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Validation of Numerical Codes Applied to Floating Offshore Structures

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Abstract

Herein a review is made on the validation problem of numerical codes applied to floating offshore structures. Since the dynamic behaviour of offshore floating structures in water waves is in general complex and nonlinear, a numerical approach seems to be promising. However, numerical codes are likely involved with uncertainties and they at the present status show apparent scatterness in typical bechmark tests, particularly in second-order wave forces. Convergence test is the minimum requirement for the validation of numerical codes. Some other practical check points are introduced to clarify the potential error sources. It is concluded that a standard procedure for validation must be urgently established sothat numerical methods can safely be used as a rational design tool.

1 Introduction

Towards the 21st centry, ocean activities of human beings are taking place in deeper ocean ever widely and intensively. In accordance with it, a strong demand arises to estimate the dynamic behaviour of floating bodies in ocean environment accurately for a rational design basis. However, water wave problems are complicated and inherently nonlinear. Its complexity compounds with the introduction of offshore structures into the wave field. Due to the nonlinearity and complexity of the problem, an exact solution exists seldom.

Numerical approach is thus regarded as a potential candidate to solve nonlinear problems. In fact various numerical methods have been developed and sometimes they provide useful engineering solutions. Recently such a trend is accelerated with the advent of high-speed computers. It is often reported in technical journals , however, that different programs yield different results even for a well-defined problem. In order to identify error sources and eventually to reduce discrepancies, technical committees of international organizations like ITTC and ISSC carried out a series of comparative studies for ships and offshore structures. Based on these studies, it is now generally acknowledged that numerical methods are not yet mature to replace the physical

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experiments completely for engineering design and that the validation procedure for numerical codes must be urgently established.

In this paper, validation problems are considered by a critical review on related works. A particular attention is paid on second-order forces by examining two comparative studies. It is well known that floating bodies in waves are subject to wave loadings, which may be divided into linear and nonlinear components of wave steepness. Since the inertia part normally dominates the wave force, the motion response of slender-type floating structures do not suffer seriously from scale effects and tank experiments with scaled models reflect the underlying physics fairly well. The second-order force is a small fraction of the total force and a careful management is vital to successful experiments. This second-order force of small amount can invoke large slow drift motions of a moored floating body and consequently deteriorates the operational condition seriously. Two comparative studies reviewed herein are as follows : One concerns with an eight-column semi-submersible initiated by Ocean Engineering Committee of the 20th ITTC. The other one was organized by Norsk Hydro dealing with a ship and a floater. Lastly discussions are made on the role of higher-order panel methods in terms of accuracy and efficiency.

2 Mathematical Background

From the mathematical point of view, solutions must satisfy the existence, convergence and uniqueness. However, general theorems do not exist for nonlinear problems [1]. The principal result for linear initial-value problems is the so-called Lax-Richtmyer equivalence theorem which states that stability is equivalent to convergence for consistent approximations to well-posed linear problems [2]. It may be interpreted in a loose sense that a consistent approximation to a well-imposed linear problem is stable if and only if it is convergent. Thus for quasi-linear problems and most engineering problems including those formulated in frequency domain, convergence is of central interest.

For numerical solutions, in addition to these we have to examine the consistence, discretization and accuracy, which may be explained as below [3] : (1) it is crucial to prove that a particular mathematical formulation has been correctly implemented in a numerical code ; (2) any specified discretization must be shown to satisfy the assumptions and approximations made during development : (3) the results of an analysis must be compared with physical behaviour to determine the extent to which the mathematical formulation reflects reality. In a strict sense, the first two are named as verification and the third one as validation. Verification can be made by comparing numerical results with analytic solutions developed for particularly tractable geometries by increasing the number of discretization to infinity, which is often called convergence test. Validation requires carefully designed experiments. There is a substantial amount of literatures addressing this topic, for example see [4]. Hereafter, validation is used in a wider sense including verification. Typical numerical techniques applicable for free surface problems are comprehensively reviewed in [5].

3 Comparative Studies

In order to identify the major uncertainties associated with numerical codes, comparative studies have been undertaken designed for specific problems. Examples are Takagi et al. [6] and Eatock Taylor and Jefferys [7]. In the former, computational and experimental first-order motion characteristics of a semi-submersible are compared and reported in the 17th and 18th ITTC [8,9]. Eatock Taylor and Jefferys compared the first-order hydrodynamic quantities and the mean drift forces for a tension leg platform and reported their result in the 9th ISSC [10]. These studies showed that there are considerable scatters in the numerically predicted hydrodynamic forces and also apparent discrepancies are found between numerical and experimental predictions. Herein we introduce other two comparative studies, which have not yet been thoroughly assessed.

3.1 ITTC Semi-submersible

A comparative study was pursued by the 20th ITTC OE Committee for an eight-column semi-submersible, which is slightly different from that used by Takagi et al.. The reason for choosing the new model was that intensive experiments for the model were conducted by the Ship and Ocean Engineering Laboratory, Mitsubishi Heavy Industries Ltd., Japan. The main characteristics and outline are given in [11]. Its configuration is illustrated below to help readers' understanding.

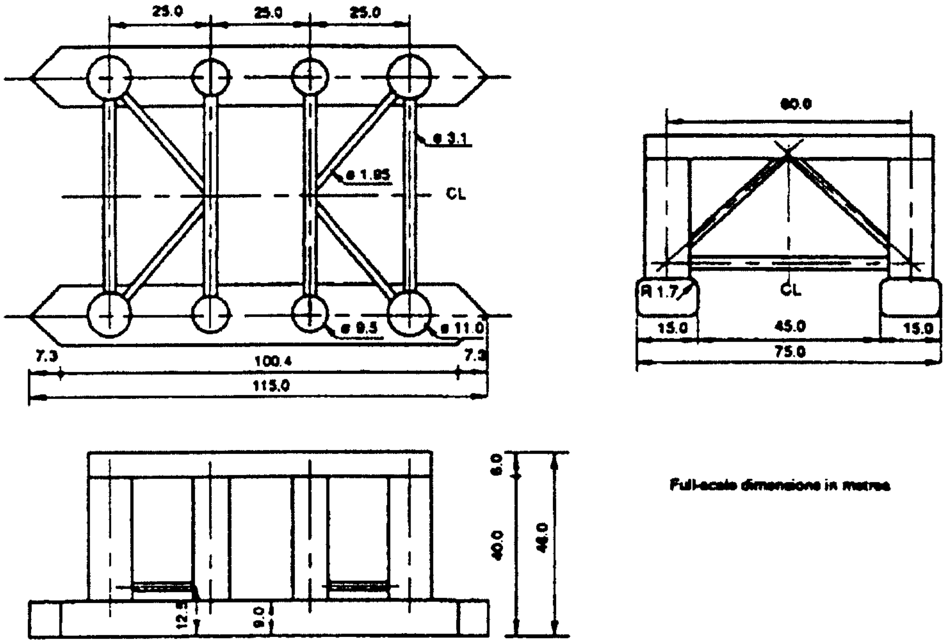


Figure 1: Semi-submersible Configuration

The total number of entries for this study was 24 and the details of their calculation methods were comprehensively summarized in the report, in which individual participant remained unidentified. Based on comparisons of numerical results, it was concluded that an increased number of panels do not necessarily lead to more accurate results and also that there are large differences in the drift forces from different programs especially for sway drift forces, although they show the same overall trend.

18 entries submitted numerical results for the drift forces. Among them, 7 entries used the farfield momentum method and the rest the direct pressure integration method. The mean and standard deviation are computed and depicted in Fig.2 for the surge drift force in head waves and in Fig.3 for the sway drift force in beam waves. In the figures, σ means one standard deviation, and the drift force is normalized by $\rho g \zeta_a^2 L$, where ζ_a denotes the wave amplitude and L ship's length. It is to note that the number of entries changes with wave period. For example, all entries are found only for those beam waves shorter than 13.6 sec. 15 entries submitted results for both the surge and sway drift forces for waves shorter than 26.6sec.

In the figures, solid lines correspond to the mean value and dotted lines to the values within one standard deviation. The model data are indicated by circles. It is observed that numerical results deviate considerably from experiments for short and long waves. The Coefficients of Variation (COV) for the surge and sway drift forces are 3.90 and 2.46, respectively. But the scatterness is sharply reduced to 1.74 and 1.41, when the forces are computed by the farfield method. Other factors like viscous effects and inclusion of all the braces do not affect the drift forces significantly. It is believed that these high values of COV are mainly caused by the fact that the model has 8 surface-piercing columns and the disturbed flow must be highly complex. In addition, it is to note that a small deviation casts a high value of COV because the mean values are close to zero. From this study, it may be concluded that the farfield method is less involved with scatterness in computing the horizontal drift forces compared to the nearfield method.

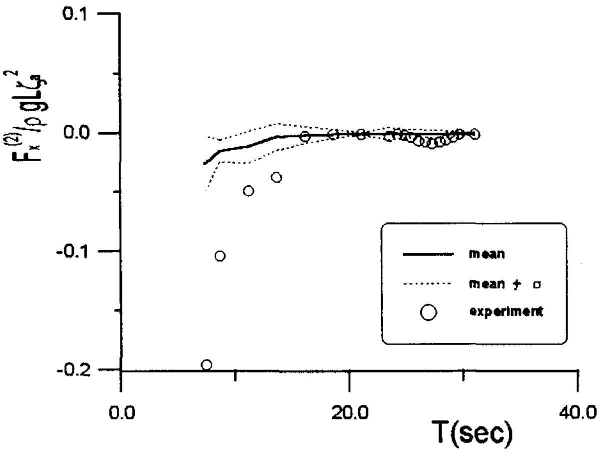


Figure 2: Surge Drift Forces on Semi-submersible in Head Waves

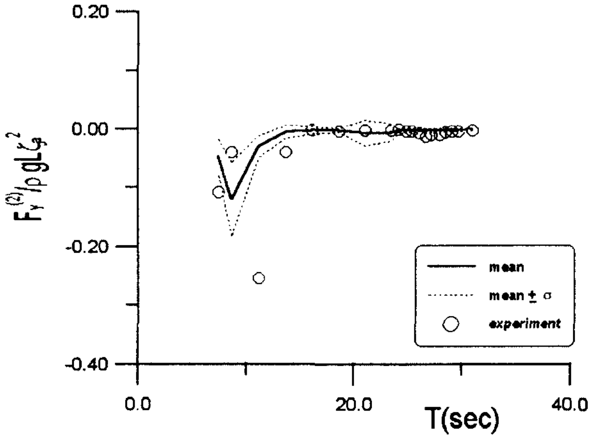
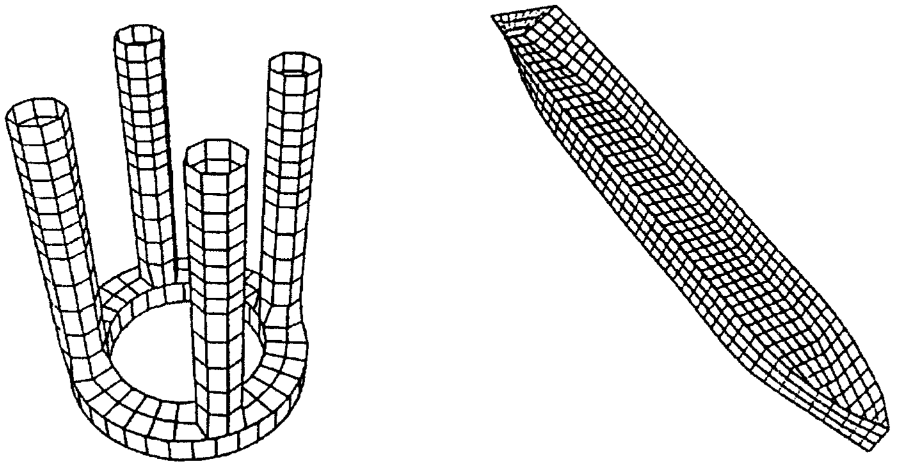


Figure 3: Sway Drift Forces on Semi-submersible in Head Waves

3.2 FPS 2000

Another interesting comparative study was undertaken by Norsk Hydro called FPS 2000 (Floating Production System 2000). The results from the study are documented in a series of reports [12,13] and partly cited in the 11th ISSC in viewpont of verification [3]. Nevertheless, it seems to be pertinent to examine this comparative study once again and to discuss in some detail. 23 institutions participated in the program by providing their estimates on hydrodynamic quantites and motion responses for two predefined floating production units. These are a Deep Draft Floater (DDF) and a Turret Moored Ship (TSP) as shown in Fig. 4.



(a) Deep Draft Floater (b) Turret Mored Ship

Figure 4: Typical Panel Representation for DDF and TPS

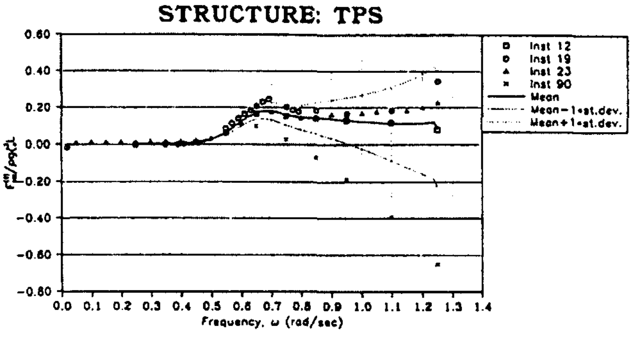
All institutions except one used three dimensional panel methods in computing hydrodynamic quantities. Meandrift forces were obtained either by direct pressure integration or by farfield momentum consideration. The scatterness of numerical results is again represented in terms of COV. For the DDF, the average value of COV for first-order hydrodynamic quantites was 16%, and it is reduced to 9% after a revision. But the average COV for the mean drift force still mounts to 18%. The revision was made by excluding those results which fall in the following criteria :
(1) wrong input has been reported.
(2) error in program has been reported.
(3) method other than 3D radiation/diffraction has been applied.
(4) unadequate discretization.
(5) unphysical results.

Meanwhile for the TPS, the first-order quantites have an average COV less than 3%, but the mean drift forces have an average COV of about 30%. It is interesting to note that the COV is in the order of one magnitude less, if the mean surge and sway drift forces are calculated by the momentum consideration. Fig.5 shows the mean drift forces in sway for TPS with 10 degree heading obtained by the direct pressure integration and the momentum consideration. The individual institution is again kept anonymous and represented only by number. It is clearly indicated in the figure that the momentum method is involved with less scattered results. Compared to the case of the eight-column semisubmersible discussed above, the scatterness has drastically decreased, which is most of all owing to the recent improvement of numerical techniques.

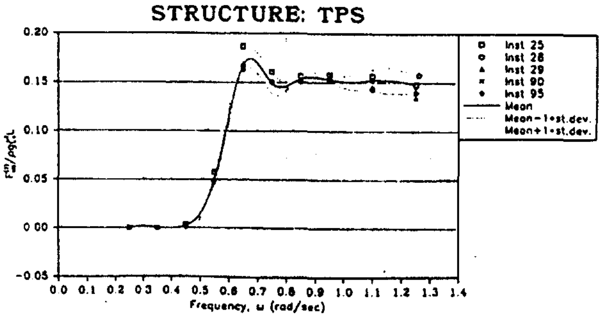
From the comparative study, it may be concluded that the first-order problem is computed quite accurately by most of computer codes, if a sufficient number of panels is used in discretization. But the mean drift force shows apparent discrepancies. The discrepancy in the horizontal components, however, can be significantly reduced by using the momentum method. In general, the input is consistent and the modelling is adequate for the problem under consideration, if the input satisfies
(1) area of wetted surface
(2) displacement
(3) hydrostatic parameters .

4 Convergence Test

In order to investigate the rate of convergence of the wave loads with increasing the number of panels, several runs were carried out at MIT with WAMIT program [14]. The maximum panels for discretization of the DDF was 7896. Extensive numerical experiments indicate that it is essential to concentrate panels near corners and waterlines for an accuarate evaluation of the drift forces. It is also pointed out in the case of linear hydrodynamic forces for the DDF that the lowest value was presented by an



(a) Direct Pressure Integration



(b) Momentum Consideration

Figure 5: Mean Drift Forces in Sway for TPS with 10 degree Heading

institution using few panels in the vertical direction on the columns, and thus obtained much lower wave excitations than others. It implies that hydrodynamic forces are sensitive not only to the total number of panels but also to the way of panel distribution. It is particularly the case for constant panel methods. Fig.6 illustrates the rate of convergence of the surge drift forces on the DDF as a function of the parameter 100/N, where N is the total number of panels. Two frequencies are considered. The numerical results obtained by the pressure integration method and the momentum method approach close as the number of panels tends to infinity. In all cases, the asymptotic rate of convergence appears to be linear, but the slope is slightly larger in the case of the pressure integration, particularly at higher frequencies. Based on this convergence test, it is possible to judge the degree of the consistence and convergence of the numerical codes.

In addition to the convergence test, the accuracy of numerical codes for computing hydrodynamic forces can be indirectly examined by

(1) low/high frequency estimates on added mass
(2) Haskind relation
(3) symmetry
(4) high frequency asymptotic values for drift forces

(5) momentum consideration.

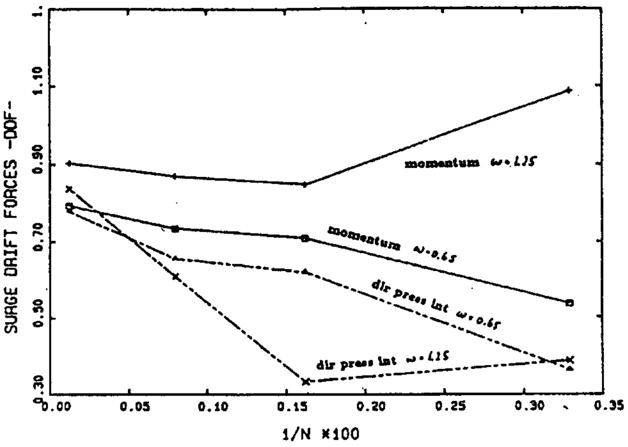


Figure 6: Convergence Test for Surge Drift Force for DDF.

5 Higher-order Panel Methods

An important aspect in numerical computations is the type of panels. Recently higher-order panels are popular and widely used [15], because they are capable of representing geometries and physical quantities more accurately. For example, constant panel methods (CPM) always render π as solid angle for convex-shaped body surfaces even for corners and edges, while higher-order panels can evaluate the solid angle more accurately. Thus the numerical solutions of velocity potential by using constant panel methods always approach exact values from the upper bound.

Xü and Yue [16] intensively investigated the convergence problem of higher-order panels for various types of boundary conditions by using bi-quadratic curvilinear elements (QBEM). They clearly demonstrated that QBEM is superior to CPM for any type of boundary conditions. For example, for a required maximum relative error of 10^{-3}, QBEM and CPM need a total number of panels approximately 150 and 2,000, respectively, even for the case of a pure Neumann problem on a smooth boundary. It implies that higher-order panel methods are two orders of magnitude more efficient than CPM. Liu et al. [17,18] computed the linear and mean second-order hydrodynamic forces acting on the ISSC TLP by using 9-node quadratic boundary elements and compared their results with those from a constant panel method. They demonstrated that their higher-order panel method needs much fewer elements and less computing time with keeping higher accuracy than the constant panel method. Another feature in higher-order panel methods is that interpolation functions of higher order are introduced for representing physical quantities. Thus when derivatives of the physical quantities are sought, interpolation functions are to be differentiated instead of the physical quantity itself. Owing to these operations, higher-order panel methods do not invite numerical distortions in wave dispersion nor numerical dampings as much as constant panel methods do [19]. It also gives continuous differential values upto the corresponding order of the interpolation functions used, which appear very sensitive where the surface curvature is highly complex [20]. The latter plays an important role, when nonlinear forces on realistic hull forms are evaluated. A comprehensive review on higher-order panel methods in relation with numerical wave tanks is made quite recently by Kim [21].

6 Conclusions

Although most numerical codes now available are able to provide reliable linear hydrodynamic forces and motion responses on and of floating offshore structures, they show apparent discrepancies in second-order forces. It is generally the case that the farfield momentum method is less involved with scatters than the direct pressure integration method in the case of the horizontal drift forces. There are ample evidences that higher-order methods are superior to constant panel methods in terms of accuracy and efficiency. A standard validation procedure for numerical codes is urgently required so that they can safely be used as a rational tool in engineering design.

Acknowledgement

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References

[1] Lenoir, M. and Martin, D., "An Application of the Principle of Limiting Absorption to the Motions of Floating Bodies," *J. Math. Anal. Appl.*, Vol.79, 1981, pp.370-83.

[2] Lax, P.D. and Richtmyer, R.D., "Survey of the Stability of Linear Finite Difference Equations", *Comm. Pure and Applied Math.*, Vol.9, 1956, pp. 267-293.

[3] Proceedings 11th ISS, 1991, Loads Committee

[4] Freitas, C.J., "Editorial Policy Statement on the Control of Numerical Accuracy", *ASME J. Fluid Engng.*, Vol.115, 1993, p.339.

[5] Yeung, R.W., "Numerical Methods in Free-Surface Flows", *Annaul Review of Fluid Mechanics*, Vol.14, 1982, pp.395-442.

[6] Takagi,M., Arai,S.I., Takezawa,S., Tanaka K. and Takagi,N., "A Comparison of Methods for Calculating the Motion of Semisubmersibles", *J. Ocean Engng.*, Vol.12, 1985, pp.45-97.

[7] Eatock-Taylor,R. and Jeffreys,E.R., "Variability of Hydrodynamic Load Prediction for a Tension Leg Platform", *J. Ocean Engng.*, Vol.13, No.5, 1986, pp.449-490.

[8] Proceedings 17th ITTC, 1984, Ocean Engineering Committee.

[9] Proceedings 18th ITTC, 1987, Ocean Engineering Committee.

[10] Proceedings 9th ISSC, 1985, Loads Committee.

[11] Proceedings 20th ITTC, 1993, Ocean Engineering Committee.

[12] Nielsen,F.G., Herfjord,K. and Loeken,A., "Floating Production Systems in Waves Results from a Comparative Study on Hydrodynamic Coefficients, Wave Force and Motion Responses", *Norske Hydro Reserach Centre*, 1990.

[13] Nielsen,F.G. and Herfjord,K., "FPS 2000 Project 1.1 Comparative Study Evaluation of Results and Discussion of Practical Methods", *Norske Hydro Reserach Centre*, 1992.

[14] Korsmeyer, F.T., Lee, C.-H., Newman, J.N. and Sclavounos, P.D., "The Analysis of Wave Effects on Tension-Leg Platforms", *OMAE'88*, Houston.

[15] Brebbia, C.A. and Domingez, J., " Boundary Elements", *Computational Mech. Publ.*, Southampton.

[16] Xü, H. and Yue, D., "Computations of Fully-Nonlinear Three-Dimensional Water Waves", *Proc. 19th Symp. on Naval Hydrodynamics, Seoul*, 1992.

[17] Liu, Y.H., Kim,C.H. and Lu, X.S., "Comparison of Higher-Order Boundary Element and Constant panel Methods for Hydrodynamic Loadings", *J. of Offshore and Polar Engng.*, Vol.1, No.1, 1991, pp.8-16.

[18] Liu, Y.H., Kim, C.H. and Kim, M.H., "The Computation of Mean Drift Forces and Wave Run-Up by Higher-Order Boundary Element Method", *Proc. 1st Intern. Offshore and Polar Engng. Conf., Edinburgh*, Vol.1, 1991,pp.476-483.

[19] Nakos, D.E. and Sclavounos, "On Steady and Unsteady Ship Wave Pattern", *Journal Fluid Mechanics*, Vol.215, 1990, pp.263-288.

[20] Hong, S.Y. and Choi, H.S., "Steady and Unsteady Ship Waves by a Higher-Order Boundary Element Method", *Proc. 20th Symp. on Naval Hydrodynamics,* Santa Barbara, 1994.

[21] Kim, C.H., "Recent Progress in Numerical Wave Tank Research : A Review", *Proc. 5th Intern. Offshore and Polar Eng. Conf.*, The Hague, 1995.