Conceptual Design and Fabrication Assessment of a Single Large-Diameter Pile Foundation for Compact Offshore Jacket Structures

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Abstract

A large-diameter single pile is a potentially attractive alternative for simplifying the foundation system of compact offshore jackets; however, concentrating all actions into one load path requires more rigorous geotechnical, structural, fabrication, and installation verification. This paper develops an integrated pre-design framework for assessing the concept. The assessment combines offshore structural design principles, soil–pile load-transfer mechanisms, axial and lateral capacity screening, tubular section stress checks, and fabrication quality planning. An illustrative reference case with a 3.0 m diameter steel pile, 60–80 mm wall thickness, 70 m total length, and 45 m embedment is used to demonstrate the influence of diameter, penetration, soil stiffness, wall thickness, and scour. The screening results indicate that axial resistance increases strongly with diameter and embedment, whereas lateral response is particularly sensitive to soil stiffness, diameter, and scour. For an illustrative combination of 20 MN axial load and 120 MN·m overturning moment, a 60 mm wall gives a combined nominal stress of approximately 337 MPa, leaving limited margin to a 355 MPa yield strength; increasing the wall to 70–80 mm reduces the stress to approximately 291–257 MPa. Fabrication reliability is governed by material traceability, ovality, alignment, welding parameters, non-destructive testing, corrosion protection, and loadout readiness. The concept can be efficient for light-to-medium topsides in relatively uniform ground, but it should not be selected merely because it reduces the number of piles. A final decision requires site-specific ground investigation, nonlinear soil–structure analysis, fatigue verification, drivability assessment, accidental limit-state checks, and installation-spread evaluation.

Keywords: fabrication, offshore jacket, quality control, single pile foundation, soil–structure interaction.

INTRODUCTION

Fixed offshore jackets remain a mature solution for oil and gas facilities, substations, monitoring stations, and other topside systems in shallow to intermediate water depths. Their safety depends on the combined performance of the jacket, foundation, seabed, and installation system. ISO 19902 provides the overarching fixed-steel-structure framework, while API RP 2A-WSD and API RP 2GEO provide established design and geotechnical guidance for offshore platforms and foundations [1]–[3]. The conventional jacket normally transfers loads through several piles driven through or adjacent to its legs. This arrangement offers redundancy and spreads the environmental overturning moment over a wide foundation footprint, but it also increases the number of tubulars, pile sleeves, welds, offshore lifts, driving operations, and inspection points.

For compact facilities with moderate topside mass, a single large-diameter pile connected to a small jacket or transition frame may reduce fabrication count and offshore installation duration. The concept resembles a monopile in its foundation behavior, but the supported superstructure can still use jacket bracing to provide elevation, access, and deck support. The transfer system is therefore not a conventional four-leg jacket foundation and should be treated as a distinct structural concept. The single pile must resist the total vertical action, base shear, overturning moment, torsion, cyclic loading, and accidental actions without the load-sharing and redundancy available in a pile group [13], [15].

The attraction of fewer foundation components can be misleading if the design process does not capture soil nonlinearity, pile–soil cyclic degradation, scour, local shell stability, weld fatigue, drivability, and the consequences of a single-point failure. Offshore soil response is strongly site dependent; design methods for axial capacity and lateral response require calibrated soil parameters and appropriate load-transfer relationships [4], [15]–[20]. Large-diameter piles can also fall outside the range of some traditional p–y formulations, motivating the use of advanced numerical analysis or more recent large-diameter pile models such as the PISA framework [21], [22].

Fabrication is equally important. A large pile is manufactured from rolled plate cans joined by longitudinal and circumferential welds. Dimensional tolerance, plate lamination, weld procedure qualification, heat input, residual distortion, non-destructive examination, coating, lifting-point design, and sea-fastening all influence final reliability. DNV offshore fabrication requirements, AWS structural welding provisions, and ISO welding-quality and inspection standards provide a basis for controlling these processes [6], [9]–[12]. Marine operations and installation planning must then confirm that the completed pile can be transported, upended, positioned, and driven within acceptable weather and equipment limits [5].

The original study identified the importance of pile diameter, penetration, soil characteristics, welding quality, and inspection. This revised paper extends that basis by establishing a transparent conceptual design case, presenting equations and screening calculations, linking structural and geotechnical decisions to fabrication consequences, and defining stage-gate criteria for technical selection. The purpose is not to certify a site-specific foundation but to show how a single-pile jacket concept should be evaluated before detailed engineering.

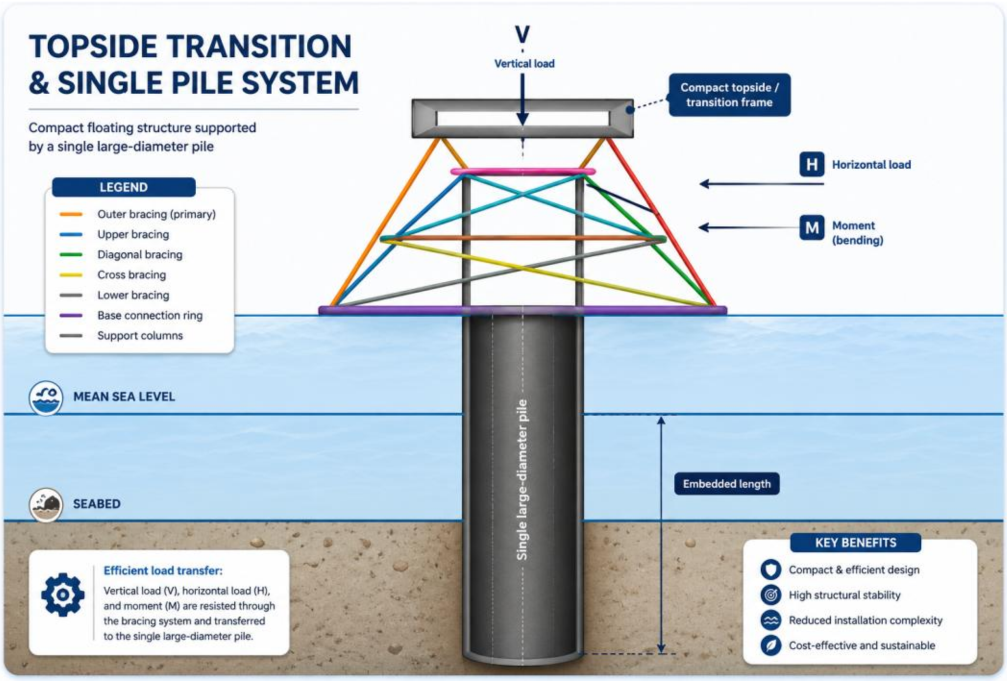

Figure 1. Conceptual load path for a compact offshore jacket supported by one large-diameter pile.

Table 1. Reference case used for transparent design screening.

Item	Reference conceptual value	Purpose / status
Water depth	35 m	Illustrative shallow-water application
Pile outer diameter, D	3.0 m	Sensitivity range 2.5–4.0 m
Wall thickness, t	60–80 mm	Structural and fabrication sensitivity
Total pile length	70 m	Includes stick-up and embedment
Embedment, L_e	45 m	Sensitivity range 35–55 m
Steel grade	Nominal f_y = 355 MPa	Conceptual screening only
Vertical design action, V	20 MN	Illustrative resultant at pile head
Horizontal design action, H	4 MN	Illustrative storm resultant
Overturning moment, M	120 MN·m	Illustrative pile-head moment
Design life	25 years	Requires fatigue and corrosion allowances
Soil profile	15 m clay over sand	Generic; not site-specific
Scour allowance	0–2 m sensitivity	To be replaced by site assessment

DESIGN BASIS AND RESEARCH CONTRIBUTION

The assessment is framed as a pre-feasibility and conceptual-design study. The reference system consists of a compact steel jacket or transition frame connected to one central tubular pile. The pile head receives the resultant vertical force V, horizontal force H, overturning moment M, and torsion T from the superstructure. The pile transfers axial compression through shaft friction and toe resistance, while lateral load and moment are resisted through distributed soil reactions, pile bending stiffness, and passive soil resistance. The design must satisfy ultimate, serviceability, fatigue, accidental, and installation limit states [1], [2], [7].

The contribution of the study is fourfold. First, it distinguishes the single-pile jacket concept from a conventional pile group and explicitly identifies the loss of foundation redundancy. Second, it combines geotechnical and structural screening rather than treating pile capacity and tubular stress as independent checks. Third, it converts fabrication from a descriptive activity into a measurable inspection-and-test plan with hold points. Fourth, it provides a decision framework that indicates when the concept should proceed to detailed analysis and when a multi-pile or alternative foundation should remain the baseline.

The numerical values in Table 1 are deliberately identified as illustrative. They are not inferred from a real offshore site and must not be used for construction. Their function is to demonstrate the influence of governing variables and to prevent qualitative conclusions from being presented as if they were verified project results.

TECHNICAL BACKGROUND

Load Transfer and Limit States

The pile-head action vector can be written as $\{F\} = \left[V, H_x, H_y, M_x, M_y, T\right]^T$. Structural analysis of the jacket provides these actions for each design situation. Geotechnical analysis then determines the displacement and rotation compatible with soil resistance. Because the foundation stiffness affects jacket natural periods and force distribution, the process is iterative rather than one-way. A fixed-base jacket model can overestimate structural stiffness, while an overly soft spring model can exaggerate displacement. The soil–foundation model should therefore be compatible with the loading level and limit state [3], [4].

Ultimate checks include axial compression and uplift, lateral capacity, overturning resistance, local shell yielding, buckling, punching or connection failure, and foundation collapse. Serviceability checks include pile-head translation, rotation, deck-level displacement, and equipment alignment. Fatigue checks address cyclic stress ranges at circumferential welds, attachments, transition details, and the jacket–pile interface; DNV-RP-C203 provides commonly used S–N and fatigue-assessment provisions [7]. Accidental checks should consider dropped objects, vessel collision, fire or blast transfer, abnormal scour, and loss of corrosion protection. ABS and DNV class frameworks reinforce the need to verify the complete lifecycle rather than only static strength [6], [8].

Axial Capacity

For a driven pile in compression, the conceptual ultimate axial resistance is expressed $as\ Q_u = Q_s + Q_b$, where Q_s is shaft resistance and Q_b is toe resistance. In a layered profile, $Q_s = \Sigma\left(\pi D\ L_i f_{\{s,i\}}\right)$ and $Q_b = A_b q_b$. Here D is pile diameter, L_i is the thickness of soil layer i, $f_{\{s,i\}}$is the unit shaft resistance, A_b is toe area, and q_b is unit toe resistance. The selected resistance model, setup effects, cyclic degradation, plugging, and installation method must follow the governing geotechnical standard and be calibrated to site data [3], [15], [16], [20].

For cohesive soil, an α-method representation f_s = αs_u is often used at screening level, whereas sand design may use effective-stress or CPT-based methods. Modern offshore pile design increasingly relies on cone penetration testing because CPT profiles provide continuous stratigraphic and resistance information. The ICP methodology illustrates how CPT-based formulations can improve axial capacity assessment compared with simple global correlations [20].

Lateral Response and Large-Diameter Effects

Lateral behavior is commonly represented by a beam supported by nonlinear soil springs. Traditional soft-clay and sand p–y formulations originate from field tests on relatively slender piles [18], [19]. Their direct application to large-diameter, low L/D foundations can be conservative or non-conservative depending on soil and loading regime. Reese and Van Impe summarize conventional lateral-pile analysis, while the PISA studies develop calibrated soil-reaction components for large-diameter monopiles [17], [21], [22].

The response depends on pile bending stiffness EI, soil stiffness, embedment, load eccentricity, cyclic history, and scour. Diameter affects both soil reaction and section stiffness. For a thin tubular section, the second moment of area scales approximately with D^3t, so a modest diameter increase can significantly reduce curvature. However, increasing diameter also increases plate thickness requirements, driving energy, lift weight, and welding demand. The optimum is therefore a coupled design decision, not a purely structural maximum-stiffness solution.

Environmental and Hydrodynamic Actions

Wave and current loading on the jacket, pile stick-up, conductors, appurtenances, and marine growth must be evaluated using an appropriate hydrodynamic model. Morison-type loading is commonly used for slender members, while diffraction or higher-order methods may be needed as diameter-to-wavelength ratios increase. Chakrabarti and Faltinsen provide the underlying offshore hydrodynamic formulations and limitations [13],

[14]. Environmental directions should be combined with operational weight, buoyancy, current, wind, and accidental situations to identify the governing pile-head resultant.

Fabrication Integrity

Fabrication quality is not a downstream administrative activity; it is part of the resistance model. Plate grade, through-thickness quality, weld details, misalignment, ovality, and residual stress affect yielding, buckling, fatigue, and drivability. DNV-OS-C401 defines offshore fabrication and testing expectations, AWS D1.1/D1.1M provides structural welding requirements, ISO 3834-2 defines comprehensive welding quality requirements, ISO 17635 organizes non-destructive testing selection, and ISO 5817 provides weld-imperfection quality levels [6], [9]–[12]. These documents should be translated into project-specific procedures, acceptance criteria, inspection stages, and records.

METHODOLOGY

The methodology combines standards review, analytical screening, sensitivity analysis, fabrication planning, and technical decision criteria. The first step defines the intended facility, water depth, environmental conditions, design life, target reliability, corrosion philosophy, and installation constraints. The second step converts superstructure analysis into pile-head actions. The third step establishes a geotechnical ground model and selects axial and lateral resistance methods. The fourth step checks tubular section capacity, deflection, rotation, fatigue-sensitive details, and connection load transfer. The fifth step converts the selected geometry into a fabrication route and inspection plan. The final step evaluates installation feasibility, residual risks, and the need for advanced analysis.

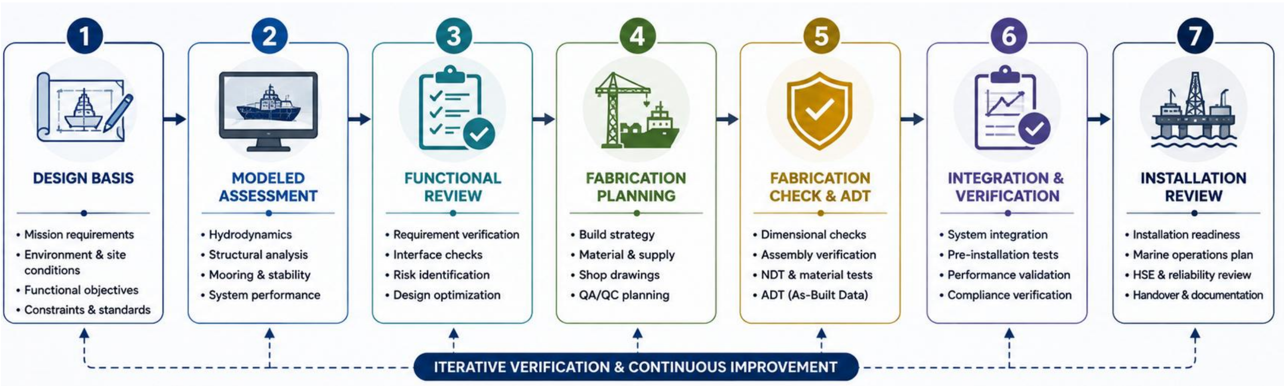

Figure 2. Integrated design–fabrication methodology adopted in this study.

For the illustrative screening, the tubular cross-sectional properties are calculated from

$$A = \frac{\pi}{4[D^2 - (D-2t)^2]}, I = \frac{\pi}{64[D^4 - (D-2t)^4]}, and\ Z = \frac{I}{\frac{D}{2}}. \tag{1}$$

The nominal combined longitudinal stress is approximated by

$$\sigma = \frac{V}{A} + \frac{M}{Z}. \tag{2}$$

This expression does not include local shell bending, stress concentration, ovality, dynamic amplification, partial factors, or buckling interaction; it is therefore used only to identify thickness sensitivity. Detailed design must apply the governing resistance equations and safety factors in ISO 19902 or the selected class standard [1]. The axial capacity sensitivity uses a generic two-layer soil profile: 15 m of clay $with\, s_u = 45\, kPa\, and\, \alpha = 0.75$, underlain by sand represented by an illustrative effective-stress shaft resistance and toe resistance. Because no site CPT or laboratory data were supplied, the values are intentionally conservative screening inputs rather than project geotechnical parameters. Lateral sensitivity is presented in normalized form to avoid implying that a simplified spring index is a certified displacement prediction.

Table 2. Progressive analysis levels for a single-pile jacket concept.

Analysis level	Model	Required input	Decision use
Level 1	Closed form / normalized screening	Geometry, section, loads, generic soil	Reject clearly unsuitable concepts
Level 2	1D beam–spring model	CPT/lab profile, calibrated p–y or PISA curves	Select diameter and penetration
Level 3	Integrated jacket–pile analysis	Directional metocean, nonlinear springs, fatigue loads	Verify global response
Level 4	3D finite-element soil–structure model	Advanced constitutive model and calibration	Resolve large-diameter or layered-soil uncertainty
Level 5	Installation and monitoring model	Hammer, soil resistance, fatigue, instrumentation	Confirm drivability and field acceptance

CONCEPTUAL STRUCTURAL SCREENING

Section Properties and Steel Quantity

For D = 3.0 m and t = 60 mm, the tubular area is 0.554 m², the second moment of area is 0.599 m⁴, and the elastic section modulus is 0.399 m³. With a steel density of 7,850 kg/m³, the line mass is approximately 4.35 t/m and the 70 m shell mass is about 305 t before allowances for weld metal, attachments, internal guides, corrosion allowance, lifting lugs, and coating. An 8% fabrication allowance would increase the handling mass to approximately 329 t. These values immediately affect plate availability, rolling capacity, crane selection, transport stability, and hammer requirements.

Table 3. Influence of wall thickness on tubular properties and fabrication weight.

Wall thickness	Area (m²)	I (m⁴)	Line mass (t/m)	Approx. 70 m shell mass (t)
50	0.463	0.504	3.64	255
60	0.554	0.599	4.35	305
70	0.644	0.692	5.06	354
80	0.734	0.783	5.76	403
90	0.823	0.872	6.46	452

Combined Axial and Bending Stress

Using the illustrative V = 20 MN and M = 120 MN·m, the nominal combined stress is approximately 337 MPa for a 60 mm wall. This is below but close to a nominal 355 MPa yield strength, leaving insufficient margin once resistance factors, corrosion allowance, fabrication tolerance, local bending, stress concentration, and buckling interaction are considered. The screening therefore indicates that 60 mm should not be accepted as a detailed-design thickness. Increasing the wall to 70 mm reduces the nominal combined stress to about 291 MPa; 80 mm reduces it to about 257 MPa. The trend is shown on Fig. 4.

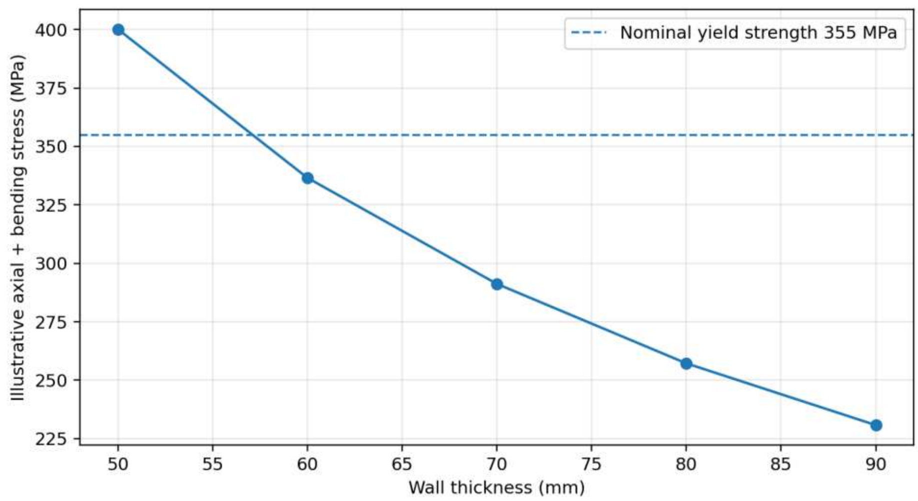

Figure 3. Illustrative sensitivity of combined nominal stress to pile wall thickness.

The stress calculation also highlights a central trade-off. A thicker pile improves strength, local stability, fatigue life, and driving robustness, but adds mass and weld volume. Local shell-buckling checks, diameter-to-thickness limits, axial–bending interaction, and weld detail classification must be completed according to the selected offshore code [1], [2]. The transition from jacket framing into the pile requires local shell or finite-element analysis because concentrated brace and ring-stiffener loads cannot be represented by global beam stress alone.

Axial Capacity Sensitivity

Figure 4 shows the expected increase in resistance with both diameter and penetration. Diameter increases perimeter and toe area, while deeper penetration mobilizes a longer shaft and may place the toe in a stronger layer. For the baseline D = 3.0 m and L_e = 45 m, the simplified calculation gives an ultimate resistance of approximately 68 MN. This should not be interpreted as a certified capacity because the assumed shaft and toe resistances are not derived from site CPT data.

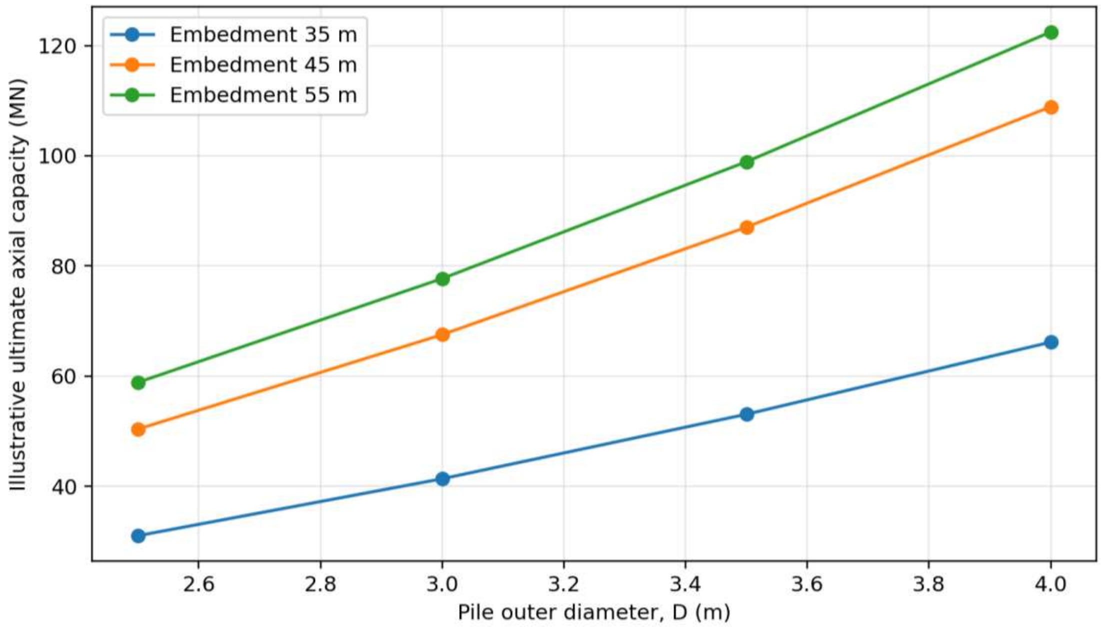

Figure 4. Illustrative axial-capacity sensitivity for the generic two-layer ground model.

After application of a global screening factor of 2.5, the corresponding nominal allowable resistance is about 27 MN, only moderately above the illustrative 20 MN design action. A site-specific method could move this margin substantially in either direction.

Table 4. Illustrative ultimate axial capacity from the screening model.

Diameter (m)	Embedment 35 m (MN)	Embedment 45 m (MN)	Embedment 55 m (MN)
2.5	31.1	50.4	58.9
3.0	41.4	67.5	77.7
3.5	53.1	87.0	98.9
4.0	66.2	108.9	122.5

Detailed axial design must evaluate compression, uplift, pile plugging, setup or relaxation, cyclic degradation, group or structural interaction where applicable, and installation effects. The single-load-path nature of the concept warrants conservative resistance modelling and independent verification. Site investigation should include CPTs to below the proposed toe, sampling and laboratory strength tests, cyclic testing where environmental cycles are significant, and geophysical correlation across the footprint [3], [4], [15].

Lateral Displacement, Rotation, and Scour

The normalized study indicates that diameter and soil stiffness can have a larger effect on pile-head displacement than a modest increase in embedment once sufficient fixity has developed. Scour has the opposite effect because it removes the most effective near-surface soil and increases the unsupported length. The figure uses a baseline displacement index of 1.0 rather than an absolute displacement prediction. A 15% diameter increase reduces the index through the approximate D^3 stiffness dependence, while a 50% increase in representative soil stiffness reduces the index proportionally. A 2 m scour allowance increases the index by about 28% in the illustrative model.

Absolute translation and rotation must be obtained from a calibrated 1D or 3D model. The analysis should include load eccentricity at the pile head, nonlinear soil reactions, gapping, cyclic accumulation, and the effect of the jacket transition on rotational restraint. The PISA models demonstrate that large-diameter piles can require additional soil-reaction components beyond a conventional single p–y curve [21], [22]. For layered ground, three-dimensional finite-element calibration or appropriately extended 1D models may be required.

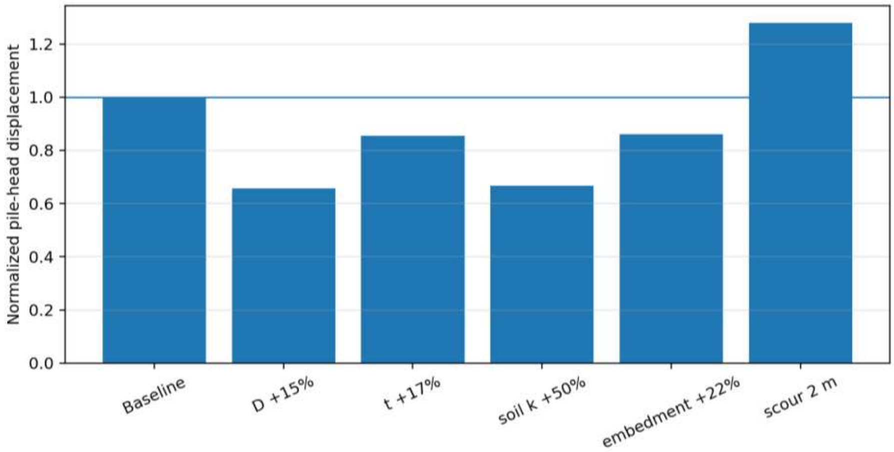

Figure 5. Normalized sensitivity of pile-head displacement to selected design changes.

FABRICATION ENGINEERING

Material and Plate Preparation

The procurement specification should define steel grade, toughness, through-thickness properties where restraint is high, carbon-equivalent limits, plate dimensions, corrosion allowance, and traceability. Mill test certificates must be linked to plate identification throughout cutting, rolling, welding, and assembly. Ultrasonic lamination checks are recommended near highly loaded attachments and weld preparations. Plate nesting should minimize waste while preserving rolling direction requirements and avoiding small closure pieces.

Plate edges are cut and prepared according to the qualified joint detail. Rolling must control diameter, ovality, local flatness, and mismatch. For a 3 m diameter shell, small geometric deviations can produce significant can-to-can fit-up problems and local bending during driving. A dimensional survey should be completed after rolling, after longitudinal welding, after circumferential joining, and before loadout.

Welding Strategy

Longitudinal seams close each rolled can, and circumferential seams join the cans into longer sections. The welding procedure specification should be supported by procedure qualification records and welder qualifications. Essential variables include process, consumable classification, preheat, interpass temperature, heat input, travel speed, backing or back-gouging method, and post-weld treatment. $AWS\,\frac{D1.1}{D1.1M}$ and the project offshore standard provide the procedural basis [6], [9].

Weld sequencing should balance shrinkage and minimize angular distortion. Mechanized submerged-arc welding is typically attractive for long, repetitive seams, but root quality, access, and repair strategy must be established. Temporary attachments should be minimized and removed under controlled procedures. All repairs require documented excavation, re-examination, and acceptance; repeated repair at the same location should trigger engineering review because of accumulated heat input and local toughness concerns.

Inspection and Test Plan

ISO 17635 should be used to plan the combination of non-destructive methods, while ISO 5817 provides weld-imperfection quality levels that can be specified according to consequence and fatigue sensitivity [11], [12]. Visual testing is required for all accessible welds, but volumetric examination is needed to detect internal lack of fusion, slag, or planar flaws. Acceptance criteria should be project-specific and consistent with fatigue class, fracture toughness, and the governing offshore standard rather than copied indiscriminately from a generic workshop practice.

Table 5. Example inspection and test plan for large-diameter pile fabrication.

Stage	Characteristic	Inspection / test	Typical control point
Plate receipt	Grade, thickness, traceability	MTC review, identification, visual inspection	Hold
Edge preparation	Bevel angle, root face, cleanliness	Dimensional and visual inspection	Witness
Rolling	Diameter, ovality, local flatness	Survey and templates	Hold
Longitudinal weld	Fit-up, parameters, internal defects	VT + UT/RT as specified	Hold
Circumferential weld	Mismatch, alignment, weld quality	VT + UT/RT; MT/PT at repairs	Hold
Final assembly	Straightness, length, attachment position	Total-station / laser survey	Hold
Coating and anodes	Surface preparation, DFT, continuity	Profile, climate, DFT and holiday test	Witness
Loadout	Weight, COG, lifting and sea fastening	Weighing, lift-point inspection, checklist	Release

Fabrication Quantity and Constructability

Assuming 3 m long cans for a 70 m pile, fabrication requires approximately 24 cans, 24 longitudinal seams, and 23 circumferential seams before considering splice strategy for transport. The total primary weld length is approximately 290 m. Longer plates reduce circumferential weld count but may exceed available rolling, handling, heat-treatment, or transport capacity. The optimum can length is therefore a yard-specific decision. Fabrication planning should confirm plate availability, roller capacity, welding station length, NDT access, storage supports, and loadout route before the geometry is frozen.

Table 6. Coupling between design variables and fabrication feasibility.

Constructability variable	Benefits of increase	Penalty / risk	Design implication
Diameter	Higher stiffness and capacity	Heavier cans, larger roller and hammer	Confirm yard and vessel limits early
Wall thickness	Lower stress and better driving robustness	Higher mass, weld volume and cost	Optimize by zone if code permits
Can length	Fewer circumferential welds	Harder handling and distortion control	Match workshop bay and transport
Penetration	Higher axial/lateral resistance	Longer driving time and refusal risk	Complete drivability study
Corrosion allowance	Longer residual life	Weight and rolling demand	Integrate with coating and CP
Attachment count	Improved installation functionality	Stress concentrations and NDT burden	Standardize and rationalize details

INSTALLATION AND MARINE-OPERATION ASSESSMENT

A pile that is structurally adequate may still be impractical to install. Marine-operation engineering should assess transport, sea fastening, upending, lowering, stabbing, temporary support, hammer selection, pile-driving fatigue, noise and environmental restrictions, and contingency for refusal. DNV-ST-N001 provides a systematic basis for marine-operation planning, including design situations, operational limits, weather forecasting, and verification [5].

Drivability analysis should use the same ground model as the capacity assessment but account for dynamic soil resistance, damping, quake, setup, and hammer–pile interaction. Required blow count and stress should be checked across the full depth. Excessive driving stress can cause yielding, fatigue damage, weld cracking, or local shell deformation. If the pile is fabricated in more than one transport section, offshore splice feasibility and inspection must be evaluated; avoiding an offshore splice is preferable when transport and crane capacities allow.

Installation tolerances are more critical for a single-pile concept because pile inclination and head-position error directly affect the entire superstructure. The jacket-to-pile connection must accommodate realistic as-installed geometry without creating unintended prying or locked-in stress. A contingency plan should define actions for early refusal, excessive inclination, damaged coating, hammer breakdown, pile run, or inability to reach target penetration.

Table 7. Example installation hazards and controls.

Installation hazard	Potential consequence	Preventive control	Contingency
Pile run	Loss of control and overstress	Soil review, follower/hammer procedure	Suspend and stabilize
Early refusal	Insufficient penetration/capacity	Drivability analysis and hammer margin	Re-strike, relief drilling, redesign
Excessive inclination	Connection misfit and lateral bias	Guide frame and survey monitoring	Corrective driving or interface redesign
High driving stress	Yielding or weld fatigue	Wave-equation analysis and instrumentation	Reduce energy, change cushion/hammer
Coating damage	Accelerated corrosion	Handling protection and inspection	Field repair and CP review
Weather exceedance	Unsafe lift or positioning	Forecasting and operational limits	About safe condition

COMPARISON WITH A CONVENTIONAL MULTI-PILE JACKET

The comparison shows that "fewer piles" is not synonymous with "lower total risk." A single pile can be economically attractive when the top side is compact, the overturning moment is moderate, competent and uniform soil is present, the pile can be fabricated and driven with available equipment, and the project values reduced offshore duration. A conventional pile group remains preferable when high overturning resistance, redundancy, difficult, layered soils, or strict displacement limits dominate. Bhattacharya emphasizes that offshore foundation selection must balance stiffness, fatigue, installation, and site conditions rather than apply a universal foundation hierarchy [23].

Table 8. Qualitative comparison of foundation concepts.

Criterion	Single large pile	Conventional multi-pile jacket	Selection implication
Foundation count	One primary pile	Typically, one pile per leg or skirt pile	Single pile reduces operations
Redundancy	Low	Higher load-sharing capability	Single-point failure requires stronger assurance
Footprint	Compact	Wider	Single pile may reduce seabed occupation
Overturning resistance	Pile bending + soil reaction	Axial couple across pile group	Multi-pile often better for large moments
Fabrication items	Fewer sleeves and piles	More tubulars and welds	Single pile simpler but heavier
Installation	One heavy critical operation	Several repetitive operations	Depends on vessel and hammer capacity
Soil variability	Highly sensitive at one location	Samples wider footprint	Single pile needs high-confidence ground model
Inspection	Fewer components	More components	Access and connection detail govern

Future removal	Potentially simpler component count	Multiple piles may require cutting	Decommissioning method must be planned

RISK-BASED DECISION FRAMEWORK

A risk register should be maintained from concept selection through installation. Likelihood and consequence are ranked for design uncertainty, fabrication defects, installation failure, environmental exceedance, and lifecycle deterioration.

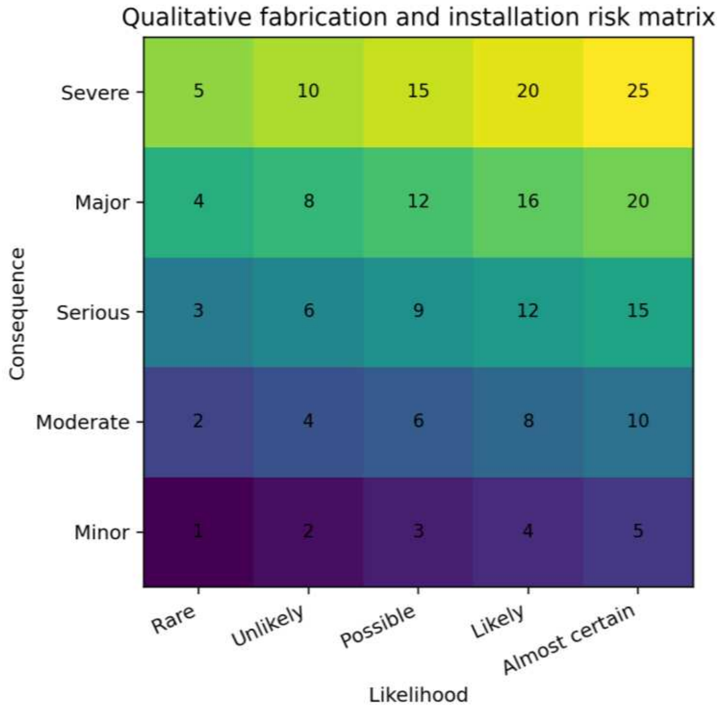

Figure 7. Qualitative risk-ranking matrix for concept selection and stage-gate review.

High risks require elimination, design change, additional investigation, full-scale testing, or independent verification. The matrix is not a substitute for reliability analysis; it is a governance tool for assigning actions and holding points.

Table 9. Proposed stage-gate criteria for progressing the single-pile concept.

Decision gate	Minimum evidence	Go criterion	No-go / recycle trigger
Concept select	Load envelope, preliminary soil model, vessel market check	Feasible load path and installation route	No credible driving or overturning solution
Pre-FEED	CPT/lab data, 1D nonlinear model, section sizing	Capacity and serviceability margins demonstrated	High sensitivity to unresolved soil layer
FEED	Integrated global model, fatigue and scour studies	Code-compliant design basis	Connection or fatigue hotspot unresolved
Fabrication release	Approved drawings, WPS/PQR, ITP, yard capability	All hold points and traceability in place	Unqualified process or unavailable equipment
Offshore release	Drivability, lifting, sea fastening, weather plan	Operational limits and contingency approved	No safe abort state or hammer margin

DISCUSSION

The integrated screening reveals that the governing discipline can shift as geometry changes. A diameter increase may solve lateral deflection but create a fabrication or installation bottleneck. A thickness increase may solve nominal stress but increase hammer demand. A deeper pile may improve capacity but increase risk of refusal and driving fatigue. The design team should therefore optimize the complete system rather than pass sequential discipline checks with fixed inputs.

The reference calculations also demonstrate why source data and units must remain explicit. A capacity number without CPT data, cyclic assumptions, resistance factors, and pile-installation method is not a design result. Similarly, stress result without section properties, load combination, local detail effects, and material factors is only a screening value. The revised framework preserves this distinction by labeling the numerical case as illustrative and by defining the analysis required before acceptance.

Recent large-diameter pile research provides useful methods but transfer from offshore wind monopiles to a compact jacket must be justified. Wind-turbine monopiles are often governed by lateral stiffness and dynamic characteristics, whereas a process or utility jacket may have different vertical load, topside center of gravity, accidental actions, and inspection requirements. PISA-type soil-reaction models can improve lateral analysis, but the foundation–superstructure connection and load spectrum remain project specific [21], [22].

Fabrication and installation records should ultimately support an as-built digital dossier containing material certificates, weld maps, procedure qualifications, NDT reports, dimensional surveys, coating records, anode data, lift certificates, driving logs, and final penetration. This information enables lifecycle integrity management and future reassessment. Paik and Thayamballi show the importance of plate and shell behavior in ultimate-strength assessment, which is directly relevant to large tubulars with fabrication imperfections [24].

LIMITATIONS AND FUTURE WORK

The study is limited by the absence of site-specific bathymetry, metocean data, geotechnical investigation, jacket geometry, fatigue load spectrum, fabrication-yard capability, and installation-equipment data. The simplified axial model does not represent CPT-based resistance, plugging, cyclic effects, or partial factors. The lateral sensitivity is normalized and does not replace a nonlinear beam–spring or 3D finite-element analysis. The nominal stress check omits shell buckling, local connection effects, corrosion loss, residual stress, and dynamic amplification. Consequently, the work should be interpreted as a structured pre-design methodology rather than a complete foundation design.

Future work should develop a project-specific integrated model, calibrate axial and lateral resistance using CPT and laboratory tests, assess scour and cyclic degradation, perform jacket–pile dynamic analysis, and complete fatigue screening of the transition connection. Full-scale or component-level tests may be appropriate for novel connection details. Reliability-based calibration and structural health monitoring should also be considered where the single-load-path consequence is high. Zaaijer discusses the influence of foundation modelling on offshore structural dynamics, while Byrne and co-workers demonstrate the value of calibrated large-diameter pile models [25], [21].

CONCLUSIONS

A single large-diameter pile may provide a technically credible foundation solution for a compact offshore jacket; however, it represents a distinct low-redundancy structural concept and should not be regarded merely as a simplified version of a conventional multi-pile jacket foundation. Its performance is primarily governed by pile diameter, penetration depth, soil stiffness, and scour conditions. The illustrative axial screening results indicate that foundation resistance increases significantly with larger pile diameters and greater embedment depths, whereas normalized lateral displacement is particularly sensitive to pile diameter, soil stiffness, and the loss of near-surface soil support caused by scour. For the illustrative 3.0 m diameter pile subjected to an axial load of 20 MN and an overturning moment of 120 MN·m, a wall thickness of 60 mm produces a nominal combined stress of approximately 337 MPa. Increasing the wall thickness to 70–80 mm reduces the screening stress to approximately 291–257 MPa, although detailed code-based checks for local buckling, fatigue, weld effects, load combinations, and material resistance remain mandatory.

These design decisions also have direct implications for fabrication and installation, because increases in pile diameter and wall thickness improve structural resistance but simultaneously increase shell mass, plate-rolling requirements, weld volume, lifting capacity, crane demand, and hammer energy requirements. Consequently, material traceability, dimensional control, qualified welding procedures, volumetric non-destructive testing, coating inspection, and loadout verification should be established as formal hold points throughout the fabrication and installation process. Fabrication quality must therefore be treated as an integral component of structural reliability rather than merely as a documentation requirement.

The concept should only progress to detailed design when site-specific geotechnical data, nonlinear soil–structure interaction analysis, fatigue assessment, scour evaluation, drivability analysis, marine operation studies, accidental-action checks, and contingency planning demonstrate acceptable safety margins. Where these requirements cannot be satisfactorily achieved, a conventional multi-pile foundation should remain the reference solution. The proposed conceptual framework is also consistent with the broader offshore support-structure requirements specified in IEC 61400-3-1 and DNV-ST-0126 [26], [27]. Classical studies on offshore pile capacity and dynamic response remain relevant for benchmarking numerical models [28], [29], while soil-strength characterization should continue to follow established geotechnical principles [30].

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