SUB-COMMITTEE ON STABILITY AND LOAD LINES AND ON FISHING VESSELS SAFETY
54th session
Agenda item 4

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DEVELOPMENT OF GUIDELINES ON SAFE RETURN TO PORT FOR PASSENGER SHIPS

An analysis of the recommendation on a standard method for evaluation of cross-flooding arrangements as presented in resolution MSC.245(83)

Submitted by Finland

SUMMARY

Executive summary:	This document contains the findings in the model tests and computational fluid dynamics (CFD) analysis of cross-flooding ducts and suggested improvements of resolution MSC.245(83)
Strategic direction:	5.2
High-level action:	5.2.1
Planned output:	5.2.1.17
Action to be taken:	Paragraph 4
Related documents:	SLF 53/INF.2, SLF 53/INF.6 and resolution MSC.245(83)

Introduction

1 The research project (EU FP7) was briefly introduced in document SLF 53/INF.2 and corrigendum. The Work Package 2 (Flooding Progression Model) had several subtasks, among others task 2.3 Experimental studies on pressure losses and task 2.4 Computational studies & CFD. Both subtasks used the cross-duct design.

1.1 The full reports "FLOODSTAND Deliverable D2.3 v.1.2.1.pdf" and "FLOODSTAND Deliverable D2.4b v.1.02.pdf" can be downloaded from the official web site of this research project "http://floodstand.aalto.fi/Info/public_download.html" and can be found under the heading "Research / Download".

Determination of discharge coefficient for a cross-duct

2 The model tests and CFD analysis of cross-flooding ducts reveal that the recommended method in resolution MSC.245(83) may result in a significant under-estimation of the cross-flooding time, as presented in the annex of this document for two different cross-duct designs.

2.1 Therefore the equation in paragraph 2.5 in the resolution should be revised to contain the k = 1 for the outlet of the duct/pipe. The outlet should not be included for the coefficient k[i] for each opening since it is already included once for the whole duct.

2.2 The regression equations for cross-ducts (figures 13 and 14 in the appendix of the resolution) should be used with care since case studies have shown that it may produce too optimistic results when compared to model test or CFD results.

3 The following revision of resolution MSC.245(83) is recommended for determining the dimensionless factor of reduction of speed F for cross-ducts:

.1 The formula in paragraph 2.5 is replaced by formula (2) in the annex to this document.

.2 Existing text in paragraph 4, Alternatives, is replaced by "Values for k can be obtained from appendix 2 or other appropriate sources. Also CFD (computational fluid dynamics) can be used to evaluate the discharge coefficient for the whole cross duct.".

.3 Removal of figures 13 and 14 with explanations from the resolution.

Action requested of the Sub-Committee

4 The Sub-Committee is invited to consider the proposal in paragraph 3 and take action as appropriate.

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ANNEX

DETERMINATION OF DISCHARGE COEFFICIENT FOR A CROSS-DUCT

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Recommended calculation method

The resolution MSC.245(83) allows the use of CFD tools or model tests for evaluation of the proper discharge coefficient (i.e. the flow reduction coefficient, *F*) for cross-flooding devices. In addition, the resolution contains regression equations (with figures 13 and 14 in the annex of the resolution), developed on the basis of systematic CFD calculations, *Pittaluga and Giannini (2006)*. However, these equations are based on a rather limited data set. In the following a more robust but still simple method is presented.

The resolution also contains (in paragraph 2.5) a very simple equation for the sum of pressure loss coefficients k_i by accounting several successive openings with different areas S_i:

$$\sum k = k_1 + \sum_{i=2}^{N} k_i \cdot \frac{S_1^2}{S_i^2} \qquad (1)$$

However, this does not contain the k = 1 for the "outlet", as required by the current interpretation of the flow reduction (discharge) coefficient *F* in MSC.245(83). Apparently, this has been forgotten in the revision of the old resolution A.266(VIII). Therefore, in this study the revised version:

$$\sum k = k_1 + \sum_{i=2}^{N} k_i \cdot \frac{S_1^2}{S_i^2} + 1 \qquad (2)$$

is applied to the test cases.

C_d = 0.6 is a reasonably good estimation for a single manhole (see e.g. *Stening, 2010*). Consequently, the pressure loss coefficient for a single manhole is:

$$k_i = \frac{1}{C_d{}^2} - 1 = \frac{1}{0.6^2} - 1 \approx 1.778 \qquad (3)$$

The pressure losses in any cross-duct design can be estimated with these simple equations (2) and (3). The validity of this method is tested with the following two separate case studies.

Case studies

Case 1: FLOODSTAND

The details of the cross-flooding arrangement have been presented in *Stening et al. (2011)* and document SLF 53/INF.2. The duct consists of 5 girders with two manholes (700 mm × 400 mm), Figure 1. The distance between adjacent girders is 3.0 m. Model tests have been performed in the scale 1:3. In addition, CFD analysis has been done both in model scale and in full-scale. In the latter case also different pressure heights at the duct

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inlet were studied. Stiffeners inside the duct were included both in the physical model and the numerical grid for CFD. Also a shorter and a longer version of the duct were tested in model scale. The model tests and results are presented in *Stening et al. (2011)*. A more comprehensive description of the test arrangement and results also for tests with manholes are given in *Stening (2010)*. The CFD analysis is presented in detail in *Visonneau et al. (2010)*.

Comparison of the obtained discharge coefficient with different methods is presented in Table 1. Distributions of the flow velocity in the duct are presented in Figure 2 and Figure 3 for model scale and full scale.

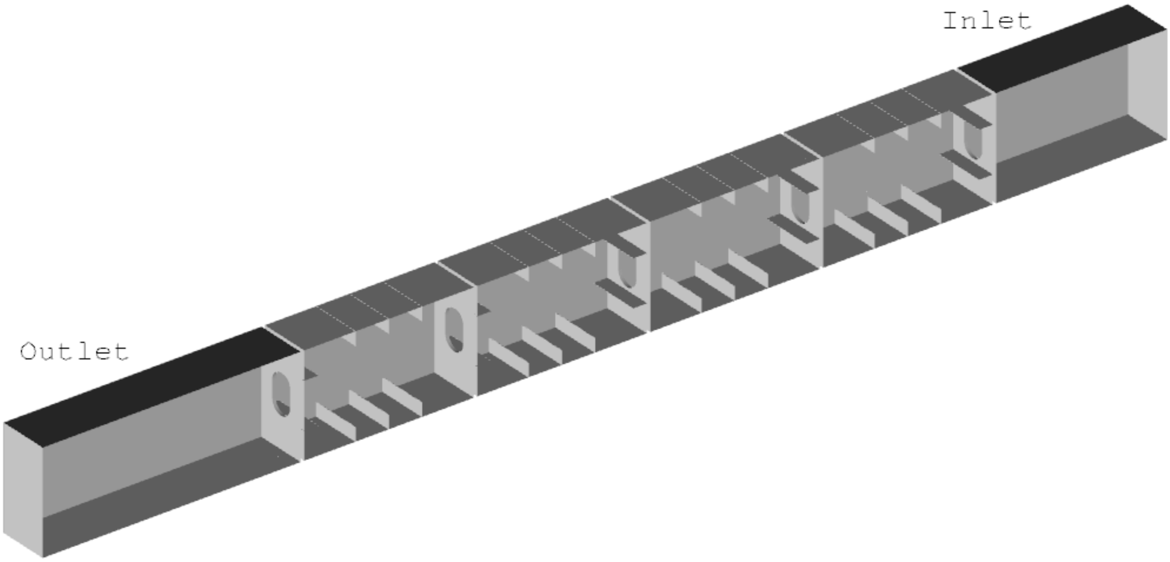

Figure 1: Symmetrical half of the studied cross-duct; the inlet and outlet zones were also included in the computational domain, *Visonneau et al. (2010)*

Table 1: Comparison of flow rates and discharge coefficients

Case	**Q (m^3/s)**	**C_d**
model test *(Stening, 2010)*	0.043	0.338
CFD model scale *(Visonneau et al., 2010)*	0.042	0.333
full-scale (CFD), H_U = 5 m, *(Visonneau et al., 2010)*	0.638	0.325
full-scale (CFD), H_U = 10 m, *(Visonneau et al., 2010)*	3.140	0.335
Regression equation *(Pittaluga and Giannini, 2006)*	–	0.452
Successive openings method	–	0.318

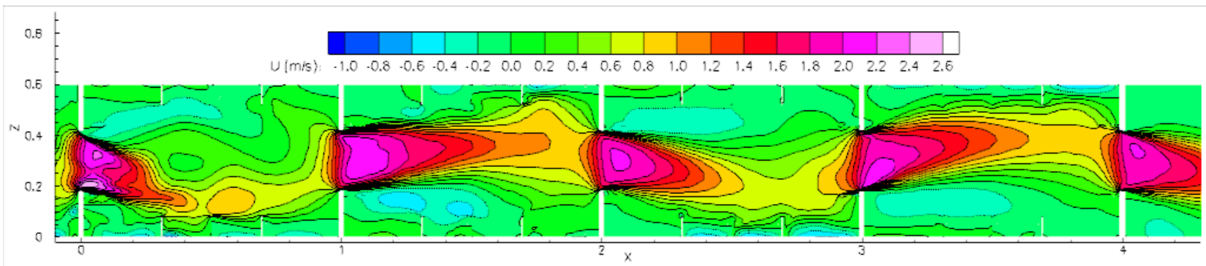

Figure 2: Flow velocity in the model scale (1:3) computation, *Visonneau et al. (2010)*

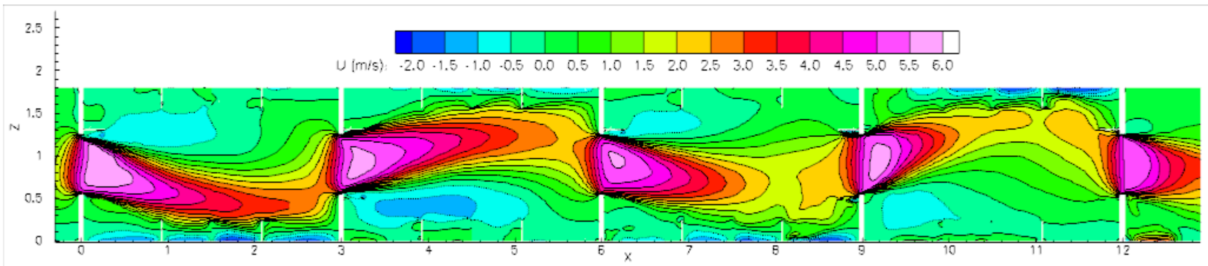

Figure 3: Flow velocity in the full-scale computation (pressure head at inlet is 10 m), *Visonneau et al. (2010)*

Case 2: Varying size of manholes in the girders

This case is another cross-duct design. In the centregirder (1 in Figure 4) there are three vertical manholes (400 mm × 800 mm) and in each side girder there is one large horizontal manhole (1300 mm × 600 mm). The symmetrical half of the cross-duct is illustrated in Figure 4.

The calculation was time-dependent with a volume of fluid (VOF) method. A commercial CFD software ANSYS Fluent was used. The model of the duct was very accurate, and e.g. all stiffeners (2, 3 and 4 in Figure 4) were included. The geometry was meshed with 600,000 tetrahedral cells. In the CFD calculations the ship motions during the equalization were not taken into account. However, in the particular case the initial heeling angle is rather small. Therefore, this is not considered to have a significant effect on the results. A visualization of the flow inside the duct is presented in Figure 5.

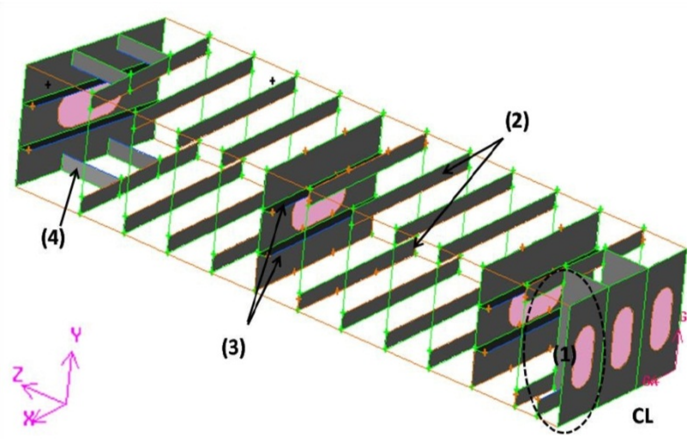

Figure 4: Symmetric half of the cross duct from the centerline (CL) and the girders with manholes

The application of the regression equations *(Pittaluga and Giannini, 2006)* in resolution MSC.245(83) for this cross-duct design is questionable since the size and number of the manholes in the girders varies. However, both regression equations for cases with 1 and 2 manholes in the girders have been tested. The results of the comparison are presented in Table 2. For this case also the cross-flooding time was calculated with three different methods: CFD, simple formula in resolution MSC.245(83) and NAPA time-domain flooding simulation. Also the air compression was taken into account. The results are shown in Table 3.

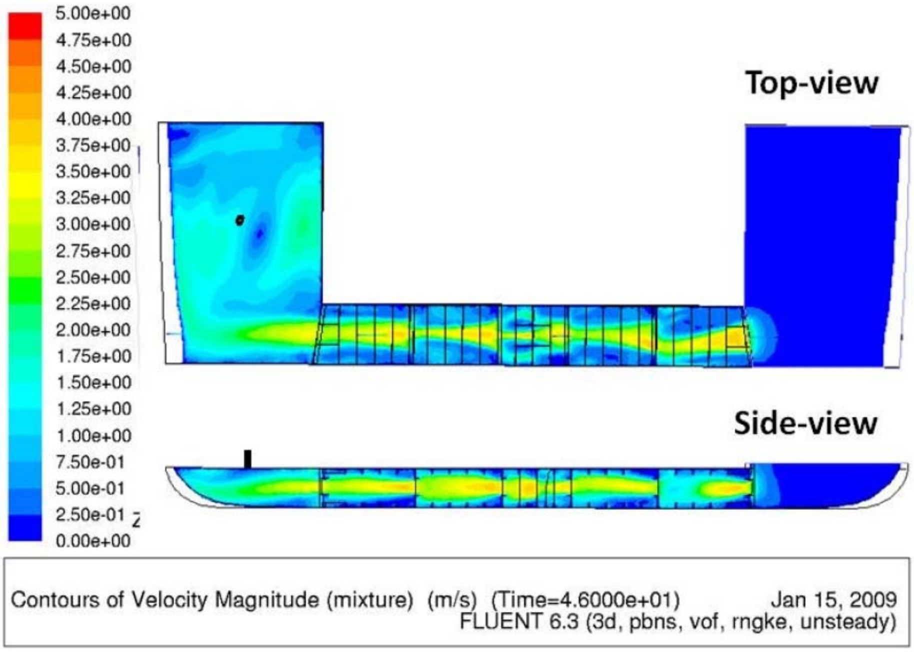

Figure 5: Velocity [m/s] at time = 46 s, illustrating how the flow behaves in the cross duct

Table 2: Comparison of discharge coefficients

method:	C_d
CFD	0.308
MSC.245(83) duct with 1 manhole	0.373
MSC.245(83) duct with 2 manholes	0.392
MSC.245(83) successive openings	0.296

Table 3: Comparison of equalization times with different methods

	Calculation method for cross-flooding time:		
Discharge coefficient method:	*CFD*	*Flood.Sim*	*MSC.245(83)*
CFD	47 s	47.8 s	46 s
MSC.245(83) duct with 1 manhole	-	34.4 s	35 s
MSC.245(83) successive openings	-	43.6 s	44 s

Conclusions

The results for all studied cross-duct design alternatives are summarized in Table 4. It should be noted that the method of successive openings (with C_d = 0.6 for each manhole) results in slightly smaller effective discharge coefficient for the whole duct than the model tests or CFD results. So it can be deduced that the method of successive openings is slightly conservative. On the other hand the regression equation (that is currently recommended in the resolution) gives notably higher (about +30%) values for the discharge coefficient. Thus the use of the regression equations may cause a significant under-estimation of the cross-flooding time.

Table 4: Comparison of discharge coefficients

Cross-duct design:	*Model test or CFD*	*Successive openings*	*Regression equation*
FLOODSTAND: L_{duct} = 6 m	0.442	0.397	0.582
FLOODSTAND: L_{duct} = 12 m	0.342	0.318	0.451
FLOODSTAND: L_{duct} = 18 m	0.287	0.273	0.382
Case Study 2 (CFD)	0.308	0.296	0.37 .. 0.39

Based on these two separate studies, it seems to be justified to use the method of successive openings instead of the regression equations for the determination of discharge coefficient for a cross-flooding duct. It should be noted that the suggested simple method does not account the distance between the girders. Thus it is likely that the pressure losses will be highly exaggerated for a cross-duct design, where the girders are very close to each other.

Furthermore, *Ogawa and Ohashi (2011)* have obtained similar results for a cross-duct design with 2 manholes in each girder. They conducted model tests in scale 1:10 and CFD analyses in both model and full scale. However, structural stiffeners inside the duct were not included.

It should be noted that dedicated CFD analysis or large scale model tests might still be necessary for more exceptional cross-flooding arrangements, where the suggested method of successive openings may not be fully valid.

Acknowledgement

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References

Ogawa, Y., Ohashi, K. 2011 Studies on an Assessment of Safety with Regard to the Damage Stability of Passenger Ships, *Proceedings of the 12th International Ship Stability Workshop*, Washington DC, U.S.A., 12-15 June 2011, pp. 271-275.

Pittaluga, C., Giannini, M. 2006. Pressure Losses Estimation for Structural Double Bottom by CFD Technique. CETENA Technical Report, Italy.

Ruponen, P., Queytey, P., Kraskowski, M., Jalonen, R., Guilmineau, E., 2011. On the calculation of cross-flooding time, manuscript submitted to *Ocean Engineering*.

Stening, M. 2010 Pressure losses and flow velocities in flow through manholes and crossducts, FLOODSTAND Deliverable D2.3, http://floodstand.aalto.fi/Info/public_download.html

Stening, M., Järvelä, J., Ruponen, P., Jalonen, R., 2011. Determination of discharge coefficients for a cross-flooding duct, *Ocean Engineering* 38, pp. 570-578.

Visonneau, M., Queutey, P., Guilmineau, E. 2010 Results of the Computational Study on the Pressure Losses in Openings, FLOODSTAND Deliverable D2.4a, http://floodstand.aalto.fi/Info/public_download.html

APPENDIX: Calculated Example

Cross duct design with 5 girders, each containing two manholes. The equation of total pressure losses in a series of successive openings is:

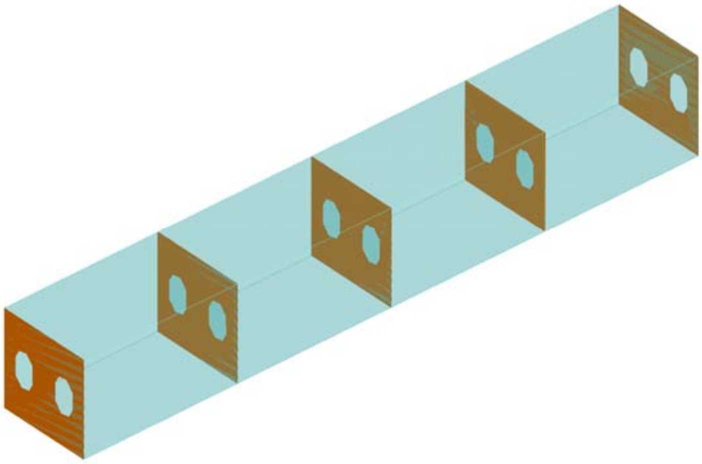
$$\sum k = k_1 + \sum_{i=2}^{N} k_i \cdot \frac{S_1^2}{S_i^2} + 1$$

where S_i is the total opening area in the i:th girder. In this case S_i = 0.491 m^2 for each girder. The pressure loss coefficient for one opening/girder is k_i = 1.778 (since $C_{d,i}$ = 0.6). Consequently:

$$\sum k = 1.778 + \sum_{i=2}^{5} 1.778 \cdot \frac{0.491^2}{0.491^2} + 1 = 9.89$$

Thus the flow reduction coefficient is:

$$F = \frac{1}{\sqrt{\sum k}} = \frac{1}{\sqrt{9.89}} \approx 0.318$$



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