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SEASCAPE SYSTEM OF EVACUATION

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ABSTRACT

Both the "Royal Commission on the Sinking of the Ocean Ranger" and the Piper Alpha Inquiry recommended that improvements be made to escape, evacuation and rescue (EER) systems employed on offshore petroleum facilities. The respective methodologies suggested for achieving these was by both the development of "performance standards" and the utilization of "goal-setting regulations". A system now exists which meets the recommendations of both public inquiries.

Following an extensive series of model testing at the Institute of Marine Dynamics in St. John's, a full operating system was installed at the Humberside Offshore Training Association (HOTA) located in Kingston-upon- Hull, United Kingdom. A total of 267 trials with resulting data gave evidence to the effective availability of this unique system.

A second system of a more advanced configuration is currently undergoing extensive trials in seas up to and including Beaufort 8. Located in Portugal Cove, Newfoundland, Canada, launches will, also, be made onto a combination of 1st year and multi-year ice, which is present in early spring.

The Life-Rescue Craft launched in February 2002 was dispatched to the northeast coast of Newfoundland in mid-April, 2002 where it was subjected to a rigorous series of ice-trials. A second set of trials in harbour/sheet ice took place between March 1-5, 2003.

This major research & development is being carried out as a multi-national joint industry/government project (JIP) involving regulators from several jurisdictions and a consortium of major operators. The project is to conclude in March/April 2004.

Seascape 2000 Inc. has received funding under a Joint Industry/Government Project to test the facility consisting of the following critical components:

1. Life Rescue Craft
2. Deployment Arm
3. Hydraulic Fall Arrestor
4. Support Structure.

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Seascape System of Evacuation @ Portugal Cove, Newfoundland, Canada

BACKGROUND

On February 14, 2002, Seascape 2000 Inc. launched its unique and effective "Life Rescue Craft". On Saturday, February 16th, the vessel went through a series of preliminary trials. These compared favourably with the results of the 1:4 scale model tests carried out at the Institute for Marine Dynamics in early 2001. At a speed of 11 knots, the "Life Rescue Craft" proved to be both extremely maneuverable and stable.

In anticipation of the recommendations of the Ocean Ranger Commission in 1985, an initiative was undertaken to develop an effective and unique evacuation and rescue system designed specifically for the environmental challenges offshore Newfoundland.

During the more than 15 years in its development, the Seascape System of Evacuation has gone through an extensive series of wave-tank tin the immediate future tests employing models with scales from 1:75 to 1:18. In 1994, successful full-scale trials were carried out on the Seascape installation at the Humberside Offshore Training Association in Kingston-upon-Hull, United Kingdom.

Seascape 2000 Inc. holds a Certificate of Approval from Transport Canada the nation's marine regulatory authority, and design appraisal documents from Lloyd's Registry of Shipping. This documentation pertains to the deployment system, which includes critical components such as the deployment arm, winch and fall arrestor, and ancillary equipment.

Seascape 2000 Inc. holds all Intellectual Property Rights (IPR) on its technology. Seascape has some 24 patents worldwide on the Seascape System and its individual components.

Also in 1994, British Gas PLC. and B.P. Exploration Company Ltd. both performed internal Risk / Reliability analysis and concluded the "availability" (successful operation) of Seascape System of Evacuation, in various circumstances, was 99 %. This compares extremely well to the historic failure rate of 86 % (Royal Institution of Naval Architects), recorded and attributed to conventional, davit-launched lifeboats.

In addition, Seascape 2000 Inc. received the 1995 Seatrade Award for Life-Saving Technology from the International Maritime Organization, United Nations. Later that same year, during a BBC television interview, Lord Cullen, Commissioner of the Public Inquiry into the Piper Alpha Disaster, publicly endorsed major advantages of the Seascape System of Evacuation.

In September of 1996, a series of comparative model tests of four evacuation systems, including Seascape, were carried out at the Institute of Marine Dynamics, National Research Council of Canada. The contractor, Offshore Design Associates, concluded that both qualitatively and quantitatively, the Seascape System of Evacuation had obvious benefits and had demonstrated better performance qualities over the other three systems. Both Transport Canada and the Government of Newfoundland and Labrador commissioned this work.

ICE TESTING LOCATION

On April 10th, 2002, the Seascape 70 person " Life-Rescue Craft"® was transported to the northeast coast of Newfoundland. Following launch, a comprehensive series of sea-trials in ice of various configurations and thickness' were carried out. Attended by industry representatives, the trials produced a satisfactory level of very positive quantitative and qualitative data.

The program conducted on April 12th, involved a series of Runs beginning early in the morning and into the night. The initial 9 Runs in the morning documented the speed and distance that the Life-Rescue Craft® traveled in ice cover ranging from 1/10th to 8/10ths. Ice drift was measured up to speeds of 1.8 knots. Additional activity demonstrated the maneuverability of the vessel in areas of heavy concentration, its ability to transfer individuals to an attending vessel and to retrieve personnel from ice floes.

Location of testing: Twillingate, Newfoundland, Canada.

Night trials were directed at maneuvering through various degrees of ice concentrations with limited visibility augmented by permanently attached searchlights. The ability to hide behind a large ice floe was also demonstrated. Photographs and video were taken throughout the entire test period.

On the 13th, April 2002, the ice moved far out to sea, but returned on the 14th, April in a heavier concentration of ice floes and brash ice. The ice formed a string estimated at 3 kilometres in length and ½ kilometre wide. The Life-Rescue Craft® made two successful passes through the ice. Ice-drift was measured at 1.8knts. No other data was collected. Photographs and video were taken.

Trials # 2 – Sheet/Harbour Ice

In furtherance to the initial satisfactory ice trials Seascape undertook a second series of ice trials from March 1s- - 5th, 2003, to provide additional data and proof as to the exceptional life saving capability of the Seascape system in offshore ice environments. Attended by industry representatives, the ice trials began on March 1st in the Twillingate Harbor. Data collected from the 1st session included ice samples and general observations of the LRC's performance in varying ice conditions. The LRC craft recorded speeds of 6.2 knots in 6.5 cm sheet ice, 5knots in 9 cm sheet ice and 1.8 knots in 10.5 cm sheet ice. Capable in ramming its way through a 24 hr refrozen channel comprised of 28 cm ice chunks at a rate of 1 boat length per ram.

Testing during the 2nd session on March 1st involved putting the LRC through point-to-point runs and collecting the relevant data. In this series of tests the LRC proved able to travel ½ NM in 5 minutes through ice 6 – 10 cm thick and 200 yards in 2mins through 12 cm ice. The LRC completed two full 360 deg turns in 5.5 cm thick ice in just 46 secs. The last run of March 1st was back towards the wharf through the channel of 28 cm thick ice chunks made earlier. The LRC was able to negotiate through the channel at a constant speed of 2.2 knots.

March 2nd yielded more positive results from point-to-points runs. Runs #9 & #10 tested the maneuverability of the LRC by taking the path of least resistance through 7-9/tenths-ice cover. The LRC was able where possible to maneuver around large ice pans 10-30m in diameter and when necessary to ram through the ice pans that were measured to be 25 cm thick. The LRC completed the 1 NM runs #9 & #10 in 24 and 19mins respectively.

On March 4th the most notable ice trial was conducted in a flow of 29 cm thick hard ice pans of 3-5 m diameter. The winds were excessive and the ice pans were heavy but the LRC was able to push through the ice pans at speeds just above 2 knots. The twin propellers proved to be of extreme benefit when navigating such ice conditions.

The last day of trials involved a series of exercises with the Search & Rescue Cormorant helicopter in which on three separate occasions the S&R Technicians were lowered and retrieved from the deck of the LRC. Afterwards the S&R personal involved in the exercises commented on the excellent performance of the LRC under the vortices generated by the helicopter. The Sar Techs were easily landed onto and lifted from the LRC deck.

On Thursday, February 27th/03, the Anne Harvey escorted the LRC north through the western run, Hamilton Sound in ice up to 4 metres thick. The LRC was towed by the Harvey for a distance of approximately 0.5 nm without incident.

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ARCTIC OFFSHORE ESCAPE, EVACUATION, AND RESCUE

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ABSTRACT

Results of a survey of the state-of-art Arctic escape, evacuation, and rescue (EER) are presented. The review covers regulations and standards, current and emerging technologies, and analytical methods for the assessment of Arctic EER performance. The status of Arctic EER international (ISO) and Canadian national standards is described. Both sets of standards are performance based, but vary in their approach. Although many different open water technologies have been adapted to some degree for Arctic use, there does not appear to be a fully operational evacuation system adequate for both open water and ice conditions. Finally, methods for assessing the risk and reliability associated with emergency operations in Arctic ice laden waters are reviewed. These methods include algorithms for human and mechanical performance generating probabilities of likely EER outcomes under different environmental, operational, emergency, and personnel conditions. Conclusions from the work are summarized.

INTRODUCTION

The Ocean Ranger and Piper Alpha marine disasters initiated extensive inquiries into the adequacy of marine EER systems. These inquiries were the Public Inquiry into the Piper Alpha disaster (Cullen, 1990), and the Royal Commission on the Ocean Ranger marine disaster (1984). Common to the results of both inquiries was the recommendation to develop performance-based standards for EER systems for offshore installations, rather than a prescriptive regulatory framework. Development for such a framework, for both open and ice populated waters, requires supporting development work on EER performance evaluation and appropriate technologies. This paper reports on current developments in EER resulting from the disaster inquiries, with particular emphasis on developments of EER for polar offshore conditions, in the regulatory, technology, and performance assessment areas.

STANDARDS AND REGULATIONS

Summary of Current Status

The author is involved in the development of Arctic EER standards for Canadian waters, under Transport Canada (TC) sponsorship, as well as on the international level

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with the International Standards Organization (ISO). As the initial step on both sets of standard developments, a worldwide Arctic EER data and literature search was conducted online, through libraries, classification societies, offshore organizations, and through contacts with petitioners and operators in polar offshore regions. Although research and development is underway, it was found that no standards, guidelines, or regulations exist for polar or ice covered water EER. Accordingly, the draft Arctic EER performance-based standards described below appear to be unique and represent a pioneering regulatory excursion into this area.

Performance-Based Standards

Performance-Based Standards (PBS) are verifiable attributes that provide qualitative targets and quantitative measures of accepted performance. The key characteristic of PBS is their focus on what must be done, rather than on how it should be done. The difference between PBS and the more traditional prescriptive standards is that PBS concentrate on the result, while prescriptive standards set out details of the process, which may or may not achieve the desired results.

Confusion results because both PBS and the traditional prescriptive standards, in a generic sense, both prescribe certain values or quantities. However, PBS prescribes performance targets; traditional standards prescribe how to do something. This “how to” approach may or may not lead to desirable targets, although it is intended that it lead to a desirable target. To avoid confusion, these traditional prescriptive standards in the balance of this paper will be referred to as the “how to” standards (HTS) in contrast with PBS.

In recent years, there has been a strong interest worldwide in developing codes and standards that are more performance based. The building industry in Australia (Foliente, 2000), Israel (Gross, 1996), USA (NBS, 1977), and Canada (Legget and Hutcheon, 1979), is undergoing a transition from HTS to PBS. Military organizations worldwide have long been the user of performance-based standards and measurement systems. Therefore, not untypically, a good working definition to form the basis of performance-based measurement can be drawn from the Canadian Department of National Defense, Defence Planning Guide, Chapter 5: Performance Measurement, 1998 (CDND, 1998) as follows:

“There are three broad elements in the performance measurement framework: Measures; Indicators; and Standards. They are defined as follows:

(a) measures are attributes that must be analyzed to determine whether the expected results are being achieved;

(b) indicators are aspects of the measures that are to be assessed; and

(c) standards are the quantitative targets or qualitative goals to be achieved.”

Focusing on the current subject of the safety of offshore installations, both the Lord Cullen Inquiry (Cullen, 1990) and the Royal Commission on the Ocean Ranger Disaster (1984) recommend a greater emphasis on performance-based standards and regulations (Sefton, 1994) in offshore safety. The Canadian Maritime Law Association (1998) also points out the need for a unified performance-based set of standards. Current worldwide SOLAS (IMO, 1974) as well as Canadian East Coast (NOPIR, 2001; CNSOPBR, 2001) regulations are substantially HTS, as are associated offshore recovery (UKOOA, 2001) standards.

Canadian PBS

The "Canadian Offshore Petroleum Installations Escape, Evacuation, and Rescue (EER) Performance-Based Standards" (PBS Development Task Force, 2002) are a set of standards intended for offshore installations in both Arctic and temperate Canadian waters to assure adequate safety for all personnel in the event of a situation which requires emergency abandonment of an installation. Primary users of the PBS are intended to be the operators and the regulators.

The PBS are divided into four principal categories, according to the EER process and its main components, as follows:

- The overall EER process;
- Escape;
- Evacuation;
- Rescue.

Each of these Standard categories, except for the first one, is subdivided into global and specific standards (Bercha et al., 2003). Global standards apply to the overall process, while specific standards apply to different approaches to each of the components. The structure of the Standards is illustrated in Figure 1.

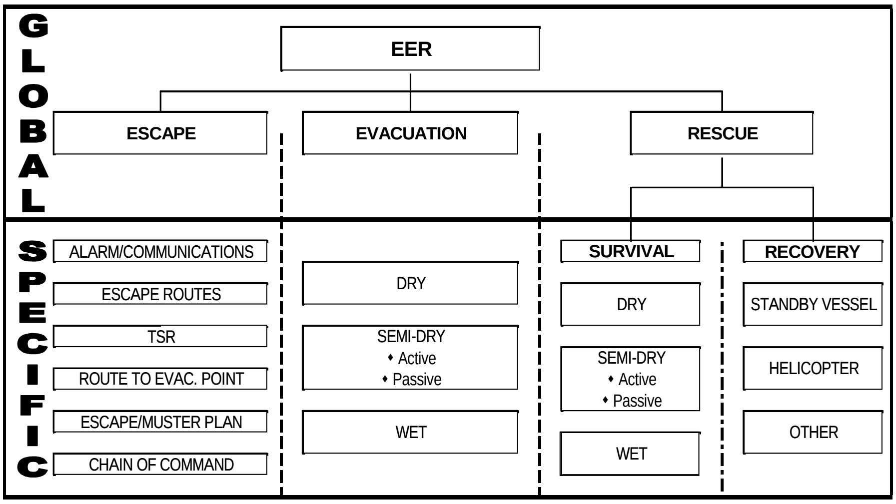

Fig. 1. Structure of Performance-Based Standards

The purpose of the Standards is to establish objective and measurable criteria to optimize the following:

- Design
- Performance
- Reliability
- Availability.

As shown in Figure 1, each of the principal components of the EER is further subdivided into a series of sub-components. Typical Standards in the above categories applying to semi-dry (or lifeboat type) systems are reproduced in Table 1. Only typical Standards in each of the main categories are given in this table. The reader is referred to view the entire set of Standards under (PBS Development Task Force, 2002), which can be viewed on either of the following websites: www.berchagroup.com or www.nrc.ca/imd/eer.

From this table, we can see typical examples of a qualitative PBS and quantitative PBS. Clearly a qualitative statement has been made in the area of design (a) and its associated performance (b). However, in the area of reliability (d), the statement made is quantitative. Essentially, it states that a certain reliability or success rate shall be achieved during an evacuation operation under a given set of weather conditions. The weather conditions for which specific reliabilities are required have been set up as described in Table 2, with a similar categorization for ice and Arctic conditions.

Table 1. Semi-Dry Active Systems PBS

(a) Design		***(b) Performance***	
i	Designed for operation and occupancy in all accident, environmental and operational conditions of the installation design.	i	General Performance: ▪ Operate under its design accident, environmental and operational conditions.
ii	The system shall be designed for a rapid, simple, and safe launching process.	ii	Launch Performance: ▪ System will have the capability to clear the installation (once launched or airborne) by at least 50 metres in minimum time for all environmental design conditions within 5 minutes.
(c) Availability		***(d) Reliability***	
▪	ach semi-dry active system shall be vailable at least 98% of the time at sea his means 1 week per year downtime).	▪	The minimum reliability of each semi-dry active evacuation system in severe weather (Beaufort 8-10) shall be at least 95%).
▪	he semi-dry active system availability hall be sufficient to provide combined vailability during installation service f all evacuation systems in accordance vith Section 7.1(g) (99.9%).	▪	The minimum weather weighted average reliability of each semi-dry active evacuation system shall be 97%.

Table 2. Weather Condition Categories Used in Standards

Category	**Beaufort Force**	**Avg. Max Wind Velocity** knots (km/hr)
Calm	0-4	16 (28)
Moderate	5-7	33 (61)
Severe	8-10	55 (102)
Extreme	11&12	64+ (118+)

Normally, the weather weighted average reliability set out in the Standards is intended to be invariant regardless of the weather conditions. Thus, in order to achieve the stated reliabilities of the total system, components will have to optimize not only the types of systems, but also their configurations and redundancies in order to achieve the overall reliability required. For example, since reliabilities are relatively low for extreme conditions, operators will have to enhance or fortify their safety systems to achieve the performance goals in areas where extreme conditions are more prevalent, in order to maintain the same weather weighted average reliability.

Table 3 sets out the general contents of the ice and cold weather Standards. Because very limited quantitative information on cold weather performance exists, the current draft of the ice and cold weather Standards (Ice Standards) is largely qualitative in its description of performance targets. The structure of the Ice Standards, however, does conform to the body of the EER Standards described above, with the proviso for a set of ice severity categories, similar to the weather categories established in Table 1. All Ice Standards can also be viewed at the above-cited websites.

Table 3. Ice and Cold Regions EER PBS Summary Contents

Section	Title		Section	Title
1.	Introduction		7	Evacuation Standards
2.	Definitions		*7.1*	*Cold Temperature*
3.	Relevant Publications		*7.2*	*Ice Fog*
4.	General Requirements		*7.3*	*Icing*
5.	Global Standards		*7.4*	*Marine Ice*
6.	Escape Standards		8	Rescue Standards
6.1	*Cold Temperature*		*8.1*	*Survival*
6.2	*Ice Fog*		*8.2*	*Recovery*
6.3	*Icing*			
6.4	*Marine Ice*			

Jurisdiction of the Canadian EER PBS will be vested in the East Coast Petroleum Boards and the National Energy Board (NEB). The Canada Nova Scotia Offshore Petroleum Board (CNSOPB) and the Canada Newfoundland Offshore Petroleum Board (CNOPB) have jurisdiction over East Coast installations in Canadian waters. The NEB has jurisdiction over the Gulf of St. Lawrence, Arctic waters, and Pacific waters within Canadian limits. These boards are currently reviewing the draft EER PBS, and expect to promulgate them in the near future following their review and editorial process.

ISO PBS

The International Standards Organization (ISO) is currently addressing performance requirements of polar offshore installations through Working Group 8 – Arctic Structures. Work by technical panels (TP's) have been ongoing for over one year under the following technical panel categories:

- TP1: Environmental
- TP2: Action / Loading / Reliability
- TP2a: Reliability
- TP2b: Ice
- TP2c: MetOcean
- TP2d: Seismic
- TP3: Foundations
- TP4: Artificial Islands
- TP5: Steel
- TP6: Concrete
- TP7: Floating
- TP8a: Facilities – Topsides
- TP 8b: Facilities – EER
- TP9: Ice Engineering.

All standards under development by these panels are to be performance-based standards (PBS), generally with the characteristics described in the first subsection of this section.

As the Canadian PBS development program had preceded the ISO EER TP8b work, many of the detailed provisions from the Canadian PBS were adopted with some modifications. However, the overall philosophy of the ISO EER PBS approach is to provide qualitative rather than quantitative performance targets through focus on the use of probabilistic and risk analytic procedures in the optimization of installation EER systems. TP2a, the reliability panel, however, is mandated to develop quantitative safety targets for not only each category of installation to guard against catastrophic and serviceability failures, but also for the associated installation EER systems and procedures.

To illustrate the content of the draft ISO EER PBS, the high level Table of Contents is given in Table 4. At this time, the ISO EER PBS are only in the form of a preliminary working draft. A committee draft is expected prior to the end of 2004, with promulgation likely by the end of 2005 or early 2006.

Table 4. ISO EER PBS Table of Contents

Section	Title		Section	Title
1	Introduction		7	Environment
2	Scope		8	EER General
3	Normative References		9	Escape
4	Nomenclature		10	Evacuation
5	EER Philosophy		11	Rescue
6	Hazards and Risk Analysis		Annex A	Environment

ARCTIC EER TECHNOLOGIES

Current EER systems function in open water with varying reliability depending on the severity of weather conditions. Factors, which would need to be incorporated in Arctic Arctic evacuation systems, are summarized in Table 5. Because of feasibility considerations, Arctic systems should also suffice for open water operation (IMO, 1974).

Table 5. Arctic Evacuation Problems

▪	Very cold. Adfreezing snow/ice obstructing mechanisms and causing slippage.
▪	No free fall or fast descent system due to ice.
▪	Ice conditions variable – dynamics and ice fraction can change quickly.
▪	Ice pressure, ride-up, adfreeze, pileup.
▪	Ice movement direction unpredictable.
▪	Visibility bad often – fog/Arctic winter.
▪	Damage to capsule greatly decreases survival.
▪	Arctic system must also work for open water.

Escape on Polar Installations

The process of escape on installations under polar winter conditions, is not significantly different from that on installations in temperate frontier regions. The escape process, by definition, is restricted to activities on the installation. Escape along outdoor walkways, stairways, and ladders may be hampered by accumulating snow, adfreezing ice, and low visibility and strong winds, but require no new technologies, rather only cold weather provisions such as non-slip surfaces, heat traced walkways or ladders, or wind and snow barriers. Full-scale trials in cold conditions have shown no significant impact of their effects on the escape process (Bercha et al., 2001).

Evacuation from Polar Installations

The conventional evacuation process needs to be significantly altered to ensure safe evacuation of ships or installations in ice. For lifeboats, alterations are needed both in the launch method and in the craft configuration while still maintaining the requisite IMO open water capability. Other methods of evacuation such as chutes, gondolas, inflatable carpets, also need significant modifications to adapt to polar conditions. The launch must safely transfer the loaded lifeboat from the installation to the ice surface or into the ice lead, in all expected conditions, including pile-ups. An indoor, heated stowage location is preferable to ensure that all mechanisms are not impaired by ice or snow buildup. The orientation and location with respect to prevailing wind and ice motion must also be considered. Bercha et al. (2004, 2003) describes different conceptual designs intended to effect safe and reliable evacuation utilizing a TEMPSC for a typical GBS with a sloped ice wall, requiring the launch mechanism to deposit the craft well beyond the toe of the ice wall or pile-up at the ice or water surface.

Rescue After Evacuation from Polar Installations

The rescue component of EER consists of the survival of the evacuees and their transfer to a safe haven. First, consider the craft in pressured broken ice. The Norwegian explorer, Fridtjof Nansen, with the help of his British Naval Architect, Colin Archer, solved this problem in 1890 with the hull design of his vessel, the *Fram*. The efficacy of the design was borne out by the fact that the *Fram* survived pressured Arctic ice in the winters of 1893-95, as well as several subsequent expeditions in later years. Nansen's principle was that "the ship should be pushed upwards by the expanding ice as it froze (or pressured) by giving the hull very rounded lines… flaring out over the ice in the main ice contact belt" (Fram, 2003). Shakelton's vessel, the *Endurance*, was not so designed (Lancing, 1999), resulting in "… pressure reached new heights…decks buckled and the beams broke…ice climbed up her sides foreward, inundating her under the shear weight of it." An adaptation of the basic lifeboat using the Fram principle, together with provisions to allow movement on solid ice, is described by Bercha (2003). For the on-ice case, the main problem is to maintain upright stability of the vessel, and to permit it to propel itself on the ice surface to a location clear of the installation hazard zone. Clearly, there is no limit to the possible on-ice locomotion designs, ranging from the amphibious *ARKTOS*, to the confirmed on- and off-ice reliable but high-energy consumptive air cushion vehicle lifeboats.

RISK AND RELIABILITY STUDIES

The setting of EER performance targets requires ways of assessing practical quantitative measures of reliability, availability, and safety. Such assessments can be based on the following:

- Full-scale and model test data
- Expert opinion based on experience
- Analytical and simulation modeling.

Unfortunately, other than the anecdotal data referred to the anals from polar exploration (Fram, 2003; Lancing, 1999), full-scale data do not exist. Some model tests are underway with preliminary results giving performance in restricted concentrations of broken ice floes. However, these tests exclude the effects of human performance and do not model conditions resulting in craft failure. Expert opinion is valuable, but little or no experience exists. Thus, at this time, the main resource for quantifying performance parameters of polar EER systems remains analytical and computer simulation. To the best of the author's knowledge, the only comprehensive Arctic EER simulators which are operational and validated to the maximum extent currently possible are those described by Bercha et al. (2004, 2000). Naturally, EER analytical studies must have been carried out by operators such as Agip, ExxonMobil, and Shell associated with their operations in the Caspian Sea and Sea of Okhosk; but, results of these are not publicly available.

Results of a set of evacuation and integrated EER reliability sensitivity studies generated by the Bercha Probabilistic EER Simulator (PEERS) for both open water (base case) and ice conditions are summarized in Table 6.

Table 6. EER Reliability in Open and Ice Covered Water

Sensitivity	Case	Description	Type	Weather: Calm .38	Mod-erate 048	Severe .13	Extreme .01	Weighted Average	Base Increment: Value	%
Base	1.1	OPEN WATER	Evac.	0.9999	0.9949	0.9266	0.1600	0.9796	0.0000	0.00
			EER	0.9924	0.8678	0.3862	0.0049	0.8439	0.0000	0.00
Ice	1.10	ICE PACK 6/10 CON-CEN-TRATION	Evac.	0.9216	0.8931	0.8210	-	0.8974	0.0822	-8.3
			EER	0.6001	0.3211	0.2501	-	0.4171	-0.4268	-50.6
	1.11	SOLID ICE SHEET – NO RUBBLE	Evac.	0.9950	-	-	-	0.9950	0.0154	1.5
			EER	0.9821	-	-	-	0.9821	0.1383	13.82

Selected EER systems based on current twin-davit TEMPSC and secondary chute systems were analyzed for a range of conditions for open and ice covered water locations (Bercha, 2004). The weather weighted average reliabilities are given in the right hand columns, together with their variation from that of the base case. As can be noted, relative to the base case, there is a marginal increase in reliability for both the evacuation (Evac) and integrated EER (EER) in solid ice, giving a percentage increase of 1.5% and 13.82%, respectively. However, there is a significant decrease in reliability for both evacuation and EER for the $^{6}/_{10}$-concentration case, primarily resulting from the dramatic decrease in EER reliability as weather conditions become more severe, resulting in the augmentation of ice pressure.

CONCLUSIONS

Significant activity in the areas of regulation, technology development, and performance analysis of polar EER is currently underway. The following conclusions may be reached from the activities described in this paper:

- Development of performance-based standards is well underway in Canada and internationally (under ISO auspices) with likely promulgation of performance-based standards worldwide within two years.
- Technology development, at least from published records, is very limited. Current polar operational evacuation systems appear to be restricted in reliability to operations under only a part of the environmental conditions likely to be encountered in ice covered and open waters.
- Performance and reliability assessment using analytical methods and computer simulation in comprehensive and well-developed, but its credibility is hampered by the lack of full-scale operational data for validation purposes.
- The imminent promulgation of performance-based reliability regulations and standards for ice covered water EER is likely to result in the acceleration of research and development of optimal EER technologies for ice conditions.

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RELIABILITY ASSESSMENT OF ARCTIC EER SYSTEMS

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ABSTRACT

Methodologies for the assessment of offshore installation EER systems have been developed utilizing various risk analytic network and simulation approaches. In this paper, the extension of a highly developed network and Monte Carlo simulation methodology to consider Arctic ice conditions impact on the emergency escape, evacuation, and rescue from floating and bottom founded installations is described. Essentially, open water EER simulation is augmented by the inclusion of cold weather and ice conditions together with estimates of their effects on human and mechanical performance of the EER system and its components. Following a description of the EER simulation principles and processes, selected Arctic and open water scenarios are described and representative results of reliabilities of different EER system configurations under a range of open water and Arctic conditions are presented. Conclusions and recommendations for further work are given.

INTRODUCTION

Current focus in the regulatory, design, and operational areas on performance rather than prescription has augmented the need for tools for the assessment of performance characteristics (Bercha 2004, 2003a). Such performance characteristics include reliability, availability, risk, and safety. Both human and mechanical performance and its interaction must be considered. There is a paucity of full-scale data even for controlled EER operations such as evacuation trials, and only anecdotal accounts of such operations for emergency situations exist. Accordingly, quantification of performance targets for emergency situations needs to be carried out largely analytically usually utilizing computer simulation techniques. The same applies even more emphatically for polar EER emergencies. No publicly available full-scale, even drill, data for EER in ice conditions exist. To keep pace with the current development of Arctic EER performance-based standards (Bercha 2003a, 2004), there is an increased demand for ways of quantifying and setting realistic but safe performance goals for all aspects of escape, evacuation, and rescue.

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EER PERFORMANCE ASSESSMENT

The principal steps of EER modeling are illustrated in the block diagram in Figure 1. Essentially, following assimilation of data (Step 1) and assessment of the key accident scenarios (Step 2) the modeling of the escape process (Step 3) is conducted. The escape process entails movement of personnel from their location at the time of the alarm to a Temporary Refuge (TR) or muster point. The evacuation process (Step 4) entails movement from the TR to a lifeboat or other device, and its launch and movement to a safe distance from the installation or vessel. Step 5 involves the rescue, which consists of survival until a rescue platform is available and subsequent transfer of evacuees to that rescue platform. In the final step (Step 6), the results of the individual component models are integrated to give an overall EER reliability or success probability for the EER system.

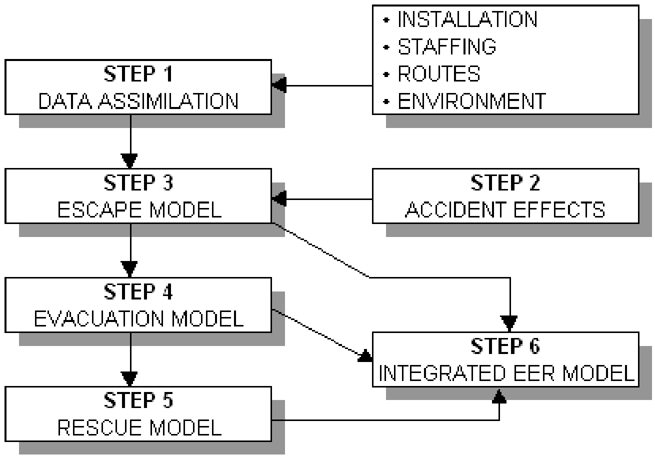

Fig. 1. EER Model Schematic

There are two principal approaches to the assessment of the reliability of a complex process such as marine EER; simulation and risk analysis. Risk analysis is effective for the definition of failures or faults, while simulation is effective for modeling time sequences of different operations in order to provide an understanding of their interaction. An optimal combination of the two has been applied in the approach described herein (Bercha, 2004b; Bercha et al., 1999).

The architecture of the software generally follows the EER modeling structure described in Figure 1 and depicted schematically in Figure 2. This figure is also the opening screen of the model in its current form. The principal modules are aligned in vertical layers, and include global, escape, evacuation, rescue, and integrated modules. These main modules each have layers of Inputs, Parameters, Analysis, and Outputs.

Inputs are user-defined quantities which characterize each unique combination of characteristics including installation geometry, weather patterns, available evacuation modes, available rescue modes, and number of people and level of emergency, to name a few. Parameters are quantities which characterize the risk and performance of a given EER system under (input) specified conditions. Examples of parameters in the human factors (HF) area include the speed with which personnel move along different portions of escape routes such as walkways, stairs, ladders, and the error rate when a decision has to be made (Bercha et al., 2003). Mechanical failure parameters, on the other hand, pertain to availability and failure of components or systems on demand. Because human performance is often ignored in marine system reliability evaluation, a section below is dedicated to this subject. The parameters are the most important determinants of results for a given simulation; they have been judiciously selected from optimal sources; where available parameters were found to be statistically inadequate, experiments or research was conducted to evaluate them. Next, the analysis stratum applies algorithms to characterize the risk and performance time of each step and their synergistic effect. Finally, outputs present these results as tables and graphs for each step and their integrated results for a specified set of circumstances.

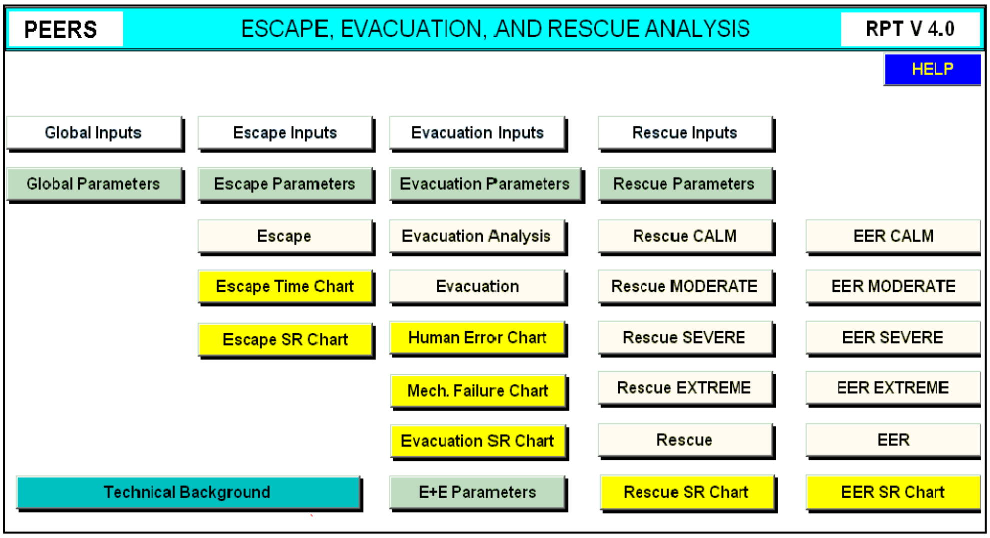

Fig. 2. Model Architecture

Specific definitions of key concepts used in this EER assessment are as follows:

- Availability - The probability that a system is capable of commencing performance when required.

- Reliability - The probability that a process, task, or activity will be successfully completed (no casualties) at any and all required stages (in a system operation when the system is available) within a required time limit (if a time limit exists).

- Success - The achievement of a process or operation without incurring one or more casualties. Success considers both availability and reliability.

HUMAN PERFORMANCE ANALYSIS

Human reliability analysis was extensively developed in the late 1950s, 1960s, and 1970s under the auspices of the U.S. Nuclear Regulatory Commission, by a variety of investigators including Swain (1963), Swain and Guttman (1983), and others (Rasmussen, 1982; Rasmussen & Pedersen, 1984). In these works, human reliability has been defined as the probability that a person correctly performs some system required activity in a required time period (if time is a limiting factor), and performs no extraneous activity that can degrade the system or the process.

Human performance is defined as the way in which a human being carries out or attempts to carry out a given task. This definition applies for the type of macro modeling of processes, tasks, and activities applicable to EER analysis. Human performance, then, for the purposes of reliability analysis as described above, has two primary components; namely, reliability or lack of mistakes with which the task is carried out, and second, the time over which the task is carried out.

One of the most influential factors influencing human performance reliability is stress. Montagne, a French essayist in the late 1500s noted "men under stress are fools, and fool themselves". This quotation reflects a commonly held view that stress is undesirable. In fact, it has been shown that the relationship between human performance and stress is non-linear – too little stress and too much stress both lead to less than optimum or deficient performance. The classical stress curve in Figure 3 (NUREG-75 WASH-1400, 1975) indicates that performance follows a curvilinear relationship with stress, from very low to extremely high.

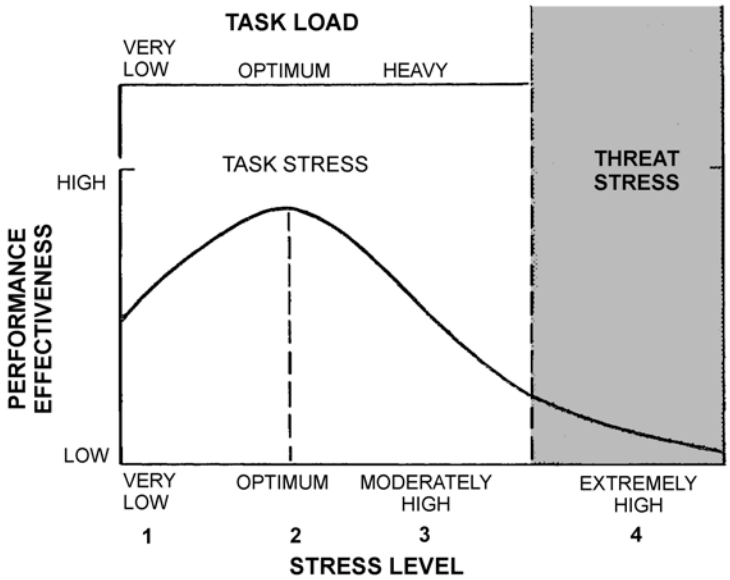

Fig. 3. Hypothetical Relationship Between Performance and Stress with Task Stress and Threat Stress Division

The effects of the first three levels of stress can be approximated by applying modifying factors to human error probability (HEP) in the EER model. The fourth level, threat stress, is qualitatively different from the other three levels – the effects of this level of stress will outweigh other performance shaping factors (HSE, 1997). A summary set of guidelines for estimating HEPs for various types of tasks as a function of stress level is presented in Table 1. The change in HEP effects with time elapsed following a high stress situation is also quantifiable (Rasmussen et al., 1984), but is not explicitly needed here.

ARCTIC EFFECTS ON HUMAN PERFORMANCE

In the context of the previous section, the stresses imposed by an Arctic environment can be considered as stressors, with their severity varying in proportion to the threat level of the EER and the severity of the environmental effects. Table 2 summarizes unique aspects of the Arctic which create stressors on human performance.

Table 1. Modifications of HEPs for the Effects of Stress on Skilled Personnel[1]

Item	Stress Level	Factors for Modifying HEPs		
		Low	Exp.	High
1	▪ Very Low (Very Low Task Load) ▪ Optimum (Optimum Task Load)	1	2	4
2	▪ Step-by-Step[2]	1	1	2
3	▪ Dynamic[3] ▪ Moderately High (Heavy Task Load)	1	1	2
4	▪ Step-by-Step	1	2	3
5	▪ Dynamic ▪ Extremely High (Threat Stress)	3	5-10	100
6	▪ Step-by-Step	2	5	20

[1] A skilled person is one with 6 months or more experience in the tasks being assessed. The "High" values can be used for novices as a first approximation.

[2] Step-by-step tasks are routine, procedurally guided tasks, such as carrying out written calibration procedures.

[3] Dynamic tasks require a higher degree of man-machine interaction, such as decision-making, keeping track of several functions, controlling several functions, or any combination of these.

Table 2. Arctic Effects on Human Performance

Stressor	Details
Cold Temperature	▪ Breathing difficulty
	▪ Muscular stiffness
	▪ Frost bite
	▪ Lowered metabolism
	▪ Hypothermia
	▪ Bulky clothing
	▪ Stiffness of suits impairing movement
Ice Adfreeze	▪ Incapacitates mechanisms
	▪ Slippery surfaces
	▪ Adds weight/mass
Combined Weather Effects	▪ Wind, snow, waves-impair HP
Marine Ice	▪ Precludes rapid descent to sea level
	▪ Can fracture if walked on
Low Visibility	▪ Ice fog, lack of solar radiation
	▪ Frosting on windows, visors, glasses
Threat Stress	▪ Fear of unknown
	▪ Disorientation

In general, these stressors can be classified in accordance with the stress levels indicated in Table 1. In a moderate set of Arctic conditions, the stress levels will be largely dominated by the operational and accident conditions, however, as the severity of the environment increases to an extreme condition such as an Arctic storm, the stress level can be considered extremely high, with the associated factors for modifying human error probability ranging up to a level of two orders of magnitude or 100.

The fact that cold alone does not greatly impair human performance was confirmed by low stress cold weather escape and evacuation performance experiments conducted by the authors (Bercha et al, 2001). There was no discernable difference in performance; in fact, the performance was slightly better under the colder conditions, perhaps because stress levels were slightly elevated from low to optimum as discussed above.

In the rescue component, however, which consists of a survival and a transfer sub-component, the cold temperatures associated with an Arctic environment will greatly decrease survival times if the evacuees are not properly protected and provisioned.

ARCTIC EFFECTS ON MECHANICAL PERFORMANCE

Current EER systems function in open water with varying reliability depending on the severity of weather conditions. Factors which need to be incorporated in Arctic EER systems, specifically for Arctic evacuation, are summarized in Table 3.

Table 3. Arctic Evacuation Problems

▪ Very cold. Adfreezing snow/ice obstructing mechanisms and causing slippage.
▪ No free fall or fast descent system due to ice.
▪ Ice conditions variable – dynamics and ice fraction can change quickly.
▪ Ice pressure, ride-up, adfreeze, pileup.
▪ Ice movement direction unpredictable.
▪ Visibility bad often – fog/Arctic winter.
▪ Damage to capsule greatly decreases survival.
▪ Thermoplastic behaviour of materials usually adversely affected in cold.
▪ Inflated components lose pressure as gas contracts in cold.
▪ Arctic system must also work for open water.

Escape on Polar Installations

The process of escape on installations under polar winter conditions, is not significantly different from that on installations in temperate frontier regions. Its optimization requires no new technologies, rather only cold weather provisions such as non-slip surfaces, heat traced walkways or ladders, or wind and snow barriers.

Evacuation from Polar Installations

The conventional evacuation process needs to be significantly altered to ensure safe evacuation of ships or installations in ice as described by Bercha (2004, 2003b, 2000). For lifeboats, alterations are needed both in the launch method and in the craft configuration while still maintaining the requisite IMO open water capability. Other methods of evacuation such as chutes, gondolas, inflatable carpets, also need significant modifications to adapt to polar conditions. A launch mechanism that can accommodate both the installation geometry and all expected ice conditions, including pile-ups, is needed.

Rescue After Evacuation from Polar Installations

Rescue consists of the survival of the evacuees and their transfer to a safe haven. A lifeboat hull needs to maintain integrity in pressured broken ice. On the ice, the vessel needs to maintain upright stability and to propel itself on the ice surface away from the installation, which could be on fire or about to explode. A simple adaptation is the provision of sled runners together with a winching mechanism, powered by either the lifeboat engine or a battery operated winch, so that the boat could winch itself to a pylon or anchor which would be deployed by appropriately qualified crew (Bercha, 2003).

RELIABILITY ASSESSMENT RESULTS FOR ARCTIC EER

The EER performance assessment process described earlier was applied to the evaluation of human and mechanical performance and its integrated effect in three representative EER scenarios as follows:

- Arctic EER using current technology.
- Arctic EER using enhanced technology.
- Non-Arctic EER using current technology.

Due to the complexity of the model, only sample and bottom line results are shown herein. A detailed discussion of the modeling steps and results is given in Bercha (2004b).

Table 4 gives a summary of the results. The resultant quantities are the human failure casualty probability (HF), the mechanical failure casualty probability (MF), and the resultant success rate (SR) in percentages. For evacuation they are shown for each of the four environmental severity conditions under weighted average as well for the weighted average (WA) for the total EER process consisting of the three components. The significance of the results is summarized in the conclusions.

Table 4. Summary of Human Factors Contributions to Arctic Evacuation and EER Reliability (All numbers are %)

		Evacuation					EER
		Calm	Moderate	Severe	Extreme	Evac. WA	EER WA
Non-Arctic	HF	1	2	36	90	7	
	MF	1	1	20	90	4	
	SR	99	96	43	10	89	70
Arctic Current	HF	1	4	54	90	11	
	MF	27	81	89	90	62	
	SR	71	14	9	10	52	28
Arctic Enhanced	HF	1	4	52	90	10	
	MF	1	1	20	90	4	
	SR	98	95	27	10	87	66

CONCLUSIONS

The following conclusions can be summarized from the work conducted:

- Assessment of polar EER system reliability can currently be carried out with available analytical techniques described in this paper.

- Although human performance plays a factor in the success of Arctic EER, its contribution is overshadowed by the shortcomings of available technological and mechanical systems to support the EER.

- Current open water technology applied to Arctic EER has an unacceptably high failure rate (72%). The mechanical failure rate of current technology in Arctic applications far outweighs the effects of human performance failure, by a factor of 5 to 1 (62 to 11).

- If advanced technologies are developed and implemented for Arctic EER, EER success rates (66) can be expected to be very similar to those of open water EER success rates (70).

- In both enhanced technology Arctic EER and current technology non-Arctic EER, human factors play a major role in success, out weighing the importance of mechanical performance – a factor of roughly 2 to 1.

- Because human performance can be enhanced through appropriate training, such training is recommended for all EER, whether based on Arctic-enhanced or current non-Arctic technology.

- Although Arctic-enhanced technologies can provide EER success rates comparable to those expected for open water applications, the conclusions above are based on speculative technologies that have not yet been developed and certainly can not be said to be proven.

- Current open water EER procedures and technologies would yield unacceptably low EER success rates (28) regardless of the level of human performance.

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ICE JAMS IN THE MOUTH OF VISTULA RIVER AND THE DANGER OF FLOODS

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ABSTRACT

Vistula is the largest Polish River. In XVII and XVIII century numerous ice jams occurred on Vistula near Gdańsk causing significant floods. In 1895 a direct, artificial channel was formed to facilitate discharge of Vistula to the Baltic Sea, however, there is still a danger of ice jam formation in the river mouth, which may result in water damming and flood moving in the upstream direction of the river. Such situation often occurred in winter and the action of icebreakers prevented ice jam formation. The following factors are important: water elevation in the sea, ice conditions in the river and in the Bay of Gdańsk, morphology of the river outlet, wind speed and direction and river discharge. Mathematical model was developed which takes into account hydraulic, morphological and ice conditions as well as possible action of icebreakers forming ice-free channel. Description of mathematical model is presented together with calculation results, their analysis and conclusions.

INTRODUCTION

Gdańsk is a city of more than a thousand years history. It is situated on the Baltic coast at the mouth of the Vistula River. Gdańsk has 460 thousand inhabitants and is a very important economic, cultural, scientific and industrial centre. The city is situated on the lowland area and is one of the most flood endangered urban agglomerations in Poland. Any flood in Gdańsk, results in considerable economic losses.

In the XVIIIth and XIXth centuries frequent floods inundated Gdańsk. These were mainly winter and spring floods caused by ice jams, which formed on the western arm of the Vistula predominantly due to its complicated layout. They occurred every 3 to 4 years and were connected with storms on the Baltic Sea resulting in the raise of water elevation. The most dangerous flood occurred in 1829, caused by ice jam near the outlet of Vistula channel (Fig.1.). The whole city of Gdańsk was covered with 2 to 3 meters deep water. As the result of this ice jam Vistula changed its main course more to the west. Shown with a dashed line in Fig. 1. Next significant flood caused also by ice jam occurred in 1840. This time Vistula breached the dunes situated along sea coast and made new outlet to the sea, now called Bold Vistula, shown with a dashed line in Fig.1.

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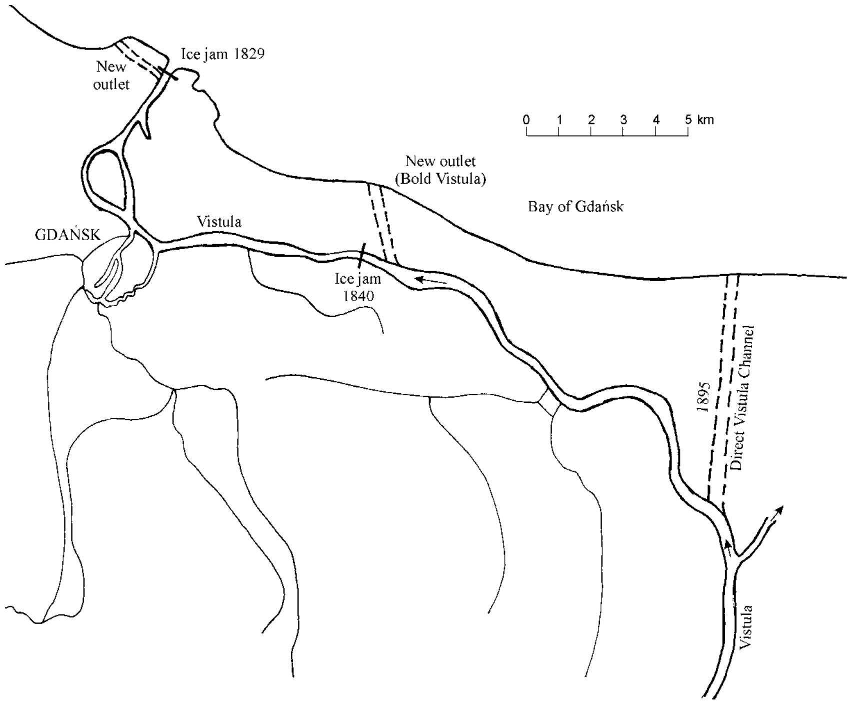

Fig. 1. Layout of the final section of Vistula River in XIX century

After long considerations it was finally decided to change completely the whole layout of the western arm of Vistula. In 1895 the final section of the Vistula was connected with the sea by means of a new direct channel protected by flood dykes on both sides. Both arms of Vistula – west and east, were closed by means of navigation locks. A special harbor was constructed in Przegalina, where the fleet of icebreakers was stationary. Since that time there was no serious flood caused by ice jam connected with high discharge in Vistula or high water elevation in the sea caused by storm. Present layout of the final section of Vistula is shown in Fig. 2.

Vistula river channel was shortened by the construction of the direct channel to the sea, which resulted in more intensive sediment transport and the deposition of sediments at the river outlet. During more than 100 years of the existence of the Direct Vistula Channel sedimentation cone formed, extending now about 3 km into the sea from the initial coastline. In front of the sedimentation cone large shoals form, which create difficult conditions for water and ice outflow. Especially dangerous situations appear when there is coincidence of large quantities of ice, winds blowing landward, and high discharges in the Vistula. In some situations very low discharges may also be dangerous. Assistance of icebreakers was very often necessary.

VISTULA RIVER AND ITS MOUTH

Vistula is the largest Polish river (1047 km long, catchment 194 000 km^2), which flows through the whole country, from south to north. The average discharge at the mouth is 1080 m^3/s, while the minimum recorded discharge was 253 m^3/s and the maximum 7840 m^3/s. Baltic is a tidless sea, however, water level variation in the Bay of Gdańsk, due to storms, is from + 1.14 m to – 0.86 m in relation to the average water elevation. Maximum wave height 2.7 m, was measured during winds blowing from directions NW and N at the speed 20 m/s. It is estimated that Vistula discharges to the Bay of Gdańsk every year 0.6 – 1.5 mln m^3 of sediment. It is mainly bed load of D_{50} = 0.55 – 1.00 mm. The influence of increased water elevations in the Bay of Gdansk can be seen up to 30 km in the upstream direction.

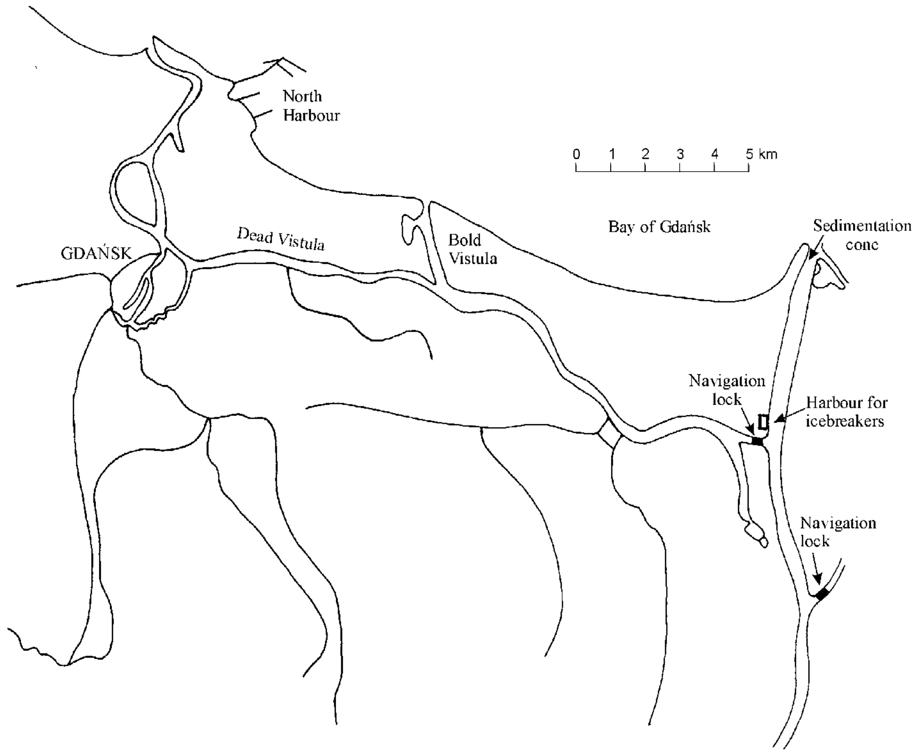

Fig. 2. Present layout of the final section of Vistula River

THE STUDY OF THE FINAL SECTION OF VISTULA RIVER

Recently study was carried out to find the best way of designing the final section of the river taking into account the deposition of sediments, which can cause dangerous situations for ice jam formation and flooding of the terrains upstream from the mouth. Within this study special attention was paid to ice cover influence on the water elevations in the final section of Vistula. This study was carried out for the final section of Vistula 37 km long, which extends from km 904 to km 941. This river section has been trained for navigation purposes and has regular cross-sections 300 – 400 m long. Bathymetry of this river section is described by means of the geometry of 50 cross-sections. River channel has flood dykes on both sides.

The model for unsteady 1 – dimensional flow with ice cover is based on de Saint Venant equations

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{\beta Q^2}{A}\right)+g.A\frac{\partial h}{\partial x}+\frac{gn^2}{R^{4/3}A}\left|Q\right|Q\right|=0\,, \tag{1}$$

$$\frac{\partial h}{\partial t}+\frac{1}{B}\frac{\partial Q}{\partial x}=0\ , \tag{2}$$

where Q is the discharge, *t* – time, *x* – longitudinal coordinate, A – cross-sectional area, β – momentum coefficient, g – acceleration due to gravity, *h* – water elevation, *R* – hydraulic radius, *B* – river width, *n* – Manning roughness coefficient.

In case of ice covered flow equivalent Manning roughness coefficient is applied taking into account river bed roughness and roughness of the underside of ice cover. The roughness coefficient for the river bed n = 0.030 was assumed for the whole river section. Calculations were carried out for ice cover over the whole river width of the thickness 0.1 m and 0.5 m. Water surface for ice free flow is shown for comparison. Exemplary results of calculations for the discharge 1000 and 4000 m^3/s are presented in Fig. 3,4,5 and 6.

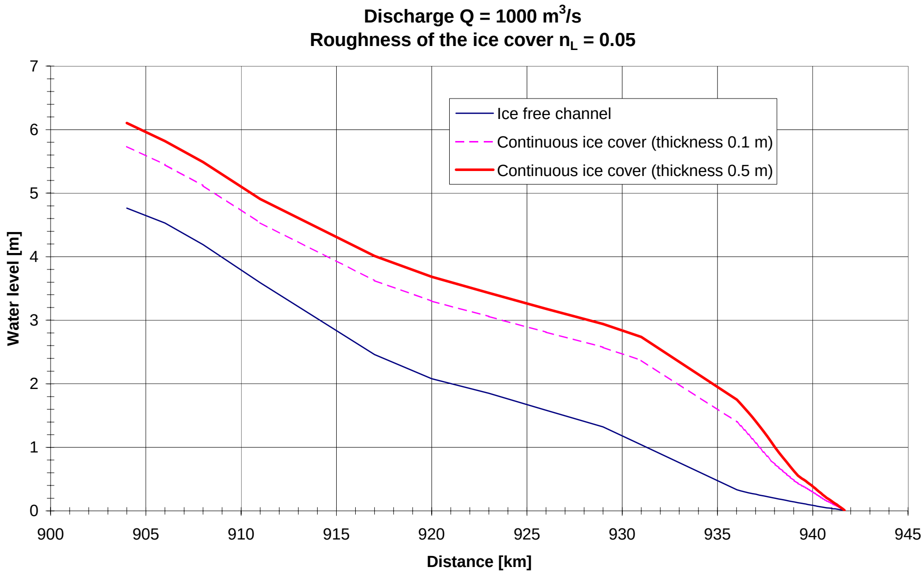

Fig. 3. Water surface for the flow with continuous ice cover along final section of Vistula, Q = 1000 m^3/s

Fig. 3 shows water surface elevations along investigated Vistula section for continuous ice cover of the thickness 0.1 and 0.5 m, and river discharge Q = 1000 m^3/s. Roughness coefficient of the underside of ice cover was assumed n_L = 0.05. This calculation was carried out for the average water elevation in the Bay of Gdańsk. One can see that the presence of ice cover results in the increase in water elevation about 1.0 m for ice cover thickness 0.1 m and about 1.5 m in comparison with free surface flow.

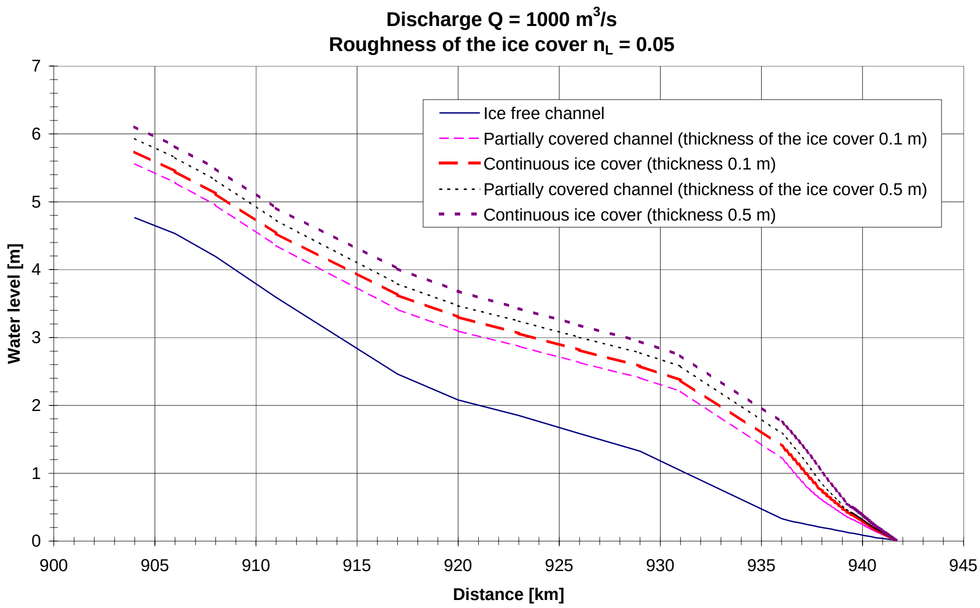

Fig 4. Water surface for the flow with partial ice cover along final section of Vistula, $Q = 1000\ m^3/s$

Fig. 4. shows water surface elevations along investigated Vistula section for the flow with partial ice cover (ice-free channel of the width 30 – 40 m, 10% of the total river width) and the discharge 1000 m^3/s. One can see that formation of ice-free channel, using ice breakers, decreases water surface elevation only about 0.2 m. Approximately the same result was obtained for ice cover thickness 0.1 and 0.5 m.

Fig. 5. shows water surface along Vistula section with continuous ice cover of the thickness 0.1 and 0.5 m in comparison with free surface flow for the discharge 4000 m^3/s. Increase in water surface with ice cover (0.1 m thick) is approximately 2.4 m and 2.8 m (ice cover 0.5 m thick) in relation to free surface flow. This increase is much higher than for the discharge $Q = 1000\ m^3/s$. The gradual increase in the elevation of water surface with ice cover takes place mainly along first 10 km of river section. Over the remaining distance both water surfaces (free and with ice cover) run nearly parallel.

The application of ice free channel of the order of 10% of the total channel width results in the decrease of water surface by about 0.4 m, which is 1/6 or 1/7 of the total increase in water elevation (Fig. 6). It is not much, however, in some instances it may be very important.

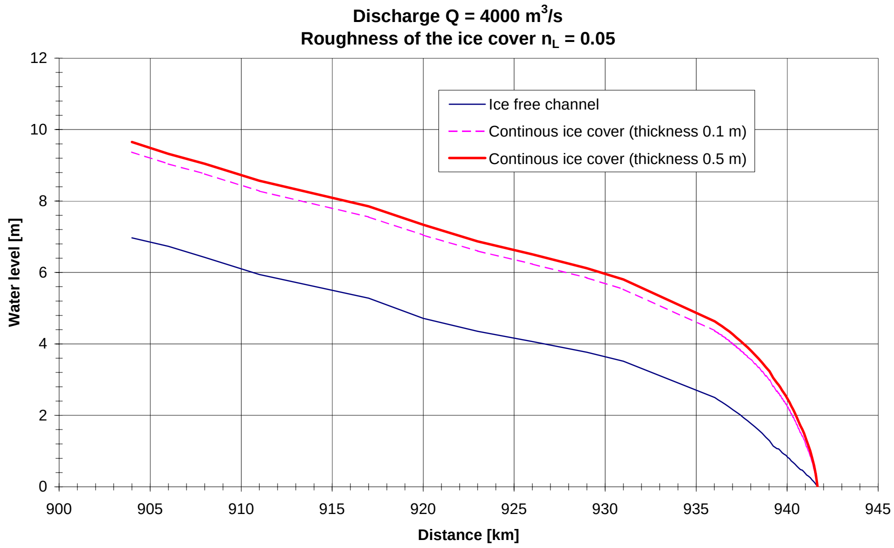

Fig. 5. Water surface for the flow with continuous ice cover along final section of Vistula, $Q = 4000\ m^3/s$

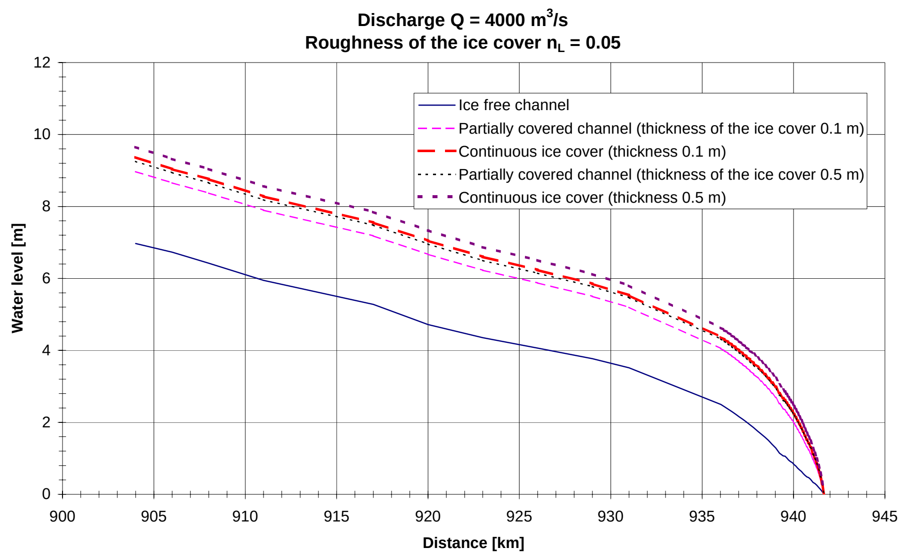

Fig. 6. Water surface for the flow with partial ice cover along final section of Vistula, Q = 4000 m^3/s

CONCLUSIONS

- Construction of direct Vistula Channel to the sea resulted in considerable reduction of flood hazard caused by ice jams, however, it did not eliminate this phenomenon completely.
- The appearance of ice cover results in high increase in water surface elevation, especially during high discharges, which can result in breaching of flood dykes.
- Regular river channel along final section of Vistula provides good possibility for the operation of ice-breakers, which require appropriate water depth.
- Formation of ice free channel in the main river channel covered with ice results in some lowering of water surface, which can have, in some cases significant value.