上海交通大學 学术文库

②

水弹性理论及其在超大型浮式结构物上的应用

THEORY OF HYDROELASTICITY AND ITS APPLICATION TO VERY LARGE FLOATING STRUCTURES

崔维成 杨建民
吴有生 刘应中 著

上海交通大学出版社

上海交通大学学术文库

水弹性理论及其在超大型浮式结构物上的应用

Theory of Hydroelasticity and Its Application to Very Large Floating Structures

Weicheng Cui (崔维成)
Jianmin Yang (杨建民)
Yousheng Wu (吴有生)
Yingzhong Liu (刘应中)
著

Shanghai Jiao Tong University

图书在版编目（CIP）数据

水弹性理论及其在超大型浮式结构物上的应用 = Theory of Hydroelasticity and Its Application to Very Large Floating Structures / 崔维成等著. 上海：上海交通大学出版社，2007
（上海交通大学学术文库）
ISBN 978-7-313-04626-0

Ⅰ.水... Ⅱ.崔... Ⅲ.水弹性力学-应用-浮式建筑物-英文 Ⅳ.①TV131.2②P754

中国版本图书馆 CIP 数据核字（2006）第 143003 号

水弹性理论及其在超大型
浮式结构物上的应用
崔维成　杨建民　吴有生　刘应中　著
上海交通大学出版社出版发行
（上海市番禺路 877 号　邮政编码 200030）
电话:64071208　出版人:韩建民
昆山市亭林印刷有限责任公司印刷　全国新华书店经销
开本:787mm×960mm　1/16　印张:30.75　字数:614 千字
2007 年 3 月第 1 版　2007 年 3 月第 1 次印刷
印数:1-2 500
ISBN978-7-313-04626-0/TV·014　定价:58.00 元

Preface

With the fast increase of the population on earth, the supply of resources from land is approaching the limit. More and more people have realized that in order to achieve a sustainable economic development, the resources in the ocean have to be relied on. This is because in the wide ocean whose area exceeds more than two thirds of the earth surface, there exist very rich resources such as sea chemical elements, minerals under the bottom, tidy energy and ocean biological resources.

The 21st century is a century of ocean. Many new industries such as ocean oil and gas, ocean chemical industry, deep-sea mining will be formed. In the exploitation of ocean resources and in the utilization of ocean spaces, the international marine community renewed the interest in studying the feasibility of using very large floating structures (VLFS). In order to ensure their safety at sea, their structural responses in the sea are of particular importance. This is fundamentally a hydroelasticity problem. Due to their extreme large sizes, it is a great challenge both in theory and computational efficiency.

The concept of hydroelasticity was first put forward by Heller and Abramson in 1959 and it was accepted as a formal discipline until the late in 1970's with the publication of the famous book by Bishop and Price in 1979. This 2D theory was only applicable to beamlike slender structure. In order to examine the fluid-structure interaction behavior of non-beamlike structures, Wu (1984) presented a general three-dimensional hydroelasticity theory for flexible bodies of arbitrary shapes traveling or stationary in waves. This marked significant progress in the development of the hydroelasticity theory but this theory still relies on a linear structural model, whose displacement is assumed small, and a linear hydrodynamics theory, implying the use of an ideal fluid, the assumption of small wave amplitude and small disturbance. This theory also adopts a frequency-domain approach by expanding the structural displacements and fluid velocity potential into structural mode components. In the last decade, due to the wide interest in VLFS, the development of the theory of hydroelasticity was speeded up. Many special international conferences or workshops were held (VLFS' 91, VLFS' 96, VLFS' 99, VLFS' 2003;

ICHMT94, ICHMT98, ICHMT2003). In the other famous international marine conferences such as ISOPE, OMAE, PRADS, many papers are related to hydroelasticity. However, all the research works are presented in separate papers. There lacks of textbooks and monographs.

With the strong support from Chinese National Natural Science Foundation Council (NSFC), Shanghai Jiao Tong University (SJTU) and China Ship Scientific Research Center (CSSRC) were able to carry out a systematic research on the hydrodynamic responses of very large floating structures. In the research process, we also studied the theory of hydroelasticity systematically.

The purpose of writing this book is two folds. One is to provide engineers, postgraduate students a textbook or a reference book on the theory of hydroelasticity. The second is to systematically report the research work or research achievements our group finished in this NSFC project. So the book is presented in the following order.

Chapter 1 gives a general introduction to very large floating structures. The basic concepts and development history of VLFS are presented. The technical problems involved in the development of VLFS are summarized from six aspects. Finally the importance of the hydroelastic response in the design of VLFS is discussed.

From the discussion of Chapter 1, it can be seen that VLFS is a typical problem of hydroelasticity and the analysis of its hydroelastic response is the key problem in the design. Therefore, extensive application of the theory of hydroelasticity will be made in this research. Although the concept has been put forward for about forty five years, the development of the theory is diverse. In Chapter 2, a historical review of the theory of hydroelasticity is given. This will provide a basis for the understanding of the next two chapters.

Chapter 3 presents a complete theory of hydroelasticity in time domain. Up to now most of the researches are carried out in frequency domain. However, nowadays, the interest to the nonlinearity and the importance of the nonlinearity become more and more significant. In order to treat these nonlinearities, time domain theory is a necessity. This chapter starts with potential theory for an arbitrary floating body, then moves on to the linear hydroelasticity theory and finally fully nonlinear hydroelasticity theory in time domain. This chapter is an important feature of this book in presenting the general theory of hydroelasticity.

Chapter 4 presents the theory of hydroelasticity in frequency domain. The main contents of the chapter come from the widely cited Ph. D thesis

(Wu, 1984), but recent developments have been accounted for. One section is dedicated to the hydroelasiticity of flexible multi-body structures. This problem is currently of great interest since it is more closely reflected the actual engineering problem. Finally, the attempts to solve the nonlinear problem in the frequency domain are discussed in the last section.

The above four chapters are basically concerned with the basic theory of hydroelasticity. The main specific feature of the book is that the general theory of hydroelasticity in time domain was given which could not be found in any other individual source. The later chapters are mainly related to the work on VLFS.

Generally there are two types of very large floating structures which have received considerable attention. They are mat-type VLFS used in Mega-float of Japan and semi-submersible type VLFS used in MOB of USA. Chapter 5 presents a comprehensive study on the mat-type VLFS. Mat-type VLFS can be modeled as a floating plate and simplified methods are possible. Existing simplified methods have been critically examined. These kind of simplified methods can be predict the order of the magnitude of the responses in some cases but the accuracy can not be very high. On the other hand, some numerical methods such as eigen function expansion method and the Green function method have very high accuracy and also the computation time is reasonable.

Chapter 6 presents some of our researches on the hydroelastic response analyses for MOB. For this type of floating structures, simplified methods are hardly possible. We applied 3D hydroelastic analysis methods in frequency domain. The main emphasis was put on the connection force. So some efforts have been given to model the connections.

Due to the extreme large size, oceanic environment at one end of the VLFS may be different from that at the other end (several kilometers away). These inhomogeneous environments can lead to large loads in connectors or cause large power expenditures in the thrusters. In this project, special emphasis was given to investigate such an effect. Chapter 7 reflects such an effort.

For the validation and verification of the various numerical methods, the experimental results are of particular importance. However, how to model the VLFS in a tank itself provides challenges. Chapter 8 summarizes the experimental techniques for VLFS. Four new tests have been carried out in the State Key Laboratory of Ocean Engineering at Shanghai Jiao Tong University. Three of them are described in this chapter.

The research work and achievements are a collection of a large group of personnel at SJTU and CSSRC. There are Professors: Weicheng Cui, Jianmin Yang, Yousheng Wu, Runpei Li, Shijun Liao, Xianglu Huang, Yingzhong Liu, Associate Professors and researchers: Ju Fan, Xingning Peng, Zhi Shu, Hui Sun, Post-doctorate research fellow: Dr. Xujun Chen, Ph. D students: Zhijun Wang, Hao Song, Lan Yu, Shixiao Fu, Haining Lv, Fan Zhang, Hengtun Ji, MSc. Students: Hongmei Yan, Jingzhe Jin, Guojian Chen. The responsible authors for the chapters are as follows. The preface, Chapter 1, Chapter 2 are written by Weicheng Cui, Chapter 3 is written by Weicheng Cui and Yingzhong Liu, Chapter 4 is written by Yousheng Wu, Chapter 5 is written by Weicheng Cui and Yingzhong Liu, Chapter 6 is written by Runpei Li, Chapter 7 is written by Weicheng Cui, Shijun Liao and Yingzhong Liu and Chapter 8 is written by Jianmin Yang. All the others worked in the project group made some contributions to the relevant sections. Weicheng Cui and Yingzhong Liu are responsible for the whole book. The authors of the book are those mainly responsible for the corresponding chapters and of course they are themselves main investigators of the corresponding research work. Although many efforts have been made by the authors to reduce the mistakes, we are not able to claim free of errors and therefore we would appreciate very much if the readers could feed back any errors they found.

This book is written for students (undergraduates and postgraduates) and practical engineers. It is quite comprehensive but present in a manner of easy-to-be-understood. The application is mainly related to VLFS although the theory presented in this book can also be applied to other types of marine structures.

Without many helps received from various sources it is impossible to finish this book. We first wish to acknowledge the financial support from NSFC, Shanghai Municipal government and Shanghai Jiao Tong University and the Acadamic Publication Foundation of Shanghai Jiao Tong University. The funding from these sources makes it possible for us to do a systematic research in this field and in particular several novel large scale model experiments. Next we would also like to acknowledge the support from Shanghai Jiao Tong University Press and professor Zhengzhi Han. They provide a lot of help in publishing the book in such a nice style. We are grateful to the reviewers whose comments have improved the clarity of the manuscript. Our heartfelt thanks go also to academician Wanxie Zhong, Dr. Shuangxing Du, Dr. Weibao Wang and Ms Jingzhe Jin.

Finally this book is dedicated to our beloved great motherland!

CONTENTS

Chapter 1
Introduction to Very Large Floating Structures

1.1 Basic Concepts of VLFS

The 21st century is the century of ocean. The vast ocean covers more than two thirds of the earth surface. Not only it reserves about 80% of the total amount of minerals and 70% of the total kinds of ecospecies in the entire earth, contains unfailing creation of energy in its tide and waves, the unfathomable ocean also provides boundless space above and under water surface. With the fast increase of the population on earth, the supply of resources from land is approaching the limit. The mankind will have to more and more rely on utilization of ocean resources and ocean space to allow for further expanding of population and sustainable economic growth. The exploitation of ocean oil and gas, extraction of ocean chemical elements, and mining of deep-sea resources have formed and will further become the most important industries all over the world. Meanwhile, great attention has been given to ocean space utilization, mainly focusing on the research and application of very large floating structures (VLFS) as a natural result during the last decades (e. g. VLFS'91, VLFS'96, VLFS'99, VLFS'2003). The concept of large modular floating structures that can be used for floating cities, airfields, ports, or manufacturing facilities is not new. A form of the concept was first enunciated by Armstrong (*circa* 1920s) for Seadrome (1940s) as stepping stones across the oceans, see Fig. 1. 1.

Up to now there is no strict definition for a VLFS. Nowadays when a VLFS is referred to, it is often meant a floating structure of several kilometers in length in distinguishing with the traditional marine structures whose length is only of several hundreds meters such as ships and platforms. Generally speaking, VLFS can be deployed near coastal islands semi-permanently or permanently, and it has

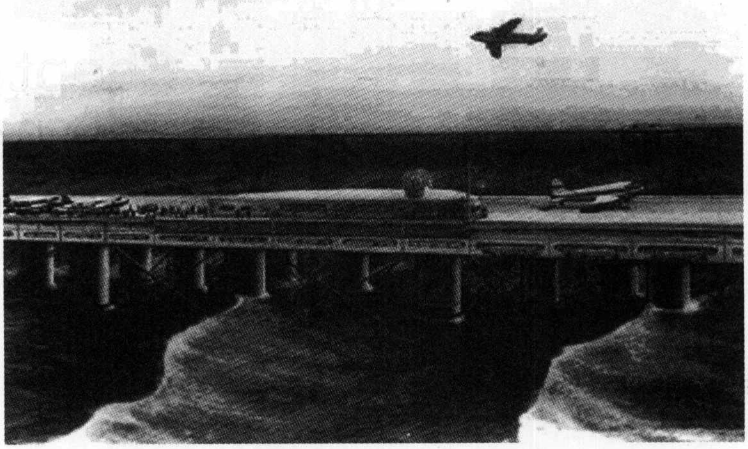

Fig. 1. 1 Armstrong's concept of Seadrome

functions of comprehension and multi-purpose. Its deployment will have great impact on the social, economical and political activities, as well as on the military balance (Cui, *et al*, 2000).

Compared to the reclaimed land, VLFS has several advantages such as more friendliness to the environment, less susceptibility to earthquakes, shorter construction period, and cheaper construction cost, especially when the water depth is deep (over 20m).

Various types of VLFSs have been investigated during the past decades. Among them the most commonly examined were the box shaped *pontoon type* and the *semisubmersible type* (Suzuki, *et al*, VLFS'96). Two types of semisubmersible VLFSs were proposed. One type is supported on a series of columns of large diameter and small depth (Semisubmersible Column Footing Type). In this case, the response characteristics can be dominated by quasi-static response (Cui, *et al*, 2000). The other type is the column and lower hull supported model (Semisubmersible Lower Hull Type), whose shape is just the extension of the conventional semisubmersible rigs. Fig. 1. 2 shows a schematic representation of the above-mentioned three types of VLFSs. It is known that pontoon type structures have less construction and maintenance costs while the semi-sub type structures have better wave damping capability (Cui, *et al*, 2000). A VLFS that consists of a pontoon type as main body and semi-submersible type wave breaking structure around the main body has thus been proposed as having