中国桥梁

(2003-2013)

Bridges in China

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中國橋梁

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李國豪題

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李国豪（1913-2005）

前言

2005 年 2 月 23 日元宵节，敬爱的李国豪老师永远离开了我们。当时，他曾积极参与前期规划工作并日夜关心的上海东海大桥即将建成，苏通长江大桥和杭州湾大桥已投入紧张的施工，舟山连岛工程的关键工程西堠门大桥也即将动工建设。2013 年 4 月 13 日是李老师的百年诞辰，我们通过遴选将进入 21 世纪以来的最近十年间新建桥梁中的 100 座具有代表性的中国桥梁汇编成册，献给李老师以及已故的桥梁界许多前辈，用以报答他们曾经给予的教诲和奠定的基础，也表达我们后辈对他们的崇高敬意和永久怀念之情。

中国桥梁在 21 世纪初又出现了一个新高潮。由于国家财力日渐充裕，为了发展中西部地区的经济，投入了巨额的交通设施建设费，沿海发达地区也继续提高交通设施水平，加密路网，以适应日益增长的交通需求，加上高速铁路建设的兴起，桥梁建设呈现出全国遍地开花的兴旺景象。然而，巨额投资也滋长了浮躁心态和好大喜功的不良倾向，出现了少数盲目追求“第一”和“之最”，不顾经济合理性的工程。这不仅违背了设计基本原则，也遭到国际同行的质疑，已引起有责任心的管理者、技术人员的警觉和反思。

本画册共分六篇，分别收集了跨海大桥、悬索桥、斜拉桥、拱桥、梁式桥和城市桥梁六类共 100 座桥梁。每座桥除精美的图片外均附有中英文的简单说明，以着重介绍该桥不同一般的特点、难点和亮点。每篇各撰写一简短的引言，对所收编的桥梁进行综合评述，简述有特殊意义的创新技术成果和存在的不足，并指出今后努力的方向。

从 1993 年为纪念李校长的 80 寿辰出版的第一本《中国桥梁》，2003 年为纪念他 90 寿辰的第二本《中国大桥》，到 2013 年的这本画册，共同记录了新中国成立以来六十余年间中国桥梁从学习和追赶、跟踪和提高到有所创新和超越的奋斗历程。李国豪老师作为中国桥梁在改革开放以来通过自主建设取得进步的首要功臣和领路人，建立了不朽的功勋。

今天，我们纪念他的百年诞辰，一定要牢记他“理论联系实际，发展桥梁科技”的教导，勇于创新，用创新的成果提高国际竞争力，克服不足，走出误区，为实现从桥梁大国走向桥梁强国的目标而继续努力。

项海帆　范立础

2013 年 1 月

中国桥梁
Bridges in China
(2003-2013)

Preface

On February 23, 2005, the date of Chinese Lantern Festival, our respected and beloved teacher Prof. Li Guohao left us forever. At the time of his passing, the Shanghai East Sea Bridge was nearly complete. The Sutong Bridge over the Yangtze River and the Hangzhou Bay Bridge, two bridges of great importance to Prof. Li which had benefitted from his personal involvement in the preliminary planning stage, were under construction. Construction was about to begin on the Xihoumen Bridge, the key project of the Zhoushan Island connection. April 13, 2013 is the one hundredth anniversary of Prof. Li's birth. To coincide with this date, we have compiled this book to showcase one hundred Chinese bridges built between 2003 and 2013. We dedicate this book to Prof. Li and other eminent experts for their contributions to bridge engineering in China. Through the publication of this book, we recognize their teaching and guidance, and express our deepest gratitude, utmost respect, and everlasting remembrance.

The beginning of 21st century ushered in a new boom in bridge construction in China as a result of the great success of Chinese economy. The central and western regions of China received major investments in new infrastructure while the developed coastal areas saw further expansion of existing highway networks to keep pace with the rapid growth of transportation. The demand for new bridges was further intensified by the development of China's high speed railway network. Together, these factors enabled bridge construction to flourish in China during the past decade. The unprecedented scale of infrastructure investment during the past ten years may result in making aggressive and impetuous decisions. In the most serious cases, officials took advantage of the power associated with their rank. As a consequence, several recent record-breaking projects actually achieved their status by violating basic rules of good design and economy. These projects have been questioned by international colleagues and criticized within China by responsible government officials, engineers, and professors.

This book presents a total of 100 bridges organized into six chapters, each representing one type of bridge: sea-crossing bridges, suspension bridges, cable-stayed bridges, arch bridges, girder bridges, and urban bridges. For each bridge, there are photographs as well as a brief explanation in both Chinese and English describing unique features and challenges. Each chapter begins with an introduction that gives a comprehensive appraisal of each type of bridge, recommending applications of technology that are associated with significant creative achievements, as well as pointing out insufficiencies and suggested directions for future improvement.

The first book *Bridges in China* was published in 1993 to commemorate Prof. Li's 80th birthday. The second book *Major Bridges in China(2003)* commemorated his 90th birthday. The current book, to be published in 2013, together with the previous two books, record the history of bridges in China over the past 60 years since the foundation of the People's Republic of China. These volumes bear witness to the progress made in bridge engineering in China, which began with a period of learning from international bridge engineering practice, followed by a period of adaptation and enhancement of international practice, to the current period in which Chinese bridge engineers have demonstrated the capacity to innovate and have assumed a position of leadership that is recognized worldwide. Since the beginning of China's economic reform and opening-up policy in 1978, Prof. Li Guohao became the pre-eminent bridge engineer in China, serving the profession through leadership inspired by a spirit of self-reliance.

Today, as we commemorate his one hundredth birthday, we must remain mindful of the primary elements of Prof. Li's teaching: to "combine theory with practice to develop bridge technology", to be bold in innovation, and to use the achievements of innovation to be competitive on the international stage, overcome shortcomings, and to avoid past mistakes. Under his guidance, we will strive to transform China from a nation of large bridges to a nation of strong bridges.

Xiang Haifan, Fan Lichu
January, 2013

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第一篇　跨海大桥
Chapter 1　Sea-crossing Bridges

引言

世界跨海大桥（包括跨越湾口）的先声是1890年苏格兰福思湾的铁路桥，而最著名的应是建于1937年跨越美国旧金山湾口的金门大桥。连接佛罗里达Keys岛（美国东南部珊瑚群岛）和迈阿密的跨海铁路高架桥是一座最早的跨海连岛桥梁，这座高架桥建于1910年，后被改建为跨海公路桥（美国1号公路Keys岛段），1935年被"Labor Day"飓风摧毁。此外，佛罗里达Keys长桥和1935年建成的丹麦公铁两用小海带老桥也是跨海桥梁的先驱，其中，小海带老桥公路桥梁的功能被1970年建成的一座新悬索桥所代替。20世纪世界最长的连岛工程是由荷兰在80年代承建的长25km的巴林和沙特之间的巴林海峡大桥。丹麦和日本两个岛国于60年代开始起步建设连岛工程，日本从关门大桥起步，于20世纪末建成明石大桥和多多罗大桥，实现了三条本四联络线的跨海连岛工程。丹麦则于1997年建成大海带桥，完成了连岛工程，并且还和瑞典合作建成了连接两国之间的厄勒海峡大桥。

中国的跨海大桥建设可以从20世纪90年代的汕头海湾大桥算起。接着，在香港回归前为连接新机场建成了青马大桥、汲水门桥及汀九桥三座连岛大桥。此时，舟山连岛工程也已开始起步，从本岛向大陆逐步连岛推进。其他沿海城市的一些连岛工程也开始前期规划。中国第一座在广阔海域的跨海连岛工程是2005年建成的上海东海大桥，它将上海市与洋山深水港连接起来，全长32.5km。东海大桥为以后的杭州湾大桥、上海崇明桥隧工程和广东珠江口的港珠澳大桥以及规划中的渤海海峡、琼州海峡和台湾海峡等未来跨海工程建设提供了宝贵经验。其中，杭州湾大桥全长36km，已于2008年北京奥运会前建成通车，上海长江桥隧工程也于2010年上海世博会前建成通车。

本画册入选的十座跨海大桥中还有澳门西湾大桥（2004年）、湛江海湾大桥（2006年）、深圳西部通道深圳湾大桥（2007年）、舟山金塘大桥（2009年）、平潭海峡大桥（2010年）、青岛海湾大桥（2010年）、宁波象山港大桥（2012年）和厦漳跨海大桥（2013年）。其中最长的是41.58km的青岛海湾大桥。

跨海工程往往存在桥隧之争。在公路隧道中过长时间行车人会感到不安全；超过10km的隧道需建造通风井，再加上应急逃生方面的不利因素，这都降低了隧道工程的竞争力。跨越海峡的公路宜寻找能避开深水的绕行路线，建造更为经济合理的长桥，如舟山连岛工程中的金塘大桥。但是，跨海桥梁与隧道相比，也存在非全天候运营的劣势，大风、大雾等恶劣天气会导致桥上交通关闭。

随着斜拉桥跨越能力的提高，为避免悬索桥水中锚碇的技术难度和昂贵造价，应采用连续多跨千米级斜拉桥的方案，既能满足分孔通航要求，又能降低造价。相信未来的琼州海峡、渤海海峡和台湾海峡工程都能用多孔千米级斜拉桥组成的公路长桥（或公铁两用桥）加以实现。

Introduction

Built in 1890, the Forth Railway Bridge in Scotland is the first of the world's major bridges to cross seas and bays. The Golden Gate Bridge which crosses San Francisco Bay, built in 1937, remains the most famous. The Overseas Railway Trestles, a series of bridges connecting the Florida Keys (a coral archipelago in southeast United States) to Miami, is most likely the first true bridge to cross the sea by linking islands. This structure was built in the early 1910s. After its destruction by the Labor Day Hurricane in 1935, it was replaced with the Overseas Highway (the Florida Keys section of U.S. Highway 1). The Old Little Belt Bridge, a combined highway and railway truss bridge built in 1935 over the Little Belt Strait in Denmark, is another precursor of modern sea-crossing bridges. Its highway function was eventually assumed by the New Little Belt Bridge, a suspension bridge built in 1970. The longest island-linking work of engineering in the last century was the 25km-long King Fahd Causeway linking Bahrain to Saudi Arabia across the Gulf of Bahrainw, which was constructed by Dutch contractors in the 1980s. Since 1960, the island nations of Denmark and Japan both completed several significant island-linking projects. Japan's program began with Kanmonkyo Bridge and culminated with the construction of three expressways connecting the islands of Shikoku and Honshu at the end of the 20th century, which incorporated the Akashi Kaikyo Bridge and the Tatara Bridge. Denmark completed the Great Belt Bridge in 1997, and constructed, in cooperation with Sweden, the Öresund Strait Bridge connecting the two countries.

The construction of sea-crossing bridges in China began with the Shantou Bay Bridge built in 1990s. Following this, three island-linking bridges, the Tsing Ma Bridge, Kap Shui Mun Bridge, and Ting Kau Bridge, were successively completed in the late 1990s to provide access to the new Hong Kong International Airport on Lantau Island. Construction of the Zhoushan island-linking project began in the late 1990s and progressed gradually from Zhoushan Island towards the mainland at Ningbo. At the same time, preliminary plans for island-linking projects in other coastal cities were made. China's first island-linking project crossing a wide expanse of ocean was the 32.5km-long Shanghai East Sea Bridge, completed in 2005, which connects the Yangshan Deep-Water Port to the mainland at Shanghai. The successful construction of this bridge provided valuable experience to guide the design and construction of subsequent sea-crossing projects, such as the 36km-long Hangzhou Bay Bridge completed before the Beijing Olympic Games in 2008, the Shanghai Chongming Bridge-Tunnel completed before the Shanghai EXPO in 2010, the Hong Kong-Zhuhai-Macao Bridge crossing the Pearl River Estuary in Guangdong, as well as the planning of future crossings of the Bohai Strait, the Qiongzhou Strait, and the Taiwan Strait.

The following ten sea-crossing bridges have been selected for this book: the Shanghai East Sea Bridge (2005), Hangzhou Bay Bridge (2008), West Bay Bridge in Macao (2004), Zhanjiang Bay Bridge (2006), Shenzhen Bay Bridge (2007), Jintang Bridge (2009), Pingtan Straits Bridge (2010), Qingdao Bay Bridge (2010), Xiangshan Harbor Bridge in Ningbo (2012), and the Xiazhang Sea-crossing Bridge (2013). The Qingdao Bay Bridge, with a total length of 41.58km, is the longest bridge in this group.

There has been competition between bridges and tunnels on sea-crossing projects. Motorists and passengers during long drives through highway tunnels feel unsafety. The need for vent wells in tunnels longer than 10km and difficulties associated with providing emergency egress also weaken the competitive advantage of tunnels. For highways crossing straits, it is feasible to choose a circuitous route and construct a more economic bridge of reasonable length to avoid deep water areas, which was done for the Jintang Bridge in the Zhoushan island-linking project. Nevertheless, tunnels tend to have a better capacity for all-weather operation than bridges, which may need to be closed to traffic during strong winds and thick fog.

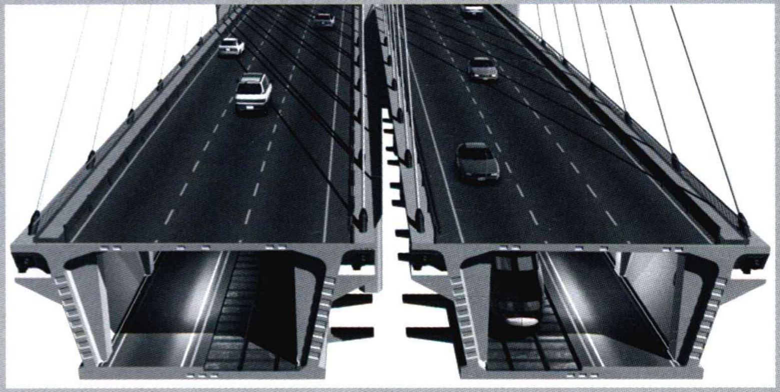
Following recent increases in the feasible span length of cable-stayed bridges, it has been suggested to use continuous multi kilometer-span cable-stayed bridges in sea-crossing projects to avoid the technical difficulties and high cost associated with the construction of underwater anchorages for suspension bridges. Continuous multi-span cable-stayed bridges are not only able to satisfy requirements for multiple navigation spans with relative ease, but are also relatively economical. It is therefore expected that future sea-crossing projects over the Qiongzhou Straits, the Bohai Strait, and the Taiwan Strait will incorporate long highway bridges or amphibious bridges for highway and railway incorporating multi kilometer-span cable-stayed bridges.

澳门西湾大桥
West Bay Bridge in Macao

澳门西湾大桥是为了缓解澳门南北向交通压力并建立海上全天候交通通道所建设的澳门第三座跨海大桥。大桥全长1825m，由斜拉桥主桥和两端引桥组成。桥面宽度分左右双幅对称布置，上层每幅桥面宽14.55m、在箱梁顶面布置三车道，下层每幅宽8m、在箱梁内设机动车和轻轨各一个车道。

主桥采用分离双幅的双塔四索面预应力混凝土斜拉桥，跨径布置为110m+180m+110m=400m，混凝土箱梁单箱单室，其顶板和底板上双层行车，斜拉索采用竖琴式稀索布置，主塔为三柱式钢筋混凝土结构，采用钻孔桩基础。引桥为四联60m跨径等高度预应力混凝土连续箱梁。

澳门西湾大桥为了满足多车道和台风期不中断行车的使用要求，将斜拉桥主梁箱梁布置成顶面和底面双层桥面，采用了特殊的箱梁横隔板技术，研制了合理的主梁预制节段剪力键及梁段分离技术。



West Bay Bridge in Macao with an overall length of 1825m is comprised of a cable-stayed main bridge and two side approach bridges. The bridge has two separate box decks arranged symmetrically. Each deck has a single one-room box cross section, and its top plate is 14.55m wide and contains three traffic lanes while its bottom plate is 8m wide and contains one traffic lane and one track of Light Rail Transit in the box.

The main bridge is a PC cable-stayed bridge with a pair of separated box decks, double three-column towers, four harp-like cable planes and three spans of 110m+180m+110m=400m. The towers are supported by bored piles foundations. The approach bridges are composed of four multiple 60m-span PC continuous box beam bridges with constant girder depth.

A special diaphragm technique was adopted to realize the traffic in the deck box. Moreover, a kind of reasonable shear key and a separating technique of girder segments were developed for the precast construction.

桥　　名：澳门西湾大桥
桥　　型：预应力混凝土箱梁斜拉桥
　　　　　四联等高度预应力混凝土连续梁桥
长　　度：1825m
桥　　址：澳门
完成日期：2004 年
设计单位：中铁大桥勘测设计院有限公司
施工单位：中铁（澳门）有限公司
　　　　　中铁大桥局集团有限公司

Name: West Bay Bridge in Macao
Type: Cable-stayed bridges with PC box deck
Four PC continuous beam bridges with even girder depth
Length: 1825m
Location: Macao
Completion: 2004
Designer(s): China Railway Major Bridge Reconnaissance & Design Institute Co., Ltd.
Contractor(s): China Railway (Macao) Co., Ltd.
China Railway Major Bridge Engineering Group Co., Ltd.

（部分图片提供者: 徐恭义）

东海大桥

East Sea Bridge