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

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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).

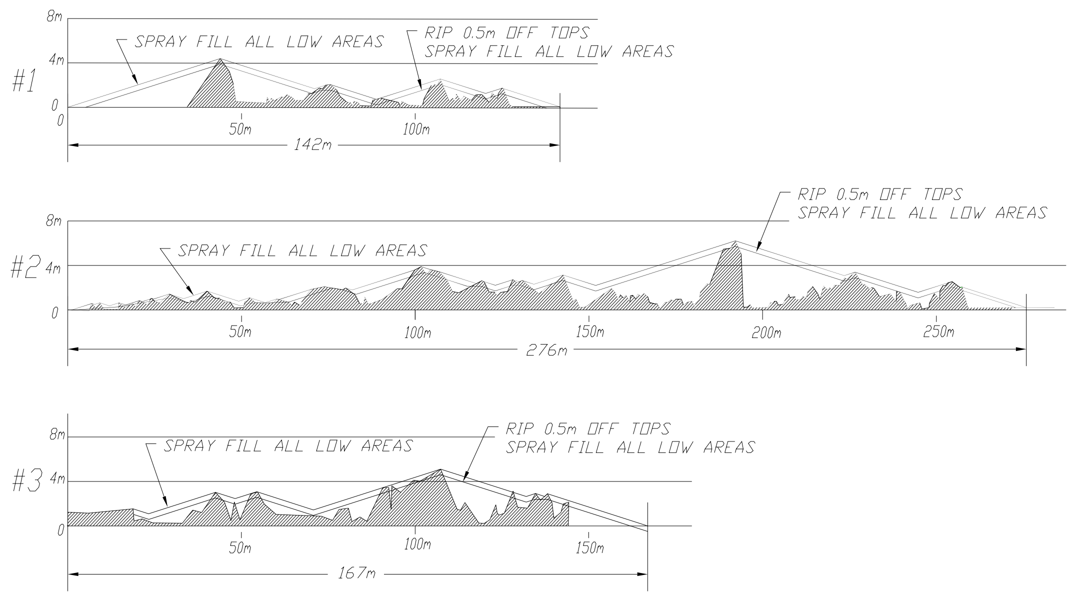

Fig. 2 Cross Section of rubble fields

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.

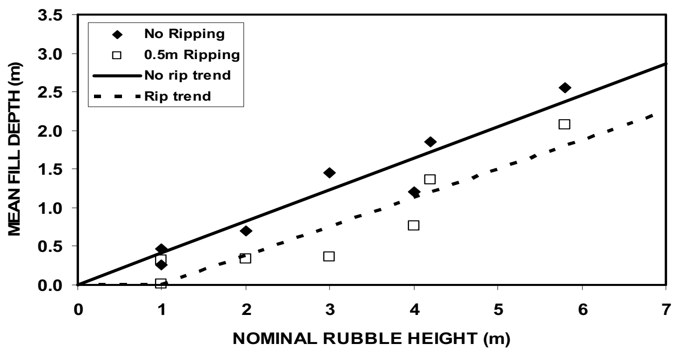

Fig. 3 Mean Fill Depth as a function of nominal rubble height

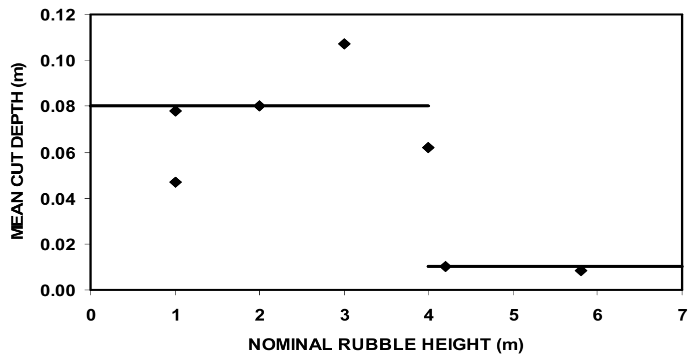

Fig. 4 Mean Cut Depth for 0.5m ripping case as a function of nominal rubble height

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.

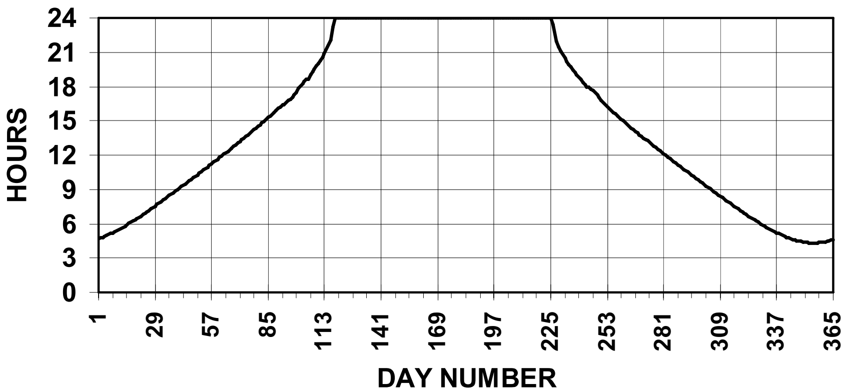

Fig. 6 Duration of Daylight at 69° 40' North

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.

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