



Question 1 Point 2

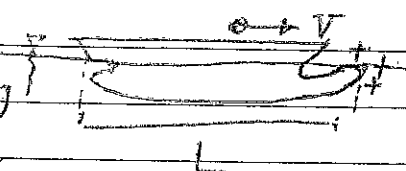
Based on Kelvin theory when high pressure point moving at speed $\vec{V}$ on water surface, it will generate waves. This wave formation is directly related to velocity. For a ship with specified length L and velocity $\vec{V}$ this wave formation is expressed by Froude number. The Froude number is defined as the ratio of inertia forces to gravity forces and expressed as: $Fr = \frac{V}{\sqrt{gL}}$ when the ship velocity is ~~large~~ ^{changing} with respect to its dimension and displacement, different scenarios and regimes of wave making might ~~have~~ happen for that ship. There are subcritical ($Fr < 1$), critical ($Fr = 1$), and

700



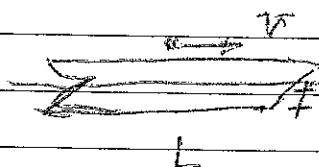
supercritical ($Fr > 1$) zones and regions that affect the wave making patterns of moving ship. This strongly influence the wave making resistance of moving bodies in water. For displacement ship this design speed (economical speed) is ^{engineered} ~~designed~~ to have froude number below 1 to reduce the resistance and fuel consumption. Another design trick for these kinds of vessel is to equip them with bulbous bow that delays the wave creation on forward side of ~~the~~ displacement ship.

Reduced
wave-making
resistance



ship with
bulbous bow

Increased
wave making
resistance.



ship without
bulbous bow

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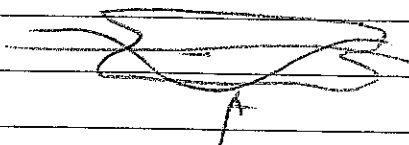
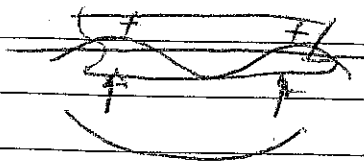
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another



DEAR



Question 2: Point 5.

For moored floating structures exposed to waves, there are first-order wave loads, ~~diffraction effects~~ and second-order wave loads.

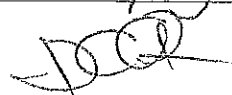
The first order wave loads include Froude-Krylov forces and diffraction loads.

The second order wave loads include mean drift forces, slow varying drift forces, and high frequency loads. The Froude-Krylov force is the pressure induced force caused by water waves (gravity waves) and calculated by integration of pressure over mean wetted surface (or instantaneous wetted surface). The diffraction loads ~~of~~ that are important for large bodies in comparison to wave length calculated by integration of velocity

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gradient potential over submerged part of a floating body. (submerged wetted surface at operating draft. This is usually done by numerical method such as 3d radiation - diffraction boundary element panel method in various irregular wave frequencies, considering potential flow theory. The mean drift force is the drag induced force caused by wave velocity on mean wetted surface (or instantaneous wetted surface). The slow varying drift forces are caused by different frequency waves intercepting floating body and high frequency loads are caused by sum-frequency of waves intercepting floater. The first order wave loads cause wave frequency motions (roll, pitch, heave) with frequencies similar or very close to intercepting waves



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The Second order wave loads cause Low frequency motions (Surge, Sway, Yaw)

with ~~very~~ different frequency rather than upcoming waves. The floating bodies usually have restoring force for wave frequency motions such as roll, pitch, heave and after perturbations they can remain upright after ~~some~~ few seconds.

the restoring force comes from positive buoyancy.

~~for~~ The Floating bodies do not have any restoring force for low frequency motions and the floater is usually harnessed by mooring system. The mean drift force cause static offset in horizontal plane while slow-varying drift forces cause oscillatory motions due to intercepting waves with different frequencies. (in the same horizontal plane)

PCD

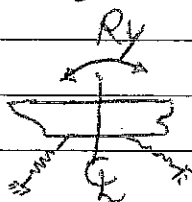


for floating body with 6-DoF motions and symmetric

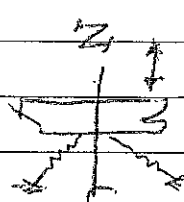
mooring: R_x



Roll

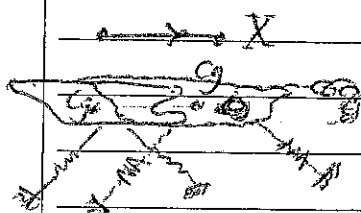


pitch

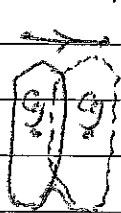


heave

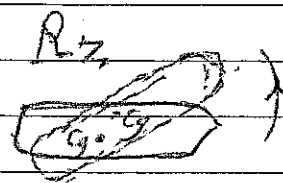
Wave-frequency motions



Surge



Sway



Yaw

The low frequency motions resulted from

second order wave loads causes platform excursions (offset) that creates extreme mooring loads.

Usually the optimum mooring design for

floating platform has symmetric stiffness and

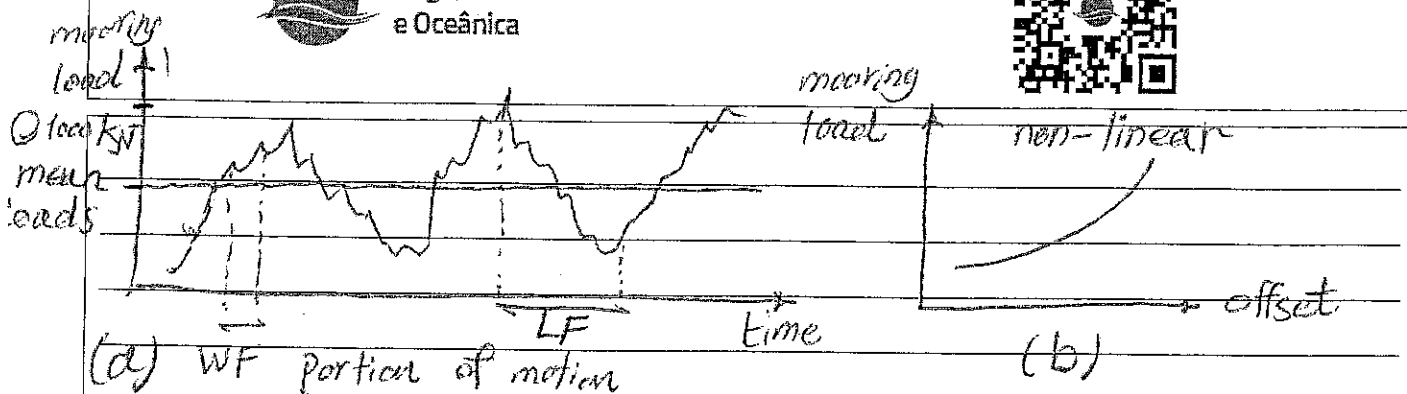
allows the platform to have 8-10% water depth

offset in all intact mooring lines and up to

15% of water depth offset in damage scenario in

extreme environmental condition of entire service life.

(50-year/return period ~~wave~~ extreme wave condition) ~~PCP~~



the stochastic environment such as random sea wave exerted will cause non-linear excitation forces on floating body and floating platform responds to this excitation loads through excursion displacement (offset). the relationship between platform offset and wave ~~from~~ loads as described earlier is very complex. the platform mooring system must compensate these low frequency motions, however, the relationship between mooring loads and platform offset as shown in figure (b) is completely non-linear and design limits for these slender structures ~~must~~ must be determined.

and operation limits for floating platform

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Based on established standards, the offshore industry ^{criteria and} necessitates the main design limits for floating structures.

The first one is ultimate limit state (ULS) that requires the structure (such as mooring line) to

withstand extreme loads due to extreme environmental ^{and as a result large offset excursions,}

conditions. It usually requires to consider a safety

factor based on material properties of structural

element (such as minimum breaking strength/loads) = MBL

$$\text{Safety factor} = \frac{\text{MBL (minimum breaking load)}}{(\text{maximum design load in extreme condition})}$$

the second criteria is accidental limit state that

require the integrity of operation while having damaged

scenario (1-line mooring line missing). the safety of operation

necessitates to have a margin and limit to compensate

for continuous operation while having damaged mooring systems

an example.

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this usually defined by a safety factor that is related to the material properties of mooring anchor structure. Considering MBL as minimum breaking strength of mooring line. The safety factor is defined as

$$S.F = \frac{\text{MBL (min. breaking strength)}}{\text{(maximum design loads in damaged scenario)}}$$

the third design criteria is fatigue limit state (FLS) that is mainly caused by slow varying drift forces for moored floating structure. the oscillating motions caused by 2-order wave loads create cyclic loadings for mooring structure ~~in ^{the} ~~case~~ ^{of} ~~cause~~ ^{of} ~~tension range~~~~ various tension ranges. these cyclic loadings then create fatigue damage that need to be calculated exactly and fatigue life of structure shall be determined. This accumulated fatigue damage is

For instance for mooring line

DOOR



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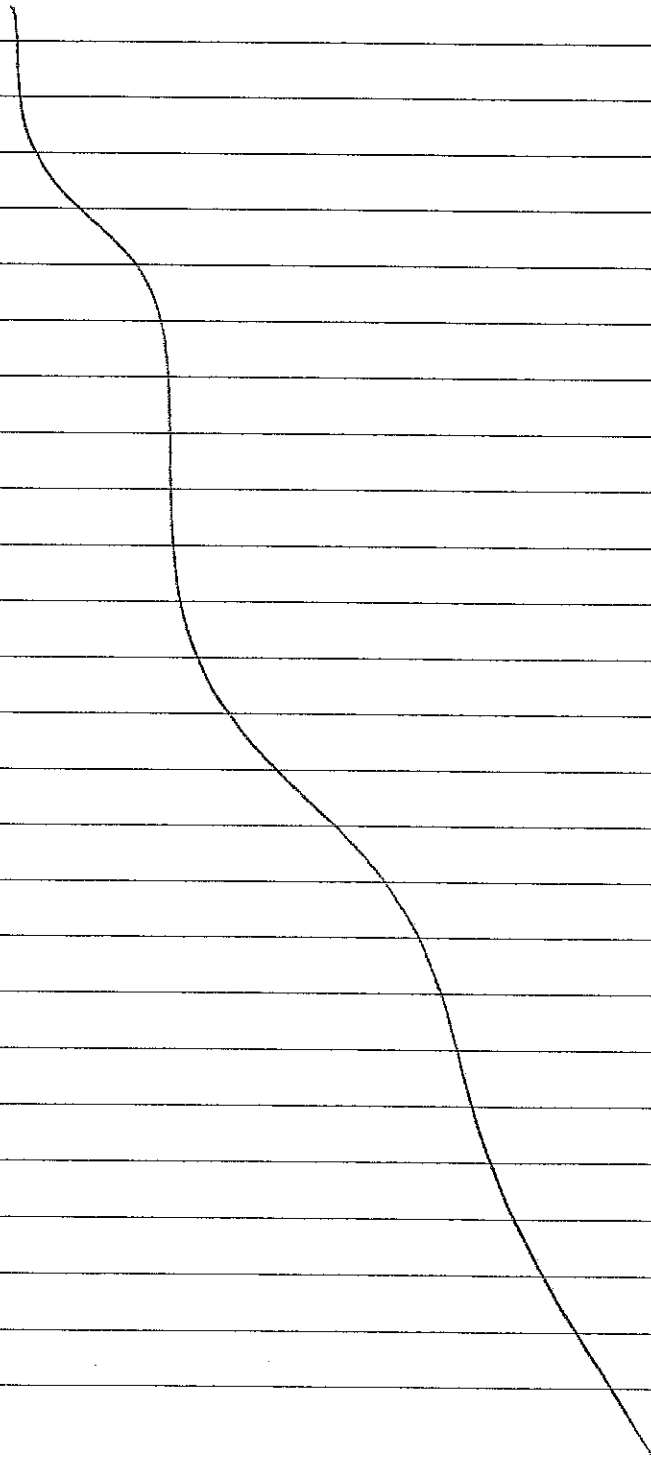
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calculated by Mises rule, T-N curve,
S-N curve
and number of load cycles in each tension range.



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Question 3: Added mass:

when floating body moves in water with velocity V , the fluid particles accelerate around the body that impose additional mass to the system which is called added mass. the floating body ^{total} mass is then

comes $(M + m_{\text{added}})$ in ~~the~~ water and must be considered in equation of motion

$$(M + m_{\text{added}}) \ddot{X} + B \dot{X} + KX = F_{\text{excitation}}$$

this added mass is proportional to fluid density (ρ sea water) and geometry (shape) of floating body. the added mass is calculated by empirical formula:

$$\text{added mass force} = \rho C_m A L \dot{U} \quad C_m = (1 + C_a)$$

Contribution

density

Inertia
coefficient

added mass
coefficient & DCR



where U is the velocity. A is the wetted surface and L is the characteristic length of the structure. C_M is the inertia coefficients that is calculated by experiment. for slender structure the $C_M \propto (KC, Re)$ means that it related to Keulegan Carpenter number and Reynolds number. for large and fat structures the added mass can be calculated by Boundary element ~~and~~ panel method through integration of ~~sub~~ submerged wetted surface in various wave frequency so that it called frequency dependent added mass coefficients.

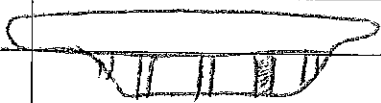
PCO



radiation damping :) When floating body oscillates ^{in water} it propagates energy. the energy dissipation appears in the form of radiation damping. The radiation damping specifically can be calculated by ~~B~~ boundary element panel method using 3d radiation-diffraction and potential flow theory in various frequencies of wave that is called frequency dependent radiation damping. ~~the~~ It is important to note that radiation damping is only acquired from potential velocity gradient ~~at~~ based on potential flow theory and do not contribute for viscous damping ^{inviscid flow}. Usually ~~a~~ Morison viscous element considered as viscous ~~for~~ correction for the total damping of structure.



Another interesting method to acquire added mass coefficients and radiation damping rather than diffraction method is using strip theory. It contributes dividing the submerged area of floating body into ^{narrow} stripes and integration of linearized wave potential eq. over the body. The accuracy of strip theory method is less than Boundary element panel method.



strip theory
application



panel mesh

Panel mesh method contribute considering 2D quadrilateral or triangular mesh over the floating body in submerged wetted areas.

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