JTG

Recommended Industry Standards of
the People's Republic of China

中华人民共和国行业推荐性标准

JTG/T 3365-01—2020(EN)

Specifications for Design of Highway Cable-stayed Bridge

公路斜拉桥设计规范

(英文版)

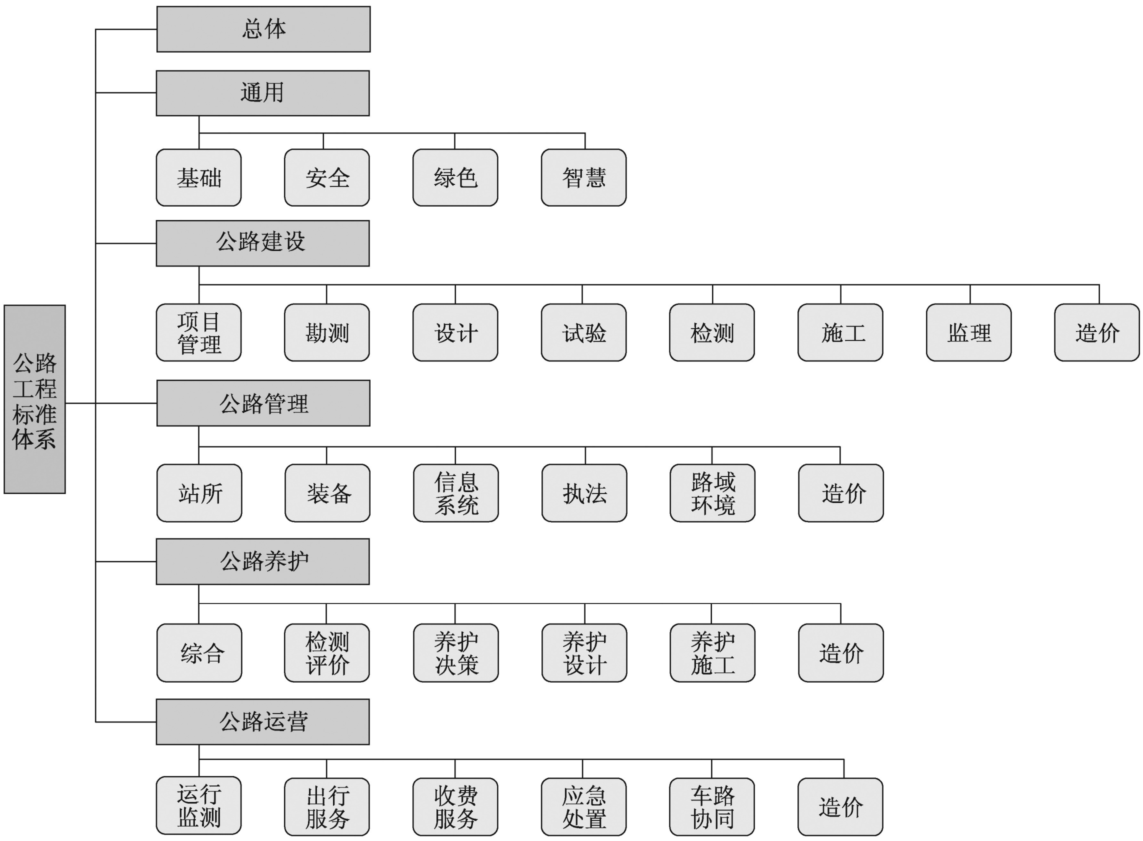
Issue Date: April 26, 2020   Effective Date: August 1, 2020

Issued by the Ministry of Transport of the People's Republic of China

英文版编译出版说明

标准是人类文明进步的成果，是世界通用的技术语言，促进世界的互联互通。近年来，中国政府大力开展标准化工作，通过标准驱动创新、协调、绿色、开放、共享的共同发展。在丝绸之路经济带与 21 世纪海上丝绸之路，即“一带一路”倡议的指引下，为适应日益增长的全球交通运输发展的需求，增进世界连接，促进知识传播与经验分享，中华人民共和国交通运输部组织编译并发布了一系列中国公路行业标准外文版。

中华人民共和国交通运输部发布的公路工程行业标准代号为 JTG，体系范围涵盖公路工程从规划建设到养护和运营管理全过程所需要的设施、技术、管理与服务标准，也包括相关的安全、环保和经济方面的评价等标准。



中国的公路标准体系有效地支撑了中国公路桥梁的快速发展，包含了多项桥梁相关的设计、施工、养护标准。目前有关桥梁设计的规范有：《公路桥涵设计通用规范》、《公路钢筋混凝土及预应力混凝土桥涵设计规范》、《公路圬工桥涵设计规范》、《公路钢结构桥梁设计规范》、《公路钢混组合桥梁设计与施工规范》、《公路斜拉桥设计规范》、《公路悬索桥设计规范》、《公路钢管混凝土拱桥设计规范》、《公路装配式混凝土桥梁设计规范》、《公路桥梁抗风设计规范》、《公路桥梁抗撞设计规范》、《公路桥梁景观设计规范》等。作为行业标准之一，《公路斜拉桥设计规范》已成为公路工程领域的一项重要标准。

截至 2024 年底，中国已建成公路桥梁 110.81 万座，总里程达 10197.58 万延米。其中，多座大跨度桥梁为斜拉桥。如今，在斜拉桥领域，尤其是在大跨度、高难度斜拉桥的建设方面，中国已处于世界领先地位。

斜拉桥在中国的应用始于 20 世纪 70 年代。经历 20 世纪 80 年代的快速发展后，20 世纪 90 年代上海建成了两座极具代表性的斜拉桥——它们均采用组合梁结构，且在当时创下了跨度纪录。一座是 1991 年建成的南浦大桥，主跨 423 m；另一座是 1994 年落成的杨浦大桥，主跨 602 m。2000 年以来，中国斜拉桥建设持续推进，这体现在多个方面：斜拉桥数量不断增加、跨度不断增大，结构形式更趋多样，施工技术不断创新。代表性工程包括：2008 年建成的苏通长江大桥，是世界首座主跨超千米（达 1088 m）的斜拉桥；2009 年建成的中国香港昂船洲大桥，主跨 1018 m；2010 年建成的湖北鄂东长江大桥，主跨 926 m；2019 年同期建成的石首长江大桥与嘉鱼长江大桥，主跨均为 828 m；2020 年建成的沪苏通长江公铁大桥，主跨 1092 m。

通过这些工程建设，我国积累了丰富的工程实践经验与科研成果，推动了斜拉桥设计理论不断完善和发展。这此经验与成果在《公路斜拉桥设计规范》中得到了充分体现，使得该规范在中国公路斜拉桥的设计、施工及养护工作中发挥着重要的作用。

2007 年我国编制并出版了《公路斜拉桥设计细则》（JTG/T D65 – 01 – 2007）（以下简称“原细则”）。为适应大跨径斜拉桥的建设发展，在原细则的基础上进行全面修订，形成了本次编译的《公路斜拉桥设计规范》（JTG/T 3365 – 01 – 2020）中文版，于 2020 年 4 月发布，2020 年 8 月 1 日实施。

《公路斜拉桥设计规范》（JTG/T 3365 – 01 – 2020）注重落实新发展理念，对标国内国际先进水平，充分吸纳了我国公路斜拉桥的设计、施工和养护中的先进成果，对斜拉桥的设计原则、计算方法、构造措施等进行了统一规定，为斜

拉桥设计提供了全面、系统、科学的技术规定和方法指导,致力于保障斜拉桥的结构安全、耐久性和使用性能。

本规范英文版的编译发布便是希望将中国的工程经验和技术成果与各国同行进行交流分享,为其他国家类似建设条件的公路桥涵建设提供参考借鉴。

本规范英文版的编译工作由中华人民共和国交通运输部委托福州大学主持完成,并由中华人民共和国交通运输部公路局组织审定。

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The People's Republic of China
Ministry of Transport
Public Notice

No.23

Public Notice on Issuing of the *Specifications for Design of Highway Cable-stayed Bridge*

The *Specifications for Design of Highway Cable-stayed Bridge* (JTG/T 3365-01—2020) is hereby issued as one of the industry standards for highway engineering to become effective on August 1, 2020. The former *Guidelines for Design of Highway Cable-stayed Bridge* (JTG/T D65-01—2007) shall be superseded from the same date.

The general administration and final interpretation of the *Specifications for Design of Highway Cable-stayed Bridge* (JTG/T 3365-01—2020) belong to the Ministry of Transport, while particular interpretation for application and routine administration of the *Specifications* shall be provided by China Merchants Communications Technology (Chongqing) Co., Ltd.

Comments, suggestions and inquiries are welcome and should be addressed to China Merchants Communications Technology (Chongqing) Co., Ltd (No. 33, Xuefu Avenue, Nan'an District, Chongqing 400067, China).

It is hereby announced.

The Ministry of Transport of the People's Republic of China
April 26, 2020

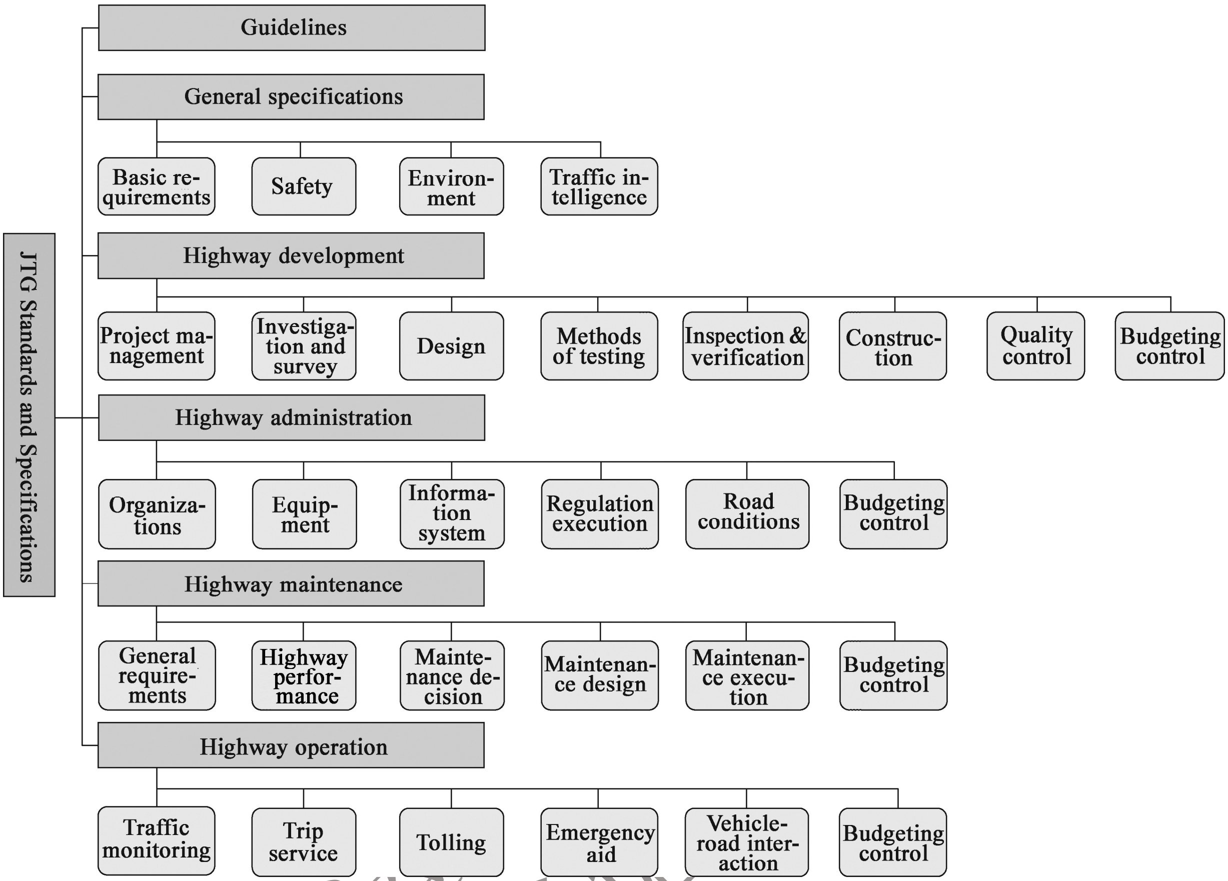
General Office of Ministry of Transport Printed on April 27, 2020

Introduction to English Version

Standards reflect the achievement of civilization, provide common languages for technical communications and improve global connectivity. In recent years, the Chinese government has been proactively implementing standardization to stimulate innovation, coordination, greenness and opening up for shared development in China and worldwide. To align with the Belt One Road Initiative for mutual development, the Ministry of Transport of the People's Republic of China organized the compilation and publication of international version of Chinese transportation industry standards and specifications to meet the increasing demands for international cooperation in transportation, enhance global connectivity, promote knowledge dissemination and sharing of experience.

JTG is the designation referring to the standards and specifications of highway transportation industry, issued by the Ministry of Transport of the People's Republic of China. This system emcompasses the entire lifecycle of highway engineering projects, from planning and construction to maintenance and operation management. It includes standards for the facilities, technologies, management, and services required throughout these processes, as well as standards related to safety, environmental protection, and economic evaluation.

In the highway standard system, it includes a number of standards for design, construction and maintenance of bridges, which have effectively supported the rapid development of highway bridges in China. The current bridge design specifications include: *General Specifications for Design of Highway Bridges and Culverts*, *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts*, *Code for Design of Highway Masonry Bridges and Culverts*, *Specifications for Design of Highway Cable-stayed Bridge*, *Specifications for Design of Highway Suspension Bridge*, *Specifications for Design of Highway Concrete-filled Steel Tubular Arch Bridges*, *Specifications for Design of Highway Precast Concrete Bridges*, *Specifications for Wind-Resistant Design of Highway Bridges*, *Specifications for Collision Design of Highway Bridges*, *Specifications for Landscape Design of Highway Bridges*, *etc*. As one of the standards, the *Specifications for Design of Highway Cable-stayed Bridge* has become an important standard in the highway engineering industry.



As of the end of 2024, 1.1081 million highway bridges with the total length of 101.9758 million meters have been built in China. Among them, many long-span bridges are cable-stayed bridges. Today, in the field of cable-stayed bridges, particularly in the construction of long-span and highly challenging cable-stayed bridges, China has achieved a world-leading position.

The application of cable-stayed bridges in China began in the 1970s. Following a period of rapid development in the 1980s, two remarkable examples were completed in Shanghai during the 1990s—both featuring composite girders and holding the span record of their era. One is the Nanpu Bridge, completed in 1991 with a main span of 423 m; the other is the Yangpu Bridge, finished in 1994 with a main span of 602 m. Since the year 2000, China's cable-stayed bridges have undergone sustained advancement, which is evident in multiple aspects: a steady increase in both the number of bridges and their span lengths, greater diversity in structural forms, and innovations in construction technologies. Notable landmark projects include: the Sutong Yangtze River Bridge (completed in 2008), the world's first cable-stayed bridge with a main span exceeding 1,000 m (reaching 1,088 m); Hong Kong's Stonecutters Bridge (2009), with a main span of 1,018 m; Hubei's Erdong Yangtze River Bridge (2010), boasting a 926-m main span; the Shishou Yangtze River Bridge and Jiayu Yangtze River Bridge (both completed in 2019), each with an 828-m main span; the Shanghai-Suzhou-Nantong Yangtze River Highway-Railway Bridge (2020), featuring a 1,092-m main span.

Throughout the seprojects, extensive engineering experience and research findings have been accumulated, leading to the refinement and development of cable-stayed bridge design theory. This progress is fully reflected in the *Specifications for Design of Highway Cable-Stayed Bridge*, resulting it a crucial role in the design, construction, and maintenance of highway cable-stayed bridges in China.

In 2007, China developed and published the *Guidelines for Design of Highway Cable-Stayed Bridge* (*JTG/T D65-01-2007*) (hereinafter referred to as the "*Guidelines* 2007"). To accommodate the development of long-span cable-stayed bridge construction, a comprehensive revision was carried out based on the *Guidelines* 2007, resulting in the Chinese version of the *Specifications for Design of Highway Cable-Stayed Bridge* (*JTG/T* 3365-01-2020. It was issued in April 2020 and became effective on August 1, 2020.

The *Specifications for Design of Highway Cable-Stayed Bridge* (JTG/T 3365-01-2020) emphasize the implementation of the new development philosophy, align with domestic and international advanced standards, and fully incorporate advanced achievements in the design, construction, and maintenance of highway cable-stayed bridges. It provides unified regulations on design principles, calculation methods, and structural detailings, offering comprehensive, systematic, and scientific technical provisions and methodological guidance. The *Specifications* is dedicated to ensuring the structural safety, durability, and service performance of cable-stayed bridges.

The release of the English version of the *Specifications* aims to share the engineering experience and technical achievements from China and provide references for other countries to build highway cable-stayed bridges with similar construction conditions.

The editing of the English version was conducted by Fuzhou University under the authorization of the Ministry of Transport of the People's Republic of China and approved by the Highway Department, the Ministry of Transport of the People's Republic of China.

The contents and numbering of the chapters, sections, clauses and sub-clauses in the English version are consistent with those in the Chinese version. In the event of any ambiguity or discrepancy between the English version and the Chinese version of the *Specifications*, the Chinese version shall prevail.

Feedbacks are welcome and will be taken into account in future editions. Please address them to the editing organization for English version in writing (Address: No. 2, Wulongjiang North Avenue, Fuzhou University Town, Fuzhou, Fujian, China, Postal Code: 350108, E-mail: baochunchen@fzu.edu.cn).

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Foreword to Chinese Version

The revision of the *Guidelines for Design of Highway Cable-stayed Bridge* (JTG/T D65-01—2007, hereinafter referred to as the "*Guidelines* 2007"), pursuant to the Notice on Planning of Compilation and Revision Programs of Highway Engineering Industry Standards and Specifications in 2014 (Transport Highway Document [2014] No. 87) issued by the General Office of the Ministry of Transport of the People's Republic of China, was carried out by the chief editing organization, China Merchants Communications Technology (Chongqing) Co., Ltd.

During the revision, the editorial team conducted extensive special studies and research works, reviewed the updated technical development and design experience in China, and referred to relevant domestic and international standards. Upon the completion of the first draft of the *Specifications*, the drafted specification was circulated for comments from relevant experts and organizations involved in design, construction, maintenance, and administration, based on which several rounds of discussion, consultation, and updating were conducted before being finalized for approval.

The *Specifications* consists of 9 chapters, including: 1 General Provisions, 2 Terms and Symbols, 3 Materials, 4 Actions, 5 General Design, 6 Detailing Design, 7 Structural Analysis, 8 Design Requirements for Construction Monitoring and Control, 9 Design for Maintenance.

The main contents of this revision include: adjusting the chapter sequence of the *Guidelines* 2007 and modifying the titles of some chapters; expanding the applicable span range of the *Specifications*; revising the design method to uniformly adopt the probability theory-based limit state design method; adding relevant provisions on the design life of the main structure and replaceable components of cable-stayed bridges, pedestrian load on the maintenance access to the main girder, steel truss girder detailing, saddle-type anchorage configuration for concrete towers, temporary fixation measures between the tower and girder, working conditions for cable replacement, and durability of maintenance and inspection facilities; revising provisions on seismic effects, safety factors for stay cables of extradosed bridges, fatigue calculation of stay cables, static analysis during construction stages, and control accuracy during the construction process.

Feedback is welcome and will be taken into account in future editions. Please address them to the chief editing organization for the Chinese version (Geng Bo, Address: No. 33, Xuefu Avenue, Nan'an District, Chongqing 400067, China; Tel. No.: 023-62653100, Fax No.: 023-62653511; Email: gengbo@cmhk.com).

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Contents

1 General Provision

1.0.1 The *Specifications* is developed for regulating and guiding the design of cable-stayed bridges in accordce with to the principles of safety, durability, applicability, environmental protection, cost-effectiveness, and aesthetics..

Commentary

This clause is revised in accordce with the provisions of the *Technical Standard of Highway Engineering* (JTG B01-2014) and the *General Specifications for Design of Highway Bridges and Culverts* (JTG D60-2015).

1.0.2 The *Specifications* is applicable to the design of newly built or reconstructed highway cable-stayed bridges with a span of less than 1000 m.

Commentary

The *Guidelines for Design of Highway Cable-stayed Bridges* (*JTG/T D*65-01—2007) (referred to as the previous edition of the Specifications) applies to the design of highway cable-stayed bridges with a span of less than 800 m. In recent years, however, numerous cable-stayed bridges with a span exceeding 800 m, even reaching the kilometer level have been constructed or are under construction in China and other countries. This revised edition of the *Specifications* incorporates the engineering experience and recent advancements in the design of highway cable-stayed bridges. Additionally, the applicable span range is extended to 1000 m, reflecting the current state of technical development in the design of highway cable-stayed bridges in China.

1.0.3 The limit state design methodology, based on the probability theory and expressed with partial factors, is adopted in the *Specifications* for design purposes.

Commentary

This clause is revised according to the provisions of the *General Specifications for Design of Highway Bridges and Culverts* (JTG D60-2015) and the *Specifications for Design of Steel Highway Bridges* (JTG D64—2015).

1.0.4 The design life of the main structures of highway cable-stayed bridges shall be 100 years. For replaceable components, such as stay cables, consideration shall be given to the feasibility of replacement, while ensuring the safety of the structures.

Commentary

According to the provisions of the *Technical Standard of Highway Engineering* (JTG B01-2014), considering the structural characteristics of the highway cable-stayed bridges and the actual situation of construction, the design life of the main structures of the highway cable-stayed bridges is determined as 100 years in the *Specifications*.

1.0.5 In the design, comprehensive consideration shall be given to the demands of construction, operation and maintenance.

Commentary

In the design of highway cable-stayed bridges, construction feasibility and reasonableness need to be considered, and attention should also be given to the ease of operation and maintenance, ensuring that the bridge structures are visible, accessible, inspectable, and repairable.

1.0.6 Advanced materials, technologies, processes, and equipment shall be actively and soundly promoted and applied.

1.0.7 In addition to the *Specifications*, the design of highway cable-stayed bridges shall also comply with the provisions in current relevant national and industry standards.

2 Terms andSymbols

2.1 Terms

2.1.1 Cable-stayed bridge

A cable-supported structure composed of girders, stay cables, and towers, in which the stay cables are anchored at the towers and girders or other carriers.

2.1.2 Girder

A component supported by stay cables and bearings, that directly carries the traffic loads transferred from the deck, also called main girder.

2.1.3 Tower

A component to anchor or support stay cables, and to transfer the cable forces to the substructure, also called pylon.

2.1.4 Stay cable

A component to sustain tensions and to support the girders.

2.1.5 Transition pier

The pier where the cable-stayed bridge is separated from the approach spans.

2.1.6 Auxiliary pier

A pier within the side span, designed to improve the overall structural rigidity and structural stress.

2.1.7 Floating system

A structural system where towers and piers are fixed, and the main girder is not supported vertically by bearing at the towers and/or is not restrained against its longitudinal movement.

2.1.8 Semi-floating system

A structural system where towers and piers are fixed, with vertical bearings at the towers to support the girders vertically, and the whole bridge structure has no longitudinal restraints or only elastic restraints.

2.1.9 Tower-girder fixed system

A structural system where the girder is fixed to towers and supported by bearings on the piers.

2.1.10 Tower-girder-pier fixed system

A structural system where girders, towers, and piers are fixed together.

2.1.11 Earth-anchored system

A structural system in which all or part of the stay cables in the side spans are anchored externally onto the ground.

2.1.12 Extradosed bridge

A bridge composed of the same main components as cable-stayed bridges, in which stresses and stress amplitudes of the stay cables are relatively small, while the main girder plays a significant role in resisting the loads.

2.1.13 Multi-tower cable-stayed bridge

A cable-stayed bridge with three or more towers.

2.1.14 Cable-stayed bridge with concrete girder

A cable-stayed bridge with a reinforced or prestressed concrete structure as the main girder.

2.1.15 Cable-stayed bridge with steel girder

A cable-stayed bridge with a steel box as the main girder.

2.1.16 Cable-stayed bridge with steel truss

A cable-stayed bridge with a steel truss as the main girder.

2.1.17 Cable-stayed bridge with composite girder

A cable-stayed bridge with a steel-concrete composite structure as the main girder.

2.1.18 Cable-stayed bridge with hybrid girder

A cable-stayed bridge in which the main girders in the side spans are partially or entirely made of concrete, while the remaining main girders are constructed of steel or composite materials.

2.1.19 Vibration suppression device of stay cable

A device for mitigating wind vibration or rain-wind induced vibration of stay cables.

2.1.20 steel anchor beam

A steel beam-type device for anchoring a stay cable on the tower.

2.1.21 Steel anchor box

A steel box-shaped device for anchoring a stay cable on the tower or the main girder.

2.1.22 strand-separating tube

A tube arranged inside the saddle for a single steel strand to pass through.

2.1.23 Restrainer

A device to restrain the longitudinal and transverse displacement to prevent excessive movement of the main girder.

2.1.24 Wind-rain-induced vibration of stay cable

The galloping of stay cables generated when rain flows along stay cables under a certain critical wind speed.

2.1.25 Final design state of bridge

Design state of a bridge upon completion, which aim to achieve a state that the tower and the girder align smoothly, the bending moments of the tower and the girder are within acceptable limits, and the forces in the stay cables are relatively uniform.

2.1.26 Vortex resonance of stay cable

Vortex shedding will occur when wind runs through stay cables, which induces a resonance of the stay cables due to the periodic forces generated by the vortices when the vortex shedding frequency is close or equal to the natural frequencies of the cables.

2.1.27 Wake galloping of stay cable

Wind-induced vibration generated when the backstay cable lies within the unstable wake galloping area of the front stay cable.

2.1.28 Parametric resonance of stay cable

The vibration that occurs in a stay cable when the natural frequency of the main girder is a multiple of the frequency of the cable's transverse vibration.

2.2 Symbols

2.2.1 Symbols of Geometric Parameters

A——cross-section area of stay cable.

D——diameter of stay cable.

l——effective span.

S——length of stay cable.

y——amplitude of stay cable vibration.

α——angle between the stay cable and the horizontal line.

2.2.2 Symbols of Material Properties

E——modified modulus of elasticity of stay cable considering the sag effect.

E_0——modulus of elasticity of steel material for stay cable.

f_d——design tensile strength of stay cable.

γ——gravity per volume of stay cable.

2.2.3 Symbols of Actions and Action Effects

f——vertical deflection induced by vehicular load (excluding impact force).

N_d——design axial tension force of stay cable.

T_0——force of stay cable before deformation.

T_1——force of stay cable after deformation.

σ——stress of stay cable.

σ_0——original stress of stay cable.

σ_1——stress of stay cable after new load applied.

3 Materials

3.1 Concrete

3.1.1 For concrete used in the components of cable-stayed bridges, the requirements for strength, modulus of elasticity, and durability shall comply with the provisions in the current *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362).

3.1.2 The concrete strength class for concrete girders and towers shall not be lower than C40.

3.2 Reinforcement

3.2.1 For reinforcing steels and prestressing steels in the reinforced and prestressed concrete members, their categories, design strength, characteristic strength, and modulus of elasticity shall comply with the provisions in the current *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362).

3.2.2 For steel plates, shape steels, plain bolts, anchorage bolts, high-strength bolts, shear studs, and welding materials, their technical requirements, physical properties as well as durability design requirements shall comply with the provisions in the current *Specifications for Design of Steel Highway Bridges* (JTG D64).

Commentary

The material of shear studs is included in this clause of the *Specifications*. The shear studs have been widely used in steel-concrete composite members of cable-stayed bridges. They are used as connectors in the anchorage zones of the steel-concrete composite towers in many cable-stayed bridges, such as the Sutong Yangtze River Highway Bridge, Shanghai Yangtze River Bridge, Chongqing Dongshuimen Yangtze River Bridge, and Chongqing Qiansimen Jialingjiang Bridge. They are also used as connectors in the steel-concrete composite girders in many cable-stayed bridges, such as the Chongqing Jiangjin Guanyinyan Bridge, the South Branch Main Bridge of the Xiazhang Bridge, and the Shuitu Jialing River Bridge.

3.3 Stay cables

3.3.1 High-strength steel wires used in stay cables shall be ϕ5 mm or ϕ7 mm steel wires, and their properties shall meet the requirements in the current standard *Hot-dip Galvanized Steel Wires for Bridge Cables* (GB/T 17101). The design tensile strength of the steel wires shall be taken in accordance with the current *Specifications for Design of Highway Steel Bridges* (JTG D64), and the characteristic tensile strength should not be less than 1670 MPa. The performance of protective coatings for the steel wires shall meet the requirements in the current relevant national or industry standards.

3.3.2 Steel strands used in stay cables shall be high-strength low-relaxation prestressing strands; their properties shall meet the requirements in the current standard *High-Strength Low Relaxation Hot-Dip Galvanized Steel Strand for Prestress* (YB/T 152). The design tensile strength of the steel strands for stay cables shall be taken in accordance with the current *Specifications for Design of Highway Steel Bridges* (JTG D64), and the characteristic tensile strength should not be less than 1770 MPa. The performance of protective coatings by plating or painting for the steel strands shall meet the requirements in the current relevant national or industry standards.

Commentary

3.3.1-3.3.2 High-strength steel wires or steel strands are generally used for stay cables. The steel wires or steel strands are generally protected by galvanizing, epoxy coating, zinc-aluminum alloy coating, etc.

3.3.3 The material properties of anchorage devices for stay cables shall meet the requirements in the current *Quality Carbon Structure Steels* (GB/T 699) or *Alloy Structure Steels* (GB/T 3077).

3.3.4 The performance of the outer protective materials for stay cables shall meet the requirements of the current *High-Density Polyethylene Sheathing Compounds for Bridge Cables* (CJ/T 297).

4 Actions

4.1 General

4.1.1 The importance factor of structure, actions and their combination used in the design of highway cable-stayed bridges shall comply with the current *General Specifications for Design of Highway Bridges and Culverts* (JTG D60) unless otherwise specified in this chapter.

4.2 Different Kinds of Actions

4.2.1 In calculating the gravity of a structure, if the volumetric reinforcement ratio of reinforced concrete or prestressed reinforced concrete (including reinforcing steels and prestressing steels) is greater than 2%, the unit weight of the structure may be calculated as the sum of the self-weight of the concrete with the volume of reinforcement deducted per unit volume and the self-weight of the reinforcement.

4.2.2 In calculating the vehicular impact force, the fundamental frequency of the structure shall be taken as that of the vertical flexure of the main girder.

4.2.3 The pedestrian load of the maintenance access on the main girder of cable-stayed bridges may be taken as 1.5 kN/m^2.

Commentary

There are no specific provisions for the pedestrian load intensity of the maintenance access on the main girder of cable-stayed bridges in the current *General Specifications for Design of Highway Bridges and Culverts* (JTG D60). By referring to relevant standards in other countries and the specific situations of the installed maintenance accesses in bridges of China, the pedestrian load intensity standard of 1.5 kN/m^2 is recommended.

4.2.4 The characteristic wind loads shall be calculated in accordance with the provisions in the current *Specifications for Wind-Resistant Design of Highway Bridges* (JTG/T 3360-01). In areas with complex wind environments, a specific study shall be conducted.

4.2.5 Temperature action shall be determined in accordance with the following provisions:

1 In calculating the structural effects caused by the temperature action, the local conditions, structural materials, and construction conditions shall be taken into account.

2 The uniform temperature actions shall be considered according to the provisions in the current *General Specifications for Design of Highway Bridges and Culverts* (JTG D60).

3 The effects of the vertical temperature gradient on main girders shall be calculated in accordance with the provisions in the current *General Specifications for Design of Highway Bridges and Culverts* (JTG D60).

4 For wide non-cantilever main girders in bridges with more than four traffic lanes, the transverse temperature gradient effects should be taken into account.

5 In the absence of measured data, the temperature gradient difference between the two sides of a concrete tower may be taken as ±5℃.

6 The temperature differences between members may be taken within the following ranges:

1) Between stay cables and concrete main girders, and between stay cables and concrete towers: ±10℃ to ±15℃;;

2) Between stay cables and steel main girders: ±10℃.

Commentary

In this revision, the provisions on the transverse temperature gradient of the main girders are supplemented. The action of the transverse temperature gradient is generally determined according to the geographic location and environmental conditions of the bridges. If no measured data are available, the relevant provisions and commentary in the current *General Specifications for Design* *of Highway Bridges and Culverts* (JTG D60) may be referenced.

4.2.6 Seismic actions at two levels (E1 and E2) shall be adopted for the seismic fortification of the cable-stayed bridges. E1 seismic action should be taken as the earthquake ground motion with a 10% probability of exceedance in 100 years, and E2 seismic action should be taken as the earthquake ground motion with a 4% probability of exceedance in 100 years. For cable-stayed bridges with a span of less than 150 m, seismic actions may comply with the provisions for the A-type bridges in *Specifications for Seismic Design of Highway Bridges* (JTG/T 2231-01). For other cases, E1 and E2 seismic actions at the bridge sites shall be determined based on the dedicated seismic safety assessments of the project sites. The seismic safety assessment of the project site should comply with the following provisions:

1 Long-period effects shall be considered in the E1 and E2 seismic actions. The period range of the design acceleration response spectrum and time history of design earthquake ground acceleration used in the calculation shall include the fundamental period of the cable-stayed bridge.

2 The spatial variation of earthquake ground motion parameters shall be considered if at the bridge site there is geological discontinuity, or the topographic features may cause significant differences in the earthquake ground motion parameters across individual piers.

3 When a bridge site is located within 30 km of a seismically active fault with the potential to generate earthquakes of magnitude 6.5 or above, the near-fault effects shall include the hanging wall effect and the directional effect of rupture. This is to fully account for the impact of the long-period segment of the design acceleration response spectrum on structural response.

Commentary

Similar to suspension bridges, cable-stayed bridges generally have a high construction cost and are difficult to repair once they are damaged. Therefore, the return period of the fortification level is set at a relatively high value. Due to the characteristics of long-period effects and large span lengths, the requirements for seismic safety assessment of engineering sites for cable-stayed bridges are similar to those of suspension bridges. Therefore, this clause is formulated by referring to the current *Specifications for Design of Highway Suspension Bridge* (JTG/T D65-05).

4.2.7 If vessel or vehicular collision actions need to be considered, the design value of the collision actions shall comply with the provisions in the current *Specifications for Collision Design* *of Highway Bridges* (JTG/T 3360-02).

4.2.8 In the calculations for the construction process, construction loads that may occur shall be taken into account according to the characteristics of bridge structures, construction methods and techniques. The construction loads include erection equipment and materials, construction personnel, loads from stacking on the bridge deck, temporary counter-weights, and wind loads during construction, etc.

4.3 Combination of Actions

4.3.1 The combination of actions shall comply with the provisions in the current *General Specifications for Design of Highway Bridges and Culverts* (JTG D60).

4.3.2 The seismic combination of actions for cable-stayed bridges shall comply with the provisions in the current *Specifications for Seismic Design of Highway Bridges* (*JTG/T* 2231-01).

4.3.3 The combination of actions for vessel collision design of cable-stayed bridges shall be adopted in accordance with the provisions in the current *Specifications for Collision Design of Highway Bridges* (JTG/T 3360-02).

5 General Design

5.1 General

5.1.1 The general design of cable-stayed bridges shall be carried out based on the requirements for the bridge's functions, technical standards, construction conditions, landscape, environmental protection and others, and consider the life cycle cost of the bridge.

5.1.2 In the general design, the arrangement of bridge spans, the arrangement of the bridge cross-section, the structural system, the construction scheme as well as the main girders, stay cables, towers, foundations, etc., shall be comprehensively compared and selected.

5.1.3 The design shall clearly specify the design life of the main structure as well as the replaceable components such as stay cables, damping devices, bearings, and expansion joints. The design life of the replaceable components shall not be lower than the values specified in Table 5.1.3.

Table5.1.3 Design life of main replaceable components

Component	Design life (Year)
Stay cable	20
External damper for stay cables	20
Damper between the tower and girder	30
Pot (rubber) bearing	25
Steel bearing	50
Expansion joint	15

Commentary

The design life of the stay cables, parapets, expansion joints, and bearings has been specified in the current *General Specifications for Design of Highway Bridges and Culverts* (JTG D60). This clause specifies the design life of the primary replaceable components in cable-stayed bridges, providing supplementary provisions for the design life of dampers and specifying the design life for different types of bearings.

5.1.4 The sequence of structural system transformations and corresponding measures to be taken during the construction shall be specified in the design.

Commentary

During the construction process of cable-stayed bridges, multiple structural system transformations are often required. The sequence of transformations and the corresponding measures to be taken are key considerations during the construction stage of cable-stayed bridges and need to be clearly specified in the design.

5.1.5 Wind resistance, earthquake resistance, collision prevention and other complex factors shall be considered comprehensively in the general design. Special research shall be conducted whenever necessary.

Commentary

A cable-stayed bridge is a flexible structure susceptible to vibration and damage under wind, earthquake, collision, and other actions. In severe cases, this may lead to safety issues for the bridge. For cable-stayed bridges in areas with high wind speeds and complex wind environments, research on the wind environment of the bridge site areas and the wind-resistant performance of the bridges shall be conducted if necessary. For cable-stayed bridges located in areas with high seismic intensity and complex site conditions, research on earthquake ground motion parameters and seismic performance of the bridges shall be carried out if necessary. For cable-stayed bridges in areas with complex navigation environments and high vessel collision forces, research on design force of vessel collision and anti-collision measures against vessel shall be conducted if necessary.

5.1.6 Technical requirements for operation and maintenance shall be specified in the design.

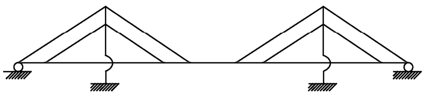
Commentary

A cable-stayed bridge is a complex structure composed of many components. During operation, the bridge may incur damages and diseases due to factors such as environmental conditions, traffic loads, and inherent structural vulnerabilities. Reasonable operation and maintenance measures are crucial for ensuring the safe operation and extending the service life of the bridge. Based on the specific characteristics and key structural elements of the cable-stayed bridge, appropriate technical requirements must be clearly defined in the design.

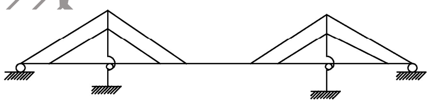
5.2 Basic Structural Systems and Types

5.2.1 A cable-stayed bridge is mainly composed of main girders, stay cables, towers, bridge piers and abutments, foundations. Auxiliary piers may be arranged in the side spans if necessary.

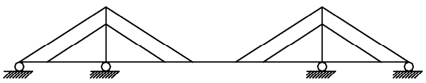
5.2.2 The following structural systems as shown in Figure 5.2.2 may be adopted for cable-stayed bridges: floating system, semi-floating system, tower-girder fixed system, and tower-girder-pier fixed system.



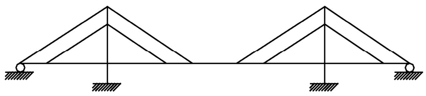
a) Floating system



b) Semi-floating system



c) Tower-girder fixed system



d) Tower-girder-pier fixed system

Figure 5.2.2 Four basic structural systems of cable-stayed bridges

Commentary

According to the connections among the main bearing components of towers, main girders and piers, the basic structural systems of cable-stayed bridges are classified into the following four categories:

1 Floating system

No vertical bearing is set on the towers for the main girder, and only longitudinal movable bearings are set on the abutments, transition piers and auxiliary piers.

2 Semi-floating system

Vertical bearings are set at the tower-pier locations to support the main girder, and the longitudinal movement is free or elastically restrained. For cable-stayed bridges with relatively small spans, there are cases where fixed bearings are set at the tower-pier locations.

3 Tower-girder fixed system

Towers and main girders are in monolithic connection, bearings are set on the piers to support the towers and the girders. For such a system, internal forces induced by temperature in the towers and main girder are small. However, the overall stiffness of this system is low, large-tonnage bearings are required, and also maintenance and replacement of the bearings are inconvenient. Therefore, this system is seldom used.

4 Tower-girder-pier fixed system

In this system, towers, piers, and main girders are fixed together, and no bearings are required at the tower locations. This configuration provides high stiffness, but also generates significant internal forces due to temperature variations. It is most suitable for single-tower cable-stayed bridges. Additionally, this system can be applied to large two-tower cable-stayed bridges with tall piers that have appropriate flexibility, for example, Changmen Bridge in Fujian with a main span of 550 m and Xinzao Pearl River Bridge in Guangdong with a main span of 350 m. This system can also be adopted in the central towers of multi-tower cable-stayed bridges, *e. g.*, the Yichang Yiling Yangtze River Bridge in Hubei (38 m + 38.5 m + 43.5 m + 2 × 348 m + 43.5 m + 38.5 m + 38 m).

At the early stage, cable-stayed bridges with the tower-girder-pier monolithic connection systems and suspended spans were constructed, such as the Maracaibo Bridge in Venezuela (with a main span of 235 m); and cable-stayed bridges with the tower-girder-pier monolithic connection systems and hinges, such as the Danshui River Bridge in China (with a main span of 134 m). This system is currently rarely used for cable-stayed bridges due to poor driving comfort.

5 Other Structural Systems

With the development of cable-stayed bridges, some other systems have also emerged.

1) Earth-anchored cable-stayed bridges

Based on the anchoring method of the stay cables, a earth-anchored system is derived for cable-stayed bridges. When the side-to-main span ratio is very small, earth anchorages can be set for the side spans to achieve system balance. If the bridge is not a single-tower earth-anchored cable-stayed bridge, devices that allow the expansion and contraction of the main girder due to temperature changes can be installed in the middle of the main span as needed.

2) Extradosed bridges

See Clause 2.1.12.

3) Cable-stayed bridge without backstay

A type of cable-stayed bridge without stay cables at the side spans. The unbalanced forces of the cables are borne by the towers. Sometimes, the towers are tilted towards the side span to balance the cable forces by their self-weight.

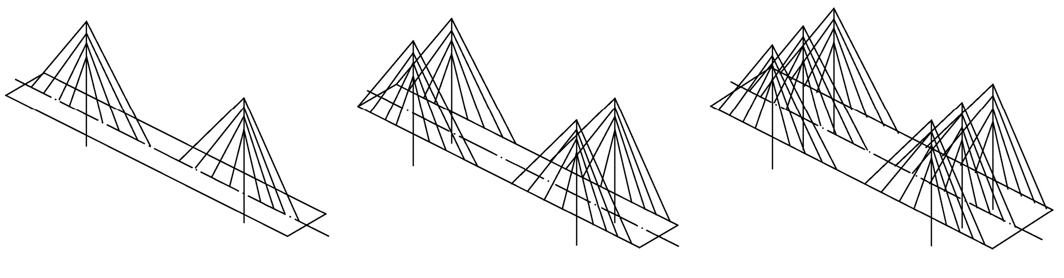
4) Hybrid system

A hybrid system is formed when cable-stayed bridges and other bridge structures cooperate with each other to carry loads, such as the ones between cable-stayed bridges and beam bridges, between cable-stayed bridges and suspension bridges, and between cable-stayed bridges and arch bridges.

5.2.3 According to the arrangement of the towers in the longitudinal direction of the bridge, the transverse arrangement of cable planes, and the materials of the main girders, the following structural types may be adopted for cable-stayed bridges:

1 In terms of the arrangement of the towers in the longitudinal direction of the bridge, single-tower, double-towers, and multi-towers may be adopted.

2 In terms of the transverse arrangement of stay cables, a single-plane, double-plane, or multi-plane configuration may be adopted, as shown in Figure 5.2.3.



a) Single-plane　　b) Double-plane　　c) Multi-plane

Figure 5.2.3 Transverse arrangement of stay cables

3 For the main girders, concrete girders, steel box girders, steel trusses, composite girders, and hybrid girders may be used.

5.2.4 The general layout and the basic parameters of a cable-stayed bridge shall be selected in accordance with the following principles:

1 The side-to-main span ratio should be 0.5 ~ 1.0 for a single-tower cable-stayed bridge and 0.3 ~ 0.5 for a double-tower cable-stayed bridge. For a multi-tower cable-stayed bridge, its side-to-main span ratio may be selected by referring to that of a double-tower cable-stayed bridge.

2 The ratio of the tower height above the bridge deck to the main span length should be in the range of 1/3 ~ 1/6 for a double- or multi-tower cable-stayed bridge, and in the range of 1/1.5 ~ 1/3 for a single-tower cable-stayed bridge.

3 In a cable-stayed bridge, the inclination angle of the outermost stay cable should not be less than 22°.

4 The depth of the main girder shall be determined comprehensively based on the bridge span, the transverse arrangement of the stay cable system, the cross-section form, and the longitudinal and transverse stress characteristics of the main girder.

5 Stay cables should be arranged in the following forms:

1) Stay cables may be arranged in either spatial or planar cable planes in the transverse direction.

2) Stay cables in the longitudinal direction should be arranged in the modified fan shape, and may also be in the harp shape, the fan shape, the star shape, etc.

3) The standard spacing of stay cables on the main girder should be 8 ~ 16 m for steel girders or composite girders, and should be 6 ~ 12 m for concrete girders.

6 Auxiliary piers shall be arranged according to the overall stiffness, structural stress conditions, navigation requirements for side spans, safety conditions during construction, and economic and applicability conditions of the cable-stayed bridge.

Commentary

This clause is formulated by summarizing the practical applications of cable-stayed bridges, proposing essential parameters to be determined in the general of the components including the main girder, tower, cables, auxiliary piers, etc. The proposed parameters apply to common cases, but for cable-stayed bridges under special conditions, appropriate adjustments to the parameters need to be made through reasonable structural arrangements.

There are many factors that affect the depth of the main girder in a cable-stayed bridge, such as the arrangement of the stay cables (cable spacing, transverse distance of the cable planes), span length, girder cross-section form, loads, etc. In practice, the proportion between the girder depth and the bridge span is also highly discrete. Therefore, no proportional relationship between the girder depth and the bridge span is provided in this clause. It needs to be determined based on specific circumstances in the design.

Stay cables are the main force-transmitting components in a cable-stayed bridge. They provide elastic supports for the main girder and transfer the loads to the towers. The stay cables should be arranged to ensure a reasonable structural force distribution. The common arrangements of stay cables along the longitudinal direction of the bridge are shown in Figure 5-1.

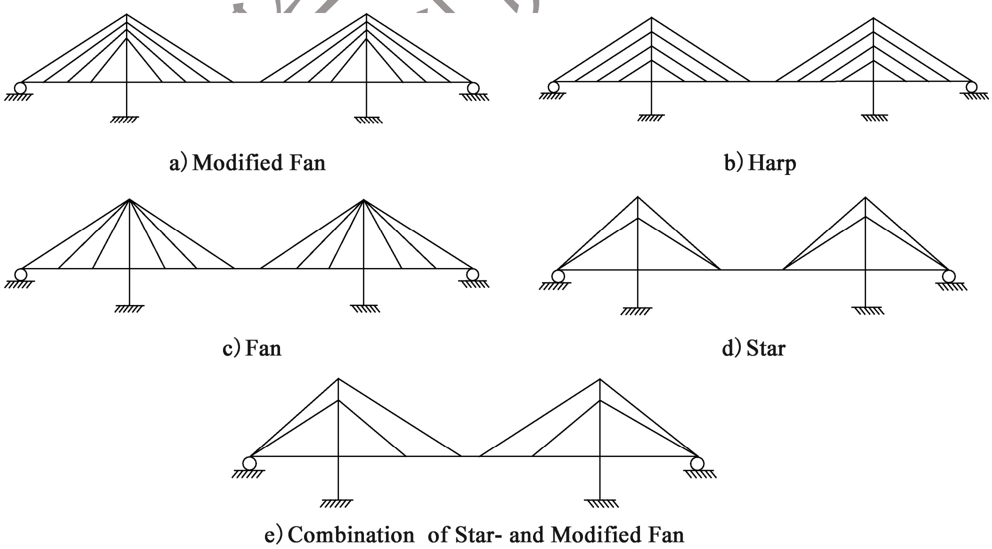


Figure 5-1 Arrangements of stay cables in the longitudinal direction of a cable-stayed bridge

5.3 Other Structural Systems and Types

5.3.1 For a multi-tower cable-stayed bridge, different constraint methods among the towers, girders and piers may be adopted for central and side towers according to the structural stress conditions. Measures to improve the overall stiffness of the system may be taken, such as increasing the stiffness of the central towers or the main girder, setting auxiliary cables to restrain the top displacement of the towers.

Commentary

A multi-tower cable-stayed bridge refers to a cable-stayed bridge with three or more towers. Examples of multi-tower cable-stayed bridges with main spans exceeding 200 m worldwide are listed in Table 5-1.

Table 5-1 Examples of multi-tower cable-stayed bridges with main spans exceeding 200m in the world

Bridge	Country	Span arrangement (m)	Type of main girder	Number of towers	Measure to improve stress
Maracaibo Bridge	Venezuela	160 + 5 × 236 + 160	Concrete girder	6	Rigid tower, cantilever system + suspended beam
Ting Kau Bridge	China	127 + 448 + 475 + 127	Composite girder	3	Auxiliary cables for the central tower
Rion-Antirion Bridge	Greece	286 + 3 × 560 + 286	Composite girder	4	Inverted V-shape tower in both directions
Yichang Yiling Yangtze River Bridge	China	38 + 38.5 + 43.5 + 2 × 348 + 43.5 + 38.5 + 38	Concrete girder	3	Close spacing of stay cables in side spans; tower-girder-pier fixed system in the central tower; two auxiliary piers for each side span
Mezcala Bridge	Mexico	57 + 79.86 + 311.44 + 299.46 + 83.84 + 67.87	Composite girder	3	Towers fixed with piers, auxiliary piers on the side spans
Binzhou Yellow River Bridge	China	42 + 42 + 300 + 300 + 42 + 42	Concrete girder	3	Tower-girder-pier fixed system in the central tower; auxiliary piers on the side spans

continued

Bridge	Country	Span arrangement (m)	Type of main girder	Number of towers	Measure to improve stress
Yueyang Dongting Lake Bridge	China	130 + 2 × 310 + 130	Concrete girder	3	Increasing the stiffness of the main girder and the towers; adding counterweight; and enhancing the tensioning level of the stay cables
Wuhan Erqi Yangtze River Bridge	China	90 + 160 + 2 × 616 + 160 + 90	Hybrid girder (Composite girder + concrete girder)	3	Increasing the self-weight of the main girder and the cross-sectional area of the stay cables
Jiashao Bridge	China	70 + 200 + 5 × 428 + 200 + 70	Steel box girder	6	Interlocking longitudinal joint in the mid-span of the main girder; double row bearings to support the main girder at piers

The T-frame + suspended beam system of the Maracaibo Bridge is an early structural system and is basically no longer used today.

The overall stiffness of a multi-main-span cable-stayed bridge is low, therefor to improve its overall stiffness is a key issue in its design. In a typical double-tower cable-stayed bridge, when the central span is loaded, the main girder of the central span deflects downward, the two towers bend towards the loaded central span, and the side spans deflect upward. The displacement of the towers towards the loaded central span is significantly restrained by the great change in the tension forces of the backstays at the end of the side spans.

If auxiliary piers are arranged in the side spans, all stay cables anchored at the outerside of the side spans and around the auxiliary piers act as restraints, similar to backstays in the side spans. This configuration enhances the overall stiffness of the bridge, reducing the upward deflections of the side spans and downward ones of the main span.

For multi-tower cable-stayed bridges, the backstays of the side spans have a weaker restraint effect on the central towers, resulting in lower overall stiffness. Besides, when only the main span is loaded, there will be a larger deflection. Therefore, improving the stiffness of the bridge system has become a key issue in the design of multi-tower cable-stayed bridges.

Increasing the stiffness of the main girder can improve the overall stiffness of a multi-tower multi-span cable-stayed bridge to some extent. However, it will inevitably increase the self-weight of the bridge. Central towers are typically designed as rigid structures, which will substantially increase the construction work amount of the towers and their foundations. If tie cables are used to restrain the displacement at the top of the central towers, several disadvantages should be considered, such as the large sag of the long cables under their self-weights, low elastic stiffness of the cables, susceptibility to failure under large wind loads, and unattractive appearance.

5.3.2 For a cable-stayed bridge with a very small side-to-main span ratio due to terrain limitations, a ground-anchored cable-stayed bridge may be adopted. Gravity anchorages, uplift piles, and other reliable anchorage forms may be used. For a ground-anchored cable-stayed bridge that is not a single-tower one, measures to allow longitudinal deformation of the main girder at the mid-span of the main span should be taken to accommodate the girder's expansion and contraction due to temperature changes.

Commentary

A few ground-anchored cable-stayed bridges have been built in China and other countries. Typical three-span ground-anchored cable-stayed bridges include: the Luna Bridge in Spain with a span arrangement of 67 m + 440 m + 67 m and an additional 36.23 m ground anchorage on each side span; the Hanjiang Bridge in Yunyang, China, with a span arrangement of 43 m + 414 m + 43 m and an additional 43 m ground anchorage on each side span. These two cable-stayed bridges are partially ground-anchored cable-stayed bridges.

In some single-span ground-anchored cable-stayed bridges, the stay cables of the main span are self-anchored while all the backstays are ground-anchored, such as the Matsuyama Bridge (main span of 96.6 m, ground anchoring length of 32.5 m) and the Chichibu Bridge (main span of 153 m, ground anchoring length of 22.5 m) in Japan, and the Ebro Bridge in Spain. The Furongjiang Bridge in Guizhou, China, is a cable-stayed bridge with an inclined tower and a single cable plane. The tower column tilts backward at an angle of 18.4°, the main span is 170 m, and all the side span cables are anchored to the gravity anchorages behind it.

5.3.3 For an extradosed prestressed concrete bridge with a relatively low tower height and a tower-girder-pier fixed system or tower-girder fixed system, the general layout and the basic parameters shall comply with the following provisions:

1 The side-to-main span ratio should be between 0.5 and 0.76.

2 The ratio of the tower height above the bridge deck to the main span length should be between 1/6 and 1/10.

3 Box section should be adopted for the main girder. When the main girder has a constant cross section, the depth-to-span ratio shall be 1/35 ~ 1/45; when the main girder has a variable cross section, the depth-to-span ratio shall be 1/25 ~ 1/30 for the section at the root of the main girder (near the pier) and 1/55 ~ 1/65 for the section at the mid-span.

4 The length of the girder portion without cable supports should be about 0.15 ~ 0.20 of the main span for the portion near the tower, 0.20 ~ 0.35 of the main span for the portion at the mid-span of the main span, and 0.20 ~ 0.35 of the side span for the portion in the side span.

Commentary

Extradosed bridges are a transitional bridge type between cable-stayed bridges and continuous beam bridges. An extradosed bridge is competitive for spans ranging from 100 m to 300 m.

In extradosed bridges, the main girders are the dominant load-bearing components, and the stay cables or panels (fin-backs) are just like some additional external tendons besides the internal ones in the prestressed concrete girders, achieving a reduction in the depth of the girders. Therefore, they have the advantages of both continuous beam bridges and cable-stayed bridges. Compared with continuous beam bridges or continuous beam bridges with rigid piers, they have the following advantages:

1 Extradosed bridges have a larger spanning capacity than continuous beam bridges. For the same span, the depth of the main girder in an extradosed bridge is much smaller than that of a continuous beam bridge, resulting in a lower structural height of the extradosed bridge.

2 For bridges with the same large span, extradosed bridges are more economical than continuous beam bridges.

3 Super-large prestressed concrete continuous beam bridges are prone to excessive deflections and premature cracking in the main girders. In extradosed bridges, these problems can be solved by actively adjusting the stay cable forces, so as to achieve the desired internal forces and alignment of the main girders.

6 Detailing Design

6.1 General

6.1.1 The detailing of primary components in cable-stayed bridges should ensure sufficient strength and stiffness, to ensure smooth force transmission, reduce stress concentration, and allow for convenient construction and maintenance.

6.1.2 In the detailing design of cable-stayed bridges, the maintenance and replacement of stay cables and other replaceable components shall be considered, and necessary spaces and structural measures shall be made provisions for.

Commentary

The components of cable-stayed bridges, such as stay cables, bearings, dampers, traffic barriers, wearing surfaces, and expansion joints, require daily maintenance during the operation period and may need to be replaced after several years of operation. In the detailing design of cable-stayed bridges, the feasibility and convenience of replacing these components shall be carefully considered.

6.2 Main Girder

6.2.1 The main girder of a cable-stayed bridge should be arranged as a continuous system.

Commentary

The main girders of cable-stayed bridges are generally arranged to be continuous, which can provide strong overall integrity of the bridge deck, smooth and comfortable driving, and easy maintenance in service.

The cantilever system with suspended beam was used in early cable-stayed bridges, such as the Morandi system implemented in the Maracaibo Bridge in Venezuela. In the Guangfu Bridge in China, a shear hinge was used to connect the cantilevers. Although such a non-continuous girder system can reduce the degree of static indeterminacy, it compromises the overall integrity of the bridge and the continuity of the deck, affecting riding comfort and making construction and maintenance more challenging. Therefore, it is seldom used.

6.2.2 The main girder may be a reinforced concrete girder, steel box girder, steel truss, or steel-concrete composite girder. The type of cross - section of the main girder shall be selected based on material, span, cable spacing, bridge width and number of cable planes, and also with comprehensive consideration of the structural load-carrying capacity, durability, wind-resistant stability, and construction methods.

6.2.3 Concrete main girders may be designed with solid slab section, double-side-box section, box section, box section with diagonal bracings, and ribbed slab section, as shown in Figure 6.2.3. The type of cross-section of concrete main girders should be selected according to the following principles:

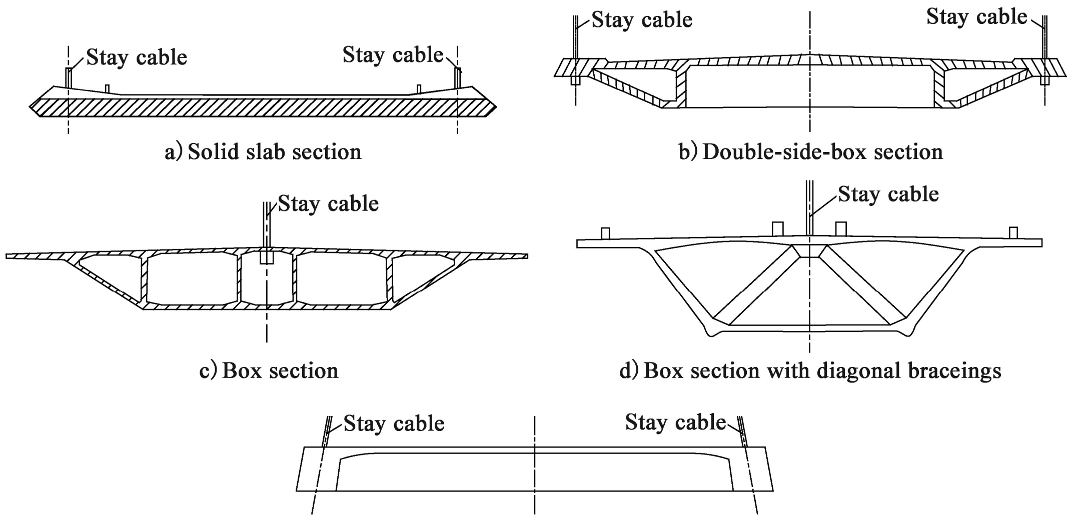


Figure 6.2.3 Typical cross sections of the main concrete girder in a cable-stayed bridge

1 The solid slab section is suitable for concrete cable-stayed bridges with a span of less than 200 m.

2 The ribbed slab section, double-side-box section, or box section is suitable for cable-stayed bridges with double cable planes.

3 The box section or box section with diagonal bracings is suitable for cable-stayed bridges with a single cable plane.

4 If the bridge deck is wide, the main girder may be designed with section of single-box multi-cell box, ribbed slab section, or double-side-box section. The number of ribs in the middle part of the deck slab may be appropriately increased if necessary.

Commentary

A solid slab with a thickness of 45 cm is adopted for the main girder in the Evripos Bridge in Greece, which has a main span of 215 m.

Similar to solid slabs, ribbed slabs are also applicable to cable-stayed bridges with double cable planes. They have been widely adopted, such as in the Tieluoping Bridge, with a main span of 322 m, and the Shaoxing Caoejiang Bridge, with a main span of 300 m.

6.2.4 Steel box girders may adopt monolithic-box section, separated-box section, or double-side-box section. Typical cross-sections of steel box girders of cable-stayed bridges are shown in Figure 6.2.4.

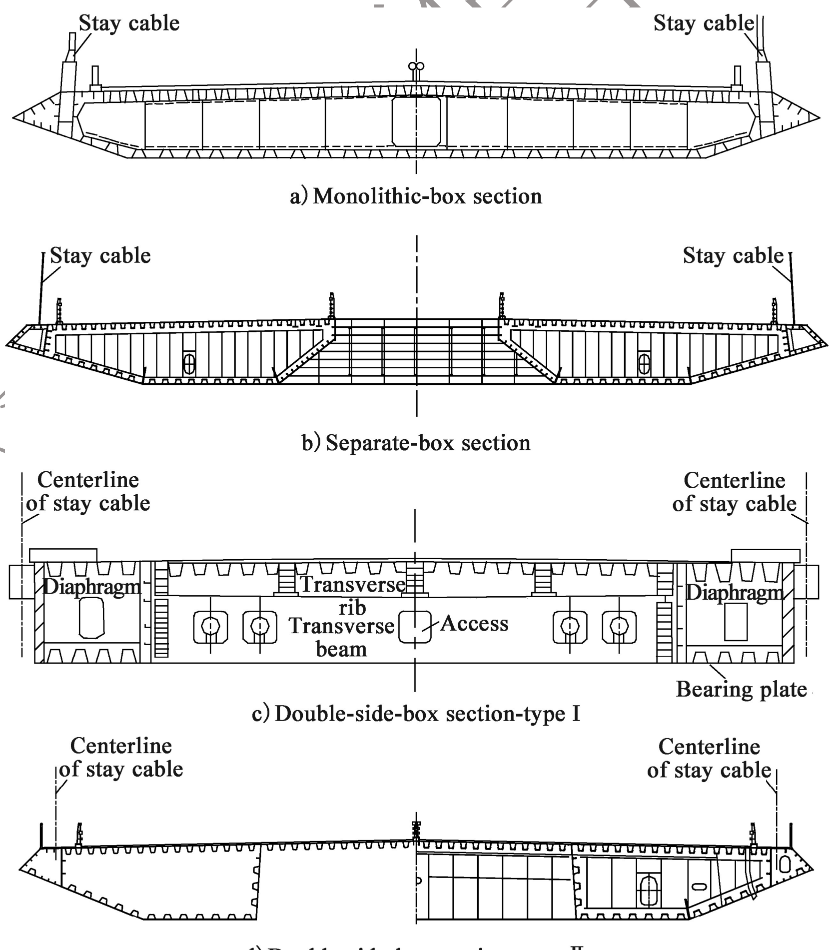


Figure 6.2.4 Typical cross-sections of steel box girders of cable-stayed bridges

Commentary

The separated box girder is supplemented in this *Specifications*. It has typical structural characteristics similar to those of a flat steel box girder, consisting of a top plate, bottom plate, webs, and diaphragms. The difference lies in that the central part is separated to form twin or multiple boxes, and these separated longitudinal girders are connected by transverse girders at certain intervals along the longitudinal direction. The separated box girders have been adopted in some cable-stayed bridges, such as the Shanghai Yangtze River Bridge, Stonecutters Bridge in Hong Kong, Wuhu Second Yangtze River Highway Bridge in Anhui Province, and Ningbo Waitan Bridge in Zhejiang Province, China.

6.2.5 Stiffening trusses may be designed according to the following principles:

1 The cross-section of the stiffening trusses may be a rectangle, an inverted trapezoid, or other cross-section forms. The typical cross-sections are shown in Figure 6.2.5-1.

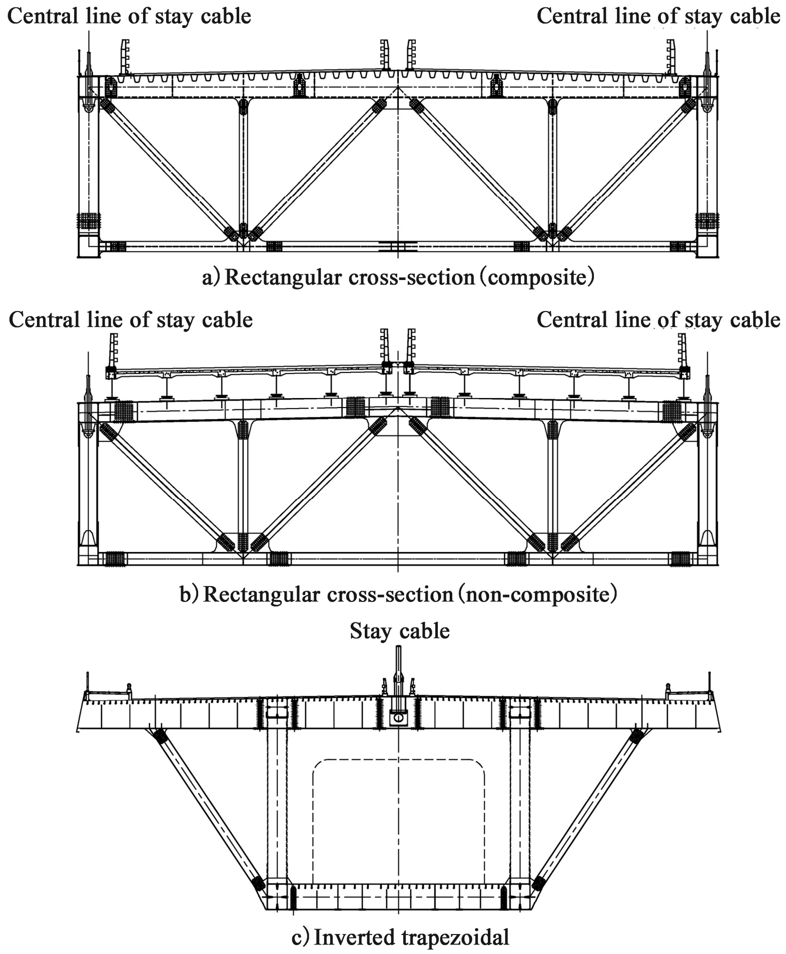


Figure 6.2.5-1 Typical cross sections of steel truss in cable-stayed bridges

2 The orthotropic steel deck or concrete deck may be used for the stiffening truss deck. The orthotropic steel deck and the truss may be integrated (composite) or separated (non-composite), as shown in Figures 6.2.5-1a and 6.2.5-1b.

3 The trusses may be Pratt, modified Warren, and Warren forms, as shown in Figure 6.2.5-2.

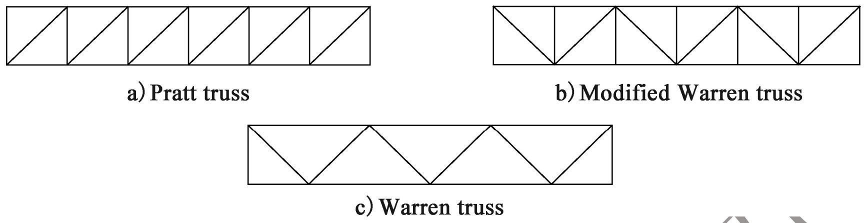


Figure 6.2.5-2 Steel truss forms

4 The depth of the main truss in a stiffening truss should be determined based on stress requirements, clearance on deck, and the detailing of the joints. The angle between the diagonal web member and the chord should be 35°~55°.

5 The bracing types shown in Figure 6.2.5-3 may be adopted as the upper and lower lateral bracing systems.

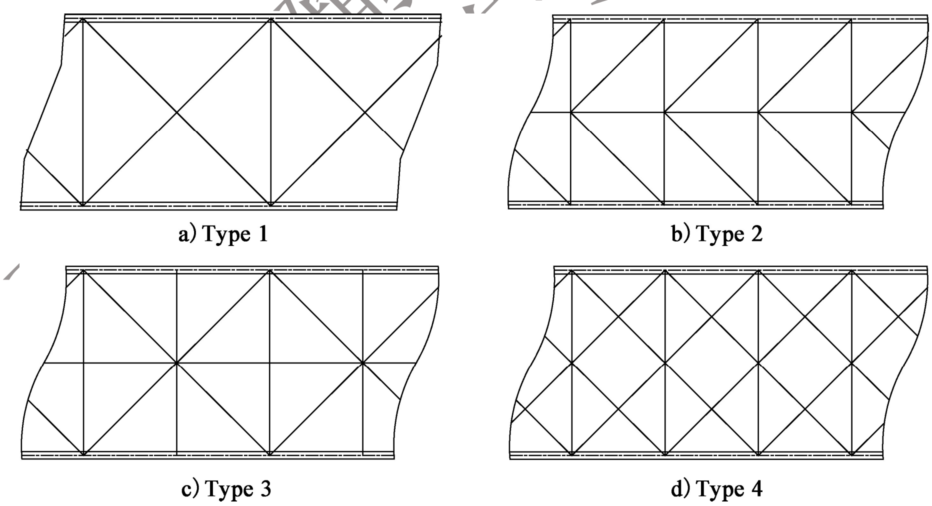


Figure 6.2.5-3 Lateral bracing systems in steel truss

Commentary

A steel truss consists of the main trusses, the transverse connection systems (transverse trusses), the lateral bracing systems, and the bridge deck. The main trusses and the transverse connection systems are composed of upper and lower chords, and web members, which are connected by means of high-strength bolts or welding.

Steel stiffeneing trusses can be easily transported in a disassembled state and require less on-site welding work, therefore they are increasingly applied in cable-stayed bridges in mountainous areas in China. The Yachihe Bridge with a main span of 800 m and the Duge Beipanjiang Bridge with a main span of 720 m, both in Guizhou, are two representative examples of steel truss cable-stayed bridges in mountainous areas. At the same time, the depth and permeability of stiffening trusses can facilitate cable-stayed bridges with double decks. Typical examples include the Shanghai-Suzhou-Nantong Yangtze River Bridge with a main span of 1092 m, the Shanghai Minpu Bridge with a main span of 708 m, the Wuhan Tianxingzhou Bridge with a main span of 504 m and the Chongqing Dongshuimen Yangtze River Bridge with a main span of 445 m.

Steel-concrete composite decks and orthotropic steel decks are two typical structures used in the steel truss of highway cable-stayed bridges. For a steel-concrete composite deck, it is beneficial for bonding between the cnocrete deck slabs and the wearing surfaces, for the durability of the wearing surfaces, and for fatigue resistance of the deck systems. However, it has a relatively large self-weight and is suitable for steel truss cable-stayed bridges with relatively smaller spans. A representative bridge that has been built is the Hubei Zhongjianhe Bridge with a main span of 400 m. The orthotropic steel deck has a light self-weight and is suitable for steel truss cable-stayed bridges in high-intensity seismic regions or those with relatively larger spans. However, special attention should be paid to the fatigue resistance of the deck system itself and the durability of the wearing surfaces. A representative bridge that has been built is the Guizhou Yachihe Bridge with a main span of 800 m.

According to whether the bridge deck participates in the stress of the main truss, the stiffening trusses of highway cable-stayed bridges can be divided into deck-truss composite type and deck-truss separated type. The former has greater overall stiffness, while the latter has more definite stress distribution and facilitates the maintenance and replacement of the bridge deck.

Theoretically, from the perspective of stress, the optimal inclination angle between the diagonal web member and the main truss plane or the vertical plane is 45°. Taking into account the depth of the steel truss, the panel length, and the structure of the gusset plate, the angle of the diagonal web member should be in the range of 35° to 55°.

In order to keep the main truss in a space-invariant system and enable it to withstand horizontal loads, longitudinal horizontal trusses (upper and lower lateral bracings) are installed between the two main trusses to form a stable spatial structure. Type 1 can make the chords deform uniformly and be subject to no bending moments because its nodes are the same as those of the chords. It is generally used in trusses with small panel lengths. An example of its application is the lower lateral bracing of the Tianxingzhou Yangtze River Bridge, which is a double-deck bridge for both highway and railway. Type 2 is generally applied to bridges with small panel lengths. When the bridge deck is relatively wide, the Type 3 (used for the lower lateral bracing of the Duge Beipanjiang Bridge) or the Type 4 (used for the upper and lower lateral bracings of the Guozigou Bridge) is often adopted. For a bridge with an orthotropic bridge deck, generally, there is no lateral bracing system.

6.2.6 The steel structure in composite girders may take the form of I-shaped girders, side box girders with small stringers, flat streamlined box girders, box girders, or steel truss girders. The typical sections are shown in Figure 6.2.6. The structural design of the composite girders shall comply with the following provisions:

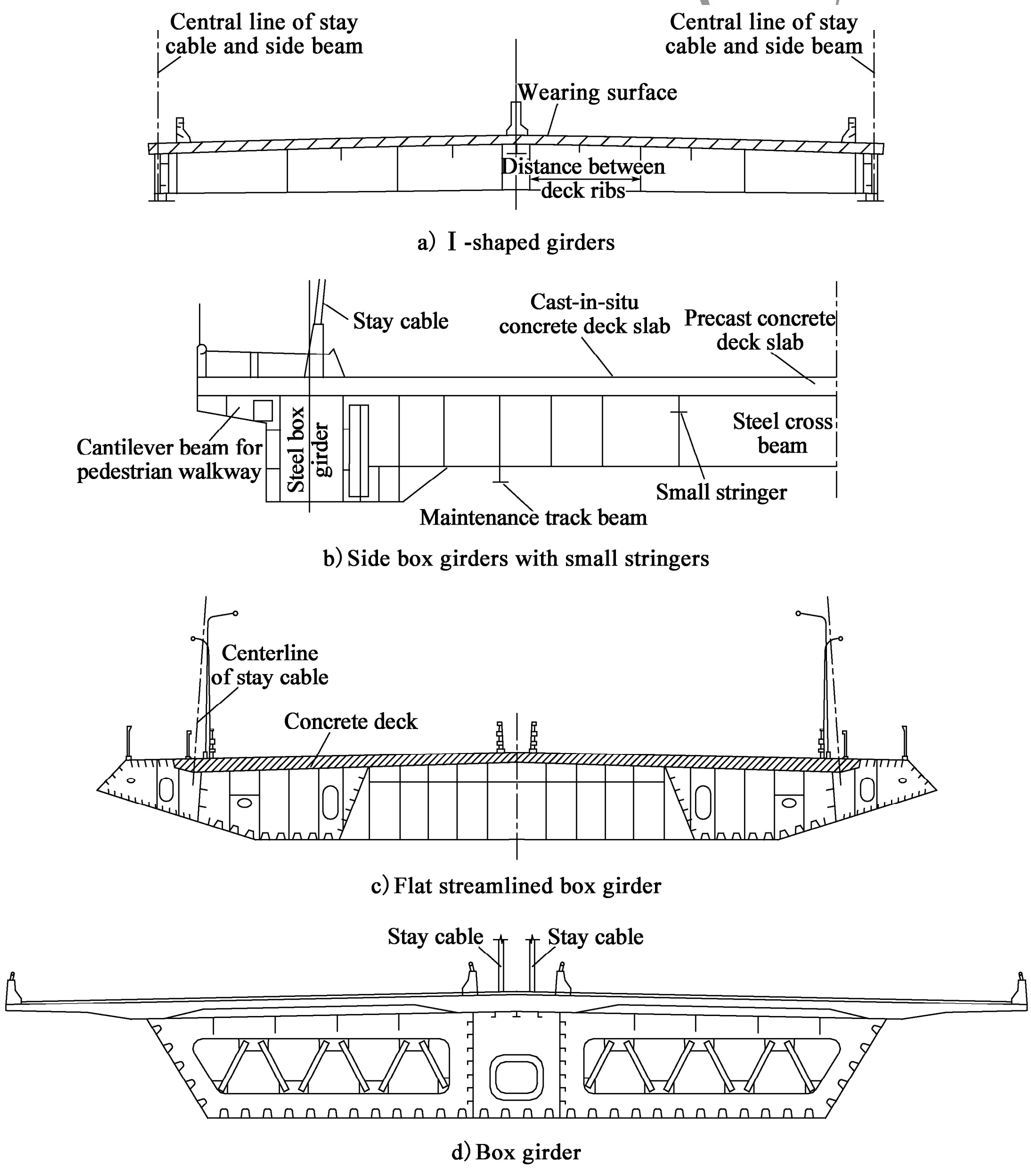
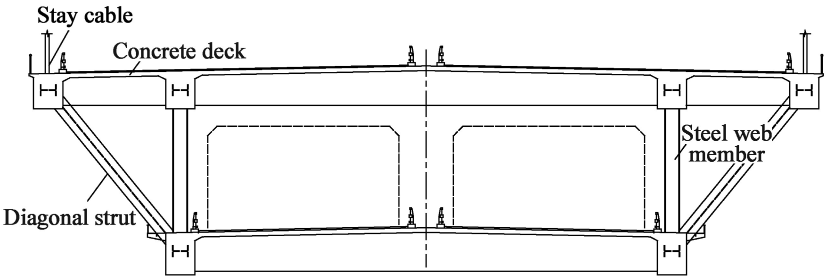


Figure 6.2.6



e) Steel truss

Figure 6.2.6 Typical cross-sections of composite girders in cable-stayed bridges

1 The thickness of the concrete deck slabs should not be less than 250 mm, and the concrete strength class should not be less than C40.

2 Concrete deck slabs shall be interconnected via wet joints, while the composite action between concrete deck slabs and steel girder top flanges shall be ensured by shear connectors, thereby forming a monolithic structural system. The design of the connection details shall be implemented in accordance with the provisions of the current *Specifications for Design and Construction of Highway Steel-concrete Composite Bridge* (JTG/T D64-01).

Commentary

Two steel I-beams are mostly adopted in the composite main girders. An application example is the Qingzhou Minjiang Bridge in Fujian, with a span of 605 m. Side box girders with small longitudinal stringers are commonly used, and an example is the Yangpu Bridge in Shanghai, with a span of 602 m. Steel-concrete composite beams also adopt other structural forms in cable-stayed bridges. For example, the composite girder formed by a flat streamlined semi-closed steel box and concrete deck slab (as shown in Figure 6.2.6c) is adopted in the Taizhou Jiaojiang Second Bridge with a span of 480 m, and the composite girder formed by steel truss and concrete deck slab (as shown in Figure 6.2.6e) is adopted in the side span of the Minpu Bridge in Shanghai.

According to a survey of cable-stayed bridges with steel-concrete composite girders that have been built or are under construction in China, the thickness of concrete deck slabs in steel-concrete composite girders is currently mainly in the range of 250 mm ~ 280 mm.

6.2.7 The detailing design of transverse connections of main girders in cable-stayed bridges shall comply with the following provisions:

1 For concrete main girders, diaphragms shall be provided at anchorages of stay cables and at

girder supports. The spacing between diaphragms should be 4 m ~ 8 m, and the thickness of a diaphragm should not be less than 200 mm.

2 For steel box main girders, diaphragms at the anchorages of stay cables and at the girder supports should be of the plate type, and diaphragms at other locations may be of the truss type. The spacing between diaphragms should not exceed 4 m. The thickness of the steel plates of the diaphragms should not be less than 10 mm.

3 For steel main trusses, the transverse connection system should adopt the form of truss with diagonal braces.

4 For composite main girders, diaphragms at the anchorages of stay cables and at the girder supports should be of the plate type. The thickness of the steel plates of the plate-type diaphragms should not be less than 10 mm.

Commentary

As the transverse connection system of the main girders, diaphragms are important components to make the main girders into monolithic spatial structures. The diaphragms can improve the torsional and shear stiffness of the main girders. When connected as a single unit with the main girders, they can enhance the transverse stiffness of the cross-section and improve the overall performance of the structure.

In the anchorage zones of stay cables of the main girder, there are local stress concentrations, and the mechanical behavior is complex. To ensure the effective transmission of tension forces from the stay cables to the main girders, a transverse connection system with high stiffness is required. Additionally, these connections should be arranged with appropriate densification, taking into account the transverse stiffness of the main girder, the span of the deck slab, and the spacing of the cables.

The diaphragms at supports need to have sufficient strength and stiffness to resist and distribute large reaction forces. To enhance their strength and stiffness, measures such as increasing the thickness of concrete plates, applying prestress, or adding stiffeners can be implemented. The distribution of normal stress at the top corner of the reserved hole in the diaphragm is influenced by the internal transition angle; a smoother transition angle results in smaller stress concentrations at the corner. To mitigate stress concentration, haunches are typically installed and the reinforcement in the diagonal direction should be strengthened.

For steel truss girders, in addition to longitudinal horizontal trusses, transverse connections are also set up between the two trusses to form a stable spatial structure with greater torsional stiffness. For double-deck bridges, due to the clearance requirement for the lower deck, the transverse connection system is a rigid frame formed by the transverse girders and the intermediate vertical members (or diagonal members) of the main truss.

6.2.8 The detailing design of the longitudinal connections of the main girders in cable-stayed bridges shall comply with the following provisions:

1 When concrete main girders are segmentally cast-in-place by the cantilever method, the connecting joints of the longitudinal prestressing strands at the segmental joints should not exceed 50% of the total number of the prestressed steel strands. When the main girders are erected by the precast segments using cantilever method, the cross-sections of the concrete main girders shall be designed in the form of tongue-and-groove joints, and prefabricated or embedded positioning components should preferably be provided. Epoxy joints shall be adopted for the joints of the main girders. The contact surfaces of the components shall be flat, closely attached, and waterproofing treatment shall be carried out. When the span of the bridge is relatively large, wet joints may be added to facilitate the adjustment of the alignment of the main girders.

2 The shop welding method should be adopted for the fabrication of the members of steel box girders and steel truss girders. The connection of the segments may be realized by high-strength bolts or welding. The top plate of the steel box girder shall be connected by welding. The longitudinal diaphragms of the steel box girder should be arranged at the center-line of the lane or along the lane line.

3 For the long-span composite cable-stayed bridge, the segment length of the main girder should be set to allow the arrangement of 1 to 2 stay cables or 2 to 4 cross beams. The shop welding method shall be adopted for the fabrication of the steel girder segments in the composite girders. The connection of the segments can be achieved by high-strength bolts or welding.

4 For a hybrid girder, connecting the girder segments with different materials shall comply with the provisions in the current *Specifications for Design and Construction of Highway Steel-concrete Composite Bridge* (JTG/T D64-01).

Commentary

1 For concrete main girders segmentally cast-in-place using cantilever method, the connecting joints of the longitudinal prestressing strands should not be all disconnected at the seg-

mental lines, so as to minimize the weakening effect on the main girders before tensioning and grouting. Usually, the joints of the prestressing strands at the segmental lines of the main girders do not exceed 50% of the total number. In order to enable the concrete of the segment to be cast to bond well with the end face of the already-cast segment, the outer end face of the completed girder segment should be roughened.

2 When the segments of the steel main girder are connected by high-strength bolts, the bolts should be arranged symmetrically with respect to the axis of the components to prevent the generation of additional stress due to eccentricity. In the case that all bolts have been aligned centrally, the drift pins are driven and then the high-strength bolts are tightened. When the segments of the steel main girder are connected by welding, temporary connection should be made first in the form of bolted maching, and then the welding connection is carried out.

3 To ensure the hoisting stiffness and control the weight of the segments, the length of the segments of the composite girder should be set to allow the arrangement of 1 to 2 stay cables and 2 to 4 cross beams.

4 The longitudinal connection of the main girders made of two different materials in the junction part of the steel-concrete hybrid girder is the most crucial technical key point in hybrid girder cable-stayed bridges. The current *Specifications for Design and Construction of Highway Steel-cncrete Composite Bridges* (JTG/T D64-01) has made detailed provisions for the design of the junction part of the steel-concrete hybrid girders, and these provisions should be followed in the design of the hybrid girders of cable-stayed bridges.

6.2.9 The length of the closure segment of the concrete main girders may be taken as 1.5 m-3.0 m. Embedded steel frames may be used as temporary connection measures, and prestress may be applied if necessary. The length of the closure segment of the steel main girders may be taken as 4.0 m - 12.0 m, and the actual length of the steel girder in the closure segment may be adjusted according to the closure temperature.

Commentary

The closure segments of the concrete main girders need to resist axial forces, bending moments and shear forces during the closure process, which are induced by temperature variations, early shrinkage of the newly cast concrete, shrinkage and creep of the concrete in the already completed structural parts, the change of the structural systems, and the construction loads. The closure segments should also overcome the influence of temperature to prevent concrete cracking. Therefore, strengthening measures need to be taken to ensure the continuity of the structure and coordinate the deformation of the girder bodies on both sides of the closure segment.

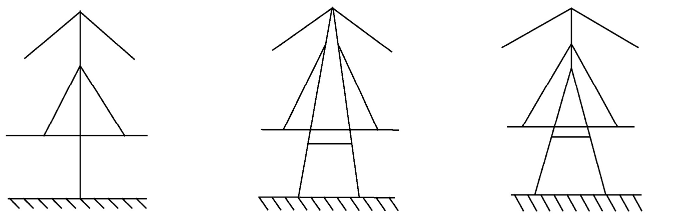
The concreting of the closure segment shall be completed as soon as possible, and the concrete shall reach the design strength at the earliest opportunity. There should be a certain construction working surface. Generally, the length of the closure segment is 1.5 m to 3.0 m. Usually, embedded rolled shapes or steel pipes as well as applying prestress are adopted as temporary connection measures.

Steel girders have high thermal conductivity and can quickly exchange heat with the surrounding air. Their structural deformation is extremely sensitive to temperature changes. Therefore, it is necessary to correctly select the closure temperature and ensure that there is enough time for the positioning of high-strength bolts during the installation and positioning of the steel girders. In addition, the temperature-induced deformation should be observed to provide a scientific basis for modifying the designed closure temperature.

6.3 Tower

6.3.1 The structural design of the tower shall meet the requirements for structural strength, stiffness, and stability during the construction and operation stages. Additionally, considerations shall be given to economic rationality, ease of construction, aesthetic appearance, and convenience for maintenance. The structural form of the tower shall be selected in accordance with the following principles:

1 The longitudinal forms of the tower may adopt the single column type, A-shape, inverted Y-shape, etc., as shown in Figure 6.3.1-1. The tower should be designed to be vertical, and it may also be designed to be inclined according to the requirements.



a) Single column　　b) A-shape　　c) Inverted Y-shape

Figure 6.3.1-1　Basic longitudinal forms of the tower

2 In the transverse direction of the bridge, the tower forms may be of single column type, double column type, portal type, vase shape, A-shape, inverted Y-shape, pagoda shape, diamond shape, etc., as shown in Figure 6.3.1-2.

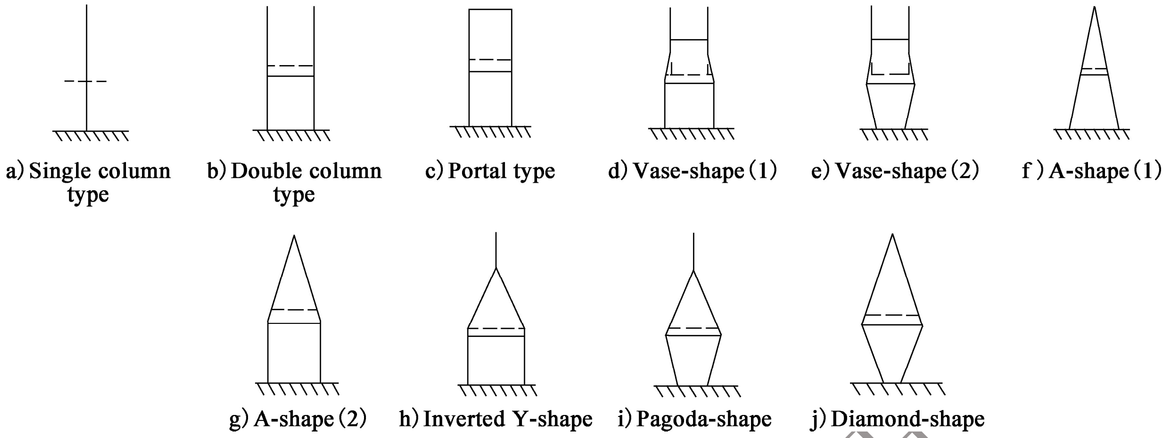


Figure 6.3.1-2 Basic transverse forms of the tower

3 The cross-section of the tower columns may be solid or hollow, and the cross-sectional form may be rectangular, I-shaped, box-shaped, or polygonal.

6.3.2 Rolled shapes shall be arranged inside the concrete towers as embedded frameworks according to construction requirements. The detailing design of the reinforcement in concrete towers shall comply with the following provisions:

1 The diameter of the vertical primary reinforcement should not be less than 25 mm.

2 The cross-sectional area of the vertical primary reinforcement should not be less than 1% of that of the concrete.

3 The diameter of the stirrups shall not be less than 16 mm, and their spacing shall not exceed the smaller value of 10 times the diameter of the vertical primary reinforcement and 200 mm.

Commentary

Tower is one of the main load-bearing components in a cable-stayed bridge. Tower columns should resist the axial compression forces induced by the vertical components of cable forces, and the bending moments and shear forces induced by the horizontal components of cable forces. In addition, tower columns need to resist the axial and horizontal forces, torsions, and bending moments in the longitudinal and transverse directions caused by the temperature variations (affected by sunlight), support settlement, wind loads, seismic forces, and concrete shrinkage and creep, etc. Therefore, more reinforcement is provided in tower columns. To increase safety reserves and reduce vertical cracking of the towers, this revision increases the minimum required diameter of the vertical primary reinforcement and stirrups. The required reinforcement specified in this clause is only the minimum limit; in actual design, the reinforcement should be reasonably designed based on calculation results.

6.3.3 Steel towers should be designed with rectangular hollow box sections; alternatively, T-shaped or quasi-cross hollow box sections may be adopted based on the specific project conditions. Vertical stiffening ribs shall be arranged on each main wall plate around the box chamber. Horizontal transverse diaphragms shall be installed inside the box chamber, and the spacing between them should not be greater than 4.0 m. The thicknesses of the outer and inner wall plates of the steel towers may be taken as different values in sections along the towers according to the force-bearing requirements, but the thickness should not be less than 20 mm.

6.4 Stay Cables

6.4.1 In consideration of the conditions of production, transportation, and installation, parallel steel wire or steel strand stay cables shall be selected for the stay cables.

Commentary

Currently, according to different materials and manufacturing methods, stay cables are generally classified into two categories: integrally-installed cables and separately-installed cables, namely parallel steel wire cables and steel strand cables.

6.4.2 Stay cables shall have intact and reliable sealing protection structures, especially at the joints between cable ends and anchorages. Stay cables shall facilitate tensioning, inspection, and replacement.

Commentary

The durability and safety of stay cables are related to whether their protective structural systems are sound and reliable. The connection between the cable body and the anchorage is the most complex and weakest part in the protection of the entire cable, and is also the place where problems are most likely to occur. In the design and manufacture, reliable sealing and protective measures must be implemented at the cable end. Special attention shall be paid to protecting the cable end sealing structure from damage, particularly during installation and, more importantly, in the long-term operation phase. This is an important measure to improve the durability and safety of stay cables and to extend their service life.

6.4.3 At the ends of stay cables, reliable measures for water drainage and moisture-proofing shall be taken into account during the construction and operation periods.

Commentary

During both the construction and operation periods, it is important to provide reliable water drainage and moisture prevention measures, such as external protective covers, drainage grooves on the lower anchor bearing plates, etc.

6.4.4 The effective protection shall be provided for stay cables above the bridge deck, and the height of vertical protection shall not be less than 2.5 m.

Commentary

To prevent stay cables from being damaged by humans or vehicle collisions, effective protective measures shall be taken within a specified range above the bridge deck.

6.4.5 Internal vibration suppression devices or external dampers should be provided at the ends of stay cables if necessary.

Commentary

Vibration, especially excessive vibration, can lead to the fatigue of stay cables and damage to their protective structures, affecting their service life. For standard bridges, internal vibration suppression devices installed within embedded pipes are effective in reducing vibration. For large cable-stayed bridges or those located in areas with frequent wind and rain, internal vibration suppression devices and external dampers are usually installed together.

6.4.6 Parallel steel wire stay cables shall comply with the following requirements:

1 The design of parallel steel wire stay cables shall meet the requirements in the current *Hot-extruded PE Protection Paralleled High Strength Wire Cable of Cable-stayed Bridge* (GB/T 18365) and *Cable of Parallel Steel Wires for Large-span Cable-stayed Bridge* (JT/T 775).

2 Cold cast anchorages should be used as the anchorages of parallel steel wire cables, and the surfaces of the anchorages shall be treated with protective coating.

Commentary

Specifications, technical requirements, test methods, and inspection rules of high-strength steel wire cables for cable-stayed bridges are specified in the current *Hot-extruded PE Protection Paralleled High Strength Wire Cable of Cable-stayed Bridge* (GB/T 18365). Structures, specifications, models, and technical requirements of parallel steel wire cables for large-span cable-stayed bridges are specified in the current *Cable of Parallel Steel Wires for Large-span Cable-stayed Bridge* (JT/T 775).

6.4.7 Steel strand stay cables shall comply with the following requirements:

1 The design of steel strand stay cables shall meet the requirements in the current *Technical Conditions for Steel Strand Cable of Cable Stayed Bridge* (GB/T 30826) and *Technical Conditions for Unbonded Steel Strand Stay Cable* (JT/T 771).

2 A single steel strand should be corrosion - protected by galvanization or epoxy coating, and covered with extruded black high-density polyethylene sheaths. High-density polyethylene tubes may be used as protective sheaths for an entire bundle of steel strands.

3 Wedge-type group anchorages or other proven and reliable anchorages may be used as anchorages of steel strand stay cables. Their structures and specifications shall meet the requirements in the current *Anchorage, Grip and Coupler for Prestressing Tendons* (GB/T 14370).

4 The overall jacking requirements during construction and operation should be considered in designing anchorages for steel strand stay cables.

Commentary

Structures, technical requirements, product acceptance and inspection, corrosion protection, installation, replacement, and inspection of steel strand stay cables in cable-stayed bridges are specified in the current *Technical Conditions for Steel Strand Cable of Cable Stayed Bridge* (GB/T 30826). The structures, specifications, technical requirements, testing methods, and installation requirements of unbonded steel strand stay cables are specified in the current *Technical Conditions for Unbonded Steel Strand Stay Cable* (JT/T 771).

Wedge-type anchorage devices used in stay cables are different from those commonly used in bonded prestressing strands in engineering projects. Usually, the wedge-type anchorage devices used in stay cables have some special structures.

6.4.8 Static loading tests or fatigue loading tests of stay cables shall meet the requirements in the current *Hot-extruded PE Protection Paralleled High Strength Wire Cable of Cable-stayed Bridge* (GB/T 18365) and *Technical Conditions for Steel Strand Cable of Cable Stayed Bridge* (GB/T 30826).

6.5 Measures for Aerodynamic Stability

6.5.1 Whenever the aerodynamic stability of cable-stayed bridges cannot meet the requirements, the following measures may be adopted:

1 Improve the structural stiffness, including increasing the stiffness of towers and girders, using spatial cables, setting auxiliary piers in side spans.

2 Use cross-sections or profiles that can improve the aerodynamic stability of main towers and main girders, including using streamlined sections with wind fairings for main girders and chamfering the main tower sections.

3 Use measures on the outer surfaces of stay cables to suppress wind-rain-induced vibration, provide internal or external dampers, and install cross ties between long cables.

4 Design the ratio of the bridge width to its span no less than 1/30.

5 Set the maintenance vehicle tracks and flow guiding devices in proper locations, and change the shape of railings.

Commentary

When the aerodynamic stabilitycannot meet the requirements, in order to increase the critical wind speed of the cable-stayed bridge, it is necessary to add aerodynamic stability measures to change the stiffness of the structural system.

The measures to improve the structural aerodynamic stability are selected based on research results and successful design experience in China and other countries. Each bridge has different structural forms, stiffness, span, width, and girder depth, and the wind speed at its location also varies. Therefore, the selected aerodynamic stability measures need to be adjusted to meet the specific requirements of the bridge in question.

6.6 Anchorage System

6.6.1 Anchorages on the girder top slab, inside the box girder, on the inclined diaphragm of the girder, at both sides of the girder, and at the girder bottom should be used to anchor stay cables to concrete girders, as shown in Figure 6.6.1.

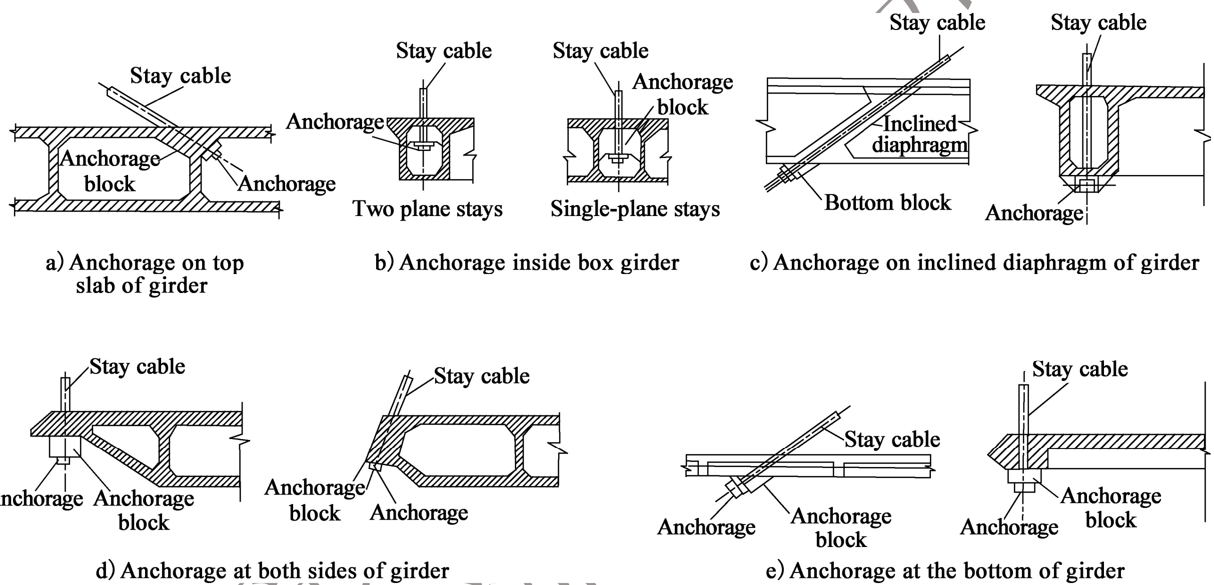


Figure 6.6.1 Fundamental types of anchorage of stay cable in concrete girder

Commentary

Stay cables are usually anchored at the top slab, the bottom slab, or the mid-height of the main girders. An anchoring solid structure is generally provided on the main girders for stay cables, especially for concrete and prestressed concrete girders. The complex spatial stresses in the girder's anchorage zones can be dispersed by the solid structures with large stiffness so that the deformation and stress of the girder at the anchorage can be reduced.

6.6.2 Stay cables should be anchored to concrete towers using various methods, such as anchoring on side walls, steel anchor beams, cross-type anchoring, steel anchor boxes, and through saddles (both straddle-type and rotary-type), as illustrated in Figure 6.6.2-1 to Figure 6.6.2-6. The basic structures of the anchorages shall comply with the following provisions:

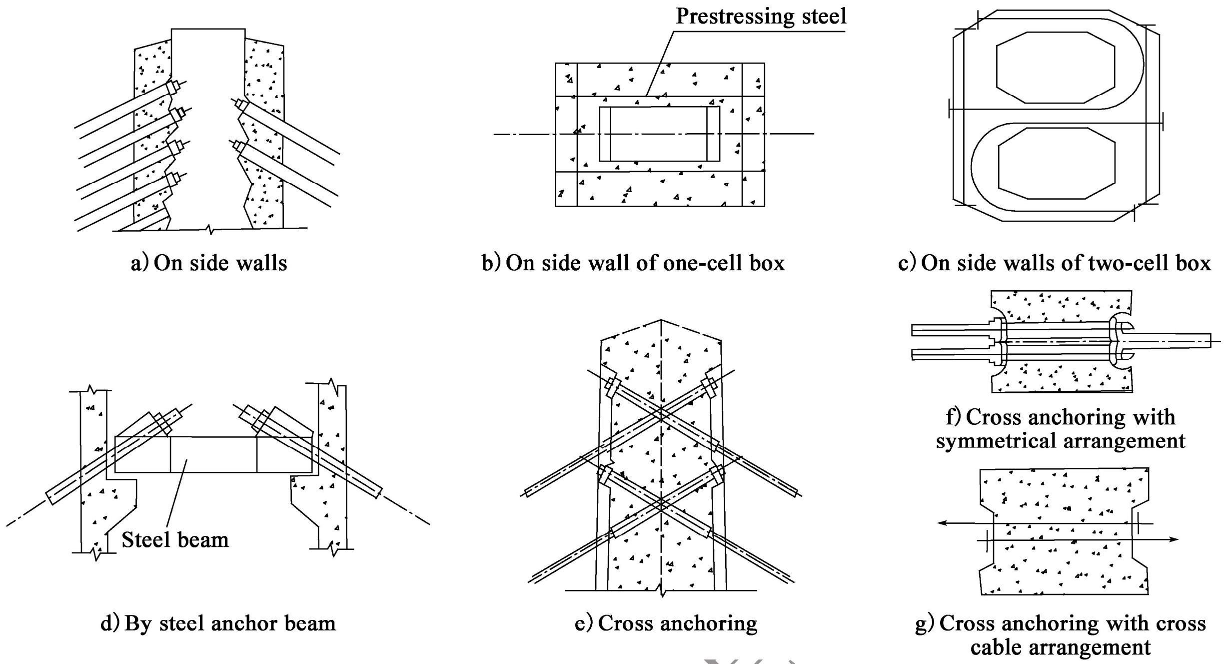


Figure 6.6.2-1　Fundamental forms of anchorages in concrete tower

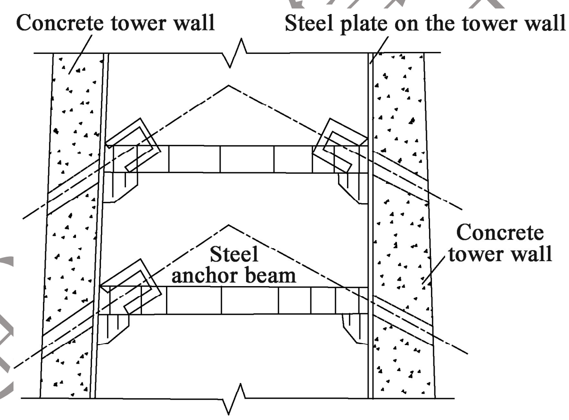


Figure 6.6.2-2　Anchorage on steel anchor beams (with corbel) inside concrete tower

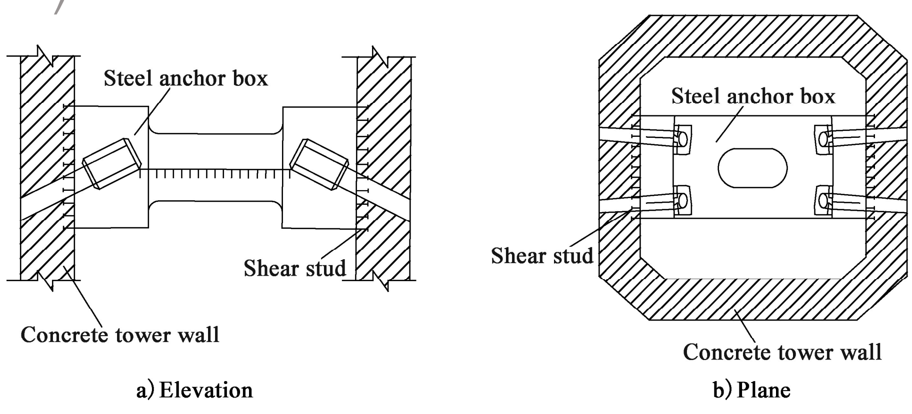
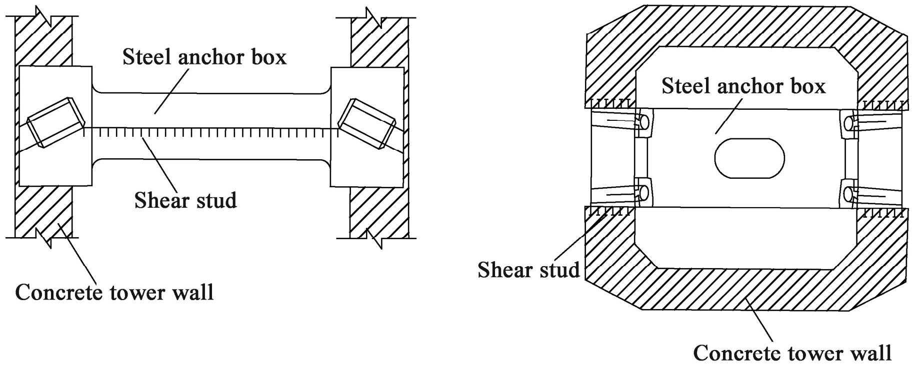
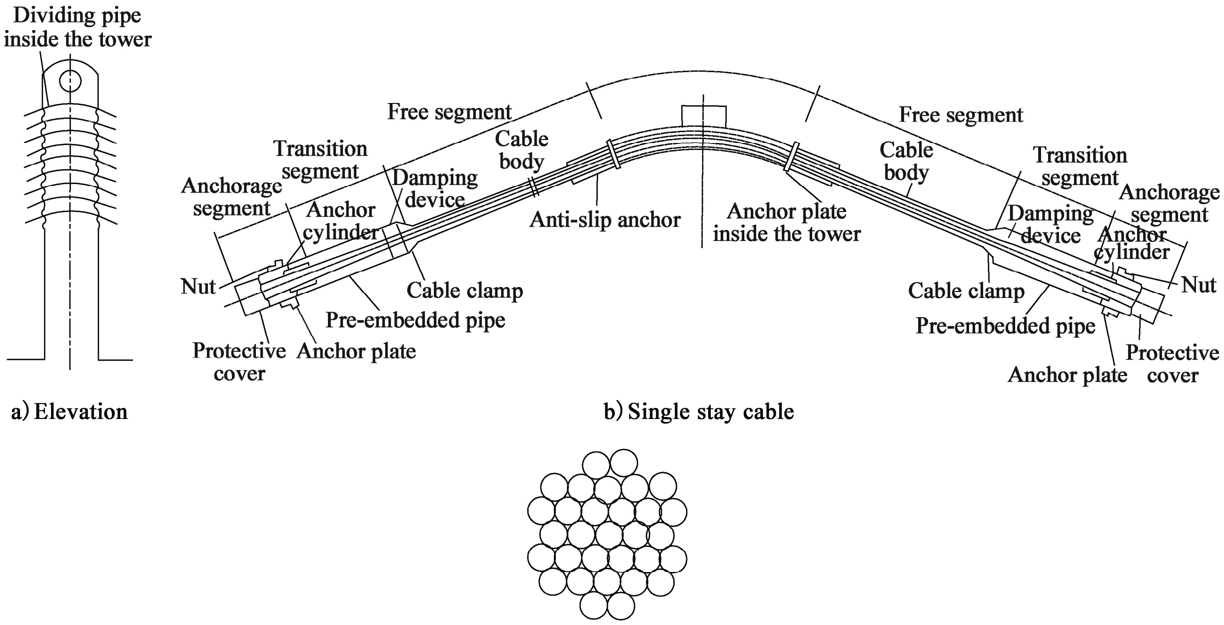


Figure 6.6.2-3　Built-in steel anchor box



a) Elevation b) Plane

Figure 6.6.2-4 External steel anchor box



a) Elevation b) Single stay cable

c) Structure of the dividing pipes

Figure 6.6.2-5 Anchorage on saddle with dividing tubes on concrete tower

1 For the cross anchoring in the solid towers, steel pipes should be embedded in the towers, and the anchor bearing plate should be installed in the towers.

2 For anchoring stay cables on side walls of hollow towers, prestressing steel shall be arranged in the side walls, and the arrangement of prestressing steel in the tower should avoid the formation of prestress blind zones.

3 For anchoring stay cables by steel anchor beam, corbels shall be provided inside the concrete tower. The corbels may be concrete or steel structures. Restrainers against longitudinal and transverse movements shall be installed at the two ends of the steel anchor beams.

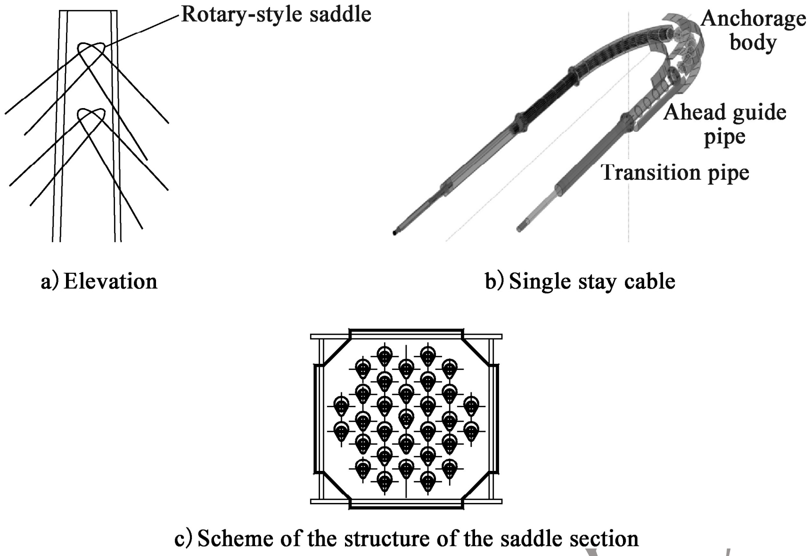


Figure 6.6.2-6 Anchorage on rotary-style saddle

4 Steel anchor boxes may consist of components such as anchor bearing plates, bearing plates, anchor webs, sleeves, and several stiffening ribs. They may be connected to the concrete towers with shear studs. The steel anchor boxes may be of the built - in or external type.

5 If the riding-type saddle (deviator saddle) is used at the top of the tower, after passing through the saddle at the top of the tower, the stay cables shall be symmetrically anchored to the main girder on both sides of the tower. This method is mostly used for extradosed prestressed concrete bridges. Wire separating tubes that can facilitate the replacement of stay cables (see Figure 6.6.2-5) should be adopted in the internal structure of the saddle.

6 If the rotary-type saddle is used at the tower top, the stay cables shall be symmetrically anchored on the left and right sides of the main girder on the same side of the tower after passing through the saddle at the top of the tower. Special-shaped wire separating tubes with a high anchoring safety factor (see Figure 6.6.2-6) should be adopted in the saddle.

Commentary

Stay cables can be anchored to the towers through cross-type anchoring, through the side walls of the tower, through steel anchor beams or steel anchor boxes, as well as through saddles. The anchorages through saddle seats are mostly used for extradosed prestressed concrete bridges, and are less used in general cable-stayed bridges. According to the different arrangement forms of the cable strands in the anchorage zone, anchorages through saddle seats can be divided into two types: riding-type and rotary-type.

1 For the cross-anchoring system, stay cables are anchored to the solid portion of the tower columns after passing through the axis of the main tower columns, where the stay cables are anchored by means of jagged grooves or jagged convex corbels. This type of anchorage was frequently used in early cable-stayed bridges with small and medium spans and is now less frequently adopted.

2 For the sidewall anchorage, stay cables are anchored directly on the toothed plate on the inner wall of the concrete tower. The anchorage zone is prestressed circumferentially to resist the tensile stresses in the tower wall. This type of anchorage is used in Nanjing Baguazhou Yangtze River Bridge, Junshan Yangtze River Bridge, etc. in China.

3 For anchorages using steel anchor beams, stay cables are anchored to the ends of the steel anchor beams that are placed on the corbels on the inner wall of the concrete tower. The rigid supports at both ends of the steel anchor beams can make slight longitudinal and transverse movements and rotations. This type of anchorage is used in cable-stayed bridges such as the Nanpu Bridge in China. It has clear force-bearing characteristics, can reduce the horizontal force on the tower wall, has small temperature-induced constraint forces, can effectively control the horizontal cracks, and makes the anchorage between cables and towers safer and more reliable.

In previous structural designs, steel anchor beams were often placed on polytetrafluoroethylene (PTFE) plates on the top surface of the concrete corbels. A new combined anchorage structure of steel anchor beam and steel corbel was first proposed and applied in the Jintang Bridge. It is composed of a steel anchor beam and a steel bracket (Figure 6-1). This new structure is applicable to the stay cables of spatial cable planes and can facilitate the construction.

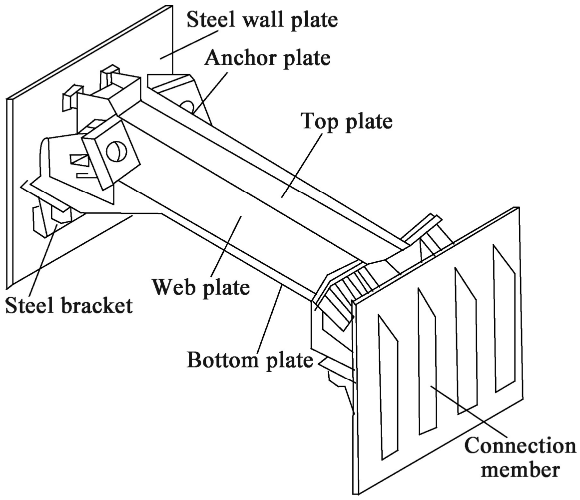


Figure 6-1 Schematic structure of the combination of steel anchor beam and steel corbel

4 Anchoring stay cables to the steel anchor box is one of the anchorage methods for long-span cable-stayed bridges, where the steel anchor box is connected to the concrete towers by shear studs. This method was first applied in the Normandy Bridge in France and the Evripos Bridge in Greece, marking the beginning of its usage in cable-stayed bridge construction. Currently, it has been used in the world's largest cable-stayed bridge, the Russky Bridge in Russia, as well as in the Hangzhou Bay Bridge, Sutong Yangtze River Bridge, Stonecutters Bridge, and Shanghai Yangtze River Bridge in China. With this anchoring method, stay cables are directly anchored to the steel anchor boxes, which can easily resist tensile forces. Although the steel anchor boxes are expensive to use, the construction work at high altitudes can be reduced, and the construction period can be shortened. Therefore, this anchoring method represents the development trend for anchoring stay cables to the towers of long-span cable-stayed bridges.

According to the relative positions between the steel anchor box and the tower wall, steel anchor boxes can be divided into two types: built-in type and exposed type.

1) The built-in type is used for tower columns with enclosed box sections, and has been used in several cable-stayed bridges, such as the Oresund Strait Bridge, which links Denmark and Sweden, the Russky Bridge in Russia, and the Stonecutters Bridge and the Sutong Yangtze River Bridge in China.

2) The exposed type is mainly used for separated towers, and has similar force-bearing characteristics to the built-in type. However, in order to ensure the reliability of the connection between the steel anchor box and the concrete tower wall, the exposed steel anchor box needs to be tightly clamped between the two concrete tower columns with circumferential prestressing steel bars. The exposed steel anchor boxes have been used in the Normandy Bridge in France, the Rion-Antirion Bridge in Greece, the Hangzhou Bay Bridge, and the Chongqing Dongshuimen Yangtze River Bridge in China. Among them, the schematic diagram of the exposed steel anchor box structure and details of shear studs of Chongqing Dongshuimen Yangtze River Bridge are shown in Figures 6-2 and 6-3, respectively.

5 The structure of the straddle-type saddle anchorage zone in the tower is similar to that of the main saddle on the tower of a suspension bridge. According to the arrangement forms of steel strands of the stay cables in the anchorage zone, the straddle-type saddle anchorages can be divided into two types: sleeve-type and wire separating tube type.

The sleeve-type anchorage has a simple structure. Using this type of anchorage, a very small cable spacing can be set on the tower to maximize the usage efficiency of the cables. However, due to the difficulty in replacing the stay cables, the sleeve-type anchorage is less frequently applied.

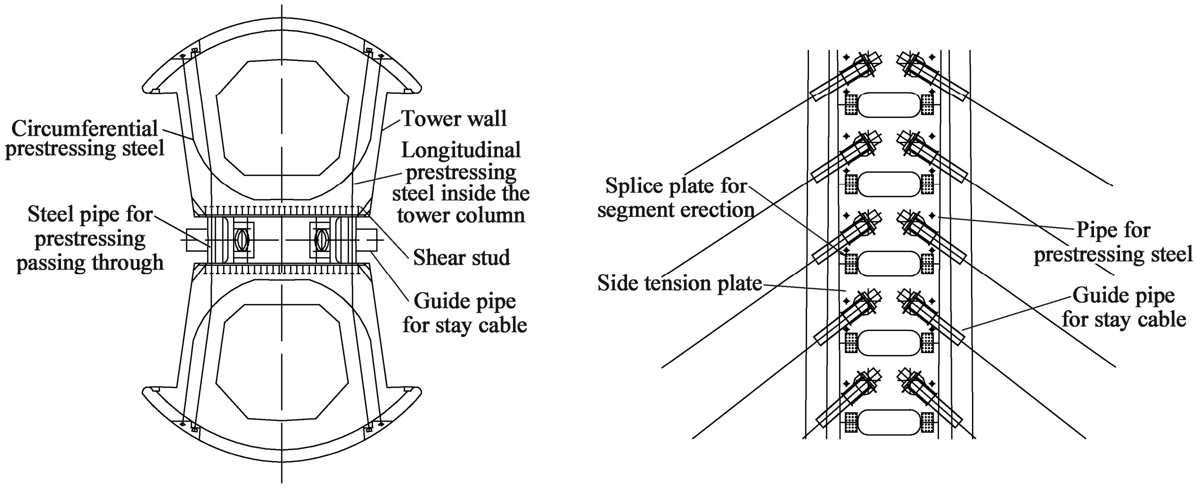


Figure 6-2　External steel anchor box structure in chongqing dongshuimen yangtze river bridge

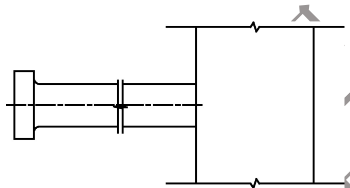


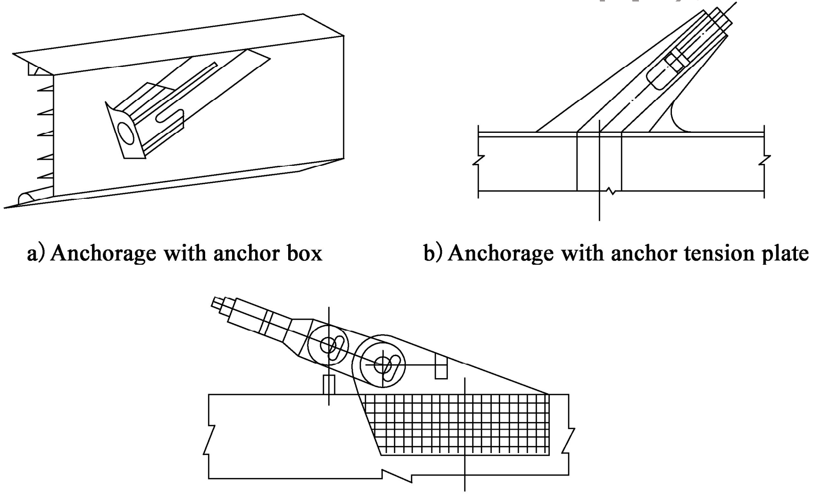
Figure 6-3　Details of shear studs in the anchorage zone in the tower of the chongqing dongshuimen yangtze river bridge

In recent years, the saddle anchorage with dividing pipes has been widely used in extradosed bridges, such as the Xiaoxihu Bridge in Lanzhou and the Jinglan Bridge in Liuzhou, China, and the Kumga Bridge in Korea. The saddle anchorage with dividing pipes greatly facilitates the replacement of stay cables. At the same time, when the steel strands are separated from each other, the flexural stress of the steel strands can be effectively reduced during small-radius bending, which successfully solves the problem that large-diameter stay cables cannot be bent with a small radius, and enables the saddle-type anchorage to be applied to conventional cable-stayed bridges.

6　The rotary saddle anchorage is a new type of anchorage for stay cable anchorage on the tower. Its saddle is in an inclined state in the tower. A stay cable firstly passes through the anchorage at one edge of the deck, then bypasses the saddle at the top of the tower, and finally goes back to the other edge of the deck at the same section, forming a rotary cable system in the same direction, anchored to the tower by the inclined saddle. The rotary saddle anchorage can simplify the structural forms of the anchorages on the tower, allowing the cable forces to be transmitted to the tower in the form of radial pressure. The rotary saddle applies saddle-type anchorage to conventional cable-stayed bridges using a turnback rotation method. The unbalanced forces on both sides of the saddle are generated by the unbalanced forces between the left and right decks of the main girder within the same span, which can eliminate the restrictions on the application of saddle anchorage in some long-span bridges caused by excessive differences in cable forces between the side spans and the central span.

The rotary saddle has been successfully applied to the Dinghuai Bridge in Wuhe, Anhui and the Second Wuhu Yangtze River Highway Bridge in China. The former bridge, the Dinghuai Bridge in Wuhe, has a span arrangement of 246 m + 125 m and a total of 16 pairs of cables. The latter, the Second Wuhu Yangtze River Highway Bridge, has a span arrangement of 100 m + 308 m + 806 m + 308 m + 100 m and 25 pairs of cables in total.

6.6.3 The anchor box, anchor tension plate, and ear plate should be used for the anchorage of stay cables to the steel main girders, as shown in Figure 6.6.3. The designs of the anchorage structure shall comply with the following provisions:



a) Anchorage with anchor box

b) Anchorage with anchor tension plate

c) Anchorage with ear plate

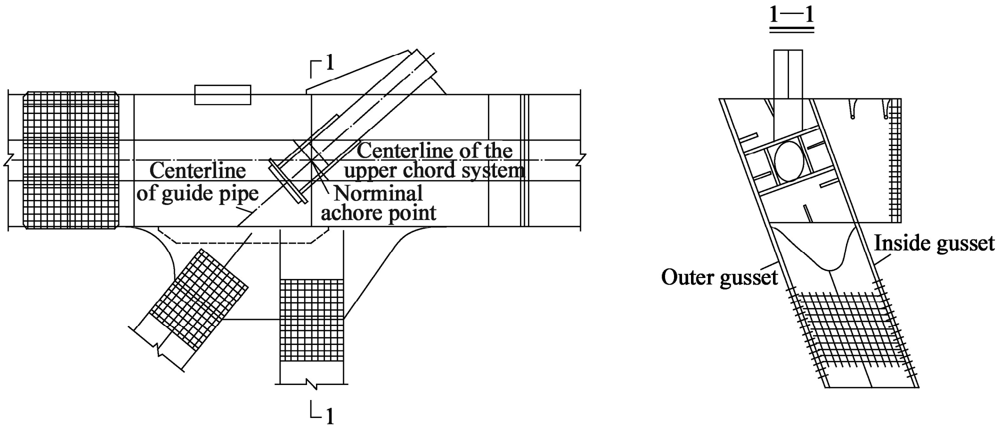
Figure 6.6.3 Anchorages for stay cables in main steel girders

1 For the anchorage in the form of an anchor box, anchor beams shall be installed within the anchor boxes for the attachment of the stay cables. The anchor beams shall be connected to the main girders by means of welding or high-strength bolts.

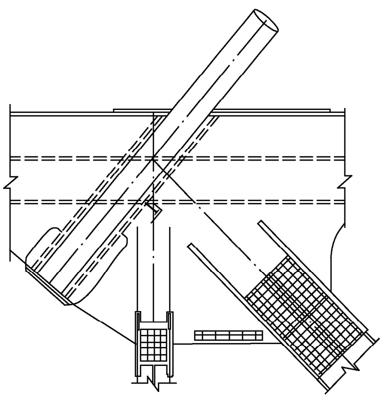
2 For the anchorage with an anchor tension plate, a thick steel plate, serving as the anchor tension plate, shall be attached to the top plate or the web plate of the main girder. A groove shall be formed on the upper part of the anchor tension plate, and the inner side of the groove shall be welded to the outer side of the anchor tube. The stay cable shall be anchored at the bottom of the anchor tube.

3 For the ear plate type of anchorage, an ear plate that extends from the web of the main girder shall be provided, and the stay cables shall be connected to it through hinged joints.

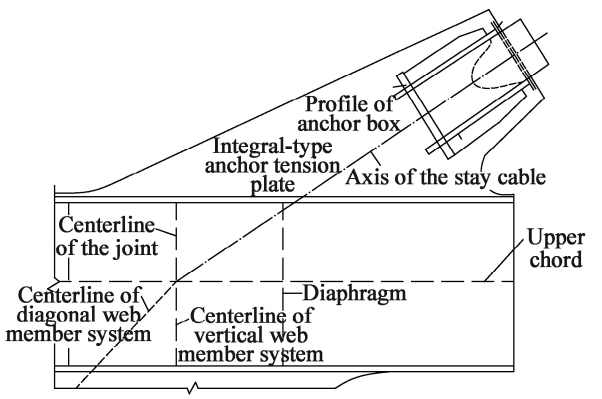
6.6.4 The anchorage zone for the stay cables anchored to the steel truss girder should be set at the joint of the main girder. The anchorages can be classified into the type embedded within the joint and the type external to the joint. Specifically, the following types may be adopted: anchor boxes embedded in chord members, anchor boxes embedded in joint gusset plates, integral anchor boxes with double tension plates, and bolt – welded anchor boxes with double tension plates, as shown in Figure 6.6.4.



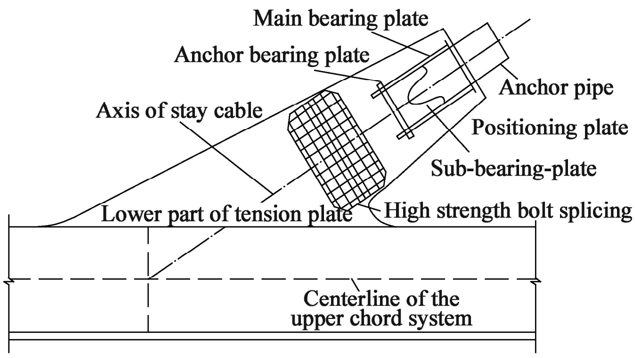
a) Anchor box embedded in the chord member



b) Anchor box embedded in the gusset plate of the joint



c) Integral-type anchorage box with double tension plates



d) Weld-bolt anchorage box with double tension plates

Figure 6.6.4 Anchorage for stay cable anchored on steel truss

Commentary

In cable-stayed bridges with stiffening trusses, the anchorage forms of the stay cables to the stiffening truss are mainly classified into the type embedded within the joint and the type external to the joint.

1 The anchorages embedded within the joint include two sub-forms: the anchor box embedded in the chord member and the anchor box embedded in the gusset plate.

1) When the anchorage structure with the anchor box embedded in the chord member is adopted, the stay cable is anchored inside the upper chord member of the truss. This type of anchorage structure is mostly applied to steel Warren trusses, such as the Zhengzhou Yellow River Highway and Railway Bridge and the Huanggang Highway and Railway Bridge. Since the anchorage point is located inside the member, the operat ing space is quite limited, making the manufacturing and installation rather difficult. The anchorage structure of the stay cable to the girder with the anchor box embedded in the chord member used in the Huanggang Highway and Railway Bridge is shown in Figure 6.6.4a).

2) In the anchorage structure with the anchor box embedded in the gusset plate, the stay cable is anchored inside the gusset plate. The load-transferring steel plate of the stay cable is directly welded to the gusset plate of the member joint, and the cable force is borne by the weld seam between the anchor box and the gusset plate. The anchorage structure with the anchor box placed below the gusset plate is mostly used in bridges with an Pratt truss as the main girder, such as the Wuhan Tianxingzhou Bridge, the Tongling Highway and Railway Yangtze River Bridge, and the Guozigou Bridge. This configuration is beneficial for the installation and maintenance of the stay cables, but the joint structure is complex, and the section will be weakened due to the anchor pipe passing through the member. The anchorage structure of the stay cable to the girder used in the Tongling Highway and Railway Yangtze River Bridge is shown in Figure 6.6.4b).

2 There are mainly two types of anchorages external to the joint: the integral anchorage box with double tension plates and the bolt-welded anchorage box with double tension plates. When the anchorage structure external to the joint is adopted, the stay cable is anchored above the top plate of the upper chord joint. In this case, the anchorage tension plates need to be welded at the corresponding positions of the joint plates on the top plate of the upper chord, or the joint plates on both sides of the upper chord joint of the main truss should be

directly extended upward to form the anchorage tension plates. Compared with the anchorage structure embedded within the joint, the anchorage structure external to the joint has the advantages of simple structure, clear force transmission mechanism, and being convenient for manufacturing, installation, and subsequent maintenance.

1) In the integral anchorage box with double tension plates, the tension plate is an integral structure. A bearing plate is welded to the upper part of the tension plate to form a closed box-type structure. The lower part of the tension plate is welded to the upper chord member of the steel girder. The stay cable passes through the anchor pipe inside the box and is fixed to the anchor bearing plate, as shown in Figure 6.6.4c) and Figure 6-4. This type of anchorage is adopted in the Shanghai Minpu Bridge in China.

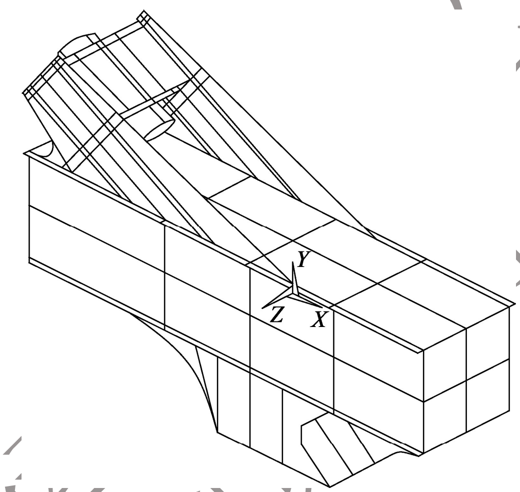
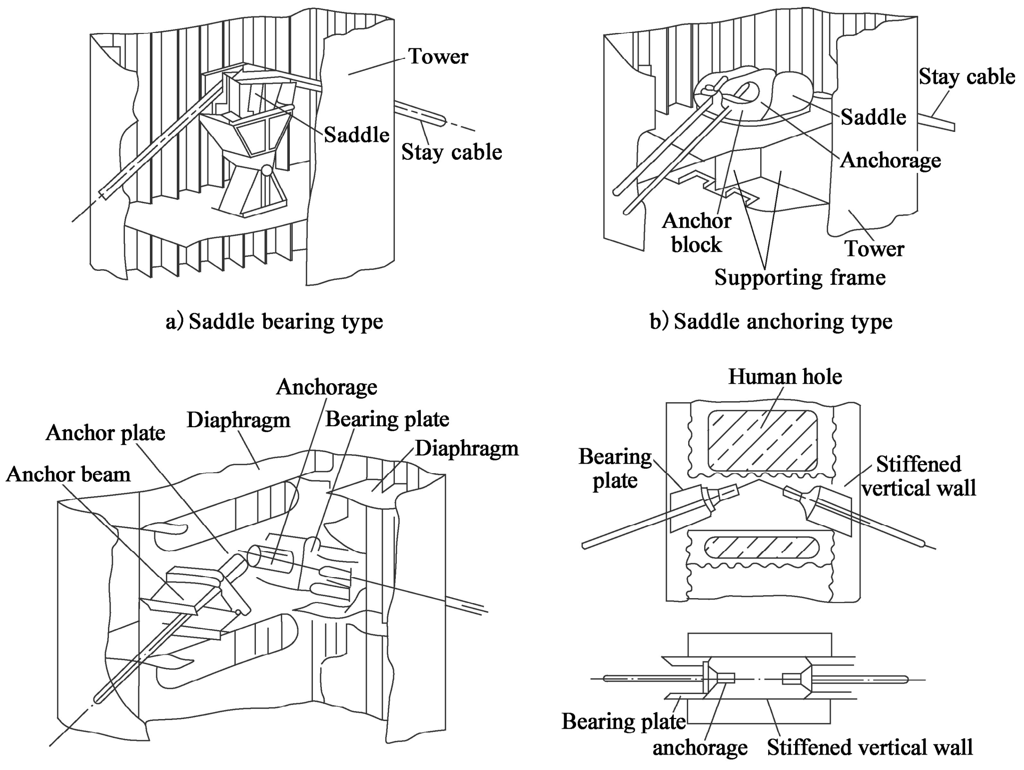


Figure 6-4 Three-dimensional diagram of monolithic anchorage box with double tension plates

2) In the bolt-welded anchorage box with double tension plates for the stay cable-girder anchorage, the tension plates are of a separated type. The upper tension plate, together with the anchor bearing plate and the bearing plate, form a closed box-type structure. The lower tension plate is integrated with the chord member of the steel girder. The upper and lower tension plates are connected by high-strength bolts. The stay cable passes through the anchor pipe inside the box and is fixed to the anchor bearing plate, as shown in Figure 6.6.4d). The separated structure facilitates the manufacturing and construction of the anchorage structure.

6.6.5 The anchorage of the stay cables to the steel tower should adopt the saddle-supported type, the saddle-anchored type, the anchor beam type, and the supporting plate type, as shown in Figure 6.6.5.



a) Saddle bearing type b) Saddle anchoring type

c) Anchor beam type d) Supporting plate type

Figure 6.6.5 Schematic diagrams of anchorages for stay cable anchored in the steel towers

6.6.6 The detailing of the anchorage zones of the stay cables shall comply with the following provisions:

1 A solid structure for the anchorage segment shall be provided on the main concrete girder. The cross-sectional dimensions of the members within the anchorage zone shall meet the requirements for the installation of the cable-passing ducts and the anchor bearing plates beneath the anchors. Additional wire fabrics or spiral reinforcements shall be provided in the local sections beneath the anchors. The structural detailing and reinforcement design shall meet the requirements of the current *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362).

2 The connections among the members in the stay cable anchorage zone of the steel main girder shall be reliable. The minimum thickness of each member shall not be less than 10 mm.

3 The dimensions of the steel bearing plate beneath the anchor shall be determined according to the jacking tonnage, the size of the jacking equipment, and the type of the anchorage device, etc. The thickness of the steel bearing plate should not be less than

20 mm. The minimum wall thickness of the anchor pipes for the stay cables shall not be less than 10 mm.

4 Stiffening plates shall be used to reinforce the connection between the anchor pipes of the stay cables and the steel bearing plate beneath the anchor.

5 The spacing of the stay cables in the anchorage zone of the tower shall not only meet the requirements for the calculated height, but also ensure sufficient space for cable tensioning and cable force adjustment, and meet the height requirements for the holes, pipes, the stroke of the jacks, and the necessary movement of the jacks.

6 The radius of curvature of the circumferential prestressing tendons in the anchorage zone of the tower should not be less than 1.5 m.

Commentary

In the anchorage zone, the configuration of stirrups and longitudinal reinforcements needs to be enhanced. Moreover, multiple layers of wire fabrics should be arranged under the anchors, or other measures should be adopted to resist and disperse the local stress beneath the anchors.

The thickness of the steel bearing plates under the anchor must be determined according to the jacking tonnage, the type of the anchorage devices, etc. When the reaction force pattern beneath the bearing plate is simplified to an equivalent uniformly-distributed reaction force and the spreading angle of the pressure distribution is required to be 45°, there are corresponding requirements for the size of the bearing plates. The requirement in this article that the thickness of the steel bearing plates should not be less than 20 mm is determined based on the actual situation in recent years, where the main girders are made of high-strength concrete and large-tonnage prestress is applied longitudinally in the main girders.

When the stay cables are anchored to the concrete tower by using steel anchor boxes, the dimensions of the steel anchor boxes should be ensured to be accurate during the manufacturing process. When installing the steel anchor boxes together with the pipes through which the stay cables pass, the accuracy of the spatial position must be guaranteed. This ensures that after installation, the centerlines of the pipes coincide with those of the stay cables, and the end faces of the anchor plates are perpendicular to the centerlines of the stay cables.

The anchor box should not be too thin to avoid the warping of the steel plate due to welding thermal stress. Generally, steel plates with a thickness of less than 10 mm are not used.

Within the local area of the stay cable anchorage zone, due to the strong concentrated forces of the stay cables and the weakening caused by the holes, the phenomena of local stress and stress concentration occur. Therefore, a certain distance should be left between adjacent anchor points to prevent stress overlap, which may affect the overall safety of the cable-stayed bridge. In addition, a certain operating space is required for cable threading and tensioning. Therefore, taking into account the structural stress, structural details, and construction process requirements comprehensively, it is necessary to leave extra dimensions beyond the edge of the stay cable anchorage zone.

Due to the size limitations of the towers, the circumferential prestressing tendons usually have a small radius of curvature, making it difficult to meet the requirements regarding the radius of curvature of prestressing tendons specified in Clause 9.4.10 of the current *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362). However, in the commentary of the Clause 9.4.10, it is noted that: For special ducts and prestressing tendons, for example, semi-circular prestressing tendons with a radius of about 1.5 mm used for hooping in towers of cable-stayed bridges, they are not restricted by this provision as special measures have been taken. According to research, in some of the completed cable-stayed bridges in China, the radius of curvature of the prestressing tendons used in the anchorage zones of the towers is around 1.5 m. A decrease in the radius of curvature will lead to an increase in prestress loss. Therefore, considering the actual situations of bridges already built in China, it is recommended that the radius of curvature of circumferential prestressing tendons should not be less than 1.5 m.

6.6.7 Except for the tower-pier-girder monolithic connection system, when the main girder of a cable-stayed bridge is constructed by the cantilever method, measures shall be taken to temporarily fix the tower-pier or tower-girder connection. These temporary fixing measures shall be removed after the main girder is closed. When the cantilever length is relatively large, temporary piers may be set up to reduce the influence of unbalanced loads on the tower (pier) and girder.

Commentary

During the cantilever construction process of the main girders of cable-stayed bridges, the unbalanced loads on the beam bodies on both sides of the towers, caused by factors such as the self-weight of the girders, temporary load conditions, or the occurrence of beam falling situations, will generate a certain overturning moment. Moreover, the asymmetric tension forces of the stay cables on both sides or wind loads, etc., will also exert a certain horizontal or longitudinal thrust on the main girders. When the main girder of a cable-stayed bridge with a floating system is constructed using the cantilever method, in order to ensure the safety of the structure during the construction phase, appropriate measures for the temporary fixation of the tower-girder connection are generally required. These measures will be removed after the main girder is closed.

At present, the commonly used methods for the temporary fix of the tower-girder connection in cable-stayed bridges in China and other countries are as follows:

1 In the traditional anchorage scheme, two rows of temporary fixations are arranged along the longitudinal direction of the bridge. For each row of temporary fixations, multiple support points are arranged in the transverse direction of the bridge, as shown in Figure 6-5a). In order to balance the axial forces within the main girders on both sides of the temporary fixations during the construction process, one row of temporary fixations only provides vertical constraints to the main girders, while the other row provides both vertical and horizontal constraints to the main girders simultaneously. The Nanjing Dashengguan Yangtze River Bridge adopted this type of anchorage method.

2 In order to resist the effect of extreme transverse wind and reduce the shear force borne by the temporary fix structures, transverse wind-resistant bearings are added on both sides of the main girders based on the traditional fix scheme, as shown in Figure 6-5b). The transverse wind-resistant bearings usually take the form of steel tubes installed on both sides of the main girders.

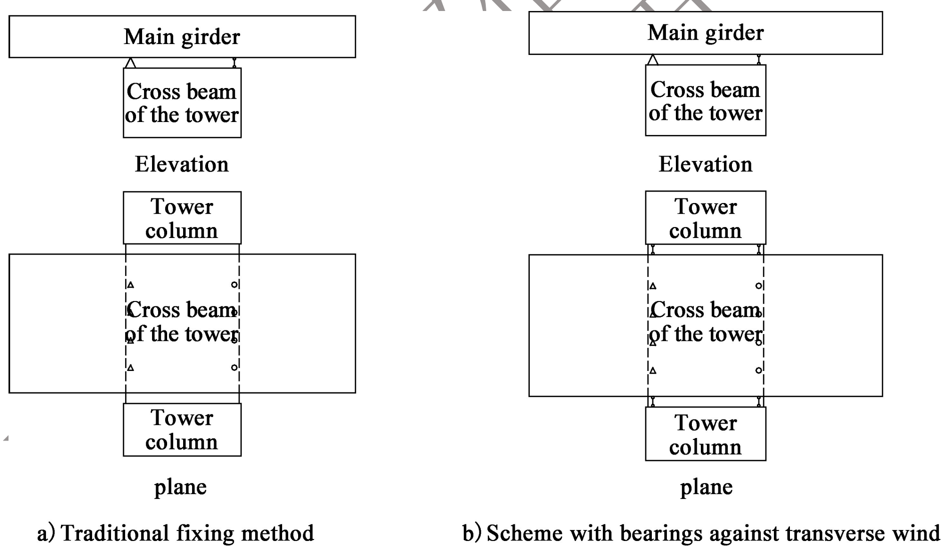


Figure 6-5 Temporary fix between girder and pier

3 In order to reduce the large shear forces generated at the temporary fixations due to the asymmetry of cable forces between the side-span and mid-span, the differences in the weights of the main-girder segments between the side-span and mid-span, as well as the longitudinal slopes, the Sutong Yangtze River Highway Bridge adopted a temporary fixing form with flexible connections, as shown in Figures 6-6 and 6-7. This was done to lower the risks during the construction and removal of the temporary fixations. The pier segment was temporarily fixed vertically to the temporary supports on the lower cross-beam of the tower through cable bodies. The longitudinal constraints were provided by prestressing

tendons set at the bottom of the girder and on the cross-beam of the tower. Transversely, wind-resistant bearings were installed between the tower and the main girder. The schematic diagram of this flexible temporary anchorage is shown in Figure 6-8. A similar flexible temporary fixing form was also adopted for the Sino-North Korean Yalu River Bridge.

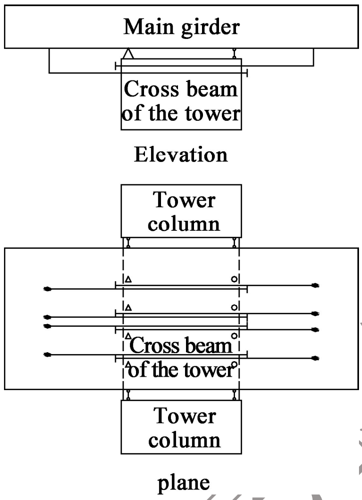


Figure 6-6　Temporary fix betweengirder and tower in sutong yangtze river highway bridge

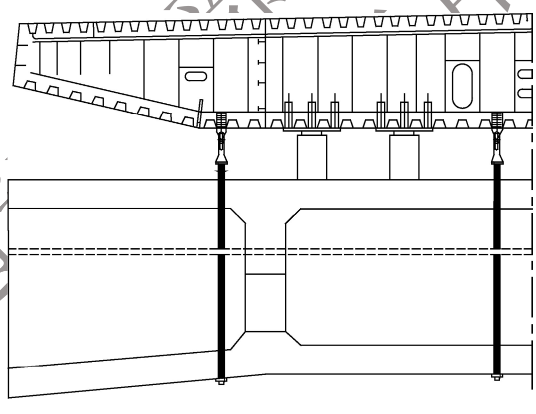


Figure 6-7　Detailing of the temporary structure for fixing the girder and tower in the vertical direction in the sutong yangtze river highway bridge

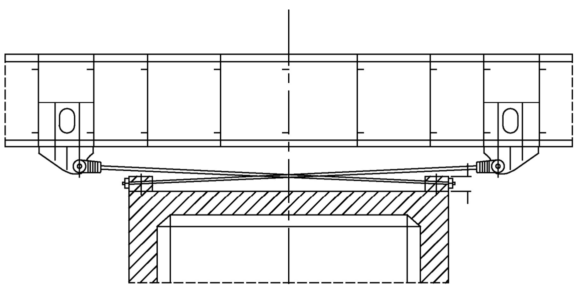


Figure 6-8　Elevation of the temporary structure for fixing the girder and tower in the vertical direction in the sutong yangtze river highway bridge

4 When the tower is a structure without crossbeams, a scheme combining vertical temporary fixation and temporary supports is usually adopted, with the anchorage columns supported on the bearing platforms. In order to control the deformation of the anchorage columns, prestress can be applied to them. This method is called the "Preloading Self-balancing Anchorage Method". The Shanghai Yangtze River Bridge, which features a herringbone-shaped tower and separated steel box girders, has adopted this type of temporary fixing form.

6.7 Auxiliary Components and Facilities

6.7.1 For wearing surfaces, asphalt concrete or cement concrete may be used, and waterproof layers shall be provided. The design of the wearing surfaces shall satisfy the following requirements:

1 Epoxy asphalt concrete, cast-in-place asphalt concrete, modified asphalt SMA, dense-graded modified asphalt concrete, or other materials that meet the service requirements may be used for the wearing surfaces on the steel deck panels. Their various properties shall comply with the provisions of the current *Specifications for Design and Construction of Pavement on Highway Steel Deck Bridge* (JTG/T 3364-02).

2 Asphalt concrete, reinforced concrete, impermeable reinforced concrete, and fiber-reinforced concrete may be used for the wearing surfaces on concrete deck slabs. The concrete strength class of the cement concrete wearing surfaces shall not be lower than C40.

6.7.2 For cable-stayed bridges, the types of bearings and the restrainers shall be reasonably selected. Bearings that bear positive and negative reaction forces shall be specially designed. Spaces shall be reserved at the bearing locations for placing jacks during bearing replacement, and the areas where the jacks bear pressure shall meet the local bearing capacity requirements.

Commentary

The design reaction forces of long-span cable-stayed bridges are relatively large. Thus, the bearings are required to allow for large displacements and rotations to accommodate the deformations of the main girders caused by braking forces, temperature variations, concrete shrinkage, creep, and the action of other loads.

In a floating system, except for being supported at both ends, the main girder is entirely suspended by stay cables. Such a support system fails to provide effective lateral support for the main girder. By installing lateral restrainers at the towers and the bearings of the two side-spans, the lateral displacement of the main girder can be restricted, and a relatively "flexible" constraint for the main girder in the lateral direction can be formed.

To faciliate replacement of bearings, positions for placing jacks and necessary working space should be provided at the pier caps and abutment caps.

6.7.3 The expansion joints shall be selected according to the expansion and contraction amount of the bridge and the requirements specified in the current *General Technical Requirements of Expansion and Contraction Installation for Highway Bridge* (JT/T 327). For the anchorage parts of the expansion joints, high - performance concrete should be used. The concrete strength class shall not be lower than C40, and the joint treatment shall be well done.

6.7.4 For cable-stayed bridges, the parameters and types of dampers should be reasonably selected according to the need, taking into account dynamic loads such as seismic forces, wind loads, and vehicle braking forces. Dampers can be arranged at the connections between the main girders and the towers, as well as between the main girders and the transition piers or auxiliary piers. Corresponding embedded devices should be set at the installation positions of the dampers, and the structure should be locally strengthened.

Commentary

The design of long-span cable-stayed bridges is often controlled by dynamic loads such as seismic forces, wind loads, and braking forces. Once dampers are installed between the main girders and the towers, they will effectively reduce the bending moment at the tower bases and the displacement of the main girders under the action of seismic forces, wind loads, and other loads.

6.7.5 When the main girders and towers of cable-stayed bridges are of enclosed steel structures, internal dehumidification systems should be installed.

6.7.6 The design of a cable-stayed bridge shall meet the following requirements regarding lightning protection, aviation, and navigable channels:

1 Lightning protection facilities shall be installed in accordance with the relevant provisions of the current *Design Specifications for Lightning Protection of Large Bridges* (QX/T 330).

2 In accordance with the requirements of aviation management, when necessary, aviation obstacle marking lamps shall be installed in line with the current *Aeronautical Obstacle Lights* (MH/T 6012).

3 When there is a navigation requirement, bridge markers and aids to navigation shall be installed at the navigation openings according to the requirements of the waterway department and the current *Aids to Navigation on Inland Waterways* (GB 5863).

6.7.7 Maintenance facilities shall be provided for cable-stayed bridges. Inspection platforms, passages, fences, ladders, internal lighting, manhole covers, and other specialized facilities for inspection and maintenance should be installed on the main girders, main towers, auxiliary piers, and junction piers of the bridges. Extra - large and large bridges should be equipped with inspection vehicles.

7 Structural Analysis

7.1 General

7.1.1 Static, stability and dynamic analyses shall be conducted for a cable-stayed bridge. The structural strength, stiffness and stability of the bridge during the construction stage and upon completion of the bridge shall meet the relevant requirements.

Commentary

The main analysis and checking contents for a cable-stayed bridge structure during the designstage are listed in Table 7-1.

Table 7-1 Structural analysis and checking contents for a cable-stayed bridge

Item	Analysis contents	Checking contents
Static analysis for a bridge in service	Analyzing the most unfavorable internal forces, stresses, and deformations of the primary structural elements under permanent and variable actions of the completed bridge	Checking the load-carrying capacity of foundations, towers, piers, main girders, stay cables, support and connection devices
		Checking the deflection of the main girder and the deformation of the Support and connection devices
	Analyzing the stresses in the typical stress-disturbed regions of the cable-stayed bridge under permanent and variable actions	Checking the load-carrying capacity of the stress-disturbed regions, including the connection regions between the tower columns and their cross beams, connection regions between the towers and the main girders, anchorage zone of the tower, anchorage zone of the main girder

continued

Item	Analysis contents	Checking contents
Static analysis for a bridge under construction	Analyzing the most unfavorable internal forces and stresses of the primary structural elements under permanent and construction actions of the bridge under construction	Checking the load-carrying capacity of the foundations, towers, piers, main girders, stay cables, support and connection devices
	Analyzing the stresses of the typical stress-disturbed region of the cable-stayed bridge under permanent and construction actions	Checking the load-carrying capacity of the stress disturbed-regions, including the connection regions between the tower columns and their cross beams, connection regions between the tower and the main girder, anchorage zone of the tower, anchorage zone of the main girder
Stability analysis	Analyzing the overall and local stability of the cable-stayed bridge under the permanent and variable actions	Checking the stability factor of the structure
	Analyzing theoverall and local stability of the cable-stayed bridge under permanent and construction actions	Checking the stability factor of structure
Dynamic analysis	Analyzing internal forces anddeformations of the structure under seismic actions	Checking the load-carrying capacity, ductile performance, and deformation performance of the foundations, towers, piers, and support and connection devices
	Analyzing the static and dynamic response of structures under wind loads	Checking the aerodynamic stability of the cable-stayed bridge, the performance of the wind-induced vibration and wind-rain-induced vibration of stay cables
	Analyzing internal forces and deformations of the structure under the vessel collision	Checking the load-carrying capacity of the foundations, towers, and piers

7.1.2 The structural calculation models, geometric characteristics, and boundary conditions of cable-stayed bridges shall reflect the actual structural conditions and mechanical characteristics, and shall comply with the following provisions:

1 For the overall static analysis, local static analysis, stability analysis, and dynamic analysis of cable-stayed bridge structures, spatial structural models should be adopted.

2 In the scheme design stage, planar bar system models can be adopted for the overall static analysis of the cable-stayed bridge structures, and the following factors shall be taken into account during the analysis:

1) Transverse distribution of the loads;

2) Conversion of cable forces when the spatial cable system is simplified into a planar cable system;

3) If the anchorage point of the stay cable is different from the centroid position of the main girder (or tower), the influence of the eccentricity of the stay cable on the internal forces of the main girder (or tower) should be considered.

3 When conducting local static analysis, the investigated region shall satisfy the Saint-Venant's principle.

Commentary

Modern cable-stayed bridges are highly statically indeterminate systems, and their structures are formed gradually. The action effects on the structures are time-dependent. Therefore, the accuracy of structural calculation models, geometric properties, boundary conditions, and other factors is closely linked to the reliability of structural analysis results.

1 Modern cable-stayed bridges have the characteristics of a wide bridge deck, a large span, and spatial flexibility. In-plane analysis cannot fully reflect the actuality of the bridge's dynamic performance and stability, especially for bridges with stiffening girders of beams and slabs (ribbed slabs, side main beams) or flat box girders. Research indicates that the dynamic and stability issues of cable-stayed bridges are not simply one-sided in-plane or out-of-plane problems; instead, they are generally coupled problems involving in-plane, out-of-plane, and torsional behaviors. Therefore, it is emphasized that for dynamic and stability analyses, a spatial structural model should be adopted, and factors such as the spatial arrangement of stay cables, structural torsion, eccentric live loads, tansverse wind loads, adjustment of asymmetric spatial cable forces, and uneven displacement of supports should be considered simultaneously.

2 The overall static analysis in the scheme design stage mainly aims to reflect the stress characteristics of the cable-stayed bridge structure and correctly identify the structural characteristics under various critical working conditions, such as structural formation,

system transformation, stay cable tensioning and cable force adjustment. In this situation, a planar bar system model can be adopted, which has been proved to be feasible by a large number of cable-stayed bridge design practices in China. When calculating with a planar bar system model, the influence of the transverse distribution of the load should be considered. When a spatial cable system (such as those in cable-stayed bridges with an A-shaped tower, an inverted Y-shaped tower, or a diamond-shaped tower, etc.) is simplified into a planar cable system for calculation, the action effect of the simplified planar cable system should be the in-plane component of the action effect of the spatial cable system, and the difference from the actual situation should be corrected.

3 According to Saint-Venant's principle, the location where the boundary conditions are applied should be kept as far away as possible from the part that is of concern in the calculation analysis, so as to avoid a significant influence of the boundary on the calculation results.

7.2 Static Analysis for Bridges in Service

7.2.1 The overall static analysis of cable-stayed bridges shall comply with the following provisions:

1 In the structural analysis of cable-stayed bridges, the influence of geometric nonlinearity should be considered, taking into account the sag effect of the stay cables, the P-Δ effect, and the large displacement effect. When calculating the action effect, the sag effect of the stay cables must be accounted for. It is possible to use the method of calculating the modified modulus of elasticity of the stay cable according to formula (7.2.1), or adopt the method of directly simulating with flexible cable elements.

$$E = \frac{E_0}{1 + \frac{(\gamma S\cos\alpha)^2}{12\sigma^3}E_0} \tag{7.2.1}$$

Where:

E——modified modulus of elasticity of stay cable considering the sag effect of the stay cable (MPa);

E_0——modulus of elasticity of steel material for stay cable (MPa);

γ——gravity per volume of stay cable (kN/m^3). It is obtained by dividing the gravity of the stay cable and its protection coating per meter by the cross-section of the stay cable (m^2);

S——length of stay cable (m);

α——angle between the stay cable and the horizontal line (°)

σ——stress of stay cable subjected to the specific loading condition (kPa);

2 In the structural analysis of a cable-stayed bridge, the influence of the foundation displacement on the structure should be considered. When the finite element model takes the foundation and other structural components into account together according to the construction formation process, the influences of the construction eccentricity of the bridge piers and towers on the foundation, as well as the influence of the transverse load of the bridge on the foundation, should be accounted for. When the foundation is analyzed separately, in addition to accounting for the influences of the construction eccentricity of the bridge piers and towers and the transverse load of the bridge, the secondary effects on the foundation caused by the action effects of the superstructure should also be considered.

3 For lateral loads such as wind loads, a planar frame model can be adopted for the analysis of the towers.

4 When the main girder is of a box structure, the influence of torsional warping should be considered. When the main girder is of a composite structure, the redistribution of structural internal forces caused by the inconsistency of the two materials of the main girder should be considered.

5 For the concrete main girders, composite main girders, hybrid main girders, and concrete towers in cable-stayed bridges, the effects of concrete shrinkage and creep shall be calculated according to the construction process and in accordance with the provisions of the current *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362).

7.2.2 The local static analysis of cable-stayed bridges shall comply with the following provisions:

1 Local analysis should be carried out for the parts with complex stress conditions, such as the connection regions between towers and girders, the anchorage positions of the stay cables, and the steel-concrete junction parts.

2 The spatial finite element method should be used for local analysis and stress calculation, and the boundary conditions of the calculation model shall be able to truly reflect the stress conditions of the actual structure.

3 When prestressed steel bars are arranged in the anchorage positions of the towers, the structural checking calculation of the anchorage positions may be carried out by using the strut-and-tie model in accordance with the provisions of the current *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362).

4 The anchorage zones of the stay cables in the steel girders shall also be analyzed for local stability and fatigue.

Commentary

1 The special parts listed in this clause have stress concentration problems and local analysis is required. In the local analysis, the nonlinear effects of the overall load effects of the structure should be taken into account.

2 The stress conditions in the anchorage zone are complex, and there are obvious stress concentration phenomena. A planar finite element model is difficult to comprehensively reflect the authenticity of the stresses in the anchorage zone. Therefore, a spatial finite element model is usually adopted. For the anchorage parts of important and large bridges with large cable forces, it is recommended to verify the calculation results of the spatial finite element model through experimental research.

3 The anchorage parts of the towers with prestressed steel bars are typical stress - disturbed regions. They can be analyzed and the reinforcement design can be carried out according to the strut-and-tie model specified in the current *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362).

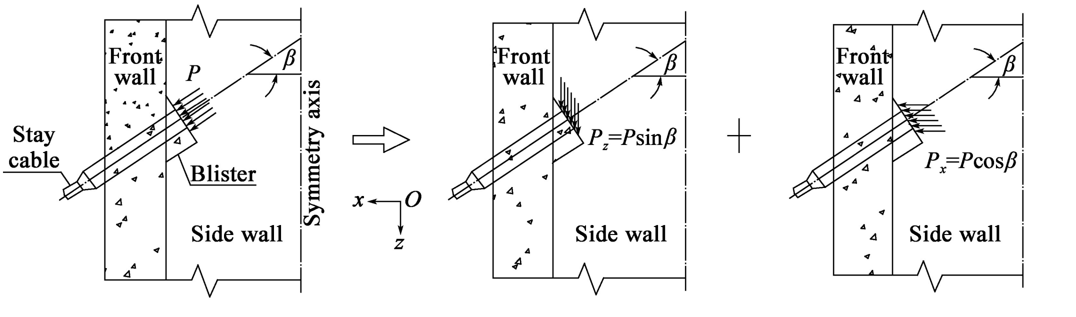
1) Determine the range of the tower anchorage zones to be considered in the reinforcement design according to Saint-Venant's principle.

2) Develop the strut-and-tie model by selecting an appropriate method from the load path method, stress trace method, force flow-line method, minimum strain energy criterion, maximum strength criterion, etc.

3) Calculate the design internal forces of the ties according to the force balance condition.

4) Design the reinforcement for the ties according to their load-carrying capacity.

The forces acting on the anchorage parts of the tower are decomposed into vertical forces and horizontal forces, as shown in Figure 7-1. The strut-and-tie model for the case of vertical forces is developed according to Figure 7-2, while the strut-and-tie model for the case of horizontal forces, as shown in Figure 7-3b), is established based on the stress distribution of the typical cross-sections depicted in Figure 7-3a).



a) General　　b) Stress in vertical direction　　c) Stress in horizontal direction

Figure 7-1　Vertical and horizontal force decomposed from the cable force on the tower anchorage

P-Design cable force; P_x- Horizontal component of the cable force; P_z- Vertical component of the cable force; β- Angle between the stay cable and the horizontal line

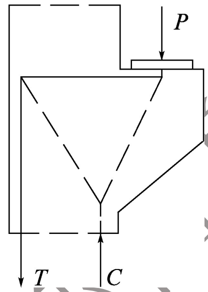
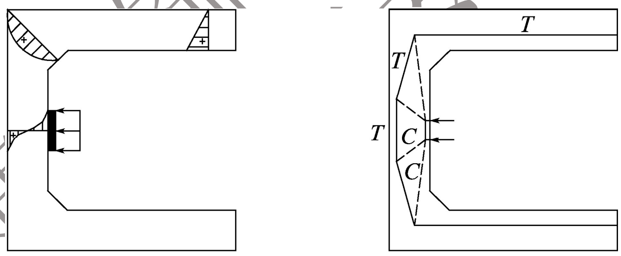


Figure 7-2　Strut-and-tie model for vertical force

T-Design force of the tie; C-Design force of the strut



a) Stress distribution of typical cross-section　　b) Strut-and-tie model

Figure 7-3　Strut-and-tie model for the horizontal force

4　The anchorage zones of the steel girders are subjected to the concentrated anchor forces of the stay cables, and the issues of their stability and fatigue are prominent.

7.2.3　When determining the final design state, the prestress effect of the prestressed concrete main girders and the effect of vehicle loads shall be considered for the cable-stayed bridge with prestressed concrete girders; the prestress effect of the bridge deck and the effect of vehicle loads shall be considered for the cable-stayed bridge with composite girders; and the effect of vehicle loads shall be considered for the cable-stayed bridge with steel box girders.

Commentary

1 At present, for the final design state of two-tower or single-tower cable-stayed bridges, the following problems are mainly considered:

1) Generally, the cable force increases with the cable length in a cable-stayed bridge. In the design, the distribution of cable forces should be as uniform as possible, while abrupt changes in the cable force are allowed in some places.

2) For the main girder, the stresses induced by the bending moment should be within the allowable range, which is a difficult and crucial point in the design of a concrete cable-stayed bridge.

3) The bending moment and the deflection of the tower should not be too large, and the influence of dead and live loads should be comprehensively considered. Under the dead load, the tower top can have a certain pre-deflection on the shore side.

4) The bearings on the side piers and the auxiliary piers should have sufficient compressive reactions under the dead load to ensure that no uplift occurs at the bearings under the live loads.

For multi-tower cable-stayed bridges, enough attention shall be paid to controlling the bending moment and top displacement of the towers. The side towers may be designed with a certain pre-deflection toward the shore side under dead load. However, deflections of the other towers' tops should remain small under the dead load, ideally approaching zero.

2 Many practical methods based on various assumptions can be used to determine the final design state of a cable-stayed bridge according to different conditions and the target of the design/optimization. Therefore, to obtain a reasonable design state in an actual project, more than one method and/or multiple analyses are commonly necessary to be implemented. The stress of the concrete main girder is often one of the controlling factors in the design of the cable-stayed bridge due to the heavy dead load and small tensile strength of the material used. Therefore, the prestressing effect and loading effect of the concrete main girder should be taken into account when determining the final design state of the cable-stayed bridge with concrete main girder.

7.2.4 Strength analysis of the main components of cable-stayed bridges shall comply with the following provisions:

1 Foundation analysis shall comply with the provisions of the *Specifications for Design of Foundation of Highway Bridges and Culverts* (JTG 3363). The analysis of gravity type ground anchors should cover the resistance to overturning and sliding, and the safety factor shall not be less than 2.0.

2 Strength analysis of the girders and towers shall comply with the following provisions:

1) Strength analysis of concrete main girders and towers shall comply with the provisions of the *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362).

2) Strength analysis of the steel towers, steel main girders, and composite main girders shall comply with the provisions of the *Specifications for Design of Steel Highway Bridges* (JTG D64).

3 Strength analysis of the stay cables shall comply with the following provisions:

1) Load-carrying capacity of stay cables shall meet the following requirement:

$$\frac{\gamma_0 N_d}{A} \leq \phi_d f_d \tag{7.2.4}$$

Where:

γ_0——importance factor of structure;

N_d——design axial tension force of stay cable (N);

A——cross-sectional area of stay cable (mm^2);

ϕ_d——correction factor for the structural system of a cable-stayed bridge. For extradosed bridges, $\phi_d = 1.5$; for other structural systems of cable-stayed bridges, $\phi_d = 1.0$;

f_d——design tensile strength of stay cable. Under persistent situations, it is chosen according to the provisions of Clause 3.3.1 or 3.3.2; under transient situations, the design tensile strength of the stay cable should be improved by 25%.

2) Fatigue analysis of stay cables shall comply with the provisions of the *Specifications for Design of Steel Highway Bridges* (JTG D64). The fatigue stress range of the stay cables in extradosed bridges shall not exceed 80MPa.

Commentary

This clause specifies the requirements for the strength analysis of the main components of cable-stayed bridges.

1 The analysis of ground anchorages in ground-anchored cable-stayed bridges is no different from that of the foundations of general bridges, except for the action of uplifting forces. The allowable displacement of the ground anchorage can be calculated by referring to the relevant provisions of the *Specifications for Design of Highway Suspension Bridges* (JTG/T D65-05).

2 In the previous edition of the *Specifications*, the strength of the stay cable was analyzed using the allowable stress method. In accordance with the provisions of the current *Specifications for Design of Steel Highway Bridges* (JTG D64), the load-bearing capacity of stay cables is required to be checked in this revision. The safety factor K specified in the previous edition of the *Specifications* is now comprehensively represented by the importance factor of the structure, the partial factor for action and the partial factor for materials for the load – bearing capacity calculation. When the ratio of dead load to live load falls between 0.9/0.1 and 0.7/0.3, the converted safety factor ranges from 2.48 to 2.56, which is essentially equivalent to the safety level of the previous edition of the *Specifications*. For extradosed bridges, the main girders are the dominant load-bearing components while the contribution of stay cables is relatively small, and the stress amplitude is also small. Therefore, the structural system correction factor for the stay cables of extradosed bridges, ϕ_d, is taken as 1.5.

In the *Specifications*, the increase coefficient of the design strength under transient situations, f_d, follows the previous edition of the *Specifications*. The current *Specifications for Design of Steel Highway Bridges* (JTG D64) specify the vehicle load model and fatigue details for the fatigue calculation of stay cables. In this revision, the fatigue calculation method is unified with that specified in the current *Specifications for Design of Steel Highway Bridges* (JTG D64). In addition, the mechanical characteristics of the stay cables of extradosed bridges are similar to those of the external prestressing cables. Therefore, for the fatigue performance of the stay cables of extradosed bridges, the requirements for the fatigue performance of the prestressing steels specified in the *Anchorage, Grip and Coupler for Prestressing Tendons* (GB/T 14370-2015) are adopte, namely, *if the anchored prestressing tendons are made of prestressing steel, the upper limit of the test stress should be* 65% *of the nominal tensile strength of the prestressing tendon*, f_{ptk}, *and the fatigue stress range should not be less than* 80 *MPa*.

7.2.5 Stiffness analysis of the main girders shall comply with the following provisions:

Concrete girder $f \leqslant l/500$ (7.2.5-1)

Steel girder $f \leqslant l/400$ (7.2.5-2)

Composite girder and hybrid girder $f \leqslant l/400$ (7.2.5-3) where:

f——vertical deflection induced by vehicular load (excluding impact force). When both positive and negative deflections induced by vehicular loads exist in the same span, *f* is the sum of the absolute values of the positive and negative deflections

l——effective span.

Commentary

Referring to the methods for determining deflections in multiple cable-stayed bridges, *f* is taken as the sum of the absolute values of positive and negative deflections. The limit of the vertical deflection of the main girders in the *Specifications* adopts the provisions in the previous edition of the *Specifications*.

7.2.6 The designed camber of the main girder should not be less than the sum of vertical deflections of the main girder caused by the concrete shrinkage and creep, as well as half of the deflection caused by vehicular load. The camber should be fitted into a smooth curve based on the deflection curve.

7.2.7 Under the persistent situations, the support systems at the tops of the transition piers and the auxiliary piers should ensure that no change in the structural system of the cable-stayed bridge will occur. The bearings on the transition piers and auxiliary piers should preferably remain in a compressive state, or reliable anti-pull devices should be installed on the bearings.

Commentary

If the bearings on the tops of the transition piers and auxiliary piers deviate from the normal compressive state, the structural force system of the cable-stayed bridge will be changed, leading to boundary nonlinearity, which negatively impacts the structural stress state. To prevent this from happening, it is generally necessary to arrange counterweights on the side spans to ensure that the bearings on the transition piers and auxiliary piers always remain in compression under the action of live loads, so as to provide a certain safety factor. In addition, bearings with reliable anti-uplift capabilities can be installed, or a tie-down device can be installed or other reliable measures can be adopted to ensure that no uplift occurs, providing a safety reserve.

7.2.8 Under the normal condition for cable replacement (when one stay cable is being replaced and the traffic in the lane adjacent to the stay cable being replaced is closed), the towers, the main girders, and the stay cables shall meet the strength, stiffness, and stability requirements of the completed bridge state.

7.3 Static Analysis for Bridges under Construction

7.3.1 Division of construction stages and analysis of bridges in construction stages shall comply with the following provisions:

1 The division of the construction stages in the construction analysis shall follow the real construction process.

2 The following stages shall be considered in the analysis for system transformation of cable-stayed bridges during the construction:

1) Installation and dismantling of temporary supports (piers) during the construction process;

2) Installation and dismantling of form travelers for cantilever construction and closure construction;

3) Transformation of temporary stay cables to permanent ones;

4) Initial tensioning of the stay cables for cable-stayed bridges constructed using full-span falsework;

5) Side-span closure and mid-span closure.

3 The following factors shall be considered for the unbalanced loads during the construction stages of cable-stayed bridges:

1) Unbalanced loads due to the asymmetric design of the two cantilevers of the main girder;

2) Unbalanced loads generated by construction processes;

3) Unbalanced loads caused by construction errors;

4) Unbalanced wind loads at the two cantilevers during the cantilever construction.

4 Stay cable forces, structural internal forces, cross-sectional stresses, support reaction forces,

displacements of the towers and main girders in the construction stages shall be analyzed.

5 The checking of members during the construction stages shall comply with the provisions of the *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362) and the *Specifications for Design of Steel Highway Bridges* (JTG D64).

Commentary

1 Due to the structural characteristics of cable-stayed bridges, the stress states of the completed bridges depend on their construction process. Therefore, key construction stages must be included in design analysis; otherwise, the actual stress states of the structure after construction may not match the designed ones, potentially leading to permanent structural unsafe states. Consequently, in order to ensure that the finally completed structure conforms to the expected stress state in the design, the construction stages in the structural analysis should be consistent with the actual construction sequence.

2 Given the permanent impact of system transformation on the structure, this clause requires calculation of the effects caused by the system transformation, specifying the items to be calculated during the system transformation. The system transformation stages that are not specified in this clause but do exist in actual construction must also be calculated. The calculation results should be combined according to the requirements of the load combinations specified in the *Specifications*. The temperature effect should be taken into account when analyzing the closure of the main girder.

The closure construction involves the transformation of the structural system. The calculation of the closure construction includes two aspects. First, permanent effects induced by the temperature change and construction loads during closure should be taken into account in the load combination according to the requirements specified in the *Specifications*. Second, the temporary effects induced by the temperature change and construction loads during closure, such as the relative displacement between the two ends of the closure segment and the influence on the stresses of the temporary structures, should also be taken into account. These temporary effects should be considered in the checking of the closure segment (including its temporary structure).

3 During the cantilever construction of the main girders, the unbalanced loads of the two cantilevers have a significant impact on the internal forces of the structure. Especially when the main girder's cantilever reaches its maximum length, such unbalanced loads can have

a severe impact, which may even lead to the failure of the bridge. Therefore, this clause emphasizes the need to analyze the cantilever construction states of cable-stayed bridges and stipulates the items for calculating the unbalanced loads during construction. The actual unbalanced loads of the structure may vary, so the design calculation should be carried out based on the possible unbalanced loads in the structure. The load combinations should be made according to the requirements specified in the relevant specifications, taking into account the characteristics of the load effects.

4 To accurately control the whole construction process, it is necessary to incorporate all the loads in each construction stage without omission in the calculations, and to list the calculation results of the internal forces, stresses, cable forces, and displacements generated at each stage, so that they can be checked and verified during the construction process.

For bridges constructed by the precast cantilever method, the cantilever construction phase should be arranged, as far as possible, in seasons with temperatures close to the design's closure temperature and minimal temperature fluctuations, to reduce the effects of temperature variations on cantilever construction.

7.3.2 During the construction of the cable-stayed bridge, temporary piers may be set up within an area that does not affect navigation. The temporary piers should be considered in the structural calculations for the bridge in the construction process. In rivers with floating debris, the impact of collisions caused by the floating debris shall be considered in the design of temporary piers.

Commentary

During the cantilever construction of the main girders, the unbalanced loads (including dead load and wind load) on the two cantilevers will have adverse effects on the safety of the bridge during construction, and in severe cases, even lead structural failure. Based on the successful experiences of the cable-stayed bridges built in China, the installation of temporary piers is the most effective measure to address these adverse effects the most effective solution is to set up temporary piers. Therefore, this clause emphasizes that temporary piers may be set up if the construction bridge site conditions permit, but the analysis of the system transformation shall be carried out.

7.3.3 The temporary pier-girder fixations of cable-stayed bridges shall meet the stress requirements in the maximum double-cantilever state and maximum single-cantilever state. The following working conditions should be considered in the design:

1 The loading condition with the maximum unbalanced vertical forces: unbalanced loads of the main girder + asymmetric wind loads.

2 The loading condition with the maximum unbalanced longitudinal forces: asymmetric tension forces of the stay cables on both sides of the tower + longitudinal wind loads.

3 The loading condition with the maximum lateral forces: symmetric lateral wind load on both sides of the tower.

4 The loading condition with the maximum unbalanced transverse forces: unbalanced and asymmetric lateral wind loads on both sides of the tower.

Commentary

When the main girder of a cable-stayed bridge is constructed by the cantilever method, appropriate measures are generally taken for temporary tower-girderf ixation to ensure the structural safety of the bridge during the construction stage.

During the cantilever construction of the main girder of a cable-stayed bridge, overturning moments may be caused by the unbalanced loads on the girder at both sides of the tower, including the self-weight of the structure, temporary loads or the girder dropping situation. In addition, the unbalancedtension forces in the stay cables or wind loads at both sides of the tower will also exert certain longitudinal or horizontal forces on the girders.

7.4 Analysis for Static Stability

7.4.1 The static stability analysis of cable-stayed bridges shall include both global and local stability, and it shall encompass the major system transformation process and major action combinations.

Commentary

Piers, towers and girders of cable-stayed bridges, which are subjected to very large compressive forces and bending moments, may buckle during construction or in the completed state. The stability mentioned here only refers to static stability, while aerodynamic stability will be discussed elsewhere. The stability analysis shall include the main system transformation process and main action combinations, and elastic or elastic-plastic stability analyses should be carried out according to specific conditions. In the elastic or elastic-plastic stability analysis, the key construction stages when the structural system undergoes transformation and the boundary conditions change should be considered, and the combination of actions should be taken into account, including dead load, construction live load, static wind load, as shown in Table 7-2. In the analysis of the bridge after completion, the action combination of dead load, temperature load, live load, static wind load, and other loads should be considered, as shown in Table 7-3.

Table 7-2 Stability analysis of some cable-stayed bridges under construction

Bridge	Construction stage	Description of loads
Sutong Yangtze River Highway Bridge	Tower only	Dead load
		Dead load + transverse wind load (35.4 m/s)
		Dead load + longitudinal wind load (35.4 m/s)
	Maximum lengths of two cantilevers	Dead load
		Dead load + transverse wind load (35.4 m/s)
		Dead load + longitudinal wind load (35.4 m/s)
	Maximum length of one cantilever	Dead load
		Dead load + transverse wind load (35.4 m/s)
		Dead load + longitudinal wind load (35.4 m/s)
Chongqing Shuangbei Jialingjiang Bridge	Maximum lengths of two cantilevers	Dead load + wind load (27.5 m/s)
	Maximum length of one cantilever	Dead load + wind load (27.5 m/s)
The First Beipanjiang Bridge	Maximum length of one cantilever	Dead load + wind load + side span self-weight (-5%) + mid span self-weight (+5%) + form traveler
		Dead load + wind load + ide span self-weight (-5%) + mid span self-weight (+5%) + form traveler (2 is adopted for impact factor)
Jiangjin Guanyinyan Yangtze River Bridge	Maximum lengths of two cantilevers	Dead load + wind load + construction load
	Maximum length of one cantilever	Dead load + wind load + construction load
Jiujiang Yangtze River Highway Bridge	Tower only	Dead load + wind load + construction load
	Maximum length of one cantilever	Dead load + wind load + construction load
Edong Yangtze River Bridge	Tower only	Dead load + wind load + construction load
	Maximum length of one cantilever	Dead load + wind load + construction load
Xiamen-Zhangzhou Bridge	Maximum length of one cantilever	Dead load + wind load + construction load

Table 7-3 Stability analysis of some cable-stayed bridges after completion

Bridge	Loading condition considered in the analysis	Description of loads
Sutong Yangtze River Highway Bridge	Completed state	Dead load
		Dead load + transverse wind load (38.9 m/s)
		Dead load + longitudinal wind load (38.9 m/s)
	Highway-I vehicular load on the entire bridge	Dead load + vehicular load
		Dead load + transverse wind load (25 m/s)
		Dead load + longitudinal wind load (25 m/s)
	Highway-I vehicular load on half of the bridge	Dead load + vehicular load
		Dead load + vehicle load + transverse wind load (25 m/s)
		Dead load + longitudinal wind load (25 m/s)
	Highway-I vehicular load on the half-width of the entire bridge	Dead load + vehicular load
		Dead load + vehicle load + transverse wind load (25 m/s)
		Dead load + vehicle load + longitudinal wind load (25 m/s)
	Highway-I vehicular load on the entire side span of the bridge	Dead load + vehicular load
		Dead load + vehicle load + transverse wind load (25 m/s)
		Dead load + vehicle load + longitudinal wind load (25 m/s)
	Highway-I vehicular load on the entire mid-span of the bridge	Dead load + vehicular load
		Dead load + vehicle load + transverse wind load (25 m/s)
		Dead load + vehicle load + longitudinal wind load (25 m/s)
Chongqing Shuangbei Jialingjing Bridge	Completed state	Dead load + transverse wind load
		Dead load + vehicular load + wind load
Jiujiang Yangtze River Highway Bridge	Completed state	Dead load + wind load
		Dead load + wind load + pedestrian load
		Dead load + wind load + pedestrian load + vehicular load fully in the mid-span
		Dead load + wind load + vehicular load fully in the spans
		Dead load + wind load + vehicular load fully in the spans + pedestrian load

7.4.2 The global stability analysis of cable-stayed bridges shall comply with the following provisions:

1 In the global stability analysis of a cable-stayed bridge, the sag effect of stay cables shall be considered.

2 For the first type of instability (elastic bifurcation buckling), the stability factor of the cable-stayed bridge shall not be less than 4. For the second type of instability (limit-load buckling considering the material nonlinearity), the safety factor shall not be less than 2.50 for concrete main girders and 1.75 for steel main girders.

7.4.3 The local stability analysis of cable-stayed bridges shall comply with the following provisions:

1 The local stability of compression-loaded plate-like members of steel main girders and towers shall be checked according to the provisions in the *Specifications for Design of Steel Highway Bridges* (JTG D64).

2 In the checking of the stability of the concrete deck in composite girders, the stresses of the deck induced by local loads shall be considered

7.5 Dynamic Analysis

7.5.1 For the computation of the dynamic characteristics of cable-stayed bridges, the natural vibration characteristics, such as vibration mode and frequency, shall be analyzed. The computational model of the structure shall reflect the actual distribution of the mass and stiffness of the bridge, and the effect of nonlinearity shall be considered in the analysis.

Commentary

The dynamic characteristics of a cable-stayed bridge serve as an indicator of its stiffness. Cable-stayed bridges, being generally flexible structures, will inevitably experience vibrations under dynamic loads such as earthquakes, wind, and vehicles. In mild cases, these vibrations can have an impact on the driving experience and the comfort of pedestrians, while in severe cases, they can even lead to the failure of the bridge. In the design calculations for seismic and wind resistance of cable-stayed bridges, natural vibration characteristics analysis (including vibration mode and natural frequency) is generally necessary. In addition, for cable-stayed bridges equipped with sidewalks, it is necessary to ensure that the natural frequencies of the bridge structure are kept away from the frequency range that may cause discomfort to pedestrians.

This clause emphasizes the correctness of the computational models. The mass distribution and stiffness of the structures in the computational model have a significant impact on the computed dynamic response, and efforts should be made to reflect the engineering reality as accurately as possible. If elevated pile caps are used, the mass of the caps shall be included in the computational models.

7.5.2 The seismic design of cable-stayed bridges shall comply with the following provisions:

1 The seismic design of cable - stayed bridges shall follow the flow chart in Figure 7.5.2.

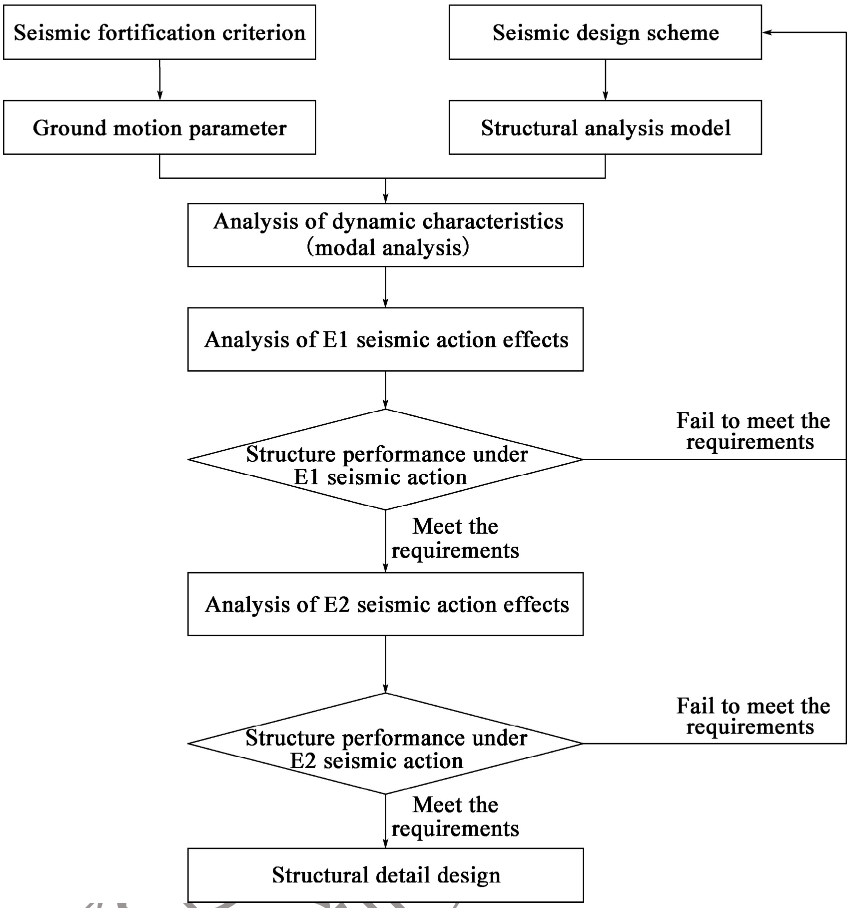


Figure 7.5.2 Seismic design flowchart for cable-stayed bridges

2 The performance-based method of two-level seismic fortification shall be adopted for the seismic design of cable-stayed bridges. Their seismic design targets shall conform to the provisions in Table 7.5.2 - 1. Special research shall be conducted for special requirements.

Table 7.5.2-1 Seismic design targets for cable-stayed bridges

Member	E1 seismic action		E2 seismic action	
	Post-earthquake serviceability requirement	Damage state	Post-earthquake serviceability requirement	Damage state
Foundation	In normal service	Structure behaves elastically, and is undamaged basically	In normal service without repair	Structure may be slightly damaged locally
Auxiliary pier, transition pier	In normal service	Structure behaves elastically, and is undamaged basically	In normal service after simple repair	Structure may be slightly damaged locally

continued

Member	E1 seismic action		E2 seismic action	
	Post-earthquake serviceability requirement	Damage state	Post-earthquake serviceability requirement	Damage state
Tower	In normal service	Structure behaves elastically, and is undamaged basically	In normal service after simple repair	Structure may be slightly damaged locally
Main girder, stay cable	In normal service	Structure behaves elastically, and is undamaged basically	In normal service without repair	Structure may be slightly damaged locally
Support and connection devices	In normal service	Structure behaves elastically, and is undamaged basically	In normal service after simple repair	Structure may be slightly damaged locally

3 The E1 seismic effect of cable-stayed bridges may be analyzed using the response spectrum method or linear time-history method, while the E2 seismic effect may be analyzed using the nonlinear or linear time-history method. All the analysis methods shall comply with the current *Specifications of Seismic Design for Highway Engineering* (JTG B02) and *Specifications for Seismic Design of Highway Bridges* (*JTG/T* 2231-01).

4 The checking of seismic performance for cable-stayed bridges shall focus on their key members, such as foundations, auxiliary piers, transition piers, towers, and support and connection devices. The checking criteria shall meet the requirements specified in Table 7.5.2-2. Special studies should be conducted when there are special requirements.

Table 7.5.2-2 Checking criteria of seismic performance of cable-stayed bridges

Structural member	Seismic fortification level	
	E1 seismic action	E2 seismic action
Foundation	The load-carrying capacity of the foundations is checked according to the provisions in the *Specifications for Design of Foundation of Highway Bridges and Culverts* (JTG 3363)	The design bending moment of the foundation under the seismic combination of actions is less than the equivalent yield bending moment of the section (including compression force), which is computed according to the provisions in the *Specifications for Seismic Design of Highway Bridges* (*JTG/T* 2231-01). The load-carrying capacity of the ground is checked according to the provisions in the current *Specifications of Seismic Design for Highway Engineering* (JTG B02) and the *Specifications for Design of Foundation of Highway Bridges and Culverts* (JTG 3363)

continued

Structural member	Seismic fortification level	
	E1 seismic action	E2 seismic action
Auxiliary pier, transition pier	The load-carrying capacity of the piers is checked according to the provisions in *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts* (JTG 3362) and the *Specifications for Design of Steel Highway Bridges* (JTG D64)	The plastic deformation capacity and the shear resistance are checked according to the provisions of the current *Specifications of Seismic Design for Highway Engineering* (JTG B02) and the *Specifications for Seismic Design of Highway Bridges* (*JTG/T* 2231-01)
Tower		The design bending moment of the tower under the seismic combination of actions is less than the equivalent yield bending moment of the section (including compression force), which is computed according to the provisions in the *Specifications for Seismic Design of Highway Bridges* (*JTG/T* 2231-01)
Main girder, stay cable	—	The load-carrying capacity is checked according to the provisions of the Clause 7.2.4 in the *Specifications*
Support and connection devices	—	The deformation capacity and the shear resistance are checked according to the provisions of the current *Specifications of Seismic Design for Highway Engineering* (JTG B02) and the *Specifications for Seismic Design of Highway Bridges* (*JTG/T* 2231-01)

Commentary

The seismic design requirements for cable-stayed bridges are specified in this clause, referencing the provisions in the *Specifications for Seismic Design of Highway Bridges* (JTG/T 2231-01) and in the *Specifications of Seismic Design for Highway Engineering* (JTG B02).

(1) At the scheme design stage, selection of the design scheme should not only based on functional requirements and static analysis results. Instead, the seismic performance of the bridge should be taken into comprehensive consideration, and a good seismic structural system should be selected as far as possible. Since the 1970s, through summarizing the experiences of major earthquake disasters, people have discovered that conceptual design is more important than numerical design for the seismic design of structures.

Due to the uncertainty and complexity of seismic motion, as well as the difference between the assumptions of the computational models of the structures and the actual situations, it is difficult to effectively control the seismic performance of the structures in the seismic analysis.

At the preliminary design or technical design stage, detailed analysis of seismic response and comprehensive verification of seismic performance of the bridge structure are required, and seismic isolation and energy dissipation design should be carried out if necessary. By using seismic isolation and energy dissipation technology, the period of the main vibration modes of the structure increases, making the structure fall within a range of smaller seismic energy or increasing the energy dissipation of the structure, so that its seismic response can be reduced. Long-span bridges are inherently long-period structures, and the seismic isolation and energy dissipation design should focus on improving the energy dissipation capacity in order to increase damping and disperse seismic forces. In addition, considering the randomness of earthquakes, attention should also be paid to seismic detailing measures.

(2) The two-level seismic fortification method has been basically adopted in the design of cable-stayed bridges built in China, as shown in Table 7-4. Generally, the fortification criteria are as follows:

——E1 seismic action, a 10% probability of exceedance in 100 years with a corresponding return period of 950 years, is adopted to check the strength and stress of the structures;

——E2 seismic action, a 3% to 5% probability of exceedance in 100 years with a corresponding return period of about 1950 - 3283 years, is adopted to check the ductility, displacement and deformation of the structures.

Under the seismic action E2, local cracking may occur in the foundation, auxiliary piers, transition piers, and towers, but the cracks should be able to close after the earthquake under the action of the structure's self-weight.

Table7-4 Seismic fortification criterion for some cable-stayed bridges in China

Bridge	Fortification criterion
Sutong Yangtze River Highway Bridge	E1: 10% in 100 years, structural stresses are checked to meet the requirements for the serviceability limit state
	E2: 4% in 100 years, structural resistances are checked to meet the requirements for the ultimate limit state (considering ductility), and the displacement and deformation are checked

continued

Bridge	Fortification criterion
Edong Yangtze River Bridge	E1: 10% in 100 years, structural strength is checked, the main structures are close to or just enter the yielding state
	E2: 3% in 100 years, structural displacements are checked, main structures meet the requirement for the ultimate limit state
Jingyue Yangtze River Highway Bridge	E1: 10% in 100 years, structural strength and stresses are checked
	E2: 5% in 100 years, structural displacements or deformations are checked
Beicha Main Bridge of the Xiamen-Zhangzhou Bridge	E1: 10% in 100 years, towers, auxiliary piers and side piers remain basically elastic
	E2: 5% in 100 years, the equivalent yield strength of towers, auxiliary piers and side piers is checked
Shanghai Yangtze River Bridge	E1: 10% in 100 years, towers, girders and piles remain elastic, auxiliary piers and side piers remain elastic basically, bearings can work properly
	E2: 3% in 100 years, towers remain elasticity, girders and piles remain elasticity, auxiliary piers and side piers can meet the requirement for displacement without collapse due to their sufficient ductility, shear damages of bearings are allowed
Wanzhou Yangtze River Bridge	E1: 10% in 100 years, structures operate within the elastic range and are basically undamaged
	E2: 4% in 100 years, repairable local damages of structures are allowed, with minimum impact on vehicle traffic
Jintang Bridge	E1: 10% in 100 years, main structures meet the requirements for the serviceability limit state
	E2: 5% in 100 years, main structures meet the requirements for the ultimate limit state, the structural displacements and deformations are checked
Jiashao Bridge	E1: 10% in 100 years, cracks of towers are checked, the strength of the auxiliary piers and transition piers are checked to meet the requirements for the ultimate limit state
	E2: 3% in 100 years, the strengths of the towers are checked to meet the requirements for the ultimate limit state, and the deformations of the auxiliary piers and transition piers are checked, considering the ductility

3 The towers, auxiliary piers, transition piers and their foundations, as well as support and connection devices are seismically vulnerable members in a cable-stayed bridge, and are the key focuses of the seismic design. This has been proven by earthquake damage to cable-stayed bridges. For example, during the 1999 Taiwan earthquake on September 21, the lower portion of a tower in a cable-stayed bridge was damaged; and during the Kobe earthquake in 1995, the steel rocker bolts on the piers of the side span of a double-deck cable-stayed bridge with a main span of 485 m located in the seismic area fell off.

7.5.3 The wind resistance calculation of cable-stayed bridges shall comply with the following provisions:

1 The aerodynamic stability of cable-stayed bridges shall be analyzed according to the *Specifications for Wind-Resistant Design of Highway Bridges* (JTG/T 3360-01) or by using other effective methods. Wind tunnel tests shall be conducted whenever necessary.

2 The critical construction stages and the main system transformation process shall be considered in the aerodynamic stability analysis of cable-stayed bridges.

3 Wind-induced vibration and wind-rain-induced vibration of stay cables shall be analyzed under the following provisions:

1) When the cross-sections of stay cables are not guaranteed to be circular, the critical wind speed for galloping of the stay cables shall be calculated.

2) When stay cables consist of two or more parallel cables, with the spacing between the upstream and downstream cables in the wind direction ranging from $6D$ to $40D$ (D being the diameter of the upstream cable), and the distance between the downstream cables and the center of the wake being in the range of $2D$ to $4D$, the wake galloping of the downstream cables shall be considered.

3) When the outer protective layer of the stay cable has a circular section, the critical wind speed for vortex resonance of the stay cable shall be calculated.

4) In the calculation of the wind-rain-induced vibration of stay cables, the related parameters may be determined according to the current *Specifications for Wind-Resistant Design of Highway Bridges* (JTG/T 3360-01) or the results of wind tunnel tests.

Commentary

The requirements for the wind-resistance design of cable-stayed bridges are specified by referring to the provisions in the current *Wind-resistant Design Specification for Highway Bridges* (*JTG/T* 3360-01).

(1) Cable-stayed bridges are flexible structures and have sensitive wind dynamic stability characteristics. Therefore, attention should be paid to the wind dynamic stability of the structure during design. In practice, not all cable-stayed bridges require wind-induced stability analysis. Whether a cable-stayed bridge should be analyzed for its wind-induced stability needs to be determined according to the importance of the bridge, the span, the stiffness of the structural system, and the wind speed at the bridge site. In the design, the critical wind speed of the cable-stayed bridge shall be computed according to the relevant provisions of the current *Specifications for Wind-Resistant Design of Highway Bridges* (JTG/T 3360-01), and the critical wind speed shall be determined through wind tunnel tests whenever necessary.

(2) Typical working conditions should be taken into account during the wind resistance checking calculation for cable-stayed bridges in the construction stage, including when the cable-stayed bridge's tower has been concreted but the construction formwork hasn't been removed yet, free-standing towers, the maximum double-cantilever state, and the maximum single-cantilever state. When the cable-stayed bridge's tower has been concreted but the construction formwork hasn't been removed yet, the windward area of the structure is the largest, and the structure is in the most perilous state under the static wind load, thus it is necessary to conduct a static force check on the structure. Free - standing towers are tall structures, and there is a possibility of galloping or vortex resonance occurring under the action of wind loads, so their aerodynamic stability shall be checked. In the case that the cantilever length of the girder reaches the maximum value before closure of the side span for a cable-stayed bridge under construction, the structure is in an unfavorable stress state if unbalanced lateral wind loads act on both sides of the tower, and two states shall be checked:

——when the structure is subjected to lateral wind loads, a spatial model should be used for the analysis;

——when the structure is subjected to different uplift forces generated by lateral wind force acting on the bottom of the main girders on the two sides of the tower, the structure may be modeled as a planar frame system, in which the uplift forces are considered as static loads.

7.5.4 The vessel collision design of cable-stayed bridges should comply with the provisions in the current *Specifications for Collision Design of Highway Bridges* (JTG/T 3360-02).

8 Design Requirements for Construction Monitoring and Control

8.1 General

8.1.1 Construction monitoring and control shall be carried out during the construction of cable-stayed bridges. The construction control shall be based on the designed construction sequence. Simulation and analysis of the construction process shall be conducted in light of the actual construction scheme and materials to define the control targets for each construction step, ensuring that the alignment and internal forces of the bridge meet the design requirements upon completion of construction.

Commentary

One of the characteristics of cable-stayed bridges is the close connection between their design and construction. The construction method not only affects the structural stress during construction but also has a significant impact on the final stress state and alignment of the completed bridges. To ensure that the bridge achieves its designed state upon completion, construction monitoring and control are necessary.

Construction monitoring and control includes two key components: monitoring and control. In construction monitoring, the structural status and environmental parameters during the construction process should be monitored through tracking observation, so as to provide the basis for construction control. In construction control, on-site errors are eliminated through control means such as force application and adjustment of the installation position of the main girders, making the alignment and internal forces of the structure meet the design requirements.

8.1.2 During the construction monitoring and control of cable-stayed bridges, the structural geometric dimensions, unit weight, elastic modulus, and other structural parameters shall be measured during construction, and shrinkage and creep strains shall be estimated. Additionally, the stress states of structures, including prestressing, tensile force of stay cables, and structural deformation, shall be closely monitored. Tracking calculations and analyses shall be carried out according to the measured values to determine whether the construction of the current stage meets the control accuracy requirements and to identify the necessary control measures for the subsequent construction stages. This approach aims to make the bridge as close as possible to its designed state upon completion.

Commentary

Cable-stayed bridges are constructed with various construction working conditions, making them susceptible to the accumulation of errors throughout the construction process. After years of practice, it has been realized that the errors are caused by the difference between the theoretical calculated values and the actual values of the structural parameters such as geometric dimensions, unit weight, elastic modulus, and concrete shrinkage and creep coefficients. Therefore, in order to achieve the design state when the bridge is completed, it is necessary to identify these errors during the construction process. There are two ways to identify them: one is to measure these parameters directly, and the other is to indirectly estimate these parameters through the measurement of the stress state of the bridge. After identifying the parameter errors, the structural analysis model should be modified, the subsequent construction process should be analyzed more accurately, and more effective control measures for the subsequent construction should be proposed, so as to make the bridge as close as possible to the final design state.

8.2 Basic Requirements

8.2.1 Before construction, the construction process shall be simulated to calculate the cable forces and the alignment of the structure, and the calculated values shall be checked against the design values.

Commentary

The construction process determined in the design is generally rather rough and there may be certain differences compared with the actual construction steps. Therefore, a detailed construction process should be considered in the simulation calculations for construction monitoring to obtain the alignments and internal forces of the structures to be achieved in each construction step.

8.2.2 During construction, stress and alignment shall be controlled simultaneously. It is advisable to aim at ensuring that the stresses of the cross-sections of the main girders, tower sections and the cable forces meet the design requirements, while also controlling the alignment of the main girder and the deformation of the tower.

Commentary

The basic requirements for construction control have been proposed, including two main aspects:

(1) The stress of each control member meets the design requirements.

(2) After the construction of the cable-stayed bridge is completed, its alignment meets the design requirements.

A cable-stayed bridge is a statically indeterminate structure, and only when the actual parameters are the same as the design ones, its stress and alignment can meet the design requirements simultaneously. In actual construction, it is difficult to simultaneously meet the accuracy requirements for both the structural stresses and the alignment of the main girder. Before construction, relevant parameters that affect the construction state of cable-stayed bridges (such as structural self-weight, elastic modulus of concrete, stiffness of members, etc.) are determined based on specifications or experience. A model are established to simulate and analyze the construction process, and then initial control data are obtained. During the construction process, on-site monitoring data should be used to analyze and determine the actual values of these relevant parameters, and then these actual values should be used to re-simulate the construction process. Only when the theoretical analysis and actual measurement results are consistent, can the model be used to control the subsequent construction process accurately and achieve the simultaneous control of the structural stresses and the alignment of the main girder.

8.2.3 The main contents of construction monitoring include the alignment of the towers, the elevation of the main girders before and after segment erection, the longitudinal displacements of the main girders, the displacement of the towers, the cable forces, the stresses of the control sections of the structures, and the foundation settlement.

Commentary

For large-span cable-stayed bridges, the pre-set offset, pre-set elevation increase, and settlement of towers are factors significantly affecting the geometric profile of the entire bridge. The requirements for tower monitoring have been added in this revision of the *Specifications*.

8.2.4 During construction, the effects of the temperature difference caused by solar radiation on the alignment of the main girders and towers shall be monitored, the patterns of temperature influence shall be mastered, and the influence of the temperature shall be effectively corrected during the simulation of the construction process.

Commentary

Years of practice have proved that the influence of temperature on the alignment of the structure cannot be speculated from the measured temperature fields of just several cross-sections. At present, the influence of temperature on the alignment of the structure is generally monitored directly on the influence of the temperature difference caused by solar radiation.

8.3 Tolerance

8.3.1 The alignment of the completed bridge shall comply with the design specifications. When there are no relevant design specifications, the deviation between the measured alignment and the control target alignment shall meet the following accuracy requirements:

1 The tolerance for the top elevation of the main girder before wearing surface construction is $\pm L/5000$, where L is the span length. The relative elevation difference of adjacent segments of the main girder shall not exceed $\pm 0.3\%$ of the segment length.

2 The plane error of the tower axis shall be controlled within $H/3000$ and shall not exceed 30 mm, where H is the height of the tower above the pile cap.

8.3.2 For the completed cable-stayed bridges, the control criteria for the difference between the measured cable force and the theoretically calculated cable force should be $\pm 5\%$; the control criteria for the difference in the tension of each steel strand within a steel strand stay cable should be $-2\% \sim 8\%$.

8.3.3 The error of the dead load gravity of concrete main girders between the actual dead load gravity value and the theoretically calculated value shall not exceed 2%, and the error of the segment weight of steel main girders compared with the theoretically calculated value shall not exceed 1%.

9 Design for Maintenance

9.1 General

9.1.1 In the construction drawing design of cable-stayed bridges, the requirements for maintenance, inspection and repair during the operation period shall be considered, and the key points for maintenance shall be proposed.

Commentary

In the past, maintenance and inspection were not considered adequately in some construction drawing designs of cable-stayed bridges. In some cases, issues were identified during service, for example:

1 There was a lack of inspection equipment, which makes it difficult to inspect the girders;

2 It was impossible to inspect the anchorages of stay cables;

3 It was impossible to inspect the cracks of the polyethylene (PE) protective layers of stay cables;

4 There was a lack of space for a jack when replacing the bearings.

Therefore, maintenance, inspection, and repair requirements need to be considered in the design.

9.1.2 Maintenance conditions shall be set in the design, taking into account the gravitational loads of maintenance facilities and personnel as well as changes of the structural gravity loads during maintenance. Structures under maintenance conditions shall be checked and calculated.

Commentary

Maintenance loads, including the gravity load of inspection facilities and maintenance personnel, must be considered in the design analysis. Additionally, operating conditions should also be considered for situations where vehicles operate on one half-width of the bridge while maintenance is conducted on the other half-width.

9.1.3 The working space for the maintenance or replacement of cable-stayed bridges' structures and componentsfor a cable-stayed bridge's structures and componentsshall be taken into account in the design process.

9.2 Design for Maintenance and Replacement

9.2.1 And maintenance passages shall be set up along the main girders, based on the structural forms of the main girders and the environmental conditions of the obstacles they span.

9.2.2 When the cable-stayed tower is a hollow tower, elevators, ladders, working platforms, and other facilities for maintenance and inspection should be installed (or erected) inside the hollow towers, together with lighting and fire-fighting equipment.

9.2.3 Embedded members required for the inspection and replacement of stay cables in the towers shall be preset in the design.

9.2.4 Inspection and maintenance accesses , as well as working platforms, shall be provided for lightning protection systems, navigation beacons, and aviation obstruction lights.

9.2.5 Inspection and maintenance accesses as well as working platforms for bearings, expansion joints, dampers and other replaceable components shall be designed.

9.2.6 Inspection and maintenance accesses as well as working platforms shall be equipped with safety railings.

9.2.7 The principles and procedures for replacement of stay cables shall be presented in the design.

9.2.8 The durability design of the facilities for inspection and maintenance shall include the following contents:

1 Nonreplaceable facilities for inspection and maintenance shall have the same design life as that of the main structure of the bridge, and the design life of the replaceable facilities shall be determined in the design.

2 Technical schemes and measures for the durability of the facilities for inspection and maintenance shall be proposed.

3 Requirements for inspection and maintenance of the facilities shall be proposed.

Wording Explanation for the *Specifications*

1 Words for strictness inthe implementation of the *Specifications*:

(1) "Must" or "must not" is used for a mandatory requirement in any circumstances.

(2) "Shall" or "shall not" is used for a mandatory requirement in normal circumstances.

(3) "Should" or "should not" is used for an advisory requirement.

(4) "May" or "may not" is used for a permissive condition that no requirement is intended.

2 The following expression is used in the citation of other specifications:

1) To state the relation between the*Specifications* and other specifications in the Chapter "General Provisions", it is expressed as "In addition to the *Specifications*, … shall also comply with the provisions in the current relevant national and industrial standards".

2) When referring to national and industrial standards in clauses of the*Specifications*, it is expressed as "shall comply with the relevant provisions in ×××××××(×××)".

3) When citing other clauses in the*Specifications*, it is expressed as "shall comply with the relevant provisions in Chapter ×of the *Specifications*", "shall comply with the relevant provisions in Section ×. ×of the *Specifications*", "shall comply with the relevant provisions in Clause ×. ×. ×of the *Specifications*", or "shall be implemented in accordance with the relevant provisions in Clause ×. ×. ×of the *Specifications*".