Probabilistic damage stability verification on *Passenger Yacht Code* motor yacht

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- Damage Stability
- Deterministic Approach
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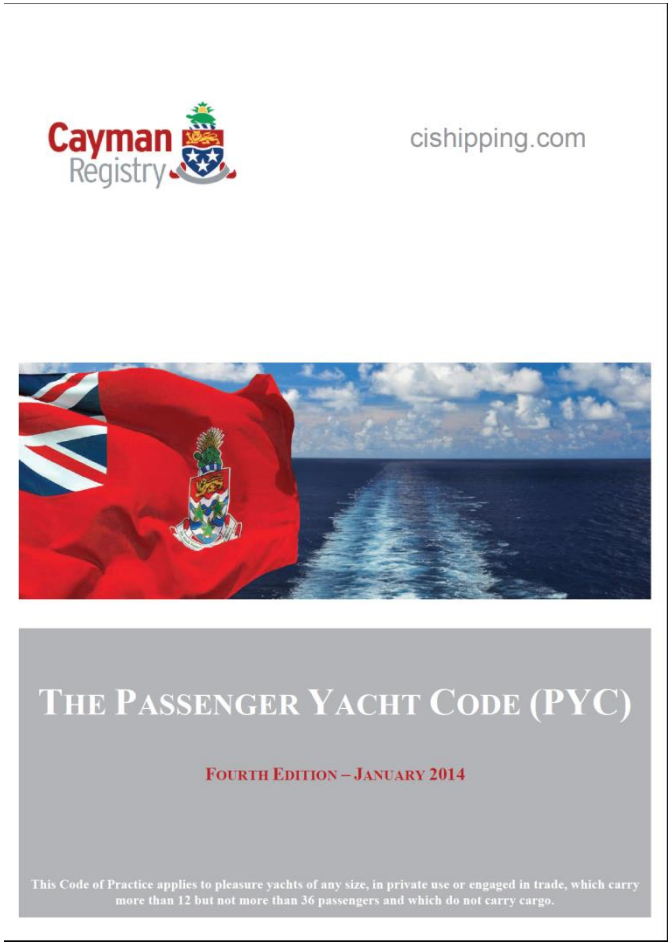
Passenger Yacht Code

- SOLAS 90
- International conventions to enorous
- PYC – equivalent to SOLAS 90 for yachts



Damage Stability

Deterministic approach

- Assumed damage scenarios
- Up to two adjacents compartments flooded

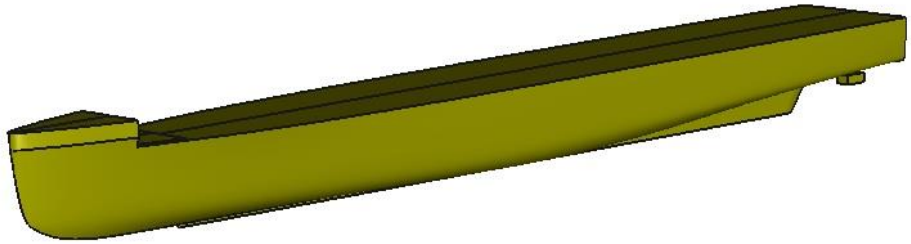
Probabilistic approach

- Statistical evidence
- More realistic approach

Objective: most effective ship subdivision

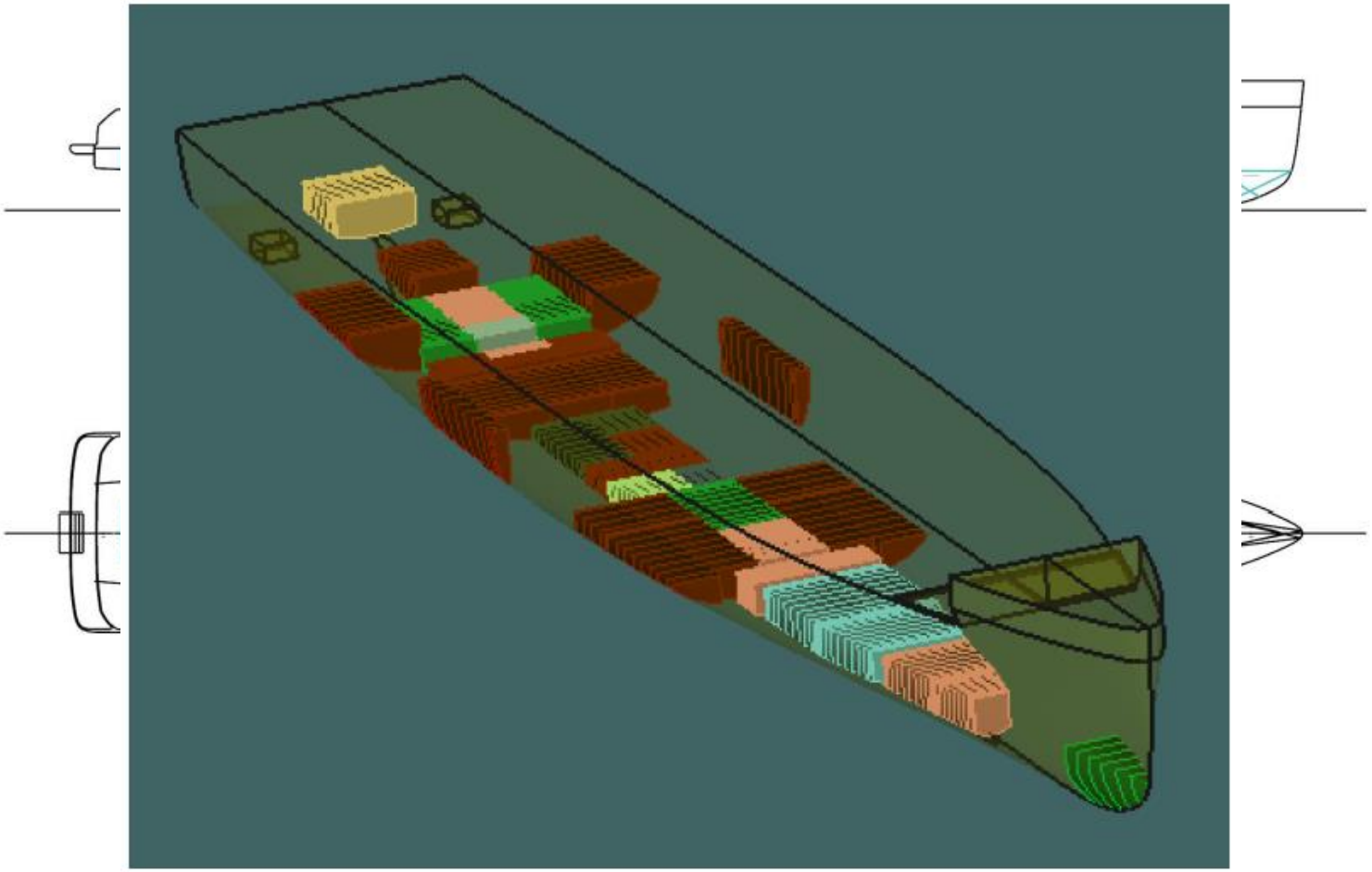
Case Study - 92 m motor yacht

- Moulded dimensions:
  - LOA = 92 m
  - B = 15,8 m
  - D = 7,7 m
- Displacement of 3178 t
- Number of crew: 28
- Number of passengers: 34



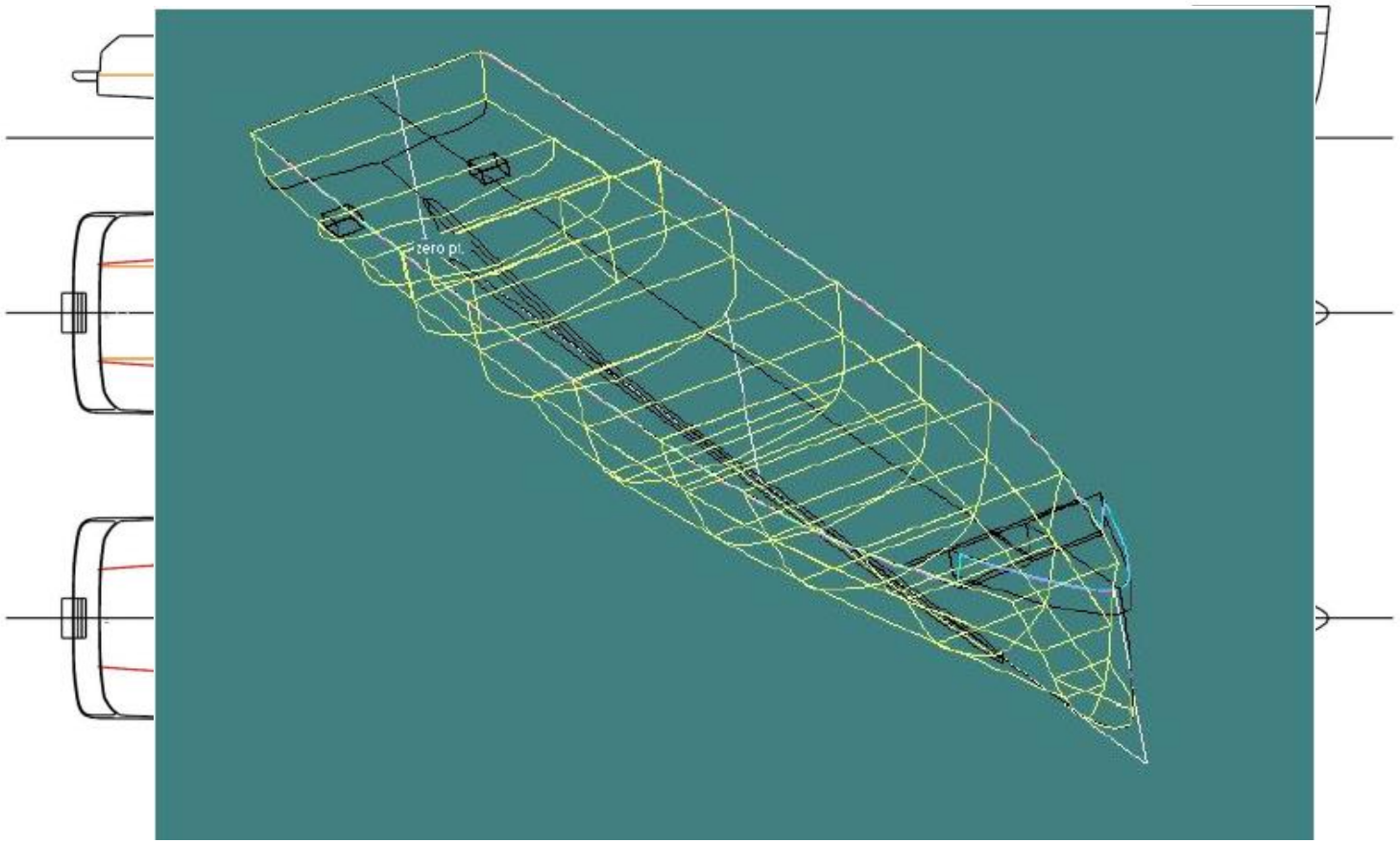
Deterministic Approach

Capacity plan - Hydromax



Deterministic Approach

Watertight compartment plan - Hydromax

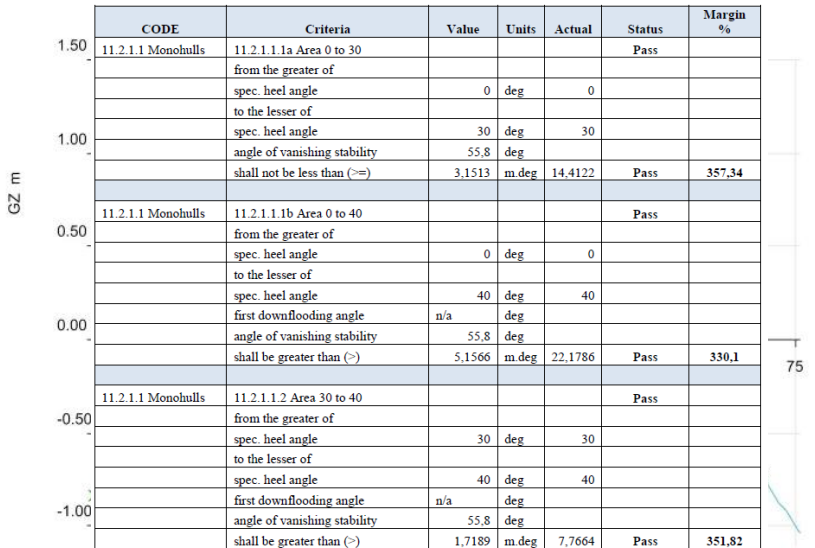


Deterministic Approach

Intact Stability Calculations

- Departure condition – 100% consumables
- Half load condition – 50% consumables
- Arrival condition – 10% consumables

Results

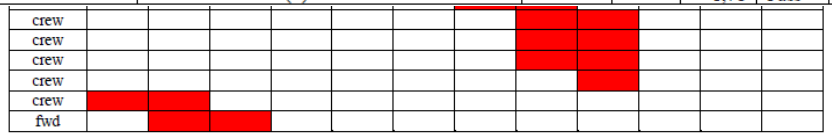


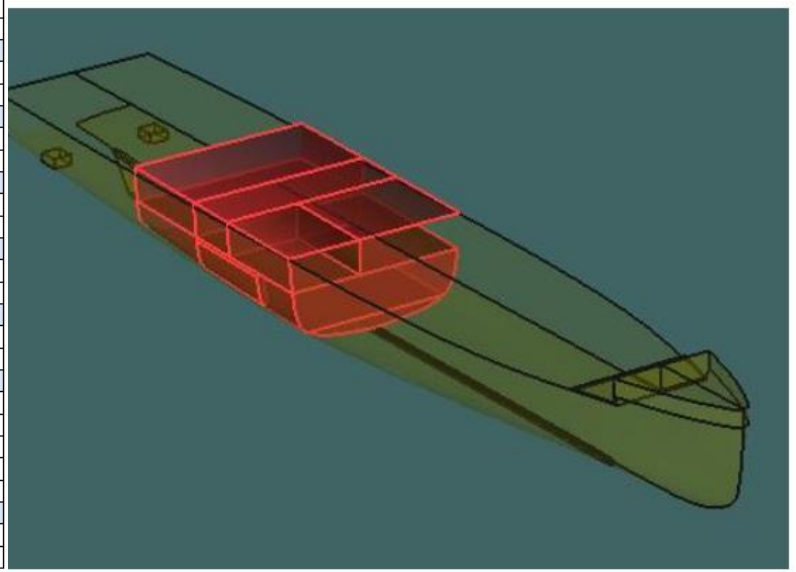
CODE	Criteria	Value	Units	Actual	Status	Margin %
11.2.1.1 Monohulls	11.2.1.1.1a Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	55,8	deg			
	shall not be less than (>=)	3,1513	m.deg	14,4122	Pass	**357,34**
11.2.1.1 Monohulls	11.2.1.1.1b Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	55,8	deg			
	shall be greater than (>)	5,1566	m.deg	22,1786	Pass	**330,1**
11.2.1.1 Monohulls	11.2.1.1.2 Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	55,8	deg			
	shall be greater than (>)	1,7189	m.deg	7,7664	Pass	**351,82**
11.2.1.1 Monohulls	11.2.1.1.3 Max GZ at 30 or greater				Pass	
	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	angle of max. GZ	30,9	deg	30,9		
	first downflooding angle	n/a	deg			
	shall be greater than (>)	0,2	m	0,829	Pass	**314,5**
	Intermediate values					
	angle at which this GZ occurs		deg	30,9		
11.2.1.1 Monohulls	11.2.1.1.4 Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	30,9	Pass	**23,64**
11.2.1.1 Monohulls	11.2.1.1.5 Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	2,089	Pass	**1292,67**

Deterministic Approach

Damage Stability Calculations

CODE	Criteria	Value	Units	Actual	Status	Margin %
11.3 Damage	11.3.1.1 Equilibrium waterline				Pass	
	shall not be less than (>=)	0,075	m	1,991	Pass	2554,67
11.3 Damage	11.3.1.4 Equilibrium angle				Pass	
	shall not be greater than (<=)	7	deg	0,3	Pass	96,14
11.3 Damage	11.3.1.4 Range of positive stability				Pass	
	shall not be less than (>=)	15	deg	41,8	Pass	178,85
11.3 Damage	11.3.1.4 Value of max. GZ				Pass	
	shall not be less than (>=)	0,1	m	0,41	Pass	310
11.3 Damage	11.3.1.4 GZ area under curve				Pass	
	shall not be less than (>=)	0,8594	m.deg	9,9577	Pass	1058,68
Enhanced	4.30(1)(a)(i) Angle of equilibrium				Pass	
	shall be less than (<)	7	deg	0,3	Pass	96,14
Enhanced	4.30(1)(a)(i) Range of residual positive				Pass	
	shall not be less than (>=)	7	deg	14,9	Pass	112,6
Enhanced	4.30(1)(a)(ii) Maximum residual GZ				Pass	
	shall not be less than (>=)	0,05	m	0,41	Pass	720
Enhanced	4.30(1)(a)(ii) Residual GM				Pass	
	shall not be less than (>=)	0,05	m	0,875	Pass	1650
Enhanced	4.30(1)(a)(iii) Margin line immersion - GZ				Pass	
	shall be less than (<)	100	%	1,78	Pass	98,22





Probabilistic Approach

Required index R

- Formula based on length and number of passengers

$$R = 1 - \frac{5000}{L_S + 2{,}5N + 15252}$$

Attained index A

- Represents a measure for the probability of survival

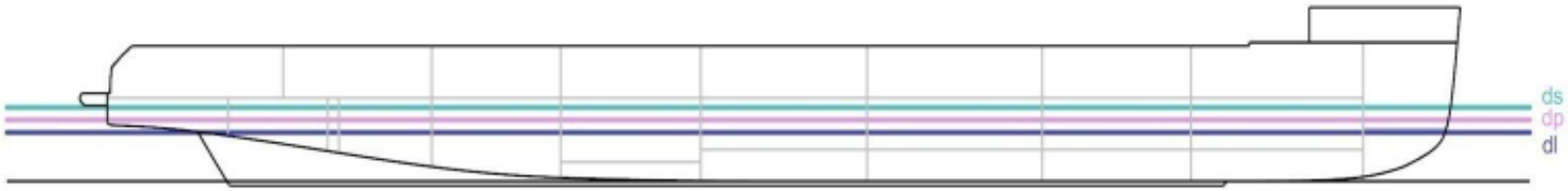
$$A = \sum_i \mathrm{p_i v_i r_i s_i}$$

Attained index ≥ **R**equred index

Probabilistic Approach

Attained index A

- Deepest subdivision draft, ds
- Light service draft, dl
- Partial subdivision draft, dp



$$A = 0.4As + 0.4Ap + 0.2Al$$

Al, Ap and Ad ≥ 0,9 R

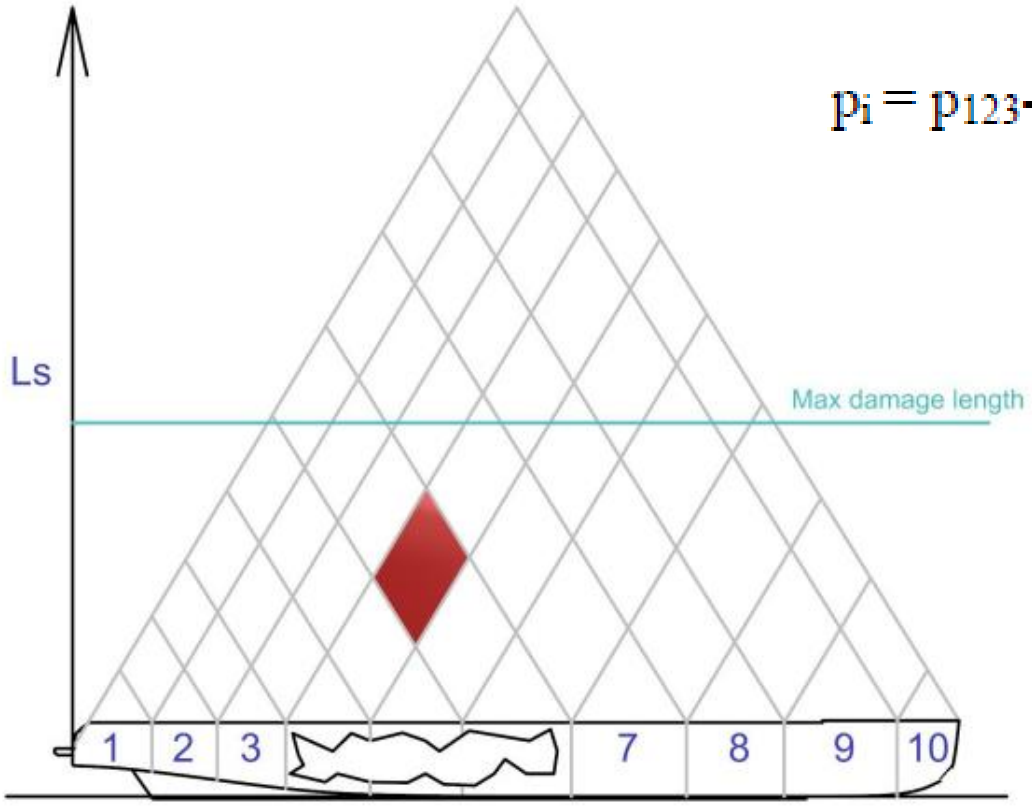
Probabilistic Approach

Attained index A

- pi – probability of a damage situation
- si – probability of a ship surviving the damage
- vi – vertical extent of the damage
- ri – transversal extent of the damage

Probabilistic Approach

Calculating Factor pi



$$p_i = p_{123} - p_{12} - p_{23} + p_2, \text{ etc.}$$

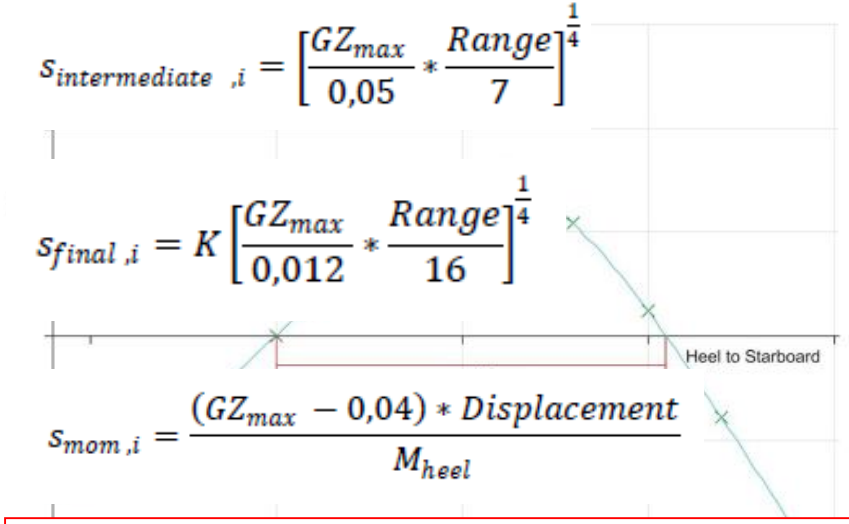
Probabilistic Approach

Calculating factor si

- *Range* – range of positive righting levers, in degrees, measured from the equlibrium heeling angle and the angle where the righting lever becomes negative
- GZmax – maximum positive righting lever

$$s_{intermediate\ ,i} = \left[\frac{GZ_{max}}{0{,}05} * \frac{Range}{7}\right]^{\frac{1}{4}}$$

$$s_{final\ ,i} = K\left[\frac{GZ_{max}}{0{,}012} * \frac{Range}{16}\right]^{\frac{1}{4}}$$



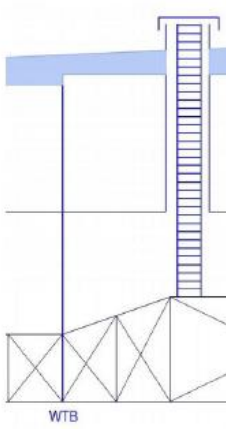
$$s_{mom\ ,i} = \frac{(GZ_{max} - 0{,}04) * Displacement}{M_{heel}}$$

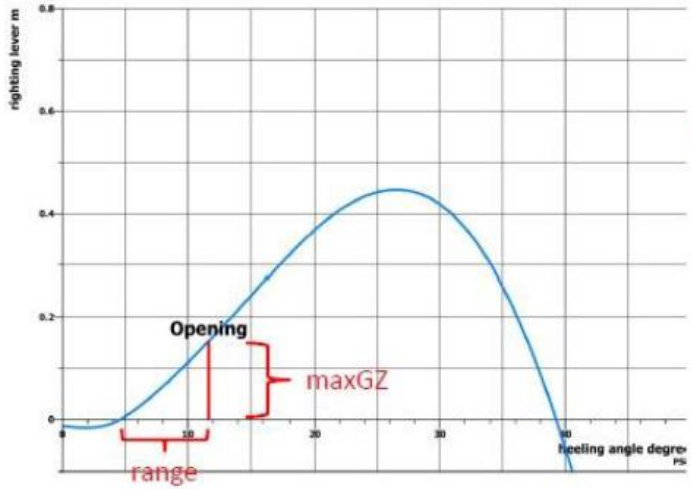
$$s_i = miminum\left\{s_{intermediate\ ,i}\ or\ s_{final\ ,i} * s_{mom\ ,i}\right\}$$

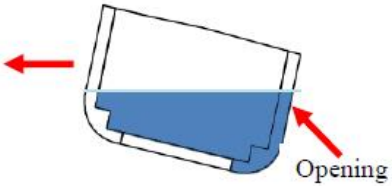
Probabilistic Approach

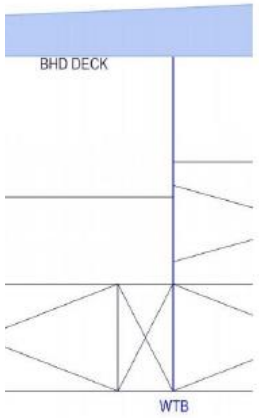
Calculating factor si

Openings





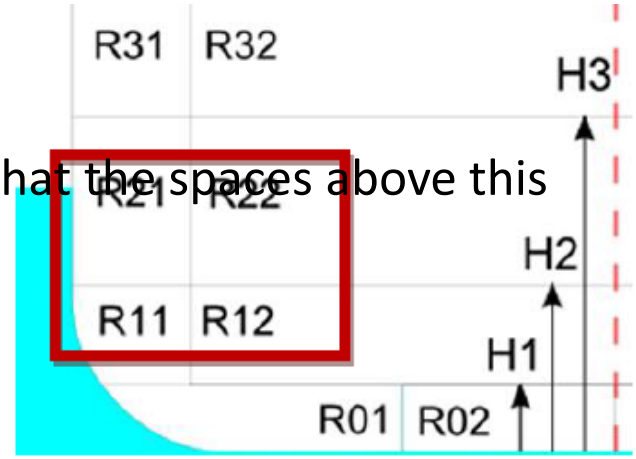




Probabilistic Approach

Calculating factor vi

- Probability that the spaces above the horizontal



Watertight deck at 4,74 m – probability that the spaces above this deck will not be flooded

Final Results of Attained Index A

Compartment	x1	x2	Damage length	T=3,985	T=4,114	T=4,2
1 compartment flooded			[m]			
1	0	8,29	8,29	0,0540	0,0495	0,0524

0,9R	Al	Ap	Ad
0,6120	0,8447	0,7853	0,8300

10	86,07	92,65	6,58	0,0407	0,0374	0,0395
2 compartments flooded						
1 and 2	0	15,11	15,11	0,0364	0,0334	0,0353
2 and 3	8,29	22,27	13,98	0,0295	0,0271	0,0287
3 and 4	15,11	31,07	15,96	0,0337	0,0309	0,0327
4 and 5	22,27	44,67	22,4	0,0423	0,0388	0,0410
5 and 6	31,07	55,87	24,8	0,0446	0,0423	0,0447
6 and 7	44,67	64,08	19,41	0,0399	0,0360	0,0380
7 and 8	55,87	75,87	20	0,0397	0,0365	0,0385
8 and 9	64,08	86,07	21,99	0,0433	0,0398	0,0420
9 and 10	75,87	92,65	16,78	0,0415	0,0381	0,0403
3 compartments flooded						
1, 2 and 3	0	22,27	22,27	0,0093	0,0101	0,0106
2, 3 and 4	8,29	31,07	22,78	0,0075	0,0081	0,0086
8, 9 and 10	64,08	92,65	28,57	0,0057	0,0062	0,0065
4 compartments flooded						
1, 2, 3 and 4	0	31,07	31,07	0,0030	0,0033	0,0035
2, 3, 4 and 5	8,29	44,67	36,38	0,0021	0,0023	0,0024
3, 4, 5 and 6	15,11	55,87	40,76	0,0005	0,0005	0,0005
4, 5, 6 and 7	22,27	64,08	41,81	0,0002	0,0002	0,0002
3, 4, 5, 6 and 7	15,11	64,08	48,97	0,0000	0,0000	0,0000
4, 5, 6 , 7 and 8	22,27	75,87	53,6	0,0000	0,0000	0,0000
5, 6, 7, 8 and 9	31,07	86,07	55	0,0000	0,0000	0,0000
6, 7, 8, 9 and 10	44,67	92,65	47,98	0,0000	0,0000	0,0000
6 compartments flooded						
1, 2, 3, 4, 5 and 6	0	55,87	55,87	0,0000	0,0000	0,0000
2, 3, 4, 5, 6 and 7	8,29	64,08	55,79	0,0000	0,0000	0,0000
3, 4, 5, 6, 7 and 8	*15,11*	*75,87*	*60,76*	*0,0000*	*0,0000*	*0,0000*
				Al	Ap	As
				0,8447	0,7853	0,8300

Al, Ap and Ad ≥ 0,9 R

$$A = 0.4As + 0.4Ap + 0.2Al$$

A (0.815037) > R (0.680054)

Comparison of Results

Lloyd's Register	Passenger Yacht Code
R = 0,68	R = 0,68
A = 0,82163	A = 0,81054

Difference of 0,8 %

Conclusions

- It is possible and safe to use this approximation for a rough estimation of the indices A and R
- Deterministic approach still the most reliable, but can be reassessed when it becomes too onerous
- Probabilistic approach consideres a large number of damage cases and requires more work but it can result in a more flexible bulkhead arrangement
- PYC and probabilistic method have been well received giving more flexibility on general arrangement and lifesaving appliances which are of high importance in the yacht industry