



# FLUVIAL PROCESS AND REGULATION FOR TIDAL ESTUARY



## 潮汐河口 河床演变与治理

浙江省水利河口研究院 熊绍隆 编著



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## 内 容 提 要

本书根据国内外 26 条河口资料,以影响河口形态及其演变的最重要且相互独立的因素,即径、潮流比值  $\alpha$  和径、潮流含沙量比值  $\beta$  的合理组合  $\alpha\beta^{1/2}$  作为分类指标,将潮汐河口分为河口湾型、过渡型和三角洲型三大类(其中Ⅱ、Ⅲ类又各分为三个亚类),较好地归纳出不同类型河口的形成条件和河床演变的主要特征。接着运用典型实例,进一步探讨了不同类型河口水沙运动和河床演变特性,概述其治理实践,并据以综合分析了潮汐河口开发治理的共同原则和各类河口的治理关键与难点。

图书在版编目(CIP)数据

潮汐河口河床演变与治理 / 熊绍隆编著. -- 北京 :  
中国水利水电出版社, 2011.1  
ISBN 978-7-5084-7733-6

I. ①潮… II. ①熊… III. ①潮汐—河口—河道演变—研究 IV. ①TV147

中国版本图书馆CIP数据核字(2010)第143543号

书 名	潮汐河口河床演变与治理
作 者	浙江省水利河口研究院 熊绍隆 编著
出版发行	中国水利水电出版社 (北京市海淀区玉渊潭南路1号D座 100038) 网址:www.waterpub.com.cn E-mail:sales@waterpub.com.cn 电话:(010)68367658(营销中心)
经 售	北京科水图书销售中心(零售) 电话:(010)88383994、63202643 全国各地新华书店和相关出版物销售网点
排 版	中国人民大学出版社印刷厂
印 刷	北京盛兰兄弟印刷装订有限公司
规 格	184mm×260mm 16开本 13印张 233千字 4插页
版 次	2011年1月第1版 2011年1月第1次印刷
印 数	0001—1500册
定 价	60.00元

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# 序 一

熊绍隆编著《潮汐河口河床演变与治理》一书,是笔者所见过的河口演变与治理的书中最完备的一本。它不但搜集了大量重要的冲积河口事例,还运用新的分类方法,科学地对河口加以分类,然后相应地说明各类河口的整治方略或模式。所以从编著者建议的河口分类法,便大致可以预见河口的整治方向,这是十分值得重视的。将河口分类和河口整治方向挂钩,而不是为分类而分类,无异于为规划整治工作者提供了一个新的捷径,是饶有实际意义的。

本书对各国大、小河口的整治做了大量报道,在一定程度上,起了河口整治工作手册的作用。手持一卷,悉心研读,便可能省却广泛查阅文献的大量工作。在小河口的整治工作中,人力、物力都未必充沛,广泛查阅各国技术资料一般更是不可能的。本书汇聚了大量的实际资料,在某种意义上说便是一本良好的小河口整治技术指南。

对我国的大型河口,如长江、珠江和钱塘江等,本书也作了详尽的介绍,可以供大河口整治工作者参考。

除了对河口泥沙冲淤及有关现象有较全面的认识和描述外,本书编著者在潮汐水力学方面也有比较深入的报道。例如他根据实测资料,指出泥沙浓度的变化滞后于潮波的传递(推导见浙江水利河口院 20 世纪 80 年代发表的论文),这个差异将影响淤积分布和总冲淤量,在潮波的计算中是值得重视的。

鉴于该书有以上特点,我愿借此机会向广大同行们推荐。

中国科学院院士

林秉南

2009 年 4 月 1 日

# FOREWORD 1

This book contains the most extensive collection of case histories on the development and regulation of alluvial tidal estuaries among all books of the same kind that have recently come to my attention. It features the adoption of a newly developed system of estuary classification that is tied in with the schemes of estuary regulation. Thus, following the system of classification presented in the book, one would also be hinted on the possible ways to regulate an estuary. This is considered quite significant in that classification is now more than mere grouping of estuaries of similar features for speedy reference. It also throws some light to illuminate the way to the rational regulation of an estuary.

So much information on the regulation of alluvial estuaries has been gathered in this book that it may also serve as a sourcebook of estuary regulation. With this book on hand, one may save much of time and expenses otherwise needed in the search of pertinent literature for reference from extensive individual publications. This is particularly desirable in the regulation of small estuaries where both manpower and financial resources are usually limited, so that under such circumstances it is often advisable to keep financing restricted as much as possible to the immediate expenses of design, construction and relocation of inhabitants.

This book also contains detailed information on such large Chinese estuaries as the Yangtze, the Pearl and the Qiantang. It could be a good reference for those engaging in the regulation of large estuaries.

In addition, it is obvious that the author is also versed in tidal

hydraulics. In-depth discussions of tidal flow problems may be found here and there in the book. For instance, the author makes it a point to indicate that the propagation of disturbances in sediment concentration lags behind that of the tidal flow. This is often observed in the field. It may also be derived from the basic equations of motion by applying the theory of characteristics. The said lag would affect both the amount and distribution of sediment deposition and is therefore not to be overlooked, especially in the cases of non-uniform estuaries.

***Member of Chinese Academy of Sciences , Professor***

*Bingnan Lin*

2009. 4. 1

## 序 二

河口是陆海交会的地带,也是海洋和流域物质交换的通道。河口资源丰富,交通便捷,物流通畅,人类活动频繁,都市发展,人文荟萃。河口的开发和保护,最受人们所关注。

在中国,有关河口现象的记载,有着悠久的历史。潮汐现象特别是涌潮和增水,公元前后已有具体描述和成因分析;河势的变化特别是黄河和钱塘江河口的河势变化都有悠久的典籍记录;河口灾害的防御、堤防修建,也有千年以上的历史。历史时期的海塘更是与长城、运河三者相并的中国古代伟大建筑。

近代的河口研究,二次世界大战以后,同海洋研究为学者重视一样受到关注,作为海岸组成部分的河口是“没有岸线的海岸”,它的种种问题也被学者们予以系统研究。中国对现代河口的研究,起始于20世纪50年代,有关部门成立了专门的研究机构,并在经济建设的带动下,开展了大、中型河口基本资料的搜集和主要问题的探索。经过几十年的资料积累,就河口的基本问题、整治措施与工程总结等相继出版了多种专著,涉及河口理论、河床演变、河口治理等多个领域,包括长江、黄河、珠江、钱塘江河口等大、中型河口的专门论述,它们不仅极大地促进了本学科的发展,同时也丰富了相邻学科如海洋科学、海岸工程和港口工程的内容。

最近,浙江省水利河口研究院熊绍隆教授在他30余年从事河口研究及具体河口治理工作中,积累和收集了丰富的实际资料,总结其实践经验,撰写了这本《潮汐河口河床演变与治理》专著,探讨了河口分类,探索了河口河床演变规律,探究了各类河口治理的途径,还就河口研究中应予关注的若干问题提出了自己的见解,这一专著为河口研究开拓了新的思路。

就河口分类问题,著者分为两个层次予以划分。第一个层次从形态学出发,依据众所熟知的三角洲河口和喇叭形河口两大类型,引

进一种被前人称之为过渡型的第三种类型。第二个层次考虑河口双向水流及其挟带泥沙的动力因素和物质条件,寻择其作为河口分类的综合指标,并于过渡型和三角洲型之下,又各分为3个亚类。这是河口分类研究中一种新的探索。

在此基础上,编著者运用各类河口的典型实例,进一步探讨不同类型河口水流、泥沙运动和河床演变的基本规律,重点总结各类河口成功治理的经验;进而综合分析了潮汐河口开发治理的共同原则和不同类型河口治理的关键点与难点之所在。根据各类河口共性的初步认识,因地制宜地结合具体河口的个性及其区位优势,能较好地制定河口综合整治开发规划,达到河口合理开发之目的。

本书作者特别就潮汐河口开发治理的基本原则及各类河口治理的关键问题给出了系列启示。这其中,我认为在科学技术高度发展的今天,人类驱动力对于潮汐河口开发更需顺应河口发展的基本模式和河口河床演变的基本规律,以求河口开发与保护更为有效。人类有能力对各类河口实施工程控制,但各类河口都有其发展的自然规律,工程措施须与之相适应,正如该书作者指出的河口整治应该尽量“维持河口原属类型”,河口资源开发也必须以“动态平衡”来妥善处理开发与保护的矛盾。

这本书对研究者而言,提供了学习机会和启示,河口研究者也将对该书的主要观点予以检验并丰富其内容。

中国工程院院士

陈吉余

2009年3月24日



## FOREWORD 2

Estuary is a contact zone of continent with sea and is the thoroughfare of goods exchange for the sea and watershed. There are abundant resources, convenient communication, fluent goods circulation, frequent human activity, advanced cities and long-standing culture. The exploitation and protection of estuaries have been intensely concerned by people.

There is a long-standing history for records of estuary phenomenon in China. The tide phenomenon, especially the tidal bore, the water raising and their reason had been described and analyzed at the front and back of A. D. There are long-standing records of river regime change in estuaries, especially the Yellow River Estuary and the Qiantang Estuary as well as the history of disaster prevention with building dyke in more than thousand years. The ancient seawall with the Great Wall and the Grand Canal are called three ancient great constructions of China.

After the Second World War, the estuary research likewise the sea research has been intensely concerned. As a constituent of the coast, the estuary is the coast of non shoreline and there are a number of problems studied by scholars systematically. The research of modern estuary in China began in 1950s. The special research organizations were established at the relevant departments. Spurred by economic construction the essential data were collected and the principal problems were studied for the large and middle estuaries. Through accumulating data and research in tens years, the diversified special writings for the estuary theory, fluvial process and regulation including special writings of Changjiang, Yellow River,

Zhujiang and Qiantang estuaries were republished, which not only has extremely promoted development of the related subjects but also has brought forth plentiful content of close subjects such as oceanography, coast and harbor engineering.

Accumulating abundant data and summarizing experience for estuary research and regulation more than 30 years, Professor Xiong Shaolong, who works in Zhejiang Institute of Hydraulics and Estuary, wrote a book named *Fluvial Process and Regulation for Tidal Estuary* recently. The classification of tidal estuary, the fluvial process and the regulation for each kind of estuary are studied in this book. He presented his personal opinion for a number of questions concerned estuary research. This writings carved out a new thread of thought for estuary research.

As for the estuary classification, two levels are divided in this book. First and foremost, according to delta and funnel-shaped estuaries as all known gained from morphology, the transition estuary named by predecessors is leaded to estuary classification. The second, considering the reversing movement characteristics of flow and sediment in tidal estuary and looking for combination classification index consisted of flow and sediment factors reasonably, the transition and delta estuaries could be further divided into three sub-types respectively. This is a new exploration for estuary classification research.

Based on the estuary classification research, the essential law of the flow-sediment movement and fluvial process for different kind of estuary are further investigated by using corresponding typical estuary examples with emphasis on summary experiences of success regulation. Then the common principles of regulation and exploitation for tidal estuaries, the difficulty and key point in regulation for different kind of estuary are comprehensively analyzed. On

the basis of realization about common characteristics for each kind of estuary, the comprehensive regulation and exploitation projects of estuary could be made well with combination of their individuality and region superiority so that the reasonable exploitation of estuary could be realized.

This book gives a series of enlightenment, special for basic principles of estuary regulation and exploitation and for key point of regulation in different kind of estuary. I think that the exploitation of tidal estuary must obey fundamental model of estuary evolution and basic law of fluvial process in estuary which could make exploitation and protection of estuary more efficient. The mankind has ability to carry out engineering control for estuary but the engineering measures must suit for nature law of estuary development. As mentioned in this book, the estuary regulation construction “ought maintain original type of estuary as full as possible” and the exploitation of the estuary resources “should remain dynamic equilibrium” to treat contradiction between exploitation and protection.

This book presented researchers with reference and enlightenment and the principal point of view will be examined and enriched by estuary researchers.

***Member of Chinese Academy of Engineering , Professor***

*Chen Jiguo*

2009. 3. 24

# 前 言

潮汐河口以其陆海相通的区位优势常成为各国或地区的交通枢纽与经济中心。资源丰富、人口稠密、经济发达的潮汐河口,其治理经历了以筑堤防灾和航运为重点的漫长历程,当前已提升到人与自然和谐共处、协调发展的综合整治开发高度。河口受径、潮流交互作用,具有典型非恒定往复流特征,水流、泥沙运动远较单向流的河流复杂,河床演变更是千差万别。本书在河口水流、泥沙运动特性研究的基础上,始终抓住影响河口河床演变的主要因素——动力和物质条件(径、潮流和泥沙),充分注意河口不同于河流的双向来流、来沙特点,根据国内外26条河口资料,以径、潮流比值 $\alpha$ 和径、潮流含沙量比值 $\beta$ 的合理组合 $\alpha\beta^{1/2}$ 作为分类指标,对潮汐河口进行了新的系统分类。 $\alpha$ 反映径、潮流交互作用的动力影响, $\beta$ 表征泥沙往复运动的纽带作用,两者为影响河口形态及其演变的主要且相互独立的因素。随后运用投影寻踪动态聚类模型(PPDC)对分类的合理性予以论证。在此基础上,根据分类指标 $\alpha\beta^{1/2}$ 将潮汐河口分为河口湾型、过渡型和三角洲型三大类,其中Ⅱ、Ⅲ类又各分为3个亚类,并较好地归纳出不同类型河口的形成条件和河床演变的主要特征。接着,运用各类河口的典型实例,进一步分析了不同类型河口水流、泥沙运动和河床演变特性,概述其治理实践和经历的曲折。在对不同类型河口水沙运动和河床演变主要特征认识的基础上,结合各类典型河口治理的经验与教训,综合分析了潮汐河口开发治理的共同原则和各类河口的治理关键与难点。根据各类河口的共性,因地制宜地结合具体河口个性与其自然、经济地理的区位优势,才能较好地制定科学的河口综合整治规划,从而实现经济、合理、高效开发利用之目的。

本书的1、2章分析了潮汐河口水流、泥沙运动的一般特性;3章探讨了潮汐河口分类指标与河口分类、各类河口的形成条件与河床演变的主要特征;4章为潮汐河口治理的一般原则;5~9章以典型实例叙述了不同类型(包括主要亚类)河口水沙运动、河床演变与治理实践;10章为潮汐河口治理开发的综合思考,初步归纳了潮汐河口开发治理的共同原则和各类河口的治理关键与难点;根据作者多年从事河口工程科研及设计30余年的体会,11章论述了潮汐河口工程科研方法与部分施工技术的合理运用。

早在20多年前,导师谢鉴衡教授(中国工程院院士)就要求我努力积累知识,注意总结经验、教训,争取编写一部有关潮汐河口河床演变的专著。40余年

的科研及设计实践,多少有了一些体会,于是,便利用工作间隙和节假日,历时2年有余得此拙作。在编著过程中,所在单位浙江省水利河口研究院大力支持,两位老专家戴泽衡、李光炳教授级高级工程师始终热情关怀并审阅初稿,提出了若干宝贵意见,余炯副总工程师生前也一直关心书籍的编写,教授级高级工程师林炳尧、耿兆铨、潘存鸿等同仁审阅了第3章,恽才兴、陈文彪、李泽刚教授分别审阅了7、8、9章并提供了尚未发表的资料和新近的研究成果,高级工程师曾剑在应用投影寻踪动态聚类模型进行河口分类验证、工程师李君和副研究馆员郎忘忧等同仁在制图与资料收集等方面给予诸多协助,中国科学院院士林秉南教授、中国工程院院士陈吉余教授更是热情关怀,分别为本书作序并提出宝贵意见,在此,一并表示衷心的感谢。

在潮汐河口分类、不同类型河口河床演变与治理等方面,本书的归纳、分析及其结论仅仅是初步的,内中谬误在所难免,希望它能起到抛砖引玉、促进深入研究的作用。本书亦可供从事潮汐河口规划、科研、建设、管理单位科技人员及大专院校相关专业师生参考。

本书的出版得到了国家“水体污染控制与治理科技重大专项(2009ZX07424-001)”的资助,仅在此表示感谢。

**熊绍隆**

2009年4月7日

# PREFACE

With the geographical advantages of connecting land and sea, the tidal estuaries characterized by abundant resources and dense population have usually become national/regional hubs and economic centres. Building dykes to prevent disaster and navigation used to be the focus of estuary regulation, which has now advanced to an integrated level where human and nature can develop in a harmonious and coordinated manner. The interaction between runoff and tidal current leading to the typical unsteady reversing flow in tidal estuary makes both the flow and the sediment transport more complicated with highly varied fluvial process than those of uniflow. On the basis of researching kinematical characteristics of current and sediment, grasping always the dynamic and material conditions, focusing on the unique to-and-fro movement characteristics of flow and sediment in tidal estuaries, the new systematic classification of tidal estuaries is presented in this book by adopting the combination index named  $\alpha\beta^{1/2}$  in 26 estuaries all over the world, in which  $\alpha$  is the ratio of river runoff to tidal flow,  $\beta$  is the ratio of sediment concentration of runoff to that of tidal current. In other words,  $\alpha$  stands for dynamic influence of alternate action with runoff and tidal current, and  $\beta$  represents the tie action in reversing movement of sediment. Both  $\alpha$  and  $\beta$  are the main independent factors affecting the estuary morphology and fluvial process. The rationality about the classification index of tidal estuaries is verified by using the Projection Pursuit Dynamic Cluster Model (PPDC). With the index  $\alpha\beta^{1/2}$ , the tidal estuaries are classified into three types including firth estuary, transition estuary and delta estuary, in which the latter two types could be further divided into three sub-types. Then the formation conditions, the essential characteristics of the flow-sediment movement and fluvial process could be summarized well for different kinds of estuary. The essential characteristics of the flow-sediment movement and fluvial process for each kind of tidal estuary are further investigated by using corresponding typical estuary examples, with generalization of practice and experiencing circuitousness in regulation. On the basis of above mentioned undersdading, the common principles of



regulation and exploitation for tidal estuaries, the difficulty and key point in regulation for each kind of tidal estuary are comprehensively analyzed. According to the main characteristics for different kinds of estuary, the comprehensive regulation and exploitation project for tidal estuaries could be made well with combination of their individuality and region superiority.

Chapter 1 and Chapter 2 analyze respectively the common characteristics of the flow and the sediment movement. Chapter 3 discusses the classification index for tidal estuaries, the formation conditions and the essential characteristics of the flow-sediment movement and fluvial process for different kinds of estuary. Chapter 4 generalizes the general regulation principles for tidal estuaries. Chapter 5 to Chapter 9 describe further the essential characteristics of the flow-sediment movement and fluvial process, the regulation practice and the experiencing circuitousness for different tidal estuaries by using typical estuary examples of each kind. Chapter 10 analyzes comprehensively the common principles of regulation and exploitation for tidal estuaries, the difficulty and key point in regulation for each kind of estuary. According to the author's experience of 30 odd years in estuary research and design, the Chapter 11 expounds a reasonable application of research methods and several construction techniques for estuary regulation.

More than 20 years ago, Professor Xie Jianheng (Member of Chinese Academy of Engineering, my supervisor) asked me to write a book about fluvial process and regulation for tidal estuary by accumulating knowledge energetically and summarizing experience and lessons attentively. The research and design practices of more than 40 years provide certain realization to complete this book by using work intervals and holidays in more than 2 years. The Zhejiang Institute of Hydraulics and Estuary (my employer) provided much support to the book's compilation. Professors, Senior Engineers Dai Zeheng and Li Guangbing always showed much concern and reviewed the book's draft. The late Deputy Chief Engineer Yu Jiong had consistently concerned for the compilation about this book. Professors, Senior Engineers Lin Bingyao, Gen Zhaoquan and Pan Cunhong reviewed the Chapter 3. Professors Yun Caixing, Chen Wenbiao and Li Zegang reviewed the Chapters 7~9 respectively and furnished their unpublished data and latest research results. Senior Engineer Zen Jian in estuary classification verification by using the Projection Pursuit Dynamic Cluster Model (PP-

DC), Engineer Li Jun and Associate Librarianship Lang Wangyou in drawing and data collection gave much help. Professor Lin Bingnan (Member of Chinese Academy of Sciences), Professor Chen Jiyu (Member of Chinese Academy of Engineering) expressed deep concern and wrote the forewords for the book respectively as well as presented valuable suggestions. I take this opportunity to express my sincere appreciation for their concern and help.

In the field of tidal estuary classification, the fluvial process and regulation for the estuaries and so on, the analyses and conclusions of this book are only preliminary and not free from errors. I wish it will play a part in promoting further research and make reference for engineers in relevant science/technology organizations (such fields as investigation, project planning, design, construction and management), as well as for teachers and students of relevant profession in universities and colleges.

The publishing of this book got financial aid from “water pollution control and management technology major project (2009ZX07424-001)”. I take this opportunity to express my gratitude.

Shaolong Xiong

2009. 4. 7



图 1.7 钱塘江河口一线潮景观图

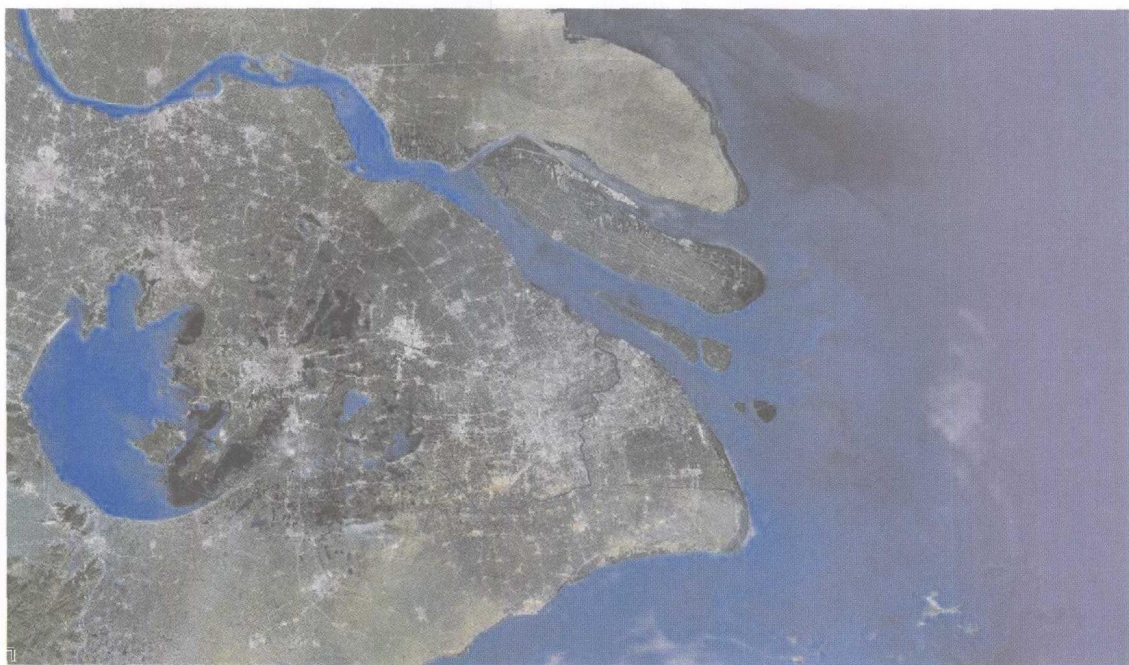


图 3.11 长江口形势图