Final Exam

Safety of Maritime Systems

Student information & declaration

Full Name: ______________________

Student ID / Matriculation Number: ______________________

Course of study: ______________________

Seat Number: ______________________

I hereby declare that I am physically and mentally capable of taking this examination and that I will complete it independently in accordance with the examination regulations.

Place, date: ______________________ Signature: ______________________

Exam facts

Date:	**12. February 2026, 11 a.m.**
Time limit:	**90 minutes**
Language:	**English**

Allowed resources:

- Provided calculator
- Formulas provided in the appendix

Instructions

- Use only the permitted resources listed above.
- All electronic devices (smartphones, smartwatches, ...) must be switched off and stored in your bag.
- Read all information and questions carefully.
- Complete all required information on this cover sheet and also sign the page. In case any of the requested information is missing, the exam is considered as failed.
- This is a closed book examination. All necessary data, including formulas can be found in the diagrams, tables and figures attached to this exam.
- Write your student ID on all answer pages and start each question on a new page.
- Write clearly and legibly; only readable answers will be graded.
- All answers, including diagrams and sketches must be in ink. Correcting fluid is not permitted. Do not use red ink.
- You may answer the questions in any order.

Marking scheme (LECTURER USE ONLY)

Percentage	0-50 %	50-55 %	55-60 %	60-65 %	65-70 %	70-75 %	75-80 %	80-85 %	85-90 %	90-95 %	95-100 %
Points	0-49.5	50.0-54.5	55.0-59.5	60.0-64.5	65.0-69.5	70.0-74.5	75.0-79.5	80.0-84.5	85.0-89.5	90.0-94.5	95.0-100
Mark	5.0	4.0	3.7	3.3	3.0	2.7	2.3	2.0	1.7	1.3	1.0
Grade	fail	pass	pass	satisfactory	satisfactory	satisfactory	good	good	good	very good	very good

Section	**Points max.**	**Points obt.**	**Remarks**
Multiple Choice	17		
Written Response	60		
Calculation	23		
Total	**100**		

Number of extra pages	**Final grade**	**Lecturer**

1 Multiple-Choice Section

*Each question in this section has only one correct answer, which must be marked with a cross (☒ or ☑). **No additional explanations** shall be given. A question will only be counted as correct if the correct answer—and no other answer—is marked. If you need to correct a previous selection, fill in the box of the incorrect answer completely (■) and then place a cross at the correct answer.*

1. What is the main error source for marine accidents? (1)
   - ☐ Technical errors
   - ☐ Human errors
   - ☐ Organizational errors

2. Which equilibrium type can be found for symmetric ships at $\varphi = 0$ (upright) if $GM \leq 0$? (1)
   - ☐ Stable equilibrium.
   - ☐ Unstable equilibrium.
   - ☐ Neutral equilibrium.
   - ☐ No equilibrium. Ship will capsize or float with angle of loll.

3. During the design of a long and slender pontoon, the main dimensions are iteratively set.
   (a) To save costs, a length reduction by 20 % is proposed. Which beam modification has to be applied to sustain the same stability level? (2)
   - ☐ $B/\sqrt[3]{0.8}$
   - ☐ $B/0.2^3$
   - ☐ $B \cdot \sqrt[3]{1.2}$
   - ☐ $B \cdot 1.2^3$

   (b) The alternative is to increase the length and to decrease the beam. What is more beneficial with respect to lightship weight? (1)
   - ☐ Reduce length and increase beam.
   - ☐ Reduce beam and increase length.
   - ☐ Since the pontoon is not in the building phase already, both result in the same weight.

4. Damage stability analyses according to SOLAS includes calculating the wind moment. Its lever arm is defined as the ... (1)
   - ☐ ... the distance between keel and vertical position of centra of lateral area above waterline.
   - ☐ ... the difference between z coordinate of buoyancy centroid and centre of lateral area above waterline.
   - ☐ ... distance between buoyancy centroid and air draught.
   - ☐ ... distance from half of the draught to the centre of lateral projected area above waterline.

5. A large metacentric height leads to... (1)
   - ☐ ... low roll accelerations.
   - ☐ ... high roll accelerations.
   - ☐ ... pure loss of stability.
   - ☐ ... parametric rolling.

6. A customer orders a filled swimming pool on deck of his vessel. What has to be considered? (1)
   - ☐ The high position lowers the values of the cross curves of stability.
   - ☐ The Free Surface Effect (FSE) results in a virtual $\overline{GM}$ increase.
   - ☐ The roll resonance period shifts to lower frequencies.
   - ☐ This acts as a passive anti-roll tank effectively limiting roll motions for high sea states.

7. The intact LCF of a merchant vessel is located exactly at $x_{LCF} = L_{PP}/2$. Water is flooding void spaces forward of the collision bulkhead. What is right? (1)
   - ☐ The vessel will float on even keel.
   - ☐ The absolute value of trim (in $[m]$) at the AP is higher.
   - ☐ The absolute value of trim (in $[m]$) is equal at FP and AP.
   - ☐ The absolute value of trim (in $[m]$) at FP is higher.

8. A vessel's hull is penetrated so that water enters an empty cargo hold. The water is to be considered as... (1)
   - ☐ ... solid mass with a centroid located at $z = 0$.
   - ☐ ... a free surface.
   - ☐ ... a reduction of the κ_v-value.
   - ☐ ... container cargo.

9. What is a typical consequence of a damage? (1)
   - ☐ Draught increases, $\overline{KB}$ decreases, ship starts to heel.
   - ☐ $\overline{KB}$ increases, $\overline{GM}$ increases, $\overline{KG}$ shifts laterally.
   - ☐ Draught increases, $\overline{KB}$ increases, $\overline{GM}$ decreases.
   - ☐ ∇ increases, $\overline{KB}$ increases, bulkheads are damaged.

10. What is true for the angle of downflooding? (1)
    - ☐ $\overline{GZ}$-curve reaches its maximum.
    - ☐ The ship heels $\varphi = 90°$, so that the side walls floods down to the water surface.
    - ☐ The critical heeling angle is reached, so that there is no restoring moment anymore.
    - ☐ Water enters through non-watertight openings.

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11. There are different regulations that have to be followed during ship design. Which authority is responsible for most of them? (1)
    - ☐ UNESCO
    - ☐ EU-ETS
    - ☐ IMO
    - ☐ WHO

12. Freeboard f is defined as ... (1)
    - ☐ ... the vertical distance from the waterline to the uppermost deck.
    - ☐ ... the amount of height left between side height and uppermost point at the bow.
    - ☐ ... the difference between height D and draught T.
    - ☐ ... the distance between freeboard deck and keel point K.

13. What type of loading is most critical regarding stability? (1)
    - ☐ Steel plates.
    - ☐ Grain.
    - ☐ Trucks.
    - ☐ Container.

14. What is regarded as the so-called angle of loll? (1)
    - ☐ Roll-amplitude in calm water.
    - ☐ Heeling angle due to negative $\overline{GM}$
    - ☐ Diving angle for submarines.
    - ☐ Specific value of over-loading (luggage over load limit).

15. High superstructures of ships ... (1)
    - ☐ ... raise G.
    - ☐ ... result in larger M.
    - ☐ ... lower B.
    - ☐ ... lower M.

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2 Written response section

In this part, questions are answered using freely formulated texts or annotation into the provided figures. Depending on the quality of the solution, partial points or full points are awarded. For all calculations use a gravitational constant of $g = 9.81 \frac{N}{kg}$ *if necessary.*

16. How is safety defined? (1)

17. Name an example of a humanitarian, a technical-organizational and an ecological measure to reduce the severity of accidents or their consequences. (3)

18. The damage stability analysis using currently valid regulations for most cargo ships requires the comparison specific ship specific indexes.

    (a) One of these indexes represents the safety level of the ship. How is it called and which index should naval architects compare it to? (2)

    (b) What can be said about the required safety level for the following two ships? (2)

    - Cargo ship, $L_{PP} = 95\,m$, 12 crew members on board.
    - A cruise ship, $L_{PP} = 125\,m$, 273 Pax on board.

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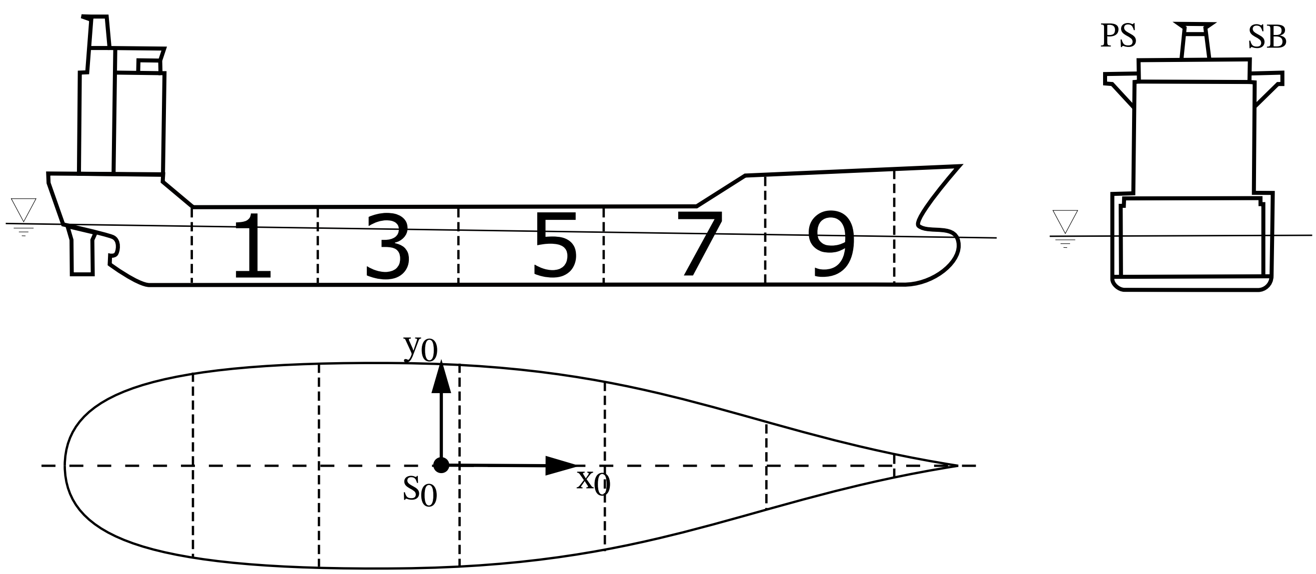
19. Name two examples how you as a hull designer can realize high GZ values at large heeling angles. (2)

20. Explain the conditions, where $\omega_e \approx 0$ occurs and, what it means regarding potential consequences for ship operation. (2)

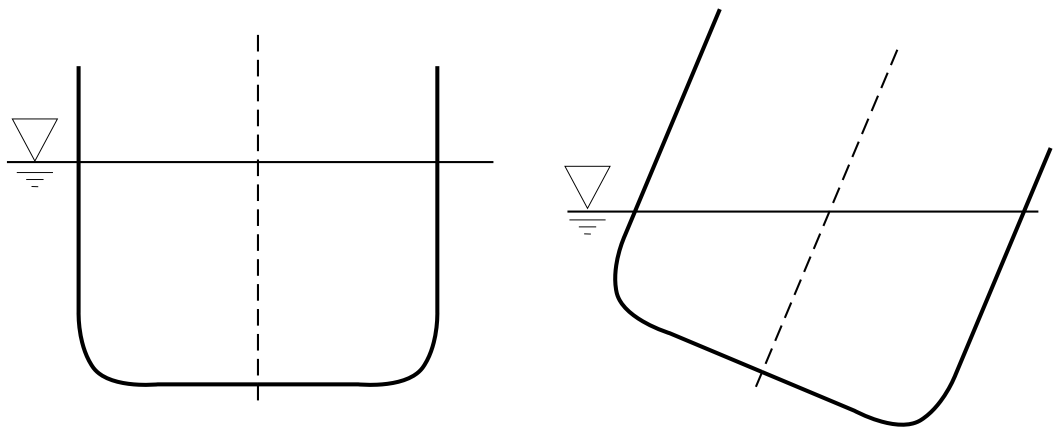
21. The ship shown in the following figure has six transversal bulkheads as well as one central longitudinal bulkhead (shown in dashed). Compartment 7 on the starboard side is flooded due to a side damage.



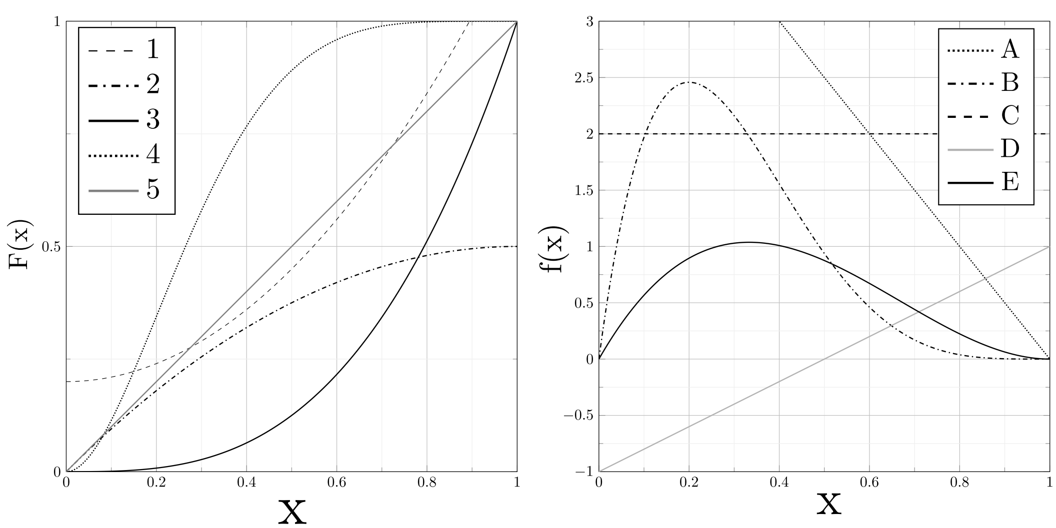
(a) In the side and front view (upper figures) sketch the resulting waterline. (2)

(b) In the top view (lower figure) shade the damaged compartment and sketch the position of the waterplane area's inertia axes after the damage. (3)

22. Below you find a sketch of a ship's main frame. Highlight the center of buoyancy, the center of gravity, the metacentric position as well as the keel point with the standard notation in both figures. For the right figure, add also the heeling lever $\overline{GZ}$ as well as $\overline{KN}$. (6)



23. Probabilistic damage stability consists of different probability distributions derived from real-world damages regarding different damage parameters. The figure beneath shows two plots similar to those used there. One of them contains possible PDF-functions, the other possible CDF functions. Complete the listed tasks.



(a) The PDF-plot contains only one valid PDF-function. The CDF-plot contains the correct function belonging to the valid PDF. Name the correct pair in the form e.g. F-8. (5)

Correct pair: ________

(b) Imagine that the correct functions shows the distributions of the damage length l related to the total ship length $L = 150\,m$. What is the median damage length l_{median}, where 50 % of the damages show smaller damage lengths? (2)

Expected result: $l_{median} =$ ____

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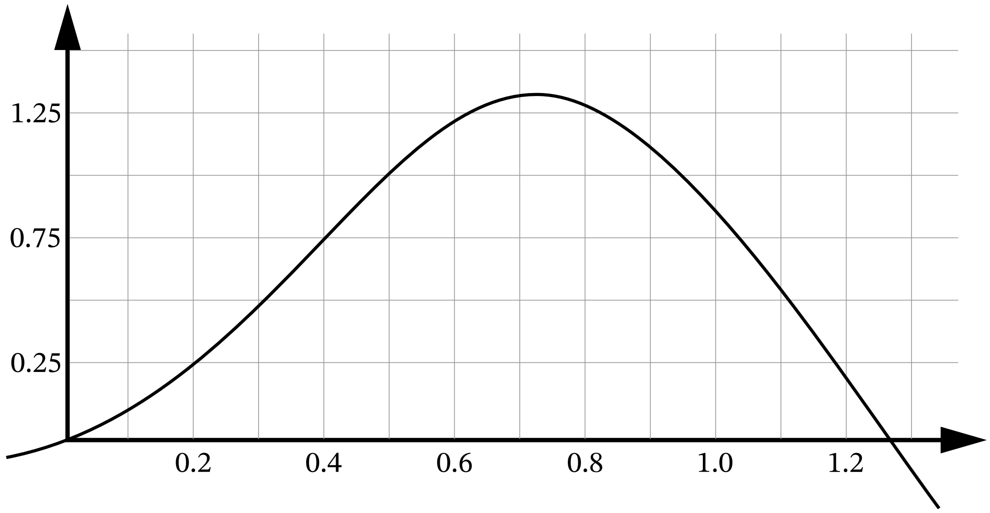
24. The shown plot presents the righting lever curve of a pontoon floating in sea water ($\rho = 1.025 \frac{t}{m^3}$ is displayed (main dimensions $L = 48\,m$, $B = 17\,m$, $D = 4\,m$, $T_0 = 2.7\,m$).



(a) Add axis descriptions to the plot (symbol and unit). (2)

(b) Mark the positions of the static and dynamic capsize angle φ_{static} and $\varphi_{dynamic}$. (2)

(c) Perform a graphical estimation of the pontoon's $\overline{GM_0}$. Subsequently read the value and enter it in the answer box. (2)

Expected result: $GM_0 =$ ____________________

(d) Draw the work needed to heel the pontoon from $\phi_1 \approx 22.9°$ to $\phi_2 \approx 28.6°$ into the diagram. Also calculate its value in $[kJ]$ and note it in the answer box. (6)

Expected result: $W =$ ____________________

(e) Qualitatively add two static heeling levers to the diagram. The first heeling lever k_1 should correspond to a stable equilibrium heeling angle of $\varphi = 11.45°$, while the heeling lever k_2 leads to a capsize. (2)

(f) Due to a different loading condition the $\overline{KG}$ of the ship is increased compared to the loading condition represented by the provided $\overline{GZ}$-curve. Draw a new $\overline{GZ}$-curve representing the same ship with a higher $\overline{KG}$. (2)

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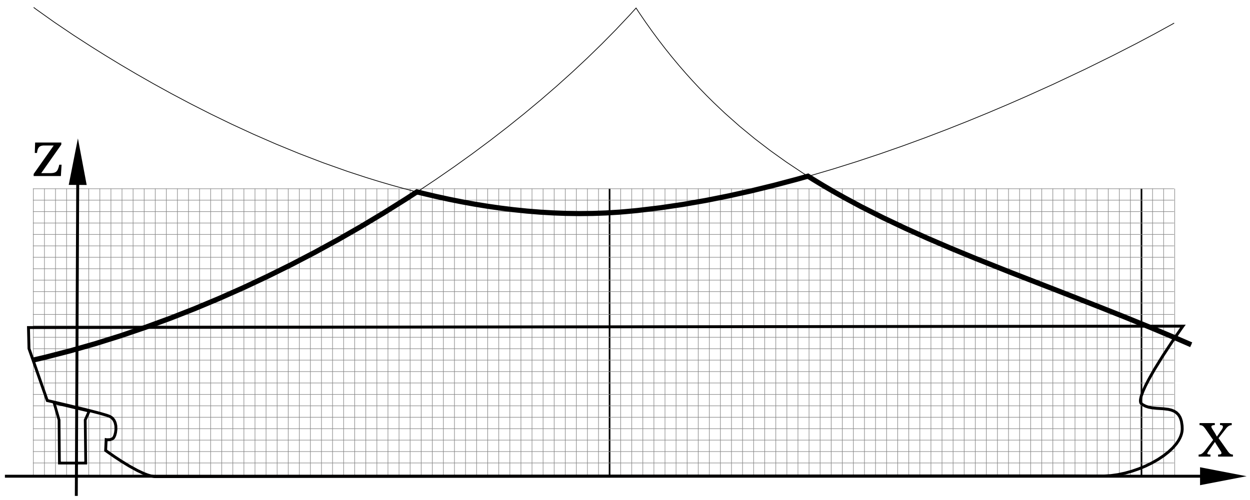
25. The subsequent figure shows a floodable length curve of a fast container ship (ship data $L_{PP} = 350\,m$, $B = 44\,m$, $c_B = 0.65$, $\kappa_v = 0.85$). The ship has two bulkheads both at the aft and forward perpendicular. Complete the listed tasks.



(a) Name the approach for damage stability analysis that is based on the floodable length curve and comment on the real-world applicability for the given ship type. (2)

(b) Provide a valid compartmentation using a maximum of eight additional transversal bulkheads. Use solid lines ranging from keel to deck for that and place them only on grid lines. The aft ship should have a one-compartment status, the fore ship a two compartment status. Fore and aft ship are divided by a bold grid line. (5)

(c) Add a dashed curve representing the minimum stability criterion for a typical tanker hull. (1)

(d) Due to a different loading condition a new value of $\kappa_v = 0.6$ is valid for all compartments. Use a solid line to show the floodable length curve for the changed condition (one single curve for all criteria). (2)

(e) Explain how the new floodable length curve influences the compartmentation. (2)

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3 Calculation Tasks

This section tests the application of knowledge through problem-solving. The quantities expected to be calculated have to be written down to the corresponding boxes below each task. The final answers must be given here, full marks can only be achieved if these are correct. However, partial marks may be awarded if a comprehensible calculation method is provided. For all calculations use a gravitational constant of $g = 9.81\frac{N}{kg}$ *if necessary.*

26. The characteristics of a sea state at a specified sailing area can be described using Pierson-Moskowitz sea spectra. The distribution of the individual wave heights can be assumed to follow a Rayleigh distribution. Complete the following task for a sea state with a significant wave height of $H_{1/3} = 4.39\,m$ and the ship main dimensions given in table 1.

    (a) Identify the spectral peak frequency ω of the sea state following the above mentioned assumptions. Explain what has to be considered during ship design regarding this frequency. (2)

    Expected Result: $\omega =$ ____________________

    (b) Derive all ship speeds in knots that are in theory dangerous for a ship sailing at following seas in a region with the presented sea conditions. Take into account at least the failure modes pure loss of stability and parametric rolling. (8)

    Expected Result: $v_{crit}\,[kn] =$ ____________________

    (c) Discuss which of the calculated ship speeds are dangerous in practice and provide reasons. (1)

    (d) Assess the extent to which the sea conditions can be classified as dangerous. (1)

Table 1: Main particulars of a fast container ship.

$L_{PP}\,[m]$	$B\,[m]$	$T_0\,[m]$	$LCF\,[m]$	$GM\,[m]$
175	28.75	11.8	92.7	0.54

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27. A merchant vessel ($L = 270\,m; B = 46\,m$) is damaged due to a collision. Both the outer hull plating and also the double bottom is penetrated and the ship does not have any longitudinal bulkhead. Complete the following tasks with the help of table 2.

   (a) The damage location is $\frac{x}{L} \approx 0.5$. Explain if this location is academic or if it would be also likely to happen in reality. (1)

   ____

   ____

   (b) Calculate the displacement Δ_{HR} and displaced volume ∇_{HR} of water flooding the damaged compartment. For this, a cuboid geometry of the $23.5\,m$ long compartment and $\kappa_v = 1$ shall be assumed. The compartment extends to the full ship beam at the whole compartment length, while the waterplane area after the damage in intact floating position (draught T_0) is $A_{WR} = 8707.4\,m^2$. (4)

   Expected Results:

   $\nabla_{HR} =$ ____

   $\Delta_{HR} =$ ____

   (c) Calculate the loss of stability ΔGM. Use the method of lost buoyancy. (8)

   Expected Result: $\Delta GM =$ ____

Table 2: Hydrostatic table for a 270 m long cargo vessel.

$T[m]$	$LCF[m]$	$KB[m]$	$\nabla[m]$	$\Delta[m]$	$LCB[m]$	$KM[m]$	$c_B[1]$	$A_W[m^2]$
3.0	141.435	1.581	20863.91	21489.83	140.51	31.87	0.560	7803.9
4.5	142.527	2.376	32902.54	33889.61	141.05	22.98	0.589	8205.3
6.0	143.565	3.168	45411.64	46773.99	141.63	18.44	0.609	8452.8
7.5	144.498	3.957	58242.04	59989.30	142.17	15.98	0.625	8647.4
9.0	144.867	4.746	71357.29	73498.01	142.64	14.55	0.638	8826.1
10.5	144.594	5.535	84737.48	87279.60	142.97	13.74	0.649	9007.9
12.0	143.696	6.330	98398.13	101350.1	143.14	13.31	0.660	9206.6
13.5	142.392	7.130	112384.8	115756.3	143.13	13.14	0.670	9450.0
15.0	140.592	7.938	126791.6	130595.4	142.97	13.16	0.681	9788.4
16.5	137.381	8.768	141836.7	146091.8	142.53	13.32	0.692	10258.9
18.0	135.120	9.614	157537.6	162263.7	141.90	13.60	0.705	10679.4
19.5	133.898	10.47	173803.1	179017.1	141.22	13.94	0.718	11025.9
21.0	133.365	11.33	190527.5	196243.4	140.57	14.29	0.730	11309.4
22.5	133.395	12.19	207644.9	213874.2	139.99	14.65	0.743	11541.8
24.0	133.589	12.70	218070.2	224612.3	139.70	14.86	0.732	11660.2

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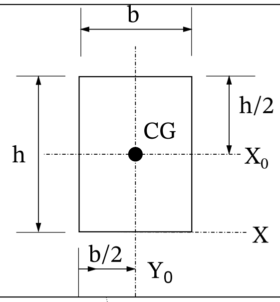
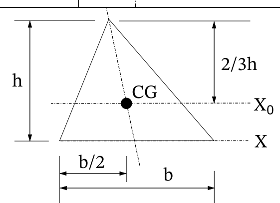
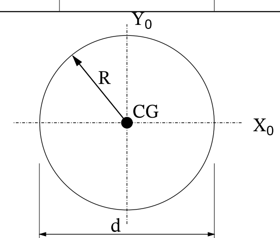
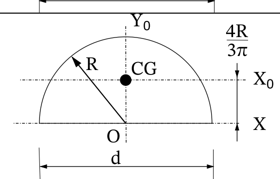
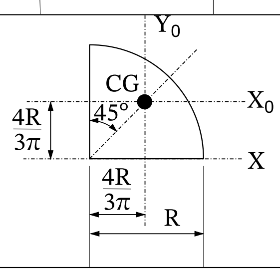
Appendix

A Useful Formulas

A.1 Inertia moments

Shape	Sketch	Area	Moment of Inertia
Rectangle		$A = b \cdot h$	$I_{X0} = \frac{b \cdot h^3}{12}$ $I_{Y0} = \frac{b^3 \cdot h}{12}$ $I_X = \frac{b \cdot h^3}{3}$
Triangle		$A = \frac{b \cdot h}{2}$	$I_{X0} = \frac{b \cdot h^3}{36}$ $I_X = \frac{b \cdot h^3}{12}$
Circle		$A = \frac{\pi \cdot d^2}{4}$	$I_{X0} = I_{Y0} = \frac{\pi \cdot d^4}{64}$
Semicircle		$A = \frac{\pi \cdot R^2}{2}$	$I_{X0} = 0.1098\, R^4$ $I_{Y0} = I_X = \frac{\pi \cdot R^4}{8}$
Quarter-Circle		$A = \frac{\pi \cdot R^2}{4}$	$I_{X0} = I_{Y0} = 0.0549\, R^4$ $I_X = \frac{\pi \cdot R^4}{16}$

A.2 Rotational Work

$W[J] = M \cdot \alpha$, with $M\,[Nm]$ being the moment and $\alpha\,[rad]$ the rotational angle.

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A.3 Intact ships in waves

Encountering frequency: $\omega_e = \frac{2\cdot\pi}{\lambda} \cdot (c - v \cdot cos(\mu))$
Roll eigen frequency: $\omega_\varphi \approx \sqrt{\frac{g\cdot\overline{GM}}{k'^2}}$
Roll radius of gyration: $k' \approx 0.4 \cdot B$

A.4 Regular waves

Wave length: $\lambda = \frac{2\pi g}{\omega^2} = \frac{g\cdot T^2}{2\pi}$
Wave period: $T = \frac{2\pi}{\omega} = \sqrt{\frac{2\pi\lambda}{g}}$
Wave number: $k = \frac{2\pi}{\lambda} = \frac{\omega^2}{g}$
Phase speed: $c = \frac{\lambda}{T} = \frac{\lambda\omega}{2\pi} = \frac{g}{\omega} = \frac{\omega}{k} = \sqrt{\frac{g}{k}} = \sqrt{\frac{g\lambda}{2\pi}}$

A.5 Sea spectra

Pierson-Moskowitz-Spectrum (defined by wind velocity): $S_{PM}(\omega) = \frac{\alpha\cdot g^2}{\omega^5} \cdot e^{-\beta\cdot\left(\frac{g}{U_{19.5}\cdot\omega}\right)^4}$
$\Rightarrow$ with standard coefficients $\alpha = 0.0081$ and $\beta = 0.74$.

Pierson-Moskowitz-Spectrum (defined by significant wave height): $S_{PM}(\omega) = \frac{a}{\omega^4} \cdot e^{\left(-\frac{b}{H_{1/3}^2\cdot\omega^4}\right)}$
$\Rightarrow$ with $a = 0.078\frac{m^2}{s^4}$ and $b = 3.136\frac{m^2}{s^4}$.
$\Rightarrow$ Peak location: $\omega_p = \frac{1.258\frac{\sqrt{m}}{s}}{\sqrt{H_{1/3}}}$

Others

Speed conversion: $1\,kn \approx 0.5144\frac{m}{s}$

B SOLAS Chapter II-1, Part B-1, Regulation 6

Required subdivision index R

1. The subdivision of a ship is considered sufficient if the attained subdivision index A, determined in accordance with regulation 7, is not less than the required subdivision index R calculated in accordance with this regulation and if, in addition, the partial indices A_s , A_p and A_l are not less than $0.9R$ for passenger ships and $0.5R$ for cargo ships.

2. For ships to which the damage stability requirements of this part apply, the degree of subdivision to be provided shall be determined by the required subdivision index R, as follows:

   (a) In the case of cargo ships greater than 100 m in length (L_s): $R = \frac{128}{L_S+152}$

   (b) In the case of cargo ships not less than 80 m in length (L) and not greater than 100 m in length (L_s):
   $R = 1 - \left[1/\left(1 + \frac{L_s}{100} \cdot \frac{R_o}{1-R_o}\right)\right]$
   where R_o is the value R as calculated in accordance with the formula in subparagraph (a).

   (c) In the case of passenger ships:

Persons on Board	R
$N < 400$	$R = 0.722$
$400 \leq N \leq 1350$	$R = N/7580 + 0.66923$
$1350 < N \leq 6000$	$R = 0.0369 \cdot Ln(N + 89.048) + 0.579$
$N > 6000$	$R = 1 – (852.5 + 0.03875 \cdot N)/(N + 5000)$

   Where:
   N = total number of persons on board

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