ANNEX 16

RESOLUTION MSC.245(83)
(adopted on 12 October 2007)

RECOMMENDATION ON A STANDARD METHOD FOR EVALUATING CROSS-FLOODING ARRANGEMENTS

THE MARITIME SAFETY COMMITTEE,

RECALLING Article 28(b) of the Convention on the International Maritime Organization concerning the functions of the Committee,

RECALLING ALSO resolution A.266(VIII) entitled "Recommendation on a standard method for establishing compliance with the requirements for cross-flooding arrangements in passenger ships", adopted by the Assembly at its eighth session,

NOTING that the above Recommendation does not include provisions for cross-flooding arrangements other than pipes (i.e., cross-flooding times through ducts) or a provision to ensure adequate air ventilation for efficient cross-flooding (i.e., to account for the restrictive effect of air counter pressure during cross-flooding),

NOTING ALSO the revised SOLAS chapter II-1 subdivision and damage stability requirements for passenger and cargo ships, adopted by resolution MSC.216(82),

RECOGNIZING the need to establish a methodology for evaluating cross-flooding arrangements on ships subject to the applicable subdivision and damage stability requirements of SOLAS chapter II-1 to ensure uniform treatment of cross-flooding and equalization arrangements,

HAVING CONSIDERED the recommendations made by the Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety at its fiftieth session,

1. ADOPTS the Recommendation on a standard method for evaluating cross-flooding arrangements, the text of which is set out in the Annex to the present resolution;

2. INVITES Governments to apply the annexed Recommendation to cross-flooding calculations and to bring the Recommendation to the attention of all parties concerned.

ANNEX

RECOMMENDATION ON A STANDARD METHOD FOR EVALUATING CROSS-FLOODING ARRANGEMENTS

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1 Definitions

$\sum k$: Sum of friction coefficients in the considered cross-flooding arrangement.

$S\ (m^2)$: Cross-section area of the cross-flooding pipe or duct. If the cross-section area is not circular, then:

$$S_{equiv} = \frac{\pi \cdot D_{equiv}^2}{4}$$

where:

$$D_{equiv} = \frac{4 \cdot A}{p}$$

A = actual cross-section area

p = actual cross-section perimeter

$\theta_0\ (°)$: Angle before commencement of cross-flooding. This assumes that the cross-flooding device is fully flooded but that no water has entered into the equalizing compartment on the opposite side of the damage (see appendix 1).

$\theta_f\ (°)$: Heel angle at final equilibrium ($\theta_f \leq \theta$).

$\theta\ (°)$: Any angle of heel between the commencement of cross-flooding and the final equilibrium at a given time.

$W_f\ (m^3)$: Volume of water which is used to bring the ship from commencement of cross-flooding θ_0 to final equilibrium θ_f.

$W_\theta\ (m^3)$: Volume of water which is used to bring the ship from any angle of heel θ to the final equilibrium θ_f.

$H_0\ (m)$: Head of water before commencement of cross-flooding, with the same assumption as for θ_0.

$H_\theta\ (m)$: Head of water when any angle of heel θ is achieved.

$h_f\ (m)$: Final head of water after cross-flooding ($h_f = 0$, when the level inside the equalizing compartment is equal to the free level of the sea).

2 Formulae

2.1 Time required from commencement of cross-flooding θ_0 to the final equilibrium θ_f:

$$T_f = \frac{2W_f}{S \cdot F} \cdot \frac{\left(1 - \sqrt{\frac{h_f}{H_0}}\right)}{\sqrt{2gH_0}} \cdot \frac{1}{\left(1 - \frac{h_f}{H_0}\right)}$$

2.2 Time required to bring the ship from any angle of heel θ to the final equilibrium θ_f:

$$T_\theta = \frac{2W_\theta}{S \cdot F} \cdot \frac{\left(1 - \sqrt{\frac{h_f}{H_\theta}}\right)}{\sqrt{2gH_\theta}} \cdot \frac{1}{\left(1 - \frac{h_f}{H_\theta}\right)}$$

2.3 Time required from commencement of cross-flooding θ_0 until any angle of heel θ is achieved:

$$T = T_f - T_\theta$$

2.4 Dimensionless factor of reduction of speed through an equalization device, being a function of bends, valves, etc., in the cross-flooding system:

$$F = \frac{1}{\sqrt{\sum k}}$$

where F is not to be taken as more than 1.

Values for k can be obtained from appendix 2 or other appropriate sources.

2.5 Cross-flooding through successive devices of different cross-section:

If the same flow crosses successive flooding devices of cross-section S_1, S_2, S_3… having corresponding friction coefficients k_1, k_2, k_3…, then the total k coefficient referred to S_1 is:

$$\Sigma k = k_1 + k_2 \cdot S_1^2 / S_2^2 + k_3 \cdot S_1^2 / S_3^2 \ldots$$

2.6 If different flooding devices are not crossed by the same volume, each k coefficient should be multiplied by the square of the ratio of the volume crossing the device and the volume crossing the reference section (which will be used for the time calculation):

$$\Sigma k = k_1 + k_2 \cdot S_1^2 / S_2^2 \cdot W_2^2 / W_1^2 + k_3 \cdot S_1^2 / S_3^2 \cdot W_3^2 / W_1^2 \ldots$$

2.7 For cross-flooding through devices in parallel that lead to the same space, equalisation time should be calculated assuming that:

$S \cdot F = S_1 \cdot F_1 + S_2 \cdot F_2 + \ldots$

with $F = 1/\sqrt{\Sigma k}$ for each device of cross-section S_i

3 Air pipe venting criteria

3.1 In arrangements where the total air pipe sectional area is 10% or more of the cross-flooding sectional area, the restrictive effect of any air back pressure may be neglected in the cross-flooding calculations. The air pipe sectional area should be taken as the minimum or the net sectional area of any automatic closing devices, if that is less.

3.2 In arrangements where the total air pipe sectional area is less than 10% of the cross-flooding sectional area, the restrictive effect of air back pressure should be considered in the cross-flooding calculations. The following method may be used for this purpose:

The *k* coefficient used in the calculation of cross-flooding time should take into account the drop of head in the air pipe. This can be done using an equivalent coefficient k_e, which is calculated according to the following formula:

$$k_e = k_w + k_a \cdot (\rho_a/\rho_w) \cdot (S_w/S_a)^2$$

where:

k_w	=	k coefficient for the cross-flooding arrangement (water)
k_a	=	k coefficient for the air pipe
ρ_a	=	air density
ρ_w	=	water density
S_w	=	cross-section area of the cross-flooding device (water)
S_a	=	cross-section of air pipe

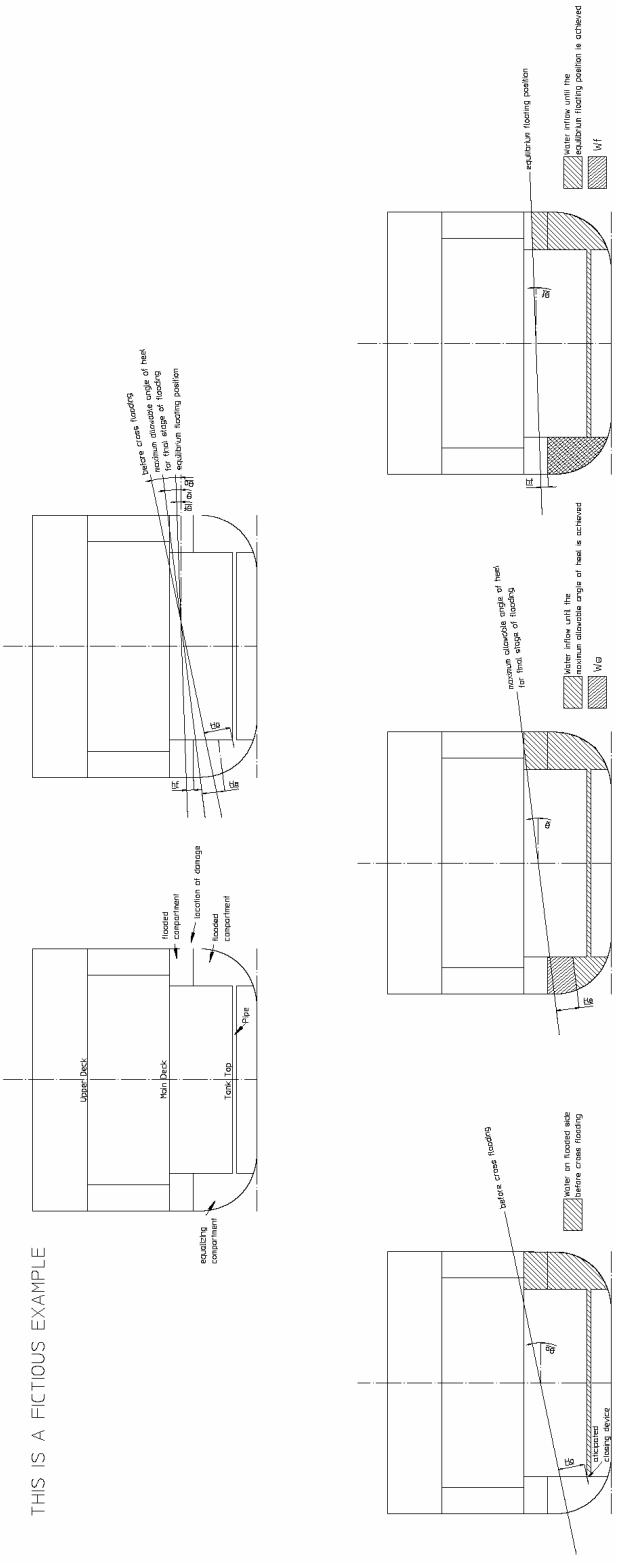
4 Alternatives

As an alternative to the provisions in sections 2 and 3, and for arrangements other than those shown in appendix 2, direct calculation using computational fluid dynamics (CFD), time-domain simulations or model testing may also be used.

APPENDIX 1

EXAMPLE FOR TREATMENT OF HEEL ANGLES AND WATER HEADS AT DIFFERENT STAGES OF CROSS-FLOODING

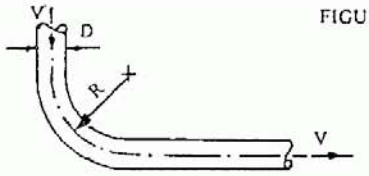
Figure 1



APPENDIX 2

FRICTION COEFFICIENTS IN CROSS-FLOODING ARRANGEMENT

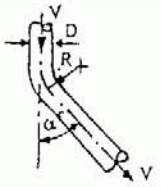
FIGURE 2



R/D	2	3	4	5	6	7
k	.30	.26	.23	.20	.18	.17

90° CIRCULAR BEND

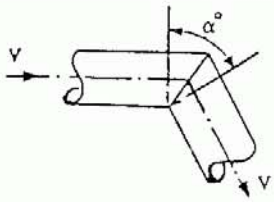
FIGURE 3



α°	15	30	45	60	75	90
k	.06	.12	.18	.24	.27	.30

RADIUS BEND R/D = 2

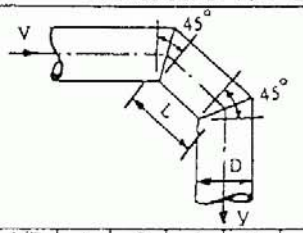
FIGURE 4



α°	5	15	30	45	60	90
k	.02	.06	.17	.32	.68	1.26

MITRE BEND

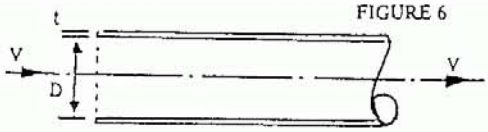
FIGURE 5



L/D	1	2	3	4	5	6
k	.41	.40	.43	.46	.46	.44

90° DOUBLE MITRE BEND

FIGURE 6



t/D	.01	.02	.03	.04	.05	≥.05
k	.83	.68	.53	.46	.44	.43

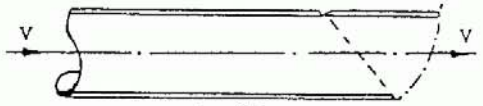
PIPE INLET

FIGURE 7

k = 1.0

PIPE OUTLET

FIGURE 8



k = 0.5

The value of k actually increases with decrease in Froude number, particularly below speeds of 2 m/sec.

NON-RETURN VALVE

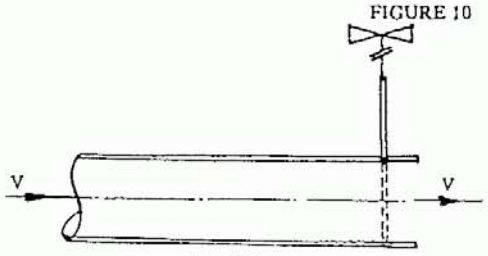
FIGURE 9

$$k = \frac{0.02}{D} \text{ per unit length}$$

The coefficient above is a mean value and does in fact vary as Reynold's number (i.e. varies with V for constant D and ν) as well as with relative roughness.

PIPE FRICTION LOSSES

FIGURE 10



k = 0.3

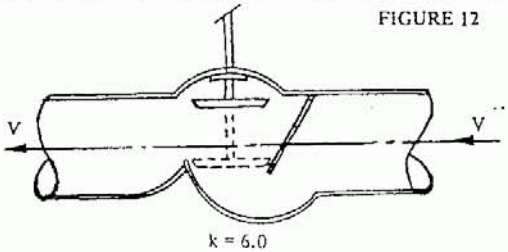
GATE VALVE

FIGURE 11

k = 0.8

BUTTERFLY VALVE

FIGURE 12



k = 6.0

DISC VALVE

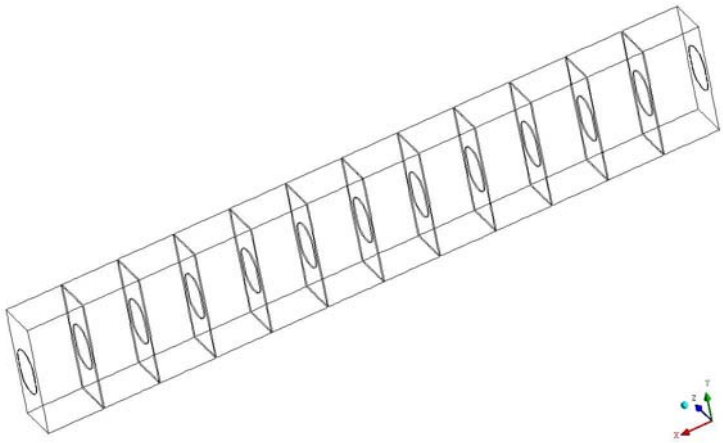
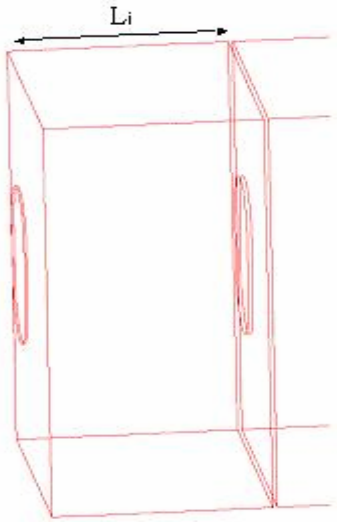


Figure 13
Cross-flooding through a series of structural ducts with 1 manhole

$$k = 0.2748 \cdot L_i + 0.0313 \qquad if \quad 0 < L_i < 1$$
$$k = -0.0986 \cdot L_i^3 + 0.6873 \cdot L_i^2 - 1.0212 \cdot L_i + 0.7386 \qquad if \quad 1 \le L_i \le 4$$
$$k = 1.34 \qquad if \quad L_i > 4$$

Note: k is the friction coefficient related to each space between two adjacent girders. k is evaluated with effective cross-section area therefore in calculations use the real cross-section area A and not S_{equiv}. The pressure loss for entrance in the first manhole is already computed in the calculation, and k = 1 has to be added to take into account the outlet losses.



L_i (in metres)

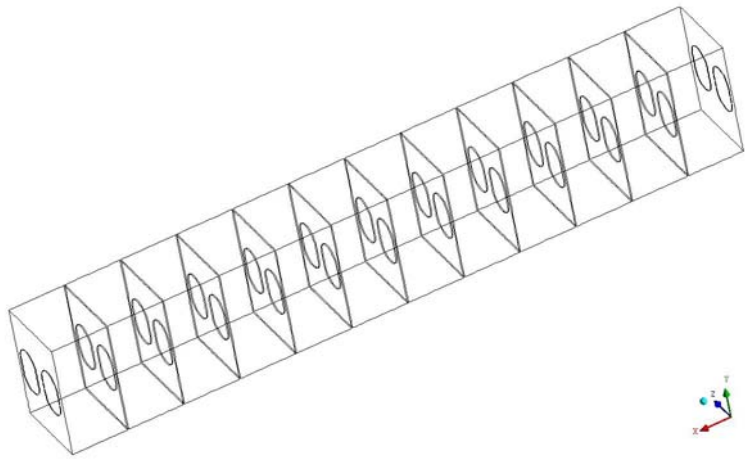


Figure 14
Cross-flooding through a series of structural ducts with 2 manholes

$$k = 0.4045 \cdot L_i + 0.0627 \qquad if \quad 0 < L_i < 1$$
$$k = 0.0424 \cdot L_i^3 - 0.3593 \cdot L_i^2 + 1.1401 \cdot L_i - 0.356 \qquad if \quad 1 \le L_i \le 4$$
$$k = 1.17 \qquad if \quad L_i > 4$$

Note: k is the friction coefficient related to each space between two adjacent girders. k is evaluated with effective cross-section area therefore in calculations use the real cross-section area A and not S_{equiv}. The pressure loss for entrance in the first manhole is already computed in the calculation, and k = 1 has to be added to take into account the outlet losses.

APPENDIX 3

EXAMPLE USING FIGURES FOR A PASSENGER SHIP

Dimension of the considered cross-flooding pipe:

Diameter	$D = 0.39\ m$
Length	$l = 21.0\ m$
Cross-section area	$S = 0.12\ m^2$
Wall thickness	$t = 17.5\ mm$

k-values for the considered cross-flooding system:

Inlet	0.45
Pipe friction $\frac{0.02l}{D}$	1.08
2 radius bends ($\alpha = 45°$)	0.36
Non-return valve	0.50
Outlet	1.00
	$\sum k = 3.39$

Sufficient air venting is assumed to be in place.

From this follows:

$$F = \frac{1}{\sqrt{\sum k}}$$

$$F = \frac{1}{\sqrt{3.39}} = 0.54$$

Time required from commencement of cross flooding θ_o to the final equilibrium condition θ_f:

$$T_f = \frac{2W_f}{S \cdot F} \cdot \frac{\left(1 - \sqrt{\frac{h_f}{H_0}}\right)}{\sqrt{2gH_0}} \cdot \frac{1}{\left(1 - \frac{h_f}{H_0}\right)}$$

Head of water before commencement of cross-flooding:

$$H_0 = 5.3m$$

Volume of water which is used to bring the ship from commencement of cross-flooding to the final equilibrium condition:

$$W_f = 365m^3$$

Final head of water after cross-flooding:

$$h_f = 1.5m$$

$$T_f = \frac{2 \cdot 365m^3}{0.12m^2 \cdot 0.54} \cdot \frac{\left(1 - \sqrt{\frac{1.5m}{5.3m}}\right)}{\sqrt{2 \cdot 9.81 {}^{m}\!/\!_{s^2} \cdot 5.3m}} \cdot \frac{1}{\left(1 - \frac{1.5m}{5.3m}\right)}$$

$$T_f = 721s = 12.0\,\text{min}$$

Time required to bring the vessel from the maximum allowable angle of heel for final stage of flooding θ to the final equilibrium condition θ_f:

$$T_\theta = \frac{2W_\theta}{S * F} \cdot \frac{\left(1 - \sqrt{\frac{h_f}{H_\theta}}\right)}{\sqrt{2gH_\theta}} \cdot \frac{1}{\left(1 - \frac{h_f}{H_\theta}\right)}$$

Maximum allowable angle of heel for final stage of flooding $\theta = 7°$

Head of water when the maximum allowable angle of heel for final stage of flooding is achieved $H_\theta = 3.7m$

Volume of water which is used to bring the vessel from the maximum allowable angle of heel for final stage of flooding to the final equilibrium condition $W_\theta = 160m^3$

$$T_\theta = \frac{2 \cdot 160m^3}{0.12m^2 \cdot 0.54} \cdot \frac{\left(1 - \sqrt{\frac{1.5m}{3.7m}}\right)}{\sqrt{2 \cdot 9.81 {}^{m}\!/\!_{s^2} \cdot 3.7m}} \cdot \frac{1}{\left(1 - \frac{1.5m}{3.7m}\right)}$$

$$T_\theta = 354s = 5.9\,\text{min}$$

Time required from commencement of cross-flooding θ_o until the maximum allowable angle of heel for final stage of flooding θ is achieved:

$T = T_f - T_\theta$ = 12.0 min – 5.9 min = 6.1 min

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