

## Workshop N2

# Damage Stability According to SOLAS 2009

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## 1. Introduction

This workshop focuses on how to perform Damage Stability **calculations according to SOLAS 2009**. The main steps needed for such a calculation are gone through. As the items are dealt with on a **general level** also users who are new to this subject can participate. The EU directive, 2003/25/EC, for water on deck calculations is also briefly dealt with.

## 2. SOLAS 2009 – ship types affected

### All passenger ships:

- Pure passenger ships
- RoRo passenger ships
- Cruise vessels

### Dry cargo ships (L ≥ 80 m)

- Container ships
- RoRo cargo ships
- Car carriers
- General cargo ships
- Bulk carriers having reduced freeboard and deck cargo (IACS Unified interpretation no. 65)
- Cable laying ships

## 3. SOLAS 2009

### 3.1 General

The followed probabilistic concept is based on **statistical data** concerning what actually happens when ships collide, in terms of sea state and weather conditions; the extent and location of the damage; the speed and course of the ship; and whether the ship survived or sank.

The focus of the concept is to determine the **probability** that a ship will **remain afloat** without sinking or capsizing as a result of an arbitrary **collision** in a given longitudinal position of the ship.

By calculating the probability of the occurrence for each of the damage scenarios and then the probability of surviving each of these damages with the ship loaded in the most probable loading conditions, an overall probability of the ship in question surviving a collision can be evaluated. This probability is referred to as the “attained **subdivision index**”, **A**.

By requiring a minimum value of A, we have a requirement for a particular ship.

**Attained index ≥ Required index**

**A** = Attained subdivision index  
 $\sum p_i \cdot r_i \cdot v_i \cdot s_i$  (over a damage)

**R** = Required index  
 Rule formula based on L and number of passengers

**Compliance with the rules means:**  
**A ≥ R**

The factors  $p$ ,  $r$ ,  $v$  and  $s$  depend on the watertight arrangement, the shape of the ship and the actual floating position according to the following:

- The probability that the damage occurs transversally only in and within the zone under consideration is represented by **factor  $p$** .
- The probability that the damage has a transverse penetration not greater than the distance to a given longitudinal boundary is represented by **factor  $r$** .
- The probability that the damage has a vertical extent that includes only the spaces below a given horizontal boundary, such as a watertight deck, is represented by **factor  $v$** .
- The probability that the ship survives the flooding caused by the damage is represented by **factor  $s$** .

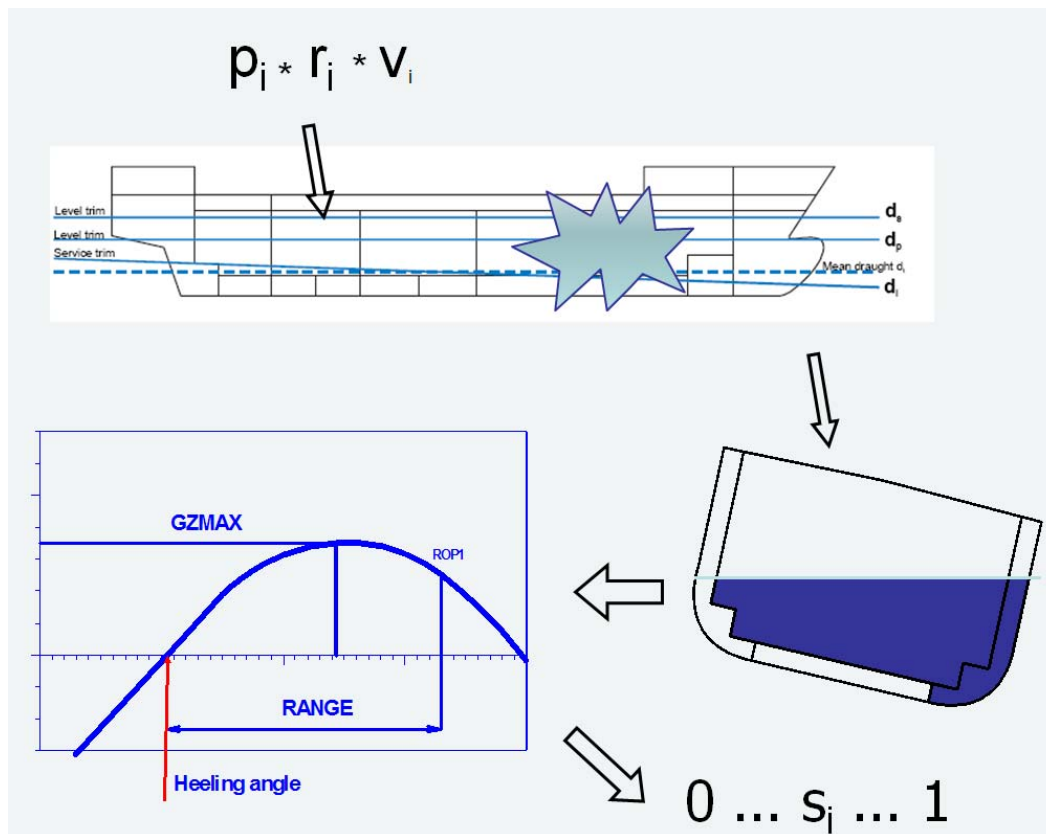


Figure 1 Calculation setup

In addition, there are deterministic requirements imposed by Regulations 8 and 9.

## 3.2 Formulas

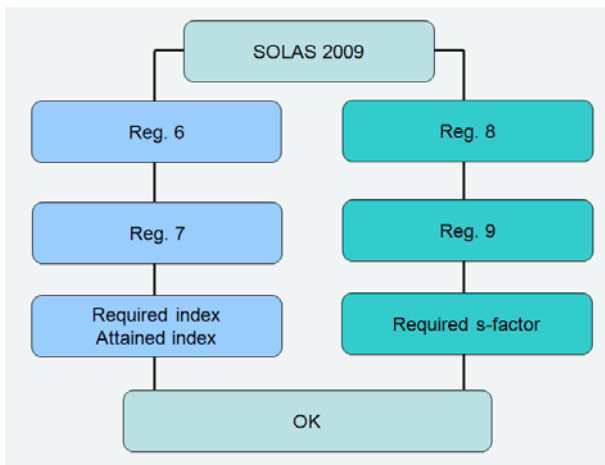


Figure 2 Rule setup

### 3.2.1 Regulation 6, required index R

#### Passenger ships:

$$R = 1 - \frac{5000}{L_s + 2.5 \cdot N + 15225}$$

$$N = N_1 + 2 N_2$$

$N_1$  = number of persons for whom lifeboats are provided

$N_2$  = number of persons (including officers and crew) the ship is permitted to carry in excess of  $N_1$



#### Cargo ships:

$$R = 1 - \frac{128}{L_s + 152} \quad L_s > 100 \text{ m}$$

$$R = 1 - \frac{1}{1 + \frac{L_s \cdot R_{Ls}}{100(1 - R_{Ls})}} \quad 80 \leq L_s \leq 100 \text{ m}$$

$R_{Ls}$  refers to the R in the upper formula



### 3.2.2 Regulation 7, attained subdivision index A

$$A = 0.4A_s + 0.4A_p + 0.2A_l$$

- 40% of its time at the deepest subdivision draught
- 40% of its time at the partial subdivision draught
- 20% of its time at the lightest service draught

$A_s, A_p$  and  $A_l \geq 0.5R$  for cargo ships

$A_s, A_p$  and  $A_l \geq 0.9R$  for passenger ships

### 3.2.3 Regulation 7-2, factor s

#### Passenger ships:

$$s_{final} = K \cdot \left[ \frac{GZ_{max}}{0.12} \cdot \frac{Range}{16} \right]^{1/4} \quad \text{Final stage}$$

$K = 1$	if	$\theta_e \leq 7^\circ$
$K = \left[ \frac{15 - \theta_e}{8} \right]^{1/2}$	if	$7 < \theta_e < 15^\circ$
$K = 0$	if	$\theta_e \geq 15^\circ$

$\theta_e$  = final equilibrium heeling angle



Calculations for **intermediate stages** of flooding should be performed whenever equalization is not **instantaneous** (equalization time > 60 s.)

$$s_{int} = \left[ \frac{GZ_{max}}{0.05} \cdot \frac{Range}{7} \right]^{1/4}$$

$$s_{mom} = \frac{(GZ_{max} - 0.04) \cdot Displ}{M_{heel}}$$

$$M_{heel} = \max(M_{pass}, M_{wind}, M_{survivalcraft})$$

$$s_i = \min(s_{int}, s_{final} \cdot s_{mom})$$



#### Cargo ships:

$$s_{final} = K \cdot \left[ \frac{GZ_{max}}{0.12} \cdot \frac{Range}{16} \right]^{1/4}$$

$K = 1$	if	$\theta_e \leq 25^\circ$
$K = \left( \frac{30 - \theta_e}{5} \right)^{1/2}$	if	$25 < \theta_e < 30^\circ$
$K = 0$	if	$\theta_e \geq 30^\circ$

$\theta_e$  = final equilibrium heeling angle



### 3.2.4 Regulation 8, special requirements concerning passenger ships

#### Regulation 8.1

Factor  $s$  must not be less than unity (1) for damages abaft the forward perpendicular when calculated as defined in Regulation 7-2.

#### Regulation 8.2-3

Factor  $s$  must not be less than 0.9 for minor side damages when calculated as defined in Regulation 7-2.

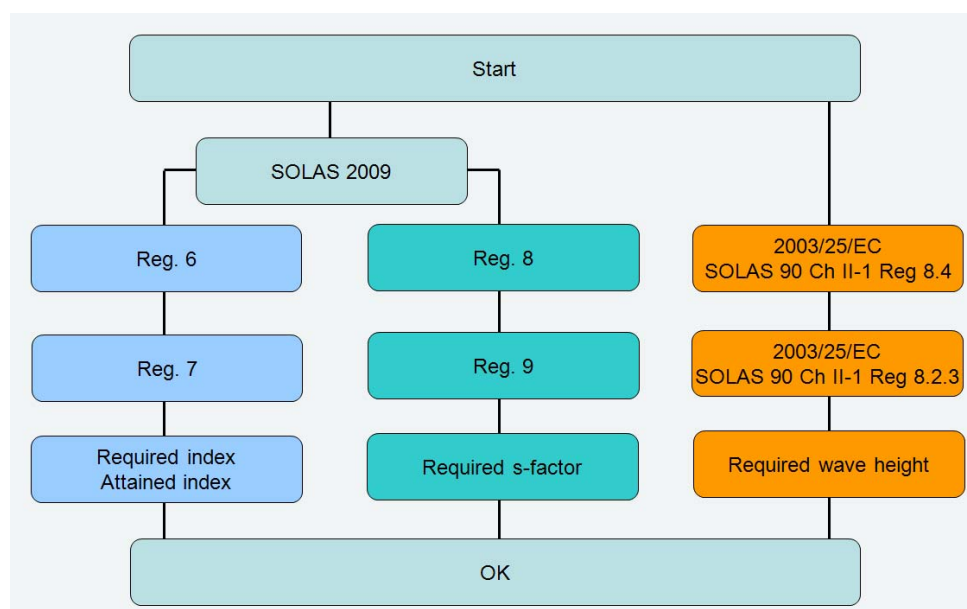
### 3.2.5 Regulation 9, double bottoms in passenger and cargo ships other than tankers

Factor  $s$  must not be less than unity (1) for double bottom damages when calculated as defined in Regulation 7-2.

## 4. In addition to SOLAS 2009 – EU water on deck calculations

As the EU directive 2003/25/EC is still valid and applies to all RORO passenger ships in international traffic operating a regular service to or from an EU port, also this rule is highly relevant even if it is not a part of SOLAS 2009.

In practice water on deck calculations are to be performed according to the Stockholm Agreement, which uses the SOLAS 90 standard as a starting point.



*Figure 3 Calculation setup for RORO passenger ships in international traffic operating a regular service to or from an EU port*

## 5. Tool for SOLAS 2009 calculations

### 5.1 General

The Manager application MGR\*PROB is the tool to be used to get fast and reliable calculation results. MGR\*PROB has again been renewed for Release 2009.1. The basic concept is kept but some additions are included.

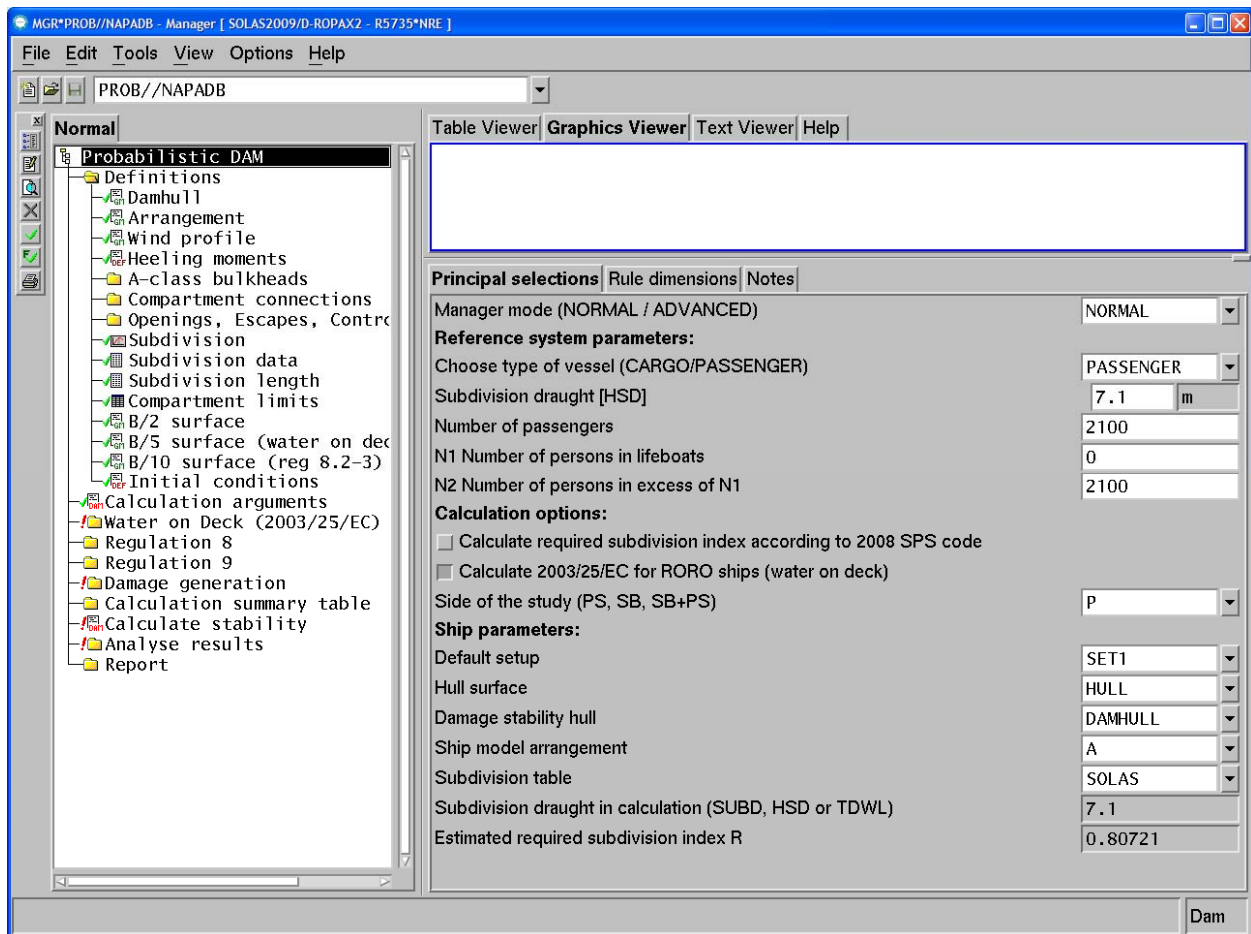


Figure 4 Manager application MGR\*PROB (Release 2009.1)

The following new items are implemented in the Manager MGR\*PROB:

- Possibility to engage an envelope reference waterline for the calculation of b-values, (see section 5.2.1)
- Water on deck calculations according to 2003/25/EC
- SPS code calculation (already in 2008.1)
- Improved damage generation in Regulation 9
- New analysing tools
- New report

## 5.2 Index calculation

As the probabilistic concept already is well-known and comprehensively covered by the Manager, this paper will limit the probabilistic scope to the matter of reference waterlines (Manager item 'Subdivision') and the novelties that are to be found in the Manager items 'Analyse results' and 'Report'.

### 5.2.1 Manager item: 'Subdivision'

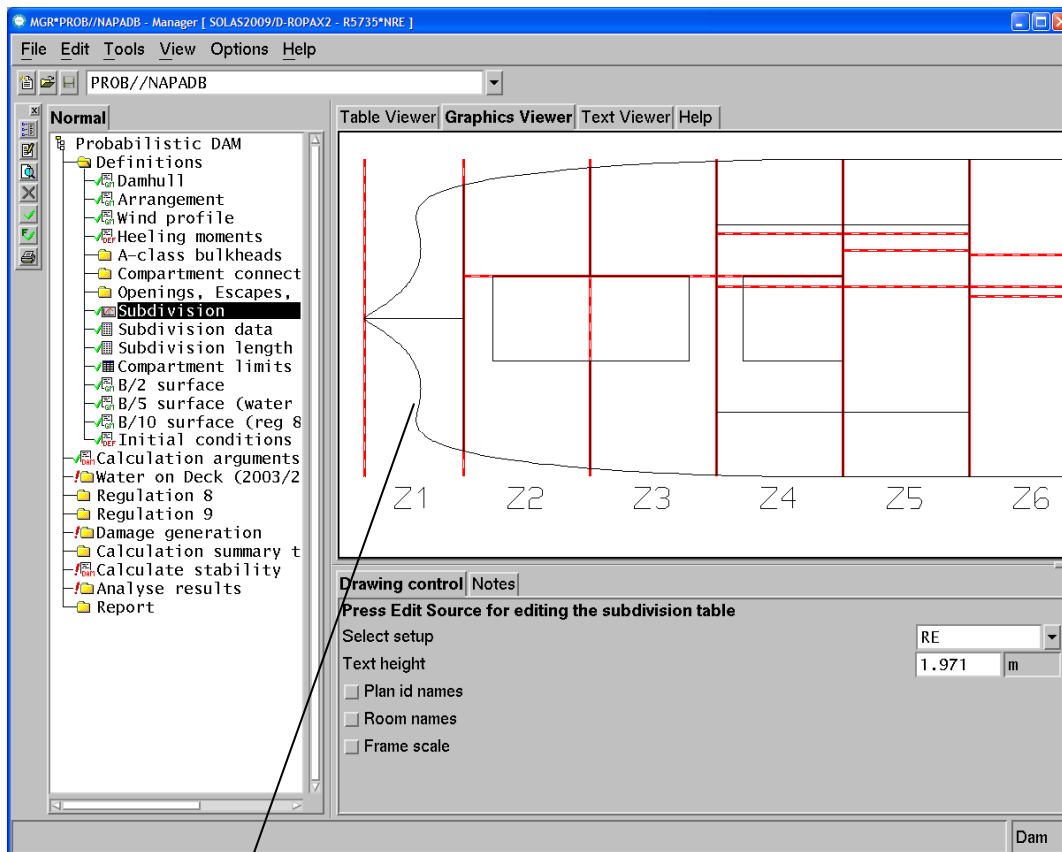


Figure 5 Manager application MGR\*PROB: subitem 'Subdivision'

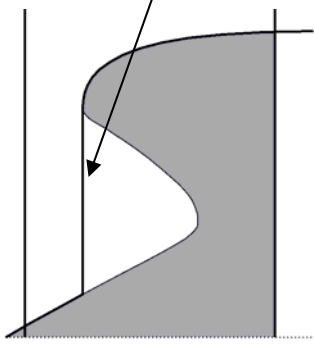


Figure 6 A straightened reference waterline

The subdivision draught waterline can now, if selected, be replaced by a straightened reference waterline for calculation purposes. The "envelope" curve includes straight parts perpendicular to the center line where multiple transversal coordinates occur, see Figure 4. The maximum transverse damage extent B/2 is then also calculated from the reference waterline.

The reference water line is shown in the subitem 'Subdivision' but the selection whether to apply it or not has to be done outside the Manager application by using the tools for defining a subdivision.



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### 5.2.2 Manager item: 'Analyse results'

#### P1S diagram:

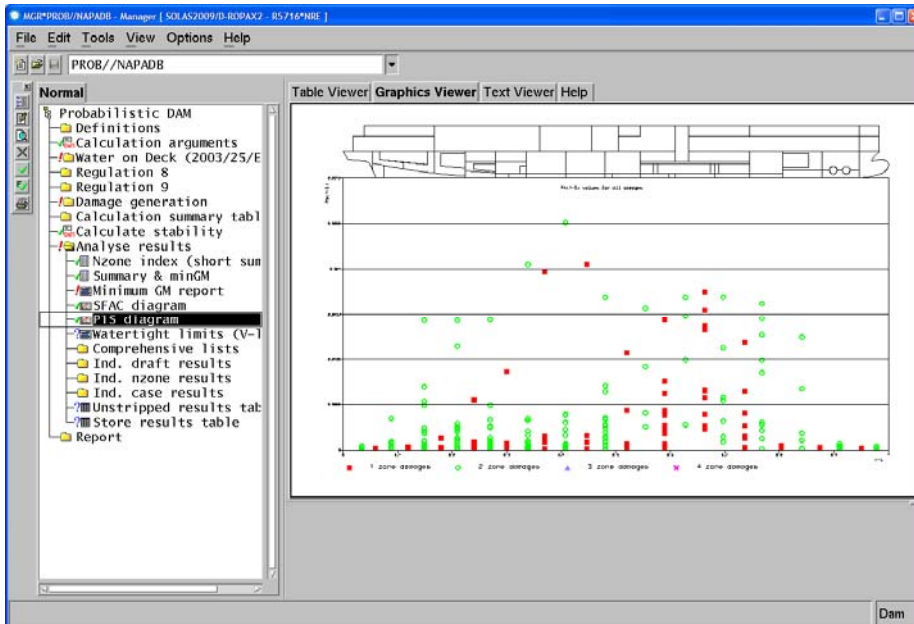


Figure 7 Manager application MGR\*PROB: subitem 'P1S diagram'

The P1S diagram has been included in order to make the calculation results more transparent. The purpose of the diagram is to identify problematic cases having a low safety level. The product  $p^*(1-s)$  is calculated for each damage case and drawn in the diagram.

#### Individual nzone results, draught and nzone index

ATTAINED INDEX FOR 1 ZONE DAMAGES					
MAX. INDEX vs. INDEX of DL/DP/DS and total ATT. INDEX					
ZONE	MAXINDEX	ATTDS	ATTD	ATTDL	ATTINDEX
21	0.02720	0.02705	0.02720	0.02720	0.02714
210	0.02024	0.00290	0.00771	0.00000	0.00424
211	0.02514	0.00149	0.00409	0.00000	0.00223
212	0.02024	0.01465	0.01889	0.00362	0.01414
213	0.01795	0.01752	0.01795	0.01792	0.01777
214	0.02514	0.02474	0.02514	0.02514	0.02498
215	0.02263	0.02249	0.02263	0.02263	0.02258
216	0.03424	0.03416	0.03424	0.03424	0.03421
22	0.01360	0.01345	0.01360	0.01360	0.01354
23	0.01578	0.01550	0.01578	0.01578	0.01567
24	0.01578	0.01410	0.01578	0.01554	0.01506
25	0.01578	0.01468	0.01578	0.00928	0.01404
26	0.01578	0.01528	0.01578	0.00583	0.01359
27	0.02514	0.02412	0.02514	0.00205	0.02011
28	0.02514	0.02414	0.02514	0.00119	0.01995
29	0.02024	0.01989	0.02024	0.00388	0.01683
TOTAL	0.33999	0.28617	0.30507	0.19791	0.27608

This new item lists the attained index for each zone and initial condition compared to the maximum potential index that could be achieved.

Figure 8 Manager application MGR\*PROB: subitem 'Ind. nzone results'

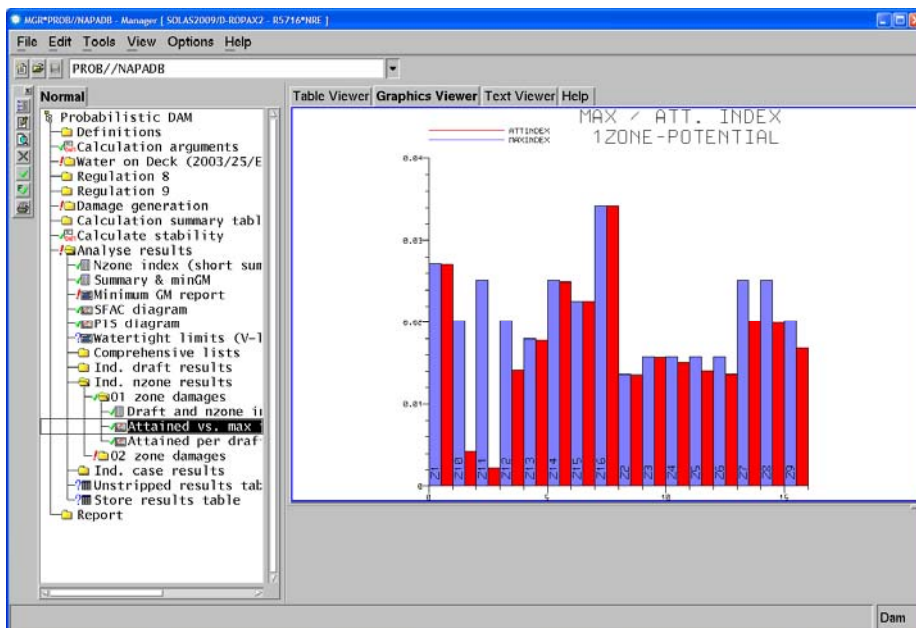
**Individual nzone results, Attained vs. max index summary**

Figure 9: Manager application MGR\*PROB: subitem 'Attained vs. max index summary'

This item shows the relation between the index potential and the total attained indexes on a zone basis.

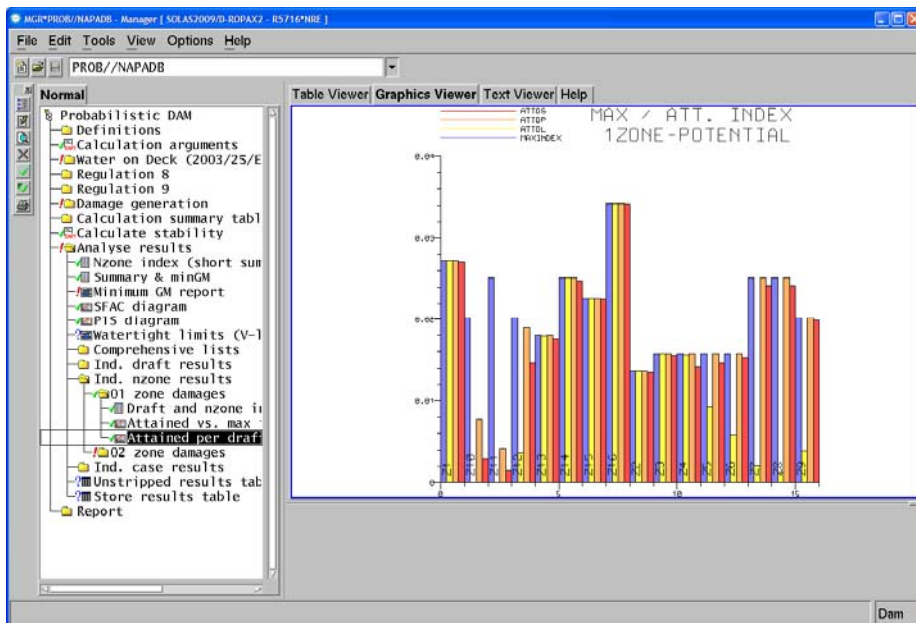
**Individual nzone results, Attained per draft vs. max index diagram**

Figure 10 Manager application MGR\*PROB: subitem 'Attained per draft vs. max index diagram'

This item shows the relation between the index potential and the total attained indexes on a zone and initial condition basis.

### 5.2.3 Manager item: 'Report'

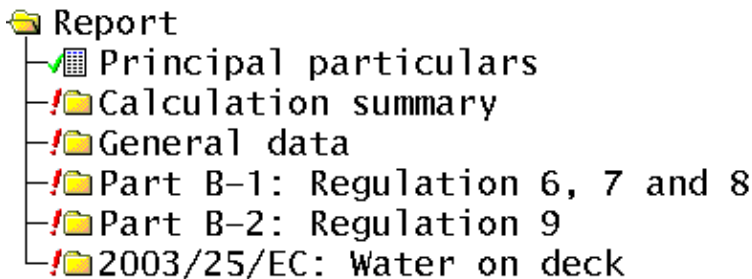


Figure 11 Manager application MGR\*PROB: subitem 'Report'

The new Report follows the main idea outlined in Explanatory Notes.

The Calculation summary is followed by the General data, which consists of ship model oriented definitions and user input. The detailed calculation results follow the structure of Chapter II-1, i.e. they are organised according to Part B-1 and Part B-2.

Results for water on deck calculations according to 2003/25/EC are included last.

## 5.3 Deterministic calculation

Regulations 8 and 9 are a solid part of SOLAS 2009 even if they are not a part of the index calculation. The calculation according to these regulations follows the deterministic concept.

### 5.3.1 Manager item: 'Regulation 8.1'

The item is visible in the Manager hierarchy tree only for passenger vessels and only if N1+N2 (defined on top level of the Manager) is 400 or more.

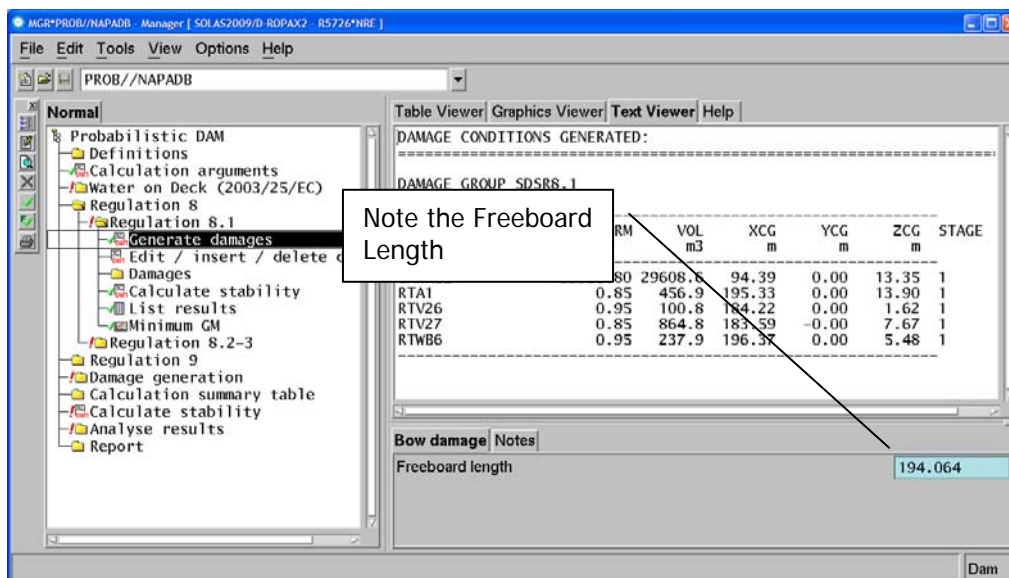


Figure 12 Manager application MGR\*PROB: subitem 'Generate damages'

Usually, we manage with one single damage, which is automatically generated according to Reg. 8.1. There is, however, the possibility to add damages to be calculated manually.

Subitem **'Calculate'** calculates the damages together with the same initial conditions and moments that are used for the index calculation.

Subitem **'List results'** lists the cases and their s-factors. Here, the Manager simply applies the command LIS DCRT together with a relevant criterion of TYPE SSOLAS (see the appendix). A minimum GM value is also calculated for each case.

Subitem **'Minimum GM'** lists the minimum GM values and draws a limit curve based on them.

### 5.3.2 Manager item: 'Regulation 8.2-3'

The item is visible in the Manager hierarchy tree only for passenger vessels.

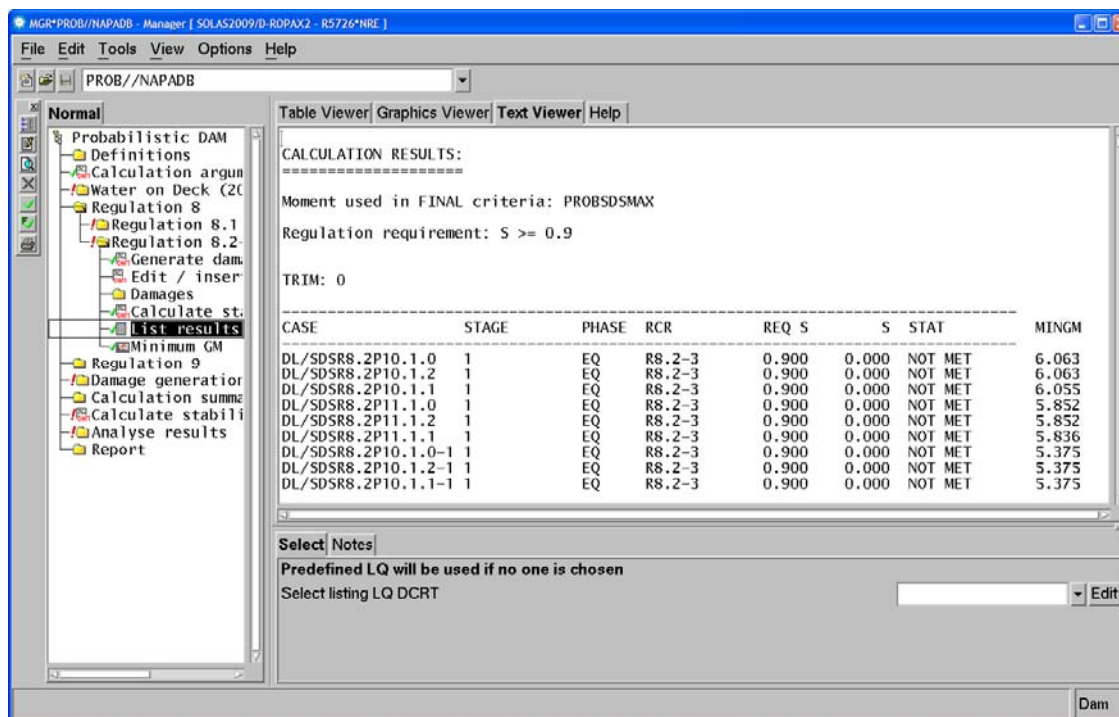


Figure 13 Manager application MGR\*PROB: subitem 'List results'

The damages are automatically generated according to the same subdivision table as in the index calculation. The difference is that the damages are longitudinally limited to the B/10 surface, which is generated or selected in the definition folder. Also here, as in Reg. 8.1., there is the possibility to add damages or remove damages from the calculation scope manually. The damages can also be modified inside the Manager application. The extents of the damages are automatically defined according to Reg. 8.2-3.

Subitem **'Calculate'** calculates the damages together with the same initial conditions and moments that are used for the index calculation.

Subitem **'List results'** lists the cases and their s-factors. Here, the Manager simply applies the command LIS DCRT together with a relevant criterion of TYPE SSOLAS (see the appendix). A minimum GM value is also calculated for each case.

Subitem **'Minimum GM'** lists the minimum GM values and draws a limit curve based on them.

### 5.3.3 Manager item: 'Regulation 9'

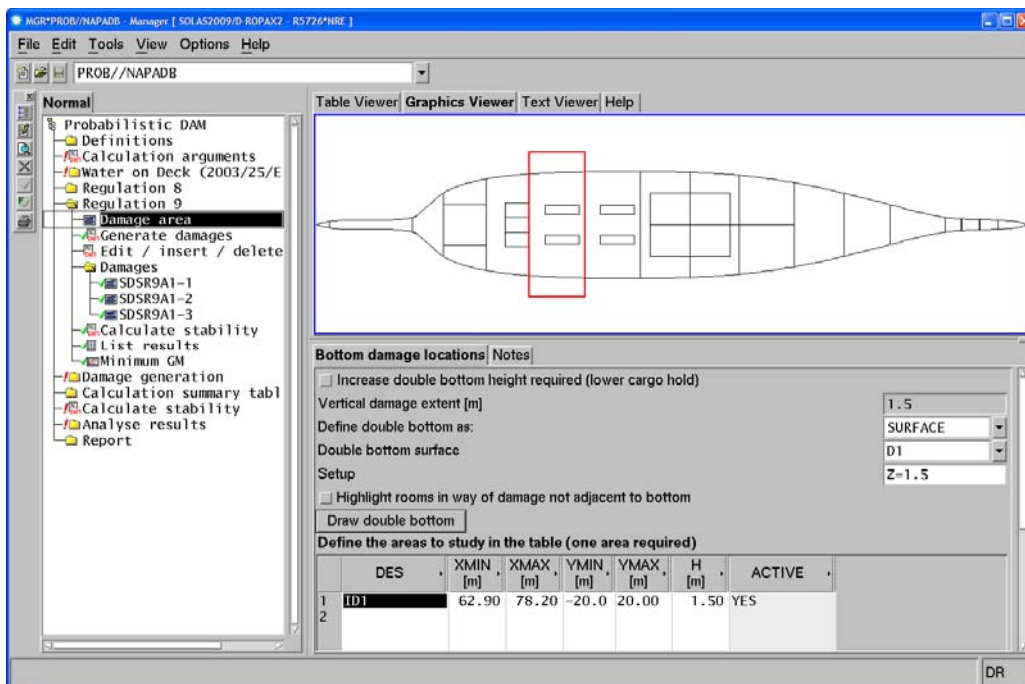


Figure 14 Manager application MGR\*PROB: subitem 'Damage area'

The damages are automatically generated according to the same subdivision table as in the index calculation. Also here, as in Reg. 8.1-3, there is the possibility to add manually defined damages or to remove damages from the calculation scope. The damages can also be modified inside the Manager application. The extents of the damages are automatically defined according to Reg. 9.

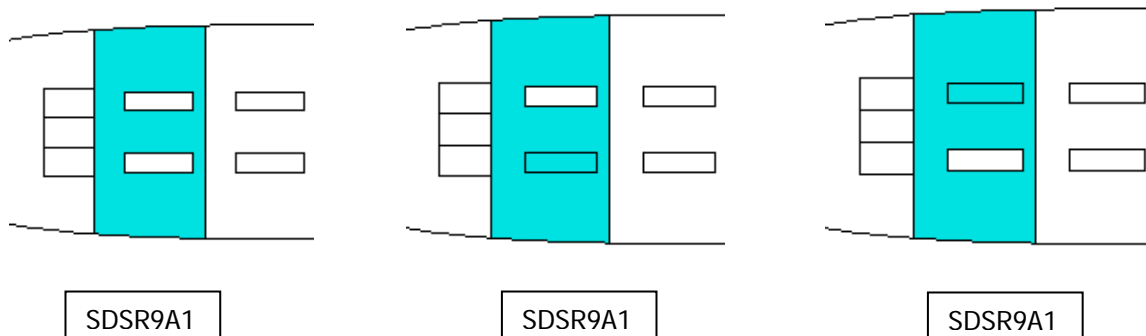


Figure 15-17 Generated damages

Subitem **'Calculate'** calculates the damages together with the same initial conditions and moments that are used for the index calculation.

Subitem **'List results'** lists the cases and their s-factors. Here, the Manager simply applies the command LIS DCRT together with a relevant criterion of TYPE SSOLAS (see the appendix). A minimum GM value is also calculated for each case.

Subitem **'Minimum GM'** lists the minimum GM values and draws a limit curve based on them.



## 6. Manager item: '2003/25/EC'

The directive 2003/25/EC, which is not a part of SOLAS 2009 is needed until the Revision of SOLAS 2009 exists.

This item can be selected on the top level of the Manager to be visible in the Manager hierarchy tree.

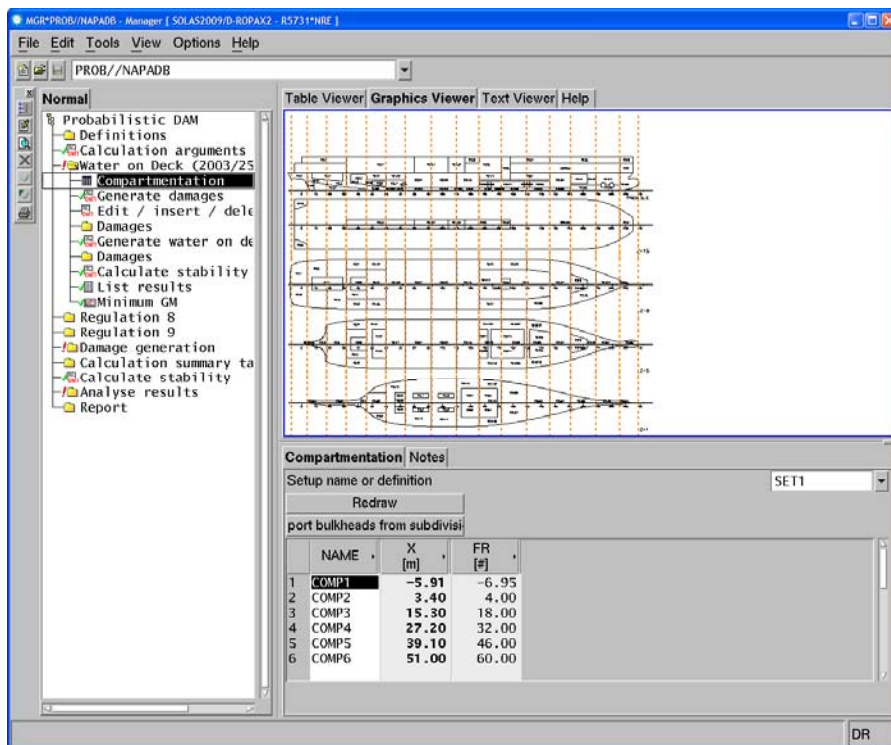


Figure 18 Manager application MGR\*PROB: subitem 'Compartmentation'

Subitem **'Compartmentation'** divides the ship into SOLAS 90 compartments. The choice whether a damage is a one or two compartment damage is made according to the x-limits defined here and how they relate to the SOLAS 90 rule length. The x-limits can be imported from the actual subdivision table or defined according to the user's own choice.

Subitem **'Generate damages'** generates the damages by using the automatic generation method based on the actual subdivision table (GEN DAM..). The damages are longitudinally limited to the B/5 surface, which is defined in the definitions folder. Damages shorter than the SOLAS 90 rule length are excluded as well as damages that are too long. The defined damages are grouped into one and two compartment damages according to the limits defined in the subitem 'Compartmentation'.

Subitem **'Generate water on deck'** adds the RORO compartment with its water on deck features to the above generated damages. The extents (x-direction) are set according to the SOLAS 90 rule length.

Subitem **'Calculate'** calculates the damages together with the same initial conditions and moments that are used for the index calculation.

Subitem **'List results'** lists the cases. Here, the Manager simply applies the command LIS DCRT together with the relevant criteria groups STO1 and STO2 (see the appendix). A minimum GM value is also calculated for each case.

Subitem **'Minimum GM'** lists the minimum GM values and draws a limit curve based on them.

## 7. End remarks

The purpose of this workshop is to demonstrate the Manager application MGR\*PROB and introduce some of the new functionality available in Release 2009.1.

## 8. Appendix – MGR\*PROB applied stability criteria

### 8.1 SOLAS 2009

#### Criterion used for SOLAS 2009, Reg. 8.1

CRIT, REG8.1  
TYPE, SSOLAS  
REQ, 1  
MOM, PROBSDSMAX  
OK

#### Criterion used for SOLAS 2009, Reg. 8.2-3

CRIT, R8.2-3  
TYPE, SSOLAS  
REQ, 0.9  
MOM, PROBSDSMAX  
OK

#### Criterion for SOLAS 2009, Reg. 9

CRIT, REG9  
TYPE, SSOLAS  
REQ, 1  
MOM, PROBSDSMAX  
OK

#### Heeling moments for SOLAS 2009

MOM, PROBSDSMAX, 'Maximum moment (PROBSDSPASS, PROBSDSWIND, PROBSDSSURV)'  
MAX, PROBSDSPASS, PROBSDSWIND, PROBSDSSURV

MOM, PROBSDSPASS, 'Passenger moment'  
CURV, CONSTANT  
MOM, @value

MOM, PROBSDSWIND, 'Wind moment'  
TYPE, WIND  
PARA, C=0.012237, PROF=PROFILE, TP2

MOM, PROBSDSSURV, 'Survival craft moment'  
CURV, CONSTANT  
MOM, @value

### 8.2 '2003/25/EC'

#### Criteria for one compartment damages

CGR, STO1, 'Stockholm agreement, 1-comp'  
CRI, V.RANGE10.ST, V.ARANGE1.ST, V.MINAREA1.ST, V.MINGZ1.ST,  
V.MINGZW1.ST, V.MINGZP1.ST, V.MINGZS1.ST, V.PROGR.ST

CRIT, V.RANGE10.ST, 'Range of pos. stab>10 deg'  
TYPE, RANGE

REQ, 10  
RANG, EQ, FAUN  
OK

CRIT, V.ARANGE1.ST, 'Min. range by attained area'  
TYPE, RANGE  
REQ, BY, AREA, 15, 0.015, -, MIN(FAUN, 22)  
RANG, EQ, FAUN  
OK

CRIT, V.MINAREA1.ST, 'Minarea of GZ-curve'  
TYPE, MINAREA  
REQ, 0.015  
RANG, EQ, MIN(22, FAUN)  
OK

CRIT, V.MINGZ1.ST, 'Min. righting lever'  
TYPE, MAXGZ  
REQ, 0.1  
RANG, EQ, MIN(22, FAUN)  
OK

CRIT, V.MINGZW1.ST, 'Min. righting lev./wind'  
TYPE, MAXGZ  
REQ, 0.04  
MOM, PROBSDSWIND  
RANG, EQ, MIN(22, FAUN)  
OK

CRIT, V.MINGZP1.ST, 'Min. righting lev./pass'  
TYPE, MAXGZ  
REQ, 0.04  
MOM, PROBSDSPASS  
RANG, EQ, MIN(22, FAUN)  
OK

CRIT, V.MINGZS1.ST, 'Min. righting lev./Surv. craft'  
TYPE, MAXGZ  
REQ, 0.04  
MOM, PROBSDSSURV  
RANG, EQ, MIN(22, FAUN)  
OK

CRIT, V.PROGR.ST, 'No progr. flooding'  
TYPE, MAXHEEL  
REQ, FA  
OK

### Criteria for two compartment damages

CGR, STO2, 'Stockholm agreement, 2-comp'  
CRI, V.RANGE10.ST, V.ARANGE2.ST, V.MINAREA2.ST, V.MINGZ2.ST,  
V.MINGZW2.ST, V.MINGZP2.ST, V.MINGZS2.ST, V.PROGR.ST

CRIT, V.RANGE10.ST, 'Range of pos. stab>10 deg'  
TYPE, RANGE  
REQ, 10  
RANG, EQ, FAUN  
OK



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CRIT, V.ARANGE2.ST, 'Min. range by attained area'  
TYPE, RANGE  
REQ, BY, AREA, 15, 0.015, -, MIN(FAUN, 27)  
RANG, EQ, FAUN  
OK

CRIT, V.MINAREA2.ST, 'Minarea of GZ-curve'  
TYPE, MINAREA  
REQ, 0.015  
RANG, EQ, MIN(27, FAUN)  
OK

CRIT, V.MINGZ2.ST, 'Min. righting lever'  
TYPE, MAXGZ  
REQ, 0.1  
RANG, EQ, MIN(27, FAUN)  
OK

CRIT, V.MINGZW2.ST, 'Min. righting lev./wind'  
TYPE, MAXGZ  
REQ, 0.04  
MOM, PROBSDSWIND  
RANG, EQ, MIN(27, FAUN)  
OK

CRIT, V.MINGZP2.ST, 'Min. righting lev./pass'  
TYPE, MAXGZ  
REQ, 0.04  
MOM, PROBSDSPASS  
RANG, EQ, MIN(27, FAUN)  
OK

CRIT, V.MINGZS2.ST, 'Min. righting lev./Surv. craft'  
TYPE, MAXGZ  
REQ, 0.04  
MOM, PROBSDSSURV  
RANG, EQ, MIN(27, FAUN)  
OK

CRIT, V.PROGR.ST, 'No progr. flooding'  
TYPE, MAXHEEL  
REQ, FA  
OK

### **Moments for '2003/25/EC'**

MOM, PROBSDSPASS, 'Passenger moment'  
CURV, CONSTANT  
MOM, @value

MOM, PROBSDSWIND, 'Wind moment'  
TYPE, WIND  
PARA, C=0.012237, PROF=PROFILE, TP2

MOM, PROBSDSSURV, 'Survival craft moment'  
CURV, CONSTANT  
MOM, @value