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Predictions of Morison-Type Forces in Irregular Waves at High Reynolds Number

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ABSTRACT

This paper summarizes some key points about the Morison formula, its background and some experiences on its application. An attempt is made to categorize the different types of flow-pile combinations to which the Morison formula applies. For irregular, high Reynolds number flows we attempted to identify the parameters that characterize a specific flow case, and how to define these parameters. Some new analyzes are presented. The most important feature of this paper may be in the area of directional waves where an extremely simple method, the so-called principal flow approach, is proposed to allow a unidirectional model to be used to predict the wave forces in directional seas. This approach proved to be extremely accurate in the range tested, namely for Keulegan-Carpenter numbers up to 35.

INTRODUCTION

The Morison formula for prediction of the forces on a long circular cylinder was originally proposed by Morison et al. (1950) on an ad hoc basis by considering two limiting cases. The first case was one in which the amplitude of the fluid motion was small relative to body dimensions, so that the flow remained unseparated, and potential theory was valid, yielding a force equal to twice the displaced mass times the fluid acceleration in the absence of the body. (Provided the cylinder diameter is short compared to the spatial variation of the flow.) In the other limiting case the fluid motion in each direction was very large, so that the flow could be considered piecewise steady and the force was given empirically as a so-called form drag force. Denoting cylinder radius, water density and velocity and acceleration as R, ρ, u and $\dot{u}$, respectively, the Morison equation then predicted a force per unit length equal to the sum of these two terms, but adjusted them by two empirical coefficients, C_m and C_d (so-called force coefficients), viz:

$$f = C_m \rho \pi R^2 \dot{u} + C_d \rho R u |u| \qquad (1)$$

The term *equation* is commonly used for Eq. 1, suggesting mathematical rigor and thus encouraging unquestioning acceptance; however, Morison's formula would better describe the character of Eq. 1. Furthermore, the symbols chosen for the coefficients, C_m and C_d, are unfortunately identical to the symbols used for the corresponding coefficients in the above-mentioned two limiting situations. In the '70s Sarpkaya established that these coefficients for a stationary cylinder in a unidirectional, harmonic, zero mean flow depended upon the Keulegan-Carpenter number KC, the Reynolds number Re and the average surface roughness ratio k/D in which k is the surface roughness diameter and D = 2R the cylinder diameter (Sarpkaya and Iscaacson, 1981). However, users and regulatory bodies were unclear on these matters. To exemplify, even the highly respected DNV rules (1982) prescribed the drag coefficient C_d as identical to the steady flow drag value (Section B2.1.5 and Fig. B.1). Further, even as late as in the 1991 DNV rules, the limit for where to apply Morison's formula was set to the point where the ratio of wavelength L to diameter D exceeded 5. An example where this criterion might be incorrect is for a circular cylinder in long waves of low amplitude, or at a depth where the wave-induced particle motion amplitude is small. Then $L/D>5$ could occur together with a very low Keulegan-Carpenter number. The latter means that there will be no separation, so that potential theory should be used, and not Morison's formula.

A very high number of experiments and some full-scale measurements have been performed to determine the forces on cylinders in waves under conditions where the flow separates, so that Morison's formula may apply. It has turned out that Morison's formula has been reasonably successful as a predictive tool, and no attempt to replace it or improve it, e.g., by adding extra terms, has been successful (Bendat and Piersol, 1986). It is, however, necessary to be discriminating concerning the flow conditions under which the Morison formula is used. In table 1 is shown a number of the most actual regular flow cases.

CLASSIFICATION OF FLOW SITUATIONS IN WHICH MORISON'S FORMULA APPLIES

A large number of experiments have dealt with a case in which the flow has been rectilinear and sinusoidal and perpendicular to the axis of a stationary test cylinder. This situation will be denoted the base case in Table 1, Case 1A. A current in-line with the oscillatory flow may also be added, Case 1B. In Table 1 are also shown other regular flow situations about a circular cylinder: Case 2 is as Case 1, but the flow direction is at an inclined angle to the cylinder, Case 3 has a wave flow in the same plane as the cylinder, i.e., a flow with circular or elliptical particle orbits, while in Case 4 a current in the same plane has been added to the flow components of Case 3, possibly at an inclined angle to the

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