Exercises on Offshore Hydrostatics

(Lecture Code OT4620)

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In this "quiz book", a number of exercises on hydromechanical problems in offshore activities are given. As far as possible, they are given here in the same order as the underlying theory has been treated in the textbook of the lecture OT4620:

Offshore Hydromechanics
(First Edition)
by
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1. Miscellaneous on Static Loads

One has a large open tank with three 100 mm diameter drain holes in its bottom. There is atmospheric pressure all around the tank. Before the tank is filled with water ($\rho = 1000$ kg/m^3) each hole is closed off in a different way:

A vertical steel pipe - just as long as the height of the tank sides - is used to close off one hole. The pipe has a diameter of 200 mm with a seal along its lower edge. The pipe weighs 600 N.

The second opening is closed off by a steel ($\rho = 7850$ kg/m^3) disk, 200 mm in diameter, with a seal along its perimeter. The plate weighs 70 N and has a nylon cord leading to the water surface.

The third opening has a plywood ($\rho = 750$ kg/m^3) cover which weighs 7 N. It is otherwise identical to the steel cover.

Questions:

a) With the pipe and the two covers in place, can the tank be filled?

b) Assuming that the tank has been filled to a depth of 5 m, which of the three drains will be easiest to open? Explain also why!

2. Miscellaneous on Static Floating Stability

Questions:

a) What is the relation between a ship's mass and its volume of displacement.

b) Give a definition (in words) of:
- the center of gravity of a structure, G,
- the center of buoyancy of a structure, B,
- the initial metacenter, M, and
- the metacenter, N_ϕ.

c) Prove for a rectangular pontoon that:

$$\overline{BM} = \frac{I_T}{\nabla} \qquad \text{and} \qquad \overline{BN_\phi} = \frac{I_T}{\nabla} \cdot \left(1 + \frac{1}{2}\tan^2\phi\right)$$

What is the generally used name of the second expression?

d) Explain why $B = M = N_\phi$ for a fully submerged structure such as a submarine.

e) Show that for a rectangular barge - with length L, breadth B and uniform draft T - one can write:

$$\overline{BM} = \frac{B^2}{12 \cdot T}$$

f) Prove that for a wall-sided ship, the vertical separation of B_ϕ and G at angle of heel ϕ is given by:

$$\overline{B_\phi Z} = \left(\overline{BG} + \frac{1}{2}\overline{BM} \cdot \tan^2\phi\right) \cdot \cos\phi$$

where $\overline{BG}$ and $\overline{BM}$ relate to the upright condition.
Show that - when this ship has a free fluid surface in a wall-sided tank - the previous expression becomes:

$$\overline{B_\phi G} = \left(\overline{BG_S} + \frac{1}{2}\left(\overline{BM} - \overline{G_S G_F}\right) \cdot \tan^2\phi\right) \cdot \cos\phi$$

where the subscripts $_S$ and $_F$ relate to the solid and fluid centers of gravity.

g) Show that the dynamical stability of a wall-sided vessel up to an angle ϕ is given by the expression:

$$P_\phi = \left(\overline{BG} \cdot (\cos\phi - 1) + \frac{1}{2}\overline{BM} \cdot \tan\phi \cdot \sin\phi\right) \cdot \rho g \nabla$$

h) A wall-sided vessel with a negative $\overline{GM}$ lolls to an angle ϕ_0. Express this angle ϕ in terms of $\overline{GM}$ and $\overline{BM}$.

i) A laden rectangular barge with a breadth of 6.00 m has a metacentric height of $\overline{GM} = -0.20$ m when floating at a uniform draft of 3.00 m. Calculate the angle of loll ϕ_0.

j) A small mass is added to a wall-sided ship on the center line at such a position as to leave trim unchanged. Show that the metacentric height is reduced if the mass is added at a height above keel greater than $T - \overline{GM}$, where T is the draft.

k) A rectangular homogeneous block (30 m long, 7 m wide and 3 m deep) is half as dense as the water in which it is floating. Calculate the metacentric height, $\overline{GM}$, and the stability lever arm, $\overline{GZ}$, at 15 degrees and 30 degrees heel.

l) In one way or another, you are involved in the design process of converting an existing ship with a length of about 200 meters into a stone-dumping vessel. You have been informed that the location of the center of buoyancy, B, at the fully laden draft and zero trim has been determined (via hydrostatic calculations) at 3.25 meters in front of the amidships section. However, accurate mass calculations show you that the center of gravity, G, of the ship in this loading condition will have a distance of about 4.75 meters in front of the amidships section.
What will be your comment on this information?

m) One has a glass tube nearly filled with water and closed at each end.
We have also an hourglass (in Dutch: "zandloper") floating in the water in the tube. The hourglass has a maximum diameter a bit less than the internal diameter of the tube. The total weight of the hourglass (including the sand in it) is only slightly less the weight of the same total volume of water - it just barely floats.
If we abruptly invert the glass tube then:
- the air bubble comes to the top immediately,
- the hourglass remains at the bottom, and
- the sand moves slowly from the upper hourglass chamber to the lower one.
Some time later, the hourglass slowly rises to the top of the tube.
Explain why it initially stays at the bottom!

Solutions:

a) -

b) -

c) -

d) -

e) -

f) -

g) -

h) $\phi = \pm \arctan\left(\sqrt{\frac{2|\overline{GM}|}{\overline{BM}}}\right)$

i) $\phi = 32.3$ degrees.

j)

k) $\overline{GM} = 1.972$ m, $\overline{GZ}_{(15)} = 0.536$ m and $\overline{GZ}_{(30)} = 1.047$ m.

l) -

m) -

3. Float-On Float-Off Pontoon

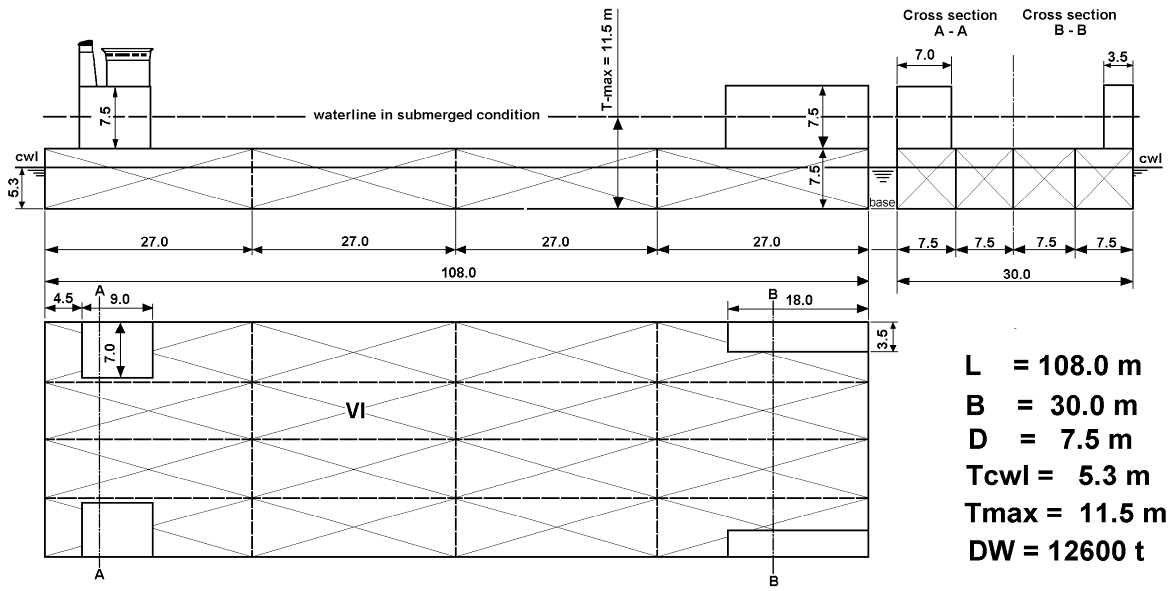

Figure 0.1: Float-On Float-Off Pontoon

In a harbor with fresh water ($\rho = 1.000$ ton/m^3) an empty rectangular Float-On Float-Off Pontoon, as given in figure 0.1 has an amidships draft of 1.55 meter in an upright even keel condition. A rough inclining experiment has been carried out, by fully filling a port side tank aft (tank VI), which is bounded by half the length of the pontoon and the longitudinal middle line plane of the pontoon, with fresh water ($\rho_{wb} = 1.000$ ton/m^3). The measured angle of heel ϕ_1 was 1.46 degrees. In the calculations, the volumes of plating, frames and other structure parts may be ignored.

a) Determine the position of the centre of gravity G_0 and the initial metacentric height $\overline{G_0M_0}$ of the empty pontoon.

b) Determine the trim angle θ_1 during the inclination experiment.

c) Determine the drafts at the four corners of the pontoon during the inclination experiment.

d) Determine the angle of heel ϕ_2 in case of an 80 per cent filled tank, during the inclination experiment.

During operation, the pontoon will be sunk down in a protected bay by loading ballast seawater ($\rho = \rho_{wb} = 1.025$ ton/m^3) in all 16 tanks. This ballast water is supposed to have an equal height h in all 16 tanks.

e) Determine the initial metacentric height $\overline{GM}$ at an even keel draft of 7.50 meter, supposing that water will just not cover the deck.

f) Determine the $\overline{GM}$-value at an even keel draft of 7.50 meter, supposing that water had just covered the deck.

g) Determine the $\overline{GM}$-value, when the pontoon has been sunk down until an even keel draft of 11.50 meter.

Now, the pontoon picks up a drill-rig, with the following specifications:
- upright even keel condition
- mass = 4920 ton
- $\overline{KG}$ = 20.00 meter
- water plane dimensions: 40 x 40 meter
- no free surfaces of liquids in any tank

h) Determine the initial metacentric height of the rig.

i) Determine the initial metacentric height of pontoon+rig, supposing that they just hit each other when de-ballasting the pontoon during loading of the rig (centre of rig above centre of pontoon).

j) Determine the initial metacentric height of pontoon+rig when all water ballast has been removed from the pontoon.

k) Determine the angle of heel when, due to an inaccurate loading of the pontoon, the centre of the rig is amidships but 1.0 meter outside the middle line plane of the pontoon.

Solutions:

a) G_0: amidships at middle line plane with $\overline{KG_0} = 4.02$ m and $\overline{G_0M_0} = 45.15$ m.

b) $\theta_1 = 0.38^0$

c) $T_{1i} = 1.28$, 2.00, 2.04 and 2.76 m, respectively.

d) $\phi_2 = 1.16^0$.

e) $\overline{GM} = 9.93$ m.

f) $\overline{GM} = 1.55$ m.

g) $\overline{GM} = 1.62$ m.

h) $\overline{GM} = 25.94$ m.

i) $\overline{GM} = 5.51$ m.

j) $\overline{GM} = 10.86$ m.

k) $\phi = 2.61^0$.

4. Metacentric Height

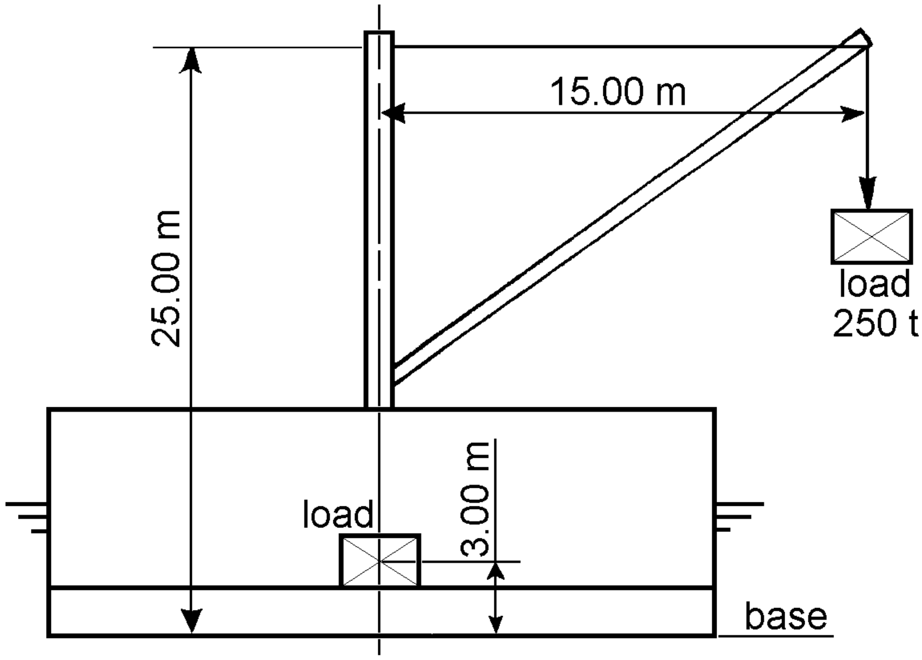

Figure 0.2: Unloading a Ship

A laden wall-sided ship with its own derrick on board, as given in figure 0.2, is floating without heel at an even keel condition in fresh water ($\rho = 1.000$ ton/m^3) with a volume of displacement ∇ of 12000 m^3. The load, which is a mass p of 250 ton, is placed in one of the holds on the tank top of the double bottom. The centre of gravity of this mass lies in the middle line plane, 3.00 meter above the base plane of the ship. The suspension point of the cargo in the derrick lies 25.00 meter above the base plane of the ship. When the derrick is turned outboard fully, this suspension point lies 15.00 meter from the middle line plane of the ship.
As soon as the mass has been hoisted from the tank top of the double bottom, the ship heels 2.0 degrees. After hoisting the mass further and turning it outboard fully, the angle of heel becomes 17.0 degrees.

Determine the initial metacentric height $\overline{G_0M}$ of the ship, before the unloading operations. The influence of the mass of the turning derrick may be ignored.

Solution: $\overline{G_0M} = 0.44$ m.

5. Unloading a Pontoon

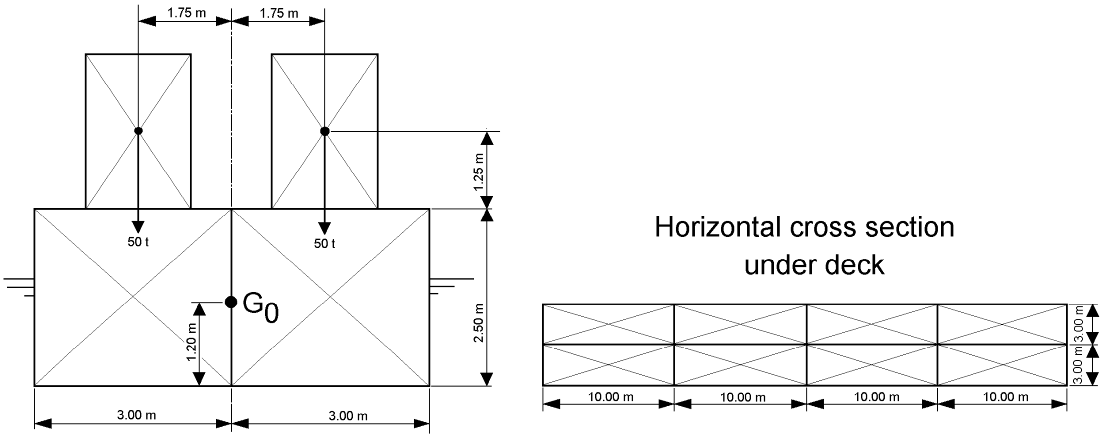

Figure 0.3: Unloading a Pontoon

An empty rectangular pontoon, subdivided in 8 watertight compartments of equal dimensions, has the following principal dimensions:

– length $L = 40.00$ meter
– breadth $B = 6.00$ meter
– depth $D = 2.50$ meter
– mass $\Delta_0 = 200$ ton

The pontoon is floating at an even keel condition in fresh water ($\rho = 1.000$ ton/m^3). The vertical position of the centre of gravity above the base plane $\overline{KG_0}$ is 1.20 meter. The pontoon is laden with two masses of $p = 50$ ton each, of which the centres of gravity are positioned at half the length of the pontoon, $y_p = 1.75$ meter from the middle line plane of the pontoon and $z_p = 1.25$ meter above the deck of the pontoon, see figure 0.3.

a) Determine the initial metacentric height of pontoon+masses.

b) Determine the angle of heel of the pontoon after unloading one of the masses. It may not be assumed that this angle is small.

c) To obtain an upright position again, two tanks will be equally filled with water ballast ($\rho_{wb} = 1.000$ ton/m^3). Determine the mass of the water ballast and the reduced initial metacentric height.

Solutions:

a) $\overline{GM} = 0.975$ m.

b) $\phi = 11.3^0$.

c) $\Delta_{wb} = 58.33$ ton and $\overline{G'M} = 1.35$ m.

6. Lift Operation by a Pontoon

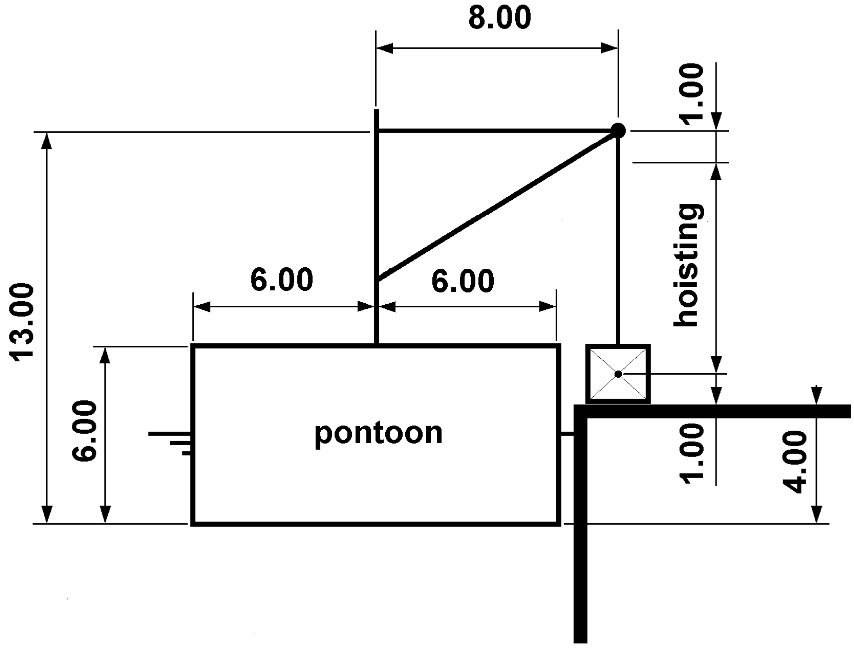

Figure 0.4: Lift Operation by a Pontoon

A rectangular pontoon has the following principal dimensions:
- length $L = 60.00$ meter
- breadth $B = 12.00$ meter
- depth $D = 6.00$ meter

One of the double bottom tanks is partly filled with fuel with a density $\rho_f = 0.900$ ton/m^3. The length of this tank l_f is 20.00 meter and the breadth b_f is 6.00 meter. The pontoon is floating at an even keel condition with a draft $T_0 = 2.50$ meter in fresh water ($\rho = 1.000$ ton/m^3). The vertical position of the centre of gravity of the pontoon, including fuel, above the base plane $\overline{KG_0}$ is 4.00 meter. A sketch of the pontoon in this situation is given in figure 0.4.
Then, a mass of $p = 100$ ton will be hoisted from the quay. When the derrick is turned outboard fully, the suspension point of the cargo in the derrick lies 13.00 meter above the base plane and 8.00 meter from the middle line plane of the pontoon.

Determine the maximum angle of heel of the pontoon during hoisting this load. The influence of the mass of the turning derrick may be ignored.

Solution: $\phi = 16.5^0$.

7. Deckload on a Drill Platform

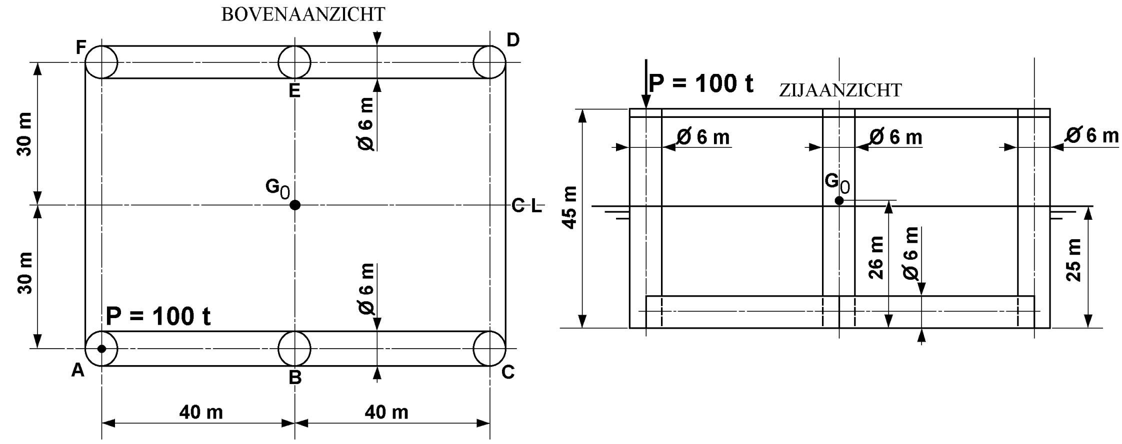

Figure 0.5: Loading a Drill Platform

A floating drill platform, as given in figure 0.5 consists of 2 sets of 3 vertical cylindrical columns with a diameter of 6.00 meters. The 3 columns of each set are connected to each other at the bottom by a horizontal cylinder with a diameter of 6.00 meters. The platform has a draft of 25.00 meters in an upright even keel condition in seawater ($\rho = 1.025$ ton/m^3). The centre of gravity G_0 is situated at 26.00 meters above the base plane. A load with a mass p of 100 ton will be placed at deck above column A.

a) Determine the drafts at the columns A, C, D and F.

To avoid heel and trim, the columns C and E will be partially filled with ballast water.

b) Determine the required amount of ballast water.

c) Determine the resulting draft of the platform.

d) Determine the initial metacentric height, including the free surface correction.

Note: The moment of inertia (second moment of areas) of a circular area with a radius R is $I_T = \pi/4 \cdot R^4$.

Solutions:

a) $T_A = 38.10$ m, $T_C = 29.18$ m, $T_D = 13.05$ m and $T_F = 21.97$ m.

b) $h_C = 3.45$ m and $h_E = 6.90$ m.

c) $T = 27.30$ m.

d) $\overline{G'M} = 1.44$ m.

8. Loading a Semi-Submersible

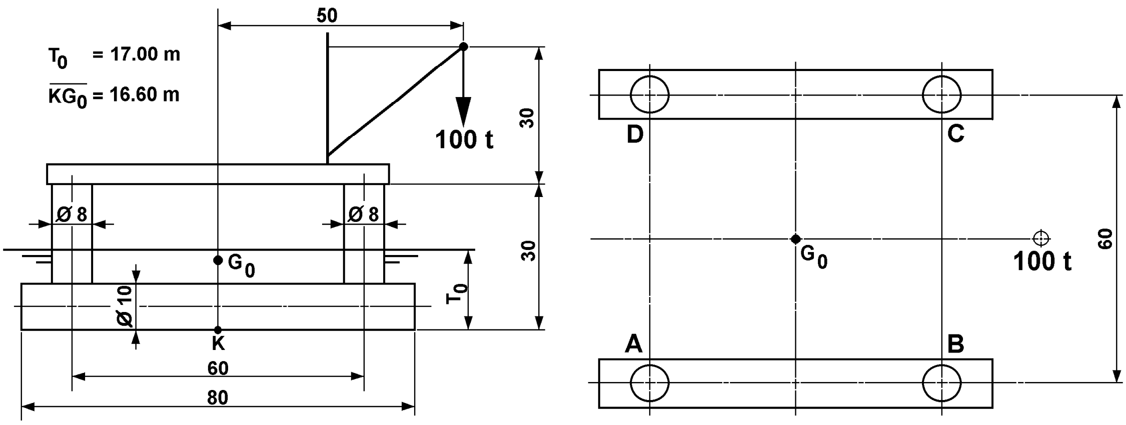

Figure 0.6: Loading a Semi-Submersible

A floating structure, as given in figure 0.6 consists of 2 sets of 2 vertical cylindrical columns with a diameter of 8.00 meters. The 2 columns of each set are connected to each other at the bottom by a horizontal cylinder with a diameter of 10.00 meters. The structure has a draft of 17.00 meters at an upright even keel condition in fresh water ($\rho = 1.000$ ton/m^3). The centre of gravity G is situated at 16.60 meters above the base plane of the structure. With a crane on the floating structure, a mass p of 100 ton will be laden from a supply ship. The top of the crane (suspension point) is in the middle line plane of the structure, 50.00 meters forward of half the length of the structure and 60.00 meters above the base plane of the structure.

Determine the drafts at the four columns A, B, C and D during hoisting the load. It may **not** be assumed that the angle of inclination is small.

Solutions: $T_A = T_D = 12.48$ m and $T_B = T_C = 22.52$ m.

9. Loading a Drill Platform

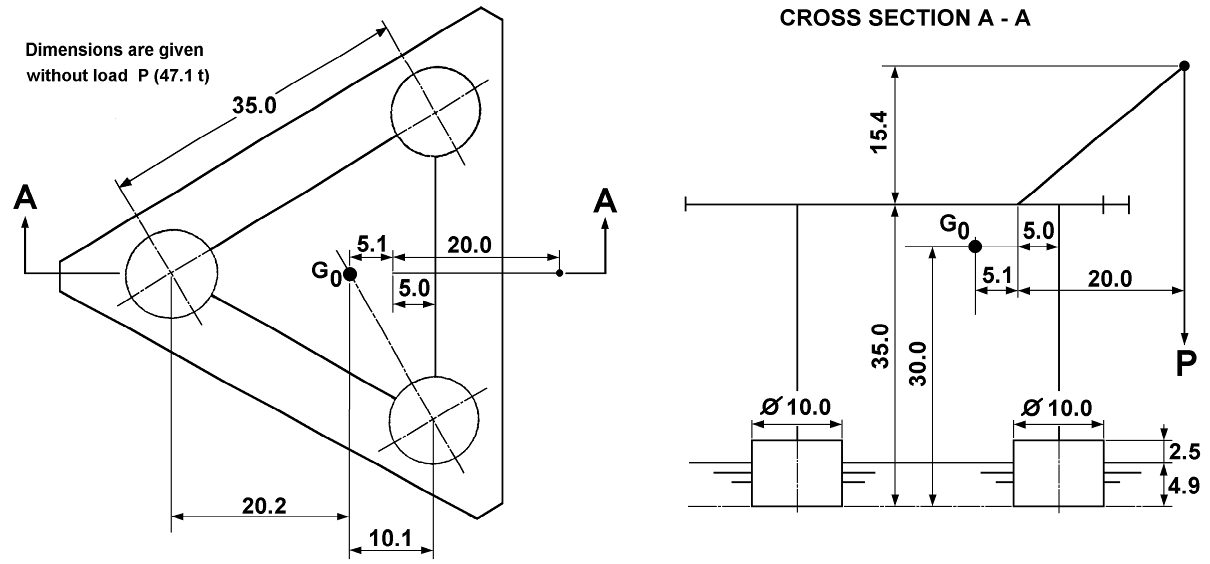

Figure 0.7: Loading a Drill Platform

A floating structure with three cylindrical floaters has a draft of 4.90 meters at an upright even keel condition in fresh water ($\rho = 1.000$ ton/m^3). Figure 0.7 shows the dimensions and details of the structure, just before a loading operation.
With a crane on the floating structure, a mass p of 47.10 ton will be laden from a supply ship. The position of the top of the crane (suspension point) is given in figure 0.7.

a) Determine the angle of inclination during hoisting the load.

b) Determine the drafts at the centres of the floaters A, B and C.

To avoid a heeling angle, ballast water has been pumped in floater A.

c) Determine the height of the ballast water in floater A.

d) Determine the reduced initial metacentric height in this condition.

Note: The moment of inertia (second moment of areas) of a circular area with a radius R is $I_T = \pi/4 \cdot R^4$.

Solutions:

a) $\phi = 4.33^0$.

b) $T_A = 3.56$ m, $T_B = 5.87$ m and $T_C = 5.87$ m.

c) $h_A = 0.75$ m.

d) $\overline{G'M} = 12.21$ m.

10. Buckling of a Drill String

Questions:

a) Explain why a drill string in a deep oil well filled with mud will buckle, even though the entire string is under tension when hanging in air.

b) What is the effect (on buckling) of adding an additional downward force on the top of the drill string?