A NUMERICAL ANALYSIS OF FIXED OFFSHORE STRUCTURE SUBJECTED TO ENVIRONMENTAL LOADING IN MALAYSIAN WATER

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ABSTRACT

This research focused on the response of the jacket structure to environmental loading. The jacket was modelled as a space frame using ANSYS finite element package. Meanwhile, the estimation of extreme value of environmental parameters based on data on Malaysia waters was carried out using MINITAB. Response of the structure under environmental loading was performed using static analysis. Interaction ratios of the members are computed based on API RP2A–WSD (1993) using MATLAB. The sensitivity of the jacket structure to variation in design parameters was investigated. From global stress analysis, one of the structure's member on a complex multiplanar leg joint, appeared to have a high utilisation of stress when assessed using API RP2A–WSD (1993). Therefore, a nonlinear finite element analysis of the multiplanar joint has been carried out to determine both the absolute load capacity of the joint, the effect of the out–of–plane loads and braces and relate these back to the strength of the critical brace acting as a Y joint. This study presents the analytical methods and results together with a calibration of the analysis against test data for Y joints. A systematic study of stresses in tubular Y joints has also been conducted using finite element analysis which covers axial loading, in–plane bending and out–of–plane bending. For each mode of loading, and for both chord and brace sides of the intersection, stress concentration factors and its distributions are calculated for selected locations. The validity of this approach is demonstrated by comparing the finite element results with the predictions of other previously published parametric equations.

ABSTRAK

Penyelidikan ini bertumpu kepada tindak balas struktur luar pantai terhadap beban persekitaran. Permodelan struktur luar pantai yang terdiri daripada kerangka dilakukan dengan menggunakan kaedah unsur terhingga ANSYS. Selain itu, anggaran nilai parameter persekitaran yang ekstrim berdasarkan data di perairan Malaysia dilakukan dengan menggunakan MINITAB. Tindak balas struktur luar pantai terhadap beban persekitaran dianalisis secara statik. Nisbah beban terhadap kapasiti elemen dikira berdasarkan API RP2A–WSD (1993) dengan MATLAB. Kepekaan struktur luar pantai terhadap parameter yang digunakan dalam rekabentuk dikaji. Daripada analisis tegasan, salah satu elemen yang terdapat pada sambungan kaki struktur didapati mempunyai nilai nisbah penggunaan tegasan yang tinggi apabila disemak dengan API RP2A–WSD (1993). Oleh itu, analisis kaedah unsur terhingga tak linear sambungan multiplanar dijalankan untuk menentukan kedua–dua nilai mutlak kapasiti beban pada sambungan, kesan beban dan cabang luar planar dan mengaitkan semula kepada kekuatan elemen kritikal yang berfungsi sebagai sambungan Y. Kajian ini mempersembahkan kaedah analitikal dan output bersama dengan kalibrasi yang dilakukan terhadap data ujikaji sambungan Y. Kajian tegasan yang sistematik juga dilakukan ke atas sambungan Y dengan menggunakan analisis kaedah unsur terhingga yang meliputi beban paksi, momen dalam planar dan momen luar planar. Bagi setiap jenis beban, dan untuk kedua–dua belah pertemuan sambungan, faktor penumpuan tegasan dikira untuk lokasi yang tertentu. Kesahan metodologi ini dipersembahkan dengan membuat perbandingan di antara output daripada analisis kaedah unsur terhingga dengan persamaan parametrik yang diterbitkan oleh penyelidik lain.

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LIST OF SYMBOLS

a_n	–	Normal particle acceleration vector
AM	–	Annual maxima
BS	–	Base shear
c	–	Wave celerity
C_b	–	Buoyancy coefficient
C_D	–	Drag coefficient
C_L	–	Lift coefficient
C_M	–	Inertia coefficient
C_W	–	Wind drag coefficient
C_{WL}	–	Wind drag coefficient for long member
C_{WS}	–	Wind drag coefficient for short member
d	–	Water depth
D	–	Diameter
D_B	–	Brace outer diameter
D_C	–	Chord outer diameter
D_e	–	Outside diameter of the pipe with insulation
D_{PM}	–	Cumulative damage ratio
E	–	Young's modulus of steel
$\overline{E}$	–	Mean square
E_p	–	Encounter probability
EDF	–	Empirical distribution function
f_a	–	Nominal axial stress

f_b	–	Nominal bending stress
f_D	–	Drag force
f_I	–	Inertia force
f_L	–	Lift force
f_S	–	Frequency of vortex
F	–	Forces
FE	–	Finite element
FT–I	–	Fisher–Tippett Type I
FT–II	–	Fisher–Tippett Type II
FT–III	–	Fisher–Tippett Type III
F(x)	–	Cumulative probability distribution
F_b	–	Allowable bending stress
F_W	–	Wind force
F_y	–	Yield stress
g	–	Gravity
G	–	Gust factor
H	–	Wave height
H_S	–	Significant wave height
H_{max}	–	Maximum individual wave height
I	–	Turbulence intensity
IPB	–	In–plane bending
ID	–	Initial distribution
k	–	Wave number
KC	–	Keulegan–Carpenter number
L	–	Wave length
L_C	–	Chord length
L_f	–	Design lifetime of a structure
L_M	–	Member length
M	–	Moments
OPB	–	Out–of–plane bending
OTM	–	Overturning moment

POT	–	Peak over threshold
$P(X)$	–	Probability of non–exceedance
$P(X < x)$	–	Probability that a randomly chosen observation X will be below x
Q	–	Bernoulli constant
Q(X)	–	Probability of exceedance
Re	–	Reynolds number
S	–	Strouhal number
S_S	–	Wave steepness
S_W	–	Frontal area (facing the wind)
SCFs	–	Stress concentration factors
SWL	–	Still water level
t	–	Time
T	–	Wave period
T_R	–	Return period
T_z	–	Mean zero–crossing period associated with the extreme storm
T_{ass}	–	Period associated with the design wave
u	–	Horizontal water particle velocity
u_n	–	Normal relative particle velocity
u_t	–	Tangential relative particle velocity
U	–	Steady velocity
U_C	–	Current velocity
U_G	–	Gust wind
U_W	–	Wind speed
V_p	–	Punching shear stress
w	–	Vertical water particle velocity
WT_B	–	Brace wall thickness
WT_C	–	Chord wall thickness
Z	–	Statistical constant
α	–	Ratio of chord length to chord radius

β	–	Frequency parameter
δ	–	Ratio of the brace diameter to chord diameter
ε	–	Perturbation parameter
ϕ	–	Velocity potential
φ	–	Angle between brace and chord
γ	–	Ratio of chord radius to the chord wall thickness
η	–	Free surface elevation
π	–	Pi
θ	–	Wave phase angle
ϑ	–	Angle around the intersection of joint
ρ	–	Density of steel
ρ_a	–	Air density
ρ_w	–	Water density
σ	–	Standard deviation
τ	–	Ratio of the wall thickness of the brace to that of the chord
ω	–	Angular frequency
ω_a	–	Apparent angular frequency
ω_r	–	Relative angular frequency
ψ	–	Stream function

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CHAPTER 1

INTRODUCTION

1.1 Research Significance

The demand for exploration and production of oil and gas has grown worldwide during the past few decades in spite of its periodic down turns. As a consequence of this general search to explore and exploit offshore energy resources, new innovations and developments have taken place in structural form, equipment technology, inspection, repair methodologies and economic field utilisation. Oil and gas will continue as the most important source of energy remainder of this century and well into the next century.

With reference to offshore production facilities, any structures employed must perform satisfactorily under service conditions while safely enduring extreme environmental events. Environmental loads such as wind, wave, tide, current and marine fouling are well known to be major contributor to the loading experienced by any offshore structures. In addition, ice and earthquake are important in some geographical location. Being of random in nature, the environmental loads chosen as design loads must not less than the most probable severest load in a time period of 100 years. The ability to predict accurately the extreme environmental loading remains an important factor in the continued safe and economic exploitation of the hydrocarbon reserves.

Secondly, the sensitivity of the structural response due to the changes in design parameters is still not well understood. The effect of variations in the design parameters is dependent on both the range of values considered and sensitivity of structural design to such variations. In this study, analyses are carried out to investigate the sensitivity of the structure response to the variations in design parameters.

One of the features of fixed offshore structures is the problem of tubular joint design. A global stress analysis of the overall structure resolves applied gravity loads and environmental loads into nominal axial and bending stresses in the various members. If local scale stress analysis is performed on tubular connection, the hot–spot stresses near the welded intersection are found several times higher than nominal, often exceeding yield and may cause it to collapse. The local analysis may involve rigorous shell theory, finite element analysis or experimental stress analysis. In this study, finite element analysis has been used to investigate local stress and ultimate static strength of tubular joint.

1.2 Research Objectives

The main objectives of the research presented in this thesis are:

a) To develop an environmental loading model for typical jacket structure in Malaysia's water.

b) To study the effects of variations in design parameters on the jacket structure.

c) To determine the load capacity of a multiplanar joint.

d) To perform stress analysis on Y joint.

1.3 Outline of Thesis

This thesis consists of nine chapters begin with the introductory chapter. The literature reviews are divided into two chapters, which is Chapter Two and Chapter Three. The division of the literature review is essential to give the readers a better understanding of the research topic as both chapters discuss two different topics in depth.

Chapter Two describes in detail the methods which are available to translate a definition of environmental conditions into the resultant steady and time dependent forces on the structure. This chapter is concerned with describing and developing methods of calculating these forces for fixed offshore structures.

Chapter Three discusses the behaviour of tubular joints under operating loads and static loads. The punching shear is used as a viewpoint from which to examine various approaches to stress analysis of tubular joints, such as thin–shell finite elements and three dimensional isoparametric finite elements.

Chapter Four describes the structural model of a typical four legged jacket structure and the modelling of the environmental parameters where the structure is situated. The statistical analysis of extreme is used to estimate extreme environmental loading experienced by the structure.

Chapter Five studies the response of the jacket structure under extreme environmental loading conditions. Analysis procedures are discussed and the selections of critical member for further analysis are also discussed. Results from the structural simulation studies in term of base shear and overturning moment, and the utilisation ratio of structural members are presented.

Chapter Six investigates the sensitivity of jacket structure to uncertainties in parameters used in design. The parameters which considered in this study are wave theory, force coefficients, wave height and period, current and its profile, wave–current interaction and wind. The design parameters were varied one at a time, within appropriate ranges, and the effects of parameters which were considered to be the measures of static strength was calculated.

In Chapter Seven, a series of nonlinear finite element analysis was carried out to determine both the absolute load capacity of the joint, the effect of the out–of–plane loads and braces and relate these back to the strength of the critical brace acting as Y joint. This study presents the analytical methods and results together with a calibration of the analysis against test data for Y joints.

Chapter Eight describes the modelling of Y joint using finite element and is subjected to simple loadings of the axial, in–plane bending and out–of–plane bending types, applied separately to the joints. The stress concentration factors and its distributions obtained from the analyses were compared with the predictions of other previously published parametric equations.

Chapter Nine presents the overall discussion on the research works which emphasises on the environmental modelling, structural analysis, sensitivity of jacket structure, strength assessment of a multiplanar joint and stress concentration factor for Y joint.

The thesis is concluded in Chapter Ten, which comprises of the summary of the works and recommendations for further research.

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