IV Rules and Guidelines

Industrial Services

6 Offshore Installations

7 Guideline for the Construction of Fixed Offshore Installations in Ice Infested Waters
This Guideline comes into force on 1st June 2005.

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Published by: Germanischer Lloyd, Hamburg
Typeset by: Guppy Designerschwarm Hamburg, Hartwig Otto
Printed by: Heydorn Druckerei und Verlag, Uetersen, Germany
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Annex A  List of Citations, Guidelines, Standards and further reading recommendations

Annex B  Expert Organisations for Cold Regions Engineering
Section 1

Introduction

1.1 Intention, scope and applicability


(2) Furthermore, safety related issues are mentioned, which are not yet included in other regulations such as SOLAS or extend beyond those considering the much more hostile environment conditions in arctic areas.

(3) The methods provided herein do not claim to deliver reliable results but represent a selection of the most easy to use approximation methods. It is strongly advised to seek technical advice from expert organisations for arctic offshore developments.

(4) Application of any of the methods given herein shall be performed with great caution. Any results should be carefully checked and because of the inadequacy of those methods available to the public, model trials for the specific solutions developed are strongly recommended.

(5) Additionally, advanced numerical simulation methods should be employed. Consultation with expert organisations that can provide applicable simulation tools is strongly recommended.

(6) In no case may any one of the methods provided herein be taken as reliable, valid method for design load calculation. Any determination processes employed and results thereof shall be agreed upon with the Authorities.

1.2 Existing Regulations and Sources of Further Information

(1) Several guidelines exist worldwide, that may contain some of those methods provided herein and/or others.

(2) For load calculation methods, definitions and theoretical backgrounds the Recommended Practice 2N issued by the American Petroleum Institute (API-RP-2N) and the National Standard of Canada CAN/CSA-S471-92 issued by the Canadian Standards Association are recommended for further reading.

(3) The former Russian standards SNiP-2.06.04-82* and VSN/BCH 41.88 contain methods for multi-leg structures but are only available in Russian.

(4) For safety related guidance, reference is given to SOLAS1 and the IMO2 “Guidelines for Ships Operating in Arctic Ice-Covered Waters”, formerly known as Polar Code

(5) Annex A contains a listing of sources cited herein, regulations and guidelines from other organisations and recommended further reading for theoretical background and additional information.

(6) Annex B lists sources of expert organisations that may assist in ice engineering projects.

1.3 Definitions

1.3.1 Ice Formations

(1) First Year Ice grows during one winter period and melts completely during the following summer.

(2) Multi Year Ice survives at least one summer period, resulting in a significant reduction in salinity to less than 2 ppt and an increase in strength after reconsolidation in the following winter.

(3) Level Ice results from the natural ice growth process and is characterised by a nearly plain, fault-free surface. It typically occurs in bights, sounds and around islands in shallow water.

(4) Rafted Ice develops from fragments of level ice, which are stacked on each other, forming a level ice area with a thickness several times that of the initial level ice.

(5) A Closed Cover extends continuously over a large area of several square kilometres.

(6) Sheet Ice is level ice extending over a large area.

---

1 SOLAS: Safety Of Life At Sea
2 IMO: International Maritime Organization, www.imo.org
(7) **Land Fast** or **Fast Ice** results from level ice growing around anchor points such as islands, stamukhas, and grounded icebergs or in very shallow waters, where the ice extends down to the seafloor.

(8) **Floes** are individual parts of a closed cover or sheet ice, classified by size as follows:

<table>
<thead>
<tr>
<th>Size</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varnothing &lt; 10m )</td>
<td>very small, ice cake</td>
</tr>
<tr>
<td>( \varnothing 10-200m )</td>
<td>small</td>
</tr>
<tr>
<td>( \varnothing 200m-1km )</td>
<td>medium</td>
</tr>
<tr>
<td>( \varnothing 1-10km )</td>
<td>large</td>
</tr>
<tr>
<td>( \varnothing &gt; 10km )</td>
<td>vast</td>
</tr>
</tbody>
</table>

(9) **Ice Rubble** results from crushing processes where level ice is broken into blocks of various sizes.

(10) **Rubble Piles** are formed in front of islands or structures when the breaking ice is not cleared around the structure.

(11) **Pressure Ridges** (or simply **Ridges**) emerge from collisions between floes, when the rubble becomes submerged under the ice sheet or are lifted atop.

(12) The upper, visible part of a Ridge is denominated the **Sail**. It consists of drained rubble or small debris and consolidates after the crushing process has stopped.

(13) The **Consolidated Layer** develops from the level ice sheet around the water level, which refreezes after the crushing process has stopped. The Consolidated Layer’s thickness usually is about twice as thick as the level ice in which the ridge is embedded.

(14) The **Keel** of a ridge is formed from the ice rubble submerged below the consolidated layer. Sea water between these ice blocks impedes consolidation; instead, friction and cohesion hold the blocks together. The draft of a ridge can be several times the sail height, strongly depending on geographical area.

(15) A **First Year Ridge** consists of the described drained sail, the consolidated layer and the unconsolidated rubble keel. In a **Multi Year Ridge**, the keel rubble consolidates as well, thus forming a much stronger ice formation.

(16) **Stamukhas** are grounded ridges, commonly forming anchor points for fast ice areas.

(17) **Rubble Fields** appear as rough, irregular ice surfaces that can contain various rafts, rubble accumulations, ridges and stamukhas.

(18) **Icebergs** are fragments of glaciers extending to the shore, mainly occurring in arctic regions. Because glacier ice is formed from snow, it is salt-free.

(19) **Spray Ice** is formed at low air temperatures by freezing rain, spray or spume from wind or waves or by artificial means such as spraying sea water at low temperatures, e.g. with fire fighting pumps.

(20) **Deck Ice** is any type of ice formed from spray water, rain, snow or other on decks, walkways, stairs, ladders and equipment.

(21) **Ice Override** can occur mainly with inclined structures and those with small freeboard (i.e. barges or artificial islands), when sea ice is pushed onto the slope or a readily developed rubble pile and slides over the deck of a structure.

(22) **Ice Islands** are floes significantly thicker than the level ice, having a mostly plain upper surface. The height can reach 10m or more while length and width are in range of 10 to 100m. Ice Islands do not necessarily have to be grounded but normally are. They can be constructed from artificial spray ice.

### 1.3.2 Basic Ice Parameters

#### 1.3.2.1 Ice Thickness \( t \)

The thickness \( t \) [m] of a level ice sheet which is to be used for calculations has to be determined from statistical sources and methods for the projected structure location upon agreement with GL.

#### 1.3.2.2 Bulk Salinity \( S_B \)

Sea Ice is formed from sea water with a certain salinity \( S_w \) [ppt]. During the freezing process, the bulk salinity \( S_B \) [ppt] of the developing ice decreases from \( S_w \) down to values of typically 5 ppt. The reduction in salinity entails changes in ice strength. Because salt molecules are too large to fit into the crystal structure of the ice itself, the salt is enclosed in liquid brine in small pockets (brine pockets). Thus, the ice crystal itself is salt free; the salinity of the sea ice can be determined by melting cores. Lower boundaries are 4 ppt for first-year ice and 2 ppt for multi-year ice.

#### 1.3.2.3 Temperature \( \vartheta \)

The ice temperature \( \vartheta \) \(^\circ\mathrm{C}\) increases in a non-linear, irregular manner from the surface to the bottom of an ice sheet, where it is approximately -1.9\(^\circ\mathrm{C}\), which is the freezing temperature for saline water (depending on exact amount of salinity). The surface temperature is dominated by the air temperature, the gradient between surface and bottom depends mainly on the time
history of air temperatures during recent days, the ice density and structure. Thus, estimating ice properties correlated to ice temperature only from the current surface temperature is inaccurate and unsafe.

### 1.3.2.4 Brine Volume $v_B$

The volume $v_B$ [ppt] of enclosed saline brine influences porosity and density of sea ice. Typical brine volumes are in the range of 20 to 100 ppt, depending on salinity, temperature, type and age of the ice. From salinity and ice temperature, $v_B$ can be estimated by:

$$v_B = 416.64 S_B^{0.88} |\theta_A|^{-0.67}$$

where:

$S_B$: Bulk Salinity after completed ice growth [ppt].

$\theta_A$: Ice temperature, averaged over the ice thickness [°C].

### 1.3.2.5 Porosity $\phi$

Naturally grown sea ice contains various inclusions and irregularities which lead to a porosity $\phi_B$ [ppt] of typically 3 to 20 ppt, approximately described by:

$$\phi_B = 193.7 + 36.18 \cdot S_B^{0.91} \cdot |\theta_A|^{-0.69}$$

Where $S_B$ and $\theta_A$ are as defined under Section 1.3.2.4.

### 1.3.2.6 Density $\rho$

1. **Density $\rho_i$ [kg/m³]** depends on salinity $S_B$, temperature $\theta$ and the age of the ice. Typical values are in range of 912 to 925 kg/m³.

2. **Sea Water** has a typical density $\rho_w$ [kg/m³] depending on the sea area considered. Because the influence of the actual value on most calculation results is very small, a standard value of 1028 kg/m³ may be used. For the Baltic Sea, a value of 1007 kg/m³ may be used.

### 1.3.2.7 Ice Strength

Tensile strength $\sigma_t$ [N/mm² = MPa], compressive strength $\sigma_c$ [MPa] and flexural strength $\sigma_f$ [MPa] are basic properties of sea ice used in any analytical or empirical model. Approximation methods to calculate these values are given in Section 2.1.

### 1.3.3 Safety related definitions

1. **Escape** describes the movement of personnel away from the dangerous areas of the platform along escape routes towards and into Temporary Safe Refuges.

2. **Escape Routes** are corridors, platforms, stairs, ladders, walkways or other leading to muster points, Temporary Safe Refuges or embarkation areas. These routes are to be clearly marked and shown on escape plans positioned in accordance with SOLAS.

3. **Temporary Safe Refuges** (TSR) are enclosed areas on the platform or vessel which protect personnel from fire, gas, explosions or other hazards for a duration of at least 2 hours. TSRs are to be located directly at or contain the embarkation areas for boarding Evacuation Crafts.

4. **Evacuation** is the total process from embarkation into Evacuation Craft, launching the craft and moving the craft away from the platform to a safe distance in a safe direction within a minimum time. The Evacuation is ended when all survivors are rescued.

5. **Rescue** means the transfer of evacuees either directly from the platform or vessel, a TSR onboard it or an Evacuation Craft to a Safe Heaven such as another Vessel, Platform, Island or Helicopter not endangered by the hazards on the evacuated platform or vessel.

### 1.4 Calculation Methodology

#### 1.4.1 Probabilistic Approach

1. Any attempt to determine ice loads on offshore structures should be based on probabilistic methods.

2. Exclusively deterministic methods only considering a maximum ice thickness should not be used since all models currently available for force determination contain great uncertainties. Where available, several competing models should be used and checked against site- and structure-specific model tests.

3. Ice parameters and corresponding forces should be analysed over the entire range of possible parameter values by using simulation techniques like Monte-Carlo Simulation.

#### 1.4.2 Uncertainties

1. Three types of uncertainties must be considered:

   1. Type I Uncertainty (CIU) arises from the natural randomness in any natural process. Ice growth, thickness, strength, motion etc. are natural processes and therefore imply natural randomness. CIU are also quantifiable random, intrinsic or inherent uncertainties.
Type II Uncertainty (CIIU) results from the incomplete ability to describe natural processes in engineering models. CIIU are also called epistemic, cognitive or modelling uncertainties.

Type III Uncertainty (CIIIU) arises from human participation in engineering processes.

In case of ice-structure interaction, the most significant uncertainties arise from the available models. It should always be considered that none of the publicly available methods delivers reliable results.

\[ v_B = 41.64 S_B^{0.88} |\theta_A|^{-0.67} \]

\[ \phi_B = 19.37 + 36.18 \cdot S_B^{0.91} \cdot |\theta_A|^{-0.69} \]

Fig. 1.1  Bulk Brine Volume vs. Salinity

Fig. 1.2  Bulk Porosity vs. Salinity
2.1.1 Ice Strength

Approximation methods for ice properties are given below. The values to be applied for location specific calculations are to be determined from statistical investigations in the considered sea area.

2.1.2 Tensile Strength

The tensile strength $\sigma_t$ [MPa] of saline ice can be approximated from:

$$\sigma_t = \left(1 - \frac{\nu_b}{\nu_0}\right)^2 \cdot \sigma_0 + S$$

Where:
- $\nu_b$: Brine volume [ppt] as given in Section 1.3.2.4
- $\nu_0$: Reference volume between 100 and 142 ppt; for calculation purposes a value of 142 ppt should be used
- $\sigma_0$: Reference strength 2.5 MPa
- $S$: Security surcharge; $S=0.4$

Typical values are in range of 0.5 to 3 MPa, see Fig. 2.1.

2.1.3 Compressive Strength

The compressive strength $\sigma_c$ [MPa] of saline ice can be approximated from:

$$\sigma_c = 2700 \cdot \dot{\varepsilon}^{1/3} \cdot \phi_B^{-1}$$

Where:
- $\dot{\varepsilon}$: Strain rate, typically $\dot{\varepsilon} = 10^{-3} \text{s}^{-1}$, depending on the rate of interaction (ice drift velocity)
- $\phi_B$: Ice porosity as given in Section 1.3.2.5

Typical values for $\sigma_c$ are in range of 0.5 and 12 MPa, see Fig. 2.2.

2.1.4 Flexural Strength

The flexural strength $\sigma_f$ [MPa] of saline ice can be approximated from:

$$\sigma_f = 1.76 \cdot e^{-5.88 \cdot \sqrt[3]{B} / 1000} = 1.76 \cdot e^{-0.19 \sqrt[3]{B}}$$
Where:

\[ \nu_B : \text{Brine volume [ppt] as given in Section 1.3.2.4} \]

Typical values for \( \sigma_f \) are in range of 0.5 to 2 MPa, see Fig. 2.3.

\[ \sigma_f = 1,76 \cdot e^{-5.88 \cdot \nu_B / 1000} = 1,76 \cdot e^{-0.39 \cdot \nu_B} \]

**Fig. 2.3** Flexural Strength vs. Salinity

### 2.2 Ice Forces on Platforms and Barriers

#### 2.2.1 Types of Interaction

At least three different types of ice-structure interaction should be considered:

**2.2.1.1 Frozen-In Condition in winter**

1. A mostly stationary ice sheet has formed and is in closest contact to the structure over large areas.
2. Forces may arise from small displacements of the ice cover and from thermal expansion of it due to temperature changes.

**2.2.1.2 Break-Up in spring**

1. The stable winter ice cover breaks up and starts to move.
2. When the stationary ice sheet breaks loose from the structure, maximum global forces should be expected, especially in case of multi-leg structures.

#### 2.2.1.3 Pack Ice Interaction

1. In non-continuous ice covers, interaction with isolated ice formations such as floes, ice islands or ridges with little level ice around them must be expected.
2. Slow interactions as well as centric and eccentric collisions at higher speeds should be investigated.
3. For dynamic interactions such as collisions, hydrodynamic effects like the hydrodynamic or added mass forces must be considered.

#### 2.2.1.4 Iceberg Collisions

1. In areas where icebergs can occur, collisions have to be considered.
2. Measures such as towing by supply or stand by vessels should be planned to prevent collisions.
3. Even if towing capacities are provided, it has to be assumed that the tow fails and a collision cannot be prevented.

#### 2.2.2 Piles and Piers

**2.2.2.1 Applicability of deterministic methods**

Forces on piles or piers may be approximated by below given methods, the results of which can significantly differ from each other and from the real values encountered at the structure. Absolute reliable predictions are impossible with these simple methods. Because of the resulting uncertainties, model tests may be necessary and required.

**2.2.2.2 Iowa-Formula**

\[ F[MN] = k \cdot D^{0.5} \cdot f^{1.1} \cdot \sigma_c \]

Where:

\[ k : \text{empirical factor given in Table 2.1} \]

### Table 2.1  Empirical factors for Iowa-Formula

<table>
<thead>
<tr>
<th>Interaction Characteristics</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving drift ice</td>
<td>0.36</td>
</tr>
<tr>
<td>Frozen-in condition at break away from</td>
<td></td>
</tr>
<tr>
<td>- Round or half-round piles</td>
<td>0.33</td>
</tr>
<tr>
<td>- Rectangular piles</td>
<td>0.39</td>
</tr>
<tr>
<td>- Wedge-shaped piles</td>
<td>0.29</td>
</tr>
<tr>
<td>Brittle ice failure (high interaction rates; ( \dot{\varepsilon} &gt; 10^{-3} \text{s}^{-1} ))</td>
<td>0.564</td>
</tr>
<tr>
<td>Ductile ice failure (low interaction rates; ( \dot{\varepsilon} &lt; 10^{-3} \text{s}^{-1} ))</td>
<td>0.793</td>
</tr>
<tr>
<td>Quasi-static interaction</td>
<td>1.128</td>
</tr>
</tbody>
</table>
D: Pile diameter or width [m]

\( t: \) Ice thickness [m]

\( \sigma_c: \) Compressive strength [MPa] as given in Section 2.1.3

### 2.2.2.3 Korzhavin’s Equation

This formula should only be used for structure-ice interactions where \( D/t < 6 \).

\[
F[MN] = I \cdot m \cdot k \cdot D \cdot t \cdot \sigma_c
\]

Where:

\( I: \) Indentation factor

\[
I = \begin{cases} 
\sqrt{5 \cdot D/t + 1} & \text{for } 6 > D/t > 1 \\
4 - 1.55 \cdot D/t & \text{for } 1 \geq D/t 
\end{cases}
\]

\( m: \) Form factor as given in Table 2.2

### Table 2.2 Form factor for Korzhavin’s Equation

<table>
<thead>
<tr>
<th>Pile geometry</th>
<th>( m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round contact edge (round pile)</td>
<td>0.9</td>
</tr>
<tr>
<td>Plain contact edge (rectangular pile)</td>
<td>1.0</td>
</tr>
<tr>
<td>120°-Wedge</td>
<td>0.81</td>
</tr>
<tr>
<td>90°-Wedge</td>
<td>0.73</td>
</tr>
<tr>
<td>75°-Wedge</td>
<td>0.69</td>
</tr>
<tr>
<td>60°-Wedge</td>
<td>0.65</td>
</tr>
</tbody>
</table>

\( k: \) Contact factor; for perfect contact (frozen-in pile) \( k=1.0 \); in all other cases for narrow piles with \( D \leq 5m \); \( k=0.4 \ldots 0.7 \).

\( D: \) Pile diameter or width perpendicular to direction of ice motion [m]

\( t: \) Ice thickness [m]

\( \sigma_c: \) Compressive strength [MPa] as given in Section 2.1.3

### 2.2.2.4 Empirical pressure boundary

The empirical maximum of ice pressure can be derived from:

\[
p = \begin{cases} 
28 \text{MPa} & \text{für } A < 0.1m^2 \\
13 \cdot \sqrt{A} \cdot \sigma_c & \text{für } 0.1m^2 \leq A \leq 42m^2 \\
2 \text{MPa} & \text{für } 42m^2 < A 
\end{cases}
\]

Where:

\( p: \) Ice pressure [MPa]

\( A: \) Contact area between ice and pile \([m^2]\); \( A = D \cdot t \)

\( \sigma_c: \) Compressive strength [MPa] as given in Section 2.1.3

The force can be calculated by multiplying the obtained pressure \( p \) by the area \( A \). This relationship can also be used for wide, vertical structures.

### 2.2.3 Conical Structures

(1) Two methods may be applied for calculating forces on conical structures. The first is explicitly given in Section 2.2.4.2 where the width \( W \) has to be replaced with the water line diameter \( D \). A simpler method is given by the following formula:

\[
F_{H} = C_{a} \cdot a_{4} \cdot C_{b} \cdot \left[a_{3} \cdot \sigma_{f} \cdot t^2 + a_{2} \cdot \rho_{w} \cdot g \cdot t \cdot D^2 \right] \\
+ C_{V} \cdot F_{a} \cdot \sigma_{f} \cdot t^2 + C_{h} \cdot a_{4} \cdot C_{r1} \cdot a_{3} \cdot \rho_{w} \cdot g \cdot t \cdot \left(D^2 - D_{1}^2 \right)
\]

(3) The vertical force can be calculated from:

\[
F_{V} = b_{1} \cdot C_{a} \cdot a_{4} \cdot C_{h} \cdot \left[a_{1} \cdot \sigma_{f} \cdot t^2 + a_{2} \cdot \rho_{w} \cdot g \cdot t \cdot D^2 \right] \\
+ b_{1} \cdot C_{h} \cdot F_{a} \cdot \sigma_{f} \cdot t^2 + b_{1} \cdot C_{a} \cdot a_{4} \cdot C_{r1} \cdot a_{3} \cdot \rho_{w} \cdot g \cdot t \cdot \left(D^2 - D_{1}^2 \right)
\]

Where

\( a_{1} \text{ to } a_{4}: \) Coefficients to be taken from fig.2.4 to fig. 2.6

\( b_{1}, b_{2}: \) Coefficients to be taken from fig. 2.7 and fig. 2.8

\( \sigma_{f}: \) Flexural strength of ice according to site-specific measurements or Section 2.1.4 [Pa]

\( t: \) Ice thickness [m]

\( \rho_{w}: \) of water; Sea Water: 1028kg/m³; Fresh Water 1000kg/m³

\( g: \) Gravitational acceleration; \( g=9.81m/s^2 \)

\( D: \) Cone diameter at the waterline [m]

\( D_{1}: \) Cone diameter at top of cone [m]

\( F_{n}: \) Froude Number, defined as \( F_{n} = \sqrt{\frac{v}{g}} \) where \( v \) is the ice velocity [m/s]

\( C_{a}: \) Inclination angle correction, to be taken as

\[
C_{a} = \begin{cases} 
1 & \text{für } \alpha < 60^\circ \\
1 + 0.05(\alpha - 60^\circ) & \text{für } \alpha \geq 60^\circ 
\end{cases}
\]
$C_b$: Breaking force correction, to be taken as

$$C_b = \begin{cases} 
1 & \text{for } \frac{\rho w \cdot g \cdot D^2}{\sigma_f \cdot t} < 10 \\
1 + 0.05 \left( \frac{\rho w \cdot g \cdot D^2}{\sigma_f \cdot t} - 10 \right) & \text{for } \frac{\rho w \cdot g \cdot D^2}{\sigma_f \cdot t} \geq 10 
\end{cases}$$

$C_v$: Velocity correction, $C_v = 10.0$

$C_r$: Friction correction, to be taken as

$$C_r = 0.4 - 0.01 \cdot \frac{\rho w \cdot g \cdot D^2}{\sigma_f \cdot t}$$

Fig. 2.4 Coefficients $a_1$ and $a_2$

Fig. 2.5 Coefficient $a_3$

Fig. 2.6 Coefficient $a_4$
2.2.4 Wide Inclined Structures

(1) Wide structures are characterized by a width that is several times greater than the maximum ice thickness to be expected.

(2) Inclined structures’ sides are sloping with an inclination angle of less than 80° from the horizontal.

2.2.4.1 Level Ice without Rubble Pile

Forces resulting from the interaction of level ice being pushed up the slope while no rubble is present in front of the structure may be estimated by the following equation:

\[
F_{H} = \left( C_{1} \cdot \sigma_{f} \cdot W \left( \frac{\rho_{w} \cdot g \cdot t^{5}}{E} \right)^{1/4} + C_{2} \cdot h \cdot t \cdot W \cdot \rho_{i} \cdot g \right) \cdot S_{F}
\]

Where:

- \( F_{H} \): Horizontal Force [N]
- \( C_{1} = 0,68 \left( \xi_{1} / \xi_{2} \right) \)
- \( C_{2} = \xi_{1} (\xi_{1} / \xi_{2} + \cos \alpha / \sin \alpha) \)
- \( \xi_{1} = \sin \alpha + \mu_{s,i} \cos \alpha \)
- \( \xi_{2} = \cos \alpha - \mu_{s,i} \sin \alpha \)
- \( \alpha \): Angle of inclination from horizontal [°]
- \( \mu_{s,i} \): Coefficient of friction between structure and ice; approximate values are given in table 2.3 but should be rounded up for estimative calculations

Table 2.3 Friction coefficients for various materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient of friction ( \mu_{s,i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sea Ice</td>
</tr>
<tr>
<td>Concrete</td>
<td>0,3</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0,05</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>0,08</td>
</tr>
<tr>
<td>(smooth)</td>
<td>0,3</td>
</tr>
<tr>
<td>(rough)</td>
<td>0,08</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>0,3*</td>
</tr>
<tr>
<td>(untreated)</td>
<td>0,2</td>
</tr>
<tr>
<td>(polished)</td>
<td>0,03</td>
</tr>
<tr>
<td>Teflon coating</td>
<td>0,25</td>
</tr>
<tr>
<td>Rustproof coating</td>
<td>0,7</td>
</tr>
<tr>
<td>Gravel Beach</td>
<td></td>
</tr>
</tbody>
</table>

*: Worst-Case estimates

\( \sigma_{f} \): Flexural strength of ice according to site-specific measurements or Section 2.1.4 [Pa]
W: Width of structure [m]

ρ_W: Density of water; Sea Water: 1028 kg/m³; Fresh Water 1000 kg/m³

g: Gravitational acceleration; g = 9.81 m/s²

t: Ice thickness [m]; Statistical site-specific maximum value is to be used

E: Modulus of elasticity for ice [Pa]; to be determined from site-specific investigations; usually in range of 2.5 MPa to 11.5 MPa

h: Height up to which the ice rides up on the slope [m]; usually total height of slope above sea level; see Fig. 2.9.

S_F: Safety Factor; S_F = 4; lower values should only be used when sufficient model tests are conducted.

### 2.2.4.2 Level Ice with rubble pile in front of the structure

Usually the structure’s geometry will prevent ice blocks from riding up onto the deck by means of vertical side walls adjacent to the upper edge of the slope, see figure 2.10. The deflected ice blocks will form a rubble pile in front of the structure. In shallow water, where the rubble pile may extend down to the seafloor, forces may be transferred directly from the rubble to the ground, reducing the global forces on the structure itself.

The forces acting on the structure may be estimated using the following formula.

\[
F_{II} = (F_b + F_{p_b} + F_b + F_L + F_T) \cdot S_F
\]
Where:

FB: Breaking force; increased due to the increased bending strength resulting from the horizontal pressure in the ice sheet; FB has to be calculated using the increased bending strength obtained from iterative calculations employing the following formula:

\[
FB = C_1 \cdot \sigma_{f,i} \cdot D \left( \frac{\rho_u \cdot g \cdot t^4}{E} \right)^{1/4} \left( 1 + \frac{\pi^2 \cdot \ell}{4 \cdot D} \right) + C_2 \cdot h \cdot t \cdot D \cdot \rho_i \cdot g
\]

Where all variables are defined as in 2.2.4.1 and

\[\ell = \left[ \frac{E \cdot t^3}{12 \cdot \rho_u \cdot g \cdot (1 - \nu^2)} \right]^{1/4}\]

\[\sigma_{f,i} = \frac{F_{b,i-1}}{L_c \cdot t} + \sigma_{f,0}\]

Where L_c is calculated from

\[L_c = W + \pi^2 \cdot \left( \frac{E \cdot t^3}{12 \cdot \rho_u \cdot g \cdot (1 - \nu^2)} \right)^{1/4}\]

Where all variables are defined as in 2.2.4.1 and

\[v: Poisson Ratio for the ice, usually 0.33\]

FB is taken as Fb,i when a sufficient convergence is achieved, usually after 3 to 7 iterations.

FPt: Push-Through Force required to push the advancing ice sheet through the rubble, calculated as:

\[FP_t = W \cdot h_R^2 \cdot \mu_{i,i} \cdot \rho_i \cdot g \cdot (1 - n) \left( 1 - \frac{\tan \theta}{\tan \alpha} \right)^2 \cdot \frac{1}{2 \cdot \tan \theta}\]

Where all variables are defined as in Section 2.2.4.1 and

\[h_R: \text{Height up to which the rubble pile extends on the slope [m]; may be smaller than the height up to which the broken pieces are pushed}\]

\[\mu_{i,i}: \text{Friction coefficient between ice and ice, usually in range } 0.1 \text{ to } 0.2\]

n: Porosity of the rubble; to be determined from field observations; for estimation values of 0.2 to 0.4 may be assumed.

\[\theta: \text{Inclination of the rubble pile surface to the horizontal [°]}\]

FR: Additional friction force resulting from the mass of rubble pushing the sheet ice down on the structure surface, calculated as:

\[FR = \frac{1}{2} \left[ \mu_{i,i} \cdot (\mu_{i,i} + \mu_{i,j}) \cdot \rho_i \cdot g \cdot (1 - n) \cdot h_R^2 \right] \cdot \sin \alpha \cdot \frac{1}{\tan \theta} - \frac{1}{\tan \alpha} \cdot \left( 1 - \frac{\tan \theta}{\tan \alpha} \right) + \frac{1}{2} \left( \mu_{i,i} + \mu_{i,j} \right) \cdot \rho_i \cdot g \cdot (1 - n) \cdot h_R^2 \cdot \cos \alpha \cdot \left( \frac{1}{\tan \theta} - \frac{1}{\tan \alpha} \right) \cdot \frac{h_R \cdot t \cdot \rho_i \cdot g}{\sin \alpha + \mu_{i,i} \cdot \cos \alpha}
\]

Where all variables are defined above and

\[c_R: \text{Cohesion of rubble [Pa]; can be estimated from } \frac{8t_b}{24t_b} \leq c_R \leq 24t_b\]

Where \(t_b [m]\) is the thickness of the ice blocks and \(c_R [kPa]\) is the cohesion.

FT: Turning force necessary to push the ice blocks to the vertical when they reach the vertical wall of the structure, calculated as:

\[FT = 1.5 \cdot \sin \theta_L \cdot \mu_{i,i} \cdot \cos \theta_L \cdot \frac{\cos \theta_L}{\sin \theta_L} \cdot \frac{1}{\mu_{i,i} \cdot \cos \theta_L}\]

SF: Safety Factor; SF = 4 for \(t < 0.5m\) and SF = 8 for \(t > 0.5m\)
(3) The model delivers results that should be treated with great caution and the design forces should be investigated by model trials and consultation of expert organizations in any case. For preliminary estimations the given values for $S_F$ should be used to obtain conservative results.
Section 3

Load Reduction Measures

(1) Additional passive or active measures may be applied to reduce the ice forces acting on structures.

(2) If any of the measures mentioned below are selected to permanently reduce the global and local design loads on the structure, it has to be ensured that the measures do not fail to achieve the required level of reduction at any time.

3.1 Local reinforcements

(1) To increase the local load bearing capacity of structural sections or single members, local reinforcements such as plating, increased wall thickness or modified constructive implementation may be used.

(2) The influence of such measures on total loads (also from waves and currents) has to be considered, since the total interaction area may increase or the changed geometry may alter the mode of interaction.

3.2 Barriers

(1) To prevent direct interaction with large, continuous ice features such as closed covers, rubble fields or ridges, barriers may be deployed around the structure.

(2) The protective effects and efficiency of the chosen type and projected arrangement of the barriers should be investigated by suitable model tests.

(3) The barriers themselves should be treated as any other offshore installation in terms of construction, transportation, installation and operation regulations as provided by “GL Rules for Classification and Construction: IV – Offshore Technology – Part 2: Offshore Installations”.

(4) To increase the stability and protective efficiency of barriers, artificial production of ice may be accomplished by spraying sea water through fire fighting pumps in cold air. This spray ice may be employed to create artificial ice barriers or increase the volume of rubble aggregated in front of barriers or structures. Spraying should not be performed if the air temperature is higher than -5°C.

(5) For further details refer to Section 6

3.3 Ice Management

(1) As an active measure to prevent interaction with continuous ice formations, ice breaking vessel support may be planned.

(2) Potential types of assistant vessels may include designated Ice Breakers, Ice Breaking Supply Vessels or Ice Breaking Tugs. The suitability of any of such vessels for the ice conditions expected in the area of deployment should be carefully investigated.

(3) Sufficient availability and clearing capacities have to be ensured at all times if ice management is selected as essential reduction measure.

(4) Deployment of vessels should be planned in advance and documented in an ice management manual which is part of the operations manual for the installation.

(5) Permanently employing ice breaking vessels on site additionally satisfies the recommended permanent presence of a rescue craft in case of emergencies (see Section 7.3)
Section 4

Materials and Construction

4.1 Steel

4.1.1 Abrasion and Corrosion

Dynamic interaction of ice formations with steel are to be expected. A combined thickness reduction of 0.5 mm/year has to be anticipated. Lower values may be appropriate if only very slow motion of the ice cover is to be expected.

4.1.2 Temperature Influences on Properties


(2) Special attention has to be paid to the provisions given there regarding strength at very low temperatures.

(3) The design temperature has to be chosen based on site specific conditions which have to be determined from long-term statistics.

4.1.3 Welding


(2) Special attention has to be paid to weather protection given there in Section C - 6.4, which are to be observed especially for on-site repair welding.

4.2 Concrete


(2) Concrete structures in arctic or sub-arctic waters are to be constructed exclusively from waterproof and frost resistant concrete.

(3) Due to the possible high local pressures (see Section 2.2.2.4) concrete of strength class B55 or greater has to be used (Nominal Strength $\beta_{WN} \geq 55$ MPa; Design strength $\beta_R \geq 30$ MPa).

(4) Abrasion results from the relative movement between concrete and ice. The rate of abrasion $R$ can be calculated from the following equation:

$$R = \left(0.0019 \cdot e^{0.7 \theta} + b\right) \cdot S$$

Where:

$R$: Rate of abrasion; mm abrasion per km ice movement

$a$: empirical factor; to be calculated from

$$a = 0.0004 \cdot p^3 - 0.0069 \cdot p^2 + 0.0485 \cdot p + 0.1682$$

$b$: empirical offset; to be calculated from

$$b = 0.0205 \cdot p - 0.0103$$

$p$: Contact pressure between ice and concrete; may be estimated as 4 times the compressive strength of ice, resulting in a range of values for $p$ from 1 to 10 MPa

$S$: Safety Factor, to be taken as 1.5

(5) The functions corresponding to the given calculation method are given in Fig. 4.1.
Fig. 4.1 Rate of abrasion as function of ice temperature and contact pressure
Section 5

Platforms

5.1 Foundations


(2) In extreme shallow waters, where freezing of the sea floor may occur, the resulting effects on soil bearing capacities and restrictions for installation have to be considered.

5.2 Global Forces

(1) Global forces acting on a structure have to be determined by any applicable means presented in this or comparable guidelines. Employment of model test is highly recommended.

(2) The structural design has to consider possible force distributions over the entire interaction area. In particular, this means that local forces can be several times higher than the global average force on the structure, since this global average force results from locally distributed pressures changing significantly over time.

(3) Dynamic loading effects from periodic ice failure have to be considered, especially for jacket-type structures. Significant excitation has to be considered and may occur at or close to the lower natural periods of the structure.

5.3 Local Forces

(1) Local forces can be significantly higher than the average force per area that can be derived from the determination of global loads.

(2) Great caution has to be used in selection of local pressures and forces on single construction areas.

(3) For upper bound estimates, Section 2.2.2.4 should be applied.

5.4 Water supply

(1) Any water systems (i.e. sea water cooling, fresh water, fire protection, sanitary systems) including pipes, valves, tanks etc. have to be protected against freezing.

(2) Suction inlets for sea water should be arranged and designed such that intake of ice is prevented. In extreme shallow water, ice may extend down to the sea bottom thus growing into inlets. Measures to ensure sea water supply under such conditions have to be provided.

(3) Ventilation pipes for tanks have to be protected from blockage due to freezing.

5.5 Deck Equipment

(1) Any equipment directly exposed to the harsh arctic environmental conditions has to be designed for and operational under these conditions at all times.

(2) Especially for structures with inclined side walls and/or a low freeboard, ice override onto the deck has to be anticipated and the equipment has to be designed to withstand or be protected from such events.

(3) The formation of rubble piles adjacent to a structure may enable ice override for higher freeboards.

(4) The formation of spray ice has to be anticipated especially in sub-arctic regions where the water surface is not or only partially ice covered and spray occurs at freezing air temperatures.

(5) Constructive measures against all types of deck icing should be provided and the consequences of the occurrence of deck icing should be included in the Ice Alert Plan (see Section 7.2).
Section 6

Protective Barriers

6.1  Foundations and Forces

(1)  Section 5.1 to Section 5.3 also applies for barriers.

(2)  If a self-stabilizing effect is to be achieved by the weight of the rubble accumulated inside the barrier, it has to be ensured that the weight will be sufficient.

6.2  Functionality

(1)  The designated degrees of ice cover destruction and load reduction for the protected structure should be clearly defined.

(2)  For any type of barrier, it has to be ensured that the designated mode of ice failure and the resulting load reduction and ice cover destruction can be certainly achieved under all ice conditions that have to be expected.

(3)  It has to be ensured that the barriers do not obstruct the evacuation of the structure in any situation. Barrier arrangements should be selected, so that the barriers themselves or the ice rubble formed by and grounded in front of them serves as a temporary safe refuge from where support vessels can safely pick up the evacuees.

6.3  Inspection

(1)  Barriers should be inspected by appropriate means and in regular intervals to ensure fitness for purpose after interaction with ice has occurred.

(2)  Inspections should be carried out in field if severe ice interaction has occurred as soon as the barriers become accessible again.

(3)  Before a barrier is redeployed at another location or repositioned after it has moved under severe ice interaction, it should be carefully inspected for local or global deformations or damages.

(4)  The position of barriers should be observed on a daily basis to monitor displacements resulting from overloads in severe ice conditions. Such global failure of a barrier can be used as strong indicator for ice situations that may lead to forces on the protected platform that exceed of its global design strength.

6.4  Installation, Removal and Relocation


(2)  The suitability of any single barrier or type of barrier has to be investigated for each designated installation site. Special attention must be paid to differing soil conditions, water depth, ice types, ice properties, drift velocities and directions etc. A site-specific assessment is required.

(3)  Any environmental impacts from the deployment of barriers should be considered and documented. Deployment authorisation by the authorities responsible for the projected location may depend on the results of such an environmental impact study.

6.5  Barrier Types

(1)  Different types of barriers may be considered for site-specific conditions. The suitability of types considered for application should be investigated by conducting model trials.

(2)  Systematic model trials (MATRA Research Project) have demonstrated that inclined roof structures with a small inclination angle of approximately 30° will be an efficient type if arranged in pairs with opposing inclination direction as shown in Fig. 6.1.
Fig. 6.1 Pair of inclined roof barriers
Section 7

Security, Life Saving and Evacuation

7.1 Existing Applicable Standards

(1) The codes and standards listed herein should be complied with, given that no regulations therein contradict each other or any regulations given within this guideline.

(2) In cases where regulations from different codes require different levels of realization for any given feature or contradict each other, the code leading to maximum safety should be complied with.

(3) For design and selection of suitable evacuation systems, the consultation of expert organizations (see Annex B) is recommended.

7.1.1 SOLAS

(1) As for any maritime structure or vessel, as far as applicable, all regulations from SOLAS should be fulfilled.

(2) Special attention is drawn at the temperature limits given within SOLAS regulations, which may in case of arctic offshore structures be insufficient. In those cases, the area specific lowest temperatures should be used for equipment and construction specifications in excess of the SOLAS limits.

7.1.2 IMO Guidelines for Ships Operating in Arctic Ice-Covered Waters

(1) In extension to the SOLAS regulations, the purpose-fit regulations given by IMO in “Guidelines for Ships Operating in Arctic Ice-Covered Waters” should be applied to any marine vessel or structure operating in ice-covered waters.

(2) It is recommended to apply the IMO Guidelines to any area where ice-covered waters and/or extreme freezing degree air temperatures may occur, though they are by their regulation G-3.2 only applicable to northern arctic waters.

7.1.3 Canadian Offshore Petroleum Installations Escape, Evacuation and Rescue Performance-Based Standards

The regulations given in the final draft of “Canadian Offshore Petroleum Installations Escape, Evacuation And Rescue Performance-Based Standards” should be applied.

7.1.4 GL Regulations

The regulations given in “GL Regulations for Life-Saving Launching Appliances” should be fulfilled as far as applicable.

7.2 Ice Alert Plan

(1) Continuous ice observation activities are required to ensure preparedness for global or local ice circumstances which endanger the safe operation and the possibility for safe evacuation of the installation.

(2) The activities required together with the responsibilities of personnel involved should be clearly defined in an Ice Alert Plan which should be integral component of the operations manual for the installation.

(3) The Ice Alert Plan should clearly state:

– the different possible alert states depending on the ice situation prevailing or upcoming including the limit conditions for the individual states such as (but not limited to) ice thickness, coverage, drift speed and direction, rubble pile height, ice forces on structures or barriers;

– the measures necessary to communicate the current alert state and any changes to it to all personnel on board the installation, to standby vessels and other installations;

– detailed instructions on any measures that have to be taken in each individual alert level, such as (but not limited to) well shutdown, increased ice observation activities, intensified ice clearing by supply vessels, partial or full evacuation of personnel;

– the functional positions that have to be appointed to personnel, such as (but not limited to) Ice Observer, Ice Advisor, Evacuation Supervisor;

– the duties and responsibilities for the Offshore Installation Manager (OIM) or Master and any other functional positions such as (but not limited to) Ice Advisor and Evacuation Craft Operators related to the different alert levels;
decision support systems for the selection of appropriate evacuation systems suitable for the prevailing or expected ice conditions;

descriptions of evacuation routes to be used depending on wind and ice drift direction and speed, the ice conditions and the type of hazard causing the evacuation such as H2S-fume, gas cloud, blow out or fire and any others that may arise;

instructions for supply vessels in case of evacuation;

7.3 Suitable Evacuation Methods

7.3.1 General Recommendations

(1) Whenever possible, evacuation by helicopter is the preferred method.

(2) The permanent presence of one or more ice breaking supply vessels on site is highly recommended whenever possible as the most flexible and readily available destination for evacuation and rescue operations.

(3) In no case should Free-Fall Evacuation Craft be considered an option when Ice crust is present, but they may be used for arctic structures during the ice-free periods.

(4) In any case, detailed investigations on possible evacuation and rescue procedures should be performed and documented in form of an Ice Alert Plan, and an Evacuation- and Rescue-Plan which both should be integral parts of the Operations Manual for the structure.

(5) Suitability of any envisioned systems should be agreed upon with GL.

7.3.2 Capabilities of Evacuation Crafts

(1) Purpose-fit Totally Enclosed Motor Propelled Survival Crafts (TEMPSC) should be used in accordance to SOLAS and IMO regulations.

(2) In addition to the SOLAS and IMO Regulations, the provided evacuation craft should be able to

- be set down in a controlled manner at a safe distance from the platform where the dynamic ice-platform interaction poses no danger to the craft;
- should not be free-falling when ice is present on the sea;
- protect the evacuees from hazardous gases and fire for at least 10 minutes after set-down;
- move away from the structure
  - in a minimum time which in no case exceeds 5 minutes
  - to a safe distance in a safe direction
  - under all environmental circumstances, especially under any combination of wind speed and direction and ice conditions regarding thickness, coverage, drift direction, drift velocity and surface geometry;
- withstand ice pressures imposed on the craft by advancing ice sheets so that no damage may occur while the craft is waiting for rescue;
- protect the evacuees from the worst arctic climate to be expected by supplying sufficient insulation and heating for a duration of at least 72 hours;
- be easily located by rescue craft by providing at least two independent electronic position transmitters;

(3) For further details, reference is given to PERD/CHC Report 11-39 “Evaluation of Emergency Evacuation Systems in Ice-Covered Waters”, see Annex A.

7.4 Survival Training for Arctic Conditions

(1) In addition to Escape, Evacuation and Rescue (EER) drills required by regulations referred to in Section 7.1, specialized survival training for all personnel who are on board of arctic vessels or structures on a regular basis should be considered an option.

(2) If not performed for all personnel, at least those crew members who are assigned responsibility in case of evacuation by the Alert and Evacuation Plans should receive such training on a regular basis to ensure that they can give guidance to the untrained crew members in case of evacuation to the ice.

7.5 Time until rescue is performed

(1) To maximize the probability of successful rescue of evacuees, the maximum time between the onset of danger leading to evacuation and the arrival of rescue craft on site should in no case exceed 72 hours.

(2) Bad weather conditions should always be accounted for in planning rescue procedures and selecting standby locations for rescue craft.
### Annex A

**List of Citations, Guidelines, Standards and further reading recommendations**

<table>
<thead>
<tr>
<th>Chapter / Section</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1.2</td>
<td>SNiP-2.06.04-82*: Loads and Actions on Hydraulic Engineering Structures (from wave, ice and currents)</td>
</tr>
<tr>
<td>Section 1.2</td>
<td>VSN/BCH 41.88: “Design of Fixed, Ice-Strengthened Platforms, 1988</td>
</tr>
<tr>
<td>Section 1.2, Section 7.1.2</td>
<td>“IMO Guidelines for Ships Operating in Arctic Ice-Covered Waters”, available as MSC/Circular 1056 and MEPC/Circular 399 from <a href="http://www.imo.org/includes/blastDataOnly.asp/data_id%3D6629/1056-MEPC-Circ399.pdf">http://www.imo.org/includes/blastDataOnly.asp/data_id%3D6629/1056-MEPC-Circ399.pdf</a></td>
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<tr>
<td>Section 1.3.2.4, Section 1.3.2.5</td>
<td>Kovacs, Austin: “Sea Ice - Part 2. Estimating the Full-Scale Tensile, Flexural and Compressive Strength of First-Year Ice” CRREL Report 96-11, 1996</td>
</tr>
</tbody>
</table>

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3 CRREL: US Army Cold Regions Research and Engineering Laboratory, www.coldregions.org
4 Proc.: Proceedings of the …
5 ISOPE: International Offshore and Polar Engineering Conference
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<thead>
<tr>
<th>Section</th>
<th>Reference</th>
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<tr>
<td>7.3</td>
<td>PERD/CHC Report 11-39 “Evaluation of Emergency Evacuation Systems in Ice-Covered Waters” prepared for the National Research Council (NRC) and the Program for Energy Research and Development (PERD) of Canada; available from <a href="http://www.chc.nrc.ca/English/Cold%20Regions/PERD/PERD_e.htm">http://www.chc.nrc.ca/English/Cold%20Regions/PERD/PERD_e.htm</a></td>
</tr>
</tbody>
</table>
Annex B

Expert Organisations for Cold Regions Engineering

For consultation purposes it is recommended to contact GL and one or more of the expert organisations listed below or any other, since this list does not claim to be complete.

**Hamburgische Schiffbau-Versuchsanstalt GmbH**
Hamburg Ship Model Basin
Bramfelder Str. 164
D-22305 Hamburg
Germany
Phone: +49-40-69203-0
Fax: +49-40-69203-345
WWW: http://www.hsva.de

**National Research Council Canada**
NRC Institute for Marine Dynamics
P.O. Box 12093
St. John’s, NF A1B 3T5
Phone: +1-709-772-4939
Fax: +1-709-772-2462
WWW: http://imd-idm.nrc-cnrc.gc.ca

**The Bercha Group**
P.O. Box 61105 Kensington P.O.
Calgary, AB T2N 4S6
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Phone: +1-403-270-2221
Fax: +1-403-270-2014
WWW: http://www.berchagroup.com

**US Army Corps of Engineers**
Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory (CRREL)
72 Lyme Road
Hanover, New Hampshire
USA 03755-1290
WWW: http://www.crrel.usace.army.mil
Recommended Bibliography Database:
www.coldregions.org

**C-Core**
Captain Robert A. Bartlett Building
Morrissey Road
St. John’s, NL
Canada A1B 3X5
Phone: +1-709-737-8354
Fax: +1-709-737-4706