IN-PLACE ANALYSIS OF JACKET OFFSHORE STRUCTURE UNDER STORM CONDITIONS

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ABSTRACT

This paper presents the details of In-place analysis of fixed jacket Platform BD. The numerical model is prepared using ANSYS ASAS structural analysis computer system. Beam stick model has been used, with multi-level sub-structuring technique, to model the whole structure. Appropriate dead load, live loads and quasi-static action of 100 yr storm have been applied to the structure. The structure-pile interaction analysis has been performed using SPLINTER, a component of the ANSYS ASAS program suite. The platform is subjected to design action, i.e combination of permanent and variable actions, and the basic Integrity checks including member strength, stability and hydrostatic collapse have been performed.

KEYWORDS: *Fixed Jacket platform, In-place analysis, pile soil interaction, storm load*

INTRODUCTION

An offshore platform, also referred to as an oil platform or oil rig is a large structure with facilities to drill wells and extract and process oil and natural gas and export the products to offshore[1,2,3,4], (Figure 1).

Platform BD is completely braced, redundant welded tubular space frame extending from an elevation at the sea bed to above the water surface. The space frame is designed to serve as the main structural element of the platform, transmitting lateral and vertical forces to the foundation. The platform is anchored directly onto the seabed, supporting a deck with space for drilling rigs, production facilities and crew quarters[4,5].

The topsides for the BD platform consists of a module support frame (MSF) which supports the main modules. The MSF consists of a cellar deck and a main deck. The modules/zones of the topside are listed in Table 1 and a general arrangement of the modules is shown in Figure 2.

Table 1: Modules of BD platform

Module	Description	Decks
BD02	Cellar deck - North	-
BD03	Cellar deck - South	-
BD05	Mud module	Main
BD06	Bulk storage module	Main
BD07	Power generation module	Main
BD08	Accommodation module	Upper
BD09	Temporary Living Quarters.	Upper
BD13	Helideck	-

The jacket for the BD Platform is an eight-legged steel structure, Figures 2, 3 and 4, weighing around 1,964t. Frames 1 to 4 have three vertical bays with Frames 1 and 4 having apparent leg batters of 1:7.126 and Frames 2 and 3 having true leg batters of 1:7.126. The bays are mainly K-braced, with additional bracing in some areas for launching purposes. Frames A and B have three vertical bays and Frames 1 and 4 have an apparent leg batter of 1:26. The bays are mainly diagonally braced, with the lower central bay X-braced. Plan bracing is provided at four Elevations: +10.10m, -5.40m, -20.90m and -36.40m.

The legs vary in size from 1512mm x 16mm below Elevation -5.40m, to 1536mm x 28mm above this elevation (i.e. in the splash zone). Leg cans of 1570mm x 45mm are fitted at the interconnections of legs and braces. Main braces vary in size from 650mm x 18mm, through to 950mm x 22mm depending on location. Thicker braces are located in the splash zone to allow for corrosion[6,7].

There are nine caissons attached to the jacket. These are listed in Table 2.

There are twelve conductors on Platform BD each 26in (660mm) diameter. They have guided supports at Elevations +10.10m, -5.40m, -29.90m and -36.40m. Conductors are externally protected against corrosion by coating systems. Gravity and environmental loads on the structure are calculated and combined and applied to the structured in similar fashion as described in various works of literature[8,9,10,11,12]. This study demonstrates the fitness for purpose of Platform BD during in place condition.

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Table 2: Appurtenance Schedule

Appurtenance	Detail
Caissons	2 x 24" Service Water
	24" Overboard Dump
	2 x 30" Firewater
	3 x 24" Seawater (disused)
	20" Shale Cuttings (disused)
Conductors	12 x 26" OD x 1" Wall Thickness

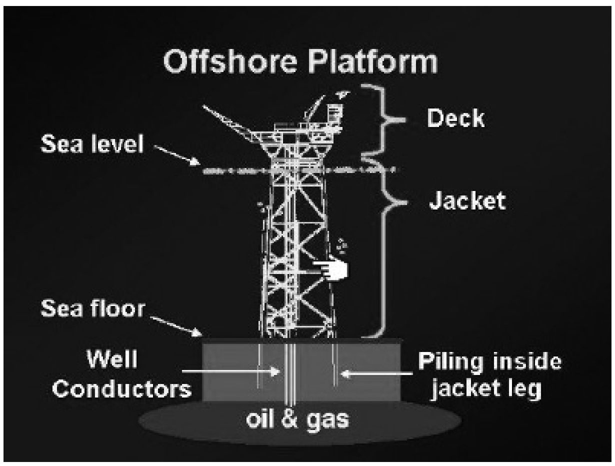

Figure 1: Typical offshore steel platform

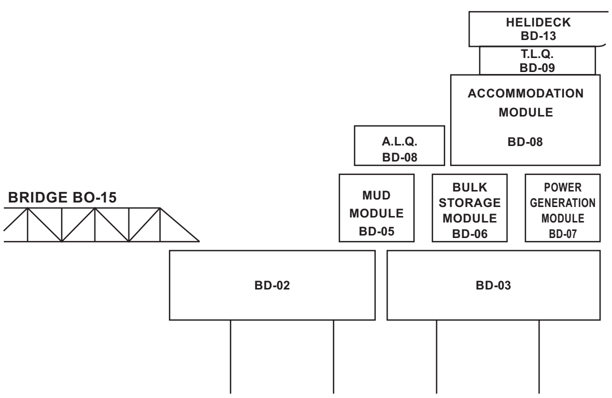

Figure 2: Arrangement of modules on BD platform

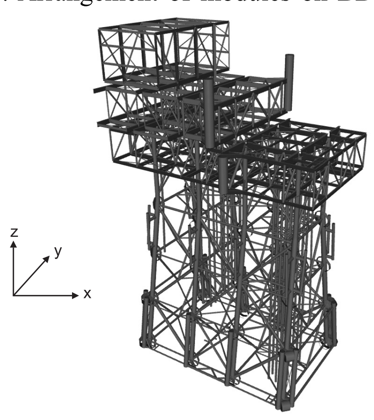

Figure 3: Isometric view of Platform BD

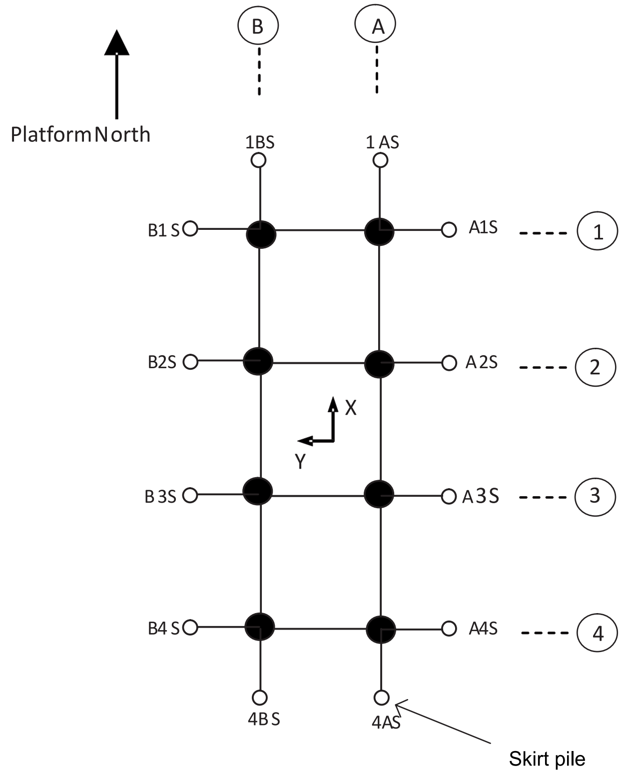

Figure 4: Layout of BD platform

Modelling

The analysis has been performed using the software ANSYS ASAS[2]. The model includes the following:

Topsides members and deck plating

Jacket structure and piles

Conductors and conductor framing members

Soil behaviour using piecewise linear T-z and P-y springs.

Structural Modelling

The platform structural model includes jacket, deck, 3 base modules and an accommodation module and helideck. The jacket has 8 leg piles and 12 skirt piles, 2 at each corner leg, and 1 at each centre leg. The skirt piles are grouted between mudline and EL -20.0m. The elevation at mudline is considered 0.0m. The jacket and deck model incorporates the following features:

- *All jacket structural primary members are modelled and includes elements for boat bumpers and secondary members supporting caissons and conductors.*

The walkway at El. +10.0m, launch runners, and piles/grout between mudline and El -20.0m are not explicitly modelled, but consideration isgiven to their stiffness, weight and hydrodynamic properties where appropriate.

- *The deck model includes main secondary floor beams at cellar deck level between main trusses and longitudinal main deck girders*
- *The modules only include the main carcase primary members for stiffness interaction with deck and jacket and are not of sufficient detail for stress recovery*
- *Wishbone elements to model connectivity between coaxial legs and piles at all plan levels. This provides connectivity between co-axial legs and internal leg piles in the later al directions only, at the plan levels*
- *12 No. 26 inch conductors between frames 1 and 2*
- *20 inch diameter shale caisson adjacent to frame 1*
- *3 No. 24 inch diameter service water caissons adjacent to frame 3*
- *2 No. 24 inch diameter services water caissons adjacent to frame 3*
- *2 No. 24 inch diameter fire water caisson adjacent to frame 1*
- *24 inch diameter overboard caisson at leg A4*
- *Axial elements are used to represent the in-plane shear stiffness of the deck plate at cellar deck level and at module floor and roof levels. Additionally, axial elements are used to repr*esent the shear stiffness of the shear plates connecting the skirt pile sleeves to the jacket legs.

Primary members are those which carry the overall load on the structure through framing action ie. legs, face and plan bracing , deck truss chords and web members. Secondary members are those which transfer load into the primary structure eg. conductor bracing, deck beams appurtenance stubs and protection frames, etc. Non-structural elements are items such as conductors and caissons which attract wave loading but are not modelled to carry load, other than the incident load directly on the element. Detail of ANSYS ASAS model is given in Table 3.

Table 3: Model statistics

ITEM	NUMBER
JACKET/DESK STRUCTURAL ELEMENTS	1693
MODULE STRUCTURAL ELEMENTS	431
HYDRODYNAMIC ELEMENTS	NIL
FOUNDATION ELEMENTS	20
ELEMENT TOTAL	2144
JACKET/DECK STRUCTURAL NODES	916
MODULE STRUCTURAL NODES	208
HYDRODYNAMIC NODES	NIL
FOUNDATION NODES	20
NODE TOTAL	1144

Reference Axis Systems

The global axis system employed in a right handed Cartesian system with the Z axis vertically upwards and the X axis parallel to Frame A and B and positive in the platform north direction. The origin of the global axes is located at the mudline at the geometric centre of the jacket.

The local element axis system used ensures that in-place and out-of plane moments and effectivel lengths are coincident with the local axis system for the integrity checks. Figure 2 and Figure 3 details the global Cartesian axis system.

Element properties

Geometric properties are defined as per the structural drawings[3] to provide a practical accurate stiffness and dead load representation of the structure. Where appropriate, the hydrodynamic properties of certain elements are adjusted to ensure an accurate generation of hydrodynamic loads.

The following material properties were assigned to the elements:

Young's Modulus	2.1GPA
Poisson's ratio	0.3
Density (in air)	7850kg/m^3

The characteristic yield stress, F_y, and the ultimate tensile stress, F_u, for different steel types and thicknesses are presented in Table 4.

Table 4: Steel characteristic yield and ultimate tensile stresses

Thicknes [mm]	F_y [N/mm^2]	F_u [N/mm^2]
≤ 32	345	460
$32 < t \leq 50$	335	460
$50 < t \leq 63$	325	460

Appurtenances

Conductors and caissons have all been modelled as non-structural elements together with their support stubs. Where appropriate member releases have been introduced to ensure the correct transfer of load back to the jacket.

Foundation model

The foundation model for the in-place analysis incorporates the non-linear structure –pile interaction behaviour[10]. All twenty piles, in their correct spatial orientation, together with geometrixc properties and actual penetrations are explicitly modelled in eight groups. The pile foundation non-linear axial and lateral responses has been simulated from derived t-z, q-z and p-y data taking into account the variable clays, sand and chalk soils[3] (Figure 5 and 6).

The soil data for the BD platform is defined as below:

Mudline to -1.5m	Aussumed as scour
-1.5m to -8.6m	Over-consolidated hard clay
-8.6 to -12.9m	Sand
-12.9m to -60.0m	Chalk

Unit skin friction development for pile capacity calculations in clay have been based on Lloyds Rules[4]. In the sand and chalk layers, however, the unit skin friction for pile capacities have been based on API RP2A[1].

Loading

The capability of the structure to withstand various types of loading is illustrated. The platform is subjected to permanent (dead) loads and environmental loads (wind load and wave load)[8,11,12]. The permanent loads are commonly called basic loads and these are combined with the environmental loads in a single load case. Various loadings and load combinations are as follows:

Basic loadcases

The basic loading data comprises the self weight of the modelled jacket and deck together with other items which are given in Table 5. Loads associated with particular items of equipment agree with the loads provided by Weight Audit Report[5].

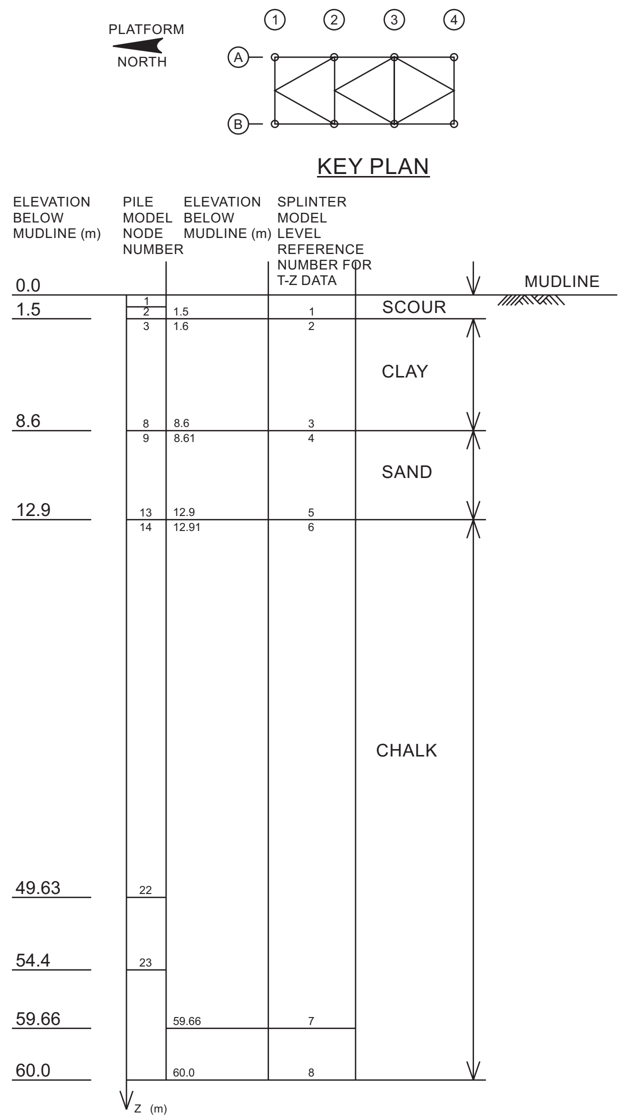

Figure 5: Non-linear foundation model T-Z

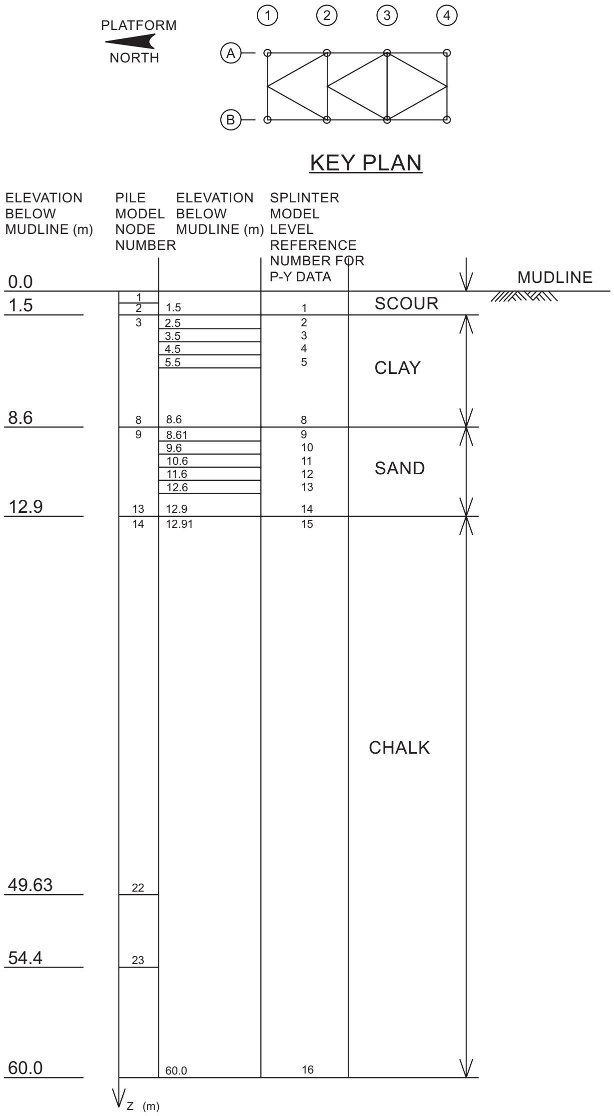

Figure 6: Non-linear foundation model P-Y

Environmental loads

The latest environmental conditions have been incorporated into the current study. Full details of the assumed environmental loads are provided in the Assessment Basis.[6] For completeness, the environmental conditions used in this study are summarised in this section. The water depths and wave parameters employed in the current study are corresponding to extreme storm conditions.

Marine growth

Table 6 gives the marine growth used in the study. The density of the marine growth has been taken as 1375kg/m3.

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Table 5: Deck loads

ASAS Load Case	Description	Load (kN)	Load Centroid (m)	
			x	y
132	JACKET MISCELLANEOUS LOADS	3,624	0.608	2.812
161	MSF - DECK SELF WEIGHT	10,625	-0.432	-0.407
162	STRUCTURE DEAD WEIGHT LOADS	8,917	-3.965	-0.389
163	MSF - DECK SHORTFALL LOADS	1,126	-0.746	0.000
164	MSF - MECHANICAL EQUIPMENT	2,382	-10.346	-0.163
165	MSF - VESSELS + CONTENTS	7,255	12.846	6.152
166	MSF - ELECTRICAL	2,226	-10.554	-0.233
167	MSF - INSTRUMENTS	307	-0.33	1.918
168	MSF - HVAC	275	-22.007	-0.986
169	MSF - FIRE SYSTEM	1,266	-6.733	2.646
170	MSF - PACKAGES	2,100	3.04	1.307
171	MSF - PIPING	4,307	2.407	-0.219
172	MSF - MISC	987	25.967	-11.318
173	DECK LIVE LOADS	2167	-	-
174	Module BD - 05	13,231	-0.03	-1.81
175	Module BD - 06	7,176	-12.9	3.63
176	Module BD - 07	7,788	-26.18	0.93
177	BD - 08	17,520	-20.01	-0.23
178	Modules BD - 09 + BD - 13	4,513	-23.43	3.09
179	LAYDOWN	5,244	-17.613	-2.813
180	SNOW	488	-2.312	0.000

Note: The x axis is in the direction of platform north
The y axis is in the direction of platform west
The origin of the coordinate system is at the centre (on plan) of the jacket
MSF - Module Support Frame (BD02 and BD03)

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Table 6: Marine growth profile

ASAS z-coordinate (m)		Elevation (m)		Thickness (mm)
From	To	From	To	
0.000	20.899	EL -36.900	EL -15.999	35
20.900	40.900	EL -16.000	EL 4.000	60
40.901	97.000	EL 4.001	EL 60.100	Nil

Still water level

The following water depths have been used for the extreme storm conditions:

Table 7: Wate depths

Description	100 - Year	
	Level relative to Datum (m)	Level relative to LAT (m)
Maximum Still Water Depth	44.9	8
Average Still Water Depth	40.25	3.35
Minimum Still Water Depth	35.6	-1.3

Current

Table 8 tabulates the current profile (10-year return period) used in the analysis. Variation in current velocities with both depth and direction have been accounted for in the analysis.

Table 8: Current Profiles (10-year return) – Extreme Storm Condition

z (m)	Elevation (m)	Current Direction (deg) 0.0	56.3	90.0	123.7	180.0	236.3	270.0	303.7
40.30	3.40	0.385	1.188	1.209	0.535	0.514	1.466	1.455	0.417
20.15	-16.75	0.385	1.188	1.209	0.535	0.515	1.466	1.455	0.417
15.00	-21.90	0.368	1.134	1.155	0.511	0.490	1.400	1.390	0.399
10.00	-26.90	0.347	1.070	1.090	0.482	0.463	1.321	1.311	0.376
5.00	-31.90	0.314	0.969	0.987	0.437	0.419	1.197	1.188	0.341
4.00	-32.90	0.305	0.939	0.956	0.423	0.406	1.159	1.151	0.330
2.00	-34.90	0.276	0.851	0.866	0.383	0.368	1.050	1.042	0.299
0.75	-36.15	0.240	0.739	0.753	0.333	0.320	0.913	0.906	0.260
0.50	-36.40	0.226	0.698	0.710	0.314	0.302	0.61	0.855	0.245
0.25	-36.65	0.205	0.632	0.643	0.285	0.273	0.780	0.774	0.222
0.10	-36.80	0.180	0.554	0.564	0.250	0.240	0.684	0.679	0.195
0.05	-36.85	0.163	0.502	0.511	0.226	0.217	0.620	0.615	0.176
0.00	-36.90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Waves

Table 9 lists the extreme 100-year return period storm waves used in the analysis.

Table 9: Extreme Storm Waves (100-year return)

No.	Direction	Direction (deg)	H_{max} (m)	$T_{ass,max}$ (s)	$T_{ass,min}$ (s)
1	North	0.0	6.8	9.9	7.0
2	North-West	56.3	9.4	11.7	8.3
3	West	90.0	11.1	12.8	9.0
4	South-West	123.7	13.3	14.1	10.0
5	South	180.0	15.3	15.2	10.7
6	South-East	236.3	15.5	15.2	10.7
7	East	270.0	13.6	14.3	10.1
8	North-East	303.7	8.7	11.3	8.0

Wind Loads

Wind forces on the deck superstructure modules have been based on a constant wind velocity of 40m/s at 10 metres above mean water level. The varioation in wind velocities with height is accounted for in the calculations as described in the specifications[7]. Wind force calculations have been performed for wind approaching from the platform south and east directions, neglecting effects of shielding where appropriate, ie. For N-S wind shielding is taken between modules. No wind loads have been applied to the jacket members and appurtrenances above water as this is considered negligible. The design wind speed used in the analysis are detailed in Table 10.

Table 10: Design wind speeds

CASE	PLATFORM DIRECTION	ANGLE DEG	WIND SPEED (M/S)	FACTOR ON LOAD	COMBINATION FACTOR S-WIND	E-WIND
STORM	S	0.00	37.4	0.874	0.874	0.000
	SE	56.30	38.7	0.690	0.690	0.648
	E	90.00	35.0	0.766	0.766	0.766
	NE	123.70	36.7	0.842	0.842	0.583
	N	180.00	39.5	0.975	0.975	0.000
	NW	236.30	40.7	1.035	1.035	-0.717
	W	270.00	40.4	1.020	1.020	0.000
	SW	303.70	40.7	1.035	1.035	-0.717

Corrosion allowance

A corrosion allowance has been deducted in the splash zone for member checks only. Thus, the wall thickness of the jacket legs has been reduced by 6mm and that of braces has been reduced by 3mm. The stiffness analysis has not included any corrosion allowance.

Hydrodynamic coefficients

The basic hydrodynamic coefficients used in the analysis are given in Table 10. The drag coefficient is the same as suggested by API RP2A (21st Edition)[1]. The value of the inertia coefficient (Cm), defined as 2.0 in API RP2A (17th Edition) and has been retained as 2.0 in the current analysis. This is conservative as a value of 1.60 on clean tubulars and 1.20 on fouled is permitted. However, loads for the in-place condition are drag dominated, so the use of a conservative value of the inertia coefficient will have little influence on the results. The hydrodynamic coefficients used in the analysis are listed in Table 11.

Table 11: Hydrodynamic coefficients

Coefficient	Clean	Fouled
Drag, C_d	0.65	1.05
Inertia, C_m	2.00	2.00

A wave kinematics factor, which is applied to horizontal wave particle velocities and accelerations, was conservatively taken as unity.

A current blockage factor of unity was taken, which is conservative.

The effect of conductor shielding was ignored.

Load Combinations

For the extreme storm analysis the following loads were included

- The 100-year return storm wave (8 directions)
- The 10-year return current profile (8 directions)
- The 10-year return storm wind (8 directions)
- Jacket self weight and buoyancy
- Marine growth
- Deck self weight and deck equipment.

The load combinations which have been used to assess the member and joint utilisations of the jacket members are detailed in Table 12. The deck load cases listed in Table 5 have been consolidated into load cases 361 to 481. Twelve load combinations were studied in the extreme storm analysis, eight for maximum pile compression accounting for full equipment loads, live loads and 90% buoyancy loads and another four for maximum pile tension adopting the dry equipment loads, full module dead loads, no live loads and full buoyancy loads.

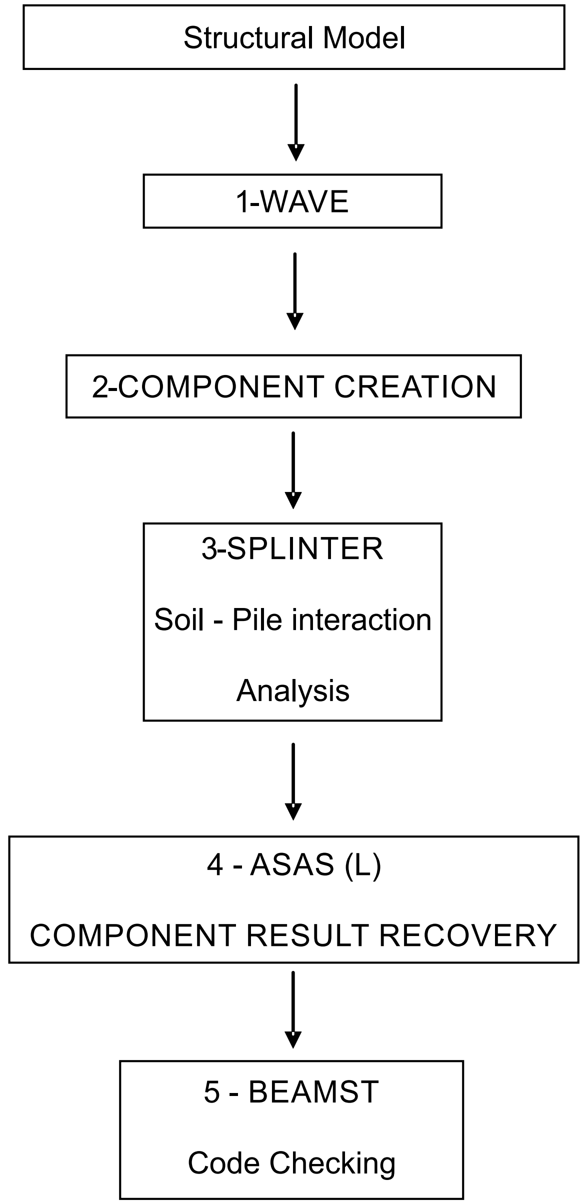

Figure 7: In-place analysis steps

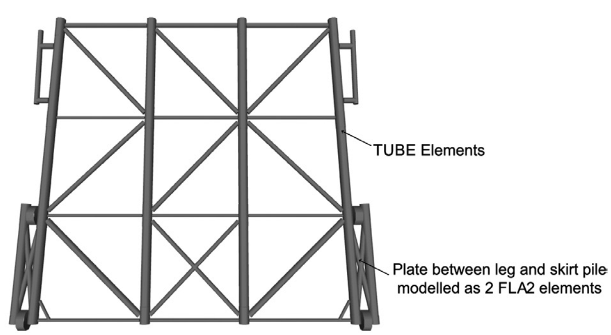

Figure 8: TUBE and FLA2 elements of Frame A

Table 12: Extreme storm load combinations

LOAD COMBINATION MATRIX: 2010 ANALYSIS (24 Waves, Pile Tens+Comp)			**Final Load Combinations**											
			Extreme Maximum Compression								**Extreme Max Tension**			
		LOAD COMBINATIONS:	SOUTH EXTREME WAVE (000deg) - Max Compression	SE EXTREME WAVE (056deg) - Max Compression	EAST EXTREME WAVE (090deg) - Max Compression	NE EXTREME WAVE (124deg) - Max Compression	NORTH EXTREME WAVE (180deg) - Max Compression	NW EXTREME WAVE (236deg) - Max Compression	WEST EXTREME WAVE (270deg) - Max Compression	SW EXTREME WAVE (304deg) - Max Compression	SE EXTREME WAVE (056deg) - Max Tension	NE EXTREME WAVE (124deg) - Max Tension	NW EXTREME WAVE (236deg) - Max Tension	SW EXTREME WAVE (304deg) - Max Tension
	LC		**1101**	**1102**	**1103**	**1104**	**1105**	**1106**	**1107**	**1108**	**1202**	**1204**	**1206**	**1208**
COMBINED LOADCASES (LOAD COMBINATIONS):														
JACKET - WEIGHT IN AIR	331		1	1	1	1	1	1	1	1	1	1	1	1
MARINE GROWTH - WEIGHT IN AIR	332		1	1	1	1	1	1	1	1	1	1	1	1
STORM BUOYANCY (WD_min)	333		0.9		0.9		0.9		0.9					
STORM BUOYANCY (WD_max)	334									0.9				1
OPERATING BUOYANCY (WD_min)	335													
OPERATING BUOYANCY (WD_max)	336													
BUOYANCY (WD_mean)	337			0.9		0.9		0.9			1	1	1	
MSF - SELF & DEAD WEIGHT (BD02&03)	361										1	1	1	1
MSF - DISCIPLINES (BD02&03)	365										0.66	0.66	0.66	0.66
MODULES - DEAD+DISCIPLINES (BD05,06,08,09&13)	375										1	1	1	1
MAX. OPERATING TOPSIDES DEAD LOADS	380		1	1	1	1	1	1	1	1				
CRANE - UNIT LOAD	441													
CRANE - UNIT MOMENT - NORTH (RY)	442													
CRANE - UNIT MOMENT - EAST(RX)	443													
LIVE LOAD (MODULE BD02 AT EL+34.1)	473		1	1	1	1	1	1	1	1				
LAYDOWN LOADS - PLATFORM	479		1	1	1	1	1	1	1	1				
SNOW LOADS - PLATFORM	480													
LIVE LOAD (BD02&BD03 AT EL+24.9 AND BD05)	481													
WIND LOAD FROM THE SOUTH (+X)	541		0.99	0.538		-0.482	-0.922	-0.538		0.577	0.538	-0.482	-0.538	0.577
WIND LOAD FROM THE EAST (+Y)	542			0.807	0.783	0.723		-0.807	-1.046	-0.866	0.807	0.723	-0.807	-0.866
South Extreme Wave (000deg, towards North [TRUE-NE])	611		1.03											
SE Extreme Wave (056deg, towards NW [TRUE-NORTH])	612			1.03							1.03			
East Extreme Wave (090deg, towards West [TRUE-NW])	613				1.03									
NE Extreme Wave (124deg, towards SW [TRUE-WEST])	614					1.03						1.03		
North Extreme Wave (180deg, towards South [TRUE-SW])	615						1.03							
NW Extreme Wave (236deg, towards SE [TRUE-SOUTH])	616							1.03					1.03	
West Extreme Wave (270deg, towards E [TRUE-SE])	617								1.03					
SW Extreme Wave (304deg, towards NE [TRUE-EAST])	618									1.03				1.03
South Operating Wave (000deg, towards North [TRUE-NE])	711													
SE Operating Wave (056deg, towards NW [TRUE-NORTH])	712													
East Operating Wave (090deg, towards West [TRUE-NW])	713													
NE Operating Wave (124deg, towards SW [TRUE-WEST])	714													
North Operating Wave (180deg, towards South [TRUE-SW])	715													
NW Operating Wave (236deg, towards SE [TRUE-SOUTH])	716													
West Operating Wave (270deg, towards E [TRUE-SE])	717													
SW Operating Wave (304deg, towards NE [TRUE-EAST])	718													

METHOD OF IN-PLACE ANALYSIS

The in-place analysis has been performed using the offshore structural analysis system ANSYS ASAS[2]. The analysis is carried out in five steps as shown in Figure 7.

Jacket Structural Model

The structure is modelled by mainly three different frame elements of ANSYS ASAS, namely, TUBE, BM3D and FLA2. TUBE elements are employed to model the jacket members which are hollow circular sections and BM3D elements are used to model the topside members which are mainly I beams.. FLA2 elements simulate plate elements between leg and skirt pile as shown in Figure 8.

CONCLUSIONS

Detailed procedure of in-place analysis for of shore structure has been presented in this paper. Different combinations of loads on the platform are considered including 100 yr return period storm. This is a very common procedure in offshore industry.

This step by step procedure of mutli-level sub-structuring technique will help the engineers in Pakistan to apply them on offshore platforms and similar structure. This procedure can also be employed in design of bridge abutments.

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