CHAPTER 48

THE INFLUENCE OF PILE DIMENSION ON FORCES EXERTED BY WAVES

by

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INTRODUCTION

The increase in applications of off-shore structures has raised a growing interest in the determination of wave forces on piles.

Both theory and model experiments have been applied to establish relations between wave characteristics, shape and dimensions of piles and wave forces exerted. As far as theory and computations are involved, the wave forces are generally assumed to be the resultant of drag and inertia forces. The influence of typical features of the flow pattern around the pile on the forces exerted is expressed in coefficients of drag (C_D) and inertia (C_M) which are, in practice, generally assumed to be dependent on the shape of the pile only. The latter assumption is not correct, which partly explains the variety in magnitude of C_D and C_M which is found in literature.

The time-dependancy of the flow pattern leads to an influence of pile dimensions relative to those of orbital motions. The aim of the paper is to draw attention to this phenomenon and to provide a possible starting point for a more reliable approach of wave forces.

The nature of forces exerted by oscillating flow is briefly discussed and illustrated by results of model experiments and computations. Subsequently model investigations on piles are described, the results of which are compared with computations for constant coefficients of drag and inertia.

FORCES IN OSCILLATING FLOW

The flow pattern of an "ideal fluid" around a two-dimensional submerged object is independent of the time-history. Viscosity of the fluid and separation, however, are disturbing factors. Though the deviations may be small for smooth slender bodies, they are predominant in flow around plates and even circular cylinders (compare potential flow and fully developed turbulent flow around a cylinder).

The oscillating flow induced by waves around piles will show a distinct time-dependancy. Integral quantities like the forces exerted on the piles cannot be derived therefore in a simple way from the time-related local velocities and accelerations in the absence of the pile.

In some cases the time-history of the flow pattern can be expressed for instance by a parameter denoting the ratio of the path of the fluid particles to the dimension of the object. This has been shown by Sarpkaya and Garrison (1) for uniformly accelarated flow around cylinders (parameter: distance of travel/diameter) and by Iversen and Balent (2) for disks accelerated under influence of a constant force (parameter: acceleration*diameter/velocity).Keulegan and Carpenter (3) have shown that for periodical oscillations the magnitude of C_D and C_M can be determined as a function of

$\frac{U_{max} T}{D} = \frac{2 \pi a}{D}$, in which:

U_{max} = maximum velocity

T = period of oscillation

a = amplitude of displacement of fluid particles

D = diameter of cylinder, resp. width of plate

This result was obtained from measurements on submerged horizontal cylinders and plates in the node of a standing wave, applying theoretically derived values for velocities and accelarations.

A number of similar experiments were carried out in the Delft Hydraulics Laboratory. In this case, however, the submerged cylinder and plate were harmonically oscillated by means of an excitator. The forces were measured as two components by means of an electronic system, viz: the component in phase with the displacements F_M (inertia) and the component in phase with the velocities F_D(drag). The measurements were performed on the 0.5 m long middle part of a plate and a cylinder with an overall length of 1,25 m and a width, resp. diameter, of D = 0.075 m. The semi amplitude of the oscillations was varied from 0.01 to 0.2 m. The period range was 0.5 to 3 sec. From the forces and the velocities and accelerations of the forced oscillation the magnitudes of C_D and C_M were computed according to the definition:

$$C_D = \frac{F_D}{\frac{1}{2}\,\rho\, D\, U_m^{\,2}}$$

$$C_M = \frac{F_M}{\frac{\pi}{4}\,\rho\, D^2 (\frac{dU}{dt})m}$$

The results are presented in fig. 1 and 2.

For a circular cylinder, C_D and C_M show moderate deviations from the magnitude in permanent flow and potential flow respectively. This is confirmed by pictures of flow patterns in uniform and accelerated flow ae presented by Rubach (4).

The flow around a plate shows important deviations due to the development of vortices at its edges, with increaeing eize and strength.

In order to get some insight into the influence of vortex formation on the magnitude of drag and inertia forces a literature study was made and a mathematical description of the flow pattern was established applying potential flow theories.

The case of a semi-infinite plate wae considered by Anton (5), where as Wedemeyer (6) carried through some computations on a plate of finite width.

The authors have computed the forces on a plate of finite width, starting from a mathematical model oomprising a set of two vortices initiated at the edges of the plate and travelling in the direction of undieturbed flow. (see figure 3). The vortices are equal in strength, however rotating in opposite directions. (Γ and $-\Gamma$). It was aesumed that the vortices travel along straight lines parallel to the direction of undisturbed flow. A justification of this assumption was found in photographs presented in (3). For any position x of the vortices, Γ is determined by U_0 and the condition of finite velocities at the edgee of the plate. Hence:

$$\Gamma = f(U_0,\ x).$$

The poeition of the vortices is a function of U_0 and the time from initiation of fluid motion in the direction considered.

$$x = f(U_0,\ t).$$

The flow pattern was then described by the complex velocity potential. The drag and inertia forces were obtained by integrating the pressures along the plate from Bernouilli's equation for non-steady flow.

Details about this theoretical approach will be published separately. The results, in term of C_D and C_M are given in figures 1 and 2, denoted as: theory D.H.L. The C_D and C_M plotted are averaged over one period of oscillation. The model does not hold for relative great values of $\frac{2\pi a}{D}$. Most remarkable is the increase in C_D for small displacements, whereas the accordance between theory and experiment is the best in this case.

WAVE FORCES ON PILES

ANALYSIS.

It may be concluded from the preceding that the application of constant C_D and C_M (dependent on the shape of the body only) may cause important deviations between computed and actual forces.

Present formulas for the computation of wave forces on piles are of the nature:

$$F_D = C_D \tfrac{1}{2} \rho D \int_{-d}^{\eta} u^2 \, dy$$

$$F_M = C_M \rho \frac{\pi}{4} D^2 \int_{-d}^{\eta} \frac{du}{dt} \, dy$$

The wave force is then the vector sum of F_D and F_M.

$$\vec{F} = \vec{F}_D + \vec{F}_M$$

It is obvious that the application of these formulas with constant coefficients is questionable.

In view of the difficulties encountered in describing the influence of the free surface and the decrease in orbital motion with depth, the results of experiments with submerged cylinders and plates cannot be applied easily to overall wave forces on piles. For quantitative information one has to rely upon model experiments, applying a parameter for the ratio of pile dimension to the amplitudes of oscillation. The fact that such a parameter is involved can also be derived from an analysis of all relevant quantities, being for a specific shape of pile:

F = wave force
H = wave height
T = wave period
d = water depth
ρ = density of water
g = acceleration of gravity
D = diameter; characteristic dimension of pile

(Viscosity is neglected, which is justified for sqare piles considered in the following).

Four dimensionless parameters can be obtained. The wave motion is characterized in a suitable way by:

$\frac{d}{gT^2}$ and $\frac{H}{gT^2}$. For the wave force: $\frac{F}{\rho g H D^2}$ can be chosen.

The remaining parameter has to include then D and a wave characteristic or water depth. Based upon considerations given before the ratio $\frac{H}{D}$ shall be used preferably. The latter parameter is not used in present formulas in an explicit way.
In view of the more complex nature of the wave forces on piles there is not much use in deriving C_D and C_M values, as they are not constant, whereas the magnitudes obtained for a specific case are often inaccurate. It is therefore recommended to establish experimental relationships between the parameters mentioned above.

EXPERIMENTS.

A number of model experiments has been carried out for various wave conditions, waterdepths and dimensions of square piles. The tests were performed in a wave flume, 0.8 m wide and 25 m long, provided with a flap-type wave generator at one end a suitable wave absorber at the other end.
The pile dimensions D and waterdepths d in the experiments were:

D = 0.025 , 0.046 and 0.063 m
d = 0.30 , 0.406, 0.555 and 0.755 m.

Wave periods were selected in such a way that for any waterdepth the ratio $\frac{d}{gT^2}$ was varied as:

$\frac{d}{gT^2}$ = 0.027, 0.037 and 0.050.

In each series of tests with constant period, the wave heights H were varied over such a range that the wave forces at constant $\frac{H}{gT^2}$ could be derived from graphs of wave force versus wave height. For $\frac{H}{gT^2}$ the values of $\frac{H}{gT^2}$ = 0.004, 0.007 and 0.012 were taken.

RESULTS.

The results are given in figures 4, 5 and 6. The wave force F_{max} denotes the maximum force in the direction of wave propagation. The graphs show $\frac{F_{max}}{\rho g D^2 H}$ versus $\frac{H}{D}$ for constant values of $\frac{d}{gT^2}$ and $\frac{H}{gT^2}$.

The test conditions include experiments on different model scales. Although there is a scattering in results, there were no scale effects observed.

It is seen that the forces increase with increasing wave steepness $\frac{H}{gT^2}$, as could be expected. For small values of $\frac{H}{D}$ the influence of the inertia force becomes predominant. Applying a theoretical value for integrated orbital accelerations, the magnitude of C_M can be estimated in the range of $\frac{H}{D} < 1$. The values which are found go up as high as $C_M \approx 3.5$.

The increase in $\frac{F_{max}}{\rho g D^2 H}$ with increasing $\frac{H}{D}$ is due to the increasing contribution of the drag force, as the square of orbital velocities is in first approximation proportional to H^2. For constant values of C_D and C_M the increase, however, should be more pronounced. This is shown in figure 7 where a comparison is given between experimental and computed forces. The computations were made for constant C_D and C_M, applying the formulas given by Reid and Bretschneider (7) and the additional computations of Borgman and Kobus (see A. Quinn: "Design of Ports and Maritime Structures".

The results represented do not allow the establishment of relationships which are generally applicable. It is obvious, however, that the application of constant coefficients may lead to deviations between actual and computed forces which cannot be accepted in view of the expenditures involved in off-shore structures and the risk of human life.

When designing off-shore structures it is recommended for the present to rely upon model experiments, applying the ratio $\frac{H}{D}$ as an independent variable.

CONCLUSIONS

- It can be shown by theory and experiment that for bodies in oscillating flow C_D and C_M are a function of the dimension of the object and the amplitude of oscillation.
- Consequently, in computationsof wave forces on piles, the assumption that C_D and C_M depend on the shape of the pile only is not correct.
- The application of present formulas may lead to important deviations between actual and computed forces.
- It is recommended to derive forces from model tests, applying the ratio $\frac{H}{D}$ as an independent variable.

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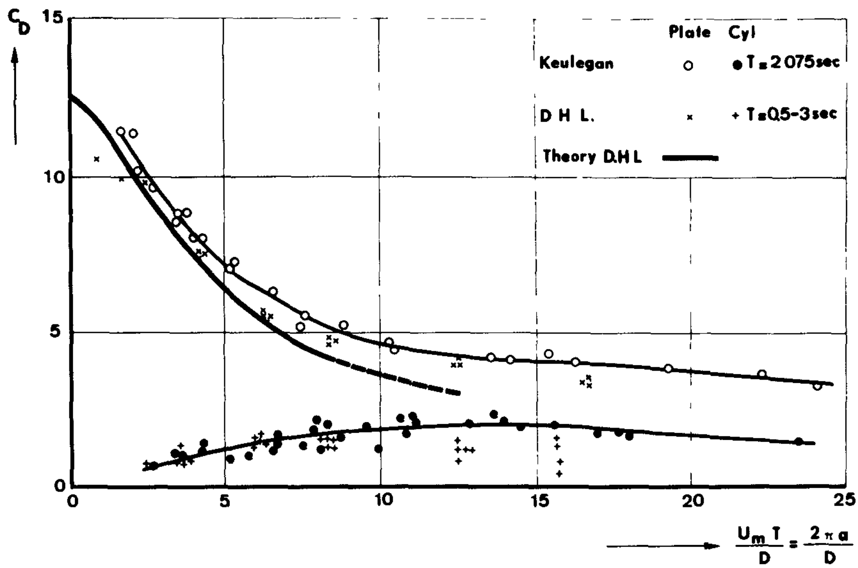

Fig. 1. C_D as a function of 2π a/D.

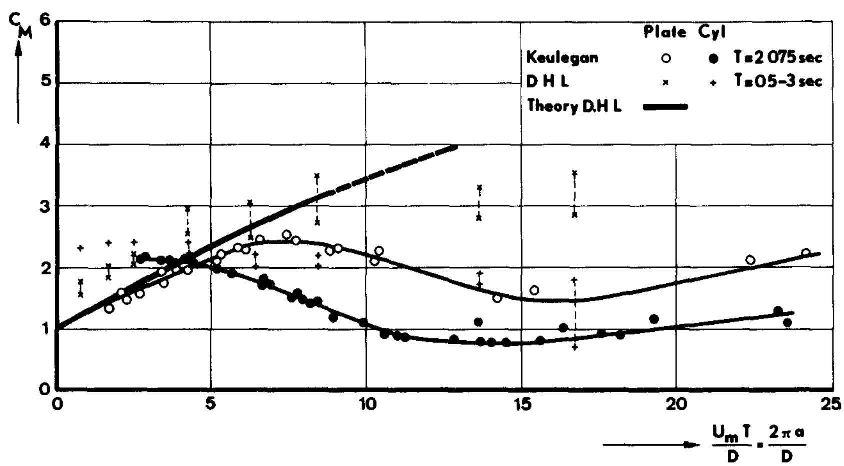

Fig. 2. C_M as a function of 2π a/D.

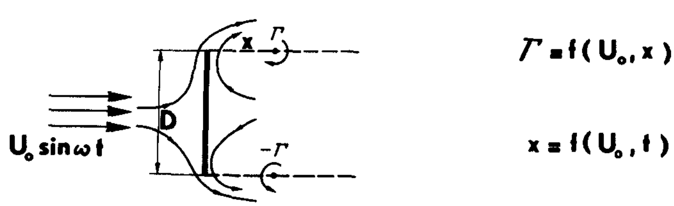

Fig. 3. Definition sketch.

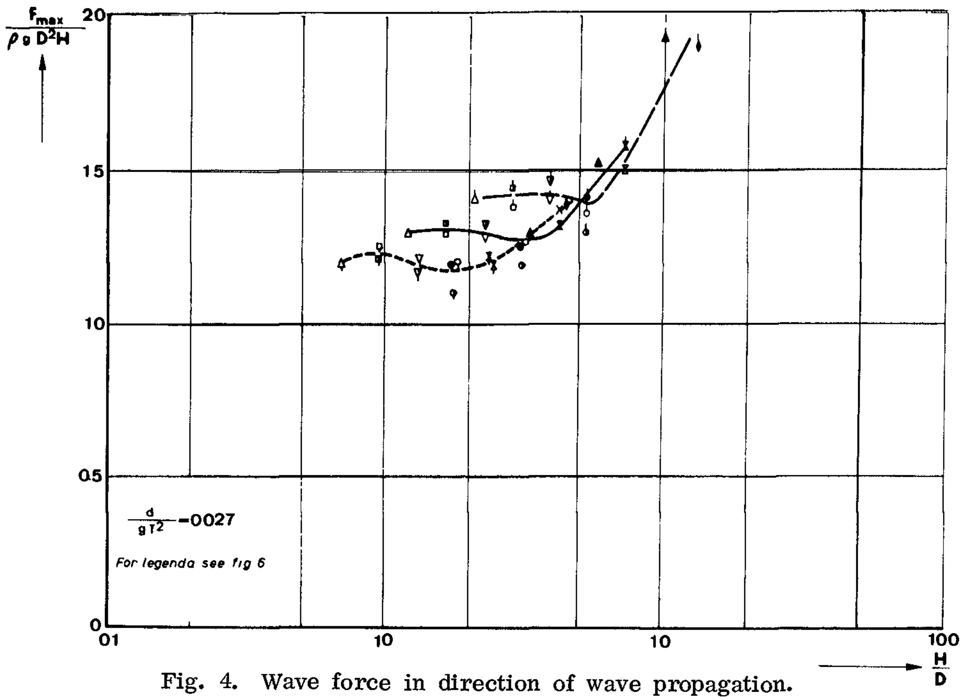

Fig. 4. Wave force in direction of wave propagation.

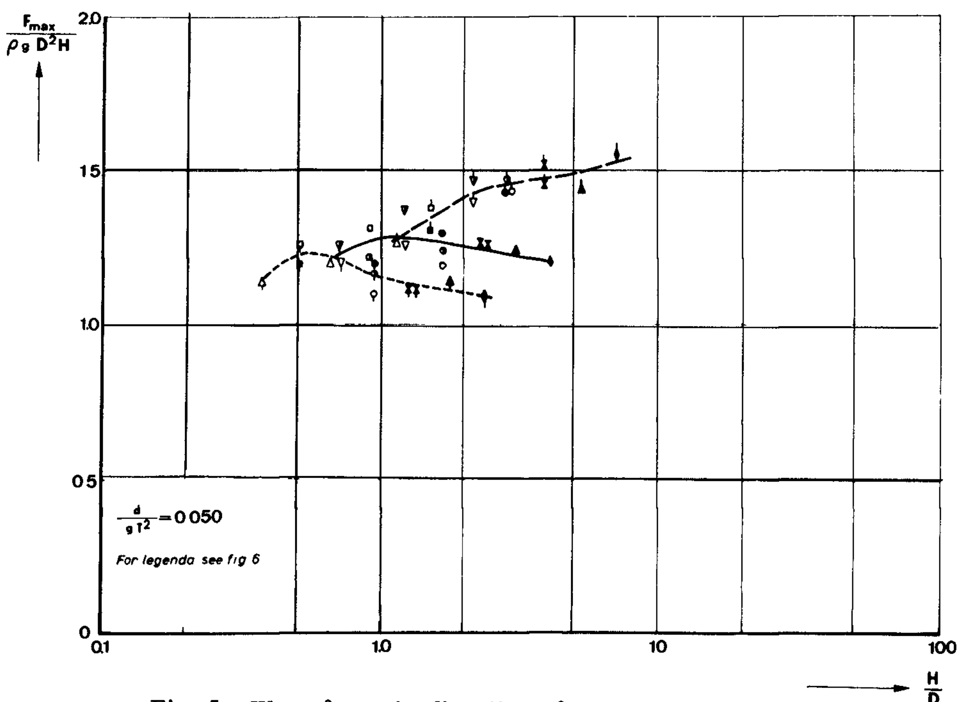

Fig. 5. Wave force in direction of wave propagation.

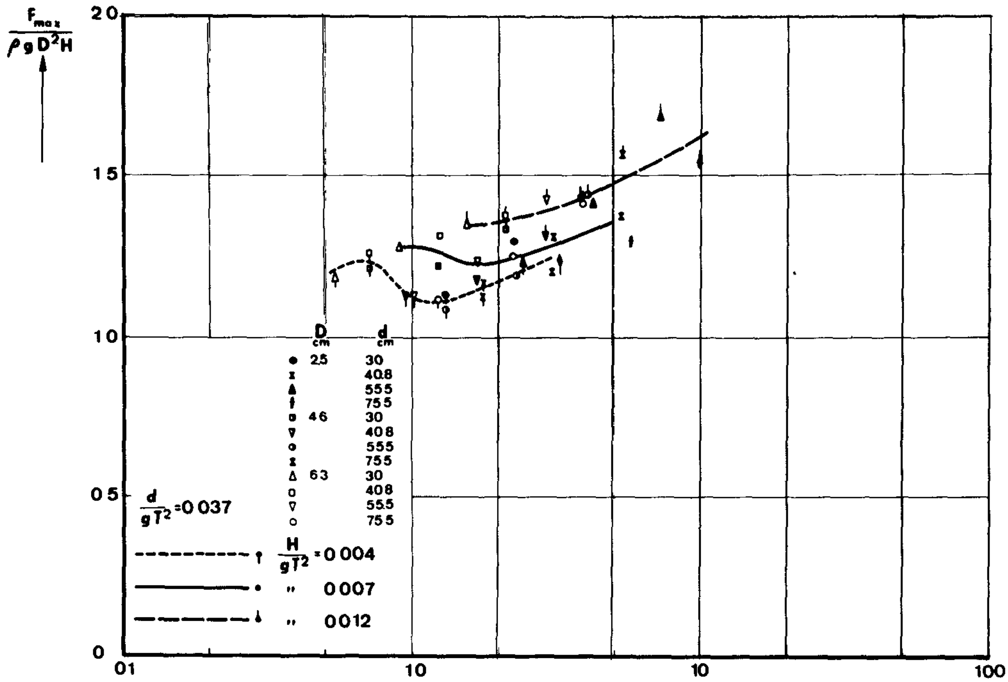

Fig. 6. Wave force in direction of wave propagation. ⟶ H/D

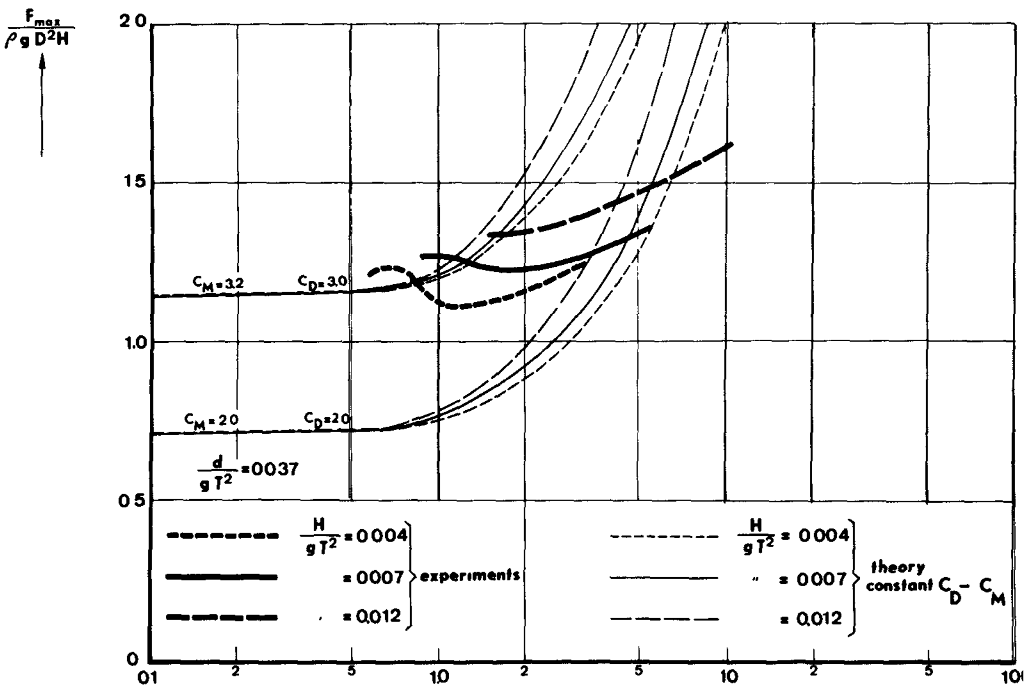

Fig. 7. Wave force in direction of wave propagation. ⟶ H/D