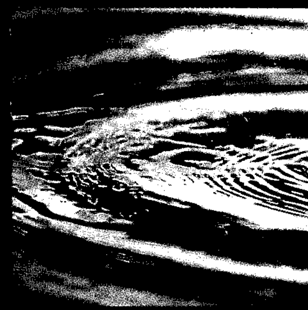

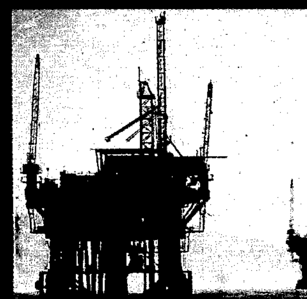

Drag and Inertia Coefficient Data for Cylinders

MARINE RESEARCH REVIEW 11

MARINE RESEARCH REVIEWS

The aim of this series of short reviews, begun in 1993, is to disseminate the results of research programmes that were administered by the Marine Technology Directorate (MTD) beyond the immediate circle of the researchers and their sponsors to a wider readership in the offshore and marine industries.

The activities of MTD Ltd are now being carried out under the banner of a new company, CMPT, The Centre for Marine and Petroleum Technology Ltd. CMPT acknowledges the support of the Offshore Safety Division of the Health and Safety Executive in the production of these six reviews of research that has some implications for the safety and lifetime integrity of offshore structures. HSE was one of the contributors to each of the projects or programmes covered. Neither the Executive, the Division nor CMPT assume any liability for the reviews nor do they necessarily reflect the views or the policy of the Executive or the Division.

Six reviews have already been published, five of them with funding from the Oil and Gas Projects and Supplies Office (OSO) of the Department of Trade and Industry.

About the Offshore Safety Division

The responsibilities for regulating health and safety offshore were unified in a single body - the Health and Safety Executive - as a result of the recommendations of the Lord Cullen enquiry into the Piper Alpha disaster. A new Offshore Safety Division was set up as a result.

Research has played an important part in ensuring safety in the North Sea and will continue to do so. A major aim is to undertake an integrated programme of projects which address both the strategic or generic investigation of offshore hazards and the related short term needs, for example to support safety case assessment. A risk-based research strategy has been developed by HSE with input from the Division's Research Strategy Board to provide a means of prioritising research effort and helping to ensure that value for money is obtained.

About CMPT

CMPT is a new organisation set up to integrate research, innovation and technology for the upstream petroleum and marine industry. It will build on the capability and services of both the Marine Technology Directorate (MTD) and the Petroleum Science and Technology Institute (PSTI), each with its track record of meeting industry needs. CMPT's objective is to be the primary focal point and resource centre upon which its members rely for the provision of expertise and the facilitation of technology to enhance business performance.

Publications like Marine Research Reviews play their part in CMPT's technology transfer, delivering new technology from CMPT research programmes into use.

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Contents

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This review is based on work at Imperial College of Science, Technology and Medicine carried out as part of the Behaviour of Fixed and Compliant Offshore Structures Managed Programme. The work was funded by the Engineering and Physical Sciences Research Council through MTD and a number of industrial sponsors (see p. 35). The researchers were Professor P.W. Bearman and Mr P.R. Mackwood.

Members of MTD may consult the full research report in the MTD library. Anyone interested in discussing the results or obtaining a disk of the complete set of data should contact:

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This review was edited for MTD by Sharon J. Clark. The series editor is Judith Mirzoeff.

Note
The Offshore Safety Division of the Health and Safety Executive has supported publication of this report to encourage dissemination of the results of research that has received public funding. This support does not imply automatic endorsement by the HSE of any of the technologies described.

Summary

An appraisal of measurements of drag and inertia coefficients for large-scale circular cylinders was carried out by researchers at Imperial College. Both smooth and rough cylinder surfaces were considered. The coefficients were measured under a range of experimental conditions including planar oscillatory flow, laboratory tests with vertical cylinders in regular and random waves, and experiments on vertical cylinders in the sea. Large-scale laboratory test data for the effects of super-imposed steady currents were also examined. Some of the large-scale laboratory studies employed scaled simulation of real sea spectra. On the whole, the agreement between the various sets of data taken with a similar cylinder surface was good, with drag coefficients for a rough surface being up to twice as large as those for a smooth surface. When a current was present, the force coefficients were found to be similar for both regular and random waves, and the drag coefficient was generally found to be slightly smaller than the wave-only case. In combined wave and current flows, Morison's equation with a single drag coefficient was found to be a good model for both the steady and oscillatory force components. It was observed that very few results exist for Keulegan Carpenter numbers above 40. Finally, some coefficients are suggested for possible design use.

Introduction

The oceans are one of the harshest natural environments where man-made structures are expected to operate. These structures are not only exposed to highly corrosive seawater, but are also subjected to significant forces, including those caused by mechanical operations carried out on the structure, those exerted by the mooring of other vessels, and those from the environment. Environmental forces can be sub-divided into wind forces and hydrodynamic forces, and it is the combined wave and current forces that make by far the largest contribution to the total loading on a structure.

In general, the current (steady) flows are well understood, and the resulting forces and their variation with flow parameters are well documented. The wave (oscillatory) flows, however, pose the biggest problem. Oscillatory flows around cylinders are extremely complex, with the wake flow during one half cycle being swept back over the cylinder to become the incident flow during the next half cycle.

In 1950, researchers proposed that the in-line loading caused by the oscillatory flow could be considered as the sum of two components: an inertia force proportional to the acceleration of the fluid, and a drag force which is a function of the fluid's velocity. From this proposal came the famous Morison's equation. Although the equation was proposed as a preliminary idea it is still used in its original form. Its failings are now well documented, but the additions and modifications that have been attempted over the years have not significantly improved the prediction of wave loading. The equation and details of its application are given in Appendix 1.

A considerable amount of research has been conducted into wave loading since the formulation of Morison's equation, and its force coefficients are now known to depend primarily upon two non-dimensional parameters, the Reynolds number, *Re*, and an oscillatory flow parameter, the Keulegan Carpenter number, *KC*. These parameters are also defined in Appendix 1.

Wave forces on a cylinder also depend on other factors. The surface finish or roughness affects cylinder flows and can lead to substantially larger in-line forces and in some cases enhanced vortex shedding and increased transverse loading. The level of roughness is usually quoted as the ratio of the roughness height to the diameter of the cylinder, k/D.

A typical offshore jacket structure may be constructed from circular members of 1 – 4 m diameter, may be exposed to wave flows with periods of 8 – 15 s, and may experience maximum *KC* numbers of perhaps 40 – 100 with *Re* in excess of 10^6. Under these conditions the flow resulting from steady and oscillatory flows is known to be separated and the cylinder is also likely to experience a transverse force perpendicular to the direction of wave propagation as a result of vortex shedding. To date, no empirical equation for transverse forces has been developed that is as reliable as Morison's equation for the in-line force.

The aim of the project reviewed here was to collect drag coefficient, C_D, and inertia coefficient, C_m data from the available literature, and, where possible, to provide a critical assessment of its quality and relevance. The data selection was restricted to in-line loading on fixed vertical cylinders where the *Re* is in excess of about 10^5 because the ultimate aim was to suggest force coefficients for use in the design process. Smaller scale experiments are discussed, however, where the findings are qualitatively relevant.

A large amount of the early literature had already been reviewed (see N. Hogben *et al.*, Estimation of fluid loading on offshore structures, *Proc. Instn. Civ. Engnrs.*, **63** (1977) 551–562), and each experiment described in terms of the location, sea state, range of conditions, and the range of C_D and C_m values obtained. Most of the early studies used wave theories to calculate particle kinematics, and it is evident from the range of force coefficients quoted that many of the results were not very reliable. For example, in one study the range of conditions was $KC = 8 - 40$, $Re = 10^5 - 10^6$, very relevant to this study, but the quoted force coefficients, $C_D = 0.4 - 1.5$ and $C_m = 2.0 - 5.0$, covered too broad a range to be useful. In the majority of more recent experiments measured particle kinematics have been used. This seems to provide sets of coefficients with far less scatter and which are, therefore, probably more reliable.

Further background information and a set of tabulated results of all the data studied are available from Professor Bearman (see p. 2 for address).