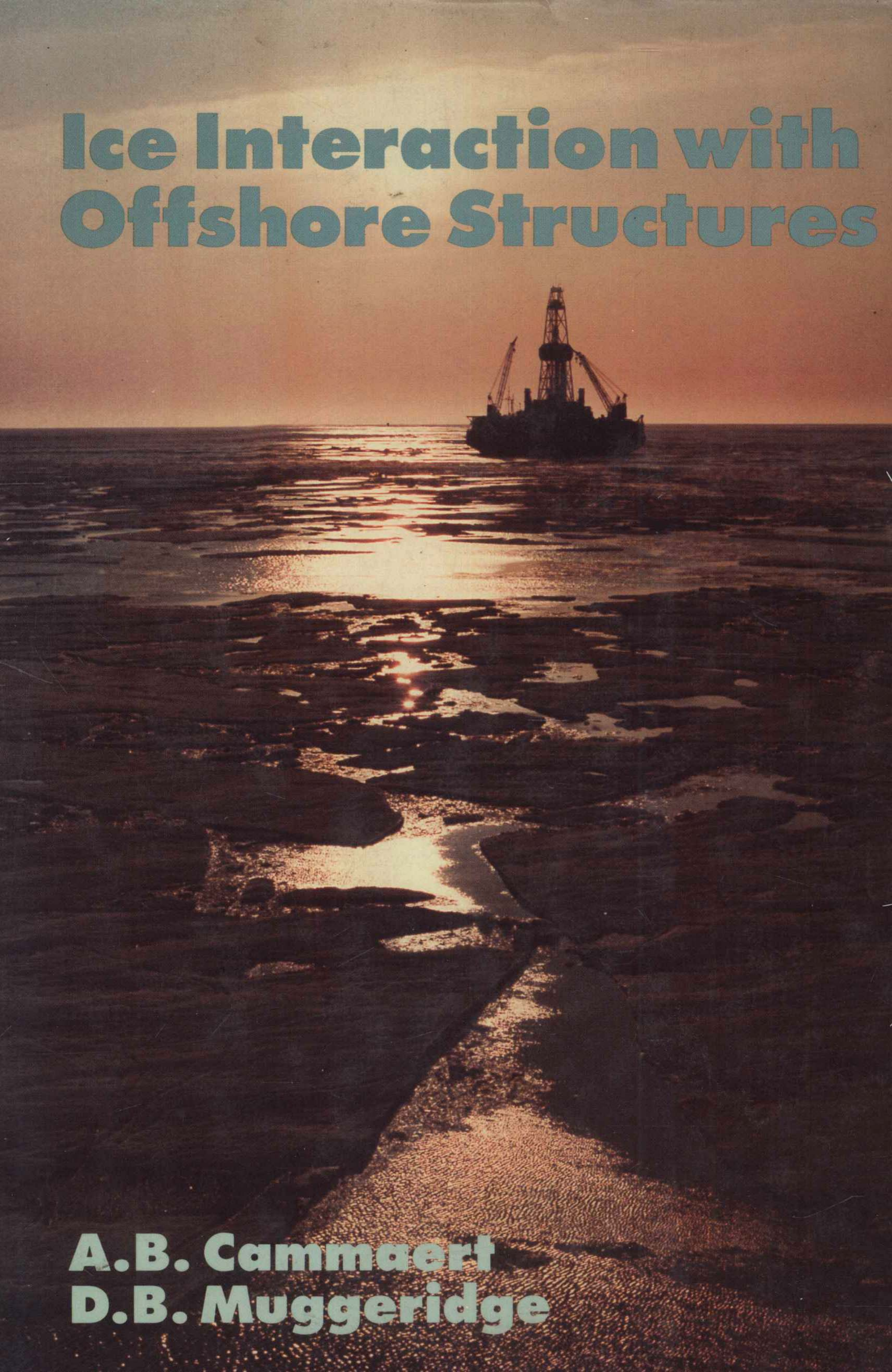
Ice Interaction with Offshore Structures



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To Faye and Hanny

Preface

The action of ice on offshore structures in Arctic regions is probably the most important environmental factor affecting their design. The magnitude of the forces resulting from continuous ice sheets, or intermittent ice features such as ridges, multi-year floes, and icebergs, plays a major role in determining structure mass and framework design. Moreover, the exterior surfaces of the structure will be most influenced by design considerations to reduce local ice loading, or the tendency for ice to pile up around the structure.

A tremendous amount of research work has been done in the past on the physical properties of ice, and its effects on structures and ships. Some of the earliest investigations were prompted by ice obstruction of northern Canadian hydro power stations in the early 1900s. The problems associated with ship operations were confronted even earlier than this, with the construction of icebreaking ships for service on rivers in northern Europe in the 1870s.

One of the first books which dealt with these topics was *Ice Engineering* by Barnes in 1928. Later work on ice mechanics was carried out principally by glaciologists, and this led to such books as *Physics of Ice* by Pounder (1965) and *Ice Physics* by Hobbs in 1974. Michel provided an excellent treatment on the mechanical behaviour of ice, in his book *Ice Mechanics* published in 1978.

More recent literature on ice effects on structures is very widespread, in the form of hundreds of published articles and research reports. A number of international forums such as the IAHR Ice Symposiums and the POAC, OMAE and OTC Conferences have served to highlight major developments. Summary reports and design guidelines by CRREL, ASCE, IAHR and API have also made major contibutions to the field.

The developments in the last two decades, in particular, have been motivated primarily by the need to exploit offshore oil and gas reserves. As a result, the authors have chosen to concentrate on sea ice, icebergs and offshore structures (both fixed and floating). Problems with freshwater ice are not covered in the text. Many of the topics in this book, however, will be of relevance to this subject and will also apply to sea ice interaction with coastal or nearshore structures.

In order to give a comprehensive treatment of the subject, the first part of the book deals with general characteristics of sea ice and icebergs, and their extent and movement in both the northern and southern hemispheres. This is followed by an in-depth treatment of the mechanical properties of sea ice and icebergs and various analytical approaches to the calculation of ice forces. The book covers other special topics such as probabilistic design techniques, local pressures, structural icing, ice management, and ice and structural instrumentation. Verification of theoretical design approaches by field tests and laboratory experiments is discussed.

Case histories are presented which attempt to illustrate the use of ice and structural properties in appropriate analytical models. We have chosen to present the case of sheet ice loads on a conical production platform, iceberg impact with a semisubmersible and a gravity base structure, and ice interaction with a flexible pile structure.

A suite of programs written in the BASIC language are provided in Appendix A to analyze ice forces on conical structures, to provide a probabilistic assessment of ice forces and to analyze the response of simple structural systems under dynamic loading. A listing and complete documentation is provided for each program.

The authors have not attempted to provide a design handbook; but rather a basic understanding and appreciation of ice mechanics and ice effects on structures. The field of ice engineering has not yet arrived at a mature stage, and a good deal of judgment and experience is still required to achieve satisfactory design results. Although the authors have tried to cover a wide range of published articles and reports, there may have been important studies which were overlooked; for this we apologize.

The contents of the book reflect part of the collective experience in research, consulting and teaching of the authors and their assessment of the relevance of the material covered. Most of the text describes material that is available in the technical literature, but a number of original results and interpretations have been included.

The book has been aimed at engineers and scientists involved in the design of offshore structures, but it will also serve as a text for graduate courses in offshore structures, and a reference text for undergraduates.

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The computer programs in the text were prepared with the help of Mr. D. Curtis of Acres International Limited, Mrs. L. Sinclair and Mr. S. Zucchet of the University of Toronto. Typing of the first draft of the text was undertaken by Mrs. M. Brown, Mrs. S. Gunning and Ms. D. McRae. We are particularly indebted to Mrs. M. Brown who was responsible for the production of the final manuscript. Mrs. S. Disley and Messrs. T. Judd, T. Hahn, T. Dyer and B. Bowers prepared camera-ready graphics for the text. Mr. W. Brown tracked down innumerable authors to ask their permission to reproduce material and Mr. L. Little prepared the author index. Ms. B. Rodden helped check innumerable citations. Dr. H. Peters edited a number of chapters.

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Contents

1
Ice Conditions in the Arctic Offshore

INTRODUCTION

The sections of this chapter will be devoted primarily to a general discussion of the extent and movement of ice in various geographic regions around the Northern Hemisphere. The prime objective will be to discuss typical sea ice types, ice feature dimensions, and ice movements. The chapter will also cover briefly some of the factors that may affect the mechanical properties of ice in a particular region.

It is impossible to characterize all aspects of offshore ice conditions in a single chapter; hence, this discussion will be of a fairly general nature. The reader is encouraged to consult the references quoted at the end of the chapter for more detailed information. For those readers not thoroughly familiar with the terminology, it would be advisable to review the Glossary of Terms at the end of the text. A word of caution is also required regarding any literal use of the data presented here for input parameters to a particular structure design since the quantity and quality of field data in certain regions is far from sufficient.

Before commencing a more detailed discussion of ice conditions, however, it may be of interest to discuss just what is meant by the ''Arctic offshore'' and to classify the general ice regimes common to all ice-covered regions.

1.1 The Arctic Offshore

The definition of what constitutes the Arctic eludes common agreement among experts. The term, *arktis*, was used by the Greeks to relate the position of the Earth to the constellation of the Great Bear—in Greek, *arktos* means bear (Muller, 1981). The name *Arctic* was first applied in modern times to the area where, for at least one day per year, the sun does not set; this area is encompassed by the Arctic Circle at latitude 66°32′N.

In engineering terms, the southern limit of the Arctic is usually defined by a zone of perennially frozen ground. Geophysicists use strong magnetic storms, aurora borealis, and radio blackouts to define the Artic boundary. Oceanographers propose that the maximum extent of pack ice in winter should be taken as the southern limit of the Arctic.

Muller (1981) suggests that the 10°C July isotherm (average monthly temperature) is closely related to the northern permafrost limit and may form a reasonable limit to the Arctic on land and at sea. He also notes that the southern limit of the subarctic should be determined by the average temperature of the four warmest months, which should be less than 10°C.

1.2 General Ice Regimes

The ice that covers the Northern Hemisphere can be reasonably divided into four well-defined ice regimes.

Landfast Ice. Landfast ice grows seaward from the coastline and stays in place throughout the winter. In spring it breaks up and drifts away, or melts. In the Beaufort Sea area off Alaska and Canada, where a gently sloping seabed occurs, the landfast ice is stabilized by small islands and grounded pressure ridges. The draft limit of such ridges defines the outer edge of the pack ice, at about the 20-m contour. In the Canadian Arctic Archipelago, the landfast ice fills entire channels regardless of the water depth, since the channels are rather constricted. Some movement occurs in most types of fast ice both during and after stabilization, since the fast ice is subject to wind and current drag forces, as well as the pressure of mobile pack ice at its outer edge.

Shear Zone. A shear zone is formed when pack ice moves against a relatively fixed boundary of land ice, or landfast ice. The compressing and shearing motion of the pack ice generates a band of highly deformed ice with a higher density of ridging than the ice further out in the ocean (Wadhams, 1980).

Seasonal Pack. Seasonal pack ice generally consists of first-year ice, which is highly mobile, although contained between the shear zone and the polar pack (as in the Beaufort Sea) or between the shear zone and the open ocean (as in the North Atlantic). It can also be contained in relatively sheltered coastal regions (such as in the interior of Baffin Bay, parts of the Bering Sea, and the Sea of Okhotsk). Occasionally, the seasonal pack may contain isolated multiyear floes and ridges, ice islands, or even icebergs.

Polar Pack. The polar, or Arctic, pack floats in the center of the Arctic Ocean, covering two-thirds of it (Michel, 1978). It is mostly multiyear ice, although some first-year ice may occur when open leads form during summer months. Figure 1.1 shows the absolute minimum and maximum extent of the polar pack, as well as principal drift patterns.

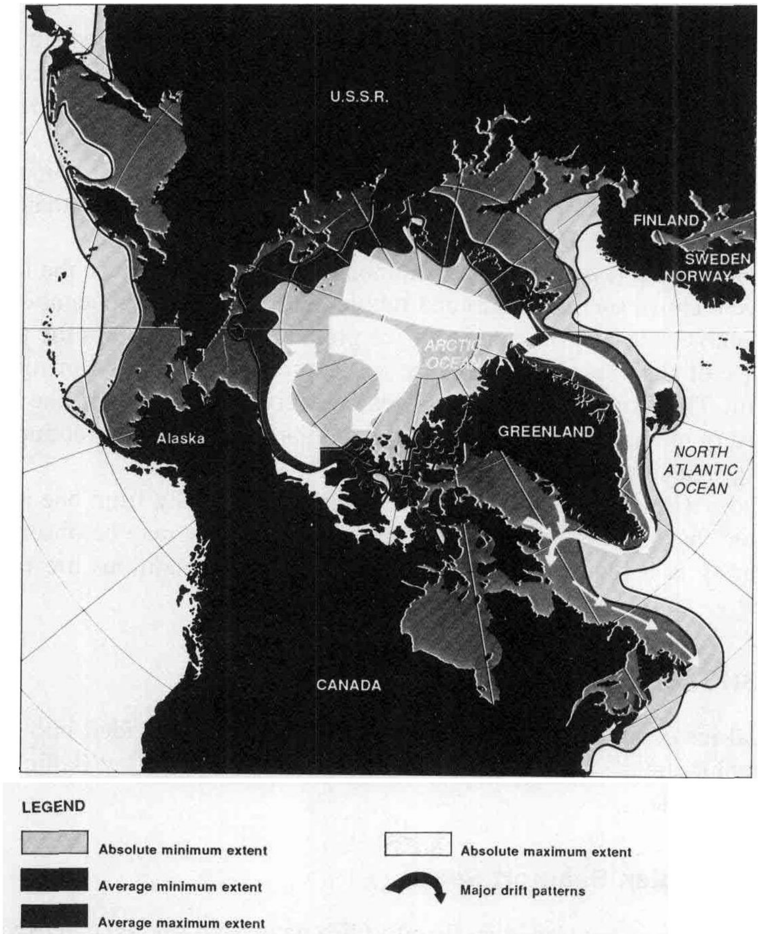

Fig. 1.1. Minimum and maximum extent of sea ice in the northern hemisphere (CIA, 1978).

1.3 Parameters Affecting Extent and Movement of Ice

As discussed further in Chap. 2, sea ice is a crystalline material with properties that depend on the size and orientation of the crystals, on salinity, and on temperature. Since the crystal structure varies with the environmental conditions present at initial ice formation, this parameter can change not only with geographical location, but also from one season to the next. Ice salinity depends both on sea water salinity and the relative age of the ice in question. Ice temperature varies primarily with air temperatures and the amount of snow cover.