TENSION LEG PLATFORM DESIGN:

OPTIMIZATION FOR VORTEX INDUCED VIBRATION

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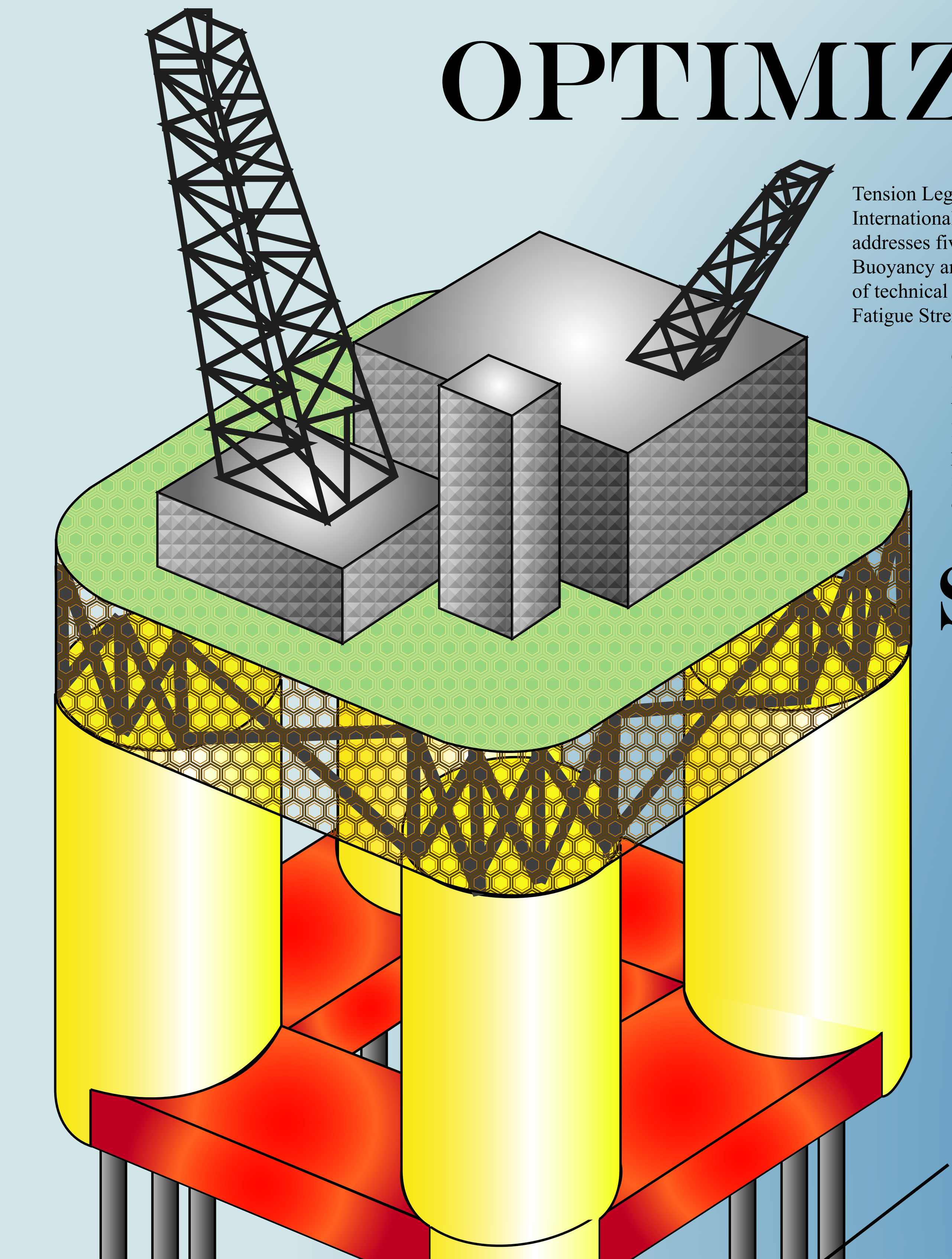
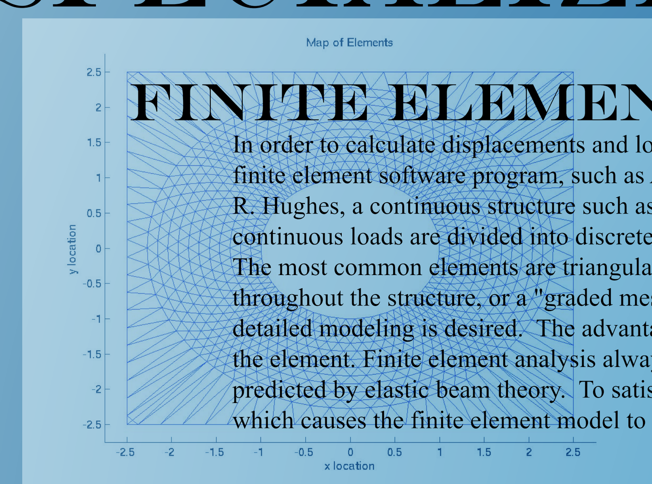


Tension Leg Platform design is a challenging and popular area of research in the offshore oil industry. In order to compete in the International Student Offshore Design Competition (ISODC), a Tension Leg Platform (TLP) was designed. Our TLP design addresses five fundamental areas of technical competency (General Arrangement and Overall Hull/System Design, Weight, Buoyancy and Stability, Global Loading, General Strength and Structural Design, Risk Assessment) and three specialized areas of technical competency unique to a Vortex Induced Vibration (VIV) optimized design (Hydrodynamics of Motions and Loading, Fatigue Strength, and Structural Analysis: global and local strength).

Our design optimization process begins with a four-caisson, four-pontoon tension leg platform, operating at a depth of 3,000 ft. Hydrostatic and hydrodynamic analysis for design iterations are performed by our own MATLAB script, which calculates the effects of motions due to Vortex Induced Vibration (VIV). Structural analysis addresses fatigue loading from VIV. Our design includes risk-based analysis and conforms to class society rules and regulations. VIV phenomena cause uncontrollable motions of offshore platforms, as well as fatigue damage and failure of components such as cables and risers. The effects of VIV need to be addressed early in the design process to avoid costly platform damage and costly retrofits, such as hydrodynamic strakes for platform tendons.

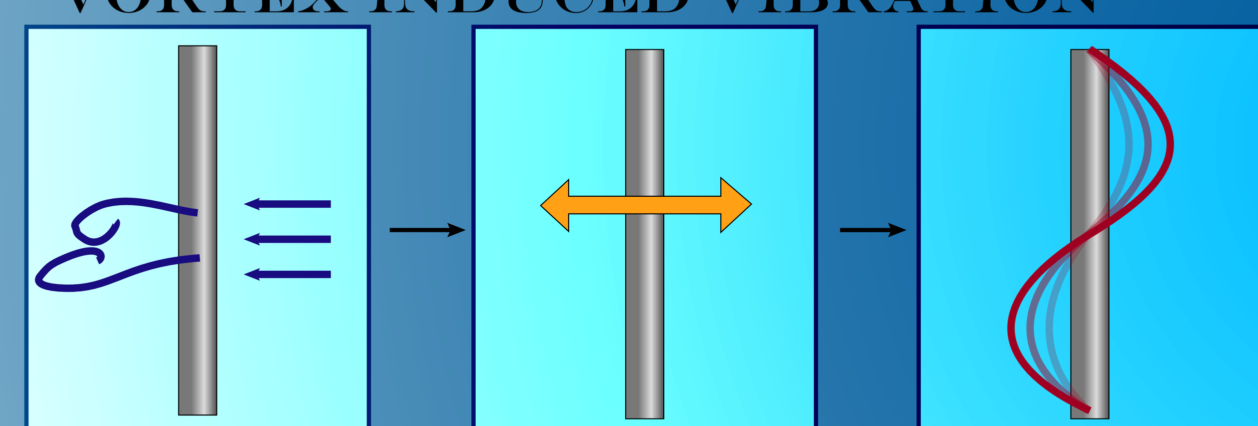
SPECIALIZED DESIGN

FINITE ELEMENT ANALYSIS



In order to calculate displacements and loads on the structure, it is common practice to use a commercial finite element software program, such as Abaqus. In finite element analysis, as described by Thomas J. R. Hughes, a continuous structure such as a plate or beam is divided into discrete elements, and continuous loads are divided into discrete nodal point loads. The elements are connected at nodes. The most common elements are triangular and rectangular elements. Elements can be the same size throughout the structure, or a "graded mesh" where the elements are smaller in the region where a more detailed modeling is desired. The advantage of triangular elements is a constant stress value within the element. Finite element analysis always predicts deflections that are less than the deflections predicted by elastic beam theory. To satisfy compatibility, a displacement function is assumed, which causes the finite element model to be stiffer than the actual structure.

VORTEX INDUCED VIBRATION



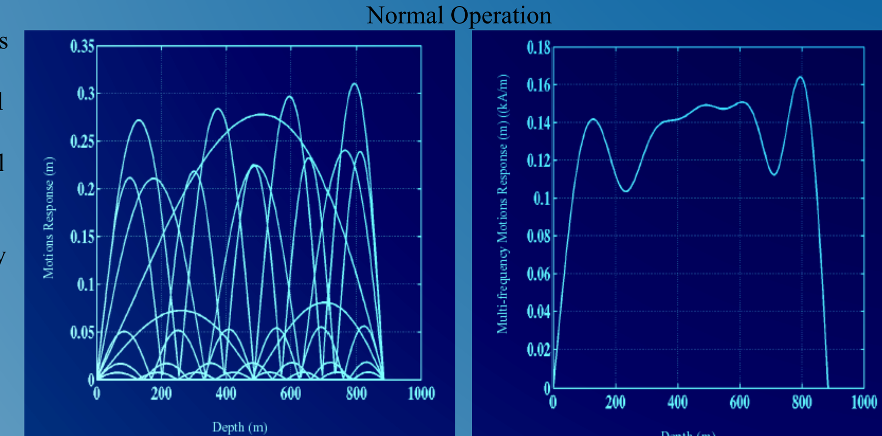
flow separtation → force on tendon → vibration

The forces that the mooring and production systems (tendons and risers) are exposed to are understood and controlled to a much lesser extent than those in the hull and superstructure or pilings. These forces are related to the random set of currents and environmental situations that will occur over the life of the system. These structures must be designed against rogue currents and storms which might only occur once every 100 years or more, but pose serious environmental, safety and economic threats.

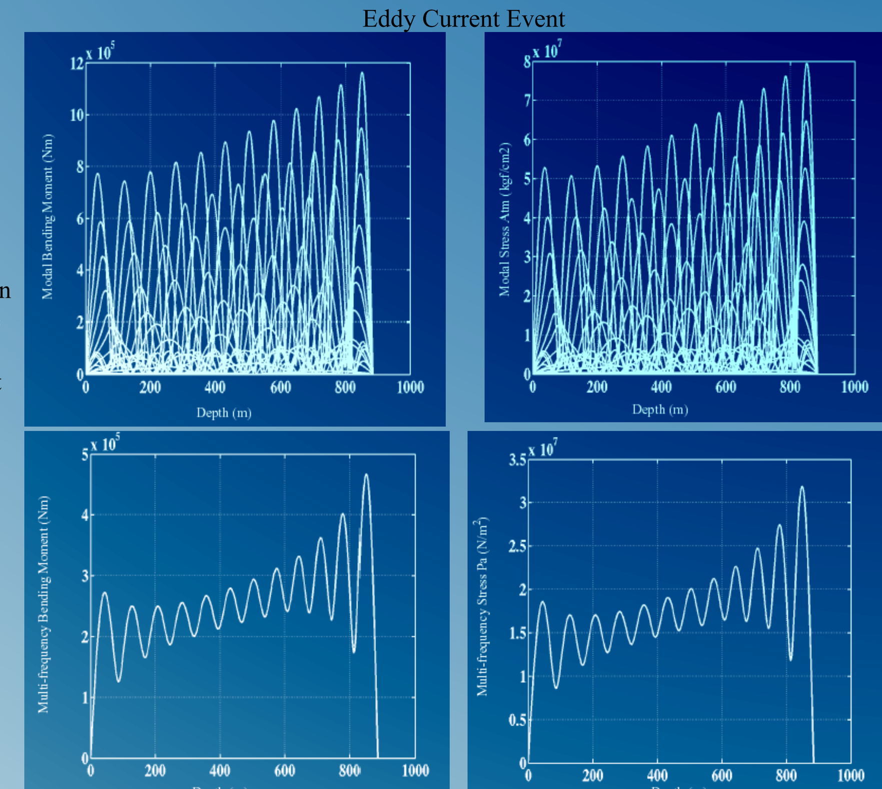
Engineers must understand and model the full range of possible environmental characteristics, then model the response of the system in these situations to ensure proper safety factors and fatigue lives. The TLP after which our design was preliminarily modeled, Shell Oil's "Brutus", is known to have had fairings retrofitted onto its risers based on problems that it did in fact experience with VIV induced fatigue. For the design of our TLP, computational analyses of the response of the tendons in varying currents was carried out using two sets of commercially viable VIV codes: VIVA and Shear7.

The first and most important part of the process is to obtain quality current profiles for varying currents, in order to see the dynamic response of the tendons in the largest cross-section of environments possible. Eight current profiles were used in our analyses. The current profiles (the 100 year storm, reduced extreme storm, normal operation, eddy current event, OTC 8606, OTC 8405, Typhoon and Non Typhoon) are published in the Offshore Technology Conference (OTC) proceedings. After obtaining a sufficient array of current conditions, the next step is to prepare the input files for the hydrodynamic code, VIVA. VIVA requires a set of input files which describe the physical and material properties of the tendons, the boundary conditions, and the currents. Once the input files are properly generated they can be fed to VIVA which then produces an extensive set of output files. The first set of results is the overall motion, first with the separate modal responses graphed independently and then the full spectrum response.

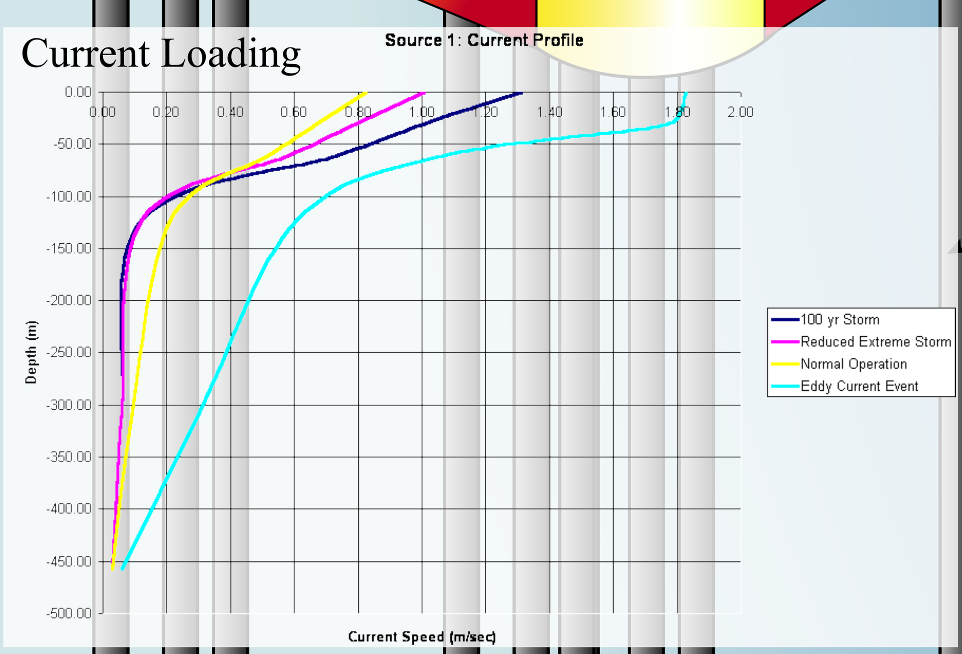
Normal Operation



Eddy Current Event



Current Loading



VIVA INPUT AND OUTPUT FILES AND DESCRIPTIONS

Input Files	Description
Risdyn.dat	Tendon Tension, current profile, damping coefficients
Rispre.dat	Riser Properties: length, number of segments, diameters, etc.
Test.dat	Boundary conditions
Risfat.dat	Fatigue constants (A,B) and stress concentration factor
Mode-def	Tells VIVA whether to calculate natural frequencies or if they are specified
Output Files	
Bend.dat	Stress response and bending moments as a function of depth
Bend-mm.dat	Multi-frequency stress response and bending moments as a function of depth
Fat.out	Fatigue life calculations
Out.dat	Motions response
Out-mm.dat	Multi-frequency motions response
Sum-sta	Summary of all motions, stress, and bending moment response

MAXIMUM DISPLACEMENTS AND PROBLEM NODES FOR EACH CURRENT CONDITION

Current	Multi-modal Displacement (cm)	Modal Displacement (cm)	Problem Mode
Normal Operation	31	16	4
100 Year Storm	24	45	6
Eddy Current Event	25	43	12
Reduced Extreme Storm	21	40	5
OTC 8045	25	49	7
OTC 8606	19	35	11 and/or 5
Typhoon	30	55	12
Non-Typhoon	27	63	2

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FUNDAMENTAL DESIGN

WEIGHT, BOUYANCY, STABILITY

Weights

total topside weight	20502 tons
hull weight	12054 tons
tendon weight	7500 tons
total vessel weight	36306 tons
total weight with 15% margin	41752 tons

System Forces

total hull displacement	51230 tons
total buoyancy	9478 tons
tendon tension	790 tons

Natural Frequency

heave	3.3 s
pitch	23.11 s
roll	23.11 s

Natural Period

heave	1.9 rad/s
pitch	0.2719 rad/s
roll	0.2719 rad/s

Effective Stiffness

heave	1.54×10^{7} lbs/ft
pitch	5.10×10^{10} lbs/ft
roll	5.10×10^{10} lbs/ft

Displacements

caissons	33740 tons
pontoons	16657 tons
tendons	833 tons

Added Mass

pontoons	116010 slugs
caissons	612840 slugs
total	1773000 slugs

Radius of Gyration

superstructure	91.88 ft
deck	61.25 ft
caissons	33.25 ft
exposed pontoons	44.63 ft
sheilded pontoons	16.62 ft

Moments of Inertia

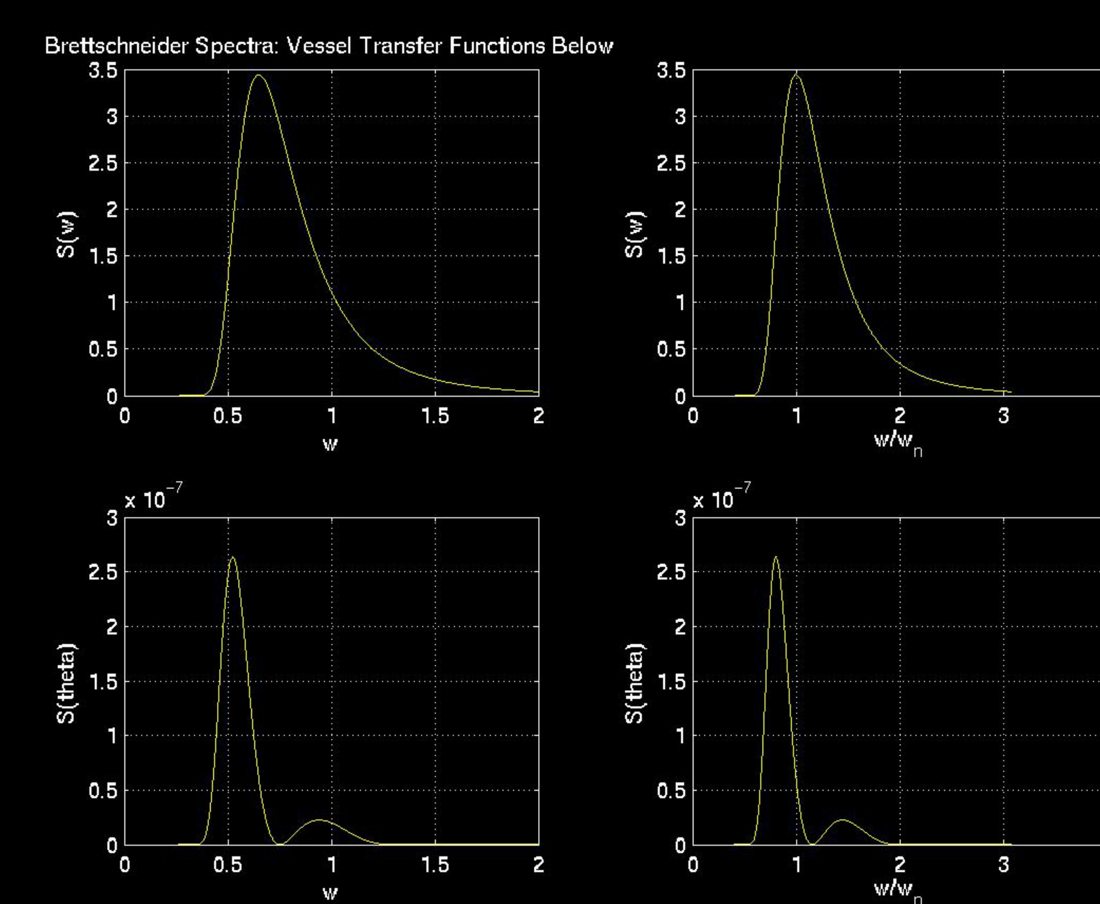
superstructure	5.92×10^{9} ft^4
deck	2.63×10^{9} ft^4
caissons	1.67×10^{11} ft^4
exposed pontoons	7.42×10^{10} ft^4
sheilded pontoons	1.03×10^{10} ft^4

Operating Environment

sea state	5
H	5 ft
natural frequency	0.65 rad/s

Waterplane Area = 13893 ft_2

Hydrodynamic Analysis



Fatigue Life

Current	Multi-Modal Minimum Fatigue Life (years)	Multi-Modal Location (m)	Modal Minimum Fatigue Life (years)
100 Year Storm	5100	833.7	43
Eddy Current Event	63	851.5	.22
Reduced Extreme Storm	68000	821.9	810
OTC 8045	1600	833.7	17
OTC 8606	240	848.5	1.5
Typhoon	6.6	851.5	.052
Non-Typhoon	43000	836.7	370

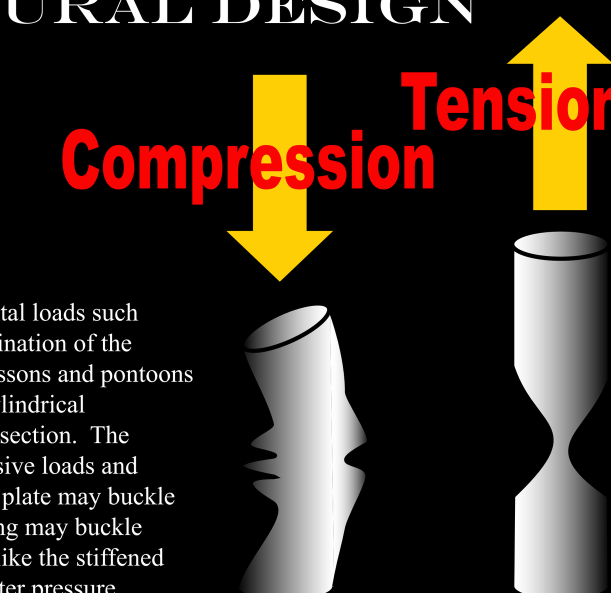
Current	Modal Location (m)	Problem Mode	Associated Stress Pa (N/m^2)
100 Year Storm	833.7	7	8×10^{6}
Eddy Current Event	851.5	12	2×10^{7}
Reduced Extreme Storm	824.9	6	4.6×10^{6}
OTC 8045	833.7	7	1×10^{7}
OTC 8606	848.5	11	1.4×10^{7}
Typhoon	854.4	13	2.9×10^{7}
Non-Typhoon	833.7	7	4.9×10^{6}

Modal and Multi-Modal Bending Moments and Stresses for Eddy Current Event Condition

Current	Multi-modal Bending Moment (Nm)	Multi-modal Stress Pa (N/m2)	Modal Bending Moment (Nm)	Modal Stress Atm (kgf/cm2)
Normal Operation	6.5 x 104	4.3 x 106	1.3 x 105	8.7 x 106
100 Year Storm	2 x 105	13.5 x 106	4.2 x 105	28 x 106
Eddy Current Event	4.7 x 105	32 x 106	10.8 x 105	80 x 106
Reduced Extreme Storm	1.1 x 105	7.5 x 106	2.2 x 105	14.9 x 106
OTC 8045	2.4 x 105	17 x 106	5 x 105	34 x 106
OTC 8606	3.5 x 105	24 x 106	7.6 x 105	53 x 106
Typhoon	7 x 105	52 x 106	16 x 105	110 x 106
Non-Typhoon	1.13 x 105	7.7 x 106	2.5 x 105	17 x 106

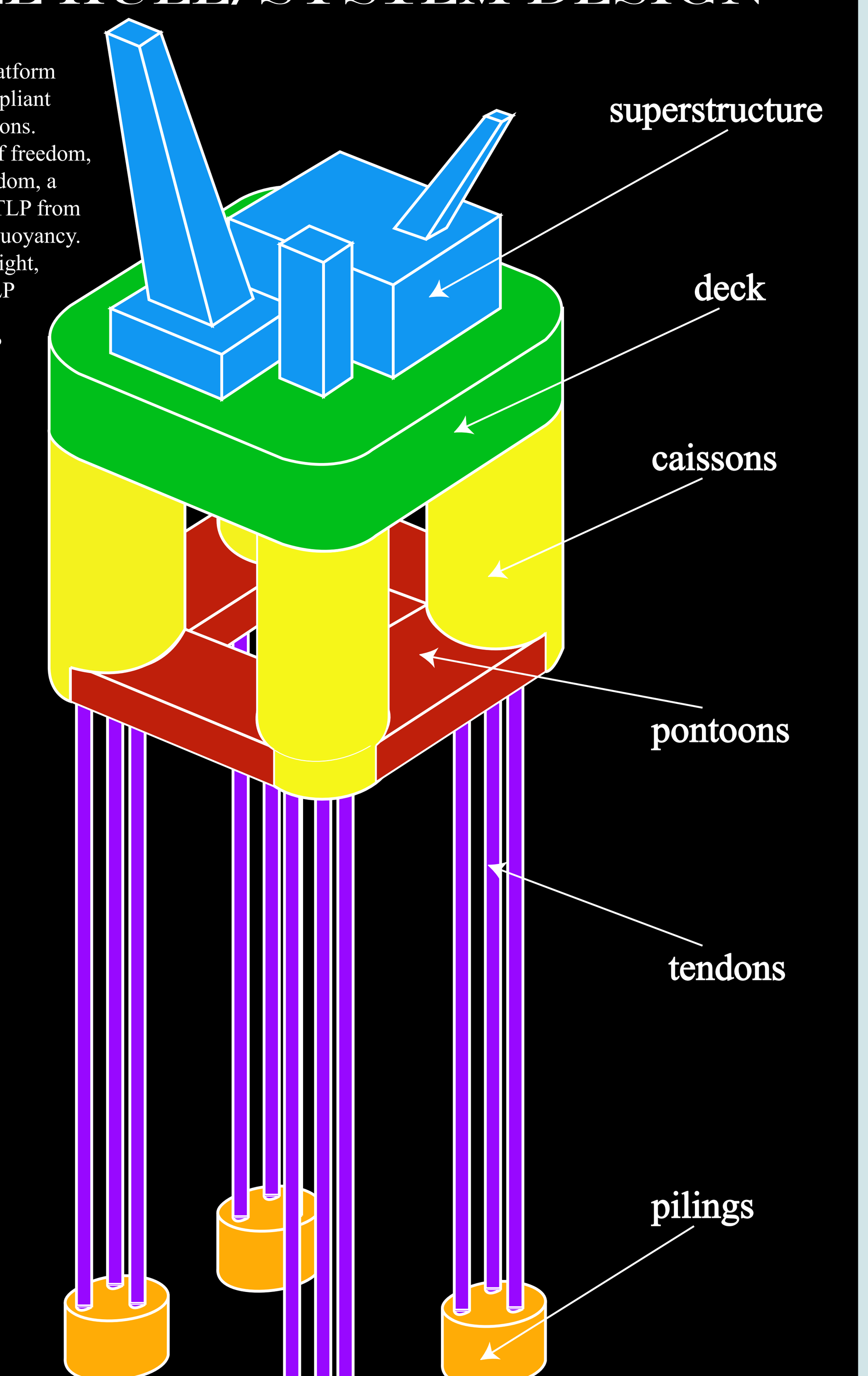
GLOBAL LOADING, STRENGTH AND STRUCTURAL DESIGN

The global loads on the structure are weight, buoyancy, and wave and current loading. The structural components of the TLP are made of steel. The critical structural components of a TLP are the tendons, foundations, caissons and pontoons, connections between columns and pontoons, deck girders, and connections between the deck and pontoons. Because they are long columns, the tendons are subject to buckling. Tendon pre-tension is a static, permanent load on the TLP foundations. Environmental loads such as wave loads and currents are variable loads, and lateral inclination of the tendons causes lateral loads on the foundations. The TLP caissons and pontoons are orthogonally stiffened shells. The caisson shells have a cylindrical cross-section and the pontoon shells have a rectangular cross section. The stiffened shells are subject to buckling failure under compressive loads and yielding under tensile loads. The stringers and attached shell plate may buckle together, the panels themselves may buckle, or the shell plating may buckle locally, while the stiffeners remain stable. The deck girders, like the stiffened shells, may buckle or yield, but are not subject to external water pressure.



GENERAL ARRANGEMENT OVERALL HULL/SYSTEM DESIGN

A TLP is a compliant, free-floating offshore platform concept. Unlike fixed offshore platforms, compliant platforms respond to external effects with motions. A TLP is compliant in the horizontal degrees of freedom, surge and sway. In the vertical degrees of freedom, the TLP is fixed. The feature that distinguishes a TLP from other moored platform concepts is its reserve buoyancy. Because the buoyancy of a TLP exceeds its weight, vertical moorings called "tendons" keep the TLP vertically stable and control heave motions. Our TLP design is based on Shell's Brutus TLP in the Gulf of Mexico.



water depth	2985 ft.
hull breadth	254 ft.
draft	85 ft.
caisson diameter	66.5 ft.
caisson height	166 ft.
pontoon width	35.5 ft.
pontoon height	23 ft.
tendon diameter	2.6667 ft.
tendon wall thickness	1.25 ft.
number of tendons	12

RISK ASSESSMENT

Determining risks and managing risks are two separate processes, once aware of your potential hazards, it is imperative that offshore engineer has a system which monitors the vessel operations so as to warn against impending problems. To ensure that a vessel, TLP in our case, is performing satisfactorily during operation, operators make use of barrier diagrams, Bow-Tie analysis and criticality reviews. Bow-tie analyses are where one connects a primary event with its potential consequences, threats, preventative measures and recovery measures. The operator must monitor the mechanical integrity of the vessel as well as the SHE (safety, health and environment) systems. Control measures, to prevent occurrences or mitigate problems, are linked to something called a platform SMS (safety management system). Most all operating platforms have one of these systems, in one form or another, and through them, they manage the key barriers to failure and the performance standards of the vessel.