International Symposium on Marine Design and Construction 2019
(SMDC 2019)

STUDY ON THE FAILURES OF RAW WATER TOWER STRUCTURAL JOINTS WHEN THE AIR GAP OF THE JACK UP RIGS IS INCREASED.

Dr. Bh.Nagesh[a], Prof. (Dr.) I.N. NiranjanKumar[b], Mrs. N. Madhu Latha[c]

[a,] *Visiting Professor in Marine Engineering Department, Andhra University, Visakhapatnam, INDIA*
[b]*Director, Indian Maritime University, Visakhapatnam Campus.*
[c]*Research Scholar in Marine Engineering Department, Andhra University, Visakhapatnam, INDIA*

ABSTRACT

It is quite common to convert the existing offshore installation from one form to another mode, depending upon the next charter requirement. The Rig Owners intend to convert the age old offshore drilling rigs which are basically designed for drilling of oil and gas (called as Mobile Offshore Drilling Unit - MODU) into Mobile Offshore Production Units (MOPUs). While doing so, the important element to be noticed is the air gap between the water line to the bottom of hull vis-à-vis the operating depth at site specific conditions. The air gap which normally increases compared to when the same has been used as a MODU, due to the reason that it is a fixed platform and regular jacking operations cannot be performed whereas rules call for the supporting structure to withstand the 100 years of wave and wind data in which case the wave height can be expected upto 14m and wind speeds of upto /exceeding 100 knots. As per rules the bottom of hull should be elevated to a height of at least 1.5m more than the highest wave that can occur including the surge, swell etc. In such a conversion the important parameter that is being missed out is the Raw Water Tower whose length also to be increased to meet the increased water depth and as such it will not be able to withstand the 100 years wave and wind criteria. This paper shows the study conducted on the Raw Water Tower (RWT) of a rig which is under conversion. The study is done by conducting the Global Strength Analysis.The Finite Element Method is used to determine the stresses and strains in various joint sections of the RWT by modelling the same in SACS modelling and FE analysis software which is extensively used in offshore industry. The structure is analysed as a discrete element model using beam elements. The stiffness analysis for the Raw Water Tower includes the computation of resultant stresses in members due to bending, shear, tensile & buckling stresses and checking it against the respective acceptable values.

1.INTRODUCTION

The Raw Water Tower (hereafter referred to as RWT), under this study, is basically a three chord truss structure. It is positioned inside a well casing in the hull located near the starboard leg well of the rig. The original length of the RWT is 38.1m. Due to the raise in air gap this has to be increased to 43.6m and due to which, if the length is extended with the same sizes of chords, bracings and pinions, it fails for the increased weight and environmental loads.

Arrangement wise, this RWT is locked at two chords through safety paws and vertical loads are carried by jacking system located at the same two chords. The horizontal loads are carried by guides located at four levels along the well casing depth wise. The rig is being converted from Mobile Offshore Drilling Unit (MODU) to Mobile Offshore Production Unit (MOPU). The picture (Fig-1) in the next page shows the general layout of the Raw Water Tower.

A lattice structure of Raw Water Tower structure assembled with tubular members is adopted for reducing the wave forces and current forces on structure to a minimum. The triangular column lattice structure of the RWT for this jack up rig consists of three (3) chords, horizontal braces and supported by diagonal braces. The strength of each chord and braces and also the joint cans of each of these tubular members is being investigated in this research.

The main objective of the analysis is to verify that whether the structure reliably performs its functions and is structurally safe in a specified environment for storm conditions throughout its life cycle. The structure strength has been evaluated considering relevant, realistic load conditions &combinations.

Keywords: Pinion, Safety Pawl, Jack Up Rig, Drag Coefficient, Inertial Coefficient, Buckling Coefficient, Stress, Chord Pipes, Bracing Pipes, Air Gap, Wave Theory, Critical Heading.

NOMENCLATURE

H [m]	Wave Height
D [m]	Water Depth
T [sec]	Wave Period
g [m/sec^2]	acceleration due to gravity
E [N/mm^2]	elastic modulus of the material

Greek Conventions

σ_y [N/mm^2] yield stress of the material.
ρ[kg/m^3] density of material

1.1 Scope of Work

The rig under study is a three legged jack-up unit. The RWT in this rig has three chords truss framed with bracings all being tubular members. The scope of work for the present study is to carry out following;It is locked at two chords through safety pawls & vertical loads are carried by jacking system located at the same two chords. The horizontal loads are carried by guides located at four levels along the well casing depth.

- To verify that the structure reliably supports the total increased weight in a specified environment for storm conditions throughout its life cycle.
- To evaluate the RWT strength considering all relevant, realistic load conditions and combinations.

To achieve the above tasks, the extreme wave analysis with dynamic effects included for Jack-up Rig have been carried out in the Structural Analysis Software, SACS 5.6. (Ref#1).

The picture below (Fig-1) shows the general Arrangement of the Raw Water Tower.

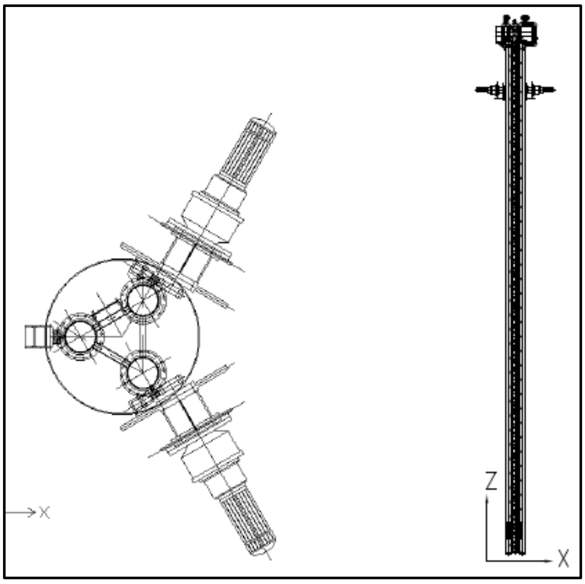

Fig-1: General Arrangement of Raw Water tower Plan & Profile Views

5. APPROACH TO THE PROBLEM

By using simple methods which have been formulated with mathematical equations and empirical relations of class rules and other guidelines, the member stress calculations have been performed by applying these empirical relations.Through manual mathematical calculations it has been observed that the structural failures of some of the members of the RWT structural lattice in way of the RWT-hull interface areas have been noticed.For validation of the calculation results of stress calculations of RWT structures, and to identify the underlying problem of structural failures, a Finite Element (FE) model has been generated inSACS software to analyse the RWT lattice structures using "finite element techniques".

The investigations have been carried out in accordance with SNAME TR 5-5A (Ref#2). For Stress calculations, guidelines given in API RP-2A WSD (Ref#3), Recommended practice for planning, designing and constructing fixed offshore platform – Working Stress Design, 21st edition, supplement 1-3, have been followed. All important calculations have been discussed in Section 7 of this technical paper.The picture below (Fig-2) shows the 3D model developed for FE analysis of the Raw Water Tower. All the chords and bracings have been defined.

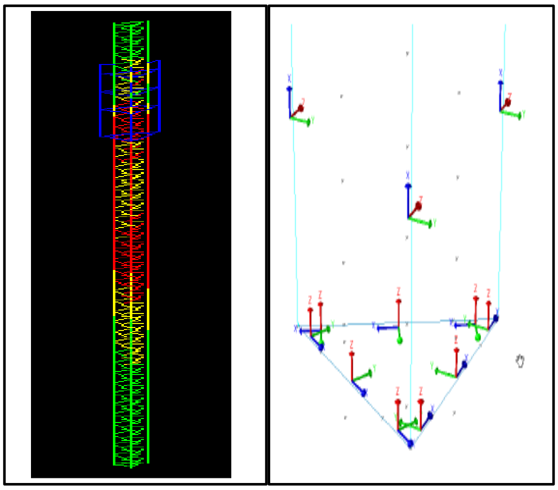

Fig-2: Raw Water tower 3D Model FE analysis

a) Specifications for Analysis:

Table-1 below shows the specifications given for carrying out the Raw Water Tower (RWT) when the rig is in elevated condition and site specific location.

Table-1: Specifications for Analysis

MAIN PARTICULARS OF THE RAW WATER TOWER (RWT)	
Length Overall	43.6 m
Chord to Chord Distance	0.93 m
Hull depth	7.0 m
Airgap	22.0 m
Lowest sea water level from Chart Datum	7.0 m
Column Submersion below Chart Datum	10.0 m

Table-1: Specifications for Analysis (Contd..)

ENVIRONMENTAL CONDITIONS:	
Water depth	50 m
Wind Speed	191.88 km/hr (103.6 knots)
Wave Height	13.42 m

Wave Period	12.00 sec
Spud can penetration	3.75 m
Current speed varies with height as below.	
0.00 m	0.0 m/s
47.0 m	0.257 m/s
50.0 m	0.514 m/s

6. OVERALL METHODOLOGY

The objective of the analysis is to verify that structural reliably supports the total increased load on RWT for the increased length due to air gap in a specified environment for storm conditions throughout its life cycle. (Ref#4).

ABS Guidance Notes for Dynamic Analysis of Self elevatingDrilling Units(Ref#5) have been used for defining the boundary conditions and load cases. The
mathematical calculations have been verified by using the structural FE model analysis. A high degree of accuracy in the analytical method has been used. To investigate its validity and verify the accuracy, due to the structure complexity, certain conventions have been adopted in constructing the actual structure of RWT for global analysis, as given in some examples in technical papers (Ref#6). The results are compared with the results of “Detailed structural analysis” of a lattice structure using the general purpose structural analysis program, SACS.

a) Well Casing Models

Well casing of the hull through which RWT passes is modelled in addition to RWTstructure. The properties of the vertical members WC1 are high andsame as used for hull in jackwhich represents the main deck is fixed vertically by giving fixity 001000. These members are named as GM1, GM2 & GM3 in the FE modelling.

These members have high stiffness properties & behave as rigidmembers. The GM3 member connected to chord 1 is modelled only to removemodel instability. It has very low stiffness thus not affecting the overall behaviour.The GM2 & GM3 members have been given 110111 member releases such thatonly vertical force is carried by these members. Also due to low stiffness of GM3member, it does not carry any load & the vertical force is carried by GM2members (& thus chord 2 & 3) only withWellCasingjack-up rig model. These fixed joints are then connected to chordwhich is the desired behaviour.

b) Boundary & Load Conditions

The RWT is connected to well casing (hull) through safety pawls vertically &guides horizontally. The well casing is fixed vertically at main deck &horizontally at first guide level. Sequence of the fixity input on each joint as shown below is Fx, Fy, Fz,Mx, My, Mz.(Ref#7)

The picture below (Fig-3) shows the boundary conditionsthat have been set for the RWT model FE analysis.

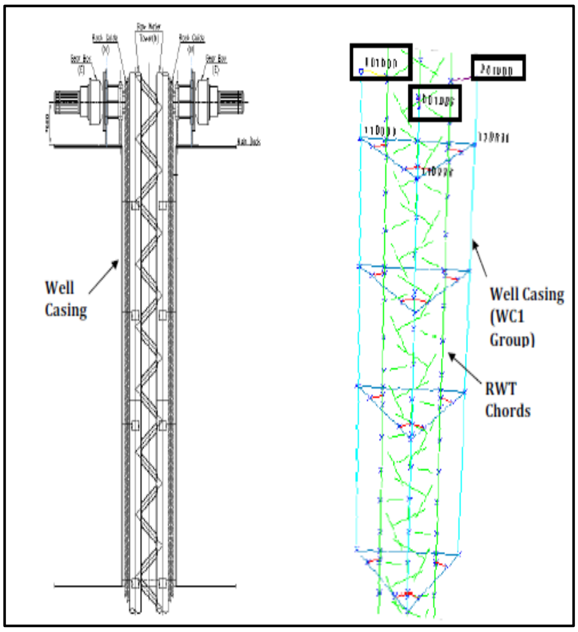

Fig-3: Raw Water tower 3D Model FE analysis

c) Gap Elements

Clamping mechanism consists of rack-type positive locking system having two sets per chord on either side. Due to virtue of clamping mechanism geometry and arrangement, for axial load, it is effective only in compression. To simulate this behaviour, these beams are modelled as gap elements (only compression elements).

The static analysis is carried out with gap elements.The self-weight, buoyancy,environmental loads (wind+wave+current) etc., are applied in relevantdirectionsand analysis is carried out to find resultantstresses & deflection in the structure.Nonlinear loadsdue P-delta effect can also be considered in software;hence, nonegative springs are used separately.

The Raw Water Tower – Hull interface is shown in the picture below (Fig-4).

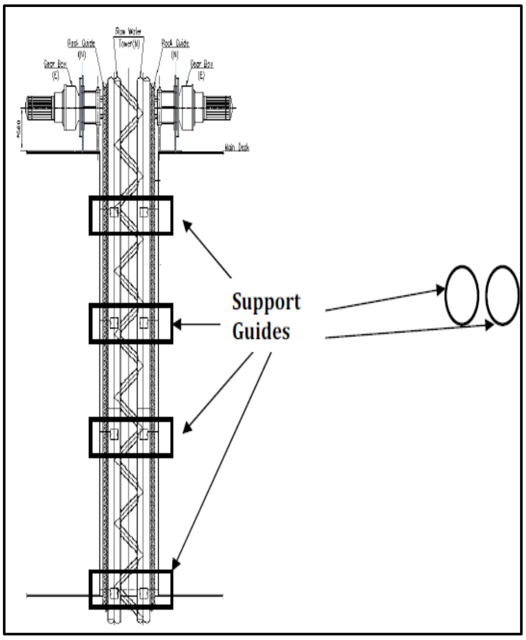

Fig-4: RWT-Hull Interface Details.

7. LOADING COMBINATION

Environmental loads such as wind, wave and current is applied on structure in respective direction. Fig-5 below showstypical environmentalload application scenario.

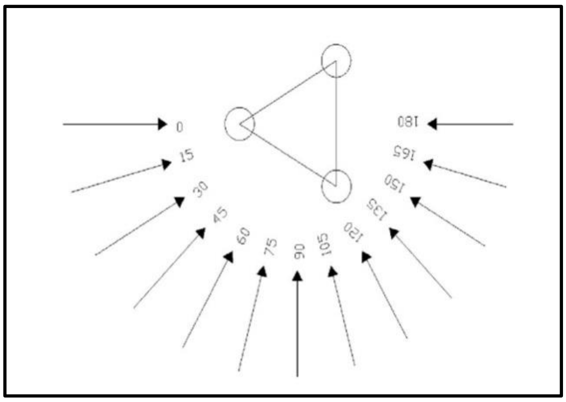

Fig-5: Wind Load Scenario on RWT.

P-delta loads have been included in analysis using respective load cases. Semi submersible pumps and their weight, RWT weight and buoyancy are considered as P-delta load cases.

Loading Combination has been considered for wind angles of 0^0, 15^0, 30^0, and so on till 180^0have been considered in storm condition. All load combinations are similar as mentioned below:

Load combination = LTSH (Self Weight) + SSP (Variable Load) + S000 (Wave+Current)+W000 (Wind) + ENVR (Wave, Current and Wind Load) + INERTIA (Dynamic loads) + PDELTA + BUOY (Buoyancy Load).(Ref#8)

a) Acceptance Criteria

As the analysis is carried out for storm condition with all the loads applied at a time, 1/3rd increase inallowable is considered in analysis.The acceptance criteria for all the member stresses, is as given in the table-2 below.

Table-2: Acceptance criteria for member stresses.

Sections (RWT)	Yield Stress (t/cm^2)	Factor of Safety	Allowable Normal Stress	Max.UC Value
Chord,Rack (API5Lx70)	4.919	1.25	3.935	1.00
Chord,Rack (API5Lx80)	5.627	1.25	4.502	1.00
Diagonal Brace (API 5lx70)	4.919	1.25	3.935	1.00
Diagonal Brace (API 5Lx80)	5.627	1.25	4.502	1.00

8. MATERIAL SELECTION

While material selection we have to consider all types of design load and working condition. For r Lattice Tubular members, the consideration parameters are higher strength/density ratio, less corrosive in sea water, high yield stress of material. After defining the FE Model in SACS software, the meshing taking place after defining the geometry, viz., the point and the curves. After the geometry definition, the material characteristics are defined for the ABS Grade AH36 steels.

Material Properties of ABS AB/AH36 (High Strength Steel)

Young's Modulus (E) : $2.1x10^{11}$ N/m^2
Poison's Ratio (n) : 0.3
Yield Stress(σ_y) : 380 MPa
Density (ρ) : 7850 kg /m^3

9. GOVERNING EQUATIONS

a) Wave and Current Forces acting on RWT structures.

Morrison's formula (1950) is used here to derive the wave and current forces on tubular members of RWT structures in sea water and wind forces above the water level. The hydrodynamic forces are calculated here on the basis of quasi-static assumption and only the horizontal forces are considered for the wave direction in each horizontal level of RWT structures assuming the current direction is identical to the wave one.In the detailed calculations of the hydrodynamic forces, the acting forces due to the particle motion of wave and current are given on each tubular member of RWT structures such as chords, horizontal braces.

b) Selection of Wave Theory.

Wave theory selection for particular location depends on water depth, wave height and time period associated with same. For present location, depend on above parameter, stream function theory of 5th order is selected. Refer Fig-6 below.

Wave Height	=	13.416 m
T_{ass}	=	12.0 sec
Water Depth	=	50.0 m
H/gT^2	=	0.0095
D/gT^2	=	0.0354

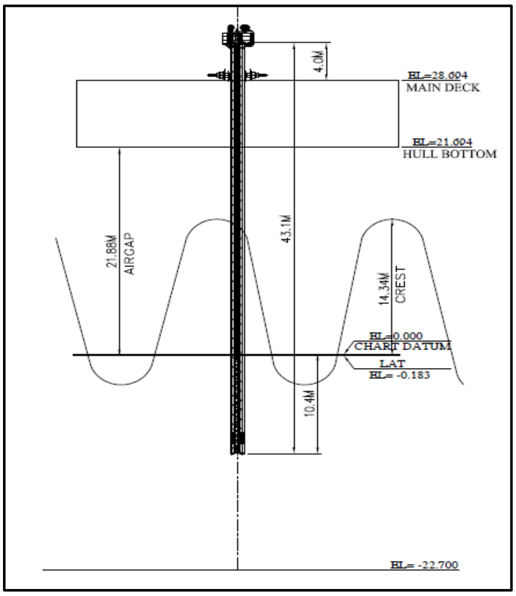

Fig-6: Air Gap estimate with respect to wave function

10. DETAILS OF DESIGN & ANALYSIS

Time varying nature of wave loads amplifies the static response of structure. To account the dynamic effect due to time varying wave loads, dynamic analysis has been carried out. Initially Eigen value analysis has been carried out to find out different mode shapes, model internal loads and stress vectors. These results are imported into extreme wave analysis to amplify the static response of structure.

a) Preliminary Design Calculations

The preliminary design calculations for member stresses have been carried out using the governing equations. The chord properties and bracing properties such as their mass and moments of inertia have been calculated using the fundamental engineering and strength of materials equations. All known and standard members and their mass moments of inertia properties have been taken from the steel designer's handbook.

b) Hydrodynamics

i) Drag & Inertia Coefficients

Morrison's equation is applicable for calculating hydrodynamic wave loads on this Jack-up Rig because the diameter of the chord is less than 20% of wavelength of design wave. For all the directions as mentioned in para 4, the drag coefficient is calculated numerically by determining the equivalent drag coefficient for complex geometrical shape of chord. Table-3 below shows the drag & inertia coefficients calculated and incorporated in the model. (Ref#9).

Table-3: Drag & Inertia coefficientfor various Heading angles.

Element	Heading angle * (deg)	Smooth Cylinder		Rough (Fouled) Cylinder	
		C_d	C_m	C_d	C_m
Chord	0	0.65	2.00	1.00	1.80
Chord	30	0.67	2.00	1.01	1.80
Chord	60	0.73	2.00	1.07	1.80
Chord	90	0.85	2.00	1.16	1.80
Chord	120	1.69	2.00	1.83	1.80
Chord	150	2.34	2.00	2.35	1.80
Chord	180	2.36	2.00	2.36	1.80
Braces	All	0.65	2.00	1.00	1.80

"*" heading angle refers to angle made by wave direction with rack plane.

ii)Current Blockage Coefficient:

The calculation shown in Table-4 below shows the estimation of current blockage parameter. Based on this calculation, a value of 0.88 has been considered as current blockage coefficient in the analysis.

Table-4: Current Blockage Coefficient.

Direction (deg)	D_e (cm)	C_{de}	D_1 (cm)	Current Blockage parameter
0	0.74	3.11	1.33	0.70
15	0.74	3.07	1.33	0.70
30	0.74	3.01	1.33	0.70
45	0.74	3.07	1.33	0.70
60	0.74	3.11	1.33	0.70
75	0.74	3.07	1.33	0.70
90	0.74	3.01	1.33	0.70
105	0.74	3.07	1.33	0.70
120	0.74	3.11	1.33	0.70
135	0.74	3.07	1.33	0.70
150	0.74	3.01	1.33	0.70

165	0.74	3.07	1.33	0.70
180	0.74	3.11	1.33	0.70

11. SUMMARY OF RESULTS

In the present case, through FE analysis it has been noticed that the cracks may be developed in some tubular members where stress concentration factors are found to be high. These locations have been discussed in the conclusions.In high cycle fatigue situations, materials performance is normally characterized by the S-N Curve. The graph depicts of a cyclical stress (S) against cycles of failures (N). Failure due to repeated loading is called fatigue.Fatigue failures are often caused by the degradation of metal surface. A rough surface finish, a scratch or oxidation will provide an initial crack. Cracks will propagate after cyclical loading and eventually lead to fatigue failure. (Ref#10).

a) Summary of Deflections

Summary of maximum deflections for combined load cases w.r.t. global coordinate system are shown in table-5 below.

Table-5: Summary of deflections.

Angle	Joint	'X' Deflection (cm)	Joint	'Y' Deflection (cm)	Joint	'Z' Deflection (cm)
0	0025	265.05	0001	-0.44	0001	-5.57
15	0025	269.74	0025	71.25	0001	-5.62
30	0025	254.62	0013	145.54	0001	-5.31
45	0025	214.15	0013	212.02	0013	5.55
60	0025	153.89	0013	264.68	0013	5.94
75	0013	78.72	0001	292.21	0013	5.72
90	0019	0.70	0001	248.34	0025	-4.47
105	0025	-48.31	0001	180.18	0025	-3.73
120	0013	-57.65	0013	100.80	0025	-2.43
135	0013	-79.13	0013	79.72	0025	-2.24
150	0013	-97.20	0013	56.50	0025	-1.99
165	0013	-114.33	0013	30.98	0001	2.33
180	0013	-119.68	0001	-0.14	0011	2.45

b)

c) Summary of UC Values

The summary of Unity Check values are as shown in the table-6 below.

Table-6: Summary of Unity Check Values

HeadigAngle	Chord W/o Rack	Chord with Rack Teech	Diagonal Brace
0	2.35	2.39	3.76
15	2.42	2.52	4.44
30	2.42	2.88	4.88
45	2.26	3.23	4.98
60	2.12	3.48	4.71
75	1.89	3.48	4.77
90	1.29	2.73	3.89
105	1.18	1.86	2.70
120	0.83	1.12	1.55
135	0.88	1.06	1.63
150	0.93	0.99	1.72
165	1.04	0.92	1.79
180	1.10	0.84	1.68

12. CONCLUSIONS

1. Based on the analysis of existing RWT presented in this report, it can be concluded that the global strength of RWT is not sufficient for increased water depth and air gap and cannot withstand the severe storm conditions of 100 knots wind and 14m wave height.

2. The RWT needs to be redesigned by increasing chord to chord distance & member scantlings to become suitable for intended operations. The increase
in chord to chord distance will increase section modulus and reduce bending moment & deflection.

3. Another fix to this problem would be to introduce one more safe pawls. In other words, the safety pawls need to be provided at all three chords (instead of only two) to enable vertical moment absorption iwo hull interface & reduce deflection.

4. The increase in weight & loads on RWT will lead to increase in required jacking & holding capacity of the jacking system.

At present all the calculations are done with zero marine growth with an aim that the owner organizations will maintain the marine growth prevention systems perfectly for next seven years of operation. However, if marine growth is also to be considered then the drag co-efficient values will increase which will lead in increased failure of structures.

The main conclusion is that the oil companies during conversion of existing vessels into new form generally miss out some minor failure items which will not be recognized in the beginning. If Raw Water Tower fails during operation in the severe weather conditions, it will be a very big disastrous situation because there will no fire water, no cooling water to the engines/GTGs and the water supply will not be there for other utilities also. A minor item failure can cause the shut of the entire production platform. Hence, during conversions, a study is to be done if any items like RWT will fail due to severe weather conditions or not.

13. ACKNOWLEDEMENTS

Authors are thankful to Pipavav Shipyard Limited Authors are also thankful to all the project membersinvolved in the Conversion project of of the ONGC Rig 'Sagar Laxmi'.

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15. AUTHORS BIOGRAPHY

Dr. Bh. Nagesh holds the current position of Vice President (Design) of ABG Shipyard Limited. He has been involved in many private and Government projects involving in quality oriented FSO & FPSO & ship Designs and Offshore Structural & piping designs, Construction Supervision etc., assimilating changes in technology and customer requirements. He has excellent skills in Riser Analysis, Pipe Stress Analysis and Pipe Surge Analysis. He is a good ship and offshore machinery & piping design engineer and has sound knowledge in structural designs of all shipboard machinery, HVAC and Piping designs.

Prof. (Dr.) I.N. Niranjan Kumar is presently holding the position of the Director of Indian Maritime University for its Vizag campus. He was a very senior most Professor of the Department of Marine Engineering, Andhra University College of Engineering, Andhra University. He has been teaching various courses at the graduate and postgraduate level for the last more than two decades. Currently he is involved in many research projects, and specializes in the areas of Thermodynamics and Heat Transfer subjects and related research activities. He is also the Chairman Board of Studies in Andhra University and member in various selection committees.

Mrs. N. Madhu Latha is an Assistant Professor in an Engineering College in Visakhapatnam. She is also a Research Scholar in Andhra University, Marine Engineering Department. She has worked in several marine organizations and also in various teaching level positions in various engineering colleges.