Pylon of an Irregular Low Pylon Cable-Stayed Bridge: A Review

Abstract: Low-tower cable-stayed bridges, as an emerging type of bridge structure, have been widely applied in bridge engineering both domestically and internationally in recent years. This paper reviews the research status and development trends of low-tower cable-stayed bridges. Firstly,itintroducesthecharacteristicsoflow-towercable-stayedbridgesandtheirimportancein bridge engineering. Subsequently, it analyzes in detail the diversity of tower forms in low-tower cable-stayed bridges, including single-column, double-column, portal, and innovative forms such as inclined-leg portal, inverted V-shape, inverted Y-shape, H-shape, diamond, etc. These towers not only vary in shape but also possess complex load-bearing capabilities. Meanwhile, this paper also outlines the design features of low-tower cable-stayed bridges, such as their graceful appearance,excellentperformance,andconvenientconstruction.Finally,itsummarizesthemain advancementsinresearchon low-towercable-stayedbridgesinrecentyears,includingstructural design, evolution of tower forms, analysis of spatial stress distribution, and other research achievements, and looks forward to their future development trends.

Keywords:Low-towercable-stayedbridge;towerform;structuraldesign;researchtrends

1 Introduction

Basedonconventionalcable-stayedbridgesandcontinuousbeambridges,toenrichthetypes of bridge structures and meet aesthetic requirements, low-tower cable-stayed bridges have emerged[7,8].Thistypeofbridgeresemblesaconventionalcable-stayedbridgeinappearancebut exhibits superior load-bearing performance compared to continuous beam bridges, featuring unique structure and design. Due to its elegant appearance, excellent performance, and convenient construction, low-tower cable-stayed bridges have achieved good development both domestically and internationally and have been actively applied in production practices.

2 Briefdescriptionofthealienbridgetower

Theshorttowercable-stayedbridgeisfavoredforitsuniquestructure,aestheticappearance, andeconomicpracticality.Commonmaintowerformsincludesingle-columntype,double-column type, portal type, and some innovative forms such as inclined portal type, inverted V-shaped, invertedY-shaped,H-shaped,diamond-shaped,etc.Theseunconventionalbridgetowersnotonly vary in shape but also exhibit complex load-bearing characteristics. In recent years, China has constructed several representative unconventional short tower cable-stayed bridges, such as ShouchunWestRoadBridge,BundBridge,LanshuBridge,etc.,showcasingtheevolutionofbridge tower forms from simple to complex, presenting a variety of changes in straightness, inclination, planar curves, and spatial curves [9,10].

SunShuyuetal.introducedtheGanzhouFeilongIslandBridge,withamainspanof150m,and its structural form is a single-tower double-cable-plane hybrid girder cable-stayed bridge. The bridges main tower has a very unique shape and is aesthetically pleasing, featuring an A-shaped bow-shaped curve tower. This article provides a detailed study of the structural design of the GanzhouFeilongIslandBridge;HeShanjingusedtheMIDASbridgestructurecalculation software to establish a spatial solid model of a water-drop shaped cable tower for a certain cable-stayed bridge based on actual engineering conditions, and conducted an analysis of the cable tower. On this basis, further analysis was carried out on the spatial stress distribution during the bridge formation stage in the lower tower column and tower beam fixation area; Shao Xudong et al. studied the core issues considered in the design of the structural system, conceptual design, reasonableinclinationangleofthecabletower,spatialforceanalysis,andstabilityofcable-stayed bridgeswithoutbackstays,aswellasconductedin-depthresearchonreasonablebridgeformation cable forces and construction control aspects; Zhou Yanfeng et al. compared and analyzed three differentformsofcabletowerstructures,adoptinganinvertedY-shapedcabletowerstructureas the background project.The article focuses on introducing the structural scheme design of the threedifferentcabletowers,brieflydescribesthemethodofestablishingcabletowermodelsusing planerod models andconductingcalculations,especially studyingtheforcecharacteristicsof key structures such as the bottom moment of the cable tower and the bonding position of the tower beamunderdifferentloadconditions;PanLupingcombinedpracticalconsiderationsTherightfork oftheAnshanYangtzeRiverBridgeisathree-towerarchedcable-stayedbridge.Thispapergivesa detailed introduction to the design of the arch towers and studies the influence of support conditions and structural layout on the three-tower arched cable-stayed bridge.

3 Studyonthestructuralsystemandlengthofno-suspension area of short tower cable-stayed bridge

Thestructuralsystemofashorttowercable-stayedbridgecanbeclassifiedintosemi-floating, tower-beamfixed,andsteelstructuresystems[1].Thelengthofthenon-suspensionzoneinashort tower cable-stayed bridge includes the length of the non-suspension zone beside the tower, the length of the side spans at the edge, and the length of the main span mid-span non-suspension zone, which are important parameters affecting the overallmechanicalperformance of the short tower cable-stayed bridge.

Liu Muyu et al. [2]studied the load effect variation patterns of key parts of the main beam of shorttowercable-stayedbridgesunderdifferenttowerheights,lengthsofunsupportedzones,and edge-to-center-span ratios by establishing spatial finite element models, deriving reasonable tower height ratios and unsupported zone lengths; Yang Guanghui and Shi Haitao derived reasonable tower span ratios, edge-main span ratios, and unsupported zone lengths through studying the internal forces and structural deformations of bridges.Chen Dewei and Fan Lichu researched the impact of unsupported zone lengths on the deflections, internal forces, and main beams of isolated tower cable-stayed bridges; Liu Fengkui et al., using the Yinhuh Short Tower Cable-Stayed Bridge as a project background, discussed the influence of live loads on the overall bridgestructureunderchangesinunsupportedzonelengths;LiuWenhuietal.[3]usingtheXiaohuxi ShortTowerCable-StayedBridgeasabackground,analyzedtheimpactofbridgetowerheighton the structure, concluding that optimizing tower height comes at the cost of increased cable-stay forces;Sun Dongli et al.,using a double-tower three-span short tower cable-stayed bridge as a background,analyzedtheeffectsofunsupportedzonelengths,edge-to-center-spanratios,tower height, bridge tower section dimensions, and cable-stay spacing on the deflections and internal forces of the main beam and bridge tower under both fixed and free boundary conditions, concludingthatunsupportedzonelengthsonlyaffecttheforcesinthemainbeamandcables,with minimalimpactonthebridgetower.LiuWenhuiandLiYanspecificallyoptimizedtheanalysisof

unsupportedzonelengthsusingtheXiaohuxiYellowRiverBridgeinLanzhouasabackground。

4 Research status of tower form of short tower cable-stayed bridge

Globally, steel tower cable-stayed bridges have undergone the development processes of steel, concrete, and steel structures[4]. From the Ströndesund Bridge in Sweden to the Daegawa Bridge and Namiya Bridge in Japan, steel tower cable-stayed bridges have been widely used in EuropeandJapan.Onlyafewsteeltowercable-stayedbridgesandsuspensionbridgeshavebeen constructed domestically, such as the Yumenlong Yellow River Bridge (352m), Dongying Yellow River Bridge (288m), Hong Kong Tingkow Bridge (448m+475m), and Nanjing Yangtze River Third Bridge(648m).TheNanjingYangtzeRiverThirdBridgetower,completedin2005,adoptedasteel-concrete composite bridge tower with the lower part below the transverse girder being concrete and the upper part being steel, marking the first use of this technology in China. The completion oftheNanjingYangtzeRiverThirdBridgefilledthegapinChinasdesignofsteeltowercable-stayed bridges, and its main tower steel-concrete composite section creatively adopted the "reinforced concrete bar shear key group" as the load-bearing connector for the first time in China.Research on the steel-concrete sections at the pier-tower junction focuses on analyzing how axial forces, shearforces,bendingmoments,andtorsionalmomentstransmittedfromtheupperpartthrough thetowercolumntransitionintotheconcretefoundation.Keytechnicalissuesinthesteel-concrete sections at the pier-tower junction generally include their positioning and detailed construction settings.Intermsoflocalstressstudies,ChenXiaolingetal.conductedstressanalysisofthetower-limber-pier consolidation area using finite element analysis software and proposed optimization schemes.WuYunfangetalThroughmechanicalpropertyanalysisandpartialanalysisofthebridge tower, the study investigated the effect of reinforcement ratio on cold wave temperature stress. Yan Haijiao et al. conducted local stress analysis at the tower pier beam fixation points and proposedanoptimizationschemeduringthemaximumdoublecantileverconstructionphase.Qin Yaoliuetal.usedANSYSsoftwaretoestablishasolidfiniteelementmodelandperformedstructural simulation calculations at the tower beam pier fixation points, proposing suggestions to improve concrete crack resistance.

Steel-concrete composite bridge towers are widely used in bridge structures due to their advantages such as convenient construction and good mechanical properties. Research on steel-concrete composite bridge towers is also extensive. Studies like those by Xing and others[5] have investigated the load transfer mechanism of the steel-concrete composite sections of bridge towers. Wu Bin et al. conducted local force analysis on the steel-concrete composite sections of truss-type bridge towers.Wang Chong et al. [6]studied the force characteristics and load transfer mechanisms of the anchor zone of bridge towers. Some scholars have researched the key design andconstructiontechnologiesforsteel-concretehybridstructuresinbridgetowers.DengLuetal. conducted model tests on variable-section elliptical steel-concrete composite bridge towers, analyzing the strain changes, failure modes, and load-bearing capacities of the steel tower walls and concrete within the towers under design loads.

5 Conclusion

The current theoretical system for short tower cable-stayed bridges has not yet been fully perfected, and in practical design, many references are made directly to the theories of conventionalcable-stayedbridges.Therefore,itis necessarytostudysomeissuesrelatedtoshort tower cable-stayed bridges to better guide on-site construction and bridge design. This paper analyzes the structural behavior of elliptic multi-span short tower cable-stayed bridges, focusing on the influence of tower-beam connection methods and bridge tower forms on load-bearing performance,aimingtofindtheoptimalstructuralsystemandbridgetowerform.Forbridgedesign, thisresearchcanprovideareferenceforselectingappropriatestructuralsystemsandbridgetower forms when designing similar bridges in the future, and also aids in understanding the stress conditionsatcriticalstructuralpoints.Theresultsobtainedcanserveasareferenceandassistance for future research and engineering practice.

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