TEACHING SEAKEEPING FOR SHIPS AND OFFSHORE STRUCTURES: A DELICATE BALANCE

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SUMMARY

Seakeeping is traditionally taught for Naval Architecture using mainly ships as examples. Many books are also available in a similar way citing ships as examples. However, in order to cater for students in Offshore or Ocean Engineering, a paradigm shift is inevitable. The author teaches seakeeping part of the module Marine Dynamics for Stage 2 (Year 1 at Singapore) students of both streams: Naval Architecture and Offshore Engineering. The available hours are limited, and within this span of time the students of both streams necessitate to be taught basic seakeeping aspects citing examples of both ships and offshore structures. This is rather a challenge. As the same group of students study another module Marine and Offshore Mechanics in Stage 3 (Final year), a delicate balance need to be maintained so that both groups of students can have equal understanding of the subsequent module with ease and comfort. The author has now done it for last five years and according to him, most of the students finally succeed to understand the module quite well. The author thinks that teaching and learning in Stage 2 has been the root of the final success. The author is delighted to see that the students finally understand fundamentals of seakeeping, not as a module of fear.

NOMENCLATURE

\( \Phi_T \)  Velocity potential (total) (N m\(^{-2}\))
\( \Phi_I \)  Velocity potential (incident) (N m\(^{-2}\))
\( \Phi_D \)  Velocity potential (diffracted) (N m\(^{-2}\))
\( \Phi_R \)  Velocity potential (radiated) (N m\(^{-2}\))
\( \Omega \)  Frequency ratio (-)
\( \xi_a \)  Wave amplitude (m)
\( \xi \)  Damping ratio (-)
\( \lambda \)  Wave length (m)
\( \omega \)  Wave circular frequency (r s\(^{-1}\))
\( \omega_n \)  Natural frequency (r s\(^{-1}\))
\( \rho \)  Density of water (kg m\(^{-3}\))
\( A_x \)  Added mass in \( x \)-mode (kg)
\( A_z \)  Added mass in \( z \)-mode (kg)
\( B_x \)  Damping in \( x \)-mode (N sm\(^{-1}\))
\( C_d \)  Oscillatory drag coefficient (-)
\( C_m \)  Inertia coefficient (-)
\( C_z \)  Restoring coefficient in \( z \)-mode
\( C_O \)  Restoring coefficient in \( \Omega \)-mode
\( C_\phi \)  Restoring coefficient in \( \phi \)-mode
\( D \)  Diameter (m)
\( F \)  Wave excitation force (N)
\( F_D \)  Frequency domain (N)
\( F_I \)  Inertia force (N)
\( F_Z \)  Vertical force (N)
\( g \)  Acceleration due to gravity (m s\(^{-2}\))
\( M \)  Displacement mass (kg)
\( RAO \)  Response Amplitude Operator (-)
\( S \)  Surface area (m\(^2\))
\( S_{\infty} \)  Spectral density of wave energy (m\(^2\) s)
\( TD \)  Time domain
\( V \)  Displacement volume (m\(^3\))
\( h \)  Water depth (m)
\( m_n \)  Spectral moment of order - n
\( n \)  Normal vector (-)
\( p \)  Dynamic pressure (kg m\(^{-2}\))
\( u \)  Horizontal velocity (m s\(^{-1}\))
\( x \)  Horizontal displacement (m)
\( z \)  Vertical displacement (m)

INTRODUCTION

This paper outlines some of the experiences of the author during his teaching of the module Marine Dynamics mainly seakeeping part since his joining Newcastle University at Singapore. The author further understood himself the difference about the application of hydrodynamics for ships and offshore structures, when he pursued his MSc by research in Marine (offshore) technology at the University of Strathclyde at United Kingdom and later his PhD works at the Delft University of Technology at Netherlands.

Seakeeping is one of the main pillars of Naval Architecture. A floating body whether it oscillates in still water or waves has been the core example of the theory of seakeeping. Physics of a floating body undergoing six-degrees of motions: coupled or non-coupled, remains as the fundamental knowledge of seakeeping. Naval Architects and Offshore Engineers use seakeeping in the field of ship design as well as for design of offshore structures respectively. Two distinct features of a floating body: body motions resulting in its hydrodynamic reaction forces and the wave excitation forces on the body again form the basis of forming and solving the equations of motions. Further, the calculation of the wave excitation forces, which primarily consists of the Froude-Krylov pressure forces and the diffraction forces for any arbitrary body geometry, needs very well defined grip. Further details are available in [1, 3, 4, and 5].

Going back to mid-fifties, the floating structures mainly remained confined to ships only. The problem of dealing with wave excitation forces on the ship was mostly solved based on a slender body theory using the strip theory including a simple way of finding added mass and damping coefficients based on experimental results as mentioned in [1]. Many pioneering works have been accomplished based on the strip theory. Assumptions were there, but results were remarkably satisfactory!
With the introduction of offshore structures in late 40s, the entire game of predicting wave excitation forces took a different turn. Suddenly, there came fixed offshore structures made of small diameter tubular structures (jackets and later jack-ups) and a few years later floating structures like semi-submersibles are also added as offshore structures. The traditional strip theory based calculation of a slender body like a ship became subject to changes. Then, one of the famous equations, the Morison equation [2] became known to designers of tubular structures. This equation till today is the only equation with all kinds of uncertainties embedded in it and yet it is the only soul saviour for calculating sea loads on offshore structures especially when the $D/\lambda$ is less than 1/5 or especially 1/20. When this remarkable equation managed to resolve issues related to the small (slender) bodies; the other side of the coin, i.e. the large (bluff) bodies also needed a separate treatment for calculating the wave excitation forces. While the basic theory is that someone needs to calculate the diffraction forces in addition to the Froude-Krylov pressure forces, it again required a simplification when the body is relatively slender. As it is not appropriate to teach the students immediately (Stage 2 level only) the numerical method of calculating the diffraction forces, the simplified version of the diffraction forces is then introduced. This simplification is applicable for both ships and offshore structures.

With subtle differences in teaching both Naval Architecture and Offshore Engineering students, the author has managed the relevant knowledge for students of both streams so that they could apply skill in Stage 3 (Final year) related modules with much more confidence. The whole exercise over the years has made the author also confident of handling similar modules in Stage 3 (Final year). According to the author, the teaching and learning using both ships and offshore structures as examples in Stage 2 (Year 1) has been the key of success. The students though with O-level and Diploma background have shown great interests and engagement with the author with a very good positive attitude of learning.

2. BACKGROUND

Newcastle University (UK) started its first international activity in Singapore by establishing the School of Marine Science and Technology in 2008 with Ngee Ann Polytechnic under FSI (Foreign Specialized Institute) programme under the name Newcastle University Marine International (NUMI). The purpose of this programme was to recruit only Diploma Graduates from any of the Polytechnics in Singapore with relevant (Diploma in Marine and Offshore Technology or Diploma in Marine Engineering) and or related Diplomas (Diploma in Mechanical Engineering, Manufacturing Engineering, etc. subject to a successful bridging programme completion). In 2010, the FSI programme was abolished, and the programme got transferred under SIT (Singapore Institute of Technology), which oversees all OUs (overseas universities) for similar operations, i.e. recruiting Diploma Graduates from all five polytechnics in Singapore. However, SIT has its own academic programmes too.

Diploma Graduates come from O-level and study three years in a polytechnic in Singapore in various disciplines including engineering. According to the author’s experiences, though most of these students lack relevant knowledge in mathematics, physics and also domain discipline yet they have a great attitude towards learning and puts efforts in all ways they can. Then, it becomes a real challenge to teach a cohort of students with most of them having difficulties to understand mathematically based modules such as seakeeping being one of them.

The author had to slog with these students right from the beginning, AY2008-2009. Initially, the module, Marine Dynamics, was included in Semester 1 of Stage 2 (Year 1 in Singapore), and for the first academic year in 2009, the results were rather not satisfactory. One of the reasons, the author quickly realized that most of the students joined the program after many years of their Diploma and some of them also joined after completing their two years of NS (National Service). Naturally, they struggled with mathematics and physics, which they require while understanding basics of seakeeping. So, the first remedial action, the author took, is to shift the module from Semester 1 to Semester 2 of Year 1 when the students attend the module of Mathematics in Semester 1. This change also allowed students sufficient time to settle in a new academic environment. This simple change helped a lot. Further changes were made in the syllabus as purely restricting to basics of seakeeping in a very structured manner of step by step learning and teaching methods. Examples were introduced also in a very logical way as tutorials to support the theory taught during the lectures. Finally, course works were given in Groups, but different assignments for different Groups with an advice that all Groups must go through all assignments just to have a feel of different problem solving thoughts.

3. THE MODULE: MARINE DYNAMICS

The module of Marine Dynamics comprises two parts: seakeeping and manouoeuvring. There are 24 lectures and 12 tutorials for the module, which are the direct contact hours. Seakeeping part is taught by the author in 12 lectures and 12 tutorials. However, the author uses at least on average 20% more lectures and tutorials in order to ensure that the students have a slow pace of learning and enough practices in tutorials. According to the author, these extra efforts at last pay well, i.e. most of the students at the end of their final year develop a good knowledge and competent skill in this subject of seakeeping (an important part of the ship and offshore hydrodynamics). The core learning and teaching in Semester 2 of Stage 2 (Year one) helped them in...
understanding the subsequent advanced modules and also related modules better.

The seakeeping part of the module has the following aims and outlines of syllabus [6]:

3.1 AIMS AND OUTLINES OF SYLLABUS

3.1 (a) Aims

1. To introduce the basic seakeeping qualities expected from a good ship and offshore design.
2. To provide knowledge underpinning the understanding of the factors influencing the seakeeping characteristics of ships and offshore structures.
3. To develop skills required to predict the seakeeping behaviour of ships and offshore structures.

3.1 (b) Outlines of the Syllabus

• Introduction to seakeeping; sea environment; regular waves and wave kinematics;
• Added mass and hydrodynamic reaction forces of floating structures;
• Wave excitation forces/moment acting on a floating structure;
• Natural frequencies of a floating structure in heave, roll and pitch,
• Uncoupled heaving motion of a floating structure; derivation and solution of motion response equations in regular waves;
• Irregular seaway; forces and motion responses in an irregular seaway.

3.2 LEARNING OUTCOMES

The seakeeping part of Module has the following learning outcomes [6]:

3.2 (a) Intended Knowledge Outcomes

On completing the seakeeping part of the module, students will be able to demonstrate knowledge and understanding of:

• Wave kinematics in regular and irregular waves.
• Added mass and hydrodynamic reaction forces.
• Wave and motion induced loading in regular and irregular seas.
• Derivation and solution of dynamic motion equations in regular and irregular seas.

3.2 (b) Intended Skill Outcomes

On completing the seakeeping part of the module, the students will have acquired or developed the following skills:

• Students will be able to calculate the natural heave, pitch and roll frequencies, as well as heave motions of a ship and an offshore floating structure in regular and irregular waves.

3.3 TEACHING METHODS AND ASSESSMENT

The seakeeping part of Module has the following teaching methods and assessment [6]:

3.3 (a) Teaching Activities

Apart from scheduled learning and teaching activities, the students spend time in preparing the assessment under guided independent study. Besides, the students spend almost 50% of their module allocated hours (10 credits are equivalent to 100 hours) in independent study of writing and studying lecture notes and general reading and problem solving.

3.3 (b) Teaching Rational and Relationship

The lectures are designed to assist students in the acquisition of a knowledge base that will facilitate understanding of concepts and detailed analysis techniques as stated in intended knowledge outcomes. The tutorial sessions are supervised activities in which the students apply the knowledge that they gain during formal lectures and private study as stated in the intended skill outcomes.

3.3 (c) Assessment Methods

The written examination allows t students to demonstrate their basic knowledge and understanding of the subject as well as to demonstrate their problem solving skills through short subject specific problems, under time pressure as required in the industry.

4. A DELICATE BALANCE OF TEACHING

4.1 SHIPS AND OFFSHORE STRUCTURES

Looking at the syllabus in 3.1 (b), the following can be understood as to why a delicate balance is obviously needed for differentiating ships and offshore structures while teaching seakeeping part of the module Marine Dynamics.

4.1.1 INTRODUCTION TO SEAKEEPING

Items like the introduction to seakeeping, sea environment, regular waves and wave kinematics are almost common to any student studying Seakeeping. However, the subtle difference about the application of knowledge for ships and offshore structures need to be tackled. One of the most important items of Seakeeping is the explanation of the six degrees of motions: surge, sway, heave, roll, pitch and yaw. The students need to be told among all these six degrees like surge, sway and
heave are rectilinear motions whereas roll, pitch and yaw are angular motions. Further, surge, sway and yaw for a free floating body have no restoring forces but heave, roll and pitch of a free floating body have restoring forces. One of the most important differences between ships and offshore structures in terms of forward velocity needs to be well clarified. A ship has a speed whereas an offshore structure does not have any speed but a floating offshore structure while undergoing slow drift oscillation [8] may have some forward velocity into the waves and out of the waves. As such, for ships encountering frequencies are used whereas for offshore structures absolute wave frequencies are referred. A ship in waves is discussed in details especially different wave headings, effective wavelength in oblique seas, deduction of encountering frequency, etc.

The following topics are well covered in understanding regular waves, wave mechanics in both shallow water and deep water:

- Environment; wind generated waves, sea, swell
- Regular Waves in shallow and deep water
- Dispersion relation in shallow and deep water
- Celerity in shallow and deep water
- Wave velocity potential and wave particle kinematics
- Wave energy
- Wave slope
- Dynamic pressure
- Wave group velocity

After covering the above items in lectures, related examples are also solved as tutorials. These examples are quite basic in nature, but still require some practice to understand some implications in using those. Some examples are given as home tutorials. Two text books have been very effective, and these are [1, 7].

4.1.2 ADDED MASS AND DAMPING

Looking back at the syllabus, item 1 is common to all students of both naval architecture and offshore engineering streams. For syllabus 2, examples need to be given for both ships and offshore structures as there are differences. A ship can be of a rectangular part like a rectangular barge, but an offshore structure can be of different sections like circular, square, elliptical, diamond shape, etc. So, added mass of different types and their condition like (free floating and fully submerged) need to be explained. The students also need some basic information about how to calculate the sectional added mass of a simple shape like a square or rhombus from the experience of the added mass of a circular section.

Apart from understanding the added mass of simple geometries from literature, a detailed description of calculating added mass and damping values of a ship-shaped structure are given using the text book [1] while using the strip theory. This will allow students to master the skill of determining the values of added mass and damping of different sections of the ship while using the strip theory.

During the same lectures, the concept of hydrodynamic reaction forces is also given due to added mass and damping force generated by the body motion. The remaining item of the reaction forces, which is the restoring force, is also mentioned but explained more when lecturing on natural frequencies of heave, roll and pitch.

Figures 1 and 2 show some typical bodies whose added mass are discussed in the lectures. There are more bodies of different geometries available in [5]. One of the important things is to understand the body geometry and their boundary conditions like floating, deeply submerged, etc. and also whether the added mass is per unit length (See Figure 1) or total mass (See Figure 2).
validating model scale tests and even sometimes measuring full scale tests. The process is rigorous but in the design stage, engineers do apply simplified theory with some approximations in order to achieve a quick initial feeling of these extreme complex phenomena.

When a structure is fixed, there will be hydrodynamic excitation forces on it due to the motions of the fluid. These forces result from mainly two reasons: one is the shear force exerted on the structure due to a change of water velocity parallel to its surface. However in case of frictionless fluid, the shearing force will be zero. The other force exerted on the structure is due to the pressure of the fluid.

Further, the hydrodynamic excitation force is based on the principle of relative motion: the forces exerted on a moving structure in still water are identical to the forces exerted on a fixed structure by the moving water when the relative motions are same. However, there will always be exceptions as the water will not usually move as uniformly as it does with a moving object in still water. When the above-mentioned relative motion concept is not applied, some kinds of measures are applied for approximations to the hydrodynamic forces.

In the case of a ship, when it is considered as a slender body, application of strip theory is quite general. Strip theory considers a ship to be made up of a finite number of transverse 2-D sections which are rigidly connected to each other. Each of these sections will have a form that closely resembles the segment of the ship that it represents. Each section is treated hydrodynamically as if it is a segment of an infinitely long floating cylinder. Fundamentally, the strip theory is valid for long and slender bodies only. In spite of this restriction, strip theory can be applied successfully for floating bodies with a length to breadth ratio larger than three \((L/B > 3)\), at least from a practical point of view.

When due to frictionless property of the fluid, the shear force is zero and the force on a fixed structure are mainly of fluid pressure origin, the effects of viscosity can also be applied depending on the size of the structure compared to its environment. For large structures, the viscosity effects can be neglected but for relatively small bodies in short and high waves, the influence of viscosity becomes important. Viscous effects are dominant in certain offshore structures (jackets and jack-ups) because of their geometries. Those fixed structure like jackets, jack-ups, are made of small diameter tubular sections compared to wavelength and thus the force regimes become equally important in both inertia as well as in viscous effects. However for other offshore structures like semi-submersibles, tension leg platforms, spars and finally ship-shaped floating structures (FPSOs, FSOS, etc.), the mechanics of wave forces mainly falls into the category of forces on large structures and this, in fact, needs diffraction theory to be involved. When floating, radiation problems also add in.

For an inviscid fluid, the force on the structure can be deduced from the following integration:

\[
F = -\int_{S} p n dS
\]  

(1)

For wave forces related to a small body structures, the famous Morison equation is applied. The Morison equation fundamentally assumes that the wave excitation force to be composed of inertia and drag forces linearly added together. The two components of forces are again different in nature: one linear and the other non-linear. Moreover, moreover, both requires an inertia coefficient and a drag coefficient (this drag coefficient is different from that in a steady flow). The values of these coefficients are available in many literatures and they are usually established by experimental results for various shapes, geometries, etc.

4.1.3 (b) Waves Excitation Forces on Large (Bluff) Structures and the Froude-Krylov Force and the simplified Diffraction Force

When the drag force is small, and the inertia force is predominant, but the structure is still relatively small, the Froude-Krylov force can be applied with some approximations. It comprises the incident wave pressure and the pressure-area method on the surface of the structure to compute the force. The advantage of this method is that the force can be obtained in a closed form applying easily determined force coefficients.

Using velocity potential, it is possible to determine the first order pressure in the fluid. When the pressure is known at every location and thus at any point of the surface of the structure then the wave excited force can be determined from the integration of the pressure over the hull.

\[
F = -\int_{S} p n dS
\]  

(2)

Apart from strip theory, for large structures like ships or large floating offshore structures, the diffraction theory generally gives better results when compared to experimental results. However, for a quick result, using simplified theory during the preliminary design stage make much more sense. For an approximate determination of the wave excitation forces, the relative-motion concept can be applied for those structures where they can be assumed to be small with respect to the wavelength.

The structure is considered fixed and subjected to regular waves, whose velocity potential is known as follows:

\[
\Phi = \frac{\zeta}{\omega} \frac{g}{\cosh \kappa h} \frac{\cosh \kappa (h + z)}{\cosh \kappa h} \sin(\kappa - \omega t)
\]  

(3)
The pressure is given by the following also:

\[ p = \rho g z + \frac{\cosh \kappa(h+z) \cos(\kappa x - \omega t)}{\cosh \kappa h} \]  

(4)

The above-mentioned approximation method now leads to the following description of the oscillatory wave excitation force:

\[ F_{\text{Total}} = F_{\text{F-K}} + F_{\text{Added Mass}} + F_{\text{Damping}} \]  

(5)

In which \( F_{\text{Froude-Krylov}} \) is the undisturbed fluid pressure force (known as Froude-Krylov pressure force or simply Froude-Krylov force), which is due to the pressure 'p' over the structure. Thus, the calculation of the force on the structure is performed assuming that the structure is not there as far as the waves are concerned. Because of this assumption, there are limitations in using this. However, it is a simple but good exercise in understanding the mechanics of wave forces especially for submerged bodies.

\[ F_{\text{Froude-Krylov}} = -\int_S p n dS \]  

(6)

In case of small bodies and when fully submerged, the Froude-Krylov force can also be reduced to:

\[ F_{\text{Froude-Krylov}} \approx \rho V \dot{u} = M \ddot{u} \]  

(7)

The forces \( F_{\text{Added Mass}} \) and \( F_{\text{Damping}} \) are components of the force \( F_{\text{Diffraction}} \). In case of a small body, where water particle velocities are assumed to be everywhere same, then

\[ F_{\text{Added Mass}} = A_s \dot{u} \]  

(8)

\[ F_{\text{Damping}} = B_s u \]  

(9)

In the above two equations, the inertial force \( F_{\text{Added Mass}} \) is the product of the added mass \( A_s \) of the structure and the acceleration, \( \dot{u} \), which is found to be the acceleration of the water particles in the undisturbed wave. The damping force \( F_{\text{Damping}} \) is the product of \( B_s \) and the water particle velocity in the undisturbed wave velocity, \( u \).

So, the total wave excitation force on a floating body or a submerged body is equal to the following:

\[ F_{\text{Total}} = F_{\text{F-K}} + F_{\text{Added Mass}} + F_{\text{Damping}} \]  

(10)

In general, the above described approximation will provide acceptable results when the diameter \( D \) of the structure is so small that \((\kappa D) < 1.2 \) or \( D \approx (0.2 \lambda) \).

The Froude-Krylov theory [4] also recognizes it is not easily applicable unless further corrections are applied due to the oscillatory flow around the structure by its presence. If the flow is inviscid and irrotational and the diffraction effect is small, this correction may be applied in the form of a force coefficient. For some structures, which are considered quite small with respect to the wavelength, a single force coefficient may suffice. However, over a range of relatively large size parameter, a single force coefficient may not be appropriate as for those structures diffraction effects appear significant and not same the Froude-Krylov force.

4.1.3 (c) Wave Excitation Forces on Small (Slender) Structures and the Inertia & the Drag force

The Morison equation was developed [2] in describing the horizontal force on a vertical pile, which is fixed on the seabed and piers through the sea surface. They came out with the first theory as follows:

\[ F_I = F_I + F_D \]  

(11)

\[ dF_I = dF_I + dF_D \]  

(12)

\[ dF_I = C_m \rho \frac{\pi}{4} D^2 \dot{u} dz \]  

(13)

Where \( dF_I \) is the inertia force on the segment ‘\( dz \)’ of the vertical cylinder, ‘\( D \)’ is the diameter of the cylinder, \( \dot{u} \) is the local water particle acceleration at the centreline of the cylinder and \( C_m \) is the inertia coefficient.

\[ dF_D = \frac{1}{2} \rho C_d D \| u \| u \]  

(14)

Where \( dF_D \) is the drag force on an incremental segment, \( dz \), of the cylinder, \( C_d \) is the drag coefficient.

Combining the above two equations, the Morison equation now turns into the following for unit length of the vertical cylinder:

\[ dF_{T,x} = C_m A_t \dot{u} + C_d A_d \| u \| u \]  

(15)

Where

\[ A_t = \rho D^2 \]  

(16)

\[ A_d = \frac{1}{2} \rho D dz \]  

(17)

As the above equation gives the force on a unit length of a vertical cylinder (See Figure 3), the total force is given by the following:

\[ F_{T,x} = \int_{-h}^{0} dF = \int_{-h}^{0} \left( C_m A_t \dot{u} + C_d A_d \| u \| u \right) \]  

(18)
4.1.3. (d) Waves Excitation Forces on Large (Bluff) Structures and the Diffraction Force

Both the Morison equation and the Froude-Krylov use have limitations in the sense that wave kinematics before and after the structure do not alter and as such the incident wave in the direction of the structure remains unaltered. However, in case of the Morison equation use, there is a flow separation phenomenon and it equally dominates the total forces. As the structure size becomes larger or the ratio \( D/\lambda \) increases more than 0.2, the original assumption does not hold any longer. In fact, the structure size takes a substantial portion of the wavelength. This results that the incident waves undergo significant changes in the form of reflection, scattering or diffraction. So, an alternative approach valid over a much wider range of \( D/\lambda \) becomes essential to calculate the wave excitation forces. So, it is now evident that the wave force calculation, in the event of such scattering or diffraction, should then take account of such scattering or diffraction effects.

So, in case of small (slender) bodies, \( \Phi_T \), can be written the following:

\[
\Phi_T = \Phi_I \quad (19)
\]

However, in case of large (bluff) bodies

\[
\Phi_T = \Phi_I + \Phi_D \quad (20)
\]

The complete boundary-value problem in the general diffraction theory has to be solved. In doing so, the fluid flow is assumed to be oscillatory, inviscid, incompressible and irrotational so that the fluid velocity may be represented as the gradient of a scalar potential, \( \Phi \). Under potential theory, the total velocity potential is then obtained as a sum of the incident and diffracted potential as written in the above equation.

In case of a floating body, the above equation will take the following form because of the radiation potential caused by the oscillation of the body originally in still water.

\[
\Phi_T = \Phi_I + \Phi_D + \Phi_R \quad (21)
\]

The wave excitation forces and the motions of large fixed bodies like concrete gravity structures or floating bodies like an FPSO/FSO or a semi-submersible/tension leg platform/spar can be solved numerically by a 3-D radiation-diffraction problem. Such numerical solution can be obtained by using established computer coding available in the market.

4.1.4 EXAMPLES FOR PRACTICE

After going through all the above methods of calculating the wave excitation forces, relevant examples must be done for students to practice the theoretical knowledge. A few sets of examples are solved as tutorials in the class, and some of those are given as home tutorials for students to practice like the following:

- Vertical Force on a floating barge in head seas
- Horizontal force on a floating barge in head seas
- Vertical force on a floating barge in beam seas
- Horizontal force on a floating barge in beam seas
- Vertical force on a floating vertical circular cylinder
- Horizontal force on a floating vertical circular cylinder
- Horizontal and vertical forces on a submerged sphere
- Horizontal and vertical forces on a submerged cylinder in head seas and in beam seas

The above examples allow students to think various ways of working principles of calculating the wave excitation forces on different types of floating and fully submerged bodies.
Figures 4 and 5 show the examples are solved in details as tutorials for students to understand the calculation of Froude-Krylov pressure force, added mass force on a floating barge in the head and the beam seas. Similarly, Figures 6 and 7 help to understand the Morison equation to calculate horizontal force. These also help in understanding the vertical force. The students are then asked to solve examples like the following as coursework.

- Vertical and horizontal forces on a fully submerged pontoon in the head seas and the beam seas.
- Vertical and horizontal forces on a vertical cylinder of circular, square, rectangular and elliptical x-section (major axis and minor axis pointing x-axis) with an attached sphere below it.
- The same as above except the sphere is replaced with a caisson and an extension of the cylinder below the caisson.

The above coursework for different groups of students provides them ample opportunity to practice. These skill developments help them later to solve a complex floating structure like a semi-submersible or a tension leg platform either with caissons or pontoons.

### 4.1.5 Natural Frequencies

Immediately after the lectures describing the different scenario of calculating the wave excitation forces on the ship as a slender or bluff body, a small (slender) body and a large (bluff) body of offshore structures, the next step is the motion calculations of the floating bodies by solving the second order differential equation. Though the general solution of the equation of motion does not comprise natural frequencies, the revised form does so in terms of the frequency ratio, \( \Omega \) and the damping ratio, \( \xi \).

The following equations 26, 27 and 28 are produced for a floating body undergoing heave motion.

While solving the equation of motion, different forms of the equation are also mentioned so that the students know different solutions of the same equation under different conditions:

- Forced damped (solution for motion)
- Forced undamped (solution for motion)
- Free damped (solution for damped frequency)
- Free undamped (solution for natural frequency)

After showing the derivation of the natural frequencies (heave, pitch and roll), the various formulae of natural frequencies are mentioned with examples solved in tutorials.

The restoring coefficient or stiffness of the spring terms is present for the heave, roll and pitch motions only.

Heave:

\[
C_z = \rho \ g \ A_{wl} \tag{22}
\]

Roll:

\[
C_\phi = \rho \ g \ V \ GM_T = g \ M \ GM_T \tag{23}
\]

Pitch:

\[
C_\theta = \rho \ g \ V \ GM_L = g \ M \ GM_L \tag{24}
\]

\[
\omega_{n,z} = \sqrt{\frac{C_z}{(M + A_z)}} \tag{25}
\]

The above equation gives the heave natural frequency. Similarly, pitch and roll natural frequencies are also mentioned with special reference to using “mass moment of inertia” and “added mass moment of inertia” due to angular motions in place of mass and added mass.

All examples mentioned in 4.1.4 are used to calculate the heave natural frequency. Additionally, roll and pitch natural frequency calculations are shown for a floating barge also. The students are required to demonstrate their knowledge of calculating \( GM_T \) and \( GM_L \) of a barge of homogeneous construction. Basics of mass moment of inertia and added mass moment of inertia are discussed using some empirical formulae. Details are again taught in Stage 3.
4.1.5 MOTIONS OF FLOATING BODIES

As mentioned above, the different forms of the equation of motions are solved. The solutions of the equation of motion are shown below.

\[
(M + A_z) \ddot{z} + B_z \dot{z} + C_z z = F_z \cos(\omega t) \tag{26}
\]

\[
z = \frac{F_z / C_z} {\sqrt{1 - (\Omega)^2 + (2\Omega \xi)^2}} \cdot \frac{B_z} {2 \sqrt{(M + A_z) C_z}} \xi = \frac{B_z} {2 \sqrt{(M + A_z) C_z}} \tag{27}
\]

\[
\tan \varepsilon = \frac{2 \xi \Omega} {1 - (\Omega)^2} \quad ; \quad \xi = \frac{B_z} {2 \sqrt{(M + A_z) C_z}} \tag{28}
\]

The equations of motions are only discussed for uncoupled equations to understand each mode of the equation of motions so that the students can master the technique of using this solution of single-degree of motion for any of the six degrees of motion. The coupled equations of motions are not discussed and thus left for the module Marine and Offshore Mechanics in Stage 3 (Final year).

4.1.6 IRREGULAR SEAWAY

4.1.6 (a) Irregular Waves

• The irregular sea surface can be represented using a linear superposition of several regular wave components of different heights, different frequencies and also with random phases.

• The direction of all these regular wave components can be uni-directional, bi-directional or even multi-directional (3-D). For simplicity of analysis, mostly irregular waves are considered as uni-directional (2-D).

• The irregular wave surface varies from time to time and place to place.

However, one of the most convenient tools to describe the irregular waves in \(FD\) and \(TD\) is using the following Figure 8 [3]. This figure gives a very relaxed way for students to understand the relation between \(FD\) and \(TD\) for irregular waves including spectral density of wave energy. While frequency domain analysis for irregular analysis is based on a linear relationship, time domain representation for irregular waves could be used for both linear and non-linear problems. This understanding is discussed but not with great details. The students would not be able to understand the different implications of its use and application. For them, understanding frequency domain analysis for irregular waves using the linear relationship is initially critical.

4.1.6 (b) Forces and Motions in Irregular Waves

The forces and motions, which are either calculated or experimentally found in regular waves, can also be treated in irregular waves, in both \(FD\) and \(TD\). However, due to the limited lecture hours, the principles of treating forces and motions are explained in irregular waves, in the frequency domain only and only the technique of obtaining an irregular wave, \(\zeta(t)\) in \(TD\), is obtained from an energy spectra. Before going through the steps of converting either force \(RAO\) or motion \(RAO\) in irregular waves, i.e. obtaining force or motion spectra and consequently several statistical properties of forces and motions, knowledge of irregular wave energy spectrum are given mentioning different types of spectra. Also discussed are various statistical properties of irregular waves like significant wave height, zero crossing period, etc.

4.1.6 (c) Wave Energy Spectrum

The energy of a single wave is given by:

\[
E = \frac{1}{2} \rho g \zeta^2 \tag{29}
\]

The total energy of a number of waves is then given by:

\[
E_T = \frac{1}{2} \rho g (\zeta^2 + \zeta^2 + \ldots + \zeta^2) \tag{30}
\]

The spectral moment is defined by the area under the spectrum

\[
m_n = \int_0^\infty \omega^n S_\zeta(\omega) d\omega \tag{31}
\]

Further details are available in [1].
4.1.6 (d) Forces and Motions in Irregular Waves

Further, while explaining the steps of converting wave energy spectrum into either a force spectrum or a motion spectrum, the importance of forward speed and thus the encountering frequency is also brought back again as past reference. For a ship with the speed, the wave spectrum, motion RAO and finally the motions spectrum – all have to be expressed as a function of encountering frequency. This is different from offshore structures.

Time domain dealing of irregular waves is not dealt with in depth. Just one example of producing irregular waves in TD from a wave spectrum in FD is explained. A simple explanation is given about FFT and INV-FFT and how these are applied into breaking a signal into its amplitude, associated frequencies and random phases and vice versa discarding the random phases. The dealing of motions in irregular waves in TD based on regular wave RAOs are not explained and these are kept for the module in Stage 3 (Final year).

5. CONCLUSIONS

Teaching seakeeping of the module Marine Dynamics for a group of students with O-level background with Diploma background is already a challenge for the author. Further, this challenge is compounded when seakeeping is to be taught for both ships and offshore structures, which has particular dissimilarities.

With some initial changes and arrangement of the entire syllabus in a step-by-step teaching (lectures and tutorials going hand-in-hand), has made it possible to bring satisfactory motivation among the students to understand the basics of seakeeping for both ships and offshore structures. The method helped to prepare the students of both Naval Architecture and Offshore Engineering streams for dealing the subsequent, directly and indirectly, related modules in Stage 3 (Final year). The author is pleased to see that the initial struggle of the students, their efforts and engagements in different forms of queries and their final understanding of knowledge and skill in seakeeping. The experiences have made the author confident of managing other mathematically based modules in Stage 3 (Final year) to follow some similar repetition.

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7. REFERENCES


8. AUTHORS BIOGRAPHY

Arun Kr Dev holds the current position of a Senior Lecturer and was the founding Director (2008-2012) of School of Marine Science and Technology, Newcastle University (Singapore). He is involved in teaching modules related to offshore engineering and naval architecture including supervision of UG and PG taught and research theses and several engagements. His main interests are ship and offshore hydrodynamics, structural design of ships and offshore structures, ships & offshore structures design and others like OSVs, DP, Arctic Engineering, LNG Technology, Renewable Energy, Optimization Technique, Shipyard Technology, etc. Before joining the Newcastle University, Dr. Dev has spent more than fifteen years in various capacities in Keppel, and Sembcorp Group in Singapore and about eight years in doing PG researches mainly in offshore hydrodynamics in the University of Strathclyde, UK and in the Delft University of Technology, NL. He is a member of SNAME and a Fellow of RINA and IMarEST. He has published more than sixty papers in international journals, conferences and symposiums.