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Introduction

1.1 Research Background

Since the dawn of the 21st century, rapid progress has been witnessed in marine resource exploitation, offshore transportation infrastructure development, and the construction of marine renewable energy projects. This trend has driven a sharp increase in the number of large-scale steel structural facilities deployed in offshore and coastal waters. Fixed offshore platforms, jacket foundations, supporting structures for offshore wind turbines, and steel components of sea-crossing bridges are generally designed for long-term service under complex environmental loads, while their in-service inspection and maintenance are constrained by harsh marine site conditions [1, 2]. The structural safety and durability of these facilities are not only tied to the operational risks and life-cycle maintenance costs of individual projects but also exert a direct impact on the full-life-cycle reliability of major marine engineering schemes. Typical configurations of marine engineering steel structures are presented in Fig. 1.1.

Marine engineering structures operate in a harsh service environment dominated by strong environment-load coupling effects. They are persistently exposed to multisource dynamic loads including wind, wave, current, and tidal action, as well as aggressive environmental stressors such as salt fog deposition, dry-wet alternation, long-term seawater immersion, and marine biological adhesion. In contrast to their onshore counterparts, offshore inspection, rehabilitation, and component replacement face far more rigorous construction constraints, with available maintenance windows severely limited by sea states and meteorological conditions. Against this backdrop, it is of critical significance to characterize and quantitatively evaluate the performance evolution of primary load-bearing members and key connection joints in marine engineering structures.



Figure 1.1 Schematic of typical structural forms in marine engineering.
 (a) Shenhai-1 semisubmersible production and storage platform. (b) Jacket platform of the Bozhong 26-6 oilfield. (c) Offshore wind power platform group. (d) Hong Kong–Zhuhai–Macao Bridge.

Tubular structures are widely used in jacket platforms, offshore wind foundations, steel tubular truss bridges, and other marine engineering projects due to their superior sectional mechanical properties, high global stiffness, flexible structural layout, and excellent torsional performance. Codes including ISO 19902 [3] put forward systematic provisions governing the design, in-service inspection, and service performance evaluation of marine structures. Compared with open-section members, circular hollow section (CHS) tubes possess higher overall stability and lower flow resistance, making them ideal primary load-bearing components for marine engineering applications. Nevertheless, the full exploitation of the structural advantages of tubular systems in practical engineering hinges largely on the performance reliability of joints. Joints undertake internal force transfer between adjacent members and meanwhile act as critical vulnerable regions prone to local plastic expansion, local buckling, and fatigue failure. Particularly in offshore wind foundations and jacket structures, numerous CHS members are assembled into integral load-bearing systems via spatial joints. The strength, stiffness, and deformation capacity of joints directly determine the structural safety margin and long-term service

reliability [4]. Against this backdrop, this book focuses on the performance evolution of tubular joints exposed to marine corrosive environments, with typical CHS T-joints under brace axial compression selected as the research object.

Driven by the pursuit of structural lightweighting, high load-bearing efficiency, and rapid on-site construction, high-strength steel has gained increasing application in marine engineering and bridge structures. As a typical representative, Q690 high-strength steel features high yield strength and superior material utilization efficiency. Under identical load-bearing demands, it enables the optimization of member section dimensions and the reduction of structural self-weight. For marine structures, reduced self-weight lowers foundation load requirements, eases transportation and hoisting difficulties, and optimizes construction arrangements, granting high-strength steel remarkable engineering application value. However, the improvement in material strength cannot be synchronously converted into proportional enhancement of overall structural performance. Welded tubular joints are extensively adopted in marine structures, where the joint region inherently combines geometric discontinuity, severe stress concentration, material inhomogeneity, and welding residual stress. With the upgrading of steel strength grade, the plastic deformation capability, local stability, and fracture susceptibility of joint regions change correspondingly, and the ultimate limit state of joints is still dominated by local deformation or stability failure. As a result, the advantages of high-strength steel are mainly reflected in the improved load-bearing efficiency of individual members, while the bearing and deformation capacities of joints fail to increase proportionally with material strength.

In terms of material mechanical characteristics, high-strength steel differs evidently from normal-strength steel in yield ratio, strain hardening capacity, and ductility reserve, which profoundly influences the mechanical response of tubular joints subjected to local plastic development and local buckling. Meanwhile, welding thermal cycles create obvious mechanical property gradients among weld metal, heat-affected zone (HAZ), and base metal. The superposition of welding residual stress and structural boundary constraints places the joint region in a complex initial stress state. For marine structures, weld toes and structural transition zones are highly susceptible to coupled corrosion and fatigue damage. In addition, the application of high-strength steel is usually accompanied by reduced wall thickness of structural members. The decreased wall thickness and increased diameter-to-thickness ratio render components more sensitive to geometric imperfections, local thickness loss, and section ovalization. For tubular joints, wall thickness governs not only local bearing capacity but also

the circumferential stiffness and ovalization resistance of the chord surface. When corrosion-induced wall thinning occurs during service, the dominant failure mechanism of joints may shift from material yielding to stability and deformation control. This further alters the bearing capacity degradation pattern of joints and restricts the applicability of existing design models.

Current design specifications for offshore wind turbine support structures (e.g., DNV-ST-0126 [5]) and design guidelines for tubular joints (e.g., International Committee for the Development and Study of Tubular Structures [CIDECT] recommendations and relevant codes [6]) have formed relatively mature engineering evaluation frameworks. Even so, their empirical databases are primarily established on uncorroded normal-strength steel joints. Systematic research on the performance degradation mechanism of high-strength steel welded joints under corrosive environments and typical loading conditions remains insufficient. Accordingly, this book investigates the performance degradation behavior of Q690 high-strength steel welded joints and CHS T-joints under marine corrosion, covering both material and structural levels.

Coastal areas are characterized by typical marine corrosive environments with high salinity, high humidity, frequent dry-wet cycling, and recurring typhoons as well as intense wind-wave actions. Based on marine environmental zoning criteria, the service environment of marine structures is generally divided into the marine atmospheric zone, splash zone, intertidal zone, and submerged zone, as illustrated in Fig. 1.2. Among these zones, the splash and intertidal zones impose the most severe corrosion aggression due to frequent dry-wet alternation, intensive salt accumulation, and sufficient oxygen supply [7–11]. Such harsh environmental conditions inevitably induce corrosion damage to key load-bearing members and their joints during service, showing obvious spatial nonuniformity in corrosion severity. In particular, the corrosion risk of welded tubular joints stems not only from uniform average wall thickness loss but also from the tendency of localized corrosion to concentrate at weld toes, weld transition regions, HAZs, and structural details prone to water stagnation [12, 13]. Once deep corrosion pits or localized wall thinning form at these vulnerable locations, they will remarkably alter the local stiffness, stress distribution, and failure mode of critical force-transfer regions. Therefore, simply evaluating corrosion severity by average thickness reduction cannot fully reflect the actual performance deterioration of vulnerable joint details.

On the other hand, marine corrosion damage presents obvious time-varying and random characteristics, and the corrosion depth cannot be linearly extrapolated at a constant rate. For experimental research, the long-term natural exposure process is difficult to be completely reproduced

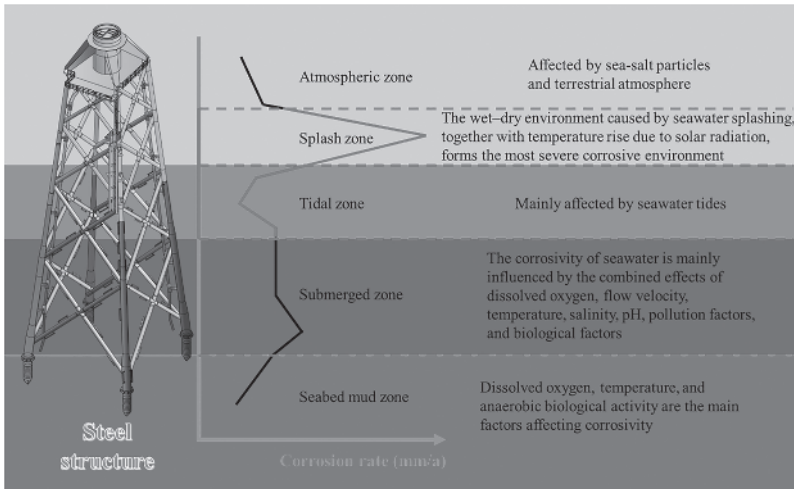


Figure 1.2 Schematic of marine environmental corrosion zoning.

in the laboratory. Hence, it is necessary to extract representative corrosion characteristics in a controllable corrosive environment and characterize the corrosion state through quantifiable indicators such as mass-loss rate, average corrosion depth, or morphological statistical parameters. On this basis, establishing a verifiable correlation between corrosion geometric characteristics and mechanical properties is an important prerequisite for evaluating the performance of high-strength steel welded joints and steel tubular joints.

In the marine service environment, tubular joints are constantly subjected to the combined long-term effects of corrosion and structural loads. Corrosion not only causes surface thinning of steel materials but also forms local pits and geometric discontinuities at welded transition zones and chord surfaces of main tubulars, altering the stress state of key joint regions, as shown in Fig. 1.3. For steel tubular joints, the brace load is transferred to the chord surface of the main tubular through welded connections. When the local geometric conditions and material properties of key force-transfer regions degrade, the stiffness, bearing capacity, and deformation development process of joints will change accordingly.

For CHS T-joints under axial compression of the brace, local indentation deformation firstly occurs on the chord surface of the main tubular, and the ultimate state is gradually reached with the expansion of the plastic zone. When corrosion concentrates on the brace-main tubular connection area or welded transition zone, local wall thinning and pitting defects

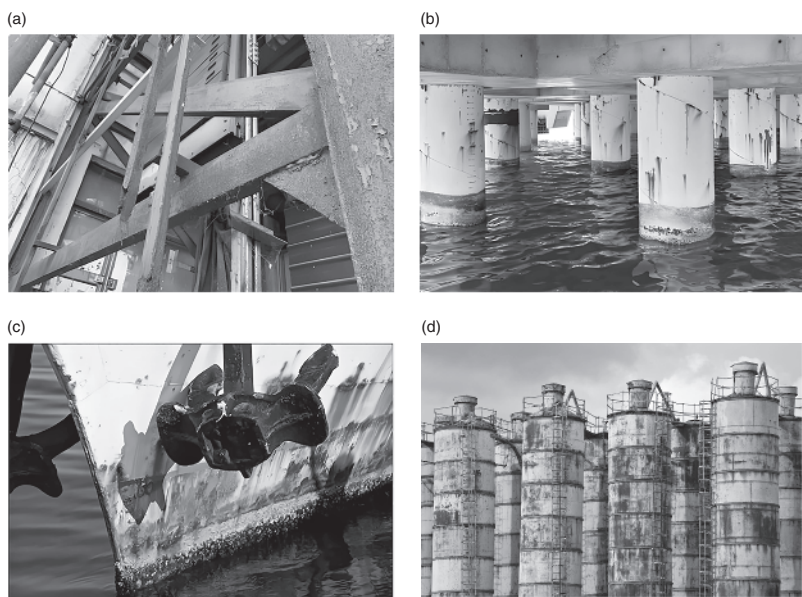


Figure 1.3 Marine corrosion damage. (a) Corrosion of steel structural members. (b) Corrosion of offshore pile foundations. (c) Splash-zone corrosion and marine biofouling. (d) Corrosion of industrial storage tanks. *Source:* (c) Stratos Giannikos / Alamy Stock Photo, (d) Mihai Simonia / Adobe Stock Photos.

weaken the regional stiffness, leading to advanced chord indentation and local instability. For thin-walled high-strength steel joints, limited ductility reserve makes local weakening more likely to amplify the structural sensitivity to stability and deformation control.

Therefore, under marine corrosive environments, it is necessary to systematically investigate the evolution law of bearing and deformation capacity of steel tubular joints by combining degradation at the material level and structural response at the joint level. Revealing the weakening mechanism of corrosion on key force-transfer regions and revising engineering evaluation models accordingly will help improve the reliability of service safety assessment for marine engineering steel tubular structures.

1.2 State-of-the-Art Research Progress

The degradation of steel materials in marine environments is predominantly governed by electrochemical corrosion processes. Chloride ions and dissolved oxygen in salt-containing thin films or seawater media accelerate

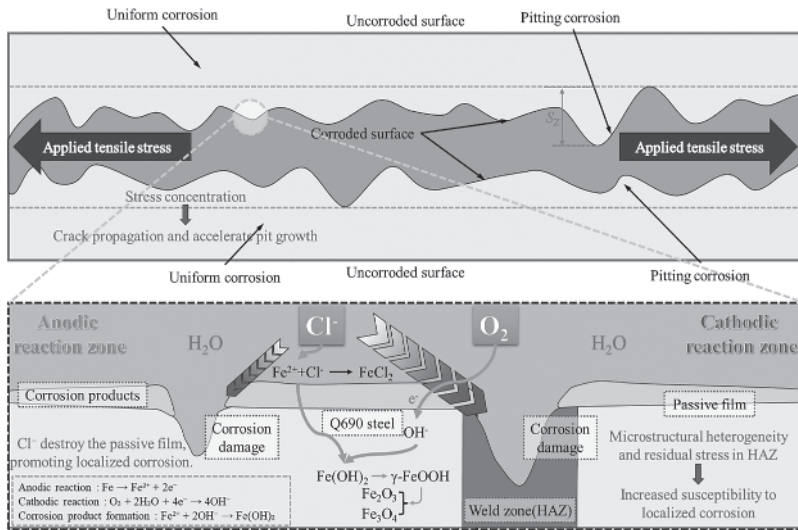


Figure 1.4 Electrochemical corrosion mechanism of high-strength steel in chloride-containing solution.

the surface reaction of steel and promote the development of local corrosion [14, 15], as illustrated in Fig. 1.4. At the initial corrosion stage, a large number of micro-galvanic cell systems form on the steel surface due to differences in microstructure, composition, and surface state. With the progression of corrosion reactions, corrosion product layers gradually form, and their compactness and adhesion further affect the diffusion of oxygen and ions, resulting in staged variations in corrosion rate [16]. For welded joint regions, inhomogeneous microstructure, performance gradients, and residual stress fields lead to more prominent differences in local electrochemical activity, making such regions generally more susceptible to corrosion than the base metal [17–20].

In terms of corrosion morphology, uniform corrosion and localized corrosion coexist for steel materials in marine environments. Uniform corrosion is manifested as overall wall thinning, which can be characterized by mass loss or average thickness loss; localized corrosion is represented by pitting corrosion with discretely distributed corrosion pits and significant geometric discontinuities [21, 22]. Typical localized corrosion morphologies are shown in Fig. 1.5. Long-term exposure results indicate that marine corrosion exhibits distinct environmental zoning characteristics and spatial inhomogeneity, with obvious differences in corrosion degree along the height of a single component and at different positions of the same joint [13].

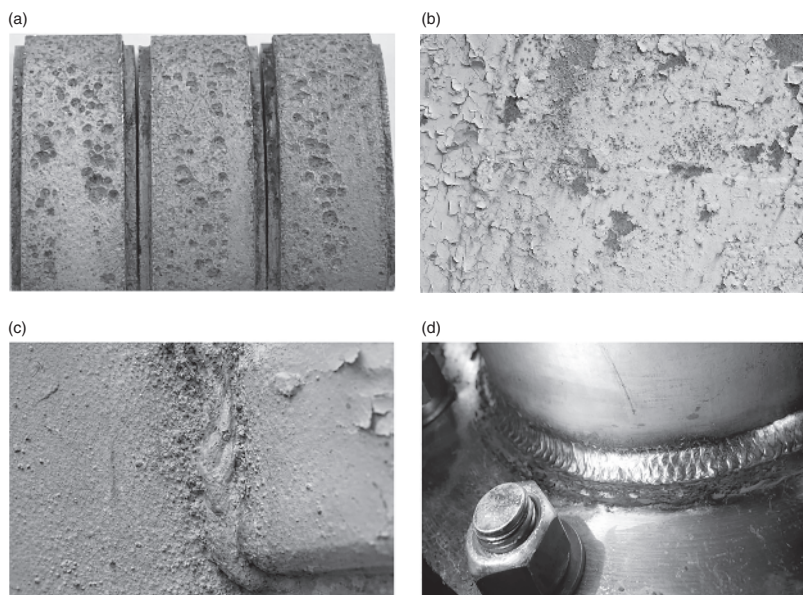


Figure 1.5 Typical localized corrosion morphologies. (a) Pitting corrosion. (b) Coating peeling and rust formation. (c) Crevice corrosion at a structural joint. (d) Corrosion around a welded point. *Source:* (b) Stanislav Samoylik / Adobe Stock Photos.

The inhomogeneity of corrosion morphology serves as an important source of mechanical property discreteness and the control effect of vulnerable parts under corrosive conditions. However, the average corrosion indicators commonly adopted in engineering evaluation are insufficient to reflect the influence of local defects on structural performance alone. Therefore, when adopting accelerated tests to simulate the corrosion process, it is essential to consider characterization parameters of both overall thinning degree and local pitting features, ensuring the consistency of corrosion-state characterization in analysis at both material and structural levels.

The time-dependent evolution law of marine corrosion damage to steel structures lays a fundamental foundation for service life prediction and reliability assessment. Long-term exposure data show that the growth of corrosion depth or mass loss does not follow a simple linear trend over time but presents distinct staged characteristics closely related to the formation of corrosion product layers, transition of oxygen diffusion-controlled stages, and continuous evolution of local defects. Melchers et al. [23–25] proposed multistage or two-stage models based on long-term marine corrosion data to approximate the corrosion loss curve, providing an operable

methodological framework for parameter calibration and life estimation. In addition to the time evolution model of average corrosion loss, researchers have introduced probabilistic methods to regard corrosion loss as a random variable or stochastic process, characterizing both the average trend and dispersion of corrosion damage simultaneously [26–28]. Further studies on corrosion rate and depth models considering dry–wet cycling and coupled tensile stress demonstrate that the time evolution law is closely related to specific exposure scenarios, and its engineering application requires parameter identification combined with environmental type, loading state, and corrosion stage [29]. Overall, in marine atmospheric zones or splash zones with intense salt fog deposition and frequent dry–wet cycling, the average corrosion depth and the maximum local pitting depth evolve in a superimposed manner, among which local extreme values are more likely to dominate the failure risk of vulnerable parts [30].

Beyond the temporal dimension, reasonable characterization of corrosion geometric features is also crucial for mechanical performance evaluation under corrosion. In recent years, statistical characterization and stochastic modeling methods have been widely developed [31]. In terms of pitting geometry description, parameters such as pit depth, pit diameter, and depth-diameter ratio show significant dispersion, among which extreme deep pits dominate structural safety. Hence, the maximum pit depth is often modeled by extreme value theory, with Gumbel and Fréchet distributions as the most common fitting forms [32–35]. Apart from extreme value modeling, surface height field data obtained via three-dimensional laser scanning, white light interferometry, and other measurement technologies can be further adopted to extract amplitude parameters and spatial parameters, comprehensively reflecting the roughness characteristics and spatial distribution laws of corroded surfaces. The ISO 25178 standard system [36, 37] provides a unified definition framework for three-dimensional surface texture parameters, facilitating the comparison and mutual recognition of results among different studies. Furthermore, corrosion depth can be regarded as a spatially correlated random field, and statistical parameters such as correlation function, non-Gaussian characteristics, and spatial intermittency are adopted to characterize corrosion inhomogeneity, enabling corroded surface reconstruction and reliability analysis [38–40].

Hence, existing studies have constructed a systematic analytical framework from multiple perspectives including corrosion mechanism, temporal evolution, and geometric statistical characterization. On the one hand, these studies verify that marine corrosion damage is characterized by staging, randomness, and spatial inhomogeneity; on the other hand, they reveal that describing corrosion state merely by average corrosion depth fails to fully

reflect the control effect of local extreme defects on structural performance. For the Q690 high-strength steel welded joints and CHS T-joints focused in this book, subsequent research needs to balance engineering measurability and local corrosion sensitivity, establishing a corrosion-state characterization method that can reflect both overall thinning degree and local morphological features to support the performance degradation analysis at material and structural levels.

Existing studies have universally confirmed that corrosion leads to the deterioration of elastic modulus, yield strength, and ultimate strength of high-strength steel, among which ductility indicators are more sensitive to corrosion and usually degrade earlier than strength indicators [41–43]. Such degradation is attributed to both the reduction of effective bearing section and local defects formed on corroded surfaces. Especially under pitting-dominated corrosion conditions, stress concentration induced by corrosion pits accelerates crack initiation and propagation, thereby significantly reducing material plasticity and residual bearing capacity [44, 45].

To quantitatively characterize the influence of corrosion geometric defects on material properties, a combined method of morphology measurement-mechanical testing-numerical reconstruction has been widely adopted in recent research. After acquiring the corroded surface height field via three-dimensional surface scanning and other measurement methods, parameters such as pit depth, pit density, and pit morphology can be extracted and further correlated with local strain concentration zones and fracture control characteristics [46–49]. Relevant studies show that with the aggravation of corrosion, the local strain concentration evolves from being controlled by a single deep pit to the interaction of multiple deep pits, resulting in obvious nonlinear degradation of macroscopic mechanical properties.

Apart from base steel materials, welded joints serve as critical vulnerable links in marine steel structures, and their corrosion sensitivity is generally higher than that of the base metal. Microstructural differences, residual stress superposition, and performance gradients among weld metal, HAZ, and base metal lead to prominent regional inhomogeneity of welded joints under marine corrosive environments [50, 51]. Previous studies indicate that the hardness, yield strength, and ductility of Q690 high-strength steel welded joints degrade under corrosion, with obvious differences in corrosion morphology, crack initiation position, and mechanical degradation path among different regions [52, 53].

In actual engineering service scenarios, corrosion rarely acts alone but always couples with external loading, making the deterioration mechanism more complex. In practical marine service environments, stress and corrosion do not act independently, and their synergistic effect often

exceeds the linear superposition of individual factors [54–56]. Existing research reveals that applied stress, prestrain, or preloading not only alters the evolution of steel surface defects and corrosion morphology but also further affects the mechanical property degradation laws of welded joints [57, 58]. For welded structures, the combined effect of residual stress field, material inhomogeneity, and corrosion defects makes welds and HAZs more susceptible to damage in marine environments [54–56]. In addition, welded regions may exhibit higher damage sensitivity under the coupling of stress and corrosion, suggesting that the early failure risk of high-strength steel welded structures in marine corrosive environments cannot be ignored [59]. Although the subsequent research of this book mainly focuses on static axial compression, existing studies confirm that stress background and residual stress distribution affect the evolution of corrosion morphology and material properties. Therefore, the coupling effect of stress and corrosion should not be neglected when analyzing the performance degradation of welded joints and joints under corrosion.

To describe the above mechanical degradation behavior quantitatively, researchers have developed a variety of theoretical models and empirical methods. To meet engineering application demands, researchers have proposed various material property degradation methods, including empirical regression models, semimechanistic models based on morphological parameters, probabilistic constitutive models, and random field models [60, 61]. Overall, existing research provides a certain foundation for the analysis of performance degradation of high-strength steel and welded joints under corrosion. Nevertheless, for Q690 high-strength steel welded joints, there is still a lack of systematic and transferable data support for stably characterizing the degradation differences among base metal, weld metal, and HAZ via engineering-accessible corrosion indicators and transferring relevant parameters to joint-level analysis.

On the basis of material-level research, further attention has been paid to the mechanical performance of steel tubular joints, which are widely used in marine engineering. CHS components are widely adopted as primary load-bearing units in spatial steel structural systems such as offshore platforms, jackets, and offshore wind foundations [62]. Steel tubular joints not only undertake internal force transfer but also serve as key parts controlling local failure modes and deformation capacity. According to the connection form between web members and chord members, steel tubular joints can be classified into T, Y, K, X, and other types. Among them, T-joints feature relatively simple configuration and clear force path, serving as the basic configuration for investigating the mechanical mechanism and design method of steel tubular joints [63, 64]. Under axial

compression of the brace, the mechanical behavior of CHS T-joints presents obvious localization characteristics. The brace load is transferred to the chord surface of the main tubular through welded connections. With the increase of load, local indentation firstly occurs on the chord surface of the main tubular, followed by gradual expansion of the plastic zone; the joint reaches the ultimate bearing state when local plastic development accumulates to a certain extent or the stability of the main tubular wall is lost. Existing studies show that the typical failure modes of uncorroded normal-strength steel T-joints include local plasticization of the main tubular wall, punching shear, and local buckling [65, 66]. These failure modes are significantly affected by geometric parameters: the diameter ratio β influences the load transfer mode between brace and main tubular, while the diameter-to-thickness ratio γ directly determines the local stability of the main tubular. Smaller β or larger γ makes joints more prone to punching shear or local buckling, whereas higher local stiffness of the main tubular tends to make main tubular plasticization the dominant failure mode [67–70]. Further numerical analysis indicates that the joint response can be generalized into three stages: linear elasticity, local plastic development, and ultimate instability, with stage transition closely related to failure modes such as local buckling and punching shear [71].

Supported by abundant experimental data, relevant design specifications have formed mature calculation systems for tubular joints. Current design methods for tubular joints are mainly established based on experimental databases. The design recommendations proposed by CIDECT [6] establish prediction formulas for bearing capacity through regression analysis of a large number of experimental data, which are adopted by Eurocode 3 [72], ISO 19902 [3], and other specifications. Taking main tubular plasticization and punching shear as the main limit states, this method possesses strong engineering operability and serves as an important foundation for the design and evaluation of steel tubular joints.

With the popularization and increasing application of high-strength steel in marine engineering, its unique mechanical characteristics bring new challenges to the traditional design theory of tubular joints, and the influence of material strength grade on joint behavior has attracted growing attention. Existing studies show that although the ultimate bearing capacity of high-strength steel CHS joints is improved, their ductility reserve is significantly reduced, strain concentration is more likely to occur in the plastic stage, and plastic development in the indentation zone is easily restricted [73–76]. Further research points out that the increase in material strength cannot be proportionally converted into the improvement of joint bearing capacity; when the yield strength reaches a certain level, the growth rate

of bearing capacity slows down, and the joint response is more dominated by local stability [77]. This implies that design formulas established based on the normal-strength steel database may produce systematic deviations when applied to high-strength steel, and the bearing capacity evaluation results are more sensitive to the selection of ultimate state criteria, making it necessary to further assess the safety margin through experimental calibration or reliability analysis [74, 78]. With the in-depth understanding of high-strength steel joint behavior, the adoption of deformation limit or strain limit as the ultimate state criterion has gained increasing attention. Relevant studies confirm that introducing deformation or strain limit criteria in the analysis of high-strength steel CHS joints helps accurately define the ultimate bearing state and characterize the evolutionary characteristics of structural response in the material nonlinear stage [79]. Therefore, it is essential to clarify the selection of ultimate criteria and their corresponding safety implications in the design and evaluation of high-strength steel joints. Overall, the mechanical mechanism, parametric influence law, and design method system of uncorroded CHS T-joints have been well established, providing a benchmark state and comparative framework for the research of corroded joints. However, systematic understanding of the ductility reserve, ultimate criteria, and applicability of design formulas for high-strength steel joints is still insufficient, which also forms an important research background for subsequent studies on corroded joints.

Compared with the ideal uncorroded state, long-term marine service environments inevitably induce corrosion damage to tubular joints and further deteriorate their mechanical performance. In marine environments, steel tubular joints are inevitably exposed to salt fog, dry-wet cycling, and splash erosion for a long time. Corrosion not only causes average wall thinning but also forms local pitting and geometric discontinuities, altering the force path, stiffness distribution, and failure mode of key joint regions. Compared with uncorroded joints, both geometric morphology and material properties of corroded joints degrade, leading to significant reduction of bearing capacity and deformation capacity. Existing studies on corroded steel tubular components show that wall thinning weakens the effective bearing section and local stability, resulting in nonlinear degradation of ultimate bearing capacity [80–82]. For joints, when local pitting is located at weld toes or key bearing areas on the chord surface of the main tubular, it further induces local stress and deformation concentration, shifting the failure mode from main tubular plasticization to local buckling or punching failure [83–85]. Therefore, the influence of corrosion is reflected not only in geometric weakening but also in local defect effects, enhanced stability sensitivity, and reduced ductility reserve.

To quantitatively evaluate the mechanical performance of corroded tubular joints, scholars have proposed multiple analytical approaches with respective advantages and limitations. In terms of analytical methods for corroded joints, existing research mainly includes the equivalent wall thickness method, explicit corrosion geometric modeling method, and stochastic corrosion modeling method. The equivalent wall thickness method reflects the corrosion influence through uniform wall thickness reduction, featuring simple calculation, and high engineering operability, but it cannot fully reflect the local stress concentration and leading failure zone caused by severe pitting corrosion. The explicit corrosion geometric modeling method can more realistically simulate the influence of local pits and inhomogeneous thinning on structural response, yet it imposes high requirements on geometric information acquisition, parametric modeling, and computational cost. The stochastic corrosion modeling method can further consider the spatial inhomogeneity and uncertainty of corrosion damage, presenting advantages in reliability analysis, while its engineering application is limited by morphological data and parameter identification conditions [86].

Nevertheless, the existing design methods still cannot fully adapt to the performance evaluation of corroded high-strength steel tubular joints. From the perspective of design methods, current bearing capacity formulas for steel tubular joints are mainly established based on uncorroded normal-strength steel experimental databases, with basic assumptions including uniform wall thickness, ideal geometric morphology, and initial material property parameters. These assumptions are no longer valid when joints suffer corrosion damage during service. The equivalent wall thickness reduction method is commonly adopted in engineering to address corrosion influence, but local pitting, material ductility degradation, and enhanced stability sensitivity cannot be fully reflected merely by thickness reduction, especially for thin-walled high-strength steel joints. In summary, research on corroded steel tubular joints has made certain progress. Nevertheless, systematic experimental data and revised methods applicable to engineering evaluation under the coupling effect of high-strength steel and marine corrosion are still insufficient. How to organically combine controlled corrosion tests, morphological measurement, and joint performance degradation analysis while ensuring engineering operability remains a key issue in current research.

Based on the above systematic review, the overall research progress can be summarized to clarify the existing research gaps. Comprehensive review of the above studies shows that relatively systematic research foundations have been established in terms of marine corrosion mechanism, corrosion morphology characterization, mechanical property degradation of

high-strength steel and welded joints, as well as the mechanical mechanism and design methods of uncorroded CHS T-joints. Particularly for uncorroded normal-strength steel joints, the bearing capacity prediction formulas and ultimate state analysis methods for steel tubular joints are mature, providing an important reference framework for subsequent research on corroded joints.

Despite the above research achievements, there still exist obvious research deficiencies when focusing on the targeted research object of this book. However, when the research scope is further narrowed to Q690 high-strength steel welded steel tubular joints under marine corrosive environments with CHS T-joints under axial compression of the brace as the typical working condition, existing research still has three deficiencies: first, there is a lack of stable and calibratable correlation between corrosion-state characterization and material degradation law, especially insufficient systematic data support for the degradation differences in different regions of welded joints; second, the degradation law at the material level has not been fully transferred to the joint level, and the coupling relationship among local corrosion geometry, material ductility degradation, and joint bearing-deformation degradation remains unclear; third, although current design formulas and simplified equivalent wall thickness methods possess engineering operability, the deviation sources, applicable boundaries, and revision paths under the combined action of high-strength steel and corrosion remain to be further clarified.

In view of the above research deficiencies, the rationality of selecting CHS T-joints as the research object can be further illustrated. The selection of CHS T-joints under axial compression of the brace as the typical research object in this book is mainly based on the following considerations: first, T-joints feature a concise configuration and a clear force path, facilitating the establishment of a definite parameter transfer relationship among material degradation, corrosion geometric weakening, and local joint response; second, typical phenomena such as local indentation of the main tubular chord surface, plastic expansion, and local instability under brace axial compression can well reflect the degradation characteristics of key force-transfer regions of joints under corrosion; third, T-joints and their axial compression working conditions form an important basis for the existing steel tubular joint experimental database and design formulas, which is convenient for comparing the experimental results of this book with current methods such as CIDECT and providing a direct basis for the subsequent proposal of revised models. Therefore, conducting research around this typical joint configuration and loading condition not only has clear mechanical pertinence but also facilitates connection with the existing design system.

Correspondingly, the core research idea and scientific problems of this book are further refined on the basis of the above research gaps. Accordingly, subsequent research needs to not only clarify the degradation mechanism of material properties after corrosion but also further reveal how such degradation is transferred to structural-level response through welded joints and key force-transfer regions of joints. Especially for thin-walled high-strength steel tubular joints, there is a stronger coupling effect among material property changes, local corrosion geometric weakening, and stability control mechanisms, which constitutes the core problem to be addressed in this book.

1.3 Key Scientific Problems and Deficiencies of Existing Research

Marine engineering structures serve under long-term corrosive environments and complex loads, with obvious time-varying performance evolution characteristics. For welded steel tubular joints adopting high-strength steel materials, joints undertake internal force transfer and are located in regions with geometric discontinuity, residual stress concentration, and high corrosion sensitivity, making their performance degradation more likely to be locally amplified and affect the overall structural safety. Combined with the aforementioned engineering background and research status, this book focuses on the following key scientific problems:

- 1) Marine corrosion is characterized by staging and spatial inhomogeneity, and microstructural differences in welded regions and residual stress fields further complicate local response. For Q690 high-strength steel, yield behavior, strain hardening capacity, and ductility reserve may change significantly with the aggravation of corrosion. How to stably characterize the mechanical property degradation of base metal and different regions of welded joints via engineering-accessible corrosion indicators lays a foundation for subsequent structural-level analysis.
- 2) The bearing capacity of steel tubular T-joints and Y-joints originates from the combined action of material properties, geometric parameters, and internal force-transfer mechanism. Under axial compression of the brace, corrosion-induced wall thinning, local pitting, and weakening of welded details may alter the local stiffness distribution and the position of vulnerable zones of joints, further affecting their failure modes, bearing capacity, and deformation capacity. Revealing the influence laws of corrosion geometric weakening on joint performance degradation and explaining the variation mechanism of joint response combined with

material-level test results is a crucial issue connecting material-level and structural-level research.

- 3) Current calculation methods for bearing capacity of steel tubular joints are mainly established based on uncorroded normal-strength steel experimental databases, with basic assumptions including uniform wall thickness, ideal geometric morphology, and initial material property parameters. The wall thickness reduction or equivalent section method is commonly adopted in engineering to address corrosion influence, yet local pitting, ductility degradation, and enhanced stability sensitivity cannot be fully reflected by a single geometric reduction. How to identify the deviation sources of current models while maintaining engineering operability and propose a calibratable and verifiable revision path is essential for engineering application.

Extensive studies have been conducted on steel corrosion behavior, welded joint performance, and bearing capacity of steel tubular joints, forming a mature research foundation. However, when the research scope is limited to Q690 high-strength steel welded steel tubular joints under marine corrosive environments with CHS T-joints under brace axial compression as the typical working condition, existing achievements still have the following deficiencies:

- 1) Most research on corroded material properties focuses on normal-strength steel, and the corrosion degree is mostly characterized by mass-loss rate or average thickness reduction, with insufficient attention paid to corrosion degradation under applied stress or preloading. There is a lack of systematic data on the degradation law of yield strength, strain hardening capacity, and ductility indicators of high-strength steel under the coupling of stress and corrosion, especially the degradation data of constitutive parameters directly related to subsequent structural analysis, which fails to form a stable and transferable parameter calibration foundation.
- 2) Welding residual stress and material inhomogeneity significantly affect local stress distribution and corrosion sensitivity, yet systematic quantification of degradation differences among weld metal, HAZ, and base metal is insufficient in existing research. Particularly in marine environments, the superimposed effect of local corrosion defects at weld toes and HAZs, residual stress, and applied stress background on local damage evolution and mechanical property degradation lacks reliable input for joint analysis.
- 3) Research on the bearing performance of uncorroded steel tubular T-joints is mature, but experimental and analytical evidence on the

evolution of corrosion-induced joint failure modes, advanced local buckling, and ductility degradation is still limited. Most existing studies simulate corrosion merely through geometric reduction, which cannot fully reflect the combined influence of local pitting and material property degradation; systematic evidence on the transition of control mechanism of high-strength steel joints under corrosion is particularly scarce.

- 4) Current bearing capacity formulas for steel tubular joints are generally established based on uncorroded component experimental databases, ignoring the influence of material property variation with corrosion degree. Engineering practices often adopt wall thickness reduction or equivalent section methods to consider corrosion effects, while the contribution of material strength and ductility degradation to joint bearing capacity is often not identified separately. How to establish a revised relationship considering both corrosion degree and material property variation within the current design framework and verify its applicability through experiments remains to be further studied.

From the perspective of research logic, the above deficiencies are not isolated but collectively reflect the insufficient connection in the research chain of corrosion-state characterization, material degradation identification, joint response analysis, and engineering model revision. If only focusing on the strength reduction of corroded materials without establishing the transfer relationship with local mechanical behavior of joints, it is difficult to explain the source of degradation of joint bearing and deformation capacity; if only analyzing joint response through geometric reduction while ignoring the deterioration of material properties in welded joint regions and their spatial differences, the control effect of key vulnerable parts is likely to be underestimated. Therefore, it is necessary to carry out comprehensive research around this chain to form a mutually corresponding and verifiable analysis framework among corrosion state, material degradation, and joint performance, so as to further support the revision of design methods and engineering evaluation.

In conclusion, conducting systematic research on the correlation among corrosion-state characterization, material degradation, and axial compression response of joints, and establishing a calibratable and verifiable revised model within the current design framework are the key directions to improve the reliability of performance evaluation for high-strength steel tubular joints in marine environments.