International Journal of Offshore and Polar Engineering
Vol. 10, No. 4, December 2000 (ISSN 1053-5381)

Wave-Current Forces on Rectangular Cylinder at Low KC Numbers

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ABSTRACT

This paper presents the results of wave and current forces acting on a surface-piercing, vertical truncated rectangular cylinder. The combined wave-current effect has been produced by towing the cylinder in regular waves, along and opposite to the wave direction. Drag and inertia coefficients are evaluated and are presented, as a function of KC number, for 2 aspect ratios of cylinders, equal to 1/2 and 2/1. The results show that drag and inertia coefficients are strongly affected by (i) variation in the aspect ratio of the cylinder and (ii) variation in the current speed. The comparison between measured forces and computed forces using Morison's equation shows good agreement.

INTRODUCTION

The increasing exploration and exploitation of ocean mineral resources has required the use of various offshore cylindrical structures. The research into hydrodynamic loading on ocean structures has concentrated mostly on circular cross-section members and relatively limited work has been carried out on wave loading on other cross-sections such as rectangular sections. The design of these sections is considered economically more viable than the conventional one of circular members. The circular sections are usually much more expensive to form joints when the members require profiling, whereas only straight cuts are necessary for a rectangular section. The square or rectangular sections find applications in many coastal and offshore structures as caissons, columns and pontoons in semisubmersibles and tension-leg platforms.

The present investigation demonstrates the behaviour of rectangular cylinders subject to wave and current loading and also supplies the hydrodynamic coefficients for the design of these sections.

Regular Waves

Sharp-edged cylindrical bodies, such as square sections, rectangular sections and flat plates, develop wider wake and shed vortices in oscillatory flow even at very low KC values. As a result, they experience larger drag coefficients than the circular cylinders. Keulegan and Carpenter (1958) investigated the loading on circular cylinder and flat plates. They have presented curves for C_D and C_M with KC numbers and reported that the variation of these hydrodynamic coefficients for flat plates is very different from that of circular cylinders. Bearman et al. (1979) conducted experiments in a U-tube water tunnel on flat plates, circular, square and diamond cross-section (flow is normal to the diagonal of the square section) cylinders to obtain C_D and C_M and found that the variation of C_M with KC showed different behaviour for different sections. At low KC numbers (KC ≤ 10), the values of C_D for flat, square and diamond sections were generally found to be decreasing with increasing KC, compared with a circular cylinder, for which the drag coefficient increases with increase in KC up to KC≤10. Beyond KC equal to 10 to 15, the curves for circular, flat and diamond sections have shown a similar trend. The square cylinder showed the highest value of C_M compared with other sections.

Graham (1980) derived theoretical expressions for inertia and drag coefficients for square and diamond cylinders due to the forces induced by separation and vortex shedding from sharp-edged bodies in oscillatory flow at low KC numbers and compared with experimental results. Heideman and Sarpkaya (1985) conducted experiments on a rectangular array of cylinders, a square array of cylinders, a rectangular prism and a square prism. The tests include steady towing in a towing tank and also with sinusoidal oscillating flow in a U-tunnel, for different angles of flow, a. From these experiments it was found that the drag coefficient for the rectangular prism approaches its steady flow value at KC ≅ 150. For angles of flow other than $a = 0$, the C_D of the rectangular prism exceeds the C_D of rectangular array. At KC = 30, the rectangular array reaches its steady flow C_D. Another notable contribution to wave loads on a vertical rectangular cylinder was made by Hamel Derouich (1991).

Regular Waves and Currents

The presence of current in the ocean is a common occurrence and several offshore platforms operate in areas where waves propagate on currents. The interaction of waves and currents and the resulting effect on the response of the structure must be considered for the design of an offshore structure. The existence of currents will change the wave parameters and the wave kinematics as to compare with waves propagating in still water.

Koterayama (1984) investigated the wave forces on a circular cylinder moving with a constant velocity through regular waves and reported that the wave force coefficients depend mainly on the reduced velocity ($U_C T/D$). Sarpkaya and Storm (1985) have conducted experiments with smooth and sand-roughened cylinders moving with constant velocity in a sinusoidally oscillating flow to determine the drag and inertia coefficients on the basis of a modified Morison's equation and found that the drag and inertia coefficients are strongly affected by the current. Further, they found that C_D and C_M for the no-current case are not identical with those obtained with coexisting flow. The variation of these coefficients is governed by the KC number, Reynolds number, relative roughness and the reduced velocity. Li and He (1995) carried out experiments on a square cylinder subjected to waves and currents

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Received January 17, 2000; revised manuscript received by the editors September 28, 2000. The original version (prior to the final revised manuscript) was presented at the Ninth International Offshore and Polar Engineering Conference (ISOPE-99), Brest, France, May 30-June 4, 1999.
KEY WORDS: Rectangular cylinder, aspect ratio, regular waves, current, low KC numbers.