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Extreme Wave Action on Large Horizontal Cylinders Located Above Still Water Level

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ABSTRACT

This paper presents the results of an experimental study of plunging wave action on a large horizontal cylinder in the splash zone. Impact pressures are found to range from localised impulsive pressures with time scales in the range of 0.001T to synchronous low-frequency pressure oscillations with oscillation time scales around 0.01T (T being the characteristic wave period). The highly impulsive cases, with peak pressures ranging from $4\rho C^2$ to $33\rho C^2$, are associated with minimal entrapped air at impact. (ρ is the water density and C is the characteristic phase speed of the wave.) The highest peak pressure is obtained when the profile of the incident wave front is concentric to the cylinder boundary. Peak pressures as high as $5.4\rho C^2$ are obtained when a large pocket of air is entrapped by the plunging wave front at impact. The entrapped air also leads to synchronous pressure oscillations over a substantial region of the cylinder's surface, covering an angular zone of about 105°. The corresponding peak impact force is about $8.6\rho C^2 R$ per unit length of the cylinder where R is the radius of the cylinder. Overall, the incident wave profile trajectory and the entrapped air are found to influence the impact load significantly.

INTRODUCTION

In a hostile sea environment, the safe and economic design of a marine structure depends significantly on the prediction of a representative design wave load. For structural members located at elevations between the mean sea level and the crest elevation, the highest loadings are those associated with wave impacts or slamming. This is especially so for horizontal structures with large dimensions compared to the incident wave height. Horizontal members such as the deck of an offshore structure are currently designed to be located well above the crest level to avoid slamming pressures. For structures such as semisubmersibles and nearshore marine structures, however, it is often possible to have a large horizontal structural member in the splash zone. Past studies of wave impacts have shown that impact forces can be more than two times higher than nonimpact forces resulting from waves of comparable wave height. Whilst a factor of two in the design wave load would mean a drastic increase in the construction cost, an underdesign would mean a risk of structural failure and, possibly, loss of lives.

In previous analyses of wave slamming on horizontal cylinders, the forces were typically modelled as the rate of change of momentum of a mass of water moving past the cylinder (Kaplan and Silbert, 1976; Sarpkaya, 1978; Kaplan, 1992). The incident wave surface was assumed to be locally flat, an appropriate condition when the diameter of the cylinder is small compared to the wave dimensions. An equivalent situation that has been examined by some researchers is that of a horizontal cylinder dropping vertically onto still water (Faltinsen et al., 1977; Armand and Cointe, 1986). During impact, the added mass per unit length of the cylinder was assumed to be equal to half the added mass associated with a long flat plate having the same water-contact width and moving in an infinite volume of still water. The slamming force, F_i, when evaluated at the moment of contact, may be reduced to the form:

$$F_i = C_s \frac{1}{2} \rho U^2 D l \tag{1}$$

where D and l are the diameter and length of the cylinder respectively, and C_s, defined as the slamming coefficient, is theoretically equal to π. The value of the slamming coefficient was found to be 2π when a wetting correction associated with a local perturbation to the water surface at impact was taken into account (Armand and Cointe, 1986).

With the impact force expressed empirically in the form of Eq. 1, laboratory measurements have yielded slamming coefficients ranging from 1 to 5 (Dalton and Nash, 1976; Faltinsen et al., 1977; Miller, 1977; Sarpkaya, 1978). These laboratory studies include drop-tests and experiments in wave tanks and U-tubes. In the wave tests, the cylinders considered were typically small compared to the dimensions of the incident wave, the diameters being less than a fifth of the incident wave height. Due to the impulsive nature of impact loading, the force signals in such studies were often affected by the dynamics of the measurement rig. This influence contributed to the wide range of slamming coefficients indicated above. Extraction of the actual wave loading (i.e. impact forces on a fixed rigid cylinder) from the monitored signal requires a complete understanding of both the structural dynamics and the wave hydrodynamics at impact, a task which is still not fully resolved.

Although the studies mentioned above have highlighted the range of impact forces possible, there are still limitations to the applicability of the results. Whilst the experimental studies offer a very wide range of possible slamming coefficients, the theoretical derivations are limited by assumptions such as a flat incident surface. It is not clear how the experimental results or the theoretical derivations may be extended to the case of steep wave impacts on a large cylinder. For example, the added mass during impact will not be half that of a plate in an infinite volume of fluid since the dimension of the cylinder is comparable to the dimen-

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