboard hazard (predominant wind direction for smoke/plume dispersion, for example) and rubble field extent. For example, Barker and Timco (2006) quantified how the size and sail height of a rubble field would impact choices of EER equipment and placement, as well as the availability or practicality of generic EER systems throughout a year at a given location.

As shown in the decision-making flowchart (Figure 3), rubble extent and geometry, as well as the timing of the formation and decay of such features, need to be taken into account when planning for an ES. Prior to actually experiencing rubble build-up at a site, a preliminary plan for preferred locations could be established, with finalization of the plan (distance from edge of rubble field, best over-ice route, location of flat/open areas within field, ice thickness determination) made once the ice around the structure[1] has formed and stabilized.

The scenarios assume that the preferred means of evacuation is by helicopter or ship and that this is not available. It also assumes that during the winter, on-ice evacuation is at most a secondary means of evacuation, while during periods of quasi-stable rubble on-ice evacuation it is a secondary or tertiary option (Wright et al., 2003; Timco and Dickins, 2005; Timco et al., 2006).

2.4.1 Scenario 1 – Large, Grounded Rubble Field with Landfast Ice, in Intermediate Water Depth

Scenario 1 will examine the situation of a platform with a large, grounded rubble field. As an example, the Tarsiut Caisson structure, used at the Tarsiut N-44 site will highlight the key points for site selection in this type of scenario. The Gulf Tarsiut Caissons together formed a structure made up of four concrete caissons, placed upon a submarine berm and filled with sand, with an additional interior sand fill. The surface was approximately 70 m in diameter, and the caissons had a low freeboard of about 5 m to the waterline. The water depth to the berm was

[1] The type of platform is not examined, due to topsides placement specifics of EER equipment. However, for scenario purposes, a minimum safe distance of 300m from a production structure with a relatively high freeboard is assumed. This value would need to be established bearing in mind each identified hazard that would require evacuation, such as a blow-out, blast effects etc. The type of structure also influences the viability of certain evacuation options. For example, the large, dredged sandbag-retained exploration drilling islands had very long, shallow berms. These features could limit the degree of access for vessels close to the drilling structure and similarly, would likely restrict the use of conventional TEMPSC. Their use is unlikely in the future, for intermediate and deeper water depths, given the logistics involved when compared with the use of caisson-type structures, however it is prudent to be aware of such limitations.

approximately 6.5 m, and the total water depth was 21 m. The Tarsiut Island Research Program (TIRP) was carried out in 1982-1983. A timeline of rubble formation, duration and decay is shown in Figure 6. By the end of January 1983, a well-developed grounded rubble field had formed around the caissons (Figure 7). At that point, the location was at the landfast ice edge, with the shear zone immediately north of the rubble field (Figure 8). During late March and through April, the landfast edge moved north of the structure, eventually extending up to 2 km north of the site (Figure 9). It was estimated from side-scan sonar profiling that the rubble field was grounded out to a water depth of 15 m (Gulf Canada Resources Limited, 1983b). The maximum longer diameter of the rubble field was 450 m, while the maximum shorter diameter was 315 m. The maximum sail height was 10 m.

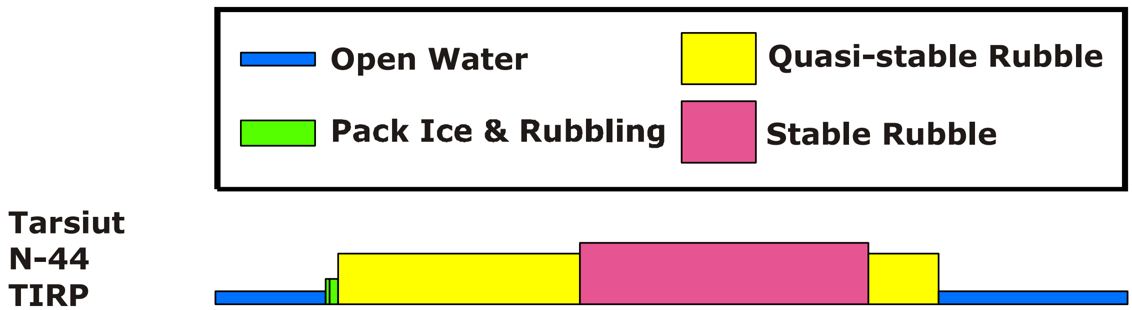

Figure 6 Timeline of rubble formation, duration and decay at Tarsiut N-44 (TIRP).

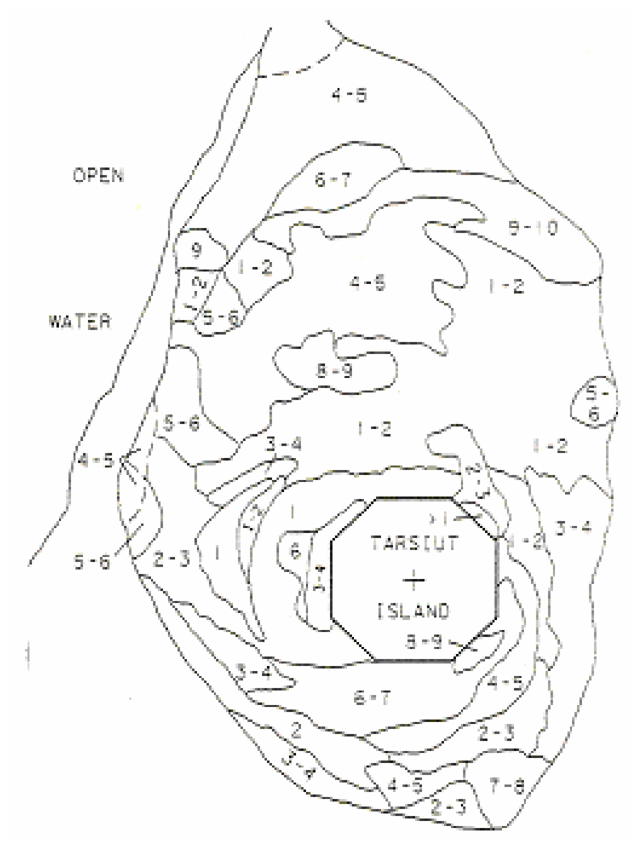

Figure 7 Rubble field extent and topography at Tarsiut N-44. North is in the direction of the top of the drawing (from Gulf Canada Resources Limited, 1983b).

Figure 8 Photograph of the rubble field at Tarsiut N-44 on February 20, 1983 (from Gulf Canada Resources Limited, 1983a).

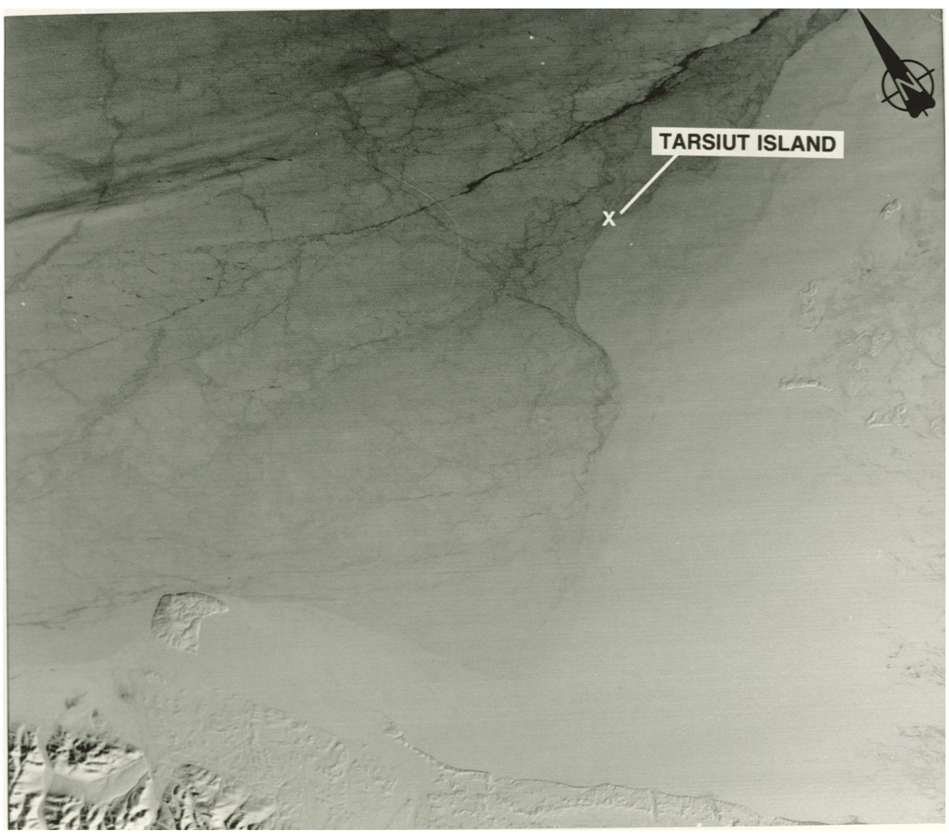

Figure 9 Satellite image of the Tarsiut N-44 site on March 15, 1983. For relative scale, Herschel Island is visible at bottom left of image (photograph from Gulf Canada Resources Limited, 1983b).

The flowchart was examined in the following order: the typical ice regime, preferred ES location and extent and topography of rubble field were examined first, followed by detailed planning. The type of ice regime at this site presents some difficulties. Tarsiut N-44 is at the edge of the landfast zone and often in moving pack, although it is usually expected to become landfast. However, it is doubtful whether a production system EER designer could be guaranteed that the structure would be in landfast ice for any given year. Examining time dependency, one could wait for the landfast ice to form before implementing an on-ice evacuation route and shelter, but at this site in 1983, the ice was only fully within landfast ice for two months. Rubble surrounded the structure for an additional five months, which would severely limit rescue vessel access (without some form of rubble removal system) for a production platform at this site. Therefore, it would be prudent at this location to have one or two evacuation routes during the quasi-stable rubble period.

By mid-December to early January, the existing rubble field at this site would allow for the deployment of an ES. Applying such factors as the orientation of the ES relative to the hazard may not be as viable during this time frame, due to the limitations imposed by the extent and topography of the rubble field. Given the above rubble field topography, an ES location at this time of year would be unable to be 300 m away from the structure. One also has to maintain a sufficient distance from the active ice edge. At Site A in Figure 10 (which shows a photograph of the rubble field at the end of January), the ES would be less than 100 m from the structure, on the somewhat level area to the west of the structure. At this spot, relatively little clearing/spraying would need to be done to create the route and the shelter pad. Alternatively, a second location is shown, Site B, that is as far from the structure as is realistic, but still a safe distance from the active edge of the rubble field. More extensive levelling/spraying would be required, as the rubble field is rougher along this route, but the ES would be approximately 110 m away from the structure. In hindsight, both of these locations would have remained viable until May. If on-ice evacuation not used during this period, alternatives would involve relying solely on helicopter evacuation, rubble management to allow vessel access or use of a vehicle that can both traverse rubble and be on thin ice/open water.

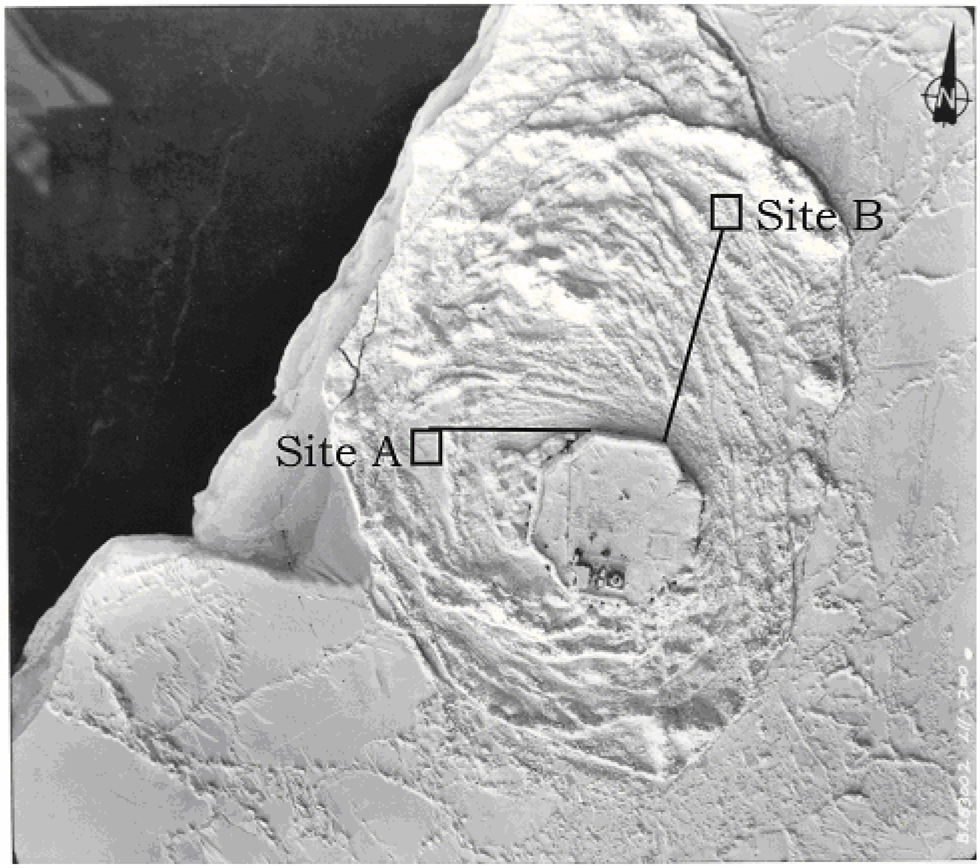

Figure 10 Possible evacuation routes and ES locations when the rubble field is not yet in landfast ice (Photograph from Gulf Canada Resources Inc. 1983b).

If landfast ice eventually encompasses the rubble and extends a safe distance from the structure, additional routes that meet the 300 m distance requirement would be possible. Once the Tarsiut N-44 site was in the landfast zone, the landfast edge was generally 1 km to 2 km away. Considerations such as orientation of the ES relative to the hazard would be more feasible. The predominant wind directions at this site are from the east and the northwest (Gulf Canada Resources Limited, 1983). For this reason, two evacuation routes could be recommended. Given the rubble extent and topography at the site, these two routes would best be placed as indicated in Figure 11, Sites C and D. The ES are away from the edge of the active zone, are on reasonably level ice, and the routes follow areas of relatively low rubble. These locations would have been useful until the end of April, when deterioration of the level ice, buckling in the rubble and the formation of melt ponds on the rubble began to appear. At that point, Sites A and B would once again have to be the primary ES locations. The potential extent of a rubble field well into otherwise open-water conditions is shown in Figure 12, the Tarsiut N-44 site in spring 1983. If an ES is not used during this period, alternatives would involve relying solely on helicopter evacuation methods or use of a vehicle that can traverse rubble.

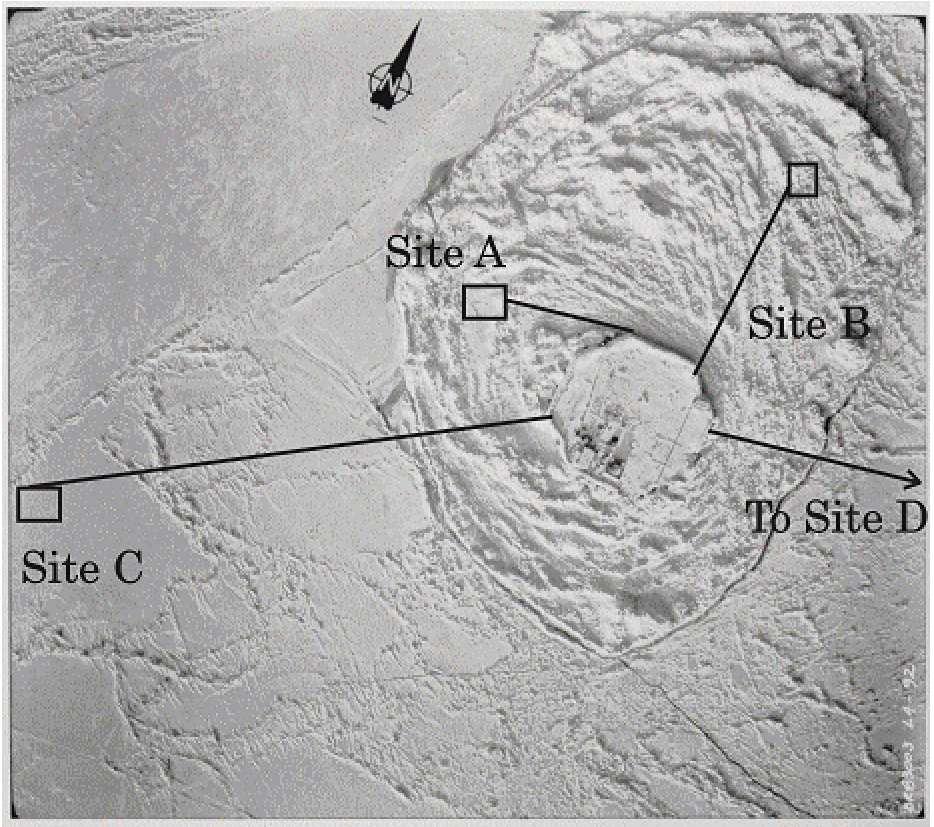

Figure 11 Evacuation routes and shelter locations for Tarsiut N-44 once the location is within landfast ice (photograph from Gulf Canada Resources Limited, 1983b).

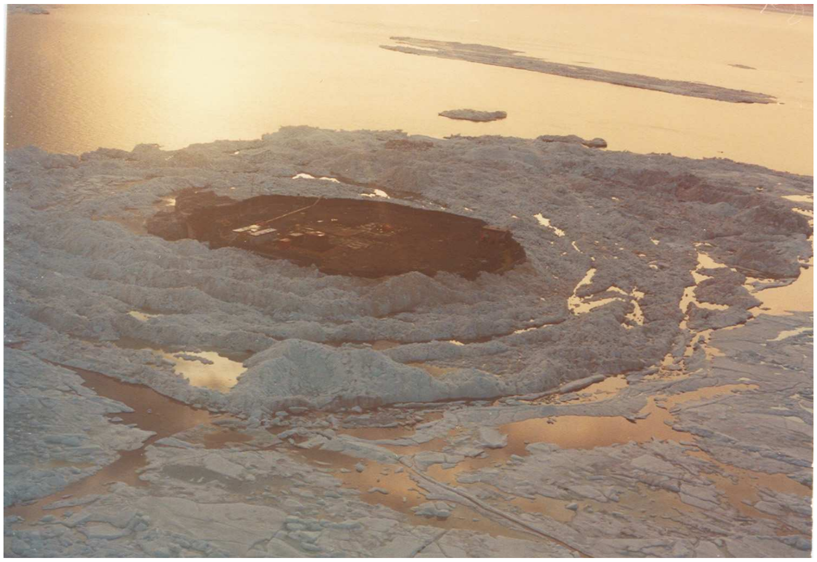

Figure 12 Deteriorating, quasi-stable rubble surrounding the Tarsiut N-44 caissons in mid-June, 1983 (photograph from Gulf Canada Resources Ltd. 1983a).

2.4.2 Scenario 2 – Grounded Rubble Field in Moving Pack Ice and Deep Water

Scenario 2 will examine the Molikpaq at the Amauligak F-24 site in 1987-1988, as an example of a structure surrounded by a grounded rubble field and moving pack ice, in deeper water. At this location, the platform was in the transition zone but had interaction with first year ice only. The water depth at the site was 32 m, with the structure set down on a berm with toe protection that raised the water depth to 13.8 m. The timeline of rubble formation, duration and decay at this site is shown in Figure 13. As a result of a large ice floe becoming lodged between the Molikpaq and the landfast ice to the south of the structure, rubble piles that developed after December 31 became stable and lasted through to the spring (Figure 14). The maximum rubble extent was achieved by March 12, 1988, when the rubble extended approximately 100 m from the structure.

Because of the moving ice at this site, the safe placement of an ES would require it to be within the rubble field, most likely at a location south-east of the Molikpaq. This would place the ES less than 60 m from the structure, in an area that would require considerable levelling or spray ice in order to create a suitable evacuation route and shelter pad (Figure 15). While this was not uncommon practice in the 1980's, as a number of locations had small, level spray ice pad areas specifically for evacuation purposes, this type of placement may not now be part of a suitable HSE Management Plan. However, the ice rubble at this location would have been relatively stable from the end of December through April (Barker and Timco, 2006). Obviously, the prime consideration at this point becomes whether a distance of 60 m from the structure, and 40 m from the active edge of the rubble field, is considered safe and practical for an ES, in light of the lack of viable alternative evacuation methods in this type of environment. If on-ice evacuation was not used, the EER strategy would likely involve relying solely on helicopter use or heavy icebreakers for year-round vessel access.

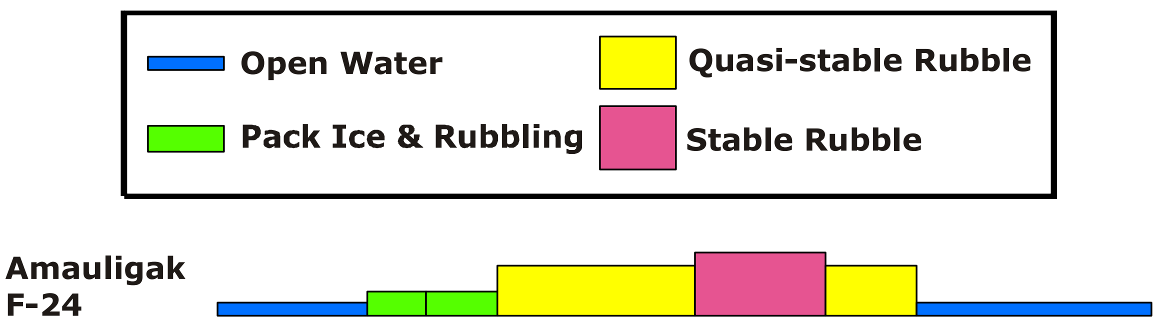

Figure 13 Timeline of rubble field formation, duration and decay at Amauligak F-24.

Figure 14 Photograph showing the high, relatively large rubble field at Amauligak F-24.

Figure 15 Aerial photograph of the rubble field at Amauligak F-24 (photograph from Gulf Canada Resources Ltd., 1989).

2.4.3 Scenario 3 – Small, Grounded Rubble Field Surrounded by Landfast Ice in Shallow Water

Scenario 3 investigates a structure surrounded by landfast ice and a small rubble field, in shallow water. Netserk F-40 was an artificial island drilled from 1975-1976. The island was constructed in 8 m of water in the landfast ice zone. There was insufficient data concerning the rubble field formation, duration and decay to create a timeline for this location. An extensive rubble pile-up developed in late October, extending approximately 106 m northwest of the structure, with a maximum height of about 7.5 m (Strilchuk, 1977). As with the other locations, until the structure is in landfast ice, evacuation routes and ES locations would be restricted to the rubble field (Figure 16). Again, the minimum distance requirement would not be met at this time. At this time of year, alternatives could involve solely relying on helicopter use and ice breaking vessels for rescue operations provided that the vessel may be accessed despite the presence of any rubble.

During the 1975-1976 field season at Netserk F-40, a frozen-in condition of the ice sheet and island was not observed (Strilchuk, 1977), and although the structure was in the landfast region, a significant movement of the ice did occur. Regardless, for this scenario, if the landfast ice encompasses the structure, evacuation routes and ES pads could be established at a number of sites with minimal levelling/spraying, due to the relatively smooth ice conditions present at that time (Figure 17). If on-ice evacuation was not used, alternatives would involve relying solely on helicopter use, use of a vehicle capable of traversing rubble or, as this location was close to land, constructing an ice road to shore.

It may be seen that for all three scenarios, that there are a number of evacuation possibilities if the ice becomes landfast. The use of an ES takes advantage of the strength and stability of the surrounding ice. However, during periods of quasi-stable ice, if preferred or primary systems are not available, EER possibilities are much more limited, compared to even periods of pack ice, when a conventional TEMPSC may still be viable. With even a relatively small degree of rubble, combined with open water or moving pack ice, evacuation becomes much more challenging. With sufficient, stable rubble, it is possible that this is a period of time when ES may be particularly needed, even as a tertiary method of evacuation unless new evacuation strategies are developed to deal with these situations.

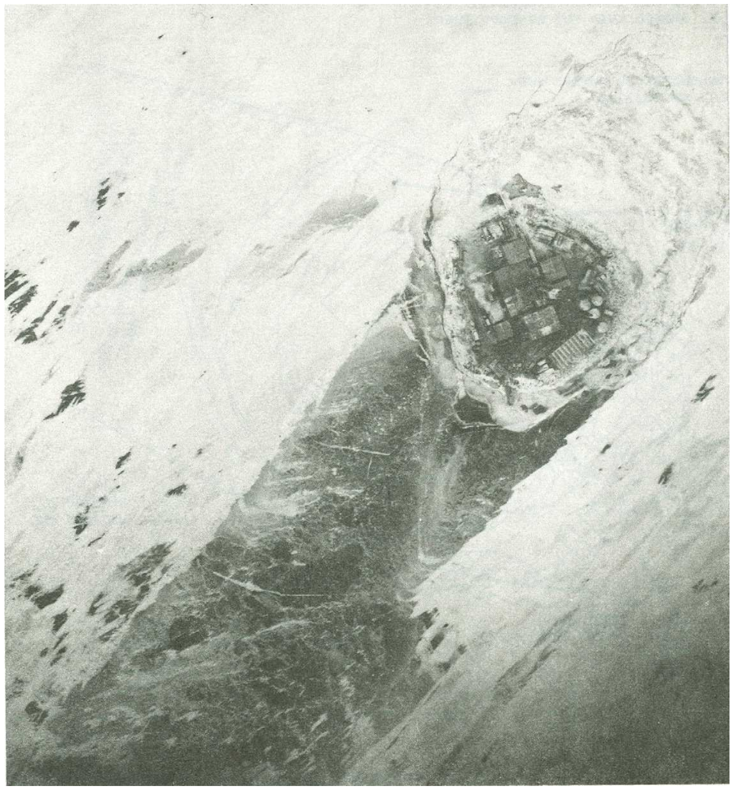

Figure 16 Photograph of Netserk F-40, on November 11, 1975 (from Strilchuk, 1977)

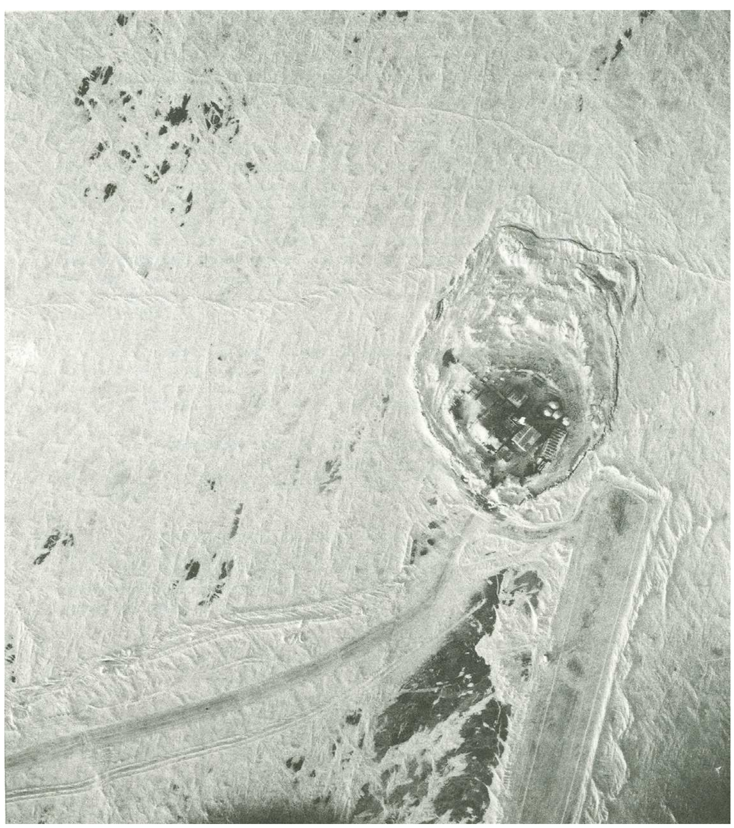

Figure 17 Photograph of Netserk F-40, on February 4, 1976 (from Strilchuk, 1977)

3. RUBBLE FIELDS AND ON-ICE EVACUATION OF PERSONNEL

One of the primary considerations for putting an ES on the ice surface is whether or not personnel can safely traverse the ice conditions that lie between the platform and a shelter. As shown in Figure 3, the preferred location and detailed planning sections of the decision-making chart help planners decide upon the safest location(s) for the shelter(s) and the best over-ice route(s). In order to quantify the effects of ice topography on evacuation plans, Barker et al. (2006) collected data on traverse rates over a variety of ice surfaces, ranging from level, groomed ice to large ridges and rubble piles, as part of this research programme. The results of the study are briefly summarized here.

In the study, five types of ice conditions were examined: level or groomed ice surfaces; low relief rubble; medium relief rubble; rough rubble; and ridges. Nominal heights were assigned to each ice condition, to try to categorize the surface roughness of each type. Heights ranged from 0 m though 7 m. Where possible, a number of routes over each ice condition were selected. The participants were timed as they initially traversed a route, then again upon their return over one of the tracked routes. Each route was documented with pictures, and hazards along the route were also noted. The study sites and selected routes for the Barker et al. (2006) study are shown in Figure 18 and Figure 19. Three of the six study sites were located at current or previous drilling sites, while the remaining three were at ridges or rubble fields that were first observed from a helicopter.

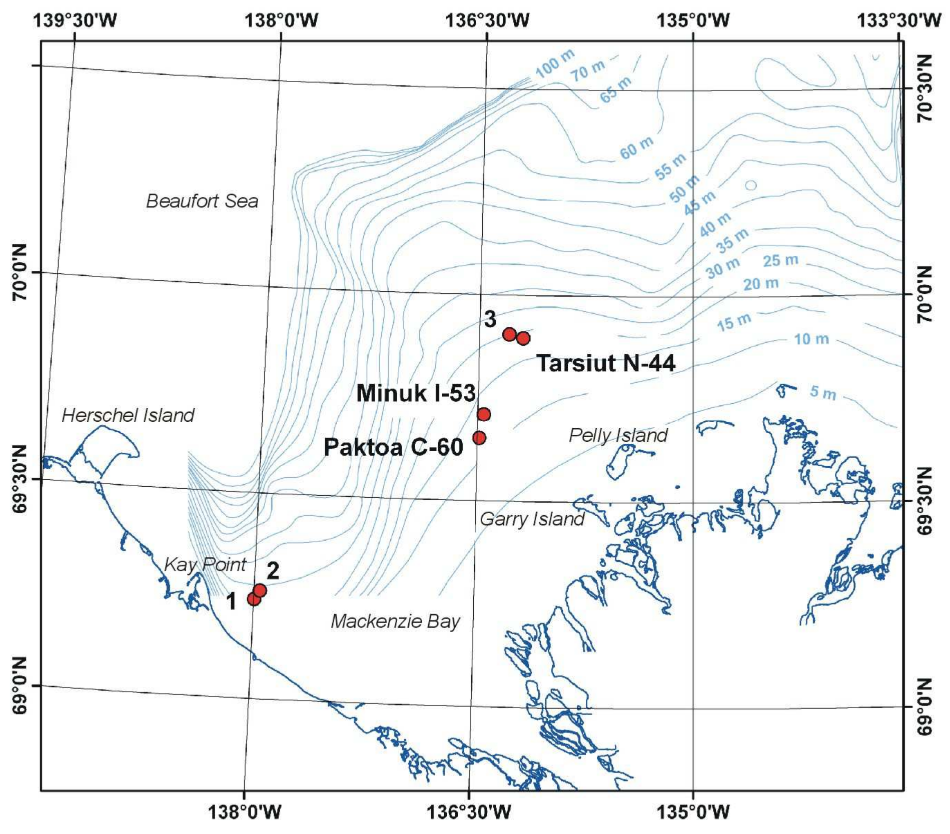

Figure 18 Study site locations

Route 1 – Groomed Trail 	Route 2 – Low Rubble 
Route 3 – Low Rubble 	Route 4 – Low Rubble 
Route 5 – Rough Rubble 	Route 6 – Medium Rubble 
Route 7 – Ridge 	Route 8 – Medium Rubble 

Figure 19a Photographs of routes studied for traverse rate evaluation

Route 9 – Low Rubble 	Route 10 – Medium Rubble 
Route 11 – Medium Rubble 	Route 12 – Low Rubble 
Route 13 – Medium Rubble 	Route 14 – Ridge 
Route 15 – Ridge 	Route 16 – Rough Rubble 

Figure 19b Photographs of routes studied for traverse rate evaluation

The field programme found that the traverse rate as a function of rubble height was:

$$r_t = 1.03e^{-0.34h} \quad [1]$$

where r_t is the traverse rate in m/s and h is the rubble height in metres. This is also shown graphically in Figure 20. The equation underestimates the traverse rate over a groomed trail, and it should be noted that it is based on the fastest traverse rates recorded. Therefore, the equation provides an upper bound of the best possible rates across the surface. Slower rates are obviously possible, especially if injured personnel are present, and this must be considered in the EER strategy. Nonetheless, Equation [1] provides a starting point for use by those responsible for planning EER strategies for an offshore facility in the Arctic.

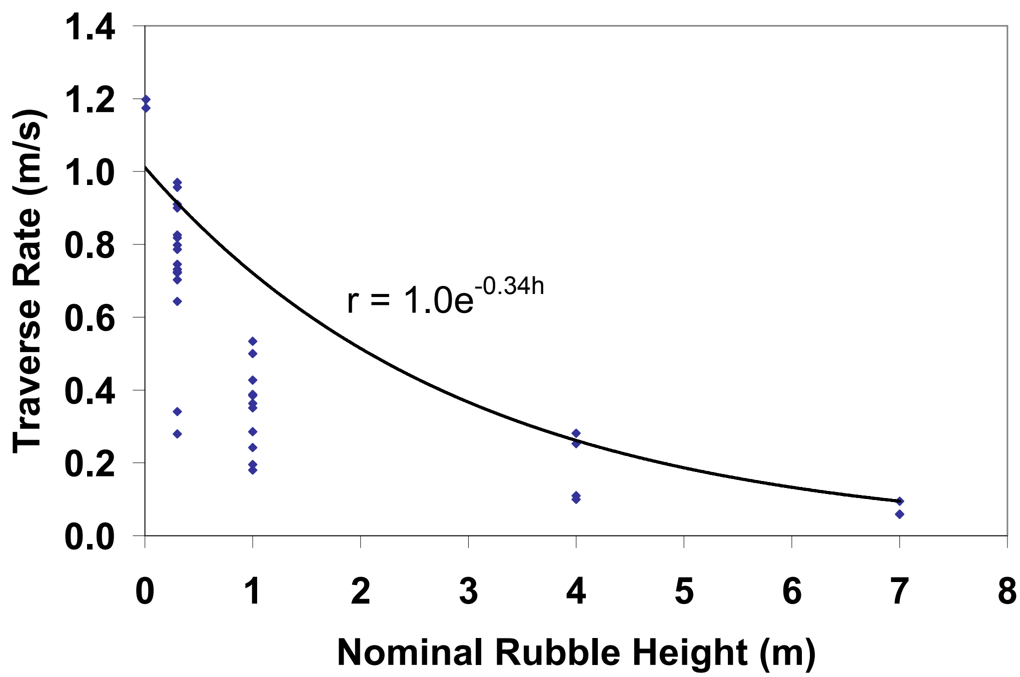

Figure 20 Plot of traverse rate against rubble height.

Additional qualitative information of ice surface topography and its effects on personnel evacuation was collected and are shown in Table 1. These factors should also be taken into account when planning the route to an ES. From Equation 1 and Table 1, it is clear that where the capability exists, a groomed route over the ice surface to an ES is the best option. This type of route is straightforward to traverse, can accommodate a number of personnel at once, rather than traveling single file, and can most likely best accommodate injured personnel as well. Other route types are possible (e.g. established path across low or medium rubble), however travel over rough rubble or ridges will greatly impair, or possibly even impede, evacuation over the ice surface.

Typical hazards along the ice surface are shown in Figure 21. As indicated in this figure, a variety of hazards may exist, many obscured by snow. ES location and route selection decisions need to take such hazards into account, in order to avoid them or mitigate their presence. For example, a limited amount of rubble may be cleared from an area, cracks may be filled or flagged, and routes may detour around large features that can not readily be removed.

Table 1 Traverse rate and qualitative evaluation based upon route type

Route Type	Average Traverse Rate (m/s)	Maximum Traverse Rate (m/s)	Path Selection Opportunity	Degree of Meandering	Darkness Effect	Potential for Injury
Groomed	1.19	1.20	high	none	low	low
Low Rubble	0.74	0.97	high	low	medium	medium
Medium Rubble	0.35	0.53	medium	high	high	medium
Rough Rubble	0.19	0.28	low	medium	high	high
Ridges	0.07	0.09	low	medium	high	high

Figure 21 Typical hazards that may be encountered on the ice surface. Clockwise from top left: snow-covered cracks; lightly-sintered, snow-filled rubble; steeply-sloped, smooth ice rubble; thick, level ice rubble.

4. CONSTRUCTION ASPECTS OF EVACUATION ROUTES TO SHELTERS

As discussed in the previous section, the ice surface and type of route over the ice can greatly affect evacuation times. This section examines the construction aspects of these various types of routes.

4.1 Route Construction and Assessment

Spencer et al. (2007) examined the construction aspects of an ES route through ice rubble, as part of this study programme (the paper is included in Appendix A). In that paper, example scenarios are used to demonstrate how route costs vary with the ice conditions that may surround a structure, and with the type of construction method(s) used to create the route. The paper steps through ice volume estimations, equipment selection and time estimates in order to determine the cost of a single route, both financially and in terms of labour/equipment requirements. Overall, it was found to be most cost-effective to minimize extensive manual labour components of any work, while the particular type of ice surface features greatly influenced the overall cost because of specific equipment use. The time involved to create the route depends on factors such as "the roughness of the ice, the horizontal dimensions of the rubble field, the equipment and manpower available on site, the time of year and local weather conditions." (Spencer et al., 2007). Both deterministic and probabilistic methods could be used to assess construction times and costs.

Again using Paktoa C-60 as an example[2], the ES site was chosen during a reconnaissance outing on January 25th. At that time, the ice was 0.6 m. The site and its route were marked off with reflectors mounted on sticks. Prior to construction of the shelter, a groomed route did not exist. Rather, a marked footpath led the way from the SDC to the proposed shelter location. At the same time, an egress route was created from the SDC down onto the ice surface (Figure 22). This trail took three days and about 30 man-hours to construct, and was completed by January 30th.

Once the D4 Cat was able to be lowered onto the ice (Figure 23), approximately 60 man hours required to created the taxiway (which was the route to the ES) and the airstrip, which were built from February 8th through the 13th. One day was used to rough in the taxiway and runway (Figure 24), while the rest of the time was used to clear these areas and flood the ice to thicken and level the surface. Figure 24 also shows that the surrounding ice at Paktoa C-60 was relatively flat during the winter of 2005-2006. The cost of using the D4 Cat was \$650/day for the operator, plus the long-term rental rate that was negotiated with the operator.

[2] All information regarding the Paktoa C-60 route construction, maintenance and ES deployment is courtesy of Horizon Ice Inc. (Sean McDermott, personal communication).

Figure 22 Egress route from the SDC onto the ice surface. The route consisted of two gangways on either side of a marked path over the rubble that had accumulated immediately beside the SDC.

Figure 23 D4 cat lowered to ice for the first time (Photograph courtesy of Horizon Ice Inc.).

Figure 24 Driving along evacuation route and taxiway (Photograph courtesy of Horizon Ice Inc.).

4.2 Route Maintenance

Regular route maintenance would be required for any established evacuation route. This maintenance would require not only inspection and repairs of the surface, but also regular mustering of personnel at the ES. By including this latter step in part of the EER strategy for the platform, personnel could have increased confidence in their ability to cross the ice surface safely, as well as increasing the likelihood that they could identify typical hazards to be aware of en route.

Depending upon the type of route to the ES, maintenance requirements could entail:

- Assessing hazards along the route
- Repairing, where possible, hazards, or if not possible, taking the necessary precautions so that either personnel are aware of them or, if severe, assessing relocation of the route
- Clearing the route of any accumulated snow
- Regrading the route if necessary
- Checking and/or replacing route markers
- Ensuring handrails, lighting, bridging apparatus, etc., if used, are in working order

The frequency of this maintenance would depend largely upon EER policies as well as the ice conditions at the site. For example, a structure in landfast ice conditions versus one surrounded by a rubble field and moving pack ice will likely have different monitoring requirements.

At Paktoa C-60, regular maintenance of the route to the ES was conducted, to a certain extent because the route to the shelter was also the airplane taxiway. However, this did not diminish the importance of inspecting the route in light of the EER strategy for the platform. The route was inspected each morning at dawn. Based upon the condition of the road, and any expected flights that day, appropriate maintenance requirements were carried out. Cracks that were less than 0.1m were left alone, but these were often coincidentally filled in when a rake attachment on the D4 Cat was used to clear snow (as shown in Figure 25). This snow clearing took place every two to three days on average, as there was an unusual amount of snow at that site. Snow that had blown onto the taxiway would be plowed off, and then the area would be dragged to remove remaining snow, so that only an ice surface remained. Plowing could be completed with the D4 plow blade, although this was inefficient due to the small size of the blade and the surface area to be cleared. Further, any snow banks that were created had to be knocked down to prevent snow drifts on the airplane taxiway, which also meant that the taxiway markers had to be removed and then reset each time.

As an ice road to shore was constructed at this site, eventually a larger road grader was obtained (Figure 26), which took a fraction of the time to plow the taxiway, runway and ring road at the SDC, compared to the two days it took the D4 cat to complete the same task. The grooves created by the heavy grader's blade as it resurfaced the ice provided ice chips that were used to dry-fill larger cracks in the surface.

Figure 25 John Lindley (Horizon) and Leonard (Cat driver) designed the rake attachment for the D4 Cat. It was fabricated onboard the SDC from an old I-beam. Once an area was levelled the rake would skim off the snow and ice debris (Photograph courtesy of Horizon Ice Inc.).

Figure 26 The heavy-duty grader with blade, deployed (Photograph courtesy of Horizon Ice Inc.).

5. EVACUATION SHELTER CONSIDERATIONS

There is, of course, the consideration of the ES itself. A shelter could take on a number of forms. In the past, where an area was bulldozed and sprayed for a small pad area close to a structure (for example, Uviluk P-66), a relatively simple shelter such as an inflatable liferaft stored in a canister was often used. This type of shelter would have the advantage of being relatively inexpensive and a number of canisters could be left on the ice surface to accommodate the required number of personnel. However, they do not typically have any source of heating, and additional supplies, clothing etc. would not necessarily be part of the kit. Of course, these latter items could also be left on the ice, if sufficiently protected from the threat of wildlife disturbances.

A more recent example at the other end of the spectrum would be the framed ES used by Devon Canada had in place during their 2005-2006 exploration drilling program at Paktoa C-60 (Figure 27 and Figure 28). The shelter location was to be a minimum of 600 m away from the SDC in the event of a blow-out, and was in fact approximately 800 m from the platform (Figure 29). As discussed in the previous section, a D4 Cat was used to clear the ice for the shelter and to tow the shelter equipment to the site, although due to the level ice conditions at the site, the D4 Cat was not absolutely necessary. The shelter equipment was moved to the site on February 10th (Figure 30), and base supports were frozen into the ice on February 11th and 12th (Figure 31). The shelter assembly was completed on the 18th of that month. Figure 32 and Figure 33 show some of the stages of the shelter assembly process.

The shelter used by Devon "cost $300 per day and was in place from February 11th to March 28th (start of construction to end of tear-down). It was stored on the SDC for some time prior to that. It took 4 people 4 days to assemble at a total of $700 per day per person. It took 3 people 3 days to disassemble at the rates above. The shelter came with a furnace, lighting, generator as well as staging etc. This was all included in the price" (Sean McDermott, Horizon Ice Inc., personal communication). With the rental cost, plus assembly and disassembly costs, the total cost of the shelter itself was approximately $31 000 CAD. The shelter was capable of accommodating a minimum of 95 personnel for a few days (Don Connelly, personal communication), with supplies for the shelter kept on the SDC near the egress route, to be taken to the ES as personnel were exiting the platform.

The International Maritime Organization Arctic Shipping Guidelines can be used as a good starting point for items that should be available for use in an ES, and for personnel travelling to an ES, along with information particular to Operators' Health, Safety and the Environment and Northern Safety Handbooks. For example, Personal Protective Equipment, that includes thermal insulating clothing suitable for the Arctic environment, Personal and Group Safety Kits and a gun for emergency wildlife protection are all recommended items.

Figure 27 The outside of the ES located at Paktoa C-60.

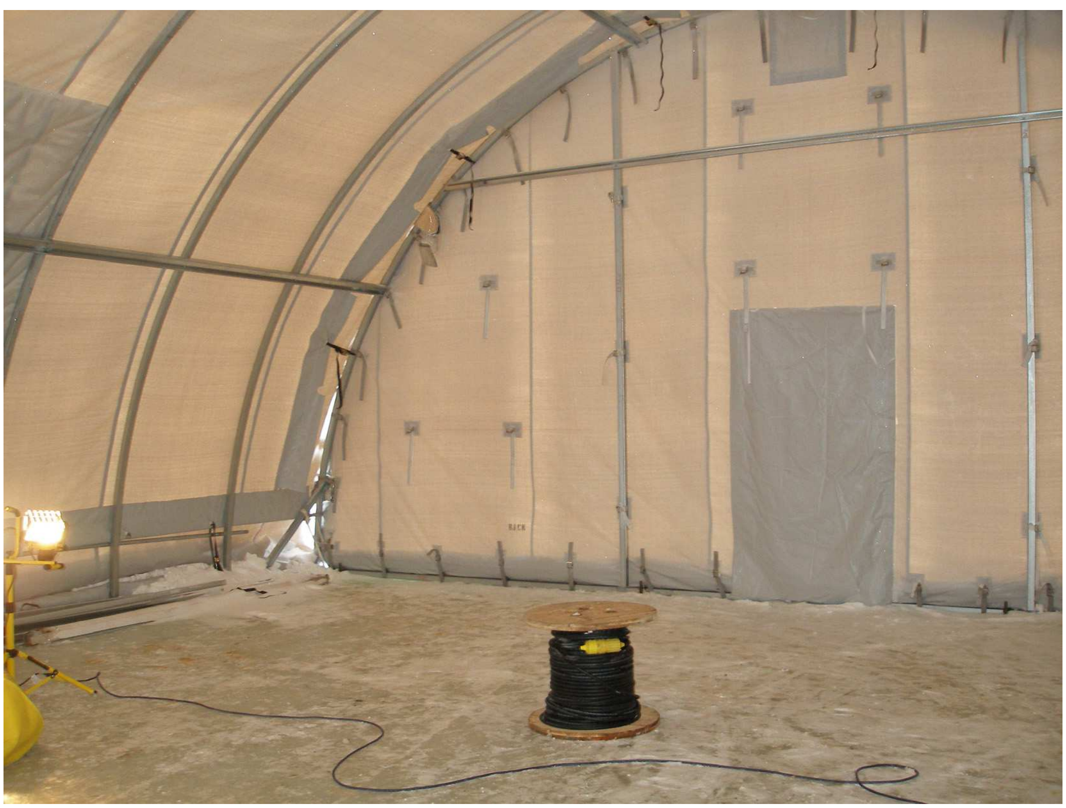

Figure 28 The inside of the ES at Paktoa C-60.

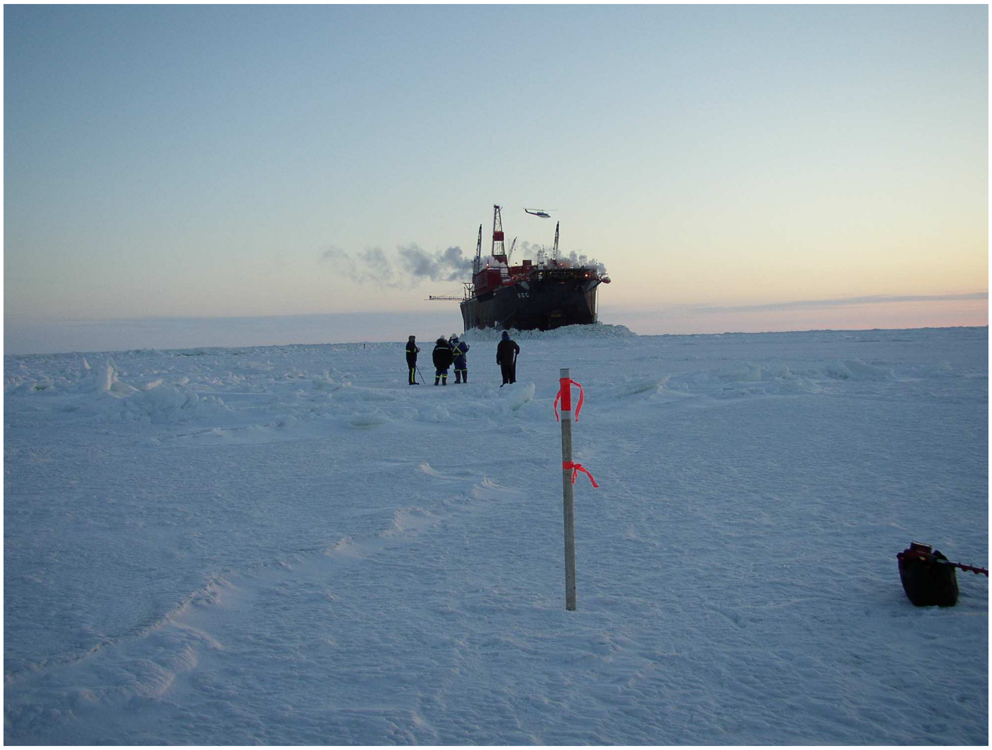

Figure 29 The ES location was chosen partially upon the fact that the area was relatively undeformed (Photograph courtesy of Horizon Ice Inc.).

Figure 30 "The evacuation shelter container is lowered to the ice and attached to the cat for towing. The length of tow cable was used to keep these two relatively heavy items from stressing the ice together" (Photograph and text courtesy of Horizon Ice Inc.).

Figure 31 Assembling the evacuation shelter base. Pins or anchors are frozen into the ice (Photograph courtesy of Horizon Ice Inc.).

Figure 32 ES assembly: Putting up the framing (Photograph courtesy of Horizon Ice Inc.).

Figure 33 ES assembly: Putting on the shelter cover (Photograph courtesy of Horizon Ice Inc.).

6. SUMMARY

6.1 Establishing Evacuation Shelters on Ice

This report and its components have shown that on-ice evacuation shelters are indeed viable and practical in Canadian Arctic conditions, as they pertain to the Beaufort Sea. Section 2.0 and Barker et al. (2007) both present decision-making processes for determining if an ES is suitable for a given location and for siting and deploying an ES. The processes account for the ice regime and rubble field geometry at a site, the type of platform being used, the preferred location of the ES, the time dependency of the ice conditions at a site and the detailed planning and implementation considerations for an ES. Field observations and measurements of ice rubble characteristics of grounding, aerial extent, development and deterioration, were reported in Barker and Timco (2006) and Barker et al. (2006a). As indicated there-in, rubble field anisotropy will play a large role in the deployment of an ES.

Barker et al. (2006b) demonstrated that under good conditions, personnel traveling over the ice to a shelter can be a viable EER strategy. Good conditions include establishing and maintaining a generally level, preferably wide, groomed route to a shelter. Such a route results in quicker traverse rates, and depending on the specifics of the route, room for more personnel, including any who are injured, rather than walking in single file. A rough, un-maintained rubble field will result in slow traverse times or progress may be completely impeded for some situations. Additionally, personnel may incur injuries traveling upon such a route. Walking sticks are specifically recommended to be part of personal Arctic kits, and hand rails, bridging equipment, lighting, footing traction aids etc., while not examined specifically in Barker et al (2006b), are potentially valuable aids as well.

Risks, costs and maintenance requirements for routes to evacuation shelters were compared in Spencer et al. (2007). Again, route type greatly affected both the labour and financial requirements for a pathway to an ES. Maintenance requirements generally involve checking for hazards (such as cracks in the ice that may be covered by snow), repairing or flagging hazards, maintaining adequate lighting (where established) and route markings and ensuring that personnel are familiar with the route. Typical costs of an ES and the labour requirements to set-up such a shelter were described in Section 5, using the ES located at Paktoa C-60 in the winter of 2006 as an example.

An example analysis of the limitations of ES placement based upon rubble field dimensions is demonstrated by each of the three scenarios in Section 2. For those particular conditions, during the quasi-stable rubble periods in the autumn and spring, the placement of an ES at a distance equal to 300 m (as an example minimum distance requirement) was not feasible. Of course, some rubble fields, such as the one at Isserk I-15, were extensive very early on in the season; therefore such a requirement could be met. This indicates that because of the highly variable nature of rubble formation, EER strategies during these periods need further development. Operators need to determine whether a minimum distance is an approach that must be observed no matter what season, or if this condition may be waived under certain conditions. If the condition must hold regardless of the season, then appropriate strategies to evacuate personnel over potentially large expanses of rubble (while not meeting a minimum distance criteria, the rubble field may still be greater than 50 m wide, for example) during the quasi-stable rubble seasons need to be developed, or access to the structure must be maintained for rescue vessels. If the condition may be waived, then the nature of the ES may also need to change from, for example, a large, enclosed shelter to canisters stored on the ice that house inflatable shelters. For those structures that become surrounded by landfast ice, meeting the minimum distance requirement at that point is generally not an issue.

The stability of a rubble field, its bearing capacity and the relative safety for personnel on the ice are all future research needs that should be clarified for additional confidence with respect to ES deployment. Aspects of these issues will be addressed through a currently-underway Program on Energy Research and Development – Marine Traffic and Safety and Northern Production research projects.

6.2 Guidelines for Safe Evacuation to an Evacuation Shelter on the Ice

Some general guidelines for safe evacuation to an ES on the ice may be drawn from this report and its components. These are as follows:

- A decision-making process for evaluating the viability of an ES at a particular site, such as the one shown in Figure 2, should be established.
- If an ES is viable, a decision-making process for site selection and timing, such as that shown in Figure 3, should be used.
- A groomed, level route is the most expedient method of transferring personnel across the ice to an ES, although a tracked path through low-relief rubble may also be suitable.
- Routes should be regularly inspected and maintained to guard against hazards along the route and to determine when an ES is no longer suitable as an EER strategy.
- Personnel should be made familiar with traveling the route, as part of EER drills, for example.
- Telescoping walking sticks should be included in the personal protective equipment provided to personnel for traveling across the ice surface to an ES, both for additional stability when crossing the ice and for hazard detection along the route.
- If an ES is part of an EER strategy, platform operators need to establish limiting factors for ES deployment, such as minimum distance from the hazard, in conjunction with codes and regulators, bearing in mind safe distances from active ice edges and situations where such limitations may not be applicable.
- Costs, labour, time and equipment requirements for establishment of a route to an ES will be largely, and unavoidably, dependent upon the type of ice that surrounds a platform.

By establishing decision-making processes to assess what locations are suitable for use of an ES and to plan the site deployment and timing of such a shelter, an ES can be a viable, successful part of an HSE management plan for offshore platforms located in the Canadian Beaufort Sea.

7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge that this study was funded by the Climate Change Technology and Innovation Initiative, Unconventional Gas Supply Program. The research conducted on rubble extent and roughness was funded through the Program on Energy Research and Development, Marine Transportation and Safety POL. The authors would like to thank Bill Livingstone and Peter Millman for access to the Devon drilling site at Paktoa C-60, and their support in many other aspects of this project. The assistance of Sean McDermott, Horizon Ice Ltd. in providing the authors with on-site support and details concerning the logistics of establishing the Paktoa C-60 ES is also gratefully recognized. The work of Paul Spencer, Bill Graham (both of Sandwell Engineering Inc.) and Dan Masterson (previously with Sandwell Engineering Inc., now ChevronTexaco Inc.) is a key component of this project, and their efforts are very much appreciated by the authors.

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APPENDIX A

Barker, A., Wright, B. and Timco, G.W. (2007) Assessment of the Viability of On-Ice Evacuation Shelters in the Beaufort Sea. Proceedings 19th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC'07, Vol. 2, pp. 801-811. Dalian, China.

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ASSESSMENT OF THE VIABILITY OF ON-ICE EVACUATION SHELTERS IN THE BEAUFORT SEA

Anne Barker [1], Brian Wright [2] and Garry Timco[1]

(1.Canadian Hydraulics Centre , Ottawa, Canada;
2.B. Wright & Associates Limited , Canmore , Canada)

ABSTRACT

This paper presents an assessment of the viability of locating evacuation shelters on landfast ice or rubble fields surrounding offshore structures in the Beaufort Sea. For platforms surrounded by stable landfast ice and/or rubble, on-ice evacuation to an evacuation shelter (ES) may be identified as part of an EER plan during the Beaufort Sea's winter season. There are a number of factors that must be recognized when considering the deployment of an ES on the ice cover around Beaufort Sea structures; for example, the stability and morphology of the ice, the location and number of routes to shelters on the ice and limitations caused of the nature of the emergency. Additionally, issues surrounding personnel access off of a platform and egress to the ES must be examined, along with key concerns about the viability of using an ES soon after freeze-up and during break-up. This paper provides some representative examples of full scale data to illustrate key points about the viability of on-ice ES deployments in winter, on a scenario basis, as a function of water depth. The information that is presented here was assembled through a combination of field experience, literature reviews, and discussions with operating personnel who are directly involved with this type of problem area.

INTRODUCTION

Although there are no production platforms presently in operation in the Canadian Beaufort Sea, there is renewed interest in pursuing offshore developments in this region in the future. As such, it is important that the issues regarding year-round EER systems be fully recognized by Regulators and Operators as soon as possible, in order to be incorporated into EER practices and platform design criteria. Several studies have addressed issues surrounding evacuation from offshore structures in ice-covered waters [such as those by Barker and Timco (2006), Bercha et al. (2004), Poplin et al. (1998a, 1998b), Timco and Dickins (2005), Timco et al. (2006) and Wright et al. (2002, 2003)]. Additionally, the International Organization for Standardization (ISO), through the TC67/SC7/WG8 Committee, is currently developing an Arctic Structures code which contains standards for EER systems in ice-covered waters. For certain scenarios, an on-ice Evacuation Shelter (ES) may be identified in the EER strategy for a structure. There are a number of factors that must be recognized when considering the deployment of an ES on the ice cover around Beaufort Sea structures. This paper addresses these factors by developing a logic diagram for the decision-making process and provides some representative examples of full scale data, to illustrate key points about the "do-ability" of on-ice ES deployments, on a scenario basis, as a function of water depth.

SELECTION OF EVACUATION SHELTER LOCATION

The main topic areas that should be addressed when evaluating the option of placing an ES on the ice around a Beaufort Sea structure include:

- the type of Beaufort Sea structure
- the type of ice regime in which it is deployed
    - ✧ the type and extent of the ice rubble that may form around the structure
    - ✧ the time dependent nature of the ice regime and ice rubble around the structure
- the preferred location of the ES(s) in relation to the structure
- the preferred location of an ES(s) in relation to the hazards that may occur
- the type and number of on-ice routes to the ES(s) placed around the structure

While the importance of such considerations is clear, the decision-making process for evaluating their impact on ES placement on the ice may not be so straightforward. This paper will identify some of the necessary considerations for decision-makers by stepping through the topic areas.

Type of Structure

The type of structure that is under consideration, and its function, are obvious factors of importance. In this regard, the only Beaufort structures for which the deployment of an on-ice ES is possible are ones that are located in landfast ice, or ones situated in deeper water pack ice areas (i.e.: in the transition zone) which will "capture" stable grounded ice rubble fields around them. Also, the function of the structure, as either an exploration or production platform, has a relationship to range of hazards that may occur and, the number of onboard personnel that may have to be evacuated.

Type of Ice Regime

The type of ice regime in which the structure is located is of obvious importance. Clearly, the structure must be located within the landfast ice zone and/or surrounded by a grounded ice rubble field that is both stable and sizable, for an on-ice ES to be feasible. In the Beaufort Sea, the landfast ice zone is the most quiescent, and should be favoured for the on-ice deployment of an ES. However, ES placements in grounded rubble fields around structures in the pack ice zone are also worthy of consideration.

Preferred Location in Relation to the Structure, in Relation to the Hazard(s) and the Type and Number of On-Ice Routes

Given suitable ice conditions around a platform for the deployment of an ES(s), namely the presence of a stable ice rubble formation and/or landfast ice, the following questions are of practical importance for any evacuation plan.

- How to get down off the platform and onto the ice, and at how many locations to allow flexibility?
- Should one or more egress pathways be "cleared" on the surrounding ice, to allow easy access to an ES(s) that have been deployed?
- How is this best done given the range of ice conditions that may be experienced along the pathway routes?
- How should these access routes to an ES(s) be maintained?
- When should this type of evacuation option be adopted as being a viable option after freeze-up, and when should it be abandoned in spring?

More specific yet ancillary issues include:

- The ability for on-board personnel (including injured personnel) to move down and off the platform, through a prepared route to an ES, the clothing they should wear, and the training they should have.
- The types of emergency supplies that should be housed in the ES(s), and related "durations", which will depend on likely rescue time frames (i.e.: hours versus days) for the evacuated personnel.

Logic Diagram

A logic diagram for the selection of an ES site(s) is given in Fig. 1. The issues that are identified in this methodology, and the logic flow for related decision- making, should be clear. Key considerations range from ice-related factors affecting the strategic placement of an ES, to considerations regarding the avoidance of the effects of any "fall-out" from the on-board problem (blow-out, fire, etc.).

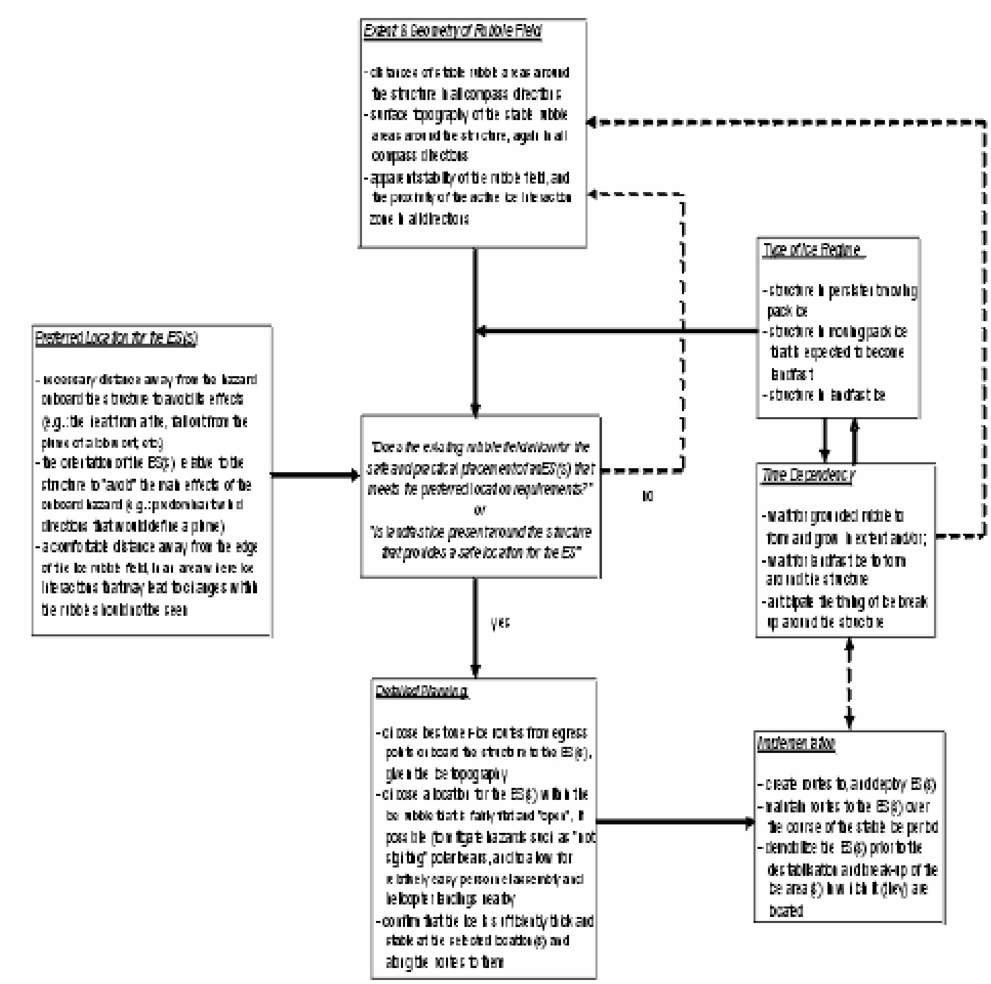


Fig.1 Basic considerations and logic flow for the selection of an appropriate evacuation shelter location. These considerations are specific to Beaufort Sea structures surrounded by ground ice rubble and/or landfast ice

EXAMPLE SCENARIOS

For the purposes of this paper, three example scenarios have been considered in terms of an appropriate "on-ice evacuation method", from a Beaufort platform to a surrounding stable ice rubble field or beyond. They include:

- a platform located in shallow waters (5m to 10m), surrounded by a small ice rubble field and in the landfast ice regime
- a platform located in intermediate water depths (15m to 20m), surrounded by a sizable grounded ice rubble field and in the landfast ice regime over most of the ice-covered season
- a deeper water platform (25m or more), surrounded by a heavily grounded ice rubble field, but located in moving pack ice throughout the winter period

Three case histories from previous structures used in the Beaufort Sea have been selected to represent these scenarios. They include:

- an artificial island at Netserk, in 8m of water
- the Tarsiut CRI in 21m of water
- the Molikpaq (on a large berm) in 32m of water

The second scenario, a structure in intermediate water, is examined in detail first. The others are studied briefly, to see how they may differ from this initial scenario. Aerial photos of the ice conditions and rubble formations were acquired while these Beaufort structures were operating, along with on-ice observations. This data has been used as a basis for the "evacuation do-ability" considerations that are outlined below, on a scenario basis. For this exercise, available data included wind data for the site, rubble maps and progressive topographies throughout the winter and so on. Obviously, such site-specific data is not available for an EER system designer in advance. However, knowing expected environmental conditions for a given location (e.g. wind speed, typical ice regime, water depth), hazard distances and preferred number of routes in advance, a number of methods exist to estimate some of the required parameters such as rubble field extent (e.g. Barker and Timco, 2006) and the main effects of the onboard hazard (predominant wind direction for smoke/plume dispersion). Prior to actually experiencing rubble build-up at a site, a preliminary plan for preferred locations could be established, with finalization of the plan (distance from edge of rubble field, best over-ice route, location of flat/open areas within field, ice thickness determination) made once the ice around the structure has formed and stabilized.

The type of structure is not examined, due to topsides placement specifics of EER equipment. However, for scenario purposes, a minimum safe distance of 300m from a production structure with a relatively high freeboard is assumed. This value would need to be established bearing in mind each identified hazard that would require evacuation, such as a blow-out, blast effects etc. The scenarios assume that the preferred means of evacuation is by helicopter or ship and that this is not available. It also assumes that during the winter, on-ice evacuation is at most a secondary means of evacuation, while during periods of quasi-stable rubble on-ice evacuation it is a secondary or tertiary option (Wright et al. (2003); Timco et al. (2005 and 2006).

Scenario 1

The Gulf Tarsiut Caissons was a structure made up of four concrete caissons, placed upon a submarine berm and filled with sand, with an additional interior sand fill. The surface was approximately 70 m in diameter, and the caissons had a low freeboard of about 5 m to the waterline. The water depth to the berm was approximately 6.5 m. The Tarsiut Island Research Program (TIRP) was carried out in 1982~1983. By the end of January 1983, a well-developed grounded rubble field had formed around the caissons (Fig. 3). At that point, the location was at the landfast ice edge, with the shear zone immediately north of the rubble field. During late March and through April, the landfast edge moved north of the structure, eventually extending up to 2 km north of the site. It was estimated from side-scan sonar profiling that the rubble field was grounded out to a water depth of 15 m. The maximum longer diameter of the rubble field was 450 m, while the maximum shorter diameter was 315 m. The maximum sail height was 10 m.

The flowchart was examined in the following order: typical ice regime; preferred ES location; extent and topography of rubble field; detailed planning. The type of ice regime at this site presents some difficulties. Tarsiut N-44 is at the edge of the landfast zone and often in moving pack, although it is usually expected to become landfast. However, it is doubtful whether a production system EER designer could be guaranteed that the structure would be in landfast ice for any given year. Examining time dependency, one could wait for the landfast ice to form before implementing an on-ice evacuation route and shelter, but at this site, the ice was only fully within landfast ice for two months. Rubble surrounded the structure for an additional five months, which would severely limit rescue vessel access (without some form of rubble removal system) for a production platform at this site. Therefore, it would be prudent at this location to have one or two evacuation routes during the quasi-stable rubble period. By mid-December to early January, the existing rubble field at this site would allow for the deployment of an ES. Applying such factors as the orientation of the ES relative to the hazard may not be as viable during this time frame, due to the limitations imposed by the extent and topography of the rubble field. Given the above rubble field topography, an ES location at this time of year would be unable to be 300 m away from the structure. At Site A in Fig. 3 (which shows a photograph of the rubble field at the end of January), the ES would be less than 100 m from the structure, on the relatively level area to the west of the structure. At this spot, relatively little clearing/spraying would need to be done to create the route and the shelter pad. Alternatively, a second location is shown, Site B, that is as far from the structure as is realistic, but still a safe distance from the active edge of the rubble field. More extensive levelling/spraying would be required, as the rubble field is rougher along this route, but the ES would be approximately 110 m away from the structure. Both of these locations would have remained viable until May.

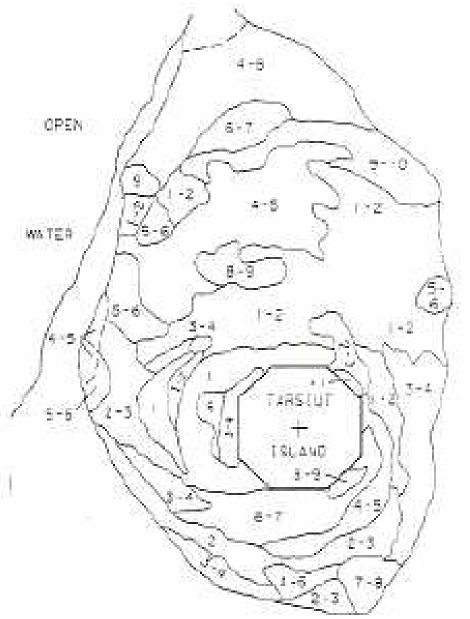


Fig. 2 Rubble field extent and topography at Tarsiut N-44. North is in the direction of the top of the drawing (Gulf Canada Resources Limited, 1983)

If landfast ice eventually encompasses the rubble and extends a safe distance from the structure, additional routes that meet the 300 m distance requirement would be possible. Once the Tarsiut N-44 site was in the landfast zone, the landfast edge was generally 1 km to 2 km away. Considerations such as orientation of the ES relative to the hazard would be more feasible. The predominant wind directions at this site are from the east and the northwest (Gulf Canada Resources Limited, 1983). For this reason, two evacuation routes could be recommended. Given the rubble extent and topography at the site, these two routes would best be placed as indicated in Fig. 4, Sites C and D. The ES are away from the edge of the active zone, are on reasonably level ice, and the routes follow areas of relatively low rubble. These locations would have been useful until the end of April, when deterioration of the level ice, buckling in the rubble and the formation of melt ponds on the rubble began to appear. At that point, Sites A and B would once again have to be the primary ES locations.

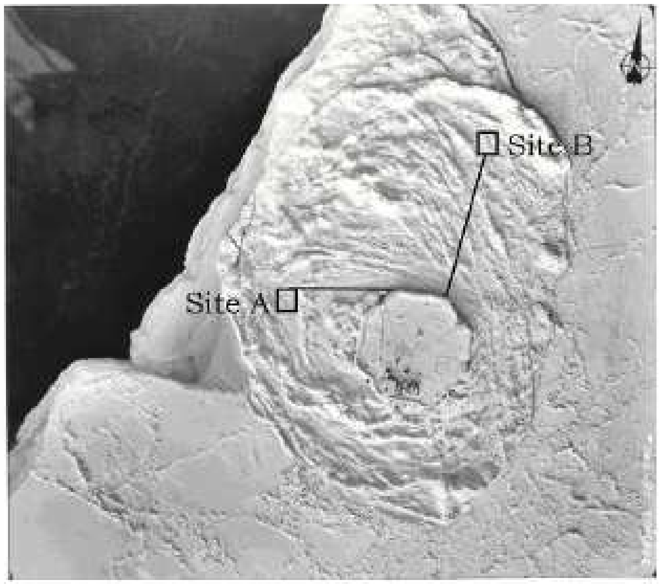


Fig.3 Possible evacuation routes and ES locations when the rubble field is not yet in landfast ice (Photograph from Gulf Canada Resources Inc. 1983)

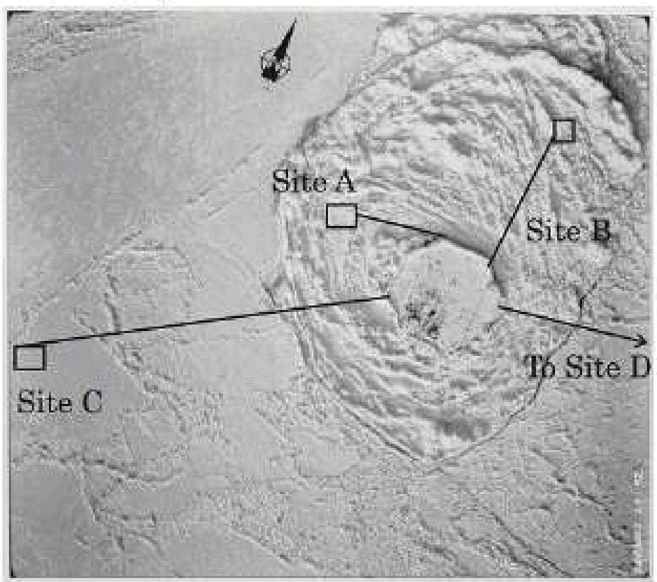


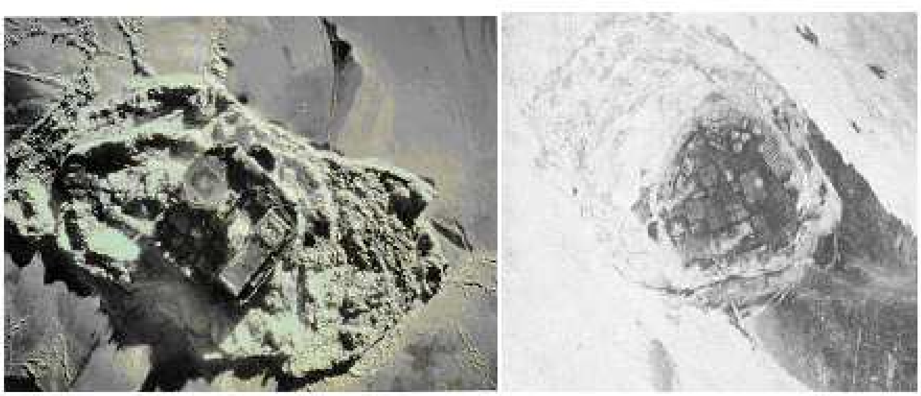
Fig.4 Evacuation routes and shelter locations for Tarsiut N-44 once the location is within landfast ice (photograph from Gulf Canada Resources Limited, 1983)

Scenario 2

The Molikpaq was located at the Amauligak F-24 site for 1987~1988. At this location, it was in the transition zone but had interaction with first year ice only. The water depth at the site was 32 m, with the structure set down on a berm with toe protection that raised the water depth to 13.8 m. As a result of a large ice floe becoming lodged between the Molikpaq and the landfast ice to the south of the structure, rubble piles that developed after December 31 became stable and lasted through to the spring. The maximum rubble extent was achieved by March 12, 1988, when the rubble extended approximately 100 m from the structure. Because of the moving ice at this site, the safe placement of an ES would require it to be within the rubble field, most likely at a location south-east of the Molikpaq. This would place the ES less than 60 m from the structure, in an area that would require considerable levelling or spray ice in order to create a suitable evacuation route and shelter pad (Fig. 5a). However, this location would have been relatively stable from the end of December through April (Barker and Timco, 2006).

Scenario 3

Netserk F-40 was an artificial island drilled from 1975-1976. The island was constructed in 8 m of water in the landfast ice zone. An extensive rubble pile-up developed in late October, extending approximately 106 m northwest of the structure, with a maximum height of about 7.5 m (Strilchuk, 1977). As with the other locations, until the structure is in landfast ice, evacuation routes and ES locations would be restricted to the rubble field (Fig. 5b). If the landfast ice encompasses the structure, evacuation routes and ES pads could be established at a number of sites with minimal levelling/spraying, due to the relatively level ice conditions present at that time.



(a) Amauligak F-24 (b) Netserk F-40

Fig. 5 Photographs of the rubble fields at Amauligak F-24 and Netserk F-40 (photographs from Gulf Canada Resources Ltd., 1989 and Strilchuk, 1977)

SUMMARY

This paper provided an assessment and analysis concerning the location and number of routes to ES located on ice rubble fields or on landfast ice. It identified the range of factors that should be accounted for when selecting an appropriate ES location on the ice adjacent to a structure. Three scenarios were presented in order to demonstrate this decision-making process.

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CONSTRUCTION ASPECTS OF BUILDING AN EVACUATION ROUTE THROUGH RUBBLE SURROUNDING BEAUFORT SEA STRUCTURES

Paul Spencer[1], Bill Graham[1], Anne Barker[2], Garry Timco[2] and Brian Wright[3]

(1. Sandwell (Alberta) Ltd., Calgary, Alberta, Canada;
2. National Research Council-Canadian Hydraulics Centre, Ottawa, Ontario, Canada;
3. B.Wright and Associates, Canmore, Alberta, Canada)

ABSTRACT

For EER plans involving on-ice evacuation methods in the winter, an emergency shelter located on the adjacent ice is an important safety element for personnel working in oil or gas facilities in the Beaufort Sea. The ice surrounding a structure can vary from thin level first year ice to grounded rubble or ridges. The speed and safety of walking over the ice surface is strongly affected by the surface roughness and degree of ice rubble. Thus, a groomed trail from an oil or gas structure to an emergency shelter should be constructed that is suitable for walking. This paper discusses the methods, equipment required, construction duration and associated risks to efficiently construct and maintain the trail. The emphasis is on practical methods that can work in the wide range of ice and weather conditions that can occur in the Beaufort Sea region during the winter and spring.

INTRODUCTION

As a part an EER (Emergency Evacuation & Rescue) system for offshore oil or gas structures working in a stationary ice environment, an on-ice emergency shelter may be provided (Timco et al, 2006; Barker et al, 2007). This shelter would be located on the ice sheet some distance away from the drilling or production structure. Any ice movement prior to landfast ice being established, will likely result in a rubble field being created in the vicinity and therefore the ice surface will be uneven. It has been assumed that walking from the facility to a shelter will be the primary means of locomotion. Other means of transport have not been excluded, for example skidoo or all-terrain-vehicle (ATV), but during an emergency situation, they may not be available.

Barker et al. (2006) have shown that the speed of walking over ice rubble is strongly affected by the unevenness of the walking surface. The travel speed over rubble fields or ridges was slow enough that frostbite on unprotected skin was a significant risk. In addition, the risk of injury from slipping or falling while traversing the uneven surface was also a factor. Particularly for inexperienced persons who have limited mobility due to a pre-existing injury. Thus to improve the safety for evacuees while walking from the structure to the emergency shelter, a trail should be constructed. Examples of a rubble field and unimproved terrain that would have to be traversed are given in Fig. 1 illustrating the need for a constructed trail.

Fig.1 Aerial photo and an unimproved route through a rubble field

GENERAL SCENARIO

The assumption is that the shelter is located a nominal distance of 500m away from the structure. In addition, we assume that the final groomed trail would be 3m wide and have a rope barrier or similar on both sides. The trail would have a smooth walking surface and have a gradient of less than or equal to 10%. This would accommodate two- way traffic on the trail, both for walking and ATV and also allow the construction equipment to move along the trail. The ice between the structure and the shelter can vary from smooth level ice to rubble ice to large ridges and hummocks. An initial route between the two locations may have to be established that is indirect in order to take advantage of sections of smooth ice. Once this route has been established, work can start on a shorter, more direct route through the presumably rougher ice surface. Alternatively, the initial route may be the final route. The trail improvement in general will consist of a combination of removing and/or moving existing ice blocks, and filling in depressions with either water or ice. After completion of trail construction, some maintenance activities such as snow drift removal, filling in cracks and checking integrity of rope barriers will have to be done.

VOLUME OF MATERIALS

To determine the time required to construct a trail, estimates of the volumes of ice that need to be moved and/or constructed are required. We have assumed that there will not be a significant amount of snow that can be harvested for trail construction. Rubble height transects of actual terrains including ridges around the Tarsiut Caisson are shown in Fig. 2 (CANMAR, 1984; Gulf, 1983).

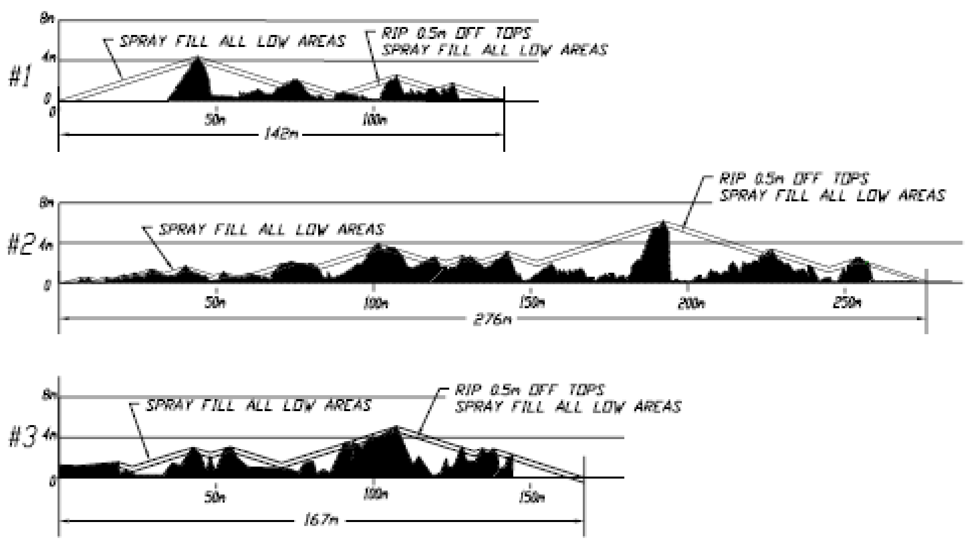

Fig. 2 Cross Section of rubble fields

These transects are considered representative of the types of terrains that occur in the Beaufort Sea. Fig. 2 shows two sets of lines, the upper lines representing the final trail surface when no material has been removed from the high points. The lower lines represent when 0.5m has been removed from the high points in the route. This depth was considered to be a reasonable value. A large amount of material removal could result in grounded ice becoming ungrounded. The average depth of the fill for the no-ripping case and the 0.5m ripping case for the various trail segments are given in Fig. 3 as a function of the nominal rubble height Barker et al. (2006). The no ripping trend line has a slope of 0.41. The 0.5m ripping trend line has a slope of 0.37 and has zero depth at a rubble height of 1.0m. The mean cut depth is the total cross sectional area removed divided by the horizontal length of the section and is presented in Fig. 4. When the nominal rubble height is less than approximately 4m, the mean cut depth is about 0.08m. At the larger rubble height, mainly from ridges, the mean cut depth is less (0.01m) because there is only one ridge in the section as opposed to the lower rubble heights where there are many peaks.

Material volumes are calculated using the regression lines in Fig. 3 and Fig. 4. For fill material, the volume is determined using the assumed 3m wide trail plus an additional 100% for the side slopes of the trail. For the cut material only the 3m wide trail width is used.

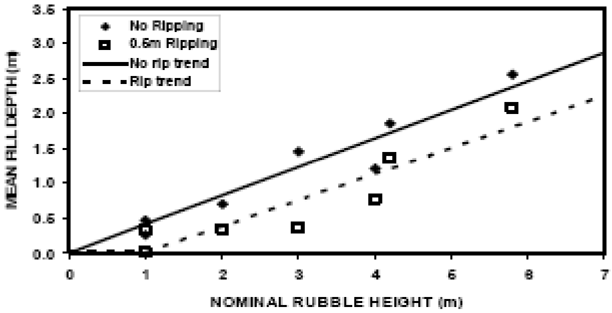

Fig. 3 Mean Fill Depth as a function of nominal rubble height

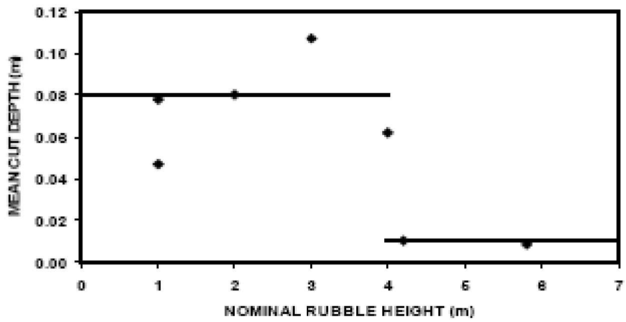

Fig. 4 Mean Cut Depth for 0.5m ripping case as a function of nominal rubble height

EQUIPMENT SELECTION

The types of equipment/procedures required to construct the trail and the estimated production rates are listed in Table 1. The selection and performance is based on experience with Arctic construction projects, for example Masterson et al. (2004), Spencer & Masterson (2006).

Table 1 Major Construction Equipment Types

Equipment/Procedure	Function	Production Rate	Cost
D3 Cat	Cut and Fill - Ice blocks - Spray ice	 - 10 m^3/hr - 100 m^3/hr	$137,000
Big Ice B-55 Flood Pump	Free Flooding	110 m^3/hr	$3,500
Wildfire BB-4 High Pressure Pump	Spray Flooding	22 m^3/hr	$5,500
Snow Maker. Uses BB-4 pump	Spray Flooding	15 m^3/hr	$7,000
Manual Moving	Cut and Fill	0.5 m^3/hr	n/a

The D3 Cat would have to be located on the structure for the whole winter. It may not be transportable to the site as neither an airstrip or a road to shore may be available. The machine will require at least 50 cm of solid ice before it is safe to operate on the ice sheet (Masterson, 1974). This may require that the ice sheet and rubble field consolidate and thicken for a period of approximately 1 week after an ice movement event for typical Beaufort Sea conditions. A lower production rate for ripping has been used when working the ice blocks compared to the spray ice. This is because the spray ice is softer than the original ice blocks and the route will be smoother when managing the spray material.

Big Ice pumps weigh approximately 20 kg and can be moved around by sled. They require a 200mm hole augured though the ice for a water supply. They are used for free flooding of the lower parts of the route. If there is a significant amount of snow on the ice sheet then the initial flood can be 0.15 to 0.2 m deep for typical winter Beaufort Sea conditions. This initial flood would require approximately 2 days time to freeze. Once it is frozen then additional floods can be applied. As long as there is a crust on the layer sufficient for foot traffic and the equipment then free flooding can continue.

The spray flooding pumps are portable units that weigh approximately 80 kg and can be moved around by sled. These units require a 150 mm diameter hole augured through the ice for the water supply. The capacity of the units would allow for the spray to reach a distance of about 30m from the unit, depending on wind speed and direction. Note that for the spray ice, 1m^3 of water produces approximately 1m^3 of ice (Instanes, 1994). The snow making equipment would use the same spray pump units but a different nozzle unit. A discussion of snow making is given in Collins & Masterson (1989).

Fig. 5 D3 Cat, Snow making equipment and free-flooding pump.

The nominal rubble height will determine what equipment is appropriate for the particular terrain. Table 2 outlines the approach for trail construction in the various types of rubble defined in Barker et al. (2006) and also illustrated in Fig. 2.

In Table 2, a mountain trail is a 1m wide trail with a grade of 10%. This would be constructed into the side of the ridge and may have to use switchbacks. The trail would have a rope barrier on the downhill side of the trail. For construction purpose, it has been assumed that $1m^3$ of ice has to be moved for each meter of trail.

Table 2 Construction Operation by Rubble Type

Rubble Type	Rubble Height	Construction Operation
Light	0.35 m	Use D3 Cat to drag surface. Use free flood to fill in low spots.
Medium	1.0 m	Use D3 Cat to remove high spots. Use free flood and/or spray flood to fill in low spots
Rough	4.0 m	Use spray flood to fill in low spots to allow access for D3. Use D3 to remove high spots and groom trail. Continue spray flooding
Ridge	7.0 m	Avoid if at all possible. Spray flood ramp to allow D3 access. Use D3 to rip ridge. Continue spray flooding. Alternatively use manual methods to construct "mountain trail" across ridge.

TIME ESTIMATES

Using the volume estimates from Fig. 3 andFig. 4, the production rates given in Table 1, the number of pieces of equipment listed in Table 3 and the trail dimensions, we can estimate the number of hours to construct a trail.

Table 3 Assumed Equipment on Site.

Item	Number Operating	Spare Units
D3 Cat	1	0
Free Flood Pumps	2	1
Spray Pumps	2	1
Manual block movers	2	0
Ice Augers	2	1
Skidoo and Sled	2	1
Chain Saw	2	1

Two examples are given for trail construction time estimates, each with various construction methods. The first is to take a severe route where the three cross sections in Fig. 2 are put end-to-end for a total distance of 585 m. The second example is to use the terrain illustrated in the right hand side of Fig. 1 for the whole 585m trail. The example terrain in Fig. 1 was classified as medium rubble (Barker et al, 2006). The results of the time estimates are given in Table 4.

In generating the estimates in Table 4 for the mountain trail case, we assumed that two ridges would be crossed using a mountain trail and that spraying of material adjacent to the ridge would not be done. The surface finishing involves flooding of the surface to bond the ice chips together to make an adequate walking surface. During working hours, we have assumed that the identified task can be performed for 50% of the time. The remaining time is spent setting up equipment, moving to the specific work locations and down time due to poor weather. The gross construction hours are given in Table 4.

Table 4 Construction Time estimates (hr)

Route	Method	Rip	Spray	Flood	Manual	Finish	Total
Severe	No rip, all fill	0	171	3	0	6	180
Severe	0.5m rip, fill	22	111	3	0	6	142
Severe	0.5m rip, mountain trail	22	16	3	280	6	327
Medium	No rip, all fill	0	40	8	0	6	54
Medium	0.5m rip	28	0	0	0	12	40

The next step is to estimate the number of days required for the trail construction. The estimates given in Table 4 are based on volumetric considerations only. The maximum amount of time available for outside work has been assumed to be from civil twilight to civil twilight. For a typical Beaufort Sea location this duration is given in Fig. 6. Working effectively and safely outside of these times would require the installation and maintenance of lighting along the trail construction route. Lighting however would improve safety for an evacuation occurring during nighttime.

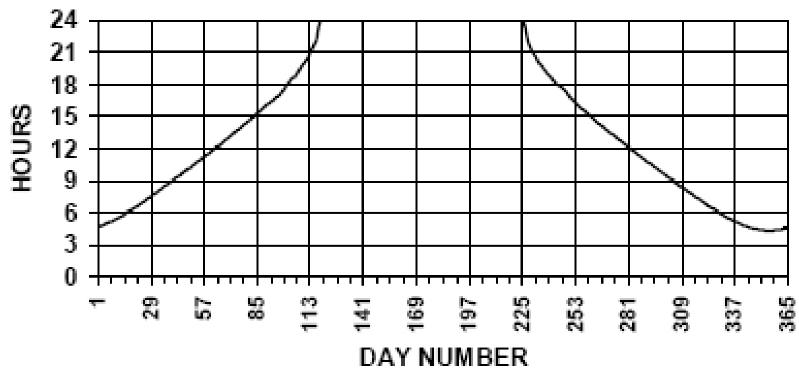

Fig. 6 Duration of Daylight at 69° 40' North

The trail construction in general includes free flooding and/or spray flooding. These processes require a curing or freezing time to allow the material to harden sufficiently for the construction equipment to move over the surface. For dedicated spray projects using large pumping units in the arctic (Masterson et al., 2004) spraying was done on a 24 hour basis with short curing periods at regular intervals. Other projects on ice air strips in northern Canada, only one work shift per day was done with no work overnight allowing for freezing of the material. For this project given the sequential nature of the construction process, only one shift per day has been assumed even if lighting has been installed. In addition, having more equipment and personnel than assumed in Table 3 may not reduce the construction duration. Finally, at typical offshore exploration structures, bunk space is in short supply and there would likely be resistance to having a large crew working on off-structure activities. Taking these factors into account, for a representative trail construction start date of January 15, the working day is 5.9 h and by the end of January is 7.8 h.

For the examples given in Table 4, the number of days to construct the trail starting on January 15, varies from as low as 7 for the most favorable procedure on medium terrain to as high as 39 days for the least favorable procedure on the severe terrain.

DISCUSSION

From the time estimates given in Table 4 the following aspects can be seen. For the medium rubble ripping 0.5 m from the high points has a significant effect on the overall project duration. For the severe situation the best solution is removing the 0.5m from the high points. Not ripping significantly increased the time for construction because of the increased volume of fill material required. The no ripping situation would apply if the D3 cat were not on site. Also it can be seen that the manual method of constructing a "mountain trail" over a ridge results in a significantly longer project duration. From a practical point of view, planning for extensive manual labor content in the project is undesirable. For a safe construction project and a safe evacuation, the presence of wildlife, particularly polar bears is a significant concern and should not be overlooked.

The time to construct a trail through rubble depends on a large number of factors including the roughness of the ice, the horizontal dimensions of the rubble field, the equipment and manpower available on site, the time of year and local weather conditions. Using the approaches outlined in this paper, deterministic construction time estimates can be made for a particular situation. Alternatively, probabilistic methods could be used to assess the construction time taking into account the various factors and uncertainties.

CONCLUSIONS

Typical terrains have been used to estimate the required material volumes for the construction of a walking trail from a Beaufort Sea structure to an emergency shelter located on the ice. Using practical equipment and procedures, time estimates have been made for trail construction. If at all possible it is best to avoid constructing a trail over ridges. If these cannot be avoided then a pathway similar to mountain trail over the ridge may have to be manually constructed. This would increase significantly the trail construction time. Using spray ice to build ramps reduces the required construction time. The use of a D3 cat or similar to remove the high parts of the route significantly reduces the amount of spay ice or flooded ice that has to be manufactured at the site.

For a medium rubble field with nominal height of 1m, a nominal 500m trail starting on January 15 could be constructed in as little as 7days. For a severe route incorporating ridges up to about 6m in elevation and starting on January 15, the trail could be constructed in as little 20days.

ACKNOWLEDGEMENTS

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