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Variability of Plunging Wave Pressures on Vertical Cylinders

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ABSTRACT

The variability of pressures resulting from plunging wave impact on a smooth vertical cylinder is examined. Based on laboratory measurements, the fluctuations in the pressure characteristics are found to be associated with two main factors: One is the significant shift in the wave breaking location relative to the cylinder location, and the other is the randomness of the wave breaking kinematics and the trapped air dynamics. The variation of the peak pressure magnitudes associated with the latter is presented. Both the mean characteristics and the probability distributions are examined.

INTRODUCTION

In the design of offshore structures, one often seeks an estimate of the extreme wave loads. It has been long known that such a loading can result from waves breaking onto the structure. Research in recent years (Sawaragi and Nochino, 1984; Kjeldsen et al. 1986; Chan and Melville, 1987, 1988; Basco and Niedzwecki, 1989; and Tan et al., 1989) has in fact shown that wave impact forces can be more than two times higher than nonimpact forces from waves of comparable amplitudes. Moreover, the corresponding impact pressures can be more than 10 times higher compared to nonimpact pressures. These impact loads are highly impulsive and transient in nature, and the physics of the impact process is complex. In a hostile ocean environment, particularly during stormy weather, the chances of encountering such wave impacts are very high. Consequently, a good knowledge of the mechanics and dynamics of wave impact is essential, especially when the overall objective is to produce a safe and economical structure

With the advent of well-controlled and programmable wave generation systems, laboratory studies of wave impacts have increased in recent years, leading to an advancement in the understanding of wave impact. In particular, it has been shown that wave impact loads from plunging waves are much higher than those from spilling and non-breaking waves (Kjeldsen et al., 1986; Basco and Niedzwecki, 1989). Also, plunging wave impact occurs not at one critical structure location relative to the wave breaking location, but over a range of locations within the region of wave breaking (Chan and Melville, 1987,1988; Tan et al., 1989). However, the characteristics of the impulsive pressures, especially the pressure maxima, vary significantly with the wave breaking location relative to the structure location. Despite this variation, the impact pressures are in general characterised by pressure maxima greater than $3\rho c^2$ (ρ is the fluid density and c is the characteristic phase speed of the wave) and pressure rise times less than $0.01T$ (T is the characteristic wave period). These impulsive pressures are typically followed by pressure oscillations with frequencies several orders of magnitude above that of the characteristic wave frequency. Noting that air is also entrapped at the impact elevations, such pressure oscillations have been attributed to the dynamics of the trapped air during impact. On the other hand, the occurrence of wave breaking prior to impact will mean that the trapped air dynamics can be random. Consequently, both the pressure maxima and the pressure oscillations may be expected to vary significantly, even when the incident waves far upstream are almost identical. Indeed, in a study of wave plunging on vertical walls, Chan and Melville (1988) have obtained a variety of pressure characteristics from repeated experiments. This result suggests that wave impact is not only transient, but can be random as well. In fact, field measurements have always been inadequate because of the difficulty in capturing the impact process.

In view of the above results, it is clear that a good estimate of the design wave impact load will not only require the statistics of a particular breaking wave, but also the statistics of the impact pressures associated with that particular wave impact. Such an attempt has been studied by Ochi and Tsai (1984), using breaking and broken waves generated from a sudden start of the wave maker. The pressure maxima were found to be reasonably approximated by $1.38\,\rho c^2$ and $1.34\,\rho c^2$ respectively, and the scatter in the pressure measurements from repeated tests was minimal. These results are different from those obtained by Chan and Melville (1987) and Tan et al. (1989), where the pressure maxima associated with cylinders of comparable dimensions are found to be much higher ($>3\rho c^2$), and the scatter in the results is also significant.

In pursuance of the above problem and the mechanics of wave impact on offshore structures, the authors have conducted a set of systematic and well-controlled experiments in the laboratory. Plunging wave pressures on a vertical cylinder are monitored and correlated to the impact process, and the variation of the pressure characteristics is examined. In the following section, the experimental simulation of the impact problem is described. This includes the simulation of wave plunging in the laboratory and the instrumentation used in capturing the impact pressures. The pressure characteristics are then correlated to the different relative wave breaking location, and the variation associated with similar relative wave breaking location are identified. The mean pressure characteristics are also presented, and the implications of the results are discussed.

Given the wide range of wave breaking kinematics possible in the ocean and the infinite variations of the relative wave breaking location and structure geometry, a detailed study of all possible combinations will render this exercise intractable. In this paper, the results are therefore limited to the extreme case of plunging wave impact on a vertical cylinder. A cylinder is used in the study as it is a common structural element in most offshore structures.

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