

WAVE DRIFT FORCE AND THE STATUS OF
RESEARCH

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A B S T R A C T

The concept of wave drift force in regular and irregular waves is explained with the aid of measurements of forces in laboratory and also at sea under different oceanographic conditions. The research work carried out so far on this subject is described. Short-comings and limitations of the work done so far are brought out and suggestions are made for future investigation.

INTRODUCTION

Energy crisis in 1973 brought a new awareness to the exploration and exploitation of hydrocarbon reserves from the oceans. Research activities in the field of ocean engineering gained momentum ever since and significant know-how on the design and construction of fixed offshore structures has been acquired in the last decade. Due to the limitation of oil reserves in shallow water areas and increased industrial demand in recent years, attention is being focussed to the extraction of oil and gas from deeper waters. Consequently floating offshore structures moored to sea bottoms are replacing fixed structures due to their technical, economical and operational advantages in deep water areas. Design and installation of mooring systems in deep waters has been drawing the attention of researchers due to the important role the systems play in the proper functioning of floating platforms. To design a mooring system economically to serve the intended purpose efficiently, knowledge of wave drift force which controls the design and cost of the system is

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vital. The research on wave drift force which was neglected hitherto has been taken up in recent years. This paper explains the concept of wave drift force and summarizes the research work done so far on this subject. The inadequacies of the information available are explained and suggestions are made for future investigation.

WAVE DRIFT FORCE

A rigid object, either freely floating or fixed, will disturb the natural pattern of the waves which surround it. The incoming waves will, on meeting the object, be partly reflected and scattered. If the object is floating freely, its oscillatory motions will also cause waves to be transmitted radially outwards. The complex wave pattern around an object at sea is, therefore, a mixture of the original undisturbed waves, reflected and scattered waves and the waves generated by the oscillating object. The conservation of wave momentum results in a net force applied to the object for each wave. For regular waves the consequence is a steady drift force resulting in a static shift of the position of the object. The forces and the corresponding moments due to a stationary irregular sea are of an irregular nature and may be split into two parts:

1. First order oscillatory forces with wave frequency;
2. Second order slowly varying forces with frequencies lower than the wave frequency.

The first order oscillatory wave forces on the subject are the cause of the well known motions with frequencies equal to the frequencies present in the spectrum of the irregular waves. These are linear motions of surge, sway, and heave and the three angular motions of roll, pitch and yaw. In general the first order wave forces are proportional to the wave height as are ensuing motions. The magnitude of the linear oscillatory motions is in the order of the height of waves.

The second order wave forces better known as the wave drift forces have been shown to be proportional to the square of the wave height. These forces, though small in magnitude, are the cause of the low frequency, large amplitude horizontal motions sometimes observed in large vessels moored in irregular waves. An example of the type of motion which can be induced by the low frequency wave drift force is shown in Fig. 1. The results given in this figure were measured by Pinkster (1974) in Netherlands Ship Model Basin during tests in irregular head waves with the model of a large LNG carrier. The vessel was moored by means of a system with linear elastic characteristics. Shown in Fig. 1 are the surge motion of the vessel and the record of the height of irregular waves, recorded simultaneously. The measurements showed that the frequency of surge motion of

the vessel was very close to its natural surge frequency and that the amplitude of motion was in the order of three to four times the amplitude of irregular waves. Tests undertaken with the same vessel in the same sea state but with various values of stiffness of mooring system showed that the mean period of the low frequency surge motion induced by the wave drift force is always near the natural period of the moored vessel. In Fig. 2 the mean surge period as measured during the tests in irregular waves is plotted against the natural surge period of the moored vessel during the corresponding test. It is seen that these values are in close agreement for a range of natural periods from 70 to 140 seconds. This phenomenon is typical in the behavior of moored vessels and is a consequence of low damping present in the system. During the same tests the forces in the mooring system were measured. As a consequence of the low frequency surge motion of the vessel, these forces were also of the low frequency type. The mean value of the mooring force in the longitudinal direction corresponded to the mean value of the drift force. In the tests in irregular waves with significant height of 2.5m and a mean period of 7.5 seconds the mean value of the wave drift force amounted to approximately 6 tons for all values of the stiffness of the mooring system which were tested.

It has been shown by Remery and Hermans (1971) that the variation in the drift force is associated with the occurrence of groups of higher waves in irregular sea. In order to demonstrate the effect of wave groups on the amplitude of the surge motion of a rectangular barge they carried out tests in a sea state consisting only of regular groups of waves with an average period of wave groups of approximately 110 seconds. The tests were carried out of a number of different stiffnesses of the mooring systems so that natural periods of surge motion varied from 65 to 160 seconds. The results of their measurements which are reproduced in Fig. 3 show decisively that resonance in the surge motion can be induced by regular wave groups with periods equal to the natural surge period of moored barge.

The tests carried out with the model of the large LNG carrier and those carried out by Remery and Hermans with a rectangular barge are examples which demonstrate the direct action of the low frequency drift motion.

The force is also capable of indirectly inducing large forces in mooring systems as will be shown by the following example of a VLCC moored to a single buoy mooring in wind, current and irregular waves. The results are again taken from model tests carried out in Netherlands Ship Model Basin. The tests were carried out with the model of a 300,000 DWT VLCC in a 2.5 knot current with an irregular wave of significant height of 2.6m and mean period of 8 seconds coming at right angles to the current. A wind speed corresponding to approximately 28 knot was coming

at the model in a direction of 45 degrees to the irregular waves and current. The mean position of the VLCC in the horizontal plane during these tests is shown in Fig. 4. This position relative to the buoy is typical for this frequently occurring condition with regard to wind, waves and current. Due to the action of current the bow hawser is constantly in taut condition. Due to the variation in the lateral wave drift force on the tanker, the vessel executed low frequency yawing motions about a vertical axis located somewhat aft of the bow. With an increase of lateral drift force the vessel yawed slightly to port. Due to this, however, the angle of attack of current was increased thus resulting in an increase in lateral current also directed to port. This in turn resulted in a considerable increase in the force in the bow hawser. A typical record of the wave height, the yawing angle and force in the bow hawser is shown in Fig. 5. The high frequency component visible in the record of the force in the bow hawser is caused by the oscillation of the moored buoy. As before, the record of the force in the bow hawser and the yawing motion show a large low frequency component, the frequency of which corresponds with the natural frequency of the system. This case is an example of the influence of the wave drift force on a system with more than one degree of freedom.

From the examples given above, an indication is given of the importance which must be attached to the wave drift force in general and the low frequency drift force in particular in the design of system by means of which large floating structures are to be moored at sea. Let us now examine the status of research on this important subject.

STATUS OF RESEARCH ON WAVE DRIFT FORCE

The cause of wave drift force was first investigated experimentally by Suyehiro in 1924. He showed that the drift is primarily associated with the rolling of floating bodies in waves. The tracks of the water particles on the weather and leeward sides of the structure acted upon by waves, were photographed and it was found that the structure of waves on the weather side was completely changed, the particles close to the model making up and down motions, while the waves on the leeward side were mixed with waves of progressive nature thus showing small orbital motion. Thus while the progressive waves are completely suppressed on the weather side only a partial destruction takes place on the opposite side. It was also found that the disturbance was not remarkable in the case of synchronism, that is, when the natural period of the structure was nearly the same as the wave period. In addition, the extent of rolling was not symmetrical but the relative motion on the weather side was far greater than that on the leeward side. Consequently, a net drift force in the direction of wave propagation was observed.

The first theoretical method to compute the drift force was presented by Watanabe (1938). This theory was based on the hydrodynamic buoyancy exerted on the floating body by the propagating waves. He deduced an expression for drift force involving the angle of roll and the actuating moment. He calculated the drift force for synchronous rolling and compared with Suyehiro's experimental values. He found that the theoretical values were nearly half the experimental ones and attributed this difference to the drifting of water particles themselves due to mass transport. However, the expressions presented were valid only under limited conditions.

Havelock (1942) suggested that the drift force caused by wave reflection accounts for a small fraction of the actual force experienced by the floating bodies, the major part of the force is associated with the pitching and heaving oscillations of the floating bodies. He further suggested that the interaction between these first order effects which in themselves are periodic may, through phase differences, give rise to steady additional resistances. He showed with numerical calculation that the contribution of pitching to drift force is about 75% while that due to heaving is only 25%. Regarding reflection he suggested that though it may be considerable in short waves, in long waves such as those we usually come across in open seas, this effect may be neglected. On the other hand, in short waves, pitching and heaving motions would be insignificant, and therefore, would not have significant effect on drift force. He, however, suggested that a complete theory would have to include wave reflection also besides heaving and pitching oscillations.

Kotchin (1952) considered the radiation problem and derived the drift forces, when a body was undergoing forced oscillations under the otherwise calm free surface of an ideal incompressible fluid. His final results were both general and simple due to the use of certain integrals over the body surface, which since then have been called Kotchin functions. The relation between Kotchin function and the potential due to the disturbance associated with the body resembles the relation between a function and its Fourier transformation.

Maruo's analysis (1960) by momentum and energy considerations considering drift forces in regular waves included both the diffraction and radiation effects. Maruo presented general expressions for the drift forces on an arbitrary body in the two dimensional case in terms of the reflected wave amplitude and in the three dimensional case in terms of Kotchin function. If the incident wave is set at zero, Maruo's final results are in agreement with Kotchin's. Maruo also showed that one part of his longitudinal drift force formula coincides with the approximate formula given by Havelock (1942). Ogawa (1966) and Kim & Chou (1970) applied

Maruo's two dimensional theory for a ship in beam and oblique waves by the strip method. Their comparisons of the theoretical predictions with experimental data show good agreements. Ogawa calculated the amplitudes of the reflected waves in the strip domain by the method of multipole expansions and Kim & Chou solved the two dimensional radiation and diffraction problems by the source technique.

Pung Niew Hu & King Eng (1966) obtained general expressions for the drift force and moment following Maruo's procedure of applying powerful momentum and energy theorems to the fluid, together with the potential theory. These expressions are quite general and can be applied to any oncoming waves with the only restriction that the wave amplitude be small. He also showed that if the ship only oscillates transversely at a velocity identical with the transverse orbital velocity of waves at the centre of the ship on the free surface (when the draft-length ratio of the ship is small) there will be no drift force and moment acting on the ship. It was shown that the drifting force and moment on an oscillating ship depend strongly on the motion of the ship, especially on the phase angle of oscillation.

The moment due to drift force was also analysed by Newman (1967). Basing his analysis on the usual techniques of linearized water wave problems with the assumptions of small wave amplitudes, he derived analytical equations for the drift force and moment on an arbitrary body and specific formulas for a slender ship. Results computed by these equations were compared with the experimental results recorded by Spens & Lalangas (1962) on a Series 60 model. The agreement between the theoretical and recorded results was not good. Newman attributed this disagreement to the use of slender body theory to predict the heave and pitch oscillations in short waves in which case the drift force is significant and the theory does not predict the oscillations correctly. It was also pointed out that the experimental data of Spens & Lalangas may not be reliable at the longer wave lengths when the force and moment are much smaller. However, the general trend of the drift forces and moments computed by using this theory was in a fair agreement with the recorded values thereby ensuring the validity of the theory.

Faltisen & Michelsen (1974) generalize Newman's results for finite fluid depth. They described the body potential by a distribution of three-dimensional source singularities on the body surface. They presented computed results for a floating box and compared them with model experiments and theoretical asymptotic values for small wave lengths. The latter were determined by a formula given by Maruo (1960). The computed results agree well with the asymptotic values and experimental data. Inoue (1977) applied the procedure suggested by Faltisen & Michelsen and also Maruo's two-dimensional drift force formula, but did not show any computed results.

In 1974, Tasai developed a method to compute transmitted and reflected wave heights in the case of both fixed and floating conditions. He showed that the drifting coefficient in the equation for drift force can be computed by the following equation:

$$R(\omega) = \cos(\epsilon_y - \epsilon_x)$$

where ϵ_y and ϵ_x are the phase differences between the incident wave and^y heaving and surging oscillations respectively. The drift forces acting on a vertical cylinder heaving in beam waves were then calculated by using the theoretical drift coefficient obtained by this method and compared with Maruo's computed results. Drift forces calculated by Maruo's theory and the exact values of reflection coefficient showed a different tendency and the value of drifting coefficient at resonance condition did not show maximum value such as in case of Suyehiro's experimental results. It was, therefore, concluded that Maruo's theory cannot explain the experimental results.

To study this disagreement between Maruo's computed results and Tasai's experimental results, Toki (1977) carried out an investigation in two dimensions. Experiments were conducted on two models, a semi-immersed circular cylinder and a catamaran hull composed of semi-immersed cylinders. Comparisons were made of the measured results with the theoretical predictions based on exact treatment of the linear potential theory. Calculated results were in fairly good agreement with the measured ones. The cause of the disagreement between Tasai's experimental results was attributed to the effect of three-dimensional motion of fluid due to three-dimensional bodies used by Tasai.

Kudo (1977) studied the three-dimensional problem to clarify this disagreement further. He investigated the drift force acting on a sphere which was fixed or freely floating in regular waves. He showed that the theoretical drift force coefficient of a fixed sphere increases monotonically with the increasing non-dimensional wave number Ka and agrees well with experimental data, thereby proving the validity of Maruo's theory further.

All the above investigations were conducted in deep water and no shallow water effect on drift force was considered. In 1975, Nojiri & Murayama conducted experiments on a two-dimensional floating body in regular waves and compared with theoretical results calculated by Maruo's theory and modified to include shallow water effect. There was good agreement between experimental and theoretical results. It was, therefore, concluded that Maruo's theory could be used in shallow waters by suitably considering shallow water effects.

Ando (1976) presented both measured and computed drift forces experienced by a floating box and a semi-submerged platform with two longitudinal hulls. His computation method seems to be the same as Ogawa's.

Goda (1976) considered a vertical circular cylinder in fluid of uniform depth and compared the experimental results with theoretical ones computed by three different methods. Recently Faltisen & Loken (1978) also have made a comparison between drift forces computed by several methods and experimental data. Their comparison concerns with ship-shaped and other floating bodies in regular waves.

Renukaradhya (1982) conducted theoretical and experimental investigations on square and circular structures in deep and shallow waters for different structure drafts and established relationships between the wave drift force and wave parameters, structure drafts and water depths. Drifting coefficients were determined by simply measuring the incident and transmitted wave heights and also maximum and minimum wave heights caused due to incidence and by applying energy principle and Healy's equation. Drifting coefficients obtained by these simple principles were compared with results obtained by using the methods suggested by Maruo and Tasai. The results from all these methods were found to be in fairly good agreement. Shallow water effect on drift force was found to be predominant when the structure draft is about twentyfive per cent of the water depth. It was also established that for waves with length greater than four times the structure length, the drift force in shallow water was greater than those in deep water and vice versa. The drift force on circular structure was found to be only 40% of those on square structures with deep draft. Renukaradhya also studied the effect of perforation on drift force in regular waves. It was found that the drift forces could be reduced by as much as 75% by providing perforations on the outer periphery of marine structures.

An aspect not considered by other investigators of the drift force has been examined by Ohkusu (1976). He derived by Maruo's two-dimensional theory the drift force experienced by a ship section in the vicinity of a two-dimensional structure and took approximately into account the hydrodynamic interaction between the bodies.

All the aforementioned studies are based on the potential theory. However, in real fluid viscous effects also exert drift force. The influence of viscosity on the drift force has been studied by Mizuno (1976). He applied Maruo's two-dimensional theory and obtained a viscous correction term to the drift force formula. According to his analysis it seems to be possible to separate at least approximately in the drift force a potential part and a viscous part, which are linearly additive.

Huse (1977) explained by viscous effects the drift force opposite to the wave propagation observed sometimes in model experiments with semi-submerged vessels. His analysis provides an approximate calculation method for the viscous contribution to the drift force on a semi-submersible. Pijfers & Brink (1977) computed from the viscous drag the steady viscous drift force experienced by a tubular semi-submersible structure in regular waves and considered also the slowly varying drift in irregular waves.

Studies concerning slowly varying drift of freely floating and moored bodies in irregular seas have been conducted by Hsu & Benkarn (1970), Remery & Hermans (1971), Pinkster (1974) and Rye, Rynning & Moshagen (1975) and various other researchers.

Hsu & Benkarn (1970) recorded the long period drift of a vessel in irregular waves and showed that the long period drift can for many cases be the completely dominating influence in determining maximum mooring line tension. They developed a method to compute the drift force in regular waves based on the concept of "the radiation stress" introduced by Longuet-Higgins and Stewart in 1960, and extended it to irregular waves. They assumed in the process that (1) the regular sea can be characterized by a sequence of waves each being assigned a defined height and period and (2) each of the waves of an irregular sea will impart to the moored vessel the same impulse which it would were it merely one of a sequence of regular waves. Good agreement between measured and calculated results provides high degree of confidence in the relevancy of the concepts introduced by Hsu & Benkarn. The drift force caused by wind and current was also measured by them. It was found that the steady force caused by constant wind and current will stiffen the mooring system. This stiffening may either increase or decrease the mooring force. In fact, under conditions such as soft mooring system and high waves, it was found that wind and current would actually help to reduce the peak mooring force. Consequently superimposing wind and current on storm waves does not always increase the peak mooring force.

Remery & Hermans (1971) conducted experiments on a rectangular barge and measured the drift force induced by wave trains consisting of regular wave groups and irregular wave trains. From the results of model test in regular waves, the mean drift force on the barge was determined as a function of the wave frequency. Using these data the long periodical surge motion of the barge was calculated. Comparison of these calculated values with model test results clearly showed the resonance phenomenon. This study was then extended to estimate the drift force in irregular waves by using the method of Hsu & Benkarn. Further it was also shown that the square of the wave motion provides information about the square of the slowly

varying envelope of an irregular train and so also about the drifting force. This means in other words that the spectral density of the square of the wave motion provides information about the mean period and magnitude of the slowly varying drift force. However due to the long wave record required for an accurate spectral analysis and the corresponding long period of time required for the analysis of the record, Remery & Hermans computed the drift force by using the method of Hsu & Benkarn on the assumption that an irregular wave train consists of a sequence of single waves of which the height is characterized by the height of the wave crest or the depth of the wave trough, while the period is determined by the adjacent zero crossings. The method of Hsu & Benkarn was again confirmed to yield fairly accurate results. However, the analysis by this method is carried out in the time domain as explained above, which requires that the actual records are at hand to dispose of wave information.

The influence of the low frequency drift force on the motions of moored vessels and the loads in the mooring system was demonstrated by Pinkster (1974) from model tests in irregular waves. He showed from actual measurements in irregular head waves with a model of a large LNG carrier that the frequencies of the surge motion was very close to the natural surge frequency and that the amplitude of the motion was in the order of three to four times the amplitude of irregular waves as explained earlier. Tests were carried with a model of a 300,000 DWT VLCC exposed to current, wind and waves simultaneously as explained earlier. The magnitude of wave drift force was again shown to be substantial under such circumstances.

Pinkster generalized the method presented by Hsu & Benkarn and applied by Remery & Hermans and gave an improved method to compute the wave drift force. According to this method which is based on spectral techniques, the spectral density of the low frequency part and the mean drifting force in irregular waves can be calculated by the following expressions:

$$S_F(\mu) = 2 \rho^2 g^2 \int_0^{\infty} S_{\zeta}(\omega) S_{\zeta}(\omega + \mu) R^4(\omega + \mu/2) d\omega$$

$$\bar{F}_d = \rho g \int_0^{\infty} S_{\zeta}(\omega) R^2(\omega) d\omega$$

In the formulation of this method, Pinkster assumes that wave spectra are narrow, so that wave heights follow a Raleigh

distribution and phases of the individual waves are distributed as white noise. To verify the validity of this method, the results computed using the above equations were compared with the experimental values presented by Remery & Hermans for a rectangular barge. The agreement was reasonably good, with the computed results being slightly higher than the experimental ones. This improved method is advantageous over that of Remery & Hermans in that there is no need to deal with the wave records directly and the time required for the computation is much less. The influence of the dimensions of the floating structure and also the influence of the higher order effects in the low frequency wave drift force are not considered in this method.

Rye, Rynning & Moshagen (1975) investigated the merits of the method proposed by Pinkster. They compared the measured surge motions of a model of semi-submersible platform with calculations, using experimentally determined drift force coefficients in regular waves and regular wave groups. It was concluded that a good correlation is obtained when the drift force coefficient is determined in regular wave groups.

It is clear from the above study that due care has to be taken when the drifting coefficient is determined experimentally. The discrepancy between the experimental results of Rye et al. and theoretical results computed by the method proposed by Pinkster may be attributed to the following reasons:

1. The theoretical description of the drifting phenomenon given by the investigators so far may be incomplete. Newman (1974) points out that when the reflection coefficient is computed from regular wave tests, influence of the low frequency pressure variations in irregular waves is not accounted for.
2. The second order slow drift force may be very weak compared to the first order forces. The "noise level" generated from the first order effects may explain some of the scattering in the determination of the reflection coefficient. The results from the regular wave group tests may be more reliable than those from the regular wave tests partly because the mass-spring system will tend to amplify the second-order slowly varying forces.
3. The "effective breadth" of the structure may vary with the wave period of this particular model. The shortest wave may tend to pass beyond the caisson submerged which, in effect, reduces the breadth of the structure.

A number of other factors may affect the results as well. Due to the wave scattering reflection from the structure, the

recordings may be biased. Wave recordings were performed with and without the presence of the structure, and the differences in the wave heights recorded were found to be lower than 12%. Also wave reflection from the beach at the end of the flume will take place. However, these effects may be assumed to be of negligible importance because the wave heights enter the formulas squared due to the nonlinearity of the phenomenon.

For the evaluation of extreme slow drift mooring forces from the experimentally determined spectrum of the surge motion of the structure, one fact should be kept in mind. The envelope of the wave trace is not normally distributed but merely follows a Raleigh distribution, which is skew. When the envelope is squared, the distribution becomes even more skew. The slow drift force input acting on the structure will, therefore, deviate from a normal distribution which, in turn, may result in a slow drift force distribution which is also skew. This effect leads to an underestimation of the extreme mooring forces evaluated from the spectrum of the surge motion of the structure.

The study of Rye et al. reveals the fact that the drift force coefficient has to be established properly, because of its fourth power contribution; thus making the result very sensitive to the accuracy of this parameter. Newman (1974) states that the quantitative accuracy of the procedure for determining the drift force coefficient may vary from one case to another and recommends to establish this coefficient from experiments in a wave train consisting of two discrete wave systems, so that the influence of the low frequency variations due to second order potential effects which do not manifest themselves in regular wave tests are included.

SUGGESTIONS FOR FUTURE RESEARCH

From the above description of the research work carried out so far by several investigators, it is clear that the work is quite substantial particularly in the last two decades. Some of the short-comings and limitations of the research work carried out so far, need attention. The computation of drift force is centred on the drifting coefficient which is determined experimentally for different individual cases. This coefficient is being treated as reflection coefficient. The coefficient is established as a function of wave frequency in regular waves and used to compute the slowly varying drift forces in irregular seas. In this treatment, the influence of the low frequency pressure variation in irregular waves is not accounted for. The drift forces in shallow water is not investigated fully. The results of investigation made so far are more quantitative than qualitative. The extent of contribution of mass transport to the steady and slowly varying drift force is still to be investigated. Drift due to viscous effects need to be further examined. In nature, drift due to

waves is superimposed with the drift force due to currents and wind. The combined effect due to waves, currents and wind has to be taken into account in the design of mooring systems. The possibility of reducing the drift on floating structures in regular and irregular waves and thereby reducing the expenditure on mooring systems has to be investigated in detail.

ACKNOWLEDGEMENT

This paper is a part of the doctoral work carried out by the author at the Faculty of Marine Science and Technology, Tokai University, Japan. The author acknowledges the help of the staff of Ocean Engineering Department of the Faculty during the course of this work. The encouragement of Dr. M. Nishimura, Dean of the Faculty without which this work would not have been completed, is gratefully acknowledged.

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DEFINITION OF SYMBOLS USED

$R(\omega)$ - Drifting coefficient R which is a function of wave frequency ω

$$= \sqrt{\frac{F_d}{n\sigma g} \zeta_A^2} \quad 1 \quad \text{for square structure}$$

$$= \sqrt{\frac{F_d}{n\sigma g} \zeta_A^2} \quad 2a \quad \text{for circular structure}$$

F_d - Wave drift force

n - Shallow water effect

$$= \frac{1}{2} \left(1 + \frac{2Kh}{\sinh(2Kh)} \right)$$

K - Wave number ($= 2\pi/L$)

L - Wave length

h - Water depth below SWL

- a - Area coefficient
 $= \frac{\text{Sectional area}}{(B \times d)}$
- B - Breadth of the body along wave direction
- d - Draft of the body below SWL
- g - Acceleration due to gravity
- ζ_A - Incident wave amplitude
- l - Length of the square body perpendicular to the direction of wave propagation
- a - Radius of circular body
- ϵ_Y - Phase difference between incident wave and heaving motion
- ϵ_x - Phase difference between incident wave and surging motion
- $S_F(\mu)$ - Spectral density of low frequency drift force
- ρ - Water density
- $S_\zeta(\omega)$ - Spectral density of irregular waves
- μ - Frequency of slow drift oscillation
- \bar{F}_d - Average drift force.