ISSN: 2414-1895 DOI: 10.6919/ICJE.202604_12(4).0021

A Review of Research Progress on Horizontal Joints in Double Steel Plate-Confined Concrete Wind Turbine Towers

Baoshuai Zhu

School of Urban Construction, Yangtze University, Jingzhou 434023, China

Abstract

With the continuous advancement of the "dual-carbon" strategy and the rapid development of large-capacity wind turbines, increasingly stringent requirements have been imposed on the bearing capacity, stiffness, stability, fatigue resistance, and construction efficiency of wind turbine towers. Although conventional steel towers, precast concrete-steel hybrid towers, and lattice towers have been widely used in engineering practice, they still show limitations in transportation, construction, maintenance, and joint performance. As a novel composite structural form, the double steel plate-confined concrete wind turbine tower combines the advantages of steel and concrete and has broad application prospects in terms of high bearing capacity, high stiffness, good ductility, and construction convenience. As the key connecting and force-transferring part of a segmental tower, the horizontal joint directly affects the overall safety and service life of the structure. This paper reviews the development demand for wind turbine towers, the structural characteristics of double steel plate-confined concrete systems, and the relevant research progress on concrete-filled steel tubular members, concrete-filled double-skin steel tubular members, and segmented tower joints. On this basis, the major problems in current studies are summarized, including insufficient understanding of the mechanical behavior under combined loading, incomplete design methods for joint bearing capacity, and limited engineering-oriented evaluation methods. Future research directions are also discussed. The review shows that the bearing mechanism and design theory of horizontal joints in double steel plate-confined concrete wind turbine towers are still under development, and further systematic studies integrating experiments, numerical simulations, and theoretical analysis are needed to support engineering application.

Keywords

Double Steel Plate-Confined Concrete; Wind Turbine Tower; Horizontal Joint; Composite Structure; Bearing Performance; Research Progress.

1. Introduction

Under the global trend of energy transition and low-carbon development, wind energy has become one of the most important renewable energy sources. In recent years, wind turbines have continuously developed toward larger unit capacity and greater hub height, which significantly increases the gravity load, overturning moment, and fatigue demand on tower structures. As a result, higher requirements have been placed on the stiffness, stability, load-bearing capacity, and durability of wind turbine towers.

At present, the most common tower forms in engineering practice include conventional steel towers, precast concrete-steel hybrid towers, and lattice towers. Conventional steel towers are highly industrialized and convenient for erection, but their application in ultra-high towers is strongly

ISSN: 2414-1895 DOI: 10.6919/ICJE.202604_12(4).0021

restricted by transportation limits. Hybrid towers can partly overcome transportation constraints, but they usually involve a large self-weight, complicated connection details, and difficulties in durability control. Lattice towers have the advantages of flexible transportation and efficient material use, but they contain numerous joints and require considerable work in assembly and maintenance. Therefore, it remains difficult for existing tower forms to simultaneously satisfy the demands of ultra-high wind turbines in terms of structural performance, construction efficiency, and long-term serviceability.

Against this background, double steel plate-confined concrete wind turbine towers have attracted increasing attention. Owing to the composite action between the inner and outer steel plates and the infilled concrete, this structural system can provide high bearing capacity, high stiffness, good ductility, and relatively efficient construction. However, as the most critical connecting component in segmentally assembled towers, the horizontal joint is subjected to axial compression, bending moment, shear force, and torsion during service. Its cracking, separation, local crushing, and frictional force transfer directly influence the continuity of force transmission and the structural safety of the entire tower. Therefore, a systematic review of the research progress on horizontal joints in double steel plate-confined concrete wind turbine towers is of both theoretical and practical significance.

2. Structural Characteristics of Double Steel Plate-Confined Concrete Wind Turbine Towers

A double steel plate-confined concrete structure consists of inner and outer steel plates with concrete filled between them, forming a typical steel-concrete composite system. This structural form makes full use of the tensile and flexural advantages of steel and the compressive strength of concrete. Through the confinement effect provided by the steel plates and the lateral support offered by the concrete, a stable composite load-resisting mechanism can be developed.

Compared with conventional steel structures, reinforced concrete structures, and ordinary concrete-filled steel tubular members, double steel plate-confined concrete structures generally exhibit better bearing capacity, stiffness, ductility, and durability. When applied to wind turbine towers, the hollow sandwich configuration can also reduce self-weight while maintaining sufficient structural performance, which is beneficial to transportation, lifting, and foundation design. In addition, the infilled concrete can mitigate local buckling of steel plates and reduce stress fluctuations, thereby improving fatigue resistance.

Nevertheless, the practical application of this new tower form still faces several technical challenges. Among them, the horizontal joint is the most important weak part controlling structural integrity and force transfer. Under high axial compression ratios and combined bending-shear-torsion actions, the horizontal joint exhibits a much more complex interfacial stress state than that of ordinary structural connections. Therefore, the mechanical behavior and bearing capacity of the horizontal joint have become key issues in the development of this structural system.

3. Research Progress in Related Fields

3.1 Research Progress on Concrete-Filled Steel Tubular Members

Concrete-filled steel tubular (CFST) members are among the earliest and most extensively studied steel-concrete composite members. Early studies mainly focused on axial load-bearing capacity and design formulas, and gradually clarified the composite mechanism between the steel tube and the infilled concrete[1-6]. These studies laid the theoretical foundation for the later development of CFST design methods.

Subsequent research extended from axial compression to bending, eccentric compression, torsion, and coupled loading conditions. Kato [7] established column curves for steel-concrete composite members, while Bradford [8] proposed design strength methods for slender concrete-filled rectangular steel tubes. These studies promoted the development of CFST theory from simple axial behavior to more complex stability and coupled stress states.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202604_12(4).0021

Overall, the studies on CFST members have provided important theoretical references for understanding confinement effects, nonlinear load transfer, and interaction between steel and concrete, all of which are relevant to the study of double steel plate-confined concrete wind turbine towers.

3.2 Research Progress on Concrete-Filled Double-Skin Steel Tubular Members

Compared with ordinary CFST members, concrete-filled double-skin steel tubular (CFDST) members have the advantages of high sectional efficiency and reduced self-weight, and they are particularly suitable for high-rise and large-span structures. Research on this type of member has shown that the inner tube, outer tube, and infilled concrete can form an efficient composite mechanism, leading to favorable strength and ductility [9-11].

Tao et al.[9,10] systematically studied the mechanical behavior of circular CFDST columns and beam-columns, and proposed simplified approaches for bearing capacity evaluation. Zhao and Grzebieta [11] investigated the strength and ductility of square CFDST members and further clarified the influence of sectional form on structural performance. These studies provide direct references for the use of double steel plate-confined concrete systems in wind turbine towers, especially in terms of confinement effects, composite action, and section optimization.

3.3 Research Progress on Segmental Tower Joints

In segmental concrete or hybrid tower systems, joints are the most critical components governing structural safety and serviceability. Existing studies indicate that the joint behavior is strongly influenced by prestress level, interface condition, loading path, and structural detailing. Once cracking, separation, or local slip occurs at the horizontal joint, the overall stiffness and bearing capacity of the tower may deteriorate significantly.

Fabian et al. [12] experimentally investigated the bearing behavior of segmented tower joints under normal and bending-shear loading, highlighting the complexity of interfacial behavior under combined actions. Fürll et al. [13] further studied segmented concrete tower joints under combined loading and demonstrated the importance of considering the coupling effect of axial force, bending, and torsion in the evaluation of joint performance. Chen et al. [14] proposed a model for the ultimate torsional moment of dry horizontal joints in prefabricated concrete towers, which emphasized the role of frictional force transfer after joint opening. More recently, Ren et al. [15] studied the compression-bending behavior of thin-walled prestressed concrete towers with horizontal joints and proposed a corresponding calculation model. These studies show that the mechanical behavior of horizontal joints in tower structures is highly nonlinear and strongly dependent on joint opening, interface contact, and friction reserve.

4. Main Problems in Current Research

Although the available studies provide useful references, research on horizontal joints in double steel plate-confined concrete wind turbine towers is still limited.

First, the mechanical behavior of horizontal joints under combined compression-bending-shear-torsion loading has not yet been fully clarified. Existing studies mostly focus on simplified loading conditions, while real wind turbine towers are subjected to multiple coupled actions during operation. As a result, the cracking evolution, contact redistribution, and frictional resistance mechanism of the joint remain insufficiently understood.

Second, current design methods are not fully applicable to this new structural form. Most existing models were developed for ordinary concrete segmental joints, conventional CFST members, or precast tower joints, and they cannot directly reflect the confinement effect of double steel plates or the composite action between steel plates and concrete. Therefore, a dedicated design method for the bearing capacity of horizontal joints in double steel plate-confined concrete towers is still needed.

Third, the influence of major parameters has not been quantitatively established. Parameters such as axial compression ratio, steel plate thickness, concrete strength, interface friction coefficient, and geometric dimensions may all significantly affect the joint bearing capacity and ductility. However, a systematic parameter-based evaluation framework is still lacking.

Finally, engineering-oriented assessment methods remain insufficient. For practical application, it is necessary to establish simplified and reliable models capable of predicting joint performance under typical wind turbine loading cases. This requires the close integration of experiments, finite element simulations, and theoretical derivation.

5. Future Research Directions

Future studies on horizontal joints in double steel plate-confined concrete wind turbine towers may focus on the following aspects.

First, more experimental work should be carried out under realistic combined loading conditions, including compression-bending, compression-torsion, and compression-bending-shear-torsion, so as to reveal the failure modes, stiffness degradation, and ductility evolution of joints.

Second, refined numerical models should be further developed. Such models need to accurately account for steel plate confinement, concrete damage, interface contact, and frictional transfer, thereby enabling systematic parametric studies.

Third, practical design methods should be established based on the combination of test results, numerical simulations, and mechanical models. These methods should be simple enough for engineering use while retaining sufficient accuracy.

Fourth, the long-term service performance of joints deserves greater attention. Since wind turbine towers are subjected to repeated wind-induced loading throughout their service life, fatigue, durability, and interface degradation should be incorporated into future research.

6. Conclusion

Double steel plate-confined concrete wind turbine towers represent a promising structural form for large-capacity and ultra-high wind turbines because they combine the advantages of steel and concrete and offer favorable bearing capacity, stiffness, ductility, and construction efficiency. However, the horizontal joint, as the key connecting and force-transferring component in segmental towers, remains the governing weak part that controls structural integrity and service performance.

Current studies on related composite members and segmented tower joints provide a useful basis for understanding this problem. Nevertheless, the bearing mechanism, parameter influence, and design theory of horizontal joints in double steel plate-confined concrete wind turbine towers are still far from mature. Further systematic studies are required to promote the engineering application of this novel structural system.

References

[1] Kloppel V K, Goder W. An investigation of the load carrying capacity of concrete-filled steel tubes and development of design formula[J]. Der Stahlbau, 1957, 26(1): 1-10.

[2] Kloppel V K, Goder W. An investigation of the load carrying capacity of concrete-filled steel tubes and development of design formula[J]. Der Stahlbau, 1957, 26(2): 44-50.

[3] Gardner J, Jacobson E R. Structural behaviour of concrete filled steel tubes[J]. ACI Structural Journal, 1967, 64(7): 404-413.

[4] Knowles R B, Park R. Strength of concrete filled steel tubular columns[J]. Journal of Structural Division, ASCE, 1969, 95(ST12): 2565-2587.

[5] Knowles R B, Park R. Axial load design for concrete filled steel tubes[J]. Journal of Structural Division, ASCE, 1970, 96(ST10): 2125-2153.

[6] Bridge R Q. Concrete filled steel tubular columns[R]. Sydney: School of Civil Engineering, University of Sydney, 1976.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202604_12(4).0021

[7] Kato B. Column curves of steel-concrete composite members[J]. Journal of Constructional Steel Research, 1996, 39(2): 121-135.

[8] Bradford M A. Design strength of slender concrete filled rectangular steel tubes[J]. ACI Structural Journal, 1996, 93(2): 229-235.

[9] Tao Zhong, Han Linhai, Huang Hong. MECHANICAL BEHAVIOUR OF CONCRETE-FILLED DOUBLE SKIN STEEL TUBULAR COLUMNS WITH CIRCULAR CULAR SECTIONS [J]. China Civil Engineering Journal, 2004, 37(10): 41-51.

[10] Tao Z, Han L H, Zhao X L. Behaviour of concrete-filled double skin (CHS inner and CHS outer) steel tubular stub columns and beam-columns[J]. Journal of Constructional Steel Research, 2004, 60(8): 1129-1158.

[11] Zhao X L, Grzebieta R. Strength and ductility of concrete filled double skin (SHS inner and SHS outer) tubes[J]. Thin-Walled Structures, 2002, 40: 199-233.

[12] Fabian K, Florian F, Thorsten B, et al. Experimental study on the joint bearing behavior of segmented tower structures subjected to normal and bending shear loads[J]. Structural Concrete, 2022, 23(3): 1370-1384.

[13] Fürll F, Klein F, Götze M, et al. Experimental study on the joint load-bearing behaviour of segmented concrete towers under combined loading[J]. Journal of Physics: Conference Series, 2024, 2767(4): 042009.

[14] Chen J L, Lin W M, Li J W. Ultimate torsional moment of dry horizontal joint for prefabricated concrete tower[J]. The Structural Design of Tall and Special Buildings, 2024, 33(15): e2156.

[15] Ren W, Zhou X H, Deng R, et al. Compression-bending behaviour of thin-walled prestressed concrete tower with horizontal joint for wind turbines: experimental study and calculation model[J]. Thin-Walled Structures, 2025, 211: 113154.