Calibration of Deterministic Parameters

Reassessment of Offshore Platforms in the Arabian Gulf

Hassan Zaghloul

DISSERTATION.COM

Boca Raton

Calibration of Deterministic Parameters:
Reassessment of Offshore Platforms in the Arabian Gulf

Dissertation.com
Boca Raton, Florida
USA • 2011

ISBN-10: 1-59942-397-9
ISBN-13: 978-1-59942-397-5

DEDICATION

To the loving memory of my father

To my mother who had the arduous task of raising four children by herself after the sudden death of my father

To my beloved wife Mine' who endured my absences and supported my passion for this research

To our sons Taha and Zaccaria who make our life beautiful

To all those who have contributed to this thesis

ABSTRACT

The Arabian Gulf oil and gas production reserves have made it one of the world's strategic producers since early 1960s, with many of the existing platforms stretched beyond their original design life. Advances in drilling technology and reservoir assessments have extended the requirement for the service life of those existing platforms even further. Extension of the life span of an existing platform requires satisfactory reassessment of its various structural components, including piled foundations.

The American Petroleum Institute Recommended Practice 2A (API RP2A) is commonly used in the Arabian Gulf for reassessment of existing platforms. The API guidelines have been developed for conditions in the Gulf of Mexico, the waters off Alaska and the Pacific and Atlantic seaboards of the USA. However, the Arabian Gulf conditions are fundamentally different to those encountered in US waters. Hence, there is a need to develop guidelines for reassessment of existing offshore structures to account for the specific conditions of the Arabian Gulf.

This thesis performs statistical analyses on databases collected during this research from existing platforms to calibrate relevant load and resistance factors for the required guidelines. The developed guidelines are based on established approaches used in developing international codes and standards such as API RP2A-LRFD.

The outcome of this research revolves around the following three main issues:

1. Calibration of resistance factors for axial capacity of piles driven in the carbonate soils

API RP2A (1993, 2000) does not quantify limiting soil parameters for piles driven in carbonate soils and provides a single factor to predict the capacity of piled foundations. This research identifies a set of limiting engineering parameters and calibrates corresponding capacity reduction factors to predict axial capacity of driven piles in the carbonate soils of the Arabian Gulf.

Further, this thesis shows that the use of a single capacity reduction factor of 0.7, an approach that is adopted in API RP2A-LRFD (1993), does not consider that axial pile capacity in existing platforms is influenced by many parameters identified in this research, including implied risk level, manning levels, variation in pile wall thickness along its depth, soil composition, hammer type, installation method, penetration ratio and the level of optimization in the original design. The reassessment guidelines developed in this research recommends a set of capacity reduction factors within a range of 0.4-1.0 to reflect the influence of the factors discussed above.

2. Development of open area live loads (OALL) on offshore platforms

API RP2A-LRFD (1993) refers to ASCE Standard 7-05 to quantify live loads. However, ASCE Standard 7-05 is only applicable to building structures and does not quantify values for OALL on offshore platforms. This thesis reveals that, unlike building structures, the magnitude of OALL on an offshore platform deck is not independent of loading conditions.

OALL values on offshore platforms are rather affected by factors such as platform size, safe working load (SWL) of materials handling equipment, expected life span of the platform, deck location on the platform (upper deck versus other decks) and the selected influence surface (pile, primary beams, secondary beams or topside columns). This research investigates those factors and recommends a simplified formula to calculate OALL. The proposed formula is a function of the SWL of the material handling equipment which dominates the magnitude of the OALL.

Reassessment applications require a combination factor for OALL, which is a function of the coefficient of variation (COV) of the mean lifetime maximum live loads. This thesis proposes a combination factor of 1.5 on the basis that the COV = 10% to 20% of the mean lifetime maximum live loads on offshore platforms, which is calculated in this research, is similar to the COV (14%) used to develop the live load combination factor (1.5) in API RP2A-LRFD (1993).

3. Effect of extreme storm conditions on the reliability of existing platforms in the Arabian Gulf

In the process of calibrating pile resistance factors and development of OALL, this research develops a set of statistical parameters for load and resistance factors. The statistical parameters are used to perform reliability analysis on a selected platform in the Arabian Gulf. The platform is selected such that the outcome of the reliability analysis is applicable to other platforms in that region.

The outcome of the reliability analysis reveals that operating overload conditions dominate the failure mechanism in the Arabian Gulf. The reliability analysis resulted in an insignificant (10^{-71}) probability of failure under extreme storm conditions compared to the higher value (10^{-6}) under operating overload conditions.

Such extreme values are only possible in a mathematical model and have little physical meaning. Nevertheless, and despite lack of a physical meaning to such extremely low failure probability value, it demonstrates that operating overload dominates the failure mechanism in the Arabian Gulf. The extremely low probability of failure is partly a result of no wave-in-deck as the wave heights are lower than the deck at high return periods.

Consequently, reassessment of existing platforms in the Arabian Gulf would be sufficiently addressed by considering operating overload conditions only. This contrasts with Section 'R' of API RP2A (1993, 2000), which focuses on extreme environmental conditions when performing reassessment.

The probabilities of failure considered in this research do not include errors and omissions (controlled by quality assurance procedures) or material deterioration (controlled by choice of materials, detailing, protective devices, and inspection and repair procedures) or reliability-based maintenance.

Addressing operating overload conditions requires attending to two issues, namely the capacity of piles driven in carbonate soils and OALL, which have been addressed in this research. The operational overload situation is likely to occur during shutdown condition or during drilling or work over activities where significant OALL are usually applied to platform decks. Such operational overload can be managed by placing signs at various open areas on the platform nominating the maximum load limits (kPa), introducing procedures that ensure that maximum load limits are not exceeded during operation and management of human behavior by reinforcing the importance of following the procedures.

The outcomes of this research are expected to have a profound influence on reassessment of existing platforms in the Arabian Gulf.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

I owe an immense debt of gratitude to my supervisor, Professor Beverley Ronalds, for her support from the formative stages of this thesis to its final draft. Her sound advice, careful guidance and conscientious reviews of several drafts of this thesis were invaluable as I travelled through the journey of this research.

I extend my appreciation to Dr. Geoff Cole and Dr. Manolis Fakas for providing valuable suggestions during this research and to Dr. Mostafa Ismail for the conscientious proof reading and making valuable suggestions to the last draft of this thesis. Thanks to Dr. Krystyna Haq for reviewing an earlier draft of this thesis.

This acknowledgment must include all scholars and academics listed in the Bibliography for providing the necessary background to this research. In particular, the direct and indirect contribution of Professor Robert Bea to this research was immensely useful and greatly appreciated. This also extends to Professor Bengt Fellenius and Dr. Frank Rausche, who provided guidance at the start of this research and offered software free of charge.

Last but not least, I appreciate the outstanding support from UWA library and administration staff at the School of Oil and Gas Engineering.

DEFINITIONS

Definitions adopted by researchers are often not uniform, so key and controversial terms are defined in this section to establish positions taken in the research. Fellenius (1999) recommended some of the following definitions adopted in this research.

Term	**Definition**
Allowable Load	Maximum load that may be safely applied to a foundation unit under expected loading and soil conditions and determined as the *Capacity* divided by the *Factor of Safety*.
Applied (Service) Load	Load actually applied to a foundation unit
Axial, Bearing, Shaft and Toe Capacity	Ultimate Resistance of the unit.
Blow count	During pile driving, the blow count represents the count of blows for a specified penetration of the pile into the soil. Typically, the count of blows is measured for a pile driven one foot into the soil and the blow count is recorded in a pile driving record.
Capacity	The maximum or ultimate soil resistance mobilized by a foundation unit. It is used as a stand-alone term and is synonymous with *Ultimate Resistance*.
Capacity, bearing	The maximum or ultimate soil resistance mobilized by a foundation unit subjected to downward loading. It is the sum of the shaft resistance and the toe or 'end bearing' resistance.
Dynamic Monitoring	The recording of strain and acceleration induced in a pile during driving and presentation of the data in terms of stress and transferred energy in the pile as well as of estimates of capacity.

Term	Definition
Factor of Safety	The ratio of maximum available resistance or of the capacity to the code allowable stress or load.
Loading Test	Refers to the situation of a test performed by loading a pile while *Load Test* is a test for finding out what load is applied to a pile.
Limit State	A state that defines the boundary between a safe and unsafe situation
Penetration Resistance	Effort required in advancing a pile. When quantified, it is either the number of blows required for the pile to penetrate a certain distance or the distance penetrated for a certain number of blows.
Pile Head	The uppermost end of a *Pile*
Pile Impedance	A material property of a pile cross-section determined as the product of the Young's modulus (E) and area (A) of the cross section divided by the wave speed (c).
Pile Point	A special type of pile shoe.
Pile Shaft	The portion of the pile between the pile head and the pile toe.
Pile Shoe	A separate reinforcement attached to the pile toe of a pile to facilitate driving, to protect the lower end of the pile and/or to increase the toe resistance of the pile.
Pile Toe	The lowermost end of a pile.
Pore Pressure	Pressure in the water and gas present in the voids between the soil grains minus the atmospheric pressure.
Probability of failure	This is an unfortunate choice of wording because it can be mistakenly treated as being synonymous with the actual rate of failure. The prefix “nominal” or “notional” is often applied to the probability of failure to emphasize its formal nature (CIRIA, 1977, Ellingwood *et al.*, 1980, Melchers, 1999). An alternative would be to use the *reliability index*, β, which is mostly free of such connotation.

Term	Definition
Quantitative Risk Assessment (QRA)	Formal and systematic approach for identifying potentially hazardous events and estimating likelihood and consequences of accidents developing from these events to people, environment and resources.
Ultimate Load	Capacity evaluated from the results of a static loading test.
Set	Penetration for one blow, sometimes penetration for a series of blows.
Setup or Soil Setup	Describes the effect of resistance increase with time after driving. This term is sometimes referred to as *Soil Freeze* but this term will not be used in this thesis as it has a different meaning for cold regions of the world.
Shaft Resistance	Calculated as the integral over the embedded pile area of the unit skin friction value
Structural Analysis	Refers to the technique of making stiffness or stress calculations while *Structural Assessment* includes the whole process of modeling the problem, analysis and interpretation of the results.
Structural Reliability Analysis (SRA)	SRA aims at determining the probability of failure of a Limit State that, in its basic form, attains an unsafe situation. In SRA, a Limit State is represented, again in its basic form, by a Limit State equation which attains a negative value for unsafe situations and a positive value for safe situations. The Limit State equation incorporates basic random variables defined by probability density functions through (a) statistical analysis of existing sample data and (b) by experience and theoretical considerations. The representation of real structural systems may involve a number of Limit States (such as buckling, yielding, fatigue or excessive deformation under various loading conditions), some of which may be represented by a number of different failure equations. In this case, the analysis needs to incorporate statistical correlation effects between the basic random variables as well as between Limit State equations (a set of basic random variables only affect the outcome of different

	Limit State equations). In this thesis, SRA is primarily concerned with calculating the probability of ultimate collapse of the total substructure due to extreme environmental storm loading. It does not treat all possible hazards to the structure from a QRA viewpoint.
Toe Resistance	Soil resistance acting on the pile toe
Transferred Energy	The energy transferred to the pile head and determined as the integral over time of the product of force, velocity, and pile impedance.
Wave Speed	The speed of strain propagation in a pile.
Wave Trace	A graphic representation against time of a force or velocity measurement.

NOMENCLATURE

Symbol	Definition
A	Side surface area of pile or a factor to account for cyclic or static loading
BOR	beginning of restrike
BS	base shear
c	Constant that accounts for the errors associated with simplification of the equation describing reliability of pile groups
C	Wave speed in m/s
CAPWAP	Case Pile Wave Analysis Program
COV	Coefficient of variation
COV_Q	Coefficient of variation of load
COV_{QD}	Coefficients of variation for dead load (QD)
COV_{QL}	Coefficients of variation for live load (QL).
COV_R	Coefficient of variation of resistance
COV_χ	Coefficient of variation of system effect
COV_ζ	Coefficient of variation of group efficiency
CS	Soil type dominated by clayey soils overlain by sandy soils
CC	Carbonate content
C(x,y)	Influence coefficient
C_{db}	Hammer damping factor
d	Mean water depth
D	Diameter of a pile or hammer damping input value
D_n	Nominal dead load

Symbol	Definition
DOE	Department of Energy
d/gT^2_{app}	Dimensionless relative depth
EOD	End of driving
E(W)	Mean of the equipment weights
E_h	Hammer efficiency
E_r	Manufacturer rated hammer energy
ETR	Energy transfer efficiency
F	Unit skin friction capacity or total axial force on the column using influence surface diagram
F(x)	A value used to approximate Cumulative Distribution Function at each value of x
FORM	First order reliability method
$f_{s,si}$	Limit on unit friction value for a silica sand with a carbonate content (CC) of 20% or lower
$f_{s,80}$	Limit on unit friction value applicable with carbonate content (CC) of 80% or greater
FOS	Factor of safety
g	Acceleration of gravity
H/gT^2_{app}	Dimensionless wave steepness
H	Wave height
HAT	Highest astronomical tide
H_s	Significant wave height
H_b	Breaking wave height
J_s	Damping constant for skin friction
J_p	Damping constant for end bearing
k_{ram}	Hammer cushion or impact block or ram stiffness

Symbol	Definition
k	Initial modulus of subgrade reaction in force per volume units
K	Coefficient of lateral earth pressure
kN	Kilo Newton = Unit of pressure measurement
L	Length of a pile or wave length
LAT	Lowest astronomical tide
L_n	Nominal live load
LT	Lifetime of T years
LRFD	Load Resistance Factor Design
m	Shape parameter for Weibull distribution
MHHW	Mean higher high water
MHLW	Mean higher low water
MLHW	Mean lower high water
MLLW	Mean lower low water
MN	Mega Newton = 1000 * kN
MPa	Mega Pascal
m_{ram}	Ram mass
MSL	Mean sea level
N	Bearing capacity factor
OALL	Open area live load
Pa	Pascal
p-y curve	Lateral soil resistance-deflection curve
$P(A_j \mid B)$	Posterior distribution on A
$P(B \mid A_j)$	Likelihood function of the data

Symbol	Definition
$P(A_j)$	Prior distribution on A
psf or lb/ft^2	Pounds per square foot
P_H	Horizontal load
P_V	Vertical load
p_u	Ultimate bearing capacity at depth X in units of force per unit length
P_f	Probability of failure
$P_{f\,a}$	Annual probability of failure
$P_{f\,L}$	Probability of failure for a lifetime of L years
PDA	Pile Driving Analyzer
q-z curve	Relation between mobilized end bearing resistance & axial tip deflection
Q	Load as described in reliability formulation
Q_t	Total capacity of a pile
Q_s	Skin friction capacity of a pile
Q_P	End bearing capacity of a pile
Q_i	Nominal load effect
Q_{mean}	Mean load
q	Unit end bearing capacity
Q_{80}	Limit on end bearing applicable to carbonate content of 80% or higher
Q_{si}	Limit on end bearing applicable to silica sand with a carbonate content of 20% or lower
R	Resistance as described in reliability formulation
R^2	Correlation coefficient value – a measure of correlation between two sets of data.
RP	Return period
R_{mean}	Mean resistance
R_m	Measured value of resistance

Symbol	Definition
R_n	Nominal resistance or predict nominal pile capacity using API RP2A
S_b	Set per blow
s_u	Undrained shear strength
SRD	Soil resistance to driving
SRA	Structural reliability analysis
SACS	Structural analysis computer software
SC	Soil type dominated by sandy soils overlain by clayey soils
SPT	Standard penetration test
t	Mobilized soil adhesion
t_{max}	Unit skin friction capacity
t-z curve	Axial load transfer relationship
T_{app}	Apparent wave period
T_p	Peak period
T_z	Mean zero-crossing period
V	Current speed
W	Wind Load
WSD	Working Stress Design
W_n	Nominal wind load
W_{ram}	Hammer ram weight
x and y	Normalized spatial variables ranging from zero to one
X and Y	Dimensions to define tributary area for a column or a pile
z	Local pile deflection
α_n	Dispersion parameter
β_T	Target reliability index