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Hydrodynamic Behavior Of Cutter Suction Dredges In Waves

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SUMMARY

When dredging in near-shore areas dredges have to operate in waves. Use is often made of a spud-pole and ladder side wires to remain on station in such environmental conditions.

During dredging operations either the cutter head is working in the breach or the cutter ladder is hoisted for e.g. replacement of the cutter head. When comparing both conditions the behavior of the dredge will essentially be different. The characteristics of the dredge's behavior obtained from model tests in both conditions will be shown.

In waves with the cutter ladder in hoisted condition the mooring loads have to be taken by the spud pole and the ladder side wires. For this condition a procedure is developed to compute the motions and spud pole forces. The computed motions of the dredge and the spud pole forces are compared with experimental data. In addition, the motions of the dredge in free-floating condition are computed to show the effect of the mooring system on the motions.

INTRODUCTION

In order to dredge trenches for pipe lines and approach channels to terminals in hard soil and in relatively shallow water, floating cutter dredges will often be used. In near-shore areas dredges have to work in waves. Often use is made of a spud pole mooring system to remain on station.

An important feature of the spud pole mooring, compared to other mooring systems of floating dredges, is the relatively high stiffness of the mooring system. One of the reasons for this high stiffness is the required accurate positioning of the cutter head in the breach.

Knowledge of the motions of the cutter head and the forces on the spud pole and the cutter head is of vital importance for the production and consequently for the economics of the project and from the point of view of the strength of the structure.

In studying the motions of and forces on the cutter suction dredge two situations may be distinguished during dredging operations. One situation is the condition that the cutter head is working in the breach, while the other is the condition that the cutter ladder is hoisted for instant replacement of the cutter head. The characteristics of the mooring loads and of the motions of the dredge are essentially different when comparing both mooring conditions.

The Characteristic Behavior of the Dredge with the Cutter Ladder in the Hoisted Condition and in the Working Condition.

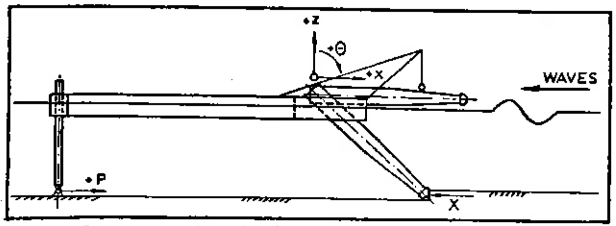


Fig. 1. Cutter suction dredge with cutter ladder in hoisted and in working condition.

Figure 1 represents both conditions in head waves. In the working condition the dredge is restrained by the spud pole, by the ladder swing wires and by the cutter head itself. Due to this mooring system the motions of the dredge are restricted. Because the cutter head may come out of the breach impact loads can occur on the cutter head. With the cutter ladder in the hoisted condition the mooring loads have to be taken by the spud pole alone. It is assumed that the spud pole end acts as a ball-joint at the sea bed. Due to the one-point spud pole mooring the dredge can carry out motions under the influence of waves.

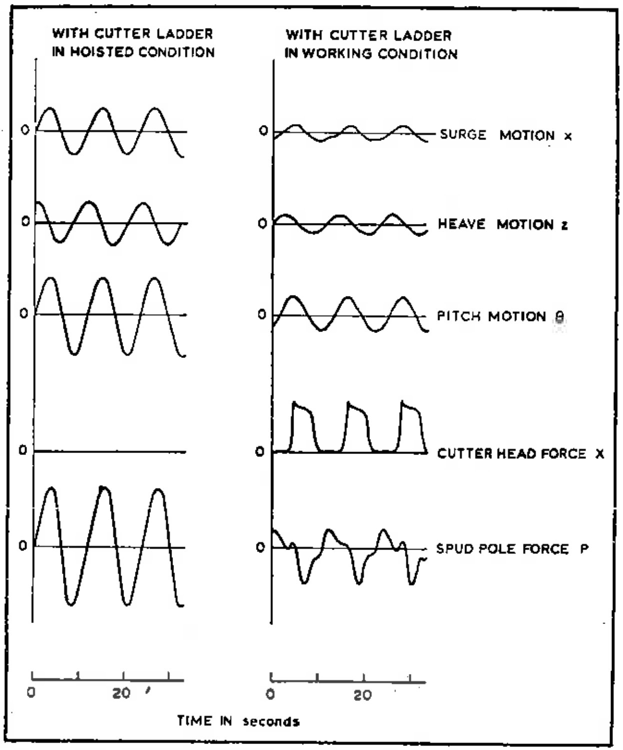


Fig. 2. The characteristics of the motion and force records in regular head waves.

Figure 2 illustrates typical dredge motions, the spud and cutter head forces. The results were obtained from model tests in regular head waves. Photographs No. 1, 2 and 3 show respectively the spud guiding system, the (scaled) elastic spud pole connected at the sea bed (ball-joint) and the simulation of the cutter head in the breach. The stiffness of the breach was assumed to represent rocky soil.

(For a detailed description of the model tests, see Proceedings of the Ninth WODCON, Vancouver, 1980 p. 899.)

Figure 2 clearly shows that the characteristics of the motions of the dredge and the mooring loads are essentially different when comparing both mooring conditions.

The Cutter Ladder Hoisted Condition as Linear Mass-Damper-Spring System.

In order to compute the motions and mooring loads in

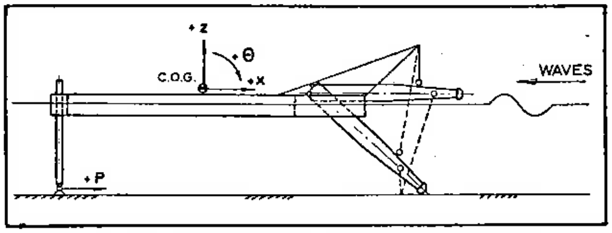


Fig. 3. The cutter suction dredge in head waves.

the cutter ladder hoisted condition the dredge will be treated as a linear system. To illustrate the procedure to compute the motions and the mooring loads we will consider a situation in which the dredge is lying in regular head waves, see Figure 3.

In still water (without waves) the dredge is in an equilibrium position. This is caused by the principles of Archimedes, which means that the weight of the floating structure is counter-balanced by the hydrostatic forces of the displaced volume of the fluid. When regular waves are involved the pressure in the fluid and so the external forces on the dredge will not be static but will fluctuate. Due to these oscillating wave exciting forces the floating dredge will move according to Newton's law of dynamics.

As an example, for the system with one degree of freedom in this case the pitch direction θ, the oscillating wave exciting moment consequently will result in oscillating pitch motions. Due to these motions of the dredge additional moments will be exerted by the fluid on the vessel. These moments are called the hydrodynamic and hydrostatic reaction moments. Besides the reaction moments exerted by the fluid, mechanical reaction moments will also be generated by the mooring system. For the system with one degree of freedom (pitch direction) Newton's law of dynamics with respect to the C.o.G. can be expressed as follows:

$$I.\ddot{\theta} = M_{wave} + M_{reaction} = M_{external}$$

in which

I = mass moment of inertia of the dredge

$\ddot{\theta} = d^2\theta/dt^2$ = pitch acceleration

M_{wave} = wave exciting moment

$M_{reaction}$ = reaction moments.

The external wave moment and reaction moments are at first approximation linearly proportional to the wave height. If the wave height increases by a factor two not only the wave exciting moment but also the motion (and therefore the reaction moments) increases by a factor two. This approximation implies that the total fluid load on a body in waves can be regarded as the sum of the loads exerted by the waves on the captive barge and the loads due to forced oscillatory motions of the barge in still water without waves.

Figure 4 shows the sum of the external fluid loads on the dredge schematically.

A more detailed description of the external reaction moments acting on the dredge due to pitch motions in still water will be given below. The hydrodynamic reaction moment can be decomposed in reaction moments due to the angular acceleration and angular velocity of the barge in still water:

- **Moment due to added inertia**

This moment is proportional to and directed opposite to the pitch acceleration of the barge and can be interpreted as an apparent increase of the moment of inertia. Due to acceleration in the motion of the barge

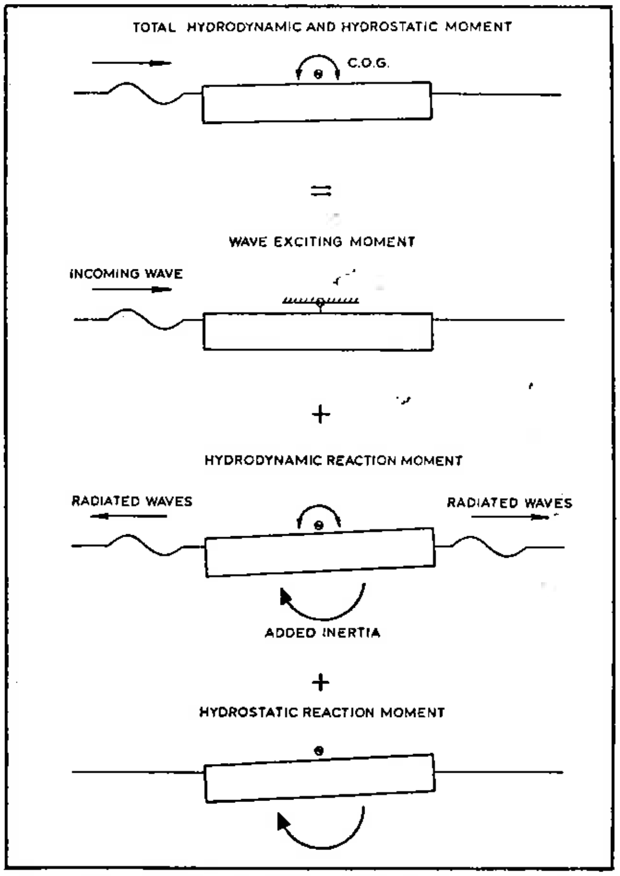


Fig. 4. The principle of superposition of the hydrodynamic and hydrostatic moments.

the surrounding water is also accelerated. Physically the moment of added inertia stands for the reaction moment caused by the pressures of the accelerated mass of water surrounding the barge. The moment due to added inertia in pitch direction caused by the acceleration θ can be written as $-a_{\theta\theta}.\theta$, in which $a_{\theta\theta}$ = coefficient of the moment due to added inertia.

- **Moment due to potential damping**

For large volume bodies like barges this moment is proportional to and directed opposite to the pitch velocity of the barge. In initially still water waves are generated radiating away from the barge due to the oscillating motions of the barge. These radiated waves transport energy (away) from the barge. This energy represents the damping of the system and is known as potential damping.

The moment of potential damping in pitch direction caused by the angular velocity θ can be written as $-b_{\theta\theta}.\theta$, in which $b_{\theta\theta}$ = coefficient of the moment due to potential damping and $\theta = d\theta/dt$ = angular pitch velocity.

The hydrostatic and mechanical reaction moments are due to the oscillating displacements of the barge in still water.

- **Hydrostatic reaction moment**

This moment is proportional to and directed opposite to the trim angle. Due to the static angle around the C.o.G. in still water a hydrostatic restoring moment will occur, see Figure 4. This hydrostatic restoring moment can be written as $-C_{\theta\theta h}.\theta$, in which $C_{\theta\theta h}$ = hydrostatic restoring coefficient. For the pitch direction $C_{\theta\theta} = MG_1.\Delta$, in which MG_1 = metacentric height in longitudinal direction and Δ = displacement weight of the barge.

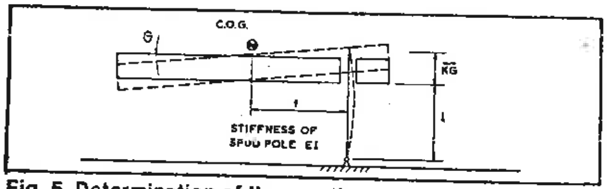


Fig. 5. Determination of the reaction moment caused by the mooring system.

- **Mechanical reaction moment**

The mechanical reaction moment is caused by the mooring system, in this case the spud pole. See Figure 5. It is assumed that in a rocky sea bed or in compacted sand no horizontal shift of the spud pole end will occur so that the characteristics of this point can be a ball-joint.

Using the load-deflection formula and assuming that $f.\theta \ll 1$ this reaction moment is proportional to and directed opposite to the trim angle. The mechanical reaction moment in pitch direction can be written as $-C_{\theta\theta s}.\theta$, in which $C_{\theta\theta s}$ = mechanical restoring coefficient. For the pitch direction $C_{\theta\theta s} = 3EI/1^3 (1 + KG)^2$.

Substituting all external moments in Newton's law of dynamics the equation of motion is derived. For example in pitch direction we will find:

$$(I + a_{\theta\theta})\,\ddot{\theta} + b_{\theta\theta}\,.\,\theta + (C_{\theta\theta h} + C_{\theta\theta s})\,.\,\theta = M_{wave}$$

With the dredge in head waves there will be three motions namely pitch $(\ddot{\theta})$, surge (x) and heave (z) as indicated in Figure 3.

In general the motions of each of these three components will cause reaction moments and forces in each of the 3 directions. This will lead to a set of coupled equations for the combined surge, heave and pitch motions. (For the complete set of equations see Proc. Ninth WODCON, Vancouver 1980 p. 899.)

For the solution of the three coupled equations of motion it is assumed that the dredge is moored in a regular wave train. The wave elevation at a point may be written as $\zeta = \zeta_a \sin\omega t$. As a consequence not only the wave exciting forces but also the motions will have a regular oscillating character. For the pitch motion 0 we will find for example:

$$\theta = \theta_a \sin(\omega t + \varepsilon_{\theta\zeta})$$

in which θ_a = amplitude pitch motion; = circular frequency of the motion which equals the frequency of the waves; t = time and $\varepsilon_{\theta\zeta}$ = phase between pitch and wave.

In order to perform the calculations it is necessary that both the wave loads on the captive barge and the hydrodynamic coefficients (the added mass and damping) as function of the frequency of the regular waves are known. The procedure to compute these quantities will be explained in the next section.

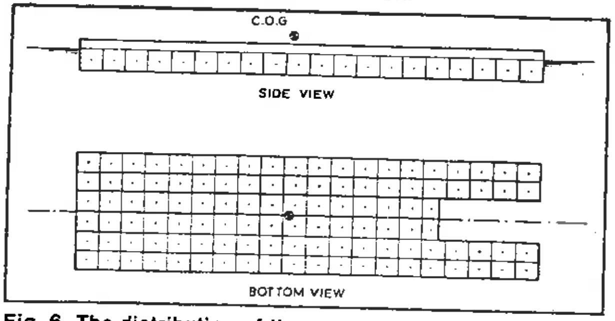


Fig. 6. The distribution of the sources and plane facet elements.

Computation of the Hydrodynamic Coefficients and the Wave Exciting Loads

At the NSMB the hydrodynamic coefficients and the wave exciting loads are calculated by means of the computer program DIFFRAC. The program is based on a three-dimensional source distribution technique for the solution of the linearized velocity potential problem. For the computations, the mean wetted part of the hull of the vessel is approximated by a number of plane facet-elements, representing a distribution of source singularities, Figure 6.

Each of the source singularities contributes to the velocity potential. For each wave frequency the wave exciting loads are determined from the solution of the potential diffraction problem (captive barge), while the hydrodynamic coefficients can be found from the solution of the potential radiation problem (forced oscillations of the barge in still water).

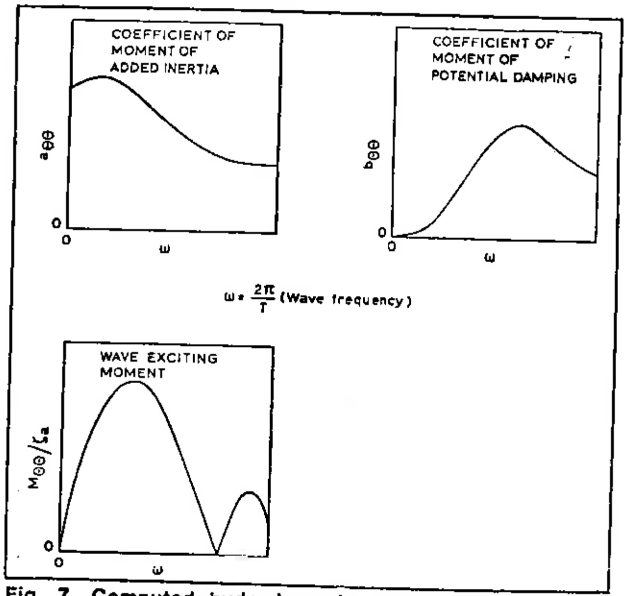


Fig. 7. Computed hydrodynamic coefficients and wave exciting moment in pitch direction.

As an example for the pitch direction the computed coefficients of the moment of added inertia ($a_{\theta\theta}$) and potential damping ($b_{\theta\theta}$) and the wave exciting moment per unit of wave amplitude for the barge to a base of wave frequency are illustrated in Figure 7. Figure 7 clearly shows that both the hydrodynamic coefficients and the wave exciting moment are frequency dependent.

Response Functions of Motions and Spud Pole Load

When all coefficients and the wave exciting loads are known the set of coupled equations of motion for head waves can be solved for a number of wave frequencies. Because the motions are solved per wave frequency the calculation procedure is called calculations in the frequency-domain. The computations results in the response functions of the motions and the spud pole loads, giving the amplitude of the quantity per unit wave amplitude and the phase relation between the quantity and the wave to a base of wave frequency.

For the range of wave frequencies corresponding to wave periods from 6 to 15 seconds, which occur in a normal sea state, the response functions have been computed for the dredge in the spud-moored and free-floating (spud pole removed) condition, both conditions with cutter ladder hoisted. The amplitude response

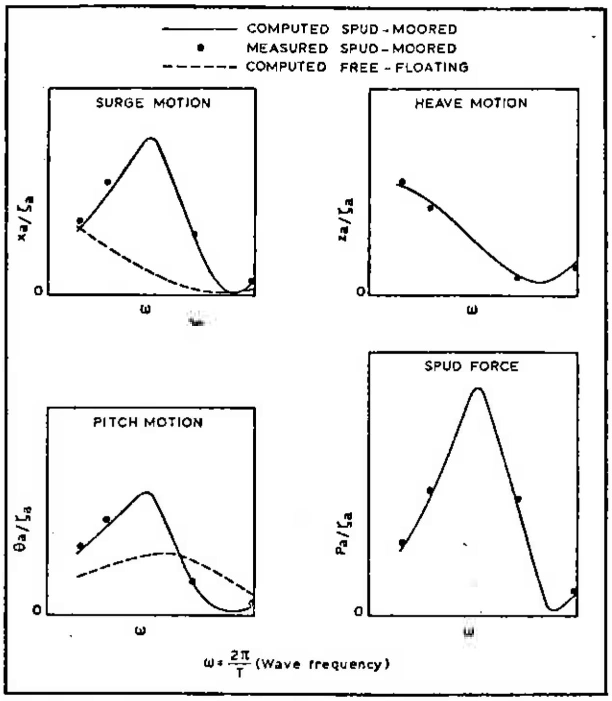


Fig. 8. Amplitude response functions of the motions and spud force in head waves.

function of the motions and the spud force, obtained from computations and model tests are given in Figure 8. From the results it can be concluded that the motions of the dredge and the spud pole force are correctly predicted. The shape of the amplitude response function of the pitch and surge motions and of the spud force show a maximum value, which occurs at the natural frequency of the coupled surge-pitch motion. Since in realistic sea states these wave frequencies may occur, large forces and moments on the spud and spud carriage can be expected.

Effect of Mooring System on Dredge Motions

In the free-floating condition the response function of the heave motion at the center of gravity is the same as in the spud-moored condition. This is due to the fact that in the spud-moored condition the spud pole restoring force will not affect the heave displacement (vertical sliding joint).

Because in the free-floating condition the strong coupling in the mooring system does not exist the response function of the surge and pitch motions of both systems are significantly different compared to the spud-moored case.

By means of the response functions of the motions in the centre of gravity of the dredge, the motions of the cutter head (the ladder in the low position), have been calculated, see Figure 3. For the calculations for both the spud-moored and the free-floating condition the following assumptions have been made:

1. The cutter head is always free from the breach.
2. The hydrodynamic loads on the cutter ladder are neglected.
3. The hoisting wires are regarded as stiff.

The amplitude response functions are given in Figure 9. The results show that at higher wave frequencies (shorter wave periods) the motions of the cutter head will be effected favorably by the spud-moored system. At lower wave frequencies (longer wave periods), however, the heave motion of the cutter head increases considerably.

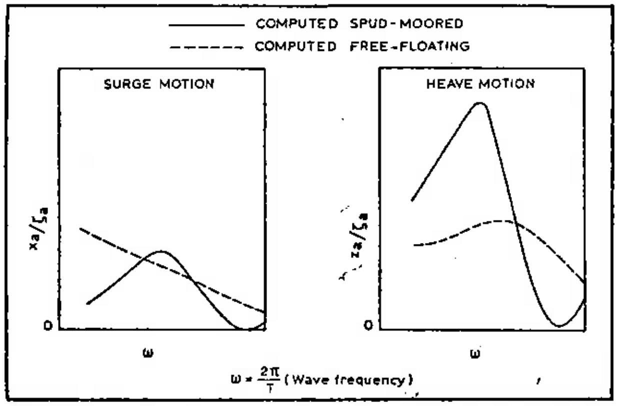
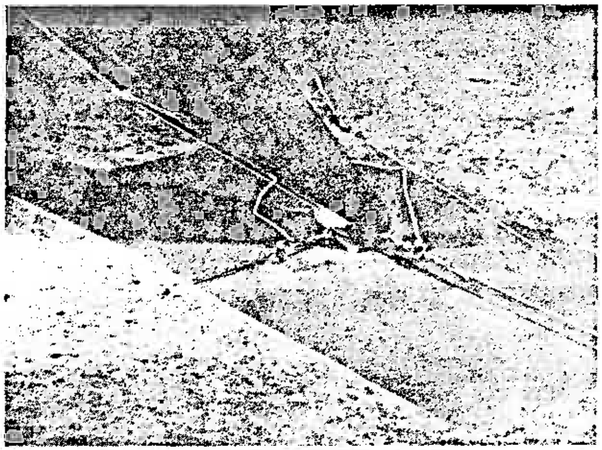
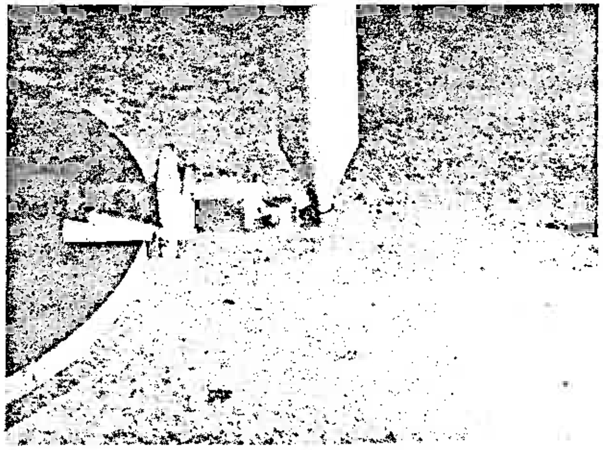


Fig. 9. Amplitude response functions of the cutter head motions in head waves.

The results shown so far are valid for the regular waves. In reality, however, waves are almost always irregular. In order to determine the motions or spud pole forces in an irregular sea use can be made of linear spectral techniques. With these techniques and using the amplitude response functions as presented in this paper important statistical properties of the motions and forces can be predicted e.g. significant and expected maximum values occurring in a particular sea state.



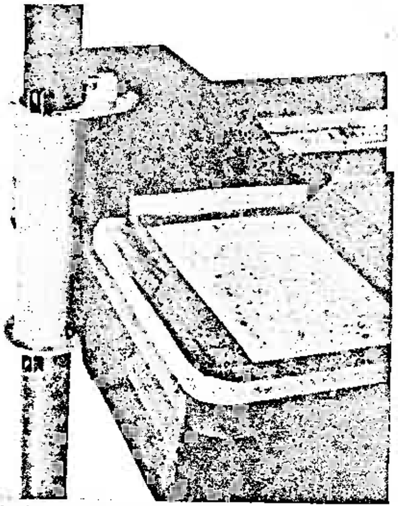
Photograph 1: Spud Guiding system.



Photograph 2: Spud connection at the sea bottom (ball-joint).

CONCLUSIVE REMARKS

In regular head waves and in rocky soil the behavior of a spud-moored cutter suction dredge with cutter head hoisted. differs considerably from that in the work-



Photograph 3: Simulation of the cutter head in the breach.

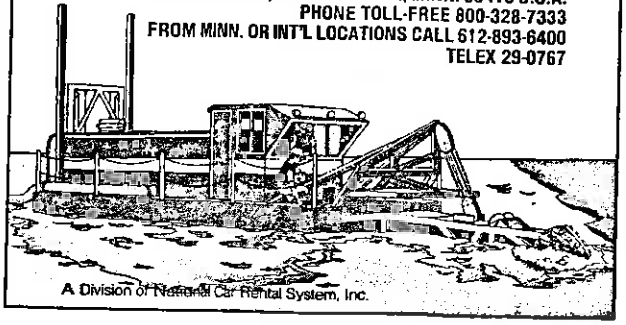
ing condition with the cutter head in the breach.

In head waves the spud-moored dredge with the cutter ladder hoisted has been treated as a linear system. Computations in the frequency-domain show that the motions of the dredge and the spud force are predicted correctly by the computer program.

In comparison with the free-floating condition, the motions of the cutter head (free from the breach) are affected favorably by the spud-mooring at the higher wave frequencies. At the lower wave frequencies, however, the heave motions of the cutter head become considerably smaller when the spud pole is removed.

ACKNOWLEDGMENT

We gratefully acknowledge the kind permission of the IHC Holland for the use of its model for this study.■



IHC Holland Secures Orders Totalling 200 Million Guilders

IHC Holland received an order for the construction of a very large trailing-suction hopper dredge for the Dutch contractor Zanen Verstoep of The Hague in April. This will be the largest vessel built to date at the covered yard of IHC Smit in Kinderdijk.

The dredge differs in a number of respects from conventional trailing dredges:

- it has a shallow draft in relation to its size;
- it can maintain an even keel at very shallow draft;
- the machinery arrangement provides a high steming speed;
- all the electrical energy is supplied by high-voltage generators driven by the main engines;
- the ship can operate in extreme climate;
- the hull is specially strengthened to permit operations in Arctic waters;
- the ship will be propelled by two controllable pitch propellers mounted in nozzles. The twin main engines are suitable for very heavy fuel oil;
- the total area of the spoil discharge openings is extremely large in comparison with existing dredges of this type;
- the dredging installation and the engineroom incorporate a wide range of measurement and control apparatus;
- up to date navigational aids and communications equipment will be installed;
- because the vessel will operate in very remote areas, special attention has been paid to the crew's quarters and to the provision of recreational facilities.

With this contract and others in recent months, the order books of the operating companies, IHC Smit, IHC Van Rees De Klop, Oranjewerf and IHC Gusto Staalbouw have together been increased by 200 million guilders.

The yards are now assured of work for the whole of 1981 and in some cases until far into 1982. A number of other important projects are now at an advanced stage of negotiation, and further orders are expected in the months ahead.

In addition to the dredge for Zanen Verstoep, the 200 million guilders worth of new business involves the following vessels:

- Two 750 cubic meter trailing-suction hopper dredges for Moroccan account; these will be built by IHC Gusto Staalbouw at Slikkerveer.
- A trailing dredge with a hopper capacity of nearly 5,000 cubic meters for a foreign contractor; this vessel will be built by IHC Smit.

These three dredges are of the split-hopper type, in which the divided hull is swung open to permit discharge of the spoil.

IHC Van Rees De Klop, in Sliedrecht, undertakes the construction of standard cutter suction dredges of the IHC Beaver type, most of which are demountable. The following newly-ordered vessels are now being built at this yard:

- An IHC Beaver 500 for Greece.
- An IHC Beaver 1500 for Italy.
- An IHC Beaver 10,000 for Taiwan.
- An IHC Beaver 2300 booster station for West Germany.
- An IHC Beaver 500 for Spain.