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ALTERNATIVE METHODS FOR THE NUMERICAL ANALYSIS OF RESPONSE OF SEMISUBMERSIBLE PLATFORMS IN WAVES

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ABSTRACT

The numerical methods that may be used to predict the linear responses of semisubmersible and tension leg platforms in waves are reviewed and criticized. Simple methods, such as the one proposed by Hooft /1/, appear to be easy to implement and fast computationally, but fail to account for interaction and free-surface effects. On the other hand three-dimensional diffraction-radiation codes require fine meshes and are expensive to run.

Two alternative methods are proposed here. The first one is only approximate, but offers valuable improvements over the Hooft's method, at a small increase in computer cost. It is therefore well suited for the stages of preliminary design. The second one, based on the theory of multipoles /7/, is an exact method, but allows for finer meshes than the usual diffraction-radiation codes.

ALTERNATIVE METHODS FOR THE NUMERICAL ANALYSIS
OF THE LINEAR RESPONSE
OF SEMISUBNERSIBLE PLATFORMS IN WAVES

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The numerical methods that may be used to predict the linear responses of semisubmersible and tension leg platforms in waves are reviewed and criticized. Simple methods, such as the one proposed by Hooft /1/, appear to be easy to implement and fast computationally, but fail to account for interaction and free-surface effects. On the other hand three-dimensional diffraction-radiation codes require fine meshes and are expensive to run.

Two alternative methods are proposed here. The first one is only approximate, but offers valuable improvements over the Hooft's method, at a small increase in computer cost. It is therefore well suited for the stages of preliminary design. The second one, based on the theory of multipoles /7/, is an exact method, but allows for finer meshes than the usual diffraction-radiation codes.

INTRODUCTION

The design of semisubmersible and tension leg platforms requires accurate and efficient numerical tools in order to minimize their wave responses. Columns and pontoons dimensions must be carefully selected in order to achieve a proper cancellation frequency and minimize the vertical loads over a wide range of wave frequencies. As the vertical loads acting upon the pontoons and at the bases of the columns are, at large wave periods, 180 degrees out of phase, small errors on either component may result in large errors for the global loads and lead to an improper design of the hull.

In this paper we shall first review two existing methods that are commonly used to compute the linear responses of semis and TLPs. Through simple illustrative cases advantages and drawbacks of both methods will be outlined, and some key phenomena, such as free-surface and interaction effects, will be investigated.

Then, in a second part, two new alternative methods will be proposed. The first one, which only yields an approximate solution, is well suited to preliminary designs or parametric studies. The second one solves the exact problem, and offers the same range of accuracy as the usual three-dimensional diffraction-radiation codes, but at a smaller computational effort. Moreover it is not restricted to semi-type geometries.

I-THE "CLASSICAL" METHODS

A common characteristic of semis and TLPs is their repetitive geometries: vertical columns running through the free-surface, and deeply submerged horizontal pontoons. Cross dimensions of the columns and of the pontoons are small as compared to their lengths, and as compared to the design wave-lengths. Nevertheless they are larger or of the same order as the wave amplitudes, so that viscous effects can be neglected on a first approximation. Another important point is that the natural frequencies of their motion do not belong to the range of the wave frequencies, so that no resonant LINEAR response may occur, and the knowledge of damping (be it viscous or potential) is not required to derive their R.A.O.s (we insist that this holds only for the linear response; resonant motion may occur due to non-linear excitation, and then damping plays a crucial role; but this is beyond the scope of the present paper).

An old, but still widely used, method that allows the linear response of semis to be computed is the so-called "Hooft's method"/1/. It consists in splitting the hulls into elementary, non interacting elements: pontoons and columns, and computing the hydrodynamic characteristics of each element separately. They are then summed up to derive the added-mass matrix and the excitation loads. Infinite fluid added mass coefficients are used and the transverse loads are obtained in a

Morison's equation manner. A minor difficulty consists in evaluating the vertical loads acting on the columns. The usual trick is to integrate the dynamic pressure due to the incident wave field at the bases of the columns, or, better, at fictitious bases slightly below. Other refinements may easily be implemented, for instance using Mac Camy - Fuchs coefficients to derive the horizontal loads upon the columns.

Because of its simplicity computer codes that are based on the Hooft's method are easy and cheap to run, and they are therefore well suited to the stages of preliminary designs. Some main drawbacks are that they yield no information on important features such as the drift forces, or the wave run-up under the deck. Last, as they are based on an approximate theory, they may not be used for the final stages of the design.

An alternative is to run three-dimensional diffraction-radiation codes, which solve the exact linear problem. One should then expect the "exact" solution to be obtained, however some recent comparisons between different codes /2/ /3/ have shown considerable scatters in the results, with the simple models based upon the Hooft's method providing better agreements with the experimental data in some cases.

The main and probably only reason for these discrepancies is due to differences in the meshes that were used to model the hulls. Because of the intricate geometry of the semis, a fine mesh is required, and this leads to prohibitive computer cost. As global vertical loads result from the sum of the loads upon the column bases and upon the pontoons (which are of opposite signs for large wave periods) small errors upon either component may result in large errors for the global loads. Therefore different meshes may yield quite different results.

To illustrate this point, let us consider the ISSC tension leg platform case /3/, for which calculations based upon two different meshes have been performed (Figure 1). The meshes used for the columns are the same in both cases, however the meshes of the pontoons are different: in the first case the cross section of the pontoons is described with 4 elements, in the second one 12 elements are used. Little differences may be observed for the surge diffraction force (Figure 2), however very large ones are obtained for the heave diffraction force, where the cancellation effect takes place (Figure 3).

On the same figure are shown the obtained results when the Kelvin part of the Green function for the pontoons singularities is removed. Hardly any differences can be observed. This shows that, because of their large submergence, the pontoons are quite insensitive to the presence of the free surface.

As a further check calculations were performed on one isolated pontoon, with different meshes (Figure 4). The obtained results for the heave added mass and for the heave diffraction force are shown on Figures 5 and 6, and compared to the values obtained using the Hooft's method. As the mesh is refined the obtained values become very close. One understands that in some cases the Hooft's method may well perform better than the sophisticated diffraction-radiation codes, if the meshes are not adequate.

Before going on to the presentation of the new methods that are proposed here, it seems appropriate to elaborate further on some complementary tests that illustrate the importance of interaction effects.

- column-pontoon interaction

In order to gain some more insight into the validity of the Hooft's method, as far as splitting the hull in non-interacting components, some numerical tests were carried on simple structures consisting of one column and two half-pontoons. The idea was to run a diffraction code on the column alone and on the two half-pontoons alone, and then on the complete structure, and check how far the obtained pressure distributions on the two sub-structures could compare with the pressure distribution on the complete structure. Different configurations were considered: column standing on the two half-pontoons (semi), or pontoons running into the column (TLP). Some difficulty occured in the analysis, due to the fact that local pressures are not quite representative of the loads (which require surface integration), but a somewhat general conclusion could be reached: that is the column "feels" the pontoons in only a small neighborhood around their junction, whereas the pontoons "feel" the column at large distances from the junction Obviously this feature has to do with free-surface effects: the column generates a diffraction potential that attenuates slowly with the horizontal distance R (as $1/\sqrt{R}$), whereas the pontoons modify the flow only locally. An important conclusion is that, close to the free surface, the flow depends little on the presence of the pontoons, but mostly on the columns distribution.

- column-column interaction

The ideal case of infinitely deep vertical columns in a wave field has been considered by many investigators /4 /5/. A recent analysis, that can easily be extended to an arbitrary number of columns, has been proposed by Mac Iver and Evans /6/. By assuming that the waves diffracted by each column can locally be considered as plane waves when they interact with another column, they reduce the problem to a linear system involving as unknowns the N*(N-1) complex amplitudes of the equivalent plane waves. When this system is solved an approximation of the total flow can be constructed in the whole fluid domain at little cost. As a further proof that this flow is little altered close to the free surface if the columns are truncated and if pontoons are present, we present on Figure 7 the R.A.O. of the free surface elevation at the center point of a 5 columns system with pontoons, as obtained from experimental results, with the values obtained from Mac Iver and Evans'theory. The agreement appears to be excellent.

How important is column-column interaction is reflected by the fact that the R.A.O. of the free surface elevation is quite different from 1, even at relatively large values of the wave period. Another indication is given by experimental values of the drift force, which typically exhibits a peak at the frequency corresponding to the sloshing mode between the columns (so that the wave length be equal to twice the horizontal distance between the centers of the columns).

11-NEW PROPOSED METHODS

II-l An approximate method

This method is an improved version of the Hooft's method and results logically from the previous remarks on interaction and free-surface effects.

We shall here only consider the diffraction problem, eventhough the radiation problem can be solved in a similar way.

Given the incident wave field (Airy wave), the first step is to derive the associated diffraction potential due to the columns only, assumed to be infinitely deep. At this stage the theory proposed by Mac Iver and Evans is used.

The following step is to truncate the columns and introduce the pontoons. At this point two different options are available:

1. the first one is to calculate the loads at the bases of the columns and on the pontoons in just the same way as in the Hooft's method, but where the "incident" wave field includes the diffracted waves due to the columns;

2. the second one is to generate a mesh of the pontoons and of the bottom parts of the columns (Figure 8), and use Rankine singularities to solve the diffraction problem, with the same "incident" wave field as in option 1. As Rankine singularities do not depend on the wave frequency the matrix can be built up once and for all prior to solving the problem for a set of wave frequencies.

A theoretical difficulty inherent to this method stems from the fact that the diffraction potential due to the infinitely deep columns is singular along their center lines and cannot be readily applied on their bases once they are truncated. In the numerical models some averaged values are used, for which no theoretical justification can be brought, and in this sense the proposed method duly deserves the adjective "approximate". However the practical justification is obvious when one compares the obtained results with numerical ones obtained by running a 3-D diffraction-radiation code (with a correct mesh). This is shown on Figure 9 which is the same as Figure 3, but where the results obtained with this new approximate method are included, together with the values given by the classical Hooft's method.

II-2 The method of multipoles

This is an exact method that again results logically from the discussions carried in the first paragraph.

The basic idea is to distinguish within the diffraction (or radiation) potential the Rankine component and the Kelvin component. For intricate geometries the Rankine component varies very quickly along the hull and therefore its determination requires a large number of facets. On the other hand, if the body is deeply submerged, the Kelvin component is much less sensitive to small variations of the geometry, and it may be obtained in an alternative way.

The proposed method may be simply illustrated by considering the case of a completely submerged structure. It is briefly outlined below but further details may be obtained in /7/.

The first step is to solve the diffraction problem by using a distribution of Rankine singularities. A diffraction potential φ_R is obtained that satisfies the boundary conditions on the body but not on the free surface.

The second step is to look for an equivalent representation of this potential through Rankine multipoles located at the center of the submerged body. Elementary multipoles are space derivatives of the elementary source singularity:

$$m_{lmn} = -\frac{1}{4\pi}\frac{\partial^l}{\partial x^l}\frac{\partial^m}{\partial y^m}\frac{\partial^n}{\partial z^n}\frac{1}{R}$$

One **may** show that for those two potentials to be equal in the fluid domain it suffices that they be equal on a sphere surrounding the body. Through least-square fit the equivalent densities of the Rankine multipoles are determined (the infinite series of multipoles being truncated at some order). *It* is then easy to add up to the Rankine multipoles their Kelvin counterparts, to produce a potential that satisfies the free surface condition but unfortunately not the body condition anymore.

However it is possible to generate an iterative process by going back to the first step, where the right-hand side of the body boundary condition is corrected by the quantity $\partial \varphi_{KM}/\partial n$, where φ_{KM} is the Kelvin part of the multipoles, and going through the same operations again and again until convergence is achieved, to some specified accuracy. Some numerical tests carried out with this method have shown that it is 10 to 20 times faster than the traditionnal diffraction theory /7/.

In the case of a structure such as a semi-submersible platform the technique consists of marrying, on the one side Rankine singularities and multipoles for the pontoons and the bottom parts of the columns, and on the other side usual Kelvin singularities for the upper parts of the columns. For instance, in the case of the ISSC tension leg platform a 480 panels mesh was performed. Of these only 20% carried regular Kelvin singularities, whereas the remaining 80% carried Rankine ones and were combined with 8 series of multipoles located at the centers of the pontoons and inside the columns. The obtained results agree perfectly with those given by the reference diffraction-radiation code for the same mesh.

DISCUSSION

The two new proposed methods have been tested upon a variety of cases, and their results compared with those given by the Hooft's method and by a diffraction radiation code. For instance Figure 10 shows the heave response of a 4 columns catamaran-type semi, as obtained from our new approximate method, from the multipole code, and from the 3-D diffraction-radiation code.

As was mentioned earlier a definitive advantage of our approximate method over the Hooft's method is that it provides estimates of the free surface motion (Figure 11) and of the horizontal drift force (Figure 12), the knowledges of which *are* valuable at preliminary design stages.

Of importance are some figures of comparative computer costs. As a reference case the complete hydrodynamic analysis (8 periods, 3 headings) of the ISSC TLP was retained, with a 480 panels mesh. Corresponding computer times (adimensionalized) are given below:

Hopft's method:	1
New approximate method (option 1):	2
New approximate method (option 2):	60
Multipoles method:	200
Diffraction radiation code:	2500

CONCLUSION

Two new alternative methods have been proposed, for the linear hydrodynamic analysis of semisubmersibles. These methods result from thorough examinations of free-surface and interaction effects, and they appear to fill in a gap between the Hooft's method, which is overly simplified, and the diffraction-radiation codes, which are prohibitively expensive for preliminary designs.

Extensions of these new methods to the analysis of the non-linear behavior of semis in regular or irregular waves appear to be possible. Some of them are already under way.

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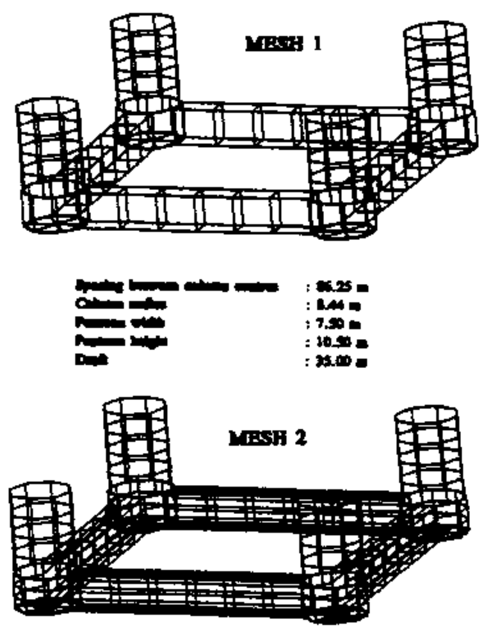

Fig. 1: Meshes of the ISSC tension leg platform

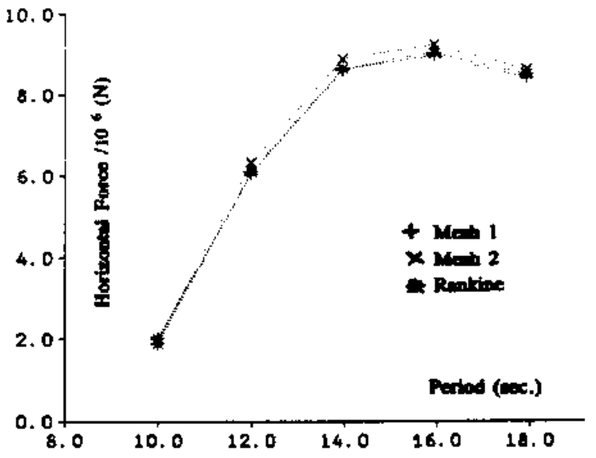

Fig. 2: Surge diffraction force (ISSC TLP)

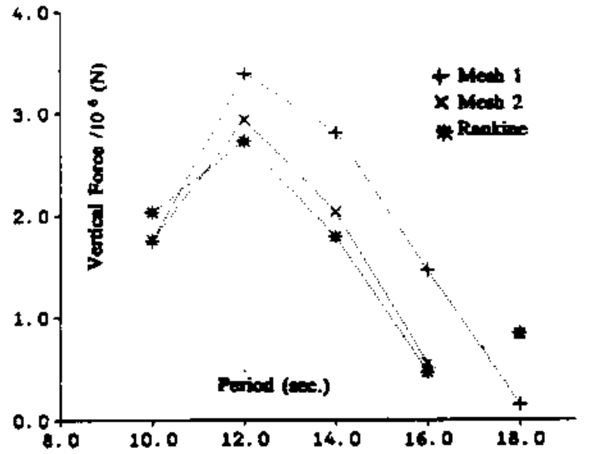

Fig. 3: **Heave** diffraction force (ISSC TLP)

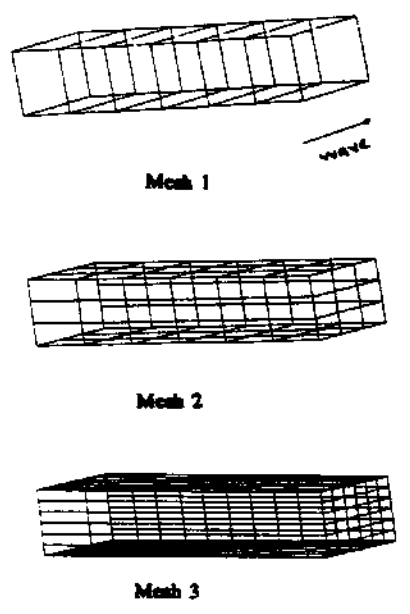

Fig. 4: Meshes of one half pontoon

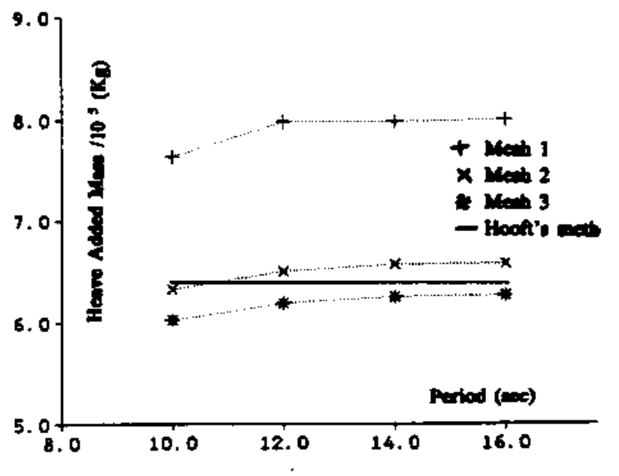

Fig. 5: Heave added mass

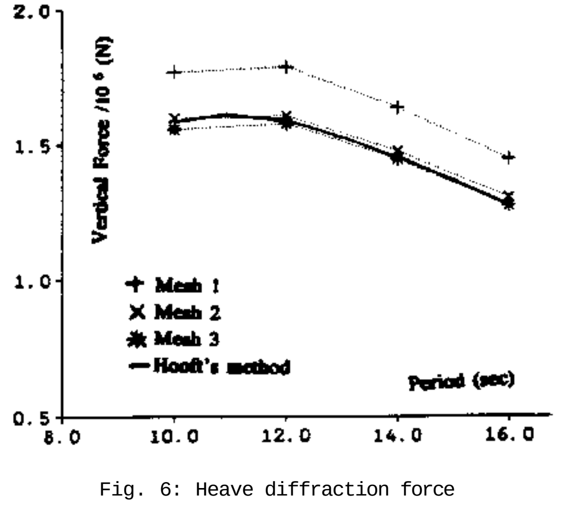

Fig. 6: Heave diffraction force

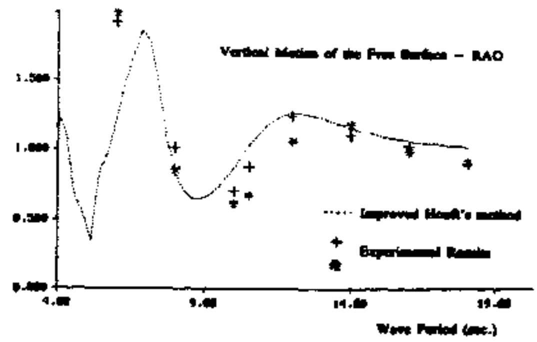

Fig. 7: R.A.O. of the free surface elevation at the center point of a pentagonal tension leg platform

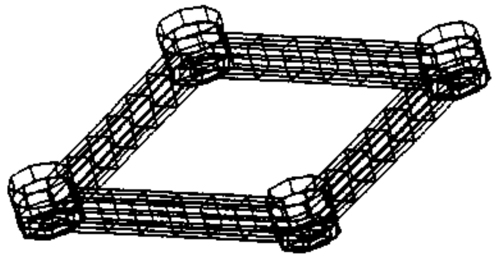

Fig. 8: Mesh of the pontoons and of the bottom parts of the columns (ISSC tension leg platform)

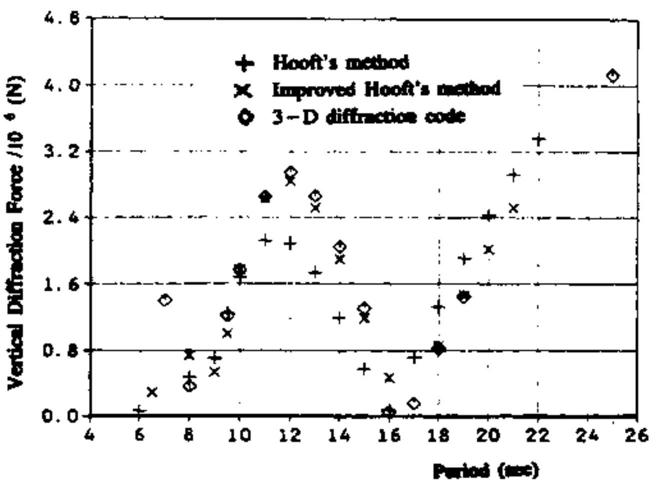

Fig. 9: Heave diffraction force

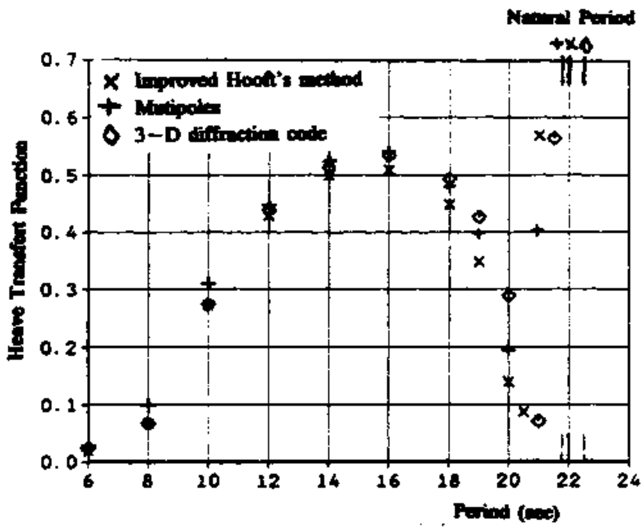

Fig. 10: **Heave** response (4 columns catamaran-type semi)

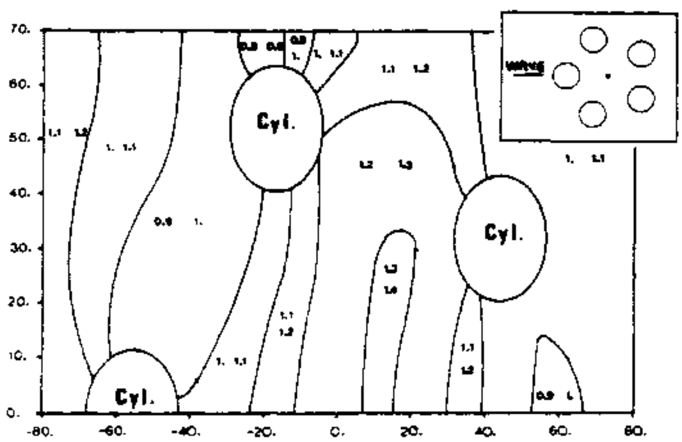

Fig. 11: RAO of the free surface vertical motion for a pentagonal platform (wave period: 12 seconds)

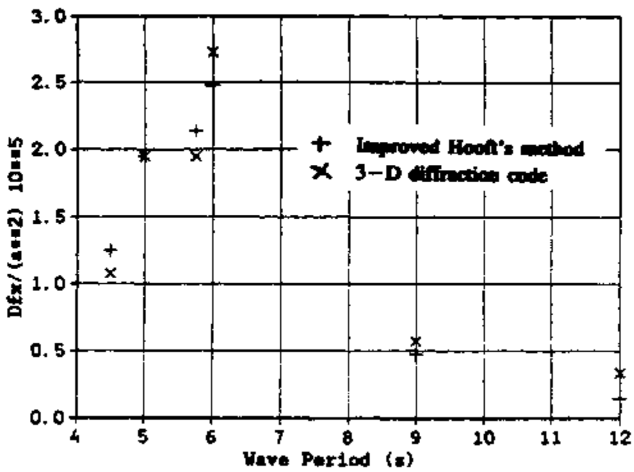

Fig. 12: Horizontal drift force on the ISSC tension leg platform