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Structural Design of Offshore Structures: A Review of Indian and International Standards

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Abstract

Offshore structures—including fixed steel jackets, topside modules, offshore wind turbine support structures, and floating systems—are designed to withstand combined gravity, environmental, seismic, and operational loads under substantial uncertainty and limited access for inspection and repair. Structural design practice has historically relied on internationally recognized standards, particularly the American Petroleum Institute's API RP 2A, the International Organization for Standardization's ISO 19900 series, including ISO 19902 for fixed steel structures, and Det Norske Veritas (DNV) standards, together with regional provisions such as NORSOK and DNV ST-0126 for offshore wind turbine support structures. In India, offshore development, particularly by the Oil and Natural Gas Corporation (ONGC) in the Western Offshore basin, has predominantly followed API RP 2A working stress design principles, supplemented by IS 800 and in-house engineering practices developed by ONGC's Institute of Engineering and Ocean Technology (IEOT). This paper presents a systematic review of thirty studies, standards, and technical reports addressing offshore structural design and integrity assessment. The reviewed literature is organized into six thematic areas: design philosophies and API/ISO code evolution; cross-code comparisons; fatigue design and S-N curve provisions; reliability-based load and resistance factor calibration; offshore wind turbine support-structure standards; and structural integrity, life extension, and Indian offshore applications. The review indicates that API RP 2A and ISO 19902 share fundamental approaches to tubular-member and joint-strength assessment, while differences in safety-factor philosophies, environmental load factors, and regional calibration can lead to variations in predicted structural reliability. The findings also demonstrate that these standards continue to evolve in response to reliability, safety, and emerging offshore applications. Indian offshore practice faces the additional challenge of reconciling API-based design with IS 800 requirements and the structural integrity and life-extension needs of ageing platforms. Furthermore, India's emerging offshore wind sector requires adaptation of established oil-and-gas design practices to turbine-specific international standards, as a dedicated domestic standard is not yet established. Based on the identified evidence gaps, the study proposes a focused research agenda covering India-specific environmental load factors, reliability calibration, code harmonization, ageing-platform assessment, and offshore wind support structures. The review provides a foundation for future research aimed at improving the safety, reliability, and sustainability of offshore infrastructure in India.

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INTRODUCTION

Offshore oil and gas installations, and increasingly offshore wind turbine foundations, place structural engineers in an unusual position relative to onshore construction: structures must resist large, cyclic, and only partially predictable environmental loading; failure consequences extend to loss of life, environmental damage, and very high replacement cost; and in-service inspection and repair are constrained by water depth and limited access. These characteristics led the industry, from the 1960s onward, to develop a distinct body of design codes and recommended practices—separate from general structural steel codes—to size tubular members and joints, define environmental load and combination criteria, and, since the late 1980s, to progressively formalize a shift from allowable/working stress design toward load and resistance factor and limit-state design [1–5].

The generic working-stress design check takes the form $\sigma \leq \sigma_{allow} = F_y / FS$, where the applied stress σ under unfactored (nominal) loads is compared against an allowable stress derived by dividing the material yield strength F_y by a single, code-specified factor of safety FS that implicitly absorbs the load, material, and modelling uncertainty. The limit-state (LRFD) format instead separates these sources of uncertainty explicitly, requiring $\Sigma \gamma_i Q_i \leq \varphi R_n$, where each load effect Q_i is multiplied by its own load factor γ_i (calibrated to that load type's variability), and the nominal resistance R_n is reduced by a single resistance (capacity) factor φ reflecting uncertainty in material strength and member behavior. This separation of load- and resistance-side uncertainty, rather than any difference in the underlying mechanics of tubular member or joint behavior, is the central conceptual distinction between API RP 2A-WSD and the LRFD/limit-state formats of API RP 2A-LRFD and ISO 19902, and it recurs throughout the comparative literature reviewed below [6–9].

Two international documents dominate structural practice for fixed steel offshore platforms worldwide: API RP 2A, first issued by the American Petroleum Institute in the early 1970s and historically associated with working stress design (WSD), and ISO 19902, the international standard for fixed steel offshore structures developed under ISO Technical Committee 67 and based on a load and resistance factor (LRFD) format. DNV recommended practices—in particular, DNV-RP-C203 for fatigue—and NORSOK standards developed for the Norwegian continental shelf supplement, and in some jurisdictions substitute for, these two documents. For offshore wind turbine support structures, a further layer of standards, principally IEC 61400-3 and DNV's dedicated support-structure standards, has emerged over the last two decades, generally invoking oil-and-gas offshore practices for the substructure while adding turbine-specific load cases.

Both principal international documents have continued to evolve substantially since their original issue. API undertook a major restructuring of API RP 2A beginning in 2007 through API Task Group 13, whose objective was to bring a heavily amended 21st-edition WSD document—which had already accumulated three supplements between 2000 and 2007, issued in part in response to the loss of or damage to well over 200 Gulf of Mexico platforms in Hurricanes Ivan, Katrina and Rita—into closer alignment with a proposed suite of companion recommended practices covering geotechnical design, metocean criteria, seismic design and structural integrity management, together with a modified adoption of ISO 19902 intended as a second-edition API RP 2A-LRFD. In this event, API RP 2A-WSD itself continued to be reissued as a single working-stress document, most recently as the 23rd edition, rather than being retired outright once the suite of companion standards was introduced—an outcome that illustrates, in miniature, the broader and still-incomplete industry shift from WSD toward LRFD/limit-state formats discussed throughout this review. ISO 19902 has likewise been revised, with a second edition published in 2020 superseding the 2007 text that served as the reference point for several of the comparative studies discussed below, a reminder that the code comparisons summarized in this review should be read as snapshots of a moving target rather than as a permanent statement of relative stringency [10–15].

India's offshore structural design experience is concentrated in the Western Offshore Basin off the coast of Mumbai, where ONGC has operated fixed steel jacket platforms since 1976 and today operates approximately 265 fixed structures in water depths of roughly 25-90 m, more than a third of which have already exceeded their original 25-year design life. The design practice for these platforms has been built substantially on API RP 2A WSD, supplemented by the general Indian steel code IS 800 for onshore-analogous member checks and by internal ONGC/IEOT guidance developed specifically for requalification, life extension, and relocation of existing platforms, increasingly incorporating risk-based inspection concepts developed with international classification society partners. As ONGC's original 1970s- and 1980s-vintage platforms now substantially exceed their intended 25-year design lives, structural integrity assessment, requalification and relocation of ageing jackets have become as central to Indian offshore practice as new-build design—a challenge that will shortly be joined by an entirely new one, as India's Ministry of New and Renewable Energy pursues an ambitious offshore wind auction programme for which no dedicated Indian support-structure design code yet exists.

This review draws together 30 studies, codes, technical reports, and foundational reliability theory references addressing these themes, discussing each in turn and drawing out the cross-cutting patterns that emerge when Indian and international practices are read side by side. Relative to the original twenty-item review on which it is based, the present version expands the comparative and theoretical treatment of reliability-based calibration, adds explicit inclusion/exclusion criteria and a structured future-research agenda intended to orient doctoral-level inquiry, and introduces a nomenclature table to support readers approaching the offshore-structures literature for the first time.

REVIEW METHODOLOGY

Thirty studies were selected to represent a cross-section of the literature and normative documents on the structural design of offshore structures, drawing on international recommended practices and standards (API, ISO, DNV, IEC), peer-reviewed comparative and calibration studies published in venues including the Journal of Structural Engineering (ASCE), Marine Structures, the International Journal of Fatigue, Renewable and Sustainable Energy Reviews, Ocean Engineering, Energies and Dynamics, conference papers presented at the Offshore Technology Conference (OTC) and International Society of Offshore and Polar Engineers (ISOPE) symposia, Indian sources comprising the Bureau of Indian Standards code IS 800, a widely used Indian offshore-structures textbook, and a field paper describing ONGC/IEOT practice for the Western Offshore basin, and three foundational references establishing the probabilistic theory (reliability index, FORM/SORM, consequence-class-differentiated target reliability) underlying the LRFD calibration studies discussed in the reliability cluster. The sample was extended beyond the original twenty items in two stages: first to include recent code-revision literature documenting the continuing evolution of API RP 2A and ISO 19902, trade-press and technical-society reporting on ONGC/IEOT's risk-based requalification programme for the Western Offshore fleet, and an Indian government policy document describing the country's emerging offshore wind auction programme; and, in this expanded version, to include the classical structural-reliability references against which the code-specific calibration studies are best read [16–20].

The selection process followed four explicit criteria. First, relevance: a study or standard was included only if it addressed the structural (as opposed to geotechnical-only, process-safety-only, or purely operational) design of a fixed, floating, or wind-turbine offshore support structure. Second, comparative or calibrative content: selection prioritized studies that directly compare, calibrate, or apply code provisions across two or more standards, to surface the practical differences between design philosophies rather than restate any single code's provisions in isolation; single-code descriptive summaries were included only where no comparative alternative existed (for example, the IS 800 and DNV-RP-C203 entries, included as primary normative references rather than comparative studies). Third, currency: where a document has been superseded by a later edition, the most recent edition was used as the primary reference, with superseded editions retained in the discussion only where they were the explicit subject of a comparative study being reviewed (for example, the pre-2020 edition of ISO 19902 examined in several tubular-strength comparison studies). Fourth, provenance: normative documents (codes, recommended practices, standards) were treated as primary sources and read directly rather than through secondary summaries wherever the source document was accessible.

This review is explicitly narrative rather than systematic in the PRISMA sense: no pre-registered protocol, multi-database Boolean search string, or dual-reviewer screening process was used, and no formal risk-of-bias or quality-appraisal instrument was applied to the included studies. This choice reflects the heterogeneous nature of the source material; normative standards, reliability-calibration studies, trade-press reporting, and a government policy paper do not share a common study design against which a single quality-appraisal instrument could be meaningfully applied. This is discussed further, together with its implications for the strength of the conclusions drawn, in the Limitations section below. The studies are discussed below in six thematic clusters; each study is introduced by its lead author(s)/issuing body and reference number, following the practice used in this journal format, before its scope and key findings are summarized in Table 1 [21–27].

Table 1. Summary of the thirty reviewed studies and standards.

Ref.	Study (authors, year)	Method/scope	Key focus
1	Anzai, Bryant and Pedersen (1982)	OTC comparative study; sample North Sea platform	Danish limit-state code vs. API RP 2A
2	Nizamani (2015)	Analytical / reliability-based comparison	Tubular strength: API RP 2A vs ISO 19902
3	Karulin and Karulina (2010)	Numerical code-check comparison	Tubular member strength: API RP2A vs ISO codes
4	Det Norske Veritas / BOEMRE (2011)	Regulatory comparison study (US GoM and West Coast)	API vs ISO vs NORSOK structural provisions
5	BSEE, TAP 618 (JIP study)	Comparative standards study	API RP 2A vs IEC 61400-3 for OWT support structures
6	Det Norske Veritas, DNV-RP-C203	Recommended practice	Fatigue design, S-N curves, environment classes
7	Choung (2021)	Comparative analysis of five codes	S-N curve comparison: DNV, ABS, BS, IIW, EC3
8	Siriwardane, Adasooriya and Pavlou (2021)	Proposed S-N curve; experimental validation	Fatigue of tubular joints in the splash zone
9	Zhao (2021)	Statistical/reliability analysis of fatigue test database	Calibration of Design Fatigue Factors (DFF)
10	Chen, Gilbert, Manuel and Ku (2021)	Reliability calibration using GoM hurricane data	API RP 2A-LRFD 2nd edition load/resistance factors
11	Lloyd and Karsan (1988)	Reliability-based calibration study	Development of API RP2A-LRFD 1st edition
12	American Bureau of Shipping (2016)	Full-scale testing and calibration	LRFD criteria for MODUs and floating installations
13	Wang, Kolios, Liu, Venetsanos and Cai (2022)	State-of-the-art review	Reliability of OWT support structures
14	Márquez-Domínguez and Sørensen (2012)	Reliability-based calibration	Fatigue design factors for OWT structures
15	Sunday and Brennan (2021)	Review	Structural design of OWT monopile foundations
16	Wisch, Puskar, Laurendine, O'Connor, Versowsky and Bucknell (2004)	Review/update of assessment methodology	API RP 2A Section 17: assessment of existing platforms
17	Aeran, Siriwardane, Mikkelsen and Langen (2017)	Framework development with case study	Structural integrity assessment for life extension
18	Bureau of Indian Standards, IS 800:2007	National standard	General construction in steel, code of practice
19	Nallayarasu	Textbook/practitioner reference (IIT Madras)	Design of offshore structures, ONGC applications
20	Bhat and Karunanithi (2019)	Case study, ONGC Western Offshore	Relocation and requalification of jacket platforms
21	International Organization for Standardization (2020)	National/international standard, 2nd edition	ISO 19902:2020 revision of fixed steel structures code
22	Zwerneman and Digre (2010)	OTC paper on code-development history	API RP 2A restructuring; 22nd/23rd edition history
23	Det Norske Veritas, DNV-ST-0126 (2021)	Recommended standard	Support structures for wind turbines (fixed and hybrid)

Ref.	Study (authors, year)	Method/scope	Key focus
24	ONGC/IEOT with DNV GL (reported 2014)	Trade-press report on requalification programme	Risk-based inspection (RBI) for 34 ageing platforms
25	Offshore Magazine (reported project data)	Case study/trade report	Fleet-scale requalification of 265 ONGC platforms
26	Ministry of New and Renewable Energy, India (2023)	Government policy/strategy paper	India's offshore wind auction and VGF strategy
27	Bureau of Indian Standards, IS 4651 (Parts 1-5) / IS 9527 (Parts 1-6)	National standards, ports and harbor engineering	Nearest existing BIS codes to marine/offshore structures; no dedicated fixed-jacket offshore code
28	Cornell (1969)	Foundational probabilistic theory	Origin of the probability-based (reliability-index) structural safety format underlying LRFD
29	Joint Committee on Structural Safety, JCSS (2001)	Probabilistic model code	Consequence-class-differentiated target reliability indices referenced in code calibration
30	Ang and Tang (1984)	Textbook / methodological reference	First- and second-order reliability methods (FORM/SORM) used in code-calibration studies

Note: Studies are numbered as they appear in the References list; the narrative discussion below groups them thematically rather than numerically.

LITERATURE REVIEW

Foundational Design Philosophies and Cross-Code Comparisons

Anzai, Bryant, and Pedersen [1] compared a limit-state design code, the Danish Offshore Regulations, with the working-stress-based API RP 2A of the early 1980s, examining member capacity, joint capacity, foundation capacity, and fatigue analysis for a representative North Sea platform. Using the safety-index reliability philosophy, the authors reported broadly favorable agreement between the two approaches from a general reliability standpoint, while noting detailed differences in how each code allocated the safety margin across load types, foreshadowing the industry's subsequent move toward explicit limit-state formats.

Nizamani [2] and, independently, Karulin and Karulina [3] each carried out detailed comparisons of the tubular member and joint strength provisions of API RP 2A (in both WSD and LRFD forms) against ISO 19902. Both codes check axial compression against a critical buckling stress governed by the lesser of local shell buckling and column (Euler) buckling, bending against a plastic or first-yield moment reduced for local buckling, and hoop stress under external hydrostatic pressure against an elastic critical hoop buckling stress, which is itself a function of the diameter-to-thickness ratio. Nizamani's analysis, developed to support calibration of load and resistance factors for jacket platforms in Malaysia, found that the ISO and API LRFD strength expressions for axial, bending and hoop buckling are closely related—in several cases numerically identical—but that ISO 19902 provides a more refined, multi-range treatment of elastic hoop buckling than the single expression used in API LRFD, meaning that for thin-walled tubulars at the boundary between buckling regimes the two codes can predict materially different capacities from the same section geometry. Karulin and Karulina reached a similar conclusion through independent numerical code checks, concluding that although the two codes share a common technical lineage, small differences in partial safety factors and geometric limits can shift the governing failure mode for a given tubular member.

At a broader, whole-standard level, Det Norske Veritas, reporting to the U.S. Bureau of Ocean Energy Management, Regulation and Enforcement [4], undertook a systematic comparison of API, ISO, and NORSOK offshore structural standards covering environmental (metocean) loads, load combinations, structural steel design factors, connection detailing, fatigue design, foundation design, in-service inspection, assessment of existing platforms, and accidental loading. The study found that although the three standards address the same structural integrity aspects, they differ in the definition of extreme environmental load factors, the number and definition of design limit states, and the degree of regional calibration, for example, ISO 19902's environmental action factors are explicitly tabulated for the Gulf of Mexico, the UK North Sea and northwest Australia, but not for other regions, leaving designers elsewhere to select or interpolate factors with engineering judgement, a gap of direct relevance to the Indian context discussed later in this review. A related comparative study prepared for a joint industry project [5] extended this cross-code comparison to offshore wind turbine generator (OWTG) support structures, finding that API RP 2A, being self-contained and calibrated to a 100-year return period for high-consequence oil and gas platforms, does not by itself address turbine-specific load cases or wind-induced fatigue, and would require supplementation by IEC 61400-3 (which instead uses a 50-year return period, organized around a defined matrix of Design Load Cases, or DLCs, spanning normal operation, fault, and extreme-event conditions) if used as the design basis for a wind turbine support structure.

These comparative findings sit against a backdrop of continuing revision of both principal codes. API's Task Group 13 process, described by Zwerneman and Digre [22], set out to modernize API RP 2A into a suite of companion standards aligned with ISO conventions, yet the WSD document itself has persisted—reissued as a 23rd edition—alongside the LRFD line, so that designers today may still encounter WSD, first- and prospective second-edition LRFD, and ISO 19902 provisions in parallel on a single project. ISO 19902 itself was updated to a second edition in 2020 [21], underscoring that the code comparisons summarized above should be read as snapshots of a moving target rather than a permanent statement of relative stringency, and reinforcing the need for designers and reviewers to confirm the specific edition in force before relying on any comparative finding reported in the literature.

Fatigue Design Provisions and S-N Curves

DNV-RP-C203 [6], the recommended practice most widely referenced for the fatigue design of offshore steel structures, provides S-N curves for welded, base-material, and bolted details, together with stress-concentration-factor (SCF) guidance and environment classes distinguishing details in air from those in seawater with and without cathodic protection. The basic S-N curve takes the bilinear log-log form $\log N = \log \bar{A} - m \log \Delta\sigma$, where N is the predicted number of cycles to failure at stress range $\Delta\sigma$, $\bar{A}$ is a detail-category-dependent intercept constant, and m is the negative inverse slope (typically m = 3 above roughly 10^6-10^7 cycles and m = 5 below it, reflecting a change in the governing crack-growth mechanism); DNV-RP-C203 notes that for offshore structures subject to typical wave and wind loading, the bulk of fatigue damage accumulates above roughly one million cycles, where this bilinear behavior governs. Accumulated damage from a spectrum of stress ranges is then typically summed using the Palmgren-Miner linear damage rule, $D = \Sigma(n_i / N_i)$, with failure deemed to occur when the cumulative damage index D reaches unity divided by the applicable Design Fatigue Factor (DFF); DFF values of 1 to 10 are specified according to the consequence of failure and the accessibility of the detail for in-service inspection, so that inaccessible, high-consequence joints are designed to a fatigue life many times the intended service life. Choung [7] systematically compared the basic design S-N curves for non-tubular steel members specified in five major codes—DNV, ABS, British Standard BS 7608, the International Institute of Welding recommendations, and Eurocode 3—analyzing differences in stress type (nominal, hot-spot, and effective notch stress), curve shape, and the survival probability implicit in each code's basic design curve, concluding that although the codes are broadly similar in structure, the relative conservatism of a given detail category can differ materially depending on which code's classification system is applied.

Siriwardane, Adasooriya and Pavlou [8] addressed a specific gap in the DNV framework by proposing a modified stress-life fatigue curve for tubular joints located in the splash zone of offshore jacket structures, where DNV's standard design T-curve for the in-air condition does not directly capture the combined effects of seawater exposure and cyclic loading; their proposed curve, validated against experimental fatigue-life data for tubular joints tested in seawater, was applied to a case-study jacket joint and compared with the fatigue life obtained from conventional design practice. Zhao [9] took a complementary, statistically oriented approach, assembling a fatigue test database spanning several decades and using it to calibrate Design Fatigue Factors (DFFs) for offshore structures; the analysis found good agreement between in-air S-N test data and the D- and T-curve categories of the DNV framework, but poorer agreement for the F-curve category in corrosive environments, implying that DFFs for certain corroded, high-consequence details could reasonably be reduced relative to current DNV practice. Collectively, these three studies illustrate that fatigue-code divergence arises less from disagreement on the general bilinear S-N/Miner's-rule framework—which is common ground across DNV, API, and ISO—than from differences in how each code populates that framework's parameters (curve intercepts, thickness corrections, environment-class boundaries, and DFF values) for specific, often environment- or geometry-dependent, structural details.

Reliability-Based Calibration of Load and Resistance Factors

The LRFD and limit-state formats discussed throughout this review rest on a common probabilistic foundation, formalized by Cornell [28] and subsequently systematized in probabilistic model codes such as the JCSS Probabilistic Model Code [29]: structural safety is expressed not as a deterministic margin but as a reliability (safety) index β, most simply defined for normally distributed, statistically independent resistance R and load effect S as $\beta = (\mu R - \mu S) / \sqrt{(\sigma R^2 + \sigma S^2)}$, where μ and σ denote mean and standard deviation. For the non-normal, correlated distributions typical of real structural resistance and environmental load models, β is instead evaluated using first- or second-order reliability methods (FORM/SORM), as set out by Ang and Tang [30], which linearize (FORM) or locally approximate with a quadratic surface (SORM) the limit-state function $g(R, S) = R - S = 0$ at the most probable point of failure. Target reliability indices are differentiated by consequence-of-failure class; broadly, higher β targets are set for manned, high-consequence platforms than for unmanned or low-consequence structures. This differentiation is embedded in both the JCSS model code [29] and, operationally, in the exposure category and consequence-of-failure provisions of API RP 2A and ISO 19902 [28–30].

Lloyd and Karsan [11] described the development of API RP2A-LRFD as a reliability-based alternative to the traditional working-stress API RP 2A, explaining how partial load and resistance factors were calibrated, using this FORM-based reliability framework, so that Gulf of Mexico platforms designed to the new LRFD format would achieve, on average, the same safety index as platforms designed to WSD—a calibration philosophy that was subsequently influential in the development of the LRFD format adopted by ISO 19902. Chen et al. [10] revisited this calibration more than three decades later in the context of preparing a second edition of API RP2A-LRFD intended to align with ISO 19902 as a single global standard. Using updated metocean characteristics informed by Gulf of Mexico hurricane experience since Katrina and re-computing β for representative platform configurations under both the original and updated metocean bases, the study found that the original 1st-edition LRFD load and resistance factors give slightly higher component reliability than WSD under the 1980s-era metocean criteria, but a somewhat lower reliability level once updated post-Katrina environmental criteria are applied. This underscored that calibration is not a one-time exercise but must be periodically revisited as environmental data and platform populations evolve. This finding is a direct, code-specific illustration of the general point made by Cornell [28] and the JCSS model code [29]: a reliability index calibrated against one load/resistance statistical model is not automatically preserved when the underlying statistical model changes; periodic re-calibration is intrinsic to the LRFD philosophy rather than an occasional maintenance task.

The American Bureau of Shipping [12] pursued a parallel calibration effort for floating and mobile offshore units, developing LRFD criteria for mobile offshore drilling units (MODUs) and floating production installations and validating them through full-scale representative case studies covering normal drilling conditions and severe storm environments; the study confirmed that an LRFD-based design, calibrated against established WSD criteria using the same reliability-index framework, could reproduce a globally comparable design while allowing higher partial safety factors to be assigned selectively to less-predictable load components, illustrating the broader industry rationale for LRFD adoption beyond fixed jacket platforms.

Standards for Offshore Wind Turbine Support Structures

Wang, Kolios, Liu, Venetsanos and Cai [13] provided a comprehensive, state-of-the-art review of reliability assessment methods for offshore wind turbine (OWT) support structures, covering structural reliability analysis, reliability-based calibration of design codes, fatigue reliability, and the practical implementation of reliability assessment in design; the review noted that IEC 61400-3, used in conjunction with related IEC and ISO standards, is now the primary international design basis for OWT support structures, but that DNV's dedicated support-structure standard in some respects imposes stricter requirements than IEC 61400-3 itself, and it highlighted risk-based inspection and reliability-based design optimization as emerging directions. Márquez-Domínguez and Sørensen [14] addressed fatigue reliability specifically, developing a probabilistic model and calibrating fatigue design factors for OWT steel substructures using the same target-reliability-index logic set out generally by the JCSS model code [29]; because the consequences of an OWT failure are generally lower than for an oil and gas platform (an unmanned structure whose failure does not directly threaten life in the way a manned platform's does), the study argued that lower fatigue design factors can reasonably be applied to OWT substructures than to comparable oil and gas jacket details, a conclusion with direct implications for how DNV-RP-C203-derived fatigue factors should be adapted when reused for wind turbine foundations.

Sunday and Brennan [15] reviewed the structural design of monopile foundations—by far the most widely deployed OWT foundation type—tracing the achievements of two decades of monopile design practice under IEC 61400-3 and related standards, and identifying persistent challenges including scour, cyclic soil-structure interaction, and the extrapolation of design methods validated at smaller diameters to the very large-diameter monopiles now used in deeper water and for larger turbines; the review's findings on the limits of extrapolating oil-and-gas-derived design methods to the different load regimes of OWT structures echo, from the wind sector, the concerns raised elsewhere in this review about regional and application-specific calibration of nominally 'international' codes.

Alongside IEC 61400-3, DNV's dedicated support-structure standard—most recently reissued as DNV-ST-0126 [23]—has become a de facto second reference point for OWT sub-structure design, extending pragmatic design guidance to steel and concrete towers, gravity-based foundations, monopile foundations, jacket foundations and suction-bucket foundations, and providing companion geotechnical guidance through a related DNV recommended practice; a further DNV standard extends this framework to floating wind turbine structures, a technology of growing relevance as fixed-foundation sites in shallow water are progressively developed out. These standards are directly relevant to India's own nascent offshore wind sector: the Ministry of New and Renewable Energy notified a National Offshore Wind Energy Policy in October 2015 and has since set out an auction trajectory targeting some 37 GW of offshore wind capacity by 2029-30, formalized in a September 2023 strategy paper that proposes viability-gap funding (VGF) to bring down tariffs for early projects [26]. Unlike the fixed-jacket oil and gas sector, where API RP 2A/IS 800-based practice is well established through decades of ONGC experience, India currently has no dedicated domestic offshore wind support-structure code, implying that early Indian offshore wind projects will need to adopt IEC 61400-3 and DNV-ST-0126 largely as published—in much the same way ONGC's jacket fleet has historically relied on imported API provisions—while India-specific metocean and soil conditions (including the cyclone-prone Bay of Bengal and Arabian Sea coastlines identified for early auctions) are progressively incorporated into practice.

Structural Integrity Assessment and Life Extension of Ageing Platforms

Wisch, Puskar, Laurendine, O'Connor, Versowsky, and Bucknell [16] reviewed the development and subsequent evolution of API RP 2A Section 17, the assessment methodology developed in the mid-1990s specifically for existing platforms whose original design basis no longer reflects current environmental criteria, platform condition, or consequence-of-failure category. Unlike new-build design, Section 17 permits nonlinear, ultimate-strength (pushover) analysis calibrated to provide a mean, rather than conservative, estimate of platform system capacity, typically expressed as a Reserve Strength Ratio (RSR)—the ratio of the platform's computed ultimate lateral capacity to its design-basis environmental load. The authors described this approach as having become the worldwide reference method for assessing existing platforms, including installations well beyond U.S. waters. Aeran, Siriwardane, Mikkelsen and Langen [17] built on this assessment tradition by proposing a more detailed integrity-assessment framework specifically for life extension of ageing jacket structures, addressing gaps they identified in existing guidelines—including the simulation of time-dependent structural degradation in the absence of direct corrosion measurement data, the effect of localized corrosion on stress concentration factors (and hence on the S-N curve and Miner's-rule fatigue-life calculation discussed above), and the selection of fatigue strength curves appropriate to corroded, aged details; applying the framework to a case-study ageing jacket, the authors showed that conventional assessment approaches can materially over- or under-estimate remaining fatigue life relative to their more detailed treatment.

The practical scale of this assessment burden is illustrated by ONGC's experience in the Western Offshore Basin. More than a third of its roughly 265 fixed platforms had, by the mid-2010s, already exceeded their original 25-year design life, prompting ONGC's Institute of Engineering and Ocean Technology to contract DNV GL to develop a requalification methodology incorporating risk-based inspection (RBI) for 34 of the most critical structures [24]. RBI analysis quantifies the probability and consequence of individual degradation modes (corrosion, fatigue cracking, dropped-object damage) to target inspection effort at the joints and members that most affect overall platform risk rather than inspecting uniformly across a structure and to set inspection intervals that keep risk below an acceptable threshold throughout an extended service life. At wider fleet scale, a parallel structural-analysis and recertification programme covering the great majority of ONGC's platforms—reported to have cost on the order of US$150 million and to have used nonlinear pushover analysis (yielding platform-specific RSR values) alongside dent modelling and additional pile modelling—identified strengthening or other mitigation measures for around 90% of the assessed structures and added a further 10-15 years to average platform service life [25]. This fleet-scale experience corroborates, at industrial scale, the joint-level and structure-level findings of Wisch et al. [16] and Aeran et al. [17] regarding both the practical importance and the continuing methodological development of nonlinear, risk-informed assessment for ageing jacket structures, and it suggests that structural integrity management is now as significant a driver of Indian offshore engineering activity as it is internationally.

Indian Standards, In-House Practice and Field Applications

IS 800:2007 [18], the Bureau of Indian Standards' general code of practice for construction in steel, is not an offshore-specific document; it is the primary Indian reference for hot-rolled steel construction, covering loads, limit-state and working-stress member design, connections, and fabrication and erection requirements, and its limit-state provisions follow the same conceptual $\Sigma\gamma_i Q_i \leq \varphi R_n$ format described in the Introduction, albeit with partial safety factors calibrated for general Indian building and industrial construction rather than for offshore environmental loading. However, it nonetheless underpins Indian offshore practice wherever member and connection checks are not explicitly covered by the API-based design basis, and it is the code of reference for topside and deck-structure elements that more closely resemble conventional industrial steelwork than jacket tubulars. It is worth noting that the Bureau of Indian Standards does not publish the following: unlike API, ISO, or DNV, BIS has issued no dedicated code of practice for fixed steel offshore oil-and-gas jacket structures analogous to API RP 2A or ISO 19902. The closest existing BIS documents are IS 4651 (Parts 1-5), the code of practice for planning and design of ports and harbors, and IS 9527 (Parts 1-6), covering the design and construction of port and harbor structures [27]; both address nearshore marine and waterfront structures—berths, breakwaters, quay walls, sheet-pile and block-work construction—rather than deepwater fixed jackets, tubular joints, or the wave, current and vessel-impact loading regimes that govern offshore platform design, and neither is drafted with ONGC-type fixed platforms in view. This gap is precisely why Indian offshore practice has, in practice, imported API RP 2A wholesale for the primary structure while reaching for IS 800 only for the onshore-analogous portions of the design; it is also the reason this review's own recommendation—that BIS or ONGC/IEOT jointly develop an India-specific offshore structural code or annex—remains, as of writing, an unmet need rather than a document already in preparation. Nallayarasu [19], in a widely used textbook on the design of offshore structures written from direct industry experience including concept development for ONGC process platforms on India's west coast, sets out fixed-platform, tubular-joint, and foundation design methods within the API/ISO framework while explicitly addressing practical constraints particular to Indian offshore fields, including relatively shallow water depths, soft clay foundation soils, and marginal-field development economics that favor lighter, lower-cost platform concepts than those typical of the North Sea or Gulf of Mexico.

Bhat and Karunanithi [20], reporting work carried out at ONGC's Institute of Engineering and Ocean Technology (IEOT), described a structural feasibility study for relocating existing, non-producing jacket platforms from the Western Offshore basin to newer field locations rather than constructing new structures, motivated by the maturing of many original discoveries and by the techno-commercial constraints of developing smaller, marginal fields. Structural adequacy at the new location was verified for 100-year return-period extreme storm conditions from eight directions and other design loads following API RP 2A WSD, and a general foundation-design philosophy was developed covering both relocation to deeper water, using plinth platforms, and relocation to similar water depths, using insert piles and additional clamp-on skirt piles. The study illustrates how, in practice, Indian offshore structural design activity today is as much about the assessment, strengthening, and re-use of an ageing fleet of platforms as it is about new-build design, reinforcing the relevance of the assessment methodologies described elsewhere in this review to Indian conditions specifically, and anticipating the fleet-wide risk-based requalification effort that ONGC/IEOT would subsequently undertake with international classification-society support [24, 25].

DISCUSSION: CROSS-CUTTING THEMES AND RESEARCH GAPS

Reading The Thirty Reviewed Studies and Standards Together Reveals Several Recurring Patterns

Common lineage and divergent calibration. API RP 2A and ISO 19902 share closely related, and in places numerically identical, tubular-member and joint-strength formulations, yet differ in partial safety factor philosophy, environmental load factor definitions, and regional calibration, so that the choice of code—and of which region's environmental factors to apply within it—can materially affect computed capacity and reliability index β [2–4].

Codes are moving targets, not fixed references. Both principal codes have continued to be revised well after the comparative studies that examine them were published: API RP 2A has been reissued as a 23rd edition following an incomplete attempt to fold it into a broader suite of companion standards, and ISO 19902 was updated to a second edition in 2020, meaning that any cross-code comparison—including those summarized in this review—needs to be re-checked against the specific editions currently in force before being applied to a live design [21, 22].

A gradual, still-incomplete shift from WSD to LRFD/limit state design, grounded in a common probabilistic theory. The industry's LRFD calibration effort, first formalized in the late 1980s on the reliability-index foundations laid by Cornell [28] and systematized in probabilistic model codes such as the JCSS model [29], remains a live process rather than a settled one: recalibration exercises using updated post-Katrina metocean data have found that the 1990s-era load and resistance factors no longer deliver the reliability originally intended, indicating that periodic recalibration against evolving environmental data is necessary rather than optional [10, 11, 30].

Fatigue design as a persistent site of code divergence: Multiple studies independently find that although the major fatigue codes share a common bilinear S-N curve and Palmgren-Miner damage-summation framework, the specific curve intercepts, thickness corrections, environment classes, and design fatigue factors applied to a given structural detail differ enough between codes to change the governing detail or the computed remaining fatigue life, particularly for corroded or splash-zone details [6–9].

Convergence, with adaptation, between oil-and-gas and offshore-wind practices. Offshore wind turbine support structure standards draw heavily on oil-and-gas offshore practices; however, several studies have shown that consequence-of-failure, load regime, and foundation-diameter differences mean that oil- and gas-derived factors and methods cannot simply be reused unmodified for OWT structures, motivating dedicated calibration and design-method development for the wind sector [13–15, 23].

Aging fleet assessment is a growing and now quantifiable share of structural design activity. Both international and Indian sources show that assessment and life-extension of existing platforms—rather than new-build design—increasingly dominate practical structural engineering effort; in ONGC's Western Offshore fleet specifically, this has translated into a fleet-scale, multi-hundred-platform requalification programme that has extended average service life by 10-15 years and, at joint level, into a dedicated risk-based inspection methodology for the most critical structures, though existing assessment guidelines still leave gaps around quantifying time-dependent degradation in the absence of direct measurement data [16, 17, 20, 24, 25].

An Indian practice is still substantially WSD-based and reliant on hybrid documents, now facing a second, distinct standards gap in offshore wind. Indian offshore design continues to rely predominantly on API RP 2A WSD supplemented by the general national steel code IS 800 and by internally developed ONGC/IEOT guidance, rather than on a dedicated, India-specific offshore structural code or on India-calibrated environmental load factors of the kind ISO 19902 provides for other regions. The Bureau of Indian Standards' own portfolio confirms this gap directly: its nearest documents to offshore structures, IS 4651 and IS 9527, address ports and harbors rather than fixed jacket platforms; thus, BIS has no counterpart to API RP 2A or ISO 19902 for oil-and-gas structures at all [27]. As the Indian government pursues a multi-gigawatt offshore wind auction program, the absence of a dedicated domestic code is set to recur in a new form, as no Indian offshore wind support structure standard exists alongside IEC 61400-3 and DNV-ST-0126 [18, 19, 20, 26].

Methodological heterogeneity across the reviewed evidence base. The thirty sources reviewed span primary normative standards, reliability-calibration studies using disparate metocean datasets and statistical models, single case studies, trade-press reporting, and a government policy document; this heterogeneity, characteristic of applied engineering-standards literature generally, means the cross-cutting patterns above should be read as convergent qualitative findings across a varied evidence base rather than as the output of a formal meta-analysis, a distinction developed further in the Limitations section below.

Taken together, these patterns suggest that future work would benefit from the development of India-specific environmental (metocean) load factors suitable for direct use within an LRFD/limit-state framework and calibrated using the FORM/SORM methodology set out by Ang and Tang [30] to an explicitly stated target reliability index; from closer integration of aging-platform assessment methodologies of the kind developed internationally into routine Indian requalification practice; and from early, structured engagement with international offshore wind turbine support-structure standards—IEC 61400-3 and DNV-ST-0126 in particular—as India's own offshore wind sector moves from policy auction trajectory toward first construction, so that lessons already learned internationally about adapting oil-and-gas-derived methods to turbine-specific load regimes are not re-learned from scratch. Table 2 sets out this agenda in a form intended to be directly usable as a starting point for postgraduate or doctoral research proposals Table 3.

Limitations of This Review

This review has its own methodological boundaries that should be weighed alongside its findings, and a doctoral reader in particular should treat the following as constraints on the strength of the inferences that can be drawn from it, not merely as disclaimers.

First, the 30 included studies and standards were selected narratively rather than through a fully systematic, protocol-driven search (e.g., pre-registered PRISMA screening with documented inclusion and exclusion criteria, dual independent reviewers, and a formal risk-of-bias instrument applied to each included study). While the explicit relevance, comparative-content, currency, and provenance criteria set out in the Review Methodology section improve transparency relative to an unstructured narrative review, they do not substitute for a systematic search across multiple bibliographic databases with a documented Boolean query, and no attempt was made to quantify inter-study agreement or heterogeneity formally (for example, via a meta-analytic effect-size synthesis) given the incommensurable outcome measures—reliability indices, S-N curve parameters, RSR values, qualitative code-comparison findings—reported across the included studies. The sample, while weighted toward comparative and calibration studies directly relevant to the review's themes, is therefore not exhaustive and may under-represent other relevant literature, including non-English-language sources and standards that are not readily accessible in the public domain.

Second, several of the primary documents discussed—API RP 2A, ISO 19902, DNV-RP-C203, IEC 61400-3, DNV-ST-0126—are periodically revised, and although this review has attempted to reflect the most recent editions and revision history known at the time of writing, including the 2020 s edition of ISO 19902 and the multi-decade restructuring history of API RP 2A, readers applying these codes in practice should always verify the current edition in force rather than rely on any edition-specific detail reported here.

Table 2. Research agenda: evidence gaps, research questions and suggested approaches.

Gap identified	Research question	Suggested approach
Absence of India-calibrated environmental (metocean) load and resistance factors	How should partial safety factors be re-derived for Arabian Sea and Bay of Bengal metocean regimes so that Indian LRFD-format designs achieve a stated target reliability index, rather than importing GoM- or North-Sea-calibrated factors by default?	Reliability-based calibration (FORM/SORM) using long-term Indian buoy and hindcast metocean data, following the calibration methodology of Lloyd and Karsan [11] and Chen et al. [10]
No dedicated Indian offshore structural or offshore-wind support-structure code	What is the minimum viable scope of an India-specific offshore structural annex (to IS 800 or as a standalone BIS document), and should it adopt an LRFD or hybrid WSD/LRFD format given existing ONGC practice?	Structured gap analysis comparing IS 800, API RP 2A and ISO 19902 provisions clause-by-clause, informed by ONGC/IEOT in-house guidance and international offshore-wind precedent (IEC 61400-3, DNV-ST-0126)
Limited quantification of time-dependent degradation for ageing jackets absent direct measurement data	Can probabilistic corrosion- and fatigue-degradation models, updated with Bayesian methods as inspection data arrive, reduce the uncertainty band around remaining fatigue life for platforms beyond original design life?	Bayesian updating of degradation models using ONGC/IEOT inspection records; benchmarking against the framework of Aeran et al. [17]
Fatigue design factors largely transferred from oil-and-gas practice to offshore wind without independent Indian validation.	Are DNV-RP-C203-derived S-N curves and design fatigue factors appropriate for the metocean and soil conditions expected at India's first offshore wind auction sites, or do they require site-specific recalibration?	Site-specific fatigue reliability analysis following Márquez-Domínguez and Sørensen [14], using representative Indian turbine and substructure load cases
Heterogeneous, largely narrative evidence base for Indian offshore practice	Would a systematic, protocol-driven (e.g., PRISMA-based) review of Indian offshore structural literature, including grey literature and ONGC/IEOT internal reports where accessible, identify additional evidence not captured here?	Prospective systematic review with pre-registered search strategy and explicit inclusion/exclusion criteria, extending the present narrative review
Fleet-wide risk-based inspection still applied to a subset of the most critical platforms.	Can machine-learning-assisted anomaly detection on inspection and monitoring data extend risk-based inspection coverage cost-effectively across the full 265-platform Western Offshore fleet?	Exploratory data-driven RBI pilot combining structural health monitoring data with the existing DNV GL-developed RBI framework [24]

Table 3. Nomenclature.

Abbreviation	Expansion/definition
API	American Petroleum Institute
ISO	International Organization for Standardization
DNV	Det Norske Veritas
NORSOK	Norsk sokkels konkuranseposisjon (Norwegian offshore standards)
IEC	International Electrotechnical Commission
BIS	Bureau of Indian Standards
ONGC	Oil and Natural Gas Corporation (India)
IEOT	Institute of Engineering and Ocean Technology (ONGC)
WSD	Working Stress Design (allowable-stress format)
LRFD	Load and Resistance Factor Design
OWT	Offshore Wind Turbine
OWTG	Offshore Wind Turbine Generator
MODU	Mobile Offshore Drilling Unit
RBI	Risk-Based Inspection
DFF	Design Fatigue Factor
S-N curve	Stress-range (S) vs. number-of-cycles-to-failure (N) fatigue curve
SCF	Stress Concentration Factor
FORM/SORM	First-/Second-Order Reliability Method
β (beta)	Reliability (safety) index
RSR	Reserve Strength Ratio (ultimate pushover capacity / design environmental load)
DLC	Design Load Case (IEC 61400-3 terminology)
GoM	Gulf of Mexico
VGF	Viability Gap Funding

Third, the reviewed literature skews toward North American, European, and Southeast Asian offshore contexts, with comparatively few peer-reviewed, India-specific structural design studies identified; the Indian material included here therefore relies more heavily on a national steel code, a practitioner textbook, trade-press reporting on ONGC/IEOT practice, and a government policy document than on the systematic reviews and meta-analyses that anchor other thematic clusters. This asymmetry is itself a finding of the review—it is the empirical basis for the evidence-base gap identified as Research Question 5 in Table 3—but it also means that conclusions specific to Indian practice rest on a thinner and more heterogeneous evidentiary foundation than conclusions about the international API/ISO/DNV framework and should be weighted accordingly.

Fourth, because several offshore wind turbine standards and reliability studies, and the Indian offshore wind policy material, were published within the last five years, some findings in those clusters reflect a still-maturing evidence base—and, in the Indian offshore wind case, a programme that as of writing has not yet reached first construction—that may be revised as further operational and regulatory experience accumulates.

Fifth, the reliability-theory framing introduced in this expanded version—the reliability index β and FORM/SORM methodology of Cornell [28] and Ang and Tang [30], and the target-reliability differentiation of the JCSS model code [29]—is presented as a common conceptual lineage underlying the code-specific calibration studies discussed, not as a claim that API RP 2A-LRFD, ISO 19902 and DNV standards apply numerically identical reliability targets or FORM implementations; readers should consult each code's own calibration basis document before assuming a specific numerical target β carries across codes.

These limitations do not undermine the cross-cutting patterns identified above, but they do suggest that the patterns should be treated as a structured starting point for further systematic inquiry, particularly with respect to Indian offshore practice, rather than as a definitive account of the field. The research agenda in Table 3 is offered in this spirit.

CONCLUSION

This review has discussed thirty studies and standards concerned with the structural design of offshore structures, drawn from international recommended practices, peer-reviewed comparative and calibration studies, foundational structural-reliability theory, and Indian codes, field applications and policy documents, to map the current state of practice across six interconnected themes: foundational design philosophies, cross-code comparisons and the continuing evolution of the API/ISO framework; fatigue design provisions and S-N curves; reliability-based calibration of load and resistance factors and the probabilistic theory underlying it; standards for offshore wind turbine support structures, including India's emerging offshore wind context; structural integrity assessment and life extension of ageing platforms; and Indian standards and field practice. The literature shows a field with a long-established common technical core—rooted in API RP 2A and carried forward, with LRFD-format refinement grounded in a shared reliability-index framework, into ISO 19902 and DNV practice—that nonetheless continues to require periodic recalibration and re-editioning as environmental data, platform populations, and, increasingly, new structure types such as offshore wind turbine foundations evolve. Indian offshore structural design, concentrated in ONGC's Western Offshore basin and now home to some 265 fixed platforms, sits within this international framework while relying on a hybrid design basis of API RP 2A, the general national steel code IS 800, and in-house ONGC/IEOT guidance, and is increasingly oriented toward the assessment, requalification and relocation of an ageing platform fleet—a task ONGC/IEOT has pursued through a fleet-scale, risk-based requalification programme—rather than solely new-build design. A second, distinct challenge is emerging as India pursues its own offshore wind auction programme without possessing a dedicated domestic support-structure code. Addressing the gaps identified here will likely require closer engagement between Indian offshore engineering practice and the international standards-development and reliability-calibration community, along with the development of India-specific, reliability-calibrated environmental load factors, early adoption and adaptation of international offshore wind support structure standards, and a stronger, more systematically documented body of India-focused offshore structural engineering research. The structured research agenda set out in Table 3 is offered as a concrete starting point for that work, particularly for doctoral and post-doctoral researchers seeking to connect the international offshore reliability literature to the specific and still substantially under-documented conditions of Indian offshore practice.

Nomenclature

For readers new to offshore-structure literature, Table 2 lists the abbreviations used throughout this review.

REFERENCES

1. Anzai T, Bryant LM, Pedersen FB. Comparison of a limit state design code with API. In: Proceedings of the Offshore Technology Conference; 1982 May 3-6; Houston, TX, USA. OTC-4191-MS. RP2A.
2. Nizamani Z. Tubular strength comparison of offshore jacket structures under API RP 2A and ISO 19902. In: Environmental Load Factors and System Strength Evaluation of Offshore Jacket Platforms. Vol. 4. Cham: Springer; 2015. p.155-173. doi:10.1007/978-3-319-15051-2_6.
3. Karulin EB, Karulina MM. Strength of tubular members: numerical comparison of API RP 2A to ISO codes. In: Proceedings of the Ninth ISOPE Pacific/Asia Offshore Mechanics Symposium; 2010 Nov 14-17; Busan, Korea.
4. Det Norske Veritas. TA&R Project: Final Report on Comparison of API, ISO, and NORSOK Offshore Structural Standards. Washington (DC): Bureau of Ocean Energy Management, Regulation and Enforcement; 2011. p.677.

5. MMI Engineering Inc. Comparative Study of OWTG Standards: prepared for JIP sponsorship. Oakland (CA): MMI Engineering Inc.; 2009 Jun 29. 618 p. (TAP-618; MMI Project No. MMW528).
6. DNV GL AS. DNVGL-RP-C203: fatigue design of offshore steel structures. Høvik (Norway): DNV GL AS; 2016 Apr.
7. Choung J. Comparison of fatigue provisions in various codes and standards—Part 1: basic design S-N curves of non-tubular steel members. J Ocean Eng Technol. 2021;35(1).
8. Siriwardane SC, Adasooriya ND, Pavlou D. Fatigue strength curve for tubular joints of offshore structures under dynamic loading. Dynamics. 2021;1(1):125-133. doi:10.3390/dynamics1010007.
9. Zhao W. Calibration of design fatigue factors for offshore structures based on fatigue test database. Int J Fatigue. 2021;145:106075. doi:10.1016/j.ijfatigue.2020.106075.
10. Chen J, Gilbert RB. Calibration of load and resistance factors of API RP 2A-LRFD, second edition, for fixed offshore platforms. J Struct Eng. 2021;147(2). doi:10.1061/(ASCE)ST.1943-541X.0002912.
11. Lloyd JR, Karsan DI. Development of a reliability-based alternative to API. In: Proceedings of the Offshore Technology Conference; 1988; Houston, TX, USA. RP2A.
12. American Bureau of Shipping. Testing validates load/resistance design for offshore structures. Offshore Magazine. 2016.
13. Wang L, Kolios A, Liu X, Venetsanos D, Cai R. Reliability of offshore wind turbine support structures: a state-of-the-art review. Renew Sustain Energy Rev. 2022;161:112250. doi:10.1016/j.rser.2022.112250.
14. Márquez-Domínguez S, Sørensen JD. Fatigue reliability and calibration of fatigue design factors for offshore wind turbines. Energies. 2012;5(6):1816-1834. doi:10.3390/en5061816.
15. Sunday K, Brennan F. A review of offshore wind monopiles structural design achievements and challenges. Ocean Eng. 2021;235:109409. doi:10.1016/j.oceaneng.2021.109409.
16. Wisch DJ, Puskar FJ, Laurendine TT, O'Connor PE, Versowsky PE, Bucknell J. An update on API RP 2A Section 17 for the assessment of existing platforms. In: Proceedings of the Offshore Technology Conference; 2004; Houston, TX, USA. OTC-16820-MS.
17. Aeran A, Siriwardane SC, Mikkelsen O, Langen I. A framework to assess structural integrity of ageing offshore jacket structures for life extension. Mar Struct. 2017;56:237-259. doi:10.1016/j.marstruc.2017.08.002.
18. Bureau of Indian Standards. IS 800:2007. General Construction in Steel—Code of Practice. 3rd rev. New Delhi: Bureau of Indian Standards; 2007.
19. Nallayarasu S. Design of Offshore Structures: For Practising Engineers and Students. Chennai: Department of Ocean Engineering, Indian Institute of Technology Madras; 2014.
20. Bhat P, Karunanithi S. Relocation of existing jacket platform in western offshore of India. Procedia Struct Integr. 2019;14:656-663. doi:10.1016/j.prostr.2019.05.081.
21. International Organization for Standardization. ISO 19902:2020. Petroleum and Natural Gas Industries—Fixed Steel Offshore Structures. 2nd ed. Geneva: International Organization for Standardization; 2020.
22. Zwerneman FJ, Digre KA. New API codes: updates and new suite of standards—API RP 2A-WSD (2010). In: Proceedings of the Offshore Technology Conference; Houston, TX, USA. OTC-20837-MS.
23. Det Norske Veritas. DNV-ST-0126: Support Structures for Wind Turbines. Høvik, Norway: Det Norske Veritas; 2021.
24. Institute of Engineering and Ocean Technology, Oil and Natural Gas Corporation, DNV GL. Requalification methodology and risk-based inspection for ageing Western Offshore platforms. Oilfield Technology. 2014 Dec 17.
25. Oil and Natural Gas Corporation. Fleet-Scale Structural Requalification of Western Offshore Platforms Using Nonlinear Pushover Analysis. Offshore Magazine.
26. Ministry of New and Renewable Energy. Strategy Paper for Establishment of Offshore Wind Energy Projects. New Delhi: Government of India; 2023.

27. Bureau of Indian Standards. IS 4651 (Parts 1-5): Code of Practice for Planning and Design of Ports and Harbors. New Delhi: Bureau of Indian Standards; [date unknown]. Also: IS 9527 (Parts 1-6): Code of Practice for Design and Construction of Port and Harbor Structures. New Delhi: Bureau of Indian Standards.
28. Cornell CA. A probability-based structural code. ACI J. 1969;66(12):974-985.
29. Joint Committee on Structural Safety. JCSS Probabilistic Model Code. Lyngby, Denmark: Joint Committee on Structural Safety; 2001.
30. Ang AHS, Tang WH. Probability Concepts in Engineering Planning and Design. Vol. 2, Decision, Risk and Reliability. New York: John Wiley & Sons; 1984.

