

跨海桥梁混凝土结构耐久性设计

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摘 要 近年来的桥梁设计十分重视提高结构物的耐久性并将其作为重要的设计原则,统一考虑合理的结构布局和构造细节。海南清澜大桥是较长的跨海桥梁,该桥梁结构的耐久性设计成为设计中的难点和重点。结合工程实践阐述结构耐久性设计的具体措施和设计要点。

关键词 跨海桥梁 混凝土结构 耐久性 涂层

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1 概述

清澜大桥位于海南省文昌市清澜镇,距离外海约4 km,跨越内部海湾连接清澜镇和东郊镇,是航天发射中心配套项目之一。清澜大桥设计方案采用主跨300 m的双塔双索面结合梁斜拉桥,跨径布置为120 m+300 m+120 m,引桥部分采用40 m跨筒支变连续小箱梁形式。采用100 a设计基准期。为保证清澜大桥混凝土结构的耐久性,工程采取了以高性能混凝土技术为核心的综合耐久性技术方案。结合清澜大桥工程的具体需要,研究跨海大桥混凝土结构耐久性策略和高性能混凝土的应用技术成为重要的课题。

2 清澜大桥环境作用分析

清澜大桥的不同部分分别处于一般大气和土壤环境、海洋大气、海水和海洋地质及滨海等环境中,按耐久性设计要求对其环境分区和环境作用需要分别进行研究。经勘察,场地地下水属松散岩类孔隙潜水、微承压水,主要赋存于粉土质砂及粉土质砾砂中,含水层富水性、透水性较好。粉土质砂与地表水水力联系密切,主要接受地表水补给,水位随海潮变化而变化,年最大变化幅度约2 m。拟建桥址区地下水对混凝土具结晶类弱腐蚀性和结晶分解复合类弱腐蚀性,场地土对混凝土无腐蚀性。桥址地处热带北缘沿海地带,具有热带和亚热带气候特点,属热带季风岛屿型气候。年平均气温为23.4~24.4℃,桥址区域常年平均湿度为85%。按《混凝土结构耐久性设计规范》(GB/T 50476-2008)的基本规定,按结构所处环境对钢筋和混凝土材料的腐蚀机理可将结构所处环境分为5类,即一般环境、冻融环境、海洋氯化物环境、除冰盐等其他氯化物环境和化学腐蚀环境。根据所处环境条

件,清澜大桥可能处于一般环境、氯化物环境和化学腐蚀环境中。清澜大桥的主要腐蚀环境为近海或海洋环境。近海或海洋环境条件分为大气区、浪溅区、潮汐区、水下区和土中区5个腐蚀区带。清澜大桥环境作用分级见表1。

近年来,随着跨海桥梁的建设,设计人员开始重视海水环境下桥梁耐久性的设计。影响混凝土耐久性的主要原因有混凝土质量问题、冻融作用、化学物质侵蚀、集料的化学反应、磨损及人为因素等。影响钢筋锈蚀的因素是多方面的,如周围介质的侵蚀、钢材的材质差、混凝土保护层的性能影响等。混凝土中钢筋锈蚀可由两种因素诱发,一是海水中 Cl^- 侵蚀,二是大气中的 CO_2 使混凝土中性化。国内外大量工程调查和科学研究结果表明,海洋环境下导致混凝土结构中钢筋锈蚀破坏的主要因素是 Cl^- 进入混凝土中,并在钢筋表面集聚,促使钢筋产生电化学腐蚀。

3 提高海工混凝土耐久性的技术措施

国内外相关科研成果和长期工程实践调研显示,当前较为成熟的提高海洋钢筋混凝土工程耐久性的主要技术措施有以下几个方面:

(1) 高性能海工混凝土

高性能混凝土就是在混凝土内掺加了粉煤灰、磨细矿渣、硅粉等复合矿物掺合料以及与之相匹配的高效减水剂,使混凝土具有高流态自密实性能且通过降低用水量使硬化后的混凝土内部孔隙减少,可以增加混凝土的密实度以消除混凝土表面及内部缺陷,同时充分发挥不同掺合料的作用,达到叠加效应,满足水化热低和抗氯离子渗透的要求。高性能海工混凝土以较高的抗氯离子渗透性为特征,其优异的耐久性和性能价格比已受到工程界的认同。

(2) 提高混凝土保护层厚度

这是提高海洋工程钢筋混凝土使用寿命的最为直接、简单而且经济有效的方法。氯离子侵入混凝土的方式主要有:毛细管作用、渗透作用、扩散

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表 1 清澜大桥环境作用分级

大桥范围	主桥桥墩 Z0~Z2		主桥桥墩 Z3~Z13 和 Z32~Z37	引桥桥墩 A0~A8	主桥桥墩 Z14~Z31			
环境作用分类	一般环境	土中环境	滨海环境		海洋环境			
环境作用分区	陆地大气区	陆地地下	接触空气中盐分的陆地大气区	海水渗入影响的陆地地下	接触空气中盐分,不与海水直接接触的大气区	接触空气中盐分,不与海水直接接触的大气区(重度盐雾)	浪溅区、潮差区	浸没于海水的水下区、海泥区
工程部位	箱梁、桥墩	桩基、承台	箱梁、桥墩	桩基、承台	箱梁、桥墩、上塔柱	桥墩、下塔柱	桥墩、海中承台	桩基、承台
环境作用分级	D 级	D 级	E 级	D 级	D 级(16.76 m 标高以上)	E 级(8.69 m 到 16.76m 之间)	F 级(-0.78 m 到 8.69 m 之间)	D 级
防腐设计注意问题	海南东北部沿海腐蚀偏高	砖红壤地质腐蚀加重	海洋大气影响加重腐蚀,影响范围扩大,影响程度增高	海水入侵和盐渍化影响会不断扩大范围和程度	海南炎热地区会加重腐蚀	海南日照和炎热影响加重腐蚀	海南日照和炎热会加重腐蚀	水温高、盐度高会加重腐蚀

作用和电化学作用。通常,氯离子的侵蚀是几种侵入方式的组合,但是,许多情况下,认为扩散是一个最主要的侵入方式。氯离子在混凝土中的浓度是随混凝土的深度(厚度)的增加而减小,说明增加混凝土保护层厚度,对于减缓氯离子的渗透量是很有效的。但是保护层厚度并不能不受限制地任意增加。当保护层厚度过厚时,由于混凝土材料本身的脆性和收缩会导致混凝土保护层出现裂缝反而削弱其对钢筋的保护作用。

(3)混凝土保护层

混凝土防护除了采用高性能混凝土外,还包括通过其它途径提高混凝土的密实度和抗渗性(例如透水模板)、混凝土表面涂覆防护(例如常用的海工混凝土防腐涂料、硅烷浸渍等)。完好的混凝土保护层具有阻绝腐蚀性介质与混凝土接触的特点,从而延长混凝土和钢筋混凝土的使用寿命。然而,大部分涂层本身会在环境的作用下老化,逐渐丧失其功效,一般寿命在 5~10 a。不利方面:环氧涂层钢筋与混凝土的握裹力降低 35%,使钢筋混凝土结构的整体力学性能有所降低;施工过程中对环氧涂层钢筋的保护要求极其严格,加大了施工难度。

(4)涂层钢筋

环氧涂层钢筋是采用特殊的表面处理技术和特殊的高压静电喷涂方法,在钢筋的金属体上形成均匀的、有一定厚度的环氧树脂保护层,使产品同时存在优良的物理特性和化学稳定性。但钢筋环氧涂层的存在会部分削弱钢筋与混凝土的粘结强度,使钢筋混凝土结构的整体力学性能有所降低;施工过程中对环氧涂层钢筋的保护要求极其严格,加大了施工难度;另外成本的明显增加也使

其推广应用受到制约。

(5)阻锈剂

阻锈剂通过提高氯离子促使钢筋腐蚀的临界浓度来稳定钢筋表面的氧化物保护膜,从而延长钢筋混凝土的使用寿命。钢筋阻锈剂的有效性与其存在于混凝土中的数量有直接关系,在严重腐蚀环境作用下,可在使用优质耐久混凝土的基础上,在混凝土中掺入钢筋阻锈剂。混凝土越密实,钢筋阻锈剂的防护效能就越高。对于难以采用涂层防护的预应力钢筋和钢索的保护,在混凝土或灌浆中掺加钢筋阻锈剂是有效的防护方法之一。

(6)阴极保护

用于混凝土中钢筋腐蚀的电化学防护技术主要为外加电流阴极保护技术。外加电流阴极保护技术的结构原理是,在钢筋混凝土内部放置一个永久性的辅助阳极,在辅助阳极与钢筋(阴极)之间连接一个直流电源,电源的负极与钢筋相接,正极与辅助阳极相接,通入的直流电流的大小必须足以迫使钢筋表面的阳极反应完全停止。阴极反应能产生氢氧根离子,使混凝土的碱度增加,这将有助于重新建立被混凝土碳酸化或氯化物侵蚀破坏的钢筋钝化层。在装有外加电流阴极保护系统的混凝土中,带负电的氯离子被阴极(钢筋)排斥,并朝着辅助阳极的方向运动,在辅助阳极表面上失去电子被氧化形成氯气,从而起到防止锈蚀的作用。采用阴极保护技术防止钢筋受到腐蚀,从而避免腐蚀产物对混凝土产生巨大膨胀作用而开裂,这是一种十分可靠和有效的技术,该技术已在国外获得广泛应用。

清澜大桥耐久性措施见表 2。

考虑当地的实际情况,如原材料的可及性、工

表 2 清澜大桥耐久性措施一览表

区段		主桥					引桥			
区域环境		上塔柱环境作用等级定为 D 级 ,下塔柱、辅助、过渡墩墩身、承台位于水位变动区、浪溅区或重度盐雾区 ,环境作用等级定为 E 级 ,桩基的环境作用等级定位 C 级					主梁、桥墩、承台环境作用等级定为 D 级 ,该区域持力层透水性好 ,受海水的一定影响 ,桩基的环境作用等级定位 C 级			
结构部位		上塔柱	下塔柱	辅助过渡墩身	承台	桩基	主梁	桥墩身	承台	桩基
环境作用等级		D	E	E	E	C	D	D	D	C
材料要求	混凝土强度等级	C50	C50	C50	C40	C30	C50	C40	C35	C25
	最大水胶比	0.4	0.36	0.36	0.34	0.4	0.4	0.4	0.4	0.4
	最小胶凝材料用量 /(kg/m ³)	≥ 340	≥ 360	≥ 360	≥ 360	≥ 340	≥ 340	≥ 340	≥ 340	≥ 340
	抗氯离子渗透系数 (56 d 龄期 10 ⁻¹² m ² /s)	≤ 1.5	≤ 1.5	≤ 1.5	≤ 2.0	≤ 3.0	≤ 1.5	≤ 1.5	≤ 3.0	≤ 3.0
	混凝土抗冻性能耐久性指数 DF/%	70	70	70	70		70	—	—	—
	56 d 最大电通量 /C	1 000	1 000	1 000	1 000	2 000	1 000	1 000	2 000	2 000
结构设计	最小钢筋保护层厚度 /mm	45	50	50	70	85	40	40	60	85
	钢筋混凝土构件裂缝宽度容许值 /mm	0.2	0.15	0.15		0.2	0.2	0.2		0.2
	预应力构件预应力度	部分预应力 A 类构件					全预应力			
附加防腐措施		表面涂装	表面涂装、外加电流阴极保护		索塔承台采用外加电流阴极保护	永久钢护筒				

艺设备的可行性等,以及经济上的合理性,清澜大桥工程采取以高性能混凝土技术为核心的综合耐久性策略和方案。但作为一个重点工程,投资大,仅

仅在设计、施工上关注耐久性远远不够的,大桥建成后必须重视桥梁的管理和养护,从而真正提高桥梁耐久性,延长桥梁使用寿命。

缓解交通压力 泸州拟新建 5 座大桥

作为四川泸州的“南大门”,泸州长江大桥首次断道维护以后,为泸州主城区内的交通带来巨大压力。泸州是一座近水城市,截至目前,在泸州市主城区内已拥有 6 座大桥。这些大桥,都是泸州市内最重要的交通命脉。近年来,随着泸州市内的车辆激增,泸州 6 座大桥上的交通流量,也随之大幅增长。据泸州交警部门统计,目前泸州市内每日大约有超过 70%的车流量,需经大桥通行。这一现象带来直接后果是长江大桥和沱江一、二桥的交通量已趋于饱和,高峰期更是超负荷运行。因此,未来几年,泸州市拟将在长、沱两江上新建 5 座大桥,以适应未来特大城市的交通需求。

新建的 5 座大桥分别为:在沱江上,修建沱江四桥和龙透关大桥;在长江上,修建邻玉长江大桥、蓝田长江大桥、茜草至城东长江大桥。这 5 座大桥修成后,将有效地缓解现有大桥的压力,同时形成联系城北、城东、城南、城西的环形交通。

目前,沱江四桥和龙透关大桥的建设工作,正在有序推进,而邻玉长江大桥、蓝田长江大桥、茜草至城东长江大桥则在进行前期准备,预计在蓝田机场正式迁建后,才能动工建设。

Abstract: Compared with the cable support flat streamlined steel bridge, the span of the continuous steel box girder bridge is smaller and its rigidity is higher. The deck pavement structures of the existing steel bridges are mainly suitable for the pavement of the cable support flat streamlined steel bridge. However, the study on the continuous steel box girder deck pavement structure is still blank in China. Based on Jiweigang Bridge of Nantong City, the article puts forward the novel deck pavement structure and carries out the special design. Since the traffic put into operation, there is no any faults and the service performance is good. The further follow-up observations are in progress.

Keywords: continuous steel box girder, bridge deck pavement structure, hot rolled asphalt mixture, SMA-13, design of mixing ratio

Study on Detection Reference Standard of SDSAP(Strength Detector of Shallow Asphalt Pavement) Fang Hengliang(58)

Abstract: In order to make SDSAP able to be better used for the detection evaluation of asphalt pavement and aiming at the different void ratios of asphalt mixture, the article preliminarily sets up the detection reference standard of SDSAP by the impact penetration experiment and the indoor strength test of instruments.

Keywords: asphalt pavement, strength detector, impact penetration, void ratio

BRIDGES & STRUCTURES

Further Discussion on Several Problems of Master Layout in Design of Arch Bridge Cui Huide(62)

Abstract: Whether or not reasonable the master layout of arch bridge is and whether or not comprehensively the problems are considered will not only directly affect the total construction cost of bridge, but also greatly influence the service, maintenance and management of bridge. The master layout of arch bridge is very important. A good design often embodies the advantage and disadvantage of the master layout. Combined with the engineering design practices, the article discusses the master layout principle in the design of arch bridge, which can be referred for the similar projects.

Keywords: bridge engineering, arch bridge, design, master layout, further discussion

Further Discussion on Calculation of Super-wide Bridge Ma Lin, Gao Jianjun, Zhao Xingzhong(65)

Abstract: The paper introduces the current situation of studying the urban super-wide bridges. The paper further discusses the stress characteristics of the urban super-wide bridges by the comparison and analysis of a typical three-span ordinary concrete continuous plate girder urban super-wide bridge with the same span of ordinary concrete continuous plate girder bridges.

Keywords: super-wide bridge, plate girder bridge, internal force analysis

Calculation and Analysis on Double-wall Steel Cofferdam for Main Bridge of a Bridge Wang Cong, Li Wenbo, Zeng Yuan(68)

Abstract: The structural type of double-wall steel cofferdam is used for the main bridge of a bridge. In order to correctly understand the deformation and stress of steel cofferdam structure and to ensure the engineering construction security, this steel cofferdam is calculated and analyzed by ANSYS software. The control performance analysis results show that the maximum deformation value of cofferdam structure is more suitable, all member stresses are lower than the limited values stipulated in the design stipulations, and the structural stability can satisfy the requirements of criterion.

Keywords: double-wall steel cofferdam, calculation and analysis, foundation of bridge pylon

Design of Concrete Structure Durability of Sea-crossing Bridge Tan Kejun(72)

Abstract: The design of bridge focuses on the improvement of structure durability and takes it as the important design principle in recent years, and unitarily considers the reasonable structure layout and construction details. Hainan Qinglan Bridge is a longer sea-crossing bridge. The durability design

of this bridge structure becomes the difficulty and keynote in the design. The article sets forth the detail measures and design gist in the design of structure durability by the engineering practices.

Keywords: sea- crossing bridge, concrete structure, durability, coating

Dynamic Characteristics and Seismic Analysis of Single Pylon Cable- stayed Bridge

..... Jia Zhiqiang, Yang Na (75)

Abstract: Taking a single- pylon double- plane composite beam (composed of combined beams and concrete beams) cable- stayed bridge as the engineering background, the article analyzes the dynamic characteristics of this bridge. Based on the theory of the finite element method, the article determines the space calculation model of this bridge, and on this basis, studies the seismic performance of this bridge by the application of response spectrum method.

Keywords: cable- stayed bridge, finite element method, dynamic characteristics, seismic performance

Analysis on Local Stress of Aixihu Bridge Zhang Lin, Zeng Tianbao (79)

Abstract: The stress of key structural parts often determines the destroying of the whole structure. Taking Aixihu Bridge as the studying object, the article analyzes the local stress of the key parts of the arch foot, suspender girder anchor point and suspender arch top anchor point. The analysis results show that the local stress of this bridge can meet the requirements of specification, but is larger than the stress value of the overall analysis. Therefore, it is very necessary to analyze the local stress of structure.

Keywords: special- shaped arch bridge, anchor point, analysis of local stress

Design Optimization of Girder Height for Pre- stressed Hollow Plate Girder Ji Yufei, Pan Zhiqiang (82)

Abstract: The article analyzes and studies the girder height of pre- stressed hollow plate girder by the practical cases. Based on the inspection testing result of pre- stressed hollow plate girder of bridge under the operation now, the partial bridges under the operation have the failure phenomenon of girder caused by the too small height of pre- stressed hollow plate girder, which greatly reduces the service life of bridge. After the comparison and checking calculation of girder height, the article analyzes the important influence of height optimization of pre- stressed hollow plate girder on the bridges from the structure stress and economy.

Keywords: hollow plate girder, girder height, design optimization

Reinforcement Design of Nanchang Changjiu Avenue Overpass Chen Chuang (84)

Abstract: Changjiu Avenue Overpass is required to reinforce because of its hollow plate bending, shear and deflection not able to satisfy the requirements of load class after its reconstruction. The article briefly introduces the methods of external prestressing tendons and carbon fiber to carry out its reinforcement and improvement.

Keywords: hollow plate, reinforcement, carbon fiber, external prestressing tendons

Summarization of Plate- Truss Model to Calculate Torsional Strength of Steel Reinforced Concrete Component

..... Zhang Yongkang, Xu Li (86)

Abstract: The article briefly introduces the existing simplified mechanics model to calculate the torsional strength of steel reinforced concrete component, points out the necessity of plate- truss model, and introduces the plate- truss model in detail. The relative experience can be referred for the relevant technical members.

Keywords: torsional strength, simplified mechanics model, plate- truss model

Aesthetic Standard for Modern Bridge Decoration Liang Yan, Li Yadong (90)

Abstract: The article analyzes the role and classification of bridge decoration, sets forth the development history of bridge decoration, and puts forward the bridge decoration standard under the current situation,