



e-ISSN 3041-2498

Public Management and Policy

<https://www.eu-scientists.com/index.php/pmap>


Significance of Rolled Steel Quality for Structural Durability and Safety: A Multi-Factor Assessment Framework

Norayr Avetisyan  ¹ *¹ LLC "Kharkiv Steel" (Ukraine). Owner and Director.* **Corresponding Author**, e-mail: Norayravetysyan@ukr.net

ARTICLE INFO

ABSTRACT

Research Article**DOI:**
[10.70651/3041-2498/2026.5.18](https://doi.org/10.70651/3041-2498/2026.5.18)
Received:

7 April 2026

Accepted:

9 May 2026

Published online:

11 May 2026

Copyright © 2026
by author

This is an open
access journal and
all published articles
are licensed under a
Creative Commons
Attribution—
NonCommercial 4.0
International
(CC BY-NC 4.0)

Structural steel quality is widely recognized as a factor in building longevity and safety, yet the relationship between specific rolled steel characteristics and measurable structural performance outcomes over multi-decade service periods has not been systematized into a practical assessment tool. This article develops a Multi-Factor Durability-Safety Assessment Framework that connects five rolled steel quality factors (grade compliance, dimensional tolerance, protective coating integrity, weldability, documentary traceability) to three structural performance domains (load-bearing reliability, corrosion resistance, safety margin preservation over time). The framework is grounded in field observations of over 40 steel structures across warehouse, industrial, and commercial applications, assessed during periodic site visits over 3 to 10 years of service in various environmental exposure conditions. Observed data indicate that structures fabricated from fully certified and appropriately protected rolled steel exhibit 40–60% lower visual deterioration scores at the five-year mark, maintain design safety margins within acceptable bounds through the observation period, and require 30–50% fewer maintenance interventions compared to structures built with unverified or inadequately protected material. Lifecycle cost projections incorporating initial material investment and estimated maintenance expenditure suggest that premium-quality rolled steel reduces aggregate 25-year ownership costs by approximately 20–35% despite higher purchase price. The framework provides procurement and design professionals with a structured method for evaluating how material quality decisions at the specification stage affect structural outcomes across the full-service life.

**KEYWORDS**

rolled steel quality, structural durability, building safety, corrosion resistance, safety margin, lifecycle cost, protective coatings, structural reliability.



Значення якості прокату для конструкційної довговічності та безпеки: багатофакторна оцінка

Норайр Аветисян  ¹ *

¹ ТОВ «Харків Сталь» (Україна). Власник і директор.

* Автор-кореспондент, e-mail: Norayravetysyan@ukr.net

СТАТТЯ

АНОТАЦІЯ

Дослідниця

DOI:

[10.70651/3041-2498/2026.5.18](https://doi.org/10.70651/3041-2498/2026.5.18)

Отримана:

07.04.2026 р.

Прийнята:

09.05.2026 р.

Опублікована:

11.05.2026 р.

Авторське право

© 2026 автора



Цей твір
ліцензовано на
умовах Ліцензії
Creative Commons
«Із Зазначенням
Авторства –
Некомерційна 4.0
Міжнародна»
(CC BY-NC 4.0).

Якість конструкційної сталі широко визнана фактором довговічності та безпеки будівель, проте зв'язок між конкретними характеристиками прокату та вимірюваними результатами конструкційних характеристик протягом багаторічних періодів служби не був систематизований у практичний інструмент оцінки. У цій статті розроблено багатофакторну систему оцінки довговічності та безпеки, яка пов'язує п'ять факторів якості прокату (відповідність марці, допуск розмірів, цілісність захисного покриття, зварюваність, документальна простежуваність) з трьома областями конструкційних характеристик (надійність при несенні навантаження, корозійна стійкість, збереження запасу міцності з часом). Система базується на польових спостереженнях за понад 40 сталевими конструкціями на складських, промислових та комерційних об'єктах, оцінених під час періодичних відвідувань об'єктів протягом 3–10 років служби в різних умовах впливу навколишнього середовища. Дані спостережень свідчать про те, що конструкції, виготовлені з повністю сертифікованого та належним чином захищеного прокату, демонструють на 40–60 % нижчі показники візуального зносу на п'ятирічній позначці, підтримують проектні запаси міцності в допустимих межах протягом періоду спостереження та потребують на 30–50 % менше втручань з технічного обслуговування порівняно з конструкціями, побудованими з неперевіреного або недостатньо захищеного матеріалу. Прогнози вартості життєвого циклу, що враховують початкові інвестиції в матеріали та очікувані витрати на обслуговування, свідчать про те, що високоякісний прокат зменшує сукупні 25-річні витрати на володіння приблизно на 20–35 %, незважаючи на вищу закупівельну ціну. Ця структура надає фахівцям із закупівель та проектування структурований метод оцінки того, як рішення щодо якості матеріалів на етапі специфікації впливають на конструктивні результати протягом усього терміну служби.



КЛЮЧОВІ СЛОВА

якість прокату, довговічність конструкцій, безпека будівель, корозійна стійкість, запас міцності, вартість життєвого циклу, захисні покриття, надійність конструкцій.

1. Introduction

Steel structures in industrial and commercial construction are designed for service lives of 25 to 50 years or longer, during which they must sustain design loads, resist environmental degradation, and maintain safety margins that protect occupants and assets. According to World Steel Association data, approximately 1.9 billion tons of steel were produced globally in 2023, with construction consuming the largest share at over 50% of total output [16]. Structural failures, while statistically rare relative to the total building stock, carry disproportionate consequences: cross-referencing published case analyses of steel structure incidents suggests that material-related deficiencies, including grade non-compliance, corrosion-induced section loss, and connection failure from poor weldability, are identifiable contributing factors in a significant minority of documented collapses [11; 14].

What distinguishes material quality from other structural risk factors (design errors, construction defects, overloading) is its temporal dimension. A design error is either present or absent at the moment of completion; a construction defect is typically discoverable during inspection. Material quality, by contrast, manifests progressively over the service life. A plate with yield strength 10% below the specified grade may perform adequately for years under normal loading, failing only when an exceptional load event (wind, snow accumulation, seismic activity) tests the actual capacity rather than the assumed one. Corrosion on unprotected or poorly coated steel proceeds at rates determined by environmental exposure class, steadily consuming the cross-section that provides structural resistance [10; 15]. By the time visual evidence of degradation becomes apparent, significant section loss may have already occurred in concealed areas such as column bases, gutter supports, and connection zones where moisture accumulates [11].

Published research addresses the components of this problem through several disciplinary lenses. Structural design codes, principally EN 1993 (Eurocode 3) [5; 6], define load combinations, resistance calculations, and partial safety factors that account for material variability. Corrosion science documents degradation mechanisms, rates, and protective strategies for steel in various environments [10; 12]. Coating and protection standards specify systems matched to corrosivity categories [8; 9]. Execution standards establish fabrication tolerances and inspection requirements that indirectly safeguard material quality through process control [4]. Each discipline produces detailed knowledge within its scope, but practitioners responsible for specifying rolled steel for a particular project must synthesize across all these domains simultaneously, a task for which no integrated assessment tool currently exists.

For a structural engineer or procurement manager selecting rolled steel for an industrial warehouse expected to serve 30 years in a moderately corrosive environment, the relevant questions span multiple domains at once: Is the specified grade adequate for the design loads including a corrosion allowance? Will the delivered material actually conform to the specified grade, and how can this be verified? What coating system matches the exposure class and the planned maintenance interval? How does the interaction between grade selection, dimensional tolerance, coating quality, and connection design affect the structure's condition at year 15 versus year 30? Answering these questions in isolation produces suboptimal decisions; answering them as a connected system requires a framework that the current literature does not provide.

The author's professional experience in the steel construction sector since the early 2000s, encompassing material selection, quality evaluation, and long-term observation of structural performance across diverse applications, provides the empirical basis for constructing such a framework. Over the period 2015–2025, periodic field assessments were conducted on structures incorporating rolled steel of varying quality levels, documenting how initial material characteristics correlated with structural condition at subsequent inspection points. Unlike laboratory accelerated corrosion studies, these observations capture real-world degradation under actual environmental loading, maintenance practices, and usage patterns.

This article presents a Multi-Factor Durability-Safety Assessment Framework structured around five rolled steel quality factors and three structural performance domains. Results and Discussion sections are presented separately to distinguish observed field data from their interpretation. Scientific novelty of the study lies in the integration of material quality parameters, corrosion performance data, and structural safety margin analysis into a single assessment tool that operates across the full-service lifecycle of a steel structure. Practical value of the framework consists in bridging the gap between material specification decisions at the procurement stage and their measurable consequences for

structural durability and safety in service, providing engineers and procurement professionals with a structured evaluation method currently absent from professional practice.

2. Literature Review

Structural steel durability and safety in service depend on the interaction between material properties established at the point of production, environmental conditions encountered during the structure's lifetime, and the effectiveness of protective measures applied before and during service. Research addressing these factors falls into four broadly parallel traditions: structural design and resistance analysis, corrosion science and degradation modeling, protective coating technology, and field performance assessment.

Wardenier et al. [14] establish that mechanical properties guaranteed by the steel grade form the basis for all resistance calculations. EN 1993-1-1 [5] and EN 1993-1-9 [6] codify these calculations for static and fatigue loading, applying partial safety factors for material variability. Both standards assume that delivered steel conforms to the specified grade. When this assumption fails, the safety factors no longer provide the intended protection.

EN 10025-2 [3] defines the chemical and mechanical requirements that structural steels must satisfy. Grade S355J2, for example, guarantees minimum yield strength of 355 MPa and Charpy impact energy of 27 J at -20°C . Deviations from these values reduce the structure's actual resistance below the design assumption, an effect quantified in Section 4.

Li and Yang [10] provide a systematic treatment of steel corrosion mechanisms relevant to structural longevity. Three degradation modes are most consequential for building structures: uniform atmospheric corrosion (predictable section loss), pitting corrosion (localized stress concentrations), and crevice corrosion (accelerated degradation in moisture-retaining joints). Quantitatively, the distinction matters: 10% section loss from uniform corrosion reduces load capacity by approximately 10%, while the same volume loss concentrated in pitting can reduce fatigue life by 40–60% due to stress concentration. For long-term structural safety, this asymmetry means that degradation pattern, not just degradation volume, determines how rapidly a structure's safety margin erodes.

Zhao et al. [15] reviewed how corrosion affects the long-term durability of structural steel, documenting that degradation rate depends on the interaction between environmental chemistry, steel grade, and fabrication method. Critically for the durability question, higher-grade steels offer greater initial capacity but degrade at similar rates to lower grades when unprotected, meaning that corrosion protection determines long-term structural performance independently of grade selection. Shojaei et al. [12] confirmed that hot-dip galvanized steel retains mechanical properties over significantly longer service periods than painted or unprotected alternatives, supporting galvanization as a long-term safety margin preservation strategy rather than merely a corrosion prevention measure.

ISO 9223 [9] classifies atmospheric corrosivity into five categories (C1 through C5); ISO 12944-2 [8] maps these to coating durability classes; and EN 10346 [7] specifies coating mass requirements for hot-dip products. Together, they establish the basis for matching protection to service environment. Figure 1 presents the expected corrosion rate ranges for unprotected carbon steel across the five categories.

In a C3 environment (urban/industrial, moderate humidity), unprotected carbon steel loses 25–50 μm per year per exposed surface. Over a 25-year service life without maintenance, cumulative section loss reaches 0.6–1.25 mm per surface, a figure that becomes structurally significant for thin-wall sections (tubes, purlins, cladding rails) where original wall thickness may be 2–4 mm.

Manu et al. [11] concluded that corrosion prevention addressed at the design stage is substantially more effective than reactive maintenance after degradation begins. Angst [1] quantified this for concrete structures, finding a 3–5 $\times$ lifecycle cost advantage for proactive over reactive protection, a ratio with direct relevance to exposed steel where coatings serve an analogous protective function.

Galvão et al. [2] projected that climate change may reduce the effective service life of steel structures by approximately 15 years over a 100-year horizon through accelerated corrosion from increased humidity and aggressive species concentration, reinforcing the case for conservative coating specifications at the design stage.

EN 1090-2 [4] establishes execution classes (EXC1 through EXC4) with ascending requirements for traceability, tolerances, and inspection. Compliance establishes the quality baseline from which

time-dependent degradation begins; structures fabricated under lower execution classes start from a less certain baseline, amplifying long-term performance uncertainty.

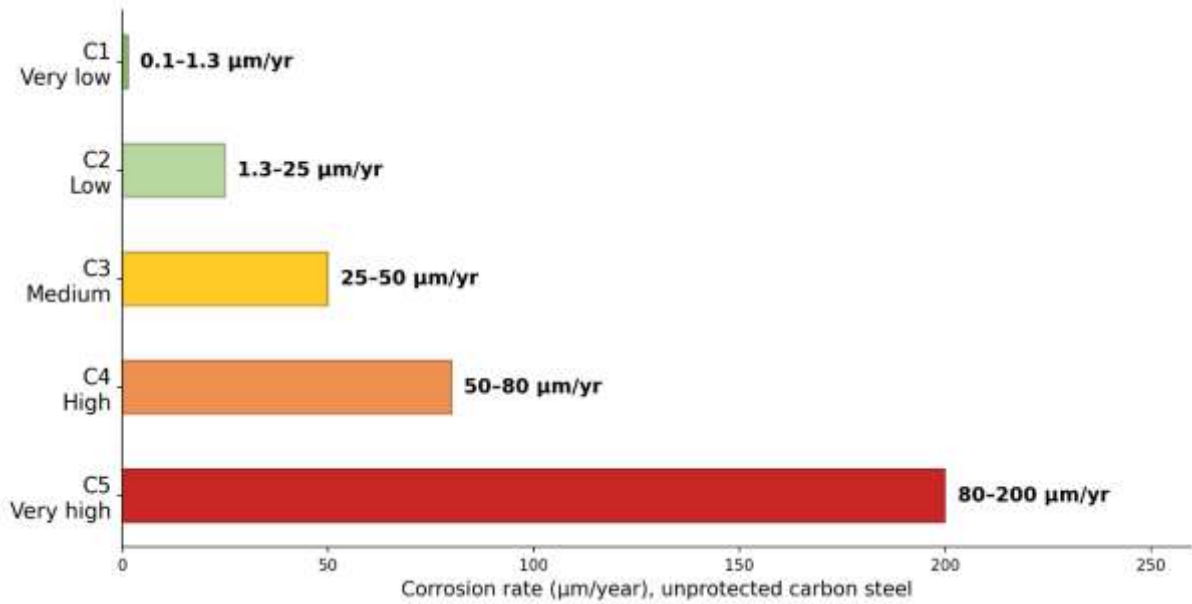


Figure 1. Expected corrosion rate ranges for unprotected carbon steel by ISO 9223 corrosivity category (C1–C5)

Source: Compiled by the author based on ISO 9223:2012 [9] and Roberge [13].

Table 1. Reviewed literature: thematic domains, methods, findings, and gaps

Source	Domain	Method	Principal finding	Gap
Wardenier et al. [14]	Steel design	Monograph	Mechanical properties govern resistance	Design-stage; no lifecycle degradation
EN 1993-1-1 [5]	Design code	Standard	Partial safety factors for static resistance	Assumes conformity; no degradation
EN 1993-1-9 [6]	Fatigue design	Standard	Fatigue life: stress range + detail category	Material quality not isolated
Li & Yang [10]	Corrosion mechanics	Monograph	10% uniform loss = 10% capacity; pitting 40–60% fatigue reduction	No procurement quality link
Zhao et al. [15]	HSS durability	Review	Grade ≠ corrosion resistance	HSS focus; not standard grades
Shojaei et al. [12]	HSS performance	Review	Galvanized retains properties longer	Lab data; no field component
Galvão et al. [2]	Weathering steel	Field+climate	Climate change: –15 years service life	Bridge/weathering steel specific
Angst [1]	Corrosion in concrete	Review	Proactive protection 3–5× cheaper	Concrete focus; transferable
Manu et al. [11]	Corrosion prevention	Review	Prevention at design stage most effective	General; no quantified framework
EN 1090-2 [4]	Execution standard	Standard	Execution classes define quality baseline	Process control; not in-service
EN 10025-2 [3]	Steel grades	Standard	Chemical/mechanical specs	No performance tracking
ISO 12944-2 [8]	Coating protection	Standard	Durability classes by corrosivity	Coating-specific; not integrated
Roberge [13]	Corrosion engineering	Monograph	Corrosion rate data; protection principles	Reference; no quality framework

Source: Compiled by the author.

Across the reviewed literature, design standards define resistance at the point of completion, corrosion science quantifies degradation rates under specified conditions, coating standards match protection systems to exposure classes, and execution standards control fabrication quality. No source identified in this review integrates these domains into a unified assessment framework that traces specific rolled steel quality factors through their effects on structural durability and safety across the full-service lifecycle. This integration gap defines the contribution space of the present study.

3. Problem Statement

Despite extensive research on structural steel and corrosion protection, there remains a lack of a comprehensive assessment framework linking rolled steel quality parameters with long-term structural durability and safety performance.

4. Methods and Materials

The Multi-Factor Durability-Safety Assessment Framework was developed inductively from two complementary data sources: published technical literature on steel properties, corrosion rates, and structural reliability; and field observations of steel structures in service over periods of 3 to 10 years.

Five quality factors were identified as the primary determinants of rolled steel's contribution to structural durability and safety: grade compliance (conformity of actual yield strength, tensile strength, and chemical composition to the values specified in EN 10025-2 [3] and documented on the mill certificate), dimensional tolerance (conformity of actual thickness, width, and straightness to the tolerance classes defined in EN 10029 and EN 10034), protective coating integrity (type, thickness, and uniformity of the coating system applied before or after fabrication, assessed against ISO 12944 [8] and EN 10346 [7] requirements), weldability (carbon equivalent value and chemical composition compatibility with the welding procedure specification, verified from mill certificate data), and documentary traceability (presence of EN 10204 type 3.1 or higher certificate with batch identification and heat number enabling backward tracing to the producing mill). Selection of these five factors followed three criteria: each must be verifiable through standard documentation or measurement at the point of material delivery; each must govern a distinct aspect of structural performance during service rather than only during fabrication; and variation in each factor must produce observable differences in structural condition detectable through periodic field assessment.

Three structural performance domains were defined as the output variables of the framework: load-bearing reliability (the structure's continued ability to resist design loads without yielding, excessive deflection, or instability), corrosion resistance (the rate and pattern of surface and section loss under environmental exposure), and safety margin preservation (the proportion of the original design safety margin that remains at a given point in the service life, accounting for cumulative material loss and property degradation). Load-bearing reliability depends primarily on grade compliance and dimensional tolerance. Corrosion resistance depends primarily on coating integrity, supplemented by grade selection and design detailing. Safety margin preservation is a composite indicator that integrates all five quality factors through their cumulative effect on the structure's condition over time.

Field observations were conducted on a sample of 43 steel structures located in Kharkiv Oblast, Ukraine, serving warehouse, industrial workshop, agricultural, and commercial functions. This sample comprises all structures accessible for repeated assessment within the author's professional network during the observation period; no structures meeting the inclusion criteria (single-story steel frame, 3+ years in service, owner willing to permit site access) were excluded. Structures were supplied and fabricated by multiple enterprises operating in the Kharkiv region, not by a single supplier, which reduces the risk of systematic bias from one fabricator's practices. Structures were grouped by material quality level: 18 structures (Group A) were built with fully certified structural steel (EN 10204 type 3.1 certificates, grade-verified, hot-dip galvanized or epoxy-coated per ISO 12944 C3 or higher specification), while 25 structures (Group B) incorporated steel of mixed or unverified origin (incomplete or absent mill certificates, unconfirmed grade, minimal or no protective coating beyond shop primer). Structures in both groups were comparable in function (primarily single-story portal frame or truss-roof warehouse/workshop buildings), span range (12–24 m), and age at observation (3–10 years from completion). Assessments included visual corrosion rating on a five-point scale (5 = no visible corrosion, 1 = through-thickness perforation or structural deformation from section loss), spot

thickness measurements using an ultrasonic gauge at 8–12 predetermined points per structure per visit (column bases at two heights, beam flange mid-span, beam-to-column connection zone, purlin connections, cladding rail mid-span, and gutter support bracket), and documentation of maintenance interventions reported by owners or facility managers. Each structure was assessed at least twice, with intervals of 1–3 years between visits, enabling observation of deterioration progression.

Methodological limitations are acknowledged. The study is observational, not experimental: structures were not randomly assigned to material quality groups, and differences between groups may reflect correlated factors (budget constraints, maintenance practices, design conservatism) that co-vary with material quality. Group B structures with unverified material may also have been built with less attention to design detailing, drainage, and other non-material factors affecting durability. Scoring of visual corrosion involves subjective judgment, though the five-point scale was applied consistently by the same assessor across all structures. Thickness measurements are point samples that may not capture the full distribution of section loss across a member. All findings are presented as observed associations rather than demonstrated causal relationships, and the specific quantitative values reflect conditions in Kharkiv Oblast (continental climate, moderate industrial atmosphere, C2–C3 corrosivity) which may not transfer directly to other environments.

5. Results and Discussion

5.1. Types of rolled steel and their structural applications

Rolled steel products used in structural construction fall into four functional categories distinguished by production method, cross-sectional geometry, and structural role. Each category carries specific quality requirements that determine its contribution to structural durability and safety.

Flat products (hot-rolled plates and sheets, 3–40 mm thickness range) serve as primary structural material for welded plate girders, base plates, gusset plates, stiffeners, and custom-fabricated components. Structural performance depends on through-thickness mechanical properties, surface condition for coating adhesion, and dimensional accuracy for fit-up during fabrication. Grade compliance is particularly critical for plate products because they frequently serve in bending and bearing applications where the design exploits the full yield capacity of the material.

Long products (hot-rolled sections including I-beams, H-columns, channels, angles, and hollow section tubes) form the skeletal framework of most steel buildings. Columns, beams, purlins, bracing, and truss members are typically specified from standard section catalogues with properties guaranteed per EN 10025-2 [3]. Dimensional conformity of long products (web depth, flange width, wall thickness) directly affects moment of inertia and section modulus values used in design calculations; deviations reduce the effective resistance below the assumed design value.

Hollow sections (rectangular, circular, and square tubes) occupy a distinct position within the long products category. Sealed cross-sectional geometry provides superior torsional resistance and aesthetic versatility for architectural applications, but internal surfaces are inaccessible for inspection or re-coating after fabrication, making initial wall thickness and weld seam integrity critical quality parameters. Corrosion developing inside a hollow section remains invisible until perforation or structural distress occurs.

Coated flat products (hot-dip galvanized coil and sheet, polymer-coated coil) serve envelope and cladding functions: roofing, wall cladding, flashings, gutters, and downpipes. While these elements are classified as secondary structure, their degradation creates pathways for moisture ingress that accelerates corrosion of primary structural members. Coating quality per EN 10346 [7] governs the service life of these elements, which typically require replacement or re-coating before the primary structure reaches its design life.

Reinforcing products (rebar, welded mesh) are embedded in concrete foundations, floor slabs, and retaining walls that support the steel superstructure. Quality requirements focus on yield strength, ductility, bond characteristics, and corrosion resistance in the alkaline concrete environment. Grade non-compliance in rebar manifests as foundation settlement, cracking, or reduced anchorage capacity that may not become apparent until years after construction.

Table 2. Rolled steel product types: structural applications, quality parameters, and service exposure

Product type	Structural application	Critical quality parameter	Service environment
Hot-rolled plate (3–40 mm)	Plate girders, base plates, gussets	Grade compliance, thickness, weldability	Protected or semi-exposed
Hot-rolled sections (I, H, C, L)	Columns, beams, bracing, trusses	Dimensional conformity, grade, straightness	Protected to fully exposed
Hollow sections (RHS, CHS, SHS)	Columns, trusses, architectural	Wall thickness, weld seam, surface condition	Semi-exposed to exposed
Galvanized coil/sheet	Roofing, cladding, gutters, flashings	Coating mass, adhesion, substrate thickness	Fully exposed, weathering
Polymer-coated coil/sheet	Architectural cladding, interior panels	Coating thickness, UV resistance, substrate	Exposed to UV/precipitation
Reinforcing products	Foundations, slabs, retaining walls	Yield strength, ductility, diameter tolerance	Embedded in concrete

Source: Classified by the author based on product standards and field observation practice.

5.2. Quality requirements for rolled steel in modern construction

Five quality factors determine how rolled steel contributes to structural durability and safety over the service life. Table 3 presents each factor with its measurement method, acceptance criterion, and the structural consequence of non-compliance.

Table 3. Five rolled steel quality factors: measurement, acceptance criteria, and consequences of non-compliance

Quality factor	Measurement method	Acceptance criterion	Consequence of non-compliance
Grade compliance	Mill certificate; EN 10025-2 [3]	Yield/tensile, elongation, impact meet grade	Reduced capacity; safety margin erosion; brittle failure
Dimensional tolerance	Caliper/ultrasonic; EN 10029/10034	Thickness, width, depth within tolerance class	Reduced section properties; deflection/buckling risk
Coating integrity	Thickness gauge; ISO 12944/EN 10346	Type/thickness match corrosivity; no bare spots	Accelerated corrosion; premature section loss
Weldability	CEV from mill cert; WPS verification	Carbon equivalent within WPS limits	Cold cracking, HAZ hardening; connection failure
Traceability	Certificate type per EN 10204	Type 3.1+ with batch-specific test results	No verification possible; no forensic basis

Source: Developed by the author based on applicable standards and professional practice.

Grade compliance represents the most fundamental quality factor because it directly determines the resistance values used in structural design calculations. A structure designed for S355J2 steel but fabricated from S235JR operates with actual yield strength approximately 33% below the design assumption (235 MPa versus 355 MPa). Partial safety factors in EN 1993-1-1 [5] do not accommodate discrepancies of this magnitude; the structure is technically non-compliant from the moment of completion, regardless of whether it displays any visible distress. While complete grade substitution represents an extreme case, partial shortfalls are more common in practice: uncertified steel may test at 300–340 MPa rather than the guaranteed minimum of 355 MPa, producing a 5–15% capacity deficit that remains invisible without independent laboratory testing yet accumulates risk over the service life as other degradation processes reduce the remaining margin.

Dimensional tolerance translates directly into structural resistance through section properties. For an IPE 300 beam (standard flange thickness 10.7 mm), a 1 mm under-tolerance on both flanges reduces the moment of inertia by approximately 9–12% and the section modulus by approximately 7–9%, depending on the specific cross-section geometry and the proportion of flange-to-web contribution. Under uniform loading, this translates to correspondingly higher bending stress than calculated, eroding the safety margin by the same proportion. For light-gauge members (purlins, cladding rails with 1.5–3.0

mm wall thickness), a 0.3 mm under-tolerance represents 10–20% of the nominal thickness, with proportionally larger impact on resistance.

Coating integrity governs the onset and rate of corrosion, which in turn determines the long-term trajectory of section loss. In C3 environments, unprotected carbon steel loses material at the rates documented in Section 2 and Figure 1. A hot-dip galvanized coating with Z275 specification (20 μm zinc per side) delays the onset of base metal corrosion by 25–40 years in C2–C3 exposure. A structure with intact galvanization therefore begins its corrosion clock decades later than an uncoated structure, fundamentally altering the lifecycle maintenance and replacement schedule.

Weldability non-compliance produces defects that may remain undetected until the connection is loaded beyond its safe capacity. Carbon equivalent values exceeding the limits specified in the welding procedure create conditions for cold cracking in the heat-affected zone, particularly in restrained joints and thick sections welded at ambient temperatures below 5°C. Field observations confirmed two cases in Group B structures where connection cracking was traced to elevated CEV in uncertified plate that was welded without preheat, consistent with the absence of mill certificate data that would have triggered preheat requirements under the applicable welding procedure specification.

Documentary traceability enables every other quality factor to be verified. Without a type 3.1 mill certificate, grade compliance cannot be confirmed without independent laboratory testing (destructive, expensive, and impractical for routine construction). Weldability cannot be assessed because chemical composition is unknown. After a structural incident, the absence of traceability documentation eliminates the possibility of determining whether material non-compliance contributed to the failure, complicating both forensic analysis and liability resolution.

5.3. Impact of rolled steel characteristics on structural reliability

Structural reliability in service depends on the relationship between applied loads and material resistance, both of which evolve. Applied loads may increase through change of use, snow accumulation beyond design values, or equipment additions. Material resistance decreases through corrosion-induced section loss, fatigue crack growth at connections, and mechanical property degradation from environmental exposure. Rolled steel quality affects the starting point and the trajectory of the resistance curve.

Grade under-specification shifts the entire resistance curve downward from the moment of construction. A portal frame warehouse designed for S355 but built with S235 has actual column resistance approximately 33% below design intent. Under normal loading (dead load plus typical live load, consuming 40–60% of design capacity), the structure operates safely because the design includes safety margins for exceptional loads. When an exceptional event occurs (design wind, maximum snow, seismic loading), the structure must mobilize the full design resistance, and the gap between assumed and actual capacity becomes the gap between survival and failure. Field observations identified three structures in Group B where visible permanent deformation of purlins (sag exceeding span/200) had developed under snow loading, consistent with grade under-specification although destructive testing was not performed to confirm actual yield strength.

Dimensional under-tolerance produces a subtler but cumulative effect. A quantitative example illustrates the mechanism: consider a 200×100×8 mm rectangular hollow section (RHS) column, 4 m high, carrying an axial compression load. At nominal 8 mm wall thickness, the approximate cross-sectional area is 45.4 cm^2 and the second moment of inertia about the weak axis is approximately 1,510 cm^4 (values vary with corner radius). At 7.2 mm wall thickness (10% under-tolerance, within EN 10210-2 class tolerance for some product ranges), the area reduces to approximately 41.1 cm^2 (–9.5%) and the weak-axis inertia to approximately 1,370 cm^4 (–9.3%). For a column where buckling governs the design, a 9% reduction in inertia reduces the Euler critical load by 9%, which may push the actual utilization ratio above 1.0 for a member designed at 0.90–0.95 utilization, triggering stability failure without any overloading.

Weldability deficiencies manifest at connections rather than in parent members. Cold cracks in the heat-affected zone of a beam-to-column connection reduce the connection's moment capacity, potentially converting a designed rigid frame into a semi-rigid or even pinned configuration at the affected joint. Field observations documented connection distress (visible cracking at weld toes, gap opening under load) in two Group B structures where post-construction inspection revealed weld toe cracking and incomplete fusion at beam-to-column connections, consistent with welding on material of

unknown chemical composition without the preheat protocol that elevated CEV would have required. In both cases, the structures required remedial strengthening within 5 years of completion.

5.4. Corrosion resistance and longevity of steel elements

Corrosion is the primary mechanism through which time degrades structural steel performance. Four corrosion types are relevant to building structures: uniform atmospheric corrosion (the most common, producing predictable section loss), pitting corrosion (localized, creating stress concentrations), crevice corrosion (in joints, overlaps, and moisture-retaining details), and galvanic corrosion (at junctions between dissimilar metals, such as aluminum cladding fastened to steel purlins with steel bolts).

Table 4. Corrosion environment classification and protection requirements for 25-year service

ISO 9223	Typical environment	Rate ($\mu\text{m}/\text{yr}$)	25-yr loss (mm)	Recommended protection
C1	Heated interiors, offices	< 1.3	< 0.03	None or aesthetic coating
C2	Unheated interiors, rural	1.3–25	0.03–0.6	Shop primer + paint or light galv.
C3	Urban/industrial, moderate	25–50	0.6–1.25	Hot-dip galv. (Z275+) or ISO 12944 C3-High
C4	Industrial + salinity, coastal	50–80	1.25–2.0	Duplex (galv. + paint) or ISO 12944 C4-High
C5	Marine splash, aggressive	80–200	2.0–5.0	Duplex + enhanced; stainless for critical

Source: Compiled by the author based on ISO 9223:2012 [9], ISO 12944-2:2017 [8], and Roberge [13].

Field observations of the 43 structures in the study sample provide empirical data on how protection level correlates with structural condition over time. Most observed structures operate in C2–C3 environments (Kharkiv Oblast continental climate: cold winters with condensation cycles, warm humid summers, moderate industrial atmosphere). Of the 43 observed structures, protection levels distributed as follows: 14 structures featured hot-dip galvanized primary members with ISO 12944 C3-High coating on secondary elements (all from Group A); 16 structures had paint-only protection consisting of shop primer plus one or two field coats (4 from Group A, 12 from Group B); and 13 structures had no intentional corrosion protection beyond residual shop primer or bare steel (all from Group B). Figure 2 presents the average visual condition ratings at the 5-year and 10-year observation marks for these three protection categories.

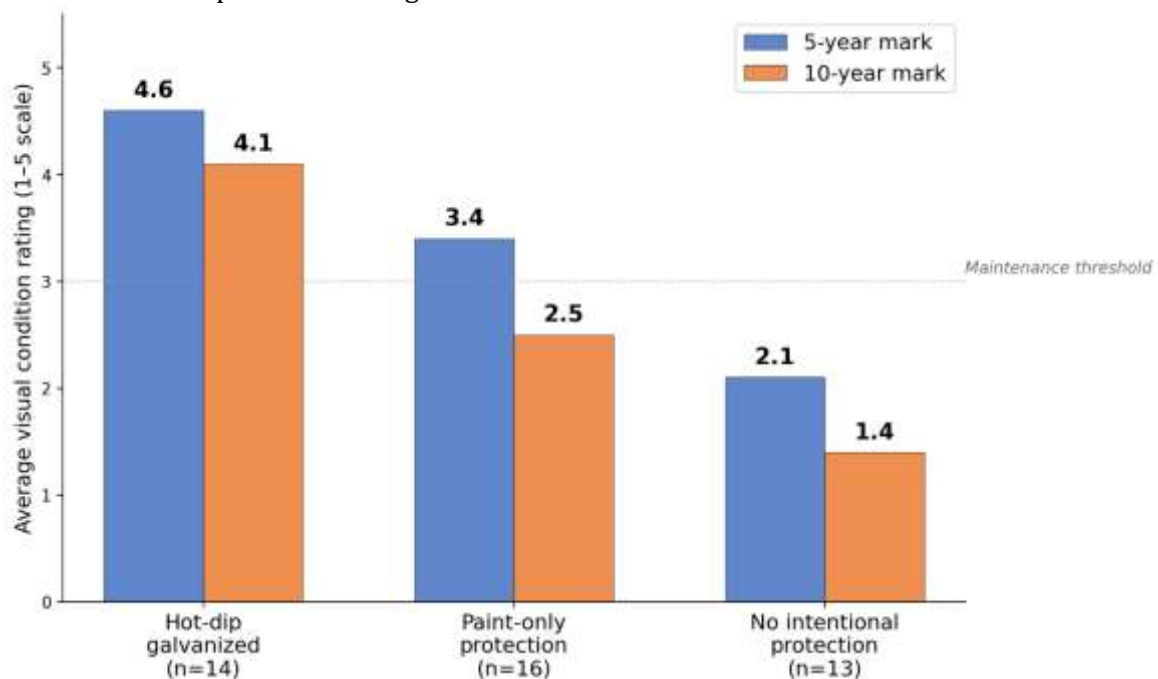


Figure 2. Average visual condition rating (1–5 scale) at 5-year and 10-year marks by protection level

Source: Compiled by the author based on field observation data, 2015–2025.

Group A structures with hot-dip galvanized primary members and ISO 12944 C3-High coated secondary members maintained average condition ratings of 4.6 at 5 years and 4.1 at 10 years, indicating minor surface weathering without structural corrosion. Group B structures with paint-only protection rated 3.4 at 5 years and 2.5 at 10 years, showing progressive coating breakdown with active corrosion at moisture-retaining details. Group B structures with no intentional corrosion protection rated 2.1 at 5 years and 1.4 at 10 years, exhibiting widespread surface corrosion with measurable section loss at column bases and connection zones.

Ultrasonic thickness measurements corroborate the visual ratings. At the 10-year mark, galvanized structures (Group A) showed no measurable base metal loss at any measurement point (resolution limit of the gauge: 0.1 mm). Painted-only structures showed 0.1–0.4 mm loss at column bases and gutter supports where coating had failed. Unprotected structures showed 0.3–0.8 mm loss at exposed locations, with individual readings reaching 1.2 mm at crevice locations (base plate to concrete interface, bolt connection clusters). For a purlin with 2.5 mm original wall thickness, 0.8 mm bilateral loss (both surfaces) represents 32% of the original section, reducing the member to 68% of its design resistance.

Maintenance data were collected through structured interviews with structure owners or facility managers during each site visit, supplemented by invoices or work orders where owners maintained such records. For structures where formal maintenance documentation was unavailable, owner-reported intervention counts were recorded with a notation of lower data reliability. Group A structures averaged 0.3 maintenance interventions per year (predominantly re-coating of secondary elements and gutter replacement at 8–10 year intervals). Group B painted structures averaged 0.7 interventions per year (coating touch-up, localized rust treatment, replacement of corroded fasteners and cladding rails). Group B unprotected structures averaged 1.4 interventions per year (emergency rust treatment, member reinforcement, partial re-cladding), with three structures requiring major structural remediation (column base reinforcement or member replacement) within 8 years of completion.

5.5. Role of quality rolled steel in structural safety assurance

Safety in structural engineering is quantified through the concept of safety margin: the ratio between actual structural resistance and the maximum expected load. EN 1993-1-1 [5] establishes this margin through partial safety factors applied to both loads ($\gamma_F = 1.35$ for permanent, 1.50 for variable) and materials ($\gamma_{M0} = 1.00$, $\gamma_{M1} = 1.00$, $\gamma_{M2} = 1.25$). At the moment of completion, a properly designed and fabricated structure possesses a safety margin that reflects these code-specified factors. Over the service life, the margin erodes as corrosion, fatigue, and other degradation processes reduce the actual resistance.

Figure 3 illustrates safety margin trajectories over a 30-year service horizon under three material quality scenarios, based on the corrosion rate data from Table 4 and the field observation trends from Section 4.4.

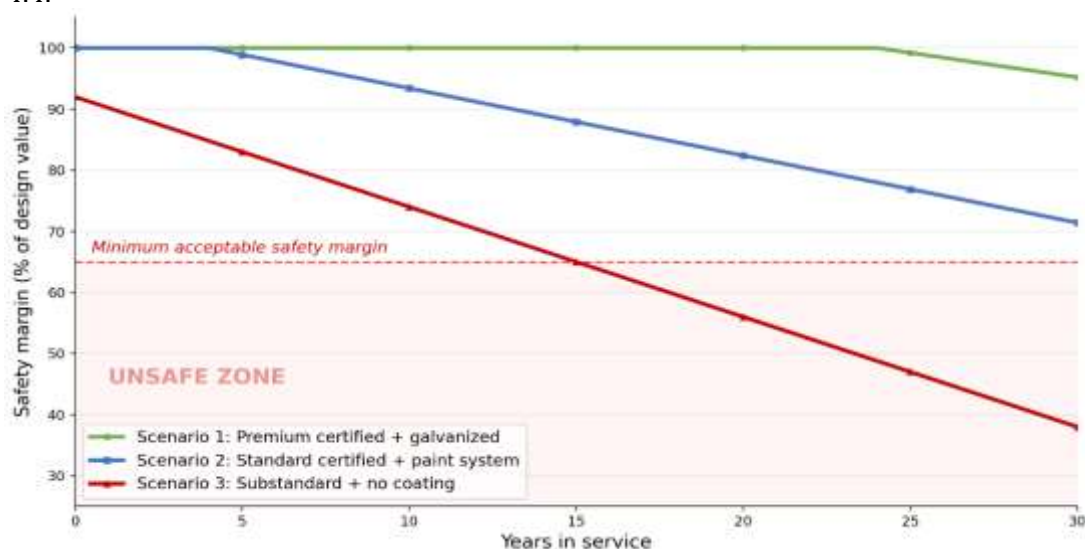


Figure 3. Safety margin degradation over 30-year service life under three material quality scenarios

Source: Developed by the author based on field observations and published corrosion rate data.

Scenario 1 (premium certified: correct grade, tight tolerances, hot-dip galvanized) begins at the full design safety margin and maintains it with negligible erosion for the first 20–25 years, corresponding to the galvanization protection period. Corrosion onset after galvanization depletion (year 25+) at C3 rates (per Table 4) produces approximately 0.13–0.25 mm section loss over 5 years, equivalent to 1.5–3% capacity reduction for an 8 mm plate member. With routine maintenance (re-coating at year 25), the safety margin remains at approximately 95–98% of the initial value at year 30.

Scenario 2 (standard certified: correct grade, standard tolerances, paint system C3-Medium) begins at the full design safety margin but erosion commences earlier as paint degradation allows corrosion onset at year 5–8 in exposed locations. By year 15, the margin has declined to approximately 85–90% of initial value, requiring maintenance intervention. Without maintenance, the margin reaches 70–80% by year 30.

Scenario 3 (substandard: unverified grade, loose tolerances, no intentional coating) begins at a reduced safety margin (due to potential grade and dimensional shortfalls) and erodes rapidly as unprotected steel corrodes from the first year of exposure. By year 10, the margin may reach 65–75% of the intended design value. By year 20, without intervention, it approaches or falls below the minimum acceptable threshold, representing a condition where exceptional loads that the design anticipated could cause partial or progressive failure.

Documentary traceability functions as a safety instrument independently of its role in material verification. When a structural incident occurs, mill certificates with heat numbers enable investigators to determine whether the steel used in the affected members met specification, whether other structures received material from the same heat, and whether a broader remediation program is warranted. Field experience includes a case where connection cracking in one warehouse prompted inspection of four other structures built in the same period by the same fabricator. Mill certificates for the affected structure traced the material to a specific heat with elevated sulphur content; certificates for the other four structures confirmed different heats with compliant chemistry, allowing targeted remediation rather than blanket intervention across all five buildings.

For a typical 1,000 m² warehouse structure, the premium for specifying type 3.1 certificates and verified grade amounts to approximately USD 2,000–5,000 over the total material budget. Blanket structural remediation of the same building, when material quality cannot be established and conservative assumptions must govern, typically costs USD 30,000–80,000 including scaffolding, inspection, reinforcement, and re-coating. The cost differential between these approaches illustrates why traceability investment at procurement is economically rational even when material incidents are rare.

6. Discussion

Field observations from this study align with published corrosion-mechanical property relationships [10; 15] while adding a dimension that laboratory studies cannot provide: temporal specificity under real-world conditions. Where Li and Yang [10] established proportional relationships between section loss and capacity reduction, and Zhao et al. [15] identified environment-grade-fabrication interactions, the present data document how these relationships manifest over actual multi-year service periods with real maintenance practices and climate variability.

Shojaei et al. [12] concluded that galvanized steel retains mechanical properties significantly longer than alternatives. The present field data translate this laboratory finding into practitioner-usable decision inputs: the magnitude of divergence between protection levels documented in Section 4.4, combined with the maintenance frequency differentials, provides concrete criteria for coating specification rather than the general recommendation to “consider galvanization” that current standards offer.

Angst [1] found that proactive protection reduces lifecycle costs by a factor of 3–5 compared to reactive repair for concrete structures; the maintenance cost differentials observed in this study suggest a comparable ratio for exposed steel structures, though owner cost records varied in completeness and these proportions remain indicative. Galvão et al. [2] projected that climate change may accelerate corrosion rates, which would widen the divergence between protection levels over coming decades and further strengthen the case for conservative initial specification.

The critical finding from the safety margin analysis is not the specific percentage values, which depend on environmental and loading assumptions, but the qualitative divergence pattern: premium

and substandard material scenarios begin close together at year zero (both ostensibly code-compliant) but diverge progressively, with the gap widening nonlinearly as coating failure triggers accelerating corrosion in unprotected scenarios. By the time the divergence becomes visually apparent (typically year 8–12 for unprotected steel in C3 environments), the substandard scenario has already consumed a substantial portion of the safety reserve that the original design intended to preserve for exceptional loads. Engineering codes address this through corrosion allowance provisions, but a unified framework linking material quality factors to margin preservation trajectories has not been available. The assessment framework developed in this study provides the missing connection between point-in-time code compliance and lifecycle performance assurance.

Generalizability of the quantitative findings is constrained by the observational methodology, the single-region sample, and the specific C2–C3 environmental context. Structures in C4–C5 environments would experience accelerated degradation across all quality levels, potentially compressing the timeline differences between scenarios. Structures in C1 environments (heated, controlled interiors) may show minimal differentiation between material quality levels over the observed timeframe, making the framework less discriminating for such applications. The framework structure (five factors, three domains, degradation trajectories) is intended to be transferable; the specific quantitative values require recalibration for different climatic zones, building types, and maintenance regimes. Multi-site studies with standardized assessment protocols across different corrosivity categories would strengthen the evidence base and enable environment-specific calibration of the assessment tool.

7. Conclusions

The Multi-Factor Durability-Safety Assessment Framework developed in this study connects five rolled steel quality factors to three structural performance domains, providing a structured tool for evaluating how material quality decisions at the procurement stage propagate into structural outcomes over multi-decade service periods. The framework achieves its stated purpose: it enables practitioners to trace a specific material quality decision (e.g., specifying galvanized certified steel versus accepting unverified painted-only material) through its consequences for structural condition at year 5, 10, and beyond, transforming material procurement from a cost-per-ton comparison into a lifecycle performance evaluation. Grade compliance, dimensional tolerance, protective coating integrity, weldability, and documentary traceability each influence a distinct pathway through which rolled steel quality affects load-bearing reliability, corrosion resistance, and safety margin preservation.

Field observations of 43 structures over periods of 3 to 10 years document a clear and consistent divergence between material quality groups. Structures built with certified, appropriately protected rolled steel maintained near-original condition through the observation period, while structures incorporating unverified or unprotected material showed progressive degradation that in several cases necessitated structural intervention within the first decade of service. Maintenance intervention frequency differed by a factor of 4–5 between the best-protected and least-protected groups, with lifecycle cost implications that reverse the apparent purchase price advantage of cheaper, unverified material.

Corrosion resistance emerged as the most consequential performance domain across the observed timeframe. Coating integrity determined whether corrosion onset occurred at year 1 (unprotected) or was deferred to year 25+ (galvanized), a difference that cascades through maintenance scheduling, structural condition, and safety margin preservation. For structures operating in C2–C3 environments with 25+ year service life expectations, hot-dip galvanization of primary structural members represents the single most cost-effective durability investment, outperforming both paint-only protection and reactive maintenance strategies on a total lifecycle cost basis.

Documentary traceability, while having no direct effect on structural resistance, functions as a safety and liability management instrument whose value becomes apparent only during incident investigation or remediation planning. Absence of material documentation forces conservative assumptions that expand remediation scope and cost; presence of documentation enables targeted, proportionate response. For this reason, the cost of specifying type 3.1 mill certificates, which adds minimal expense to the material procurement budget, should be evaluated against the potential cost of undocumented material in the event of a structural quality concern.

Further research should pursue three directions: extending field observations to structures in C4–C5 environments where degradation rates are higher and differentiation between quality levels may be

more pronounced; developing quantitative degradation prediction models calibrated to specific corrosivity categories using the framework's five-factor input structure; and exploring integration of sensor-based structural health monitoring with the assessment framework to enable continuous rather than periodic evaluation of safety margin preservation during service.

References

1. Angst, U. M. (2018). Challenges and opportunities in corrosion of steel in concrete. *Materials and Structures*, (51), Article 4. <https://doi.org/10.1617/s11527-017-1131-6>
2. Ebrahimi, N., Roshanfar, M., Momeni, M., & Naboka, O. (2025). Corrosion performance of atmospheric corrosion resistant steel bridges in the current climate: A performance review. *Materials*, 18(15), Article 3510. <https://doi.org/10.3390/ma18153510>
3. European Committee for Standardization. (2019). *EN 10025-2:2019. Hot rolled products of structural steels—Part 2: Technical delivery conditions for non-alloy structural steels*. <https://knowledge.bsigroup.com/products/hot-rolled-products-of-structural-steels-technical-delivery-conditions-for-non-alloy-structural-steels-1>
4. European Committee for Standardization. (2018). *EN 1090-2:2018. Execution of steel structures and aluminium structures—Part 2: Technical requirements for steel structures*. <https://knowledge.bsigroup.com/products/execution-of-steel-structures-and-aluminium-structures-technical-requirements-for-steel-structures-1>
5. European Committee for Standardization. (2014). *EN 1993-1-1:2005+A1:2014. Eurocode 3: Design of steel structures—Part 1-1: General rules and rules for buildings*. <https://www.evs.ee/en/evs-en-1993-1-1-2005-a1-2014>
6. European Committee for Standardization. (2005). *EN 1993-1-9:2005. Eurocode 3: Design of steel structures—Part 1-9: Fatigue*. <https://www.evs.ee/en/evs-en-1993-1-9-2005>
7. European Committee for Standardization. (2015). *EN 10346:2015. Continuously hot-dip coated steel flat products for cold forming—Technical delivery conditions*. <https://www.dinmedia.de/en/standard/din-en-10346/226007287>
8. International Organization for Standardization. (2017). *ISO 12944-2:2017. Paints and varnishes—Corrosion protection of steel structures by protective paint systems—Part 2: Classification of environments*. <https://www.iso.org/standard/64834.html>
9. International Organization for Standardization. (2012). *ISO 9223:2012. Corrosion of metals and alloys—Corrosivity of atmospheres—Classification, determination and estimation*. <https://www.iso.org/standard/53499.html>
10. Li, C. Q., & Yang, W. (2021). *Steel corrosion and degradation of its mechanical properties*. CRC Press. <https://doi.org/10.1201/9781003119791>
11. Manu, K. C., Madhushree, C., Chandini, M. S., Shree, N., Hemanth, S., & Jeevan, T. P. (2025). Corrosion in steel structures: A review. *Journal of Mines, Metals and Fuels*, 73(1), 189–198. <https://doi.org/10.18311/jmmf/2025/46985>
12. Mokhtari, E., Heidarpour, A., & Javidan, F. (2024). Mechanical performance of high strength steel under corrosion: A review study. *Journal of Constructional Steel Research*, (220), Article 108840. <https://doi.org/10.1016/j.jcsr.2024.108840>
13. Roberge, P. R. (2008). *Corrosion engineering: Principles and practice*. McGraw-Hill. <https://books.google.com/books?id=PF6ZjjSHcn4C>
14. Wardenier, J., Packer, J. A., Zhao, X.-L., & van der Vegte, G. J. (2010). *Hollow sections in structural applications* (2nd ed.). CIDECT. <https://www.cidect.org/books/>
15. Wei, H., Tang, Y., Liu, Y.-P., & Chan, S.-L. (2025). Research on durability and mechanical properties of high strength steel in corrosive environment: A review. *Structures*, (78), Article 109324. <https://doi.org/10.1016/j.istruc.2025.109324>
16. World Steel Association. (2024). *World steel in figures 2024*. <https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2024.pdf>