D2.2.2.a

Attachment to D2.2.2

Calculation of weight of ice strengthened hull structures in accordance with Russian Maritime Register of Shipping Rules

Preface

This attachment to main report D2.2.2 contains results of calculations of ice belt structure weight based on Russian Maritime Register of Shipping (RMR) Rules for the same three vessels as in the main body of the report. The reason for accomplishing such duplicating calculations is that, in accordance with opinion of the Arctic and Antarctic Research Institute (AARI), those earlier assessment presented by Lloyd's Register of Shipping (LR) and Helsinki University of Technology (HUT) did not seem fully precise and adequate.

1. Vessel particulars

Main particulars of the three vessel designs selected by LR and HUT for evaluation are presented in Table 1.1. For comparability purpose both the design and considered RMR ice classes, namely LU4, LU5 and LU6, were assumed in analysis conducted by AARI the same as in LR&HUT's.

Table 1.1. Main particulars of the considered vessels

Parameter	Vessel 1	Vessel 2	Vessel 3
Vessel type	Chemical tanker	Tanker	Tanker
Length (m)	115	219	230
Breadth (m)	18	32.2	44
Depth (m)	10.9	20.4	22.5
Draught (m)	7.6	13.9	15.3
Deadweight (t)	8 300	71 300	106 200

To conduct calculations of ice belt structure weight, some addition information, supplementing that in Table 1.1, was required. This supplementary data was invented by AARI based on several assumptions, which were common for design practice. These assumptions are presented in this paragraph below.

1. The hull shape parameters are assumed as dictated by restrictions identified in RMR Rules for ice going vessels (see Table 1.2)

Table 1.2. Hull shape parameters for LU4, LU5 and LU6 ice classes, as in RMR Rules

Ice class	Flare angle β at 0.05L from fore perpendicular	Waterline entry angle α	Stem angle φ (see definition in Fig. 1.1)
LU4	20°	40°	60°
LU5	25°	40°	45°
LU6	40°	30°	30°

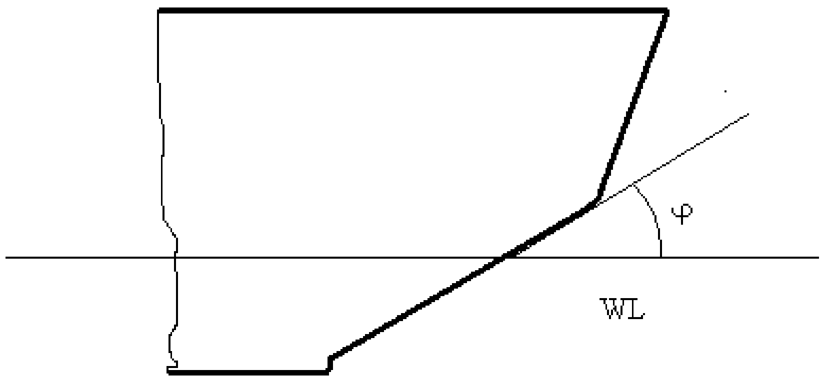

Fig. 1.1. On definition of the stem angle

2. The horizontal and vertical areas of ice belt structures are as in Fig. 1.2 and Fig. 1.3 (the signification of ice belt areas differs from using in the RMR Rules).

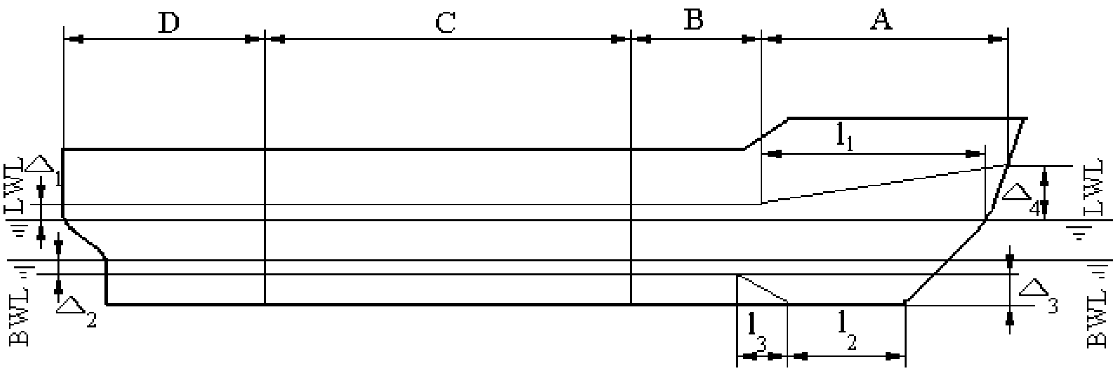

Fig. 1.2. Ice belt areas (longitudinal arrangement)

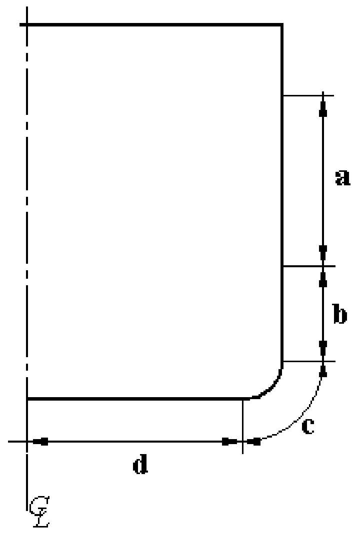

Fig. 1.3. Ice belt areas (vertical arrangement)

3. The area of each ice belt region is assumed equivalent to the area of corresponding part of shell plating plan (see Fig. 1.4). Aa, Bb, Bd, Cd, Cc, Cb, Ca, Dd, Dc and Da correspond to significations of shell plan areas. The dimensions of ice belt areas are presented in Table 1.3.

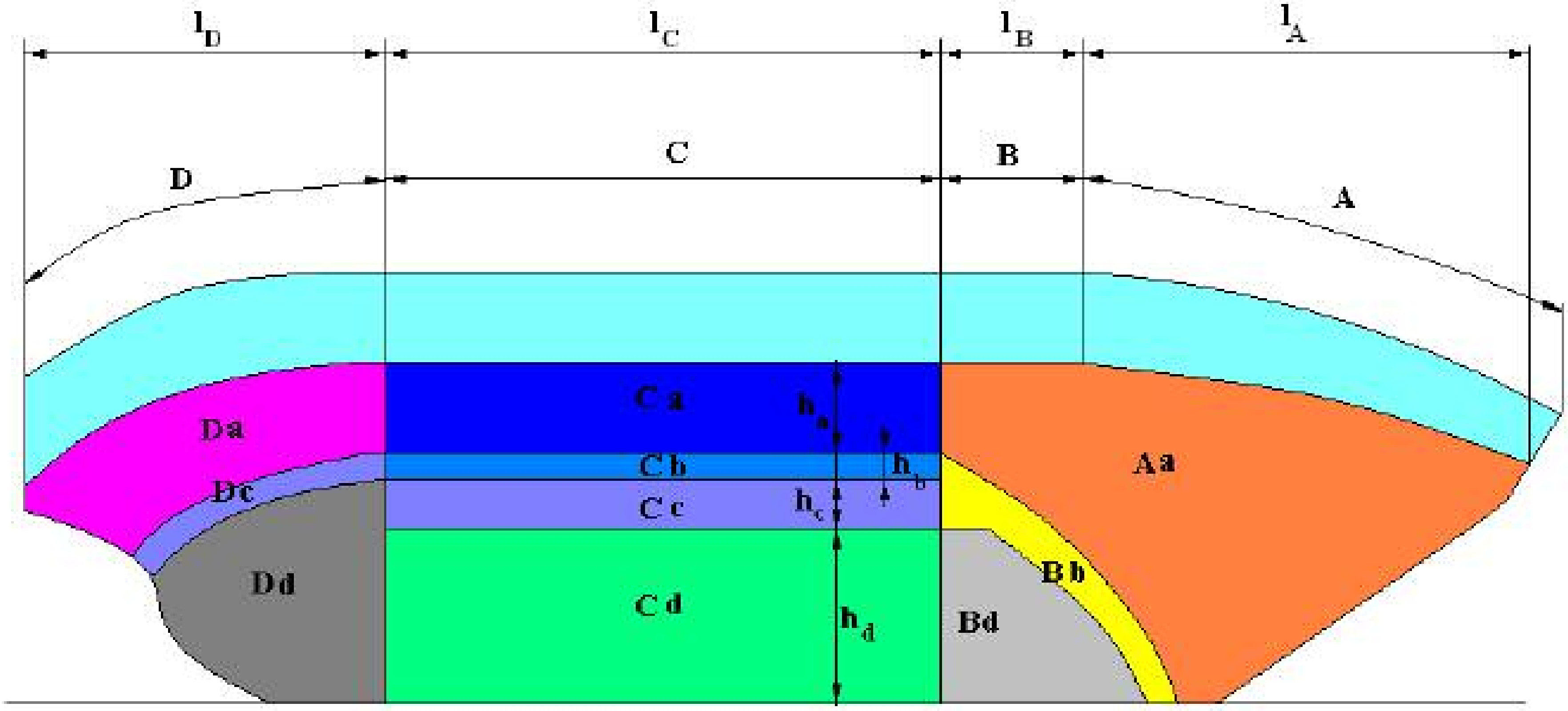

Fig. 1.4. Shell plating plan

Table 1.3. Dimensions of ice belt areas

Ice class	LU4	LU5	LU6
$\Delta_1(m)$	$0.017 \cdot B + 0.27$	$0.021 \cdot B + 0.33$	
$\Delta_2(m)$	$0.02 \cdot B + 0.32$	$0.028 \cdot B + 0.45$	
$\Delta_3(m)$	Δ_2	Δ_2	
$\Delta_4(m)$	0.6	0.8	
$l_1(m)$	$0.15 \cdot L$		
$l_2(m)$	$0.05 \cdot L$	$0.1 \cdot L$	
$l_3(m)$	1.2	1.6	
l_A	$0.155 \cdot L$		
l_B	$0.095 \cdot L + 2 \cdot \Delta_2$		
l_C	$0.61 \cdot L - 2 \cdot \Delta_2$	$0.58 \cdot L - 2 \cdot \Delta_2$	
l_D	$0.14 \cdot L$	$0.17 \cdot L$	
h_a	$0.25 \cdot T_{LWL} + \Delta_1 + \Delta_2$		
h_b	$0.5 \cdot h_{db} + 0.75 \cdot T_{LWL} - \Delta_2$		
h_c	$1.25 \cdot h_{db}$		
h_d	$\frac{B}{2} - h_{db}$		

Designations: L is vessel length; $\boldsymbol{B}$ is vessel breadth; $\boldsymbol{T_{LWL}}$ is laden waterline draught; $\boldsymbol{h_{db}}$ is double bottom height, it was calculated as $h_{db} = \frac{3}{200} \cdot L - \frac{1}{2}$; all listed values are in meters.

Using described above linear sizes, the area of corresponding ice belt regions can be estimated as follows:

$$S_{Aa} \approx h_a \cdot l_b + \frac{1}{2} \cdot l_b \cdot (h_b + h_c + h_d) + \frac{1}{2} \cdot l_a \cdot (h_a + h_b + h_c + h_d)$$

$$S_{Bb} \approx \frac{1}{2}\left[l_2 \cdot (h_d + h_c + h_b) + l_3 \cdot h_b\right]$$

$$S_{Bd} \approx \frac{1}{2} \cdot l_3 \cdot (h_d + h_c)$$

$$S_{Ca} = l_c \cdot h_a$$

$$S_{Cb} = l_c \cdot h_b$$

$$S_{Cc} = l_c \cdot h_c$$

$$S_{Cd} = l_c \cdot h_d$$

$$S_{Da} \approx 0.52 \cdot h_a \cdot (h_a + 2 \cdot h_b + 2 \cdot h_c + 2 \cdot h_d)$$

$$S_{Dc} \approx 0.52 \cdot h_c \cdot (h_c + 2 \cdot h_a + 2 \cdot h_c + 2 \cdot h_d)$$

$$S_{Dd} \approx 0.61 \cdot h_d \cdot (h_d + 2 \cdot h_a + 2 \cdot h_b + 2 \cdot h_c)$$

4. The structural topology of ice belt regions was assumed as presented in Fig. 1.5, i.e. it was supposed transverse system with ordinary frames.

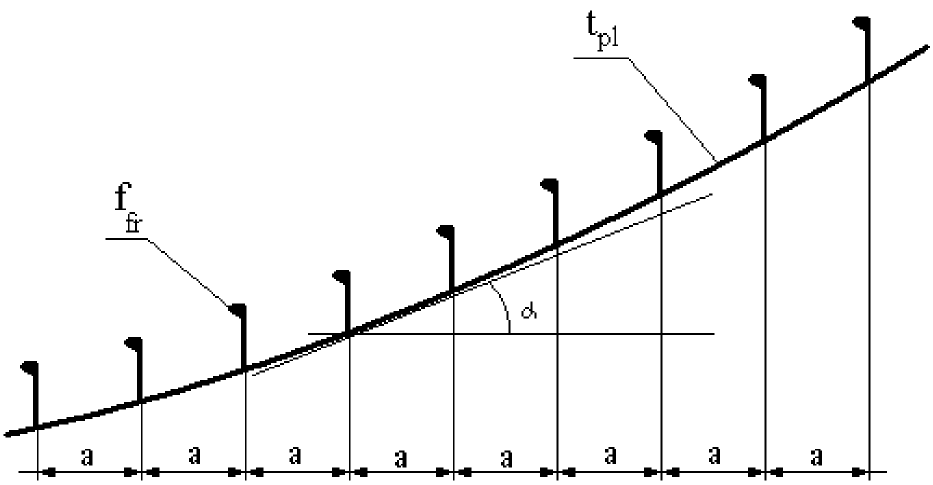

Fig. 1.5. Transverse system with ordinary frames

The spacing of transverse framing $\boldsymbol{a}$ in meters is calculated in accordance with the RMR Rules (structure with intermediate additional frames) as follows:

$$a = 0.001 \cdot L + 0.24 .$$

The actual dimension of plating panel is $a_p = \frac{a}{Cos\alpha}$.

5. The span of frames is calculated based on the following assumptions (Fig.1.6):

- The vertical distance between decks, longitudinal web framings or platforms $\boldsymbol{h_d}$=3.0m;
- The bracket leg is proportional to web height of transverse framing $c = 1.2 \cdot h_f$;
- The beams height is equal to transverse side faming $h_b = h_f$

Hence, the span of transverse side faming $\boldsymbol{s_f}$ can be calculated in the following way:

$$s_f = \frac{h_d - h_b}{Cos\beta} - \frac{c}{2} - \frac{c}{2} = \frac{h_d - h_f}{Cos\beta} - 1.2 \cdot h_f$$

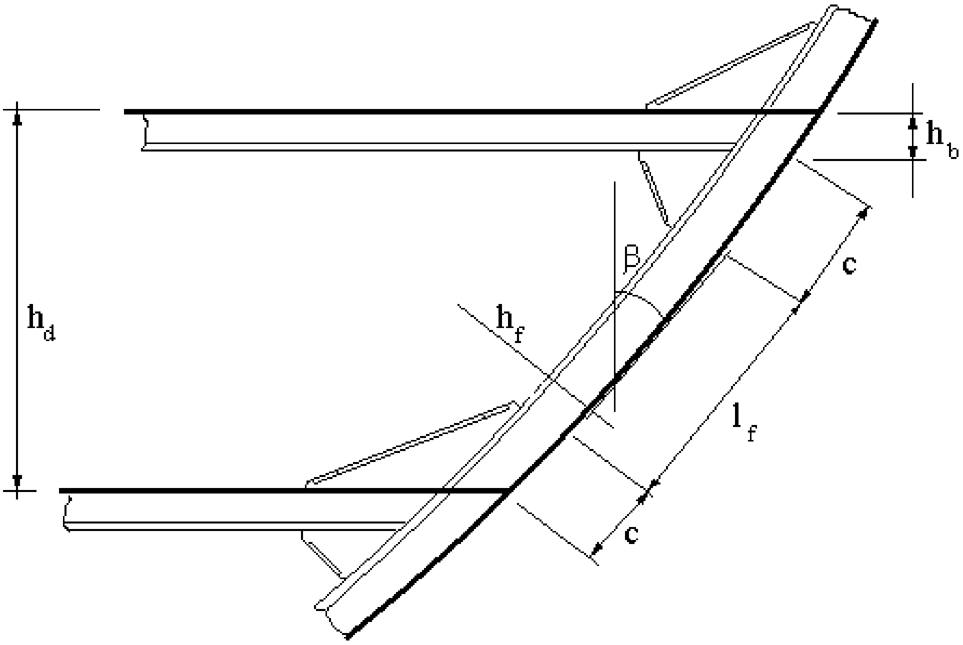

Fig. 1.6. On determination of framing span

2. Calculation formulas

The local ice load is described in RMR Rules by two parameters:

- local ice pressure $p_{ij} = k_{ij} \cdot \sqrt[6]{\Delta}$
- height of ice pressure patch $b_{ij} = r_{ij} \sqrt[3]{\Delta}$

where ***Δ*** is vessel displacement; $\boldsymbol{k_{ij}}$ and $\boldsymbol{r_{ij}}$ are coefficients depending on ice belt region and hull shape parameters, namely $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ (see Table 1.2).

In accordance with the RMR Rules ice belt plating thickness is calculated as:

$$s_{ij} = k_s \cdot f(a) \cdot \sqrt{\frac{p_{ij}}{\sigma_y}} + \Delta s_{ij}$$

where $\boldsymbol{k_s}$ is a coefficient; ***f(a)*** is a function depending on spacing ***a*** and height of design ice contact patch $\boldsymbol{b_{ij}}$; $\boldsymbol{\sigma_y}$ is yield stresses of hull steel; $\boldsymbol{\Delta s_{ij}}$ is corrosion and abrasive added plating thickness depending on ice class, ice belt structure region and planning vessel life time (the life time of 15 years was used for the analysis).

The general bearing capacity parameters of framing using for choice of framing profile are as follows:

- $\boldsymbol{W_{pl}}$ is plastic section modulus of cross section of framing with attached flange;
- ***A*** is area of cross section of framing profile web;
- $\boldsymbol{s_f}$ is thickness of framing profile web.

The procedure of profile choosing recommended by the RMR Rules is iterative. Result depends on type of selected profile. The presented analysis assumes using the rolled HP-profiles as ordinary and intermediate transverse framing.

The weight of ice belt structures for corresponding region can be calculated as follows:

$$M_{ij} = \gamma_s \cdot S_{ij} \cdot (s_{ij} + \frac{k_{br} \cdot f_{ij}}{a} \cdot Cos\alpha_{ij})$$

where $\boldsymbol{\gamma_s}$ is steel specific weight (γ_s =7850 kg/m^3); $\boldsymbol{k_{br}}$ is coefficient taking into account the additional weight of supporting brackets of ordinary and intermediate framing.

The geometrical parameters of brackets are assumed as:

Bracket thickness – $s_{br} = s_f$;

Bracket flange width – $b_{br} = 10 \cdot s_{br}$.

3. Calculation results

The analysis results are presented Tables 3.1 to 3.9 below. Tables 3.1 to 3.6 contain scantling estimates. The most essential output, namely unit structural weights, is summarized in Tables 3.7 to 3.9 (compare them with corresponding Tables 1 to 3 in the main body of the report).

Table 3.1. The design plating thickness, in mm, for Vessel 1

Region	LU6	LU5	LU4
Aa	22	20.5	18.5
Bb	21	19.5	18
Bd	21	19.5	18
Ca	18.5	16	13.5
Cb	17.5	14.5	13
Cc	17	14	13
Cd	17	14	13
Da	18.0	15.5	14.5
Dc	17	15	14
Dd	17	15	14

Table 3.2. The design plating thickness, in mm, for Vessel 2

Region	LU6	LU5	LU4
Aa	25.5	23.5	21
Bb	23	21	19.5
Bd	23	21	19.5
Ca	17.5	17.5	16.5
Cb	16.5	16	15
Cc	16	15	14
Cd	16	15	14
Da	17.5	16.5	15.5
Dc	17	16	15
Dd	17	16	15

Table 3.3. The design plating thickness, in mm, for Vessel 3

Region	LU6	LU5	LU4
Aa	34.5	295	27.5
Bb	32	26.5	25
Bd	32	26.5	25
Ca	18	18	17.5
Cb	17.5	17	16
Cc	17	16.5	15
Cd	17	16.5	15
Da	18.5	18	17
Dc	18	17	16
Dd	18	17	16

Table 3.4. The rolled HP-profile for ordinary and intermediate framing for Vessel 1

Region	LU6	LU5	LU4
Aa	300×14	220×12	180×11
Bb	300×11	200×10	180×9
Bd	300×11	200×10	180×9
Ca	280×12	180×11	160×9
Cb	280×12	180×11	160×9
Cc	240×12	180×10	160×9
Cd	240×12	180×10	160×9
Da	280×12	200×10	180×8
Dc	280×12	200×10	180×8
Dd	280×12	200×10	180×8

Table 3.5. The rolled HP-profile for ordinary and intermediate framing for Vessel 2

Region	LU6	LU5	LU4
Aa	320×14	260×13	200×12
Bb	320×12	260×11	200×10
Bd	320×12	260×11	200×10
Ca	300×13	240×12	180×11
Cb	300×13	240×12	180×11
Cc	280×13	220×12	180×10
Cd	280×13	220×12	180×10
Da	320×12	260×12	200×8
Dc	320×12	260×12	200×10
Dd	320×12	260×12	200×10

Table 3.6. The rolled HP-profile for ordinary and intermediate framing for Vessel 3

Region	LU6	LU5	LU4
Aa	430×19	370×16	320×15
Bb	400×17	370×13	320×12
Bd	400×17	370×13	320×12
Ca	370×14	340×13	300×12
Cb	340×13	320×14	300×12
Cc	340×13	320×14	300×12
Cd	340×13	320×14	300×12
Da	370×16	340×15	300×14
Dc	370×16	340×15	300×14
Dd	370×16	340×15	300×14

Table 3.7. The unit structure weights, in t/m^2, for Vessel 1

Hull area	Region	RMR ice class		
		LU6	LU5	LU4
Bow	Aa	0.30	0.24	0.20
Bow intermediate	Bb	0.28	0.20	0.19
	Bd	0.28	0.20	0.19
Midship	Ca	0.25	0.18	0.15
	Cb	0.21	0.16	0.14
	Cc	0.20	0.15	0.14
	Cd	0.20	0.15	0.14
Stern	Da	0.24	0.18	0.16
	Dc	0.22	0.16	0.15
	Dd	0.22	0.16	0.15

Table 3.8. The unit structure weights, in t/m^2, for Vessel 2

Hull area	Region	RMR ice class		
		LU6	LU5	LU4
Bow	Aa	0.22	0.26	0.31
Bow intermediate	Bb	0.32	0.23	0.21
	Bd	0.32	0.23	0.21
Midship	Ca	0.23	0.20	0.17
	Cb	0.24	0.19	0.17
	Cc	0.23	0.17	0.16
	Cd	0.23	0.17	0.16
Stern	Da	0.23	0.20	0.17
	Dc	0.25	0.20	0.16
	Dd	0.25	0.20	0.16

Table 3.9. The unit structure weights, in t/m^2, for Vessel 3

Hull area	Region	RMR ice class		
		LU6	LU5	LU4
Bow	Aa	0.46	0.37	0.34
Bow intermediate	Bb	0.41	0.27	0.27
	Bd	0.41	0.27	0.27
Midship	Ca	0.26	0.25	0.24
	Cb	0.26	0.25	0.24
	Cc	0.24	0.22	0.22
	Cd	0.24	0.22	0.22
Stern	Da	0.28	0.26	0.23
	Dc	0.28	0.25	0.22
	Dd	0.28	0.25	0.22