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Generic design framework pile foundations (fixed steel structures)

Prepared by **BOMEL Ltd**
for the Health and Safety Executive

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CONTENTS

HEALTH AND SAFETY EXECUTIVE
OFFSHORE DIVISION

GENERIC DESIGN FRAMEWORK
PILE FOUNDATIONS (FIXED STEEL STRUCTURES)

EXECUTIVE SUMMARY

To assist in attaining the HSE's objective of providing perspective and focus for Safety Case Assessment, a generic model of the structural design process for the foundations of pile supported fixed steel structures has been developed. Interfaces between the foundation design team and other stakeholders have been identified and assessments made of both the magnitude and the potential significance of the uncertainties associated with key elements of the design process.

1. INTRODUCTION

This report presents the results of work undertaken for the HSE OSD by BOMEL on behalf of the BOMEL Consortium under HSE Task Number B\0059 and BOMEL Contract Number C08930R. The HSE's objective in commissioning this activity was to provide perspective and focus for Safety Case assessment by the development of a generic model of the structural design process for the foundations of pile supported fixed steel structures, illustrating its iterative nature and highlighting the sources and degree of uncertainty associated with each stage of the design process. BOMEL's scope of work was therefore to:

- Prepare a process map of a generic design process for piled foundations of fixed steel structures.

- Identify interfaces with internal and external parties

- Identify and assess the uncertainties associated with each stage for the design process.

The generic map developed for the design process is shown in Figure 6.1 and discussed in Section 2 of this report. Internal and external interfaces are described in Section 3 and the key elements identified as subject to uncertainty are mapped in Figure 6.2 and discussed in Section 4. Table 4.1 gives an assessment of the magnitude and potential importance of the uncertainty associated with each of the elements identified.

2. GENERIC FRAMEWORK

A typical generic framework for the process of the design of piles for fixed steel structures has been developed and is presented in Figure 6.1.

The process can be divided into the following phases:

2.1 PRELIMINARY ENGINEERING

During this phase the basic parameters for the Installation must be established. These will include the selection of a preferred location for the structure taking into consideration the reservoir topography and external factors such as shipping lanes and existing and proposed pipeline routes. The required number of well slots needs to be known and conductor characteristics determined. An initial assessment of topside layout and weight is required and preliminary information is necessary in respect of pipeline risers, pump caissons and other appurtenances which will attract significant hydrodynamic loading such as riser protectors and boat landings.

If not available, a geophysical survey of the intended location should be undertaken to establish bathymetry and stratigraphy, to confirm location of any existing facilities in the area and to identify any obstacles such as wrecks. From this investigation an initial assessment of the feasibility of the proposed location can be confirmed or another location selected.

Data collection and evaluation, as necessary, is required to determine metocean parameters in respect of appropriate return periods and to determine other design criteria such as likely marine growth levels and susceptibility of the location to foundation scour.

Performance standards for the structure / foundations must be established and will normally be determined by the Duty Holder's company standards which in turn are likely to be based on industry standards such as API Recommended Practice 2A (Ref 1).

2.2 CONCEPTUAL DESIGN

From the information described above, a Design Specification can be prepared and conceptual design of the structure / foundation undertaken. In conjunction with the conceptual design, a scope of work and specification for a detailed geotechnical survey can be prepared and this work contracted. Initial feedback on likely

geotechnical properties from the field report followed by the geotechnical laboratory report and engineering report can be progressively fed into the conceptual design. If the geotechnical data indicates that initial foundation design is not acceptable further site data may be required or an alternative location may have to be considered.

2.3 DETAILED DESIGN

Once a conceptual design for the structure / foundation has been demonstrated to be technically and economically feasible, the detailed design can be undertaken.

Initial design values for topside loadings, well conductors, risers etc. can be updated and the iterative process of structure / foundation design will continue as detailed design of the topsides and pipelines etc. is progressively developed. Pile / structure connections must be designed together with pile guides, sleeves, centralisers etc..

The piled foundation design must address pile capacity, pile stress, fatigue, deflection criteria, cyclic loading and driveability for the conditions required by the performance standards which will typically include an 'Operating' condition (with 1 month to 1 year return conditions and pile capacity factor of safety of at least 2); a 'Design' condition (with 100 year return conditions and pile capacity factor of safety of at least 1.5); and a 'survival' or 'abnormal' condition (with 10,000 year return conditions and pile capacity factor of safety of at least 1.0) .

The pre-piled stability condition must also be addressed, and mud-mats designed.

2.4 SAFETY CASE AND VERIFICATION

In order to comply with the Safety Case Regulations (Ref 2) and Design and Construction Regulations (Ref 3) it will be necessary to include appropriate information in respect of performance standards for the foundation and a demonstration of compliance therewith in the Design Safety Case submission. The foundation design must be verified by an acceptable Independent Competent Person.

2.5 CONSTRUCTION AND OPERATIONAL PERFORMANCE

Although not part of the design process, it will be necessary to confirm that piles are installed in accordance with design requirements and that pile / structure connections are successfully accomplished. Where design penetrations have not been achieved it will be necessary for the designers to confirm the acceptability of the 'as-installed' conditions and for this to be independently verified. Generally the foundation design

should include sufficient contingency capacity to allow for failure to achieve target penetrations. For structures with skirt piles, consideration should be given to providing a 'spare' sleeve and pile to compensate for under-drive or a 'junked' pile.

The designers should also ensure that any and all requirements in respect of pile integrity during operation of the facility are clearly specified and included in the Operational Safety Case and in other appropriate operational documentation for the Installation. Such factors may include monitoring of scour, settlement and subsidence, and inspection of the pile/structure connections.

3. INTERFACES

There will be many internal and external interfaces associated with design of a piled foundation for a fixed steel structure. Many of these will be dependent on the organisational structure of the Duty Holder and the contractual framework for the design, fabrication and installation of the facility. From the perspective of the foundation design team these will include:

- Site Investigation
  Interface with reservoir personnel in respect of site selection and with geotechnical consultants for specification of requirements for geophysical and geotechnical investigations. The potential for subsidence associated with reservoir depletion should be reviewed and its effect on pile stresses considered.

- Wells
  Where appropriate, liaison is required with the drilling engineers to ensure drilling activities will not lead to any degradation of foundation capacity. If jack-up rigs are to be used over the structure, the effects of spud-can / pile interaction must be evaluated. The effect of spud-can holes from pre-drilling must be considered particularly in relation to achieving level tolerance prior to piling.

- Loadings
  The principal interface will be with the jacket / tower design team who will in turn be dependent on the topside designers, pipeline designers, drilling personnel, operations personnel and metocean specialists for definition of imposed gravity and environmental loadings. A philosophy for design contingency, to allow for future modifications, must be established.

- Pile Capacity / Stiffness
  There will be an interface with the geotechnical consultant who in turn will liaise with the site investigation contractor, if separate, in respect of design parameters for pile capacity calculation and pile stiffness characteristics. Group effects must be considered.

  Stiffness characteristics are generally required for the operating, extreme, abnormal or survival conditions and fatigue analysis of the structure (they may also be required for accidental ship impact scenarios and earthquake analysis).

- Pile Stresses / Displacements

  The acceptability of in-place pile stress levels and in-service fatigue acceptability will normally be assessed interactively with the structure by the jacket / tower design team as will the acceptability of the pile head displacements.

- Fabrication

  Co-ordination with the pile fabricator is necessary in respect of material and welding requirements, dimensional requirements for thickness and straightness and quality assurance of the pile material, fabrication and inspection, which, in general, requires verification.

  Co-ordination with the jacket / tower fabricator for material, fabrication and inspection of pile sleeves, shear plates and diaphragms, packers and grouting systems, etc..

- Pre-piled Stability

  The requirements for ‘mud-mats’ and other pre-piled stability requirements must be determined by the foundation designers in consultation with the geotechnical consultants, the installation contractor and the marine warranty agents.

- Installation

  An interface with the installation contractor will be necessary for load out and transportation; to determine handling and driving stresses; pile installation systems and guides; driving fatigue; and, where appropriate, requirements for add-ons, allowable stick up and site welding and inspection. Refusal criteria must be established and necessary contingency plans developed in respect of early refusal or low blow count at design penetration. The use of piles for jacket / tower levelling needs to be addressed. There will be an interface with the grouting contractor (or other specialist connection contractor) in respect of grout specifications, packers, grout lines, instrumentation and quality control, etc.. Verification of the acceptability of the 'as-installed' foundation will normally be a requirement.

- Compliance and Verification

  There will be an interface with the HSE in respect of acceptance via the Safety Case of the foundation performance standards and demonstration of the design acceptability, and with the Independent Competent Person in respect of verification of the design, fabrication and installation of the foundations.

4. UNCERTAINTY

There is uncertainty associated with all aspects of the design of piles for fixed steel structures. The principal factors have been identified and mapped as shown in Figure 6.2. Table 4.1 below lists these factors and gives a subjective assessment of both the likely magnitude and the potential significance, in respect of the initial performance, of the associated uncertainties as high, medium or low. The table is generic and is intended to cover pile foundations for all types of fixed steel structures.

The overall significance of uncertainty in the design of piled foundations is unknown but is implicitly addressed in the safety factors and other provisions recommended by codes and standards. There may be further conservatisms in the assessment of geotechnical parameters for capacity and stiffness calculation and in assessments of gravity and environmental loadings. The extent and significance of these will vary but are generally unknown.

Historic performance suggests that present pile foundation design practice is acceptable in that there are apparently no recorded losses of fixed steel Installations on the UK Continental Shelf as a result of pile foundation failure. However, the margins existing against failure for loadings experienced to date are unknown as are the potential consequences of extreme events not experienced to date.

Factor	Likely Magnitude of Uncertainty			Potential Significance of Uncertainty		
	High	Medium	Low	High	Medium	Low
PERFORMANCE STANDARDS						
Regulations			X			X
Compliance / Verification		X		X		
Codes / Standards			X	X		
Competence		X		X		
SITE INVESTIGATION						
Location			X	X		
Stratigraphy			X		X	
Sampling Procedures		X		X		
Borings / Tests Specified			X		X	

Table 4.1 Foundation Uncertainty Factors

Factor	Likely Magnitude of Uncertainty			Potential Significance of Uncertainty		
	High	Medium	Low	High	Medium	Low
GEOTECHNICAL PARAMETERS						
Sample Disturbance		X		X		
Testing Errors			X	X		
Capacity / Stiffness Model (P-y / T-z / Q-z)		X			X	
Interpretive Bias		X		X		
Reporting Errors			X	X		
LOAD CASES						
OPERATING AND DESIGN (EXTREME) CONDITIONS						
Gravity Loads						
Dead			X		X	
Live		X			X	
Environmental Loads						
Wind			X			X
Hydrodynamic Load Recipe		X		X		
Water Depth			X		X	
Surge						
Tide			X			X
Storm			X			X
Current and Profile		X			X	
Wave Theory						
Tz		X				X
Hs	X			X		
Morison's Equation		X			X	
Cd / Cm		X			X	
Marine Growth		X				X
Appurtenances / Anodes		X				X

Table 4.1 (Continued) Foundation Uncertainty Factors

Factor	Likely Magnitude of Uncertainty			Potential Significance of Uncertainty		
	High	Medium	Low	High	Medium	Low
SURVIVAL (ABNORMAL) CONDITIONS						
Gravity Loads						
Dead			X		X	
Live		X			X	
Environmental Loads						
Wind			X			X
Hydrodynamic Load Recipe		X		X		
Water Depth			X		X	
Surge						
Tide			X		X	
Storm		X			X	
Current and Profile		X			X	
Wave Theory						
Tz		X				X
Hs	X			X		
Morison's Equation		X			X	
Cd / Cm		X			X	
Marine Growth		X				X
Appurtenances / Anodes		X				X
'Extreme' Crest	X			X		
Wave in Deck	X			X		
DYNAMICS						
Wave Spectrum / Time History	X			X		
Seismic Spectrum						
Zonal Seismicity		X		X		
Site Specifics		X			X	
Liquefaction	X				X	
Added Mass		X			X	
Damping		X			X	
Impact		X				X
FATIGUE						
Service Loading System	X				X	
Driving Spectrum			X			X
MUD SLIDES			X	X		
SUBSIDENCE		X		X		

Table 4.1 (Continued) Foundation Uncertainty Factors

Factor	Likely Magnitude of Uncertainty			Potential Significance of Uncertainty		
	High	Medium	Low	High	Medium	Low
STRUCTURAL RESPONSE MODEL & PILE LOADINGS (STATIC / DYNAMIC)						
Joint Flexibility		X			X	
P-y / T-z / Q-z			X		X	
Group Effects		X			X	
Other Non-linearity		X				X
Pile / Structure Interaction		X			X	
Influence of Conductors			X		X	
Scour / Slotting			X		X	
Software			X			X
Model Uncertainty			X		X	
PILE / SOIL CAPACITY (LATERAL / VERTICAL)						
Soil plug		X			X	
Driveability		X		X		
Installation Methodology			X	X		
Long Term Time Effects (set-up)		X			X	
Cyclic Degradation	X			X		
Well Wash-out			X	X		
Shallow Gas			X	X		
Load Rate Effects	X					X
Group Effects		X		X		
PILE STEEL CAPACITY						
Area			X		X	
Section Moduli			X	X		
Yield Strength		X			X	
Material / Weld Toughness		X			X	
Defects		X		X		
FATIGUE LIFE						
Analysis Mode						
Spectral	X				X	
Deterministic	X				X	
SCFs (high / low)		X		X		
Defects		X		X		
S/N curve / FM model	X			X		
Miner's Law		X		X		

Table 4.1 (Continued) Foundation Uncertainty Factors

5. REFERENCES

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3. The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996 (S.I. 1996/913) (DCR).

6. FIGURES

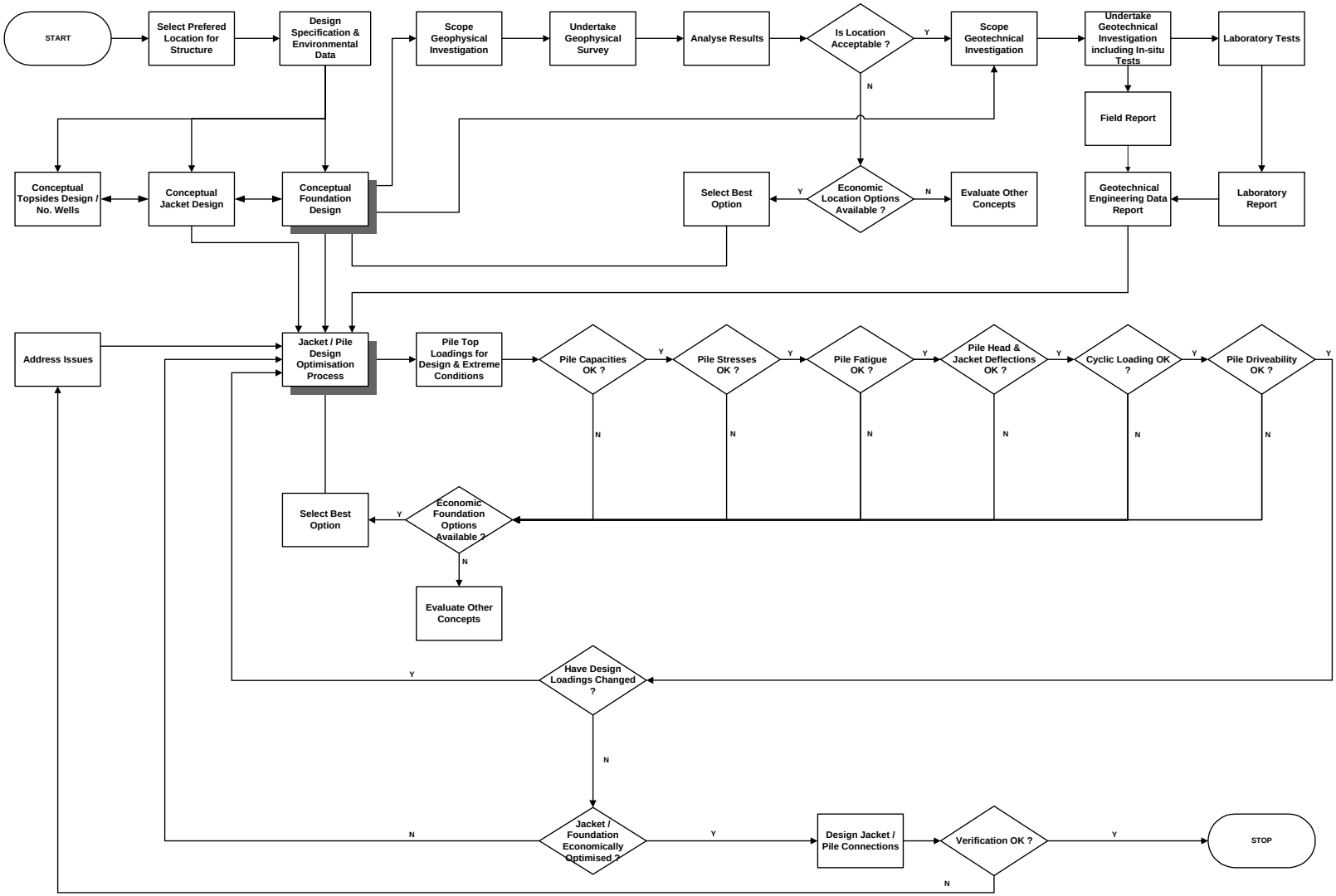

Figure 6.1 Generic Process for Design of Piled Foundations for Fixed Steel Offshore Structures

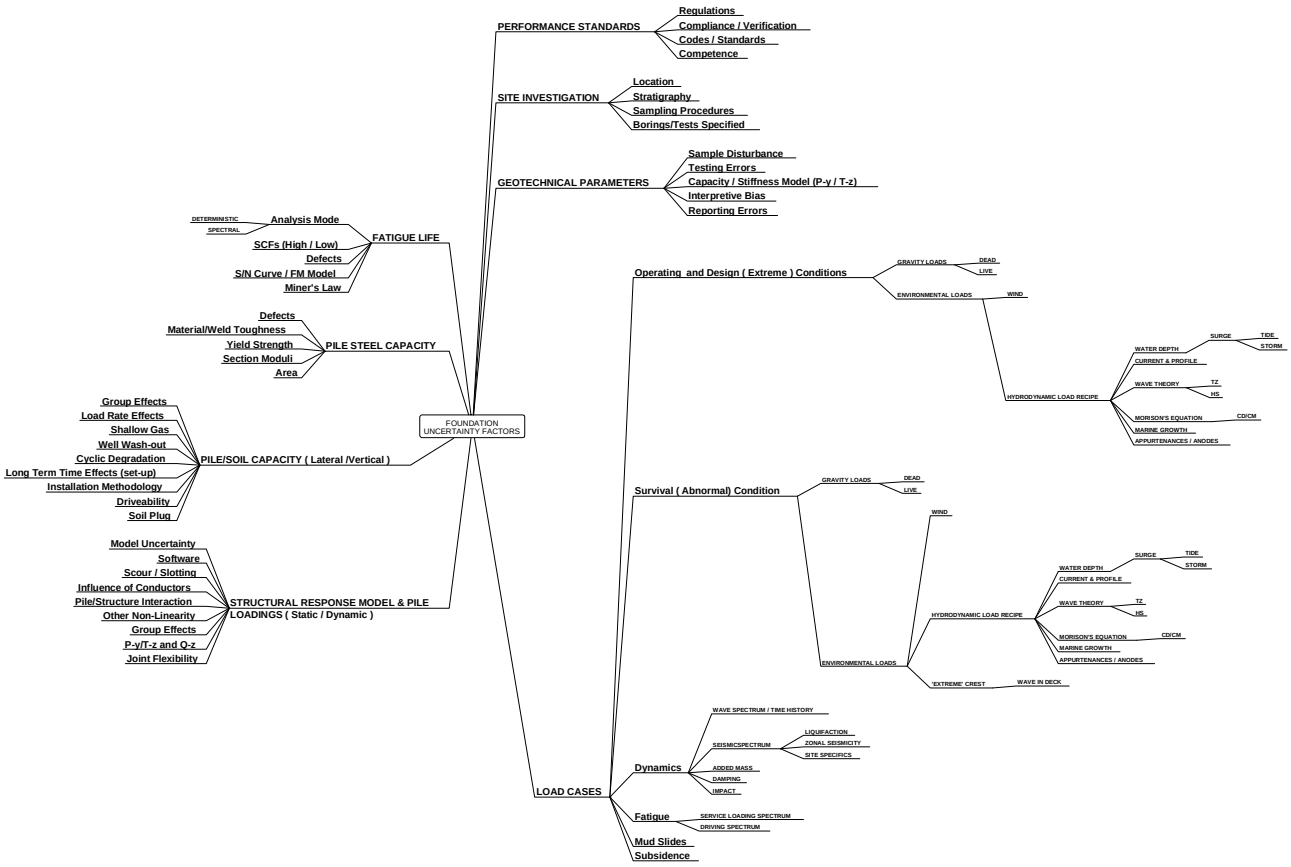

Figure 6.2 Uncertainties in Pile Design

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