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PETROBRAS

KBOS Study (Preliminary Results)

17th June 2022



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Study Input Data

Provided by Petrobras [Ref. 1]

Input Parameters:

■ Site Specific Details:

- Location: Campos Basin
- Water Depth: 107m

■ Environment:

- Assessed Combination: 95% Non-Exceedence
- Wind Wave: $H_s = 3.0\text{m}$, $T_p = 8.8\text{s}$, $\text{Gamma} = 2.0$
- Wind: $V_{\text{wind}} = 11.4\text{m/s}$
- Current (Surface): $V_{\text{curr}} = 0.82\text{m/s}$

■ EDS Sequence:

- Petrobras Standard (Baseline): 50s
- KBOS System: 9s (82% ↓)

- BAP/BOP Connector capacity is low (1,220kips.ft)

■ BOP Configurations:

- Standard BOP, Class 8: 400 ton
 - Overall Stack Height: 15.6-meter
 - LFJ: 6ksi Oil States flex joint
 - Top Tension: Tuned to achieve 45t tension at the base of the LMRP
- ‘L-LITE’ BOP, Class 4: 80 ton
 - Overall Stack Height: 7-meter
 - LFJ: 2ksi Oil States flex joint
 - Top Tension: Tuned to achieve 45t tension at the base of the LMRP



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Study Input Data

SIMA Model

Input Parameters:

- Site Specific Details:
 - Location: Campos Basin
 - Water Depth: 107m
- Base Model
 - 2 x 90ft Slick Joints
 - 40ft of Pup Joints
- LMRP Overpull (base of LMRP):
 - 100kips (45t)

	No	Cross Section	Length	Acc length	Num Elements	El length	Nodal Component
Casing	1	C3010xB	1.0	1.0	1	1.0	
	2	C3010xB	1.0	2.0	1	1.0	
	3	C3010xB	1.0	3.0	1	1.0	
	⋮	⋮	⋮	⋮	⋮	⋮	
	59	C3015x60	1.0	59.0	1	1.0	
WH -	60	C3015x60	1.0	60.0	1	1.0	
	61	C3015x60	1.0	61.0	3	0.33333	
BAP -	62	CS_WH	2.16	63.16	2	1.08	
BOP -	1	BAP	1.982	1.982	2	0.991	
	2	cs_lower_BOP	3.151	5.133	3	1.0503	
LMRP -	3	cs_upper_BOP	5.1304	10.263	5	1.0261	
	1	cs_LMRP1	2.25	2.25	6	0.375	
	2	cs_LMRP2	3.0	5.25	4	0.75	
Riser	3	cs_LMRP3	2.07	7.32	2	1.035	
	4	cs1_riser_adapter	1.94	9.26	2	0.97	LFJ
	5	cs1_slick90feet	27.432	36.692	10	2.7432	
	6	cs1_slick90feet	27.432	64.124	8	3.429	
	7	cs_20pup	6.096	70.22	2	3.048	
Tension Ring -	8	cs_20pup	7.17	77.39	2	3.585	
	9	cs_Outerbarrel	21.19	98.58	5	4.238	
	1	cs_Inner_Barrel	10.65	10.65	1	10.65	
	2	cs1_64	2.7432	13.393	1	2.7432	
	3	cs1_65	3.048	16.441	1	3.048	UFJ

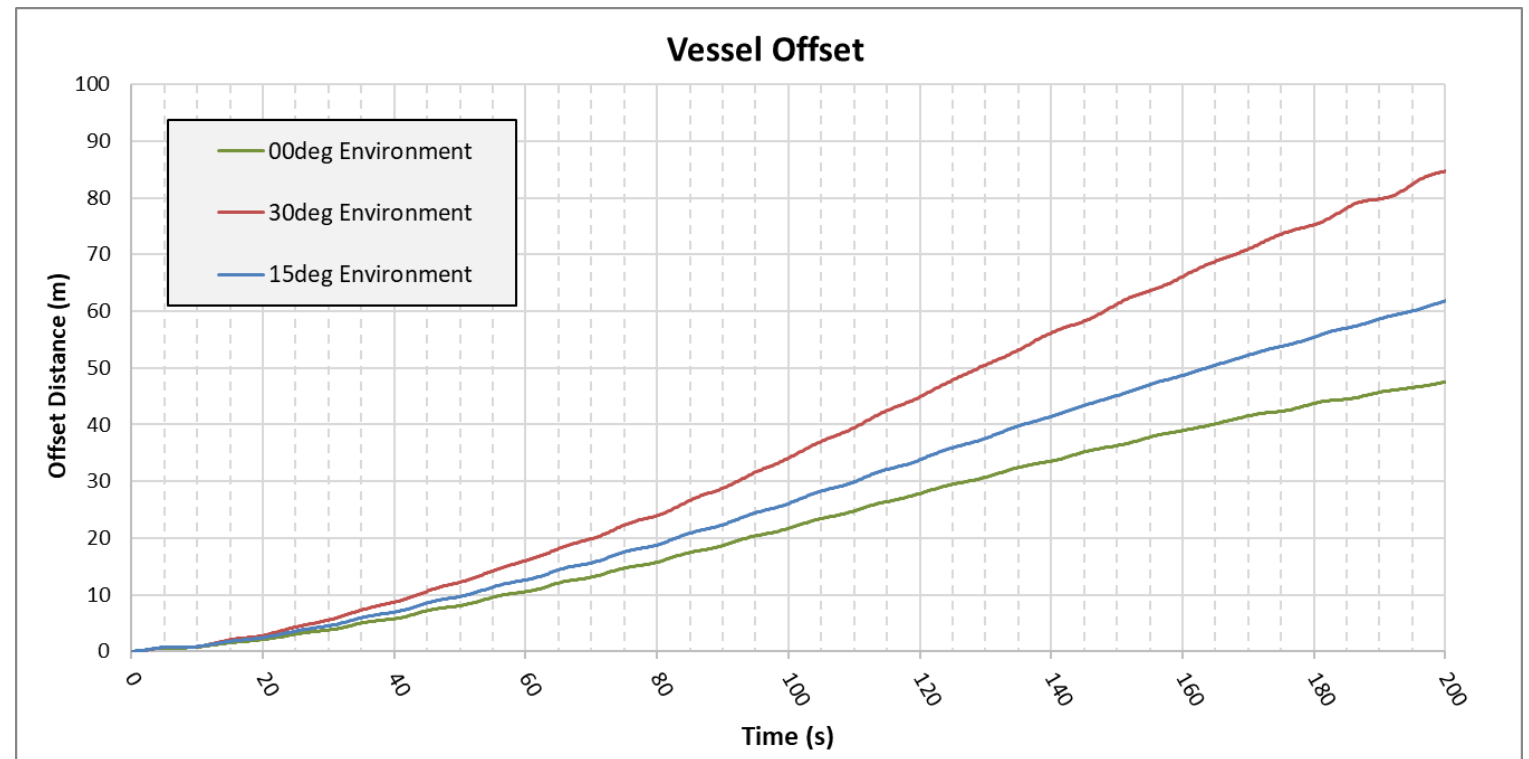
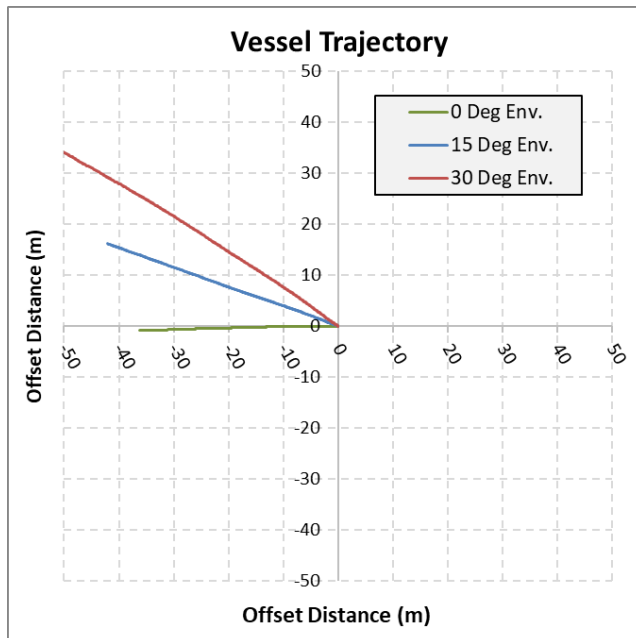


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Results

Drift-Off (PRELIMINARY)

- Environment: 95% Non-Exceedence
 - Wind Wave: $H_s = 3.0\text{m}$, $T_p = 8.8\text{s}$
 - Wind: $V_{\text{wind}} = 11.4\text{m/s}$
 - Current (Surface): $V_{\text{curr}} = 0.82\text{m/s}$





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Results

Drift-Off (PRELIMINARY)

Standard BOP Stack



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Results

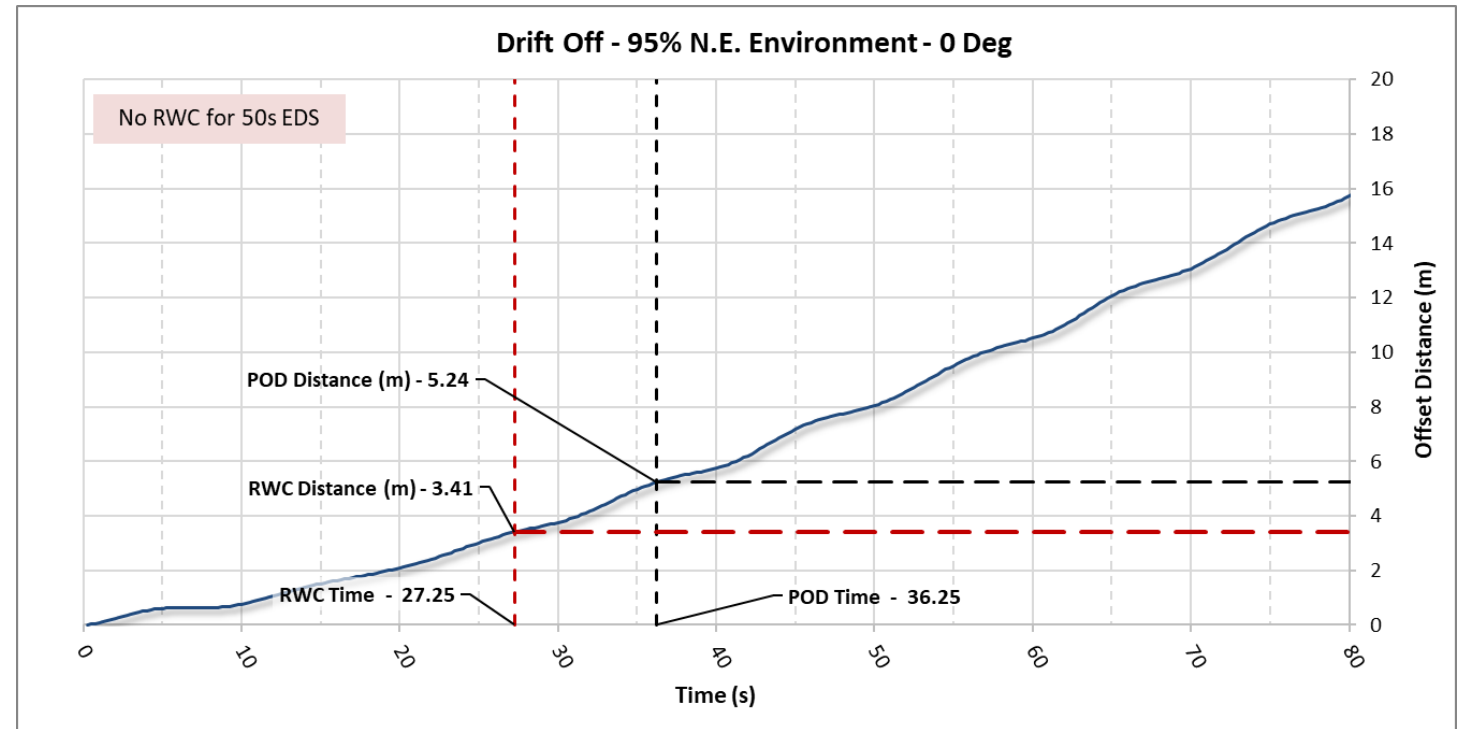
Drift-Off (PRELIMINARY)

'Standard' BOP Stack

- Environment: 95% Non-Exceedence
- 0 Degree Heading Results:

Parameter	Unit	50s EDS	9s EDS
Limiting Criteria	-	BAP/BOP Connector	BAP/BOP Connector
POD Time	s	36.2	36.2
POD Distance	m	5.2	5.2
POD % W.D.	%	4.90%	4.90%
RWC Time	s	0.0 (No RWC)	27.2
RWC Distance	m	0.0 (No RWC)	3.4
RWC % W.D.	%	0.0% (No RWC)	3.19%

- No 50s EDS RWC determined: POD time < 50s
- BAP/BOP Connector is very limiting (1,220kips.ft)
- Next limiting component POD:
 - Upper FJ at 73s (101% ↑) & 14.1m (168% ↑)





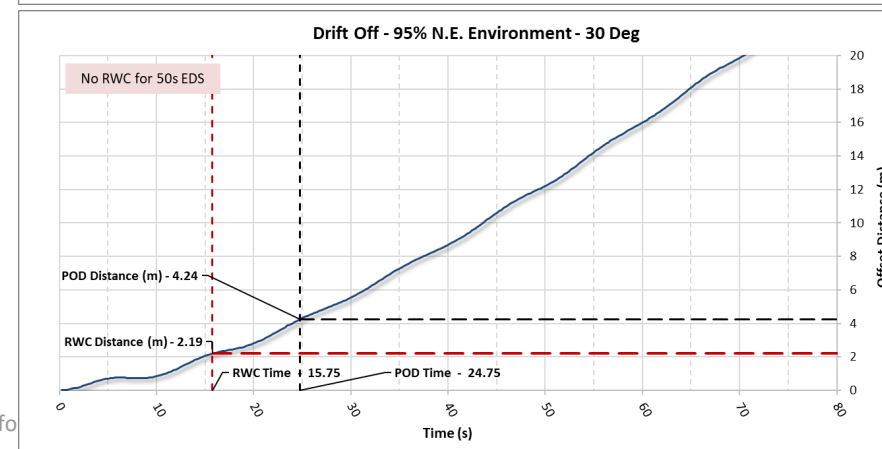
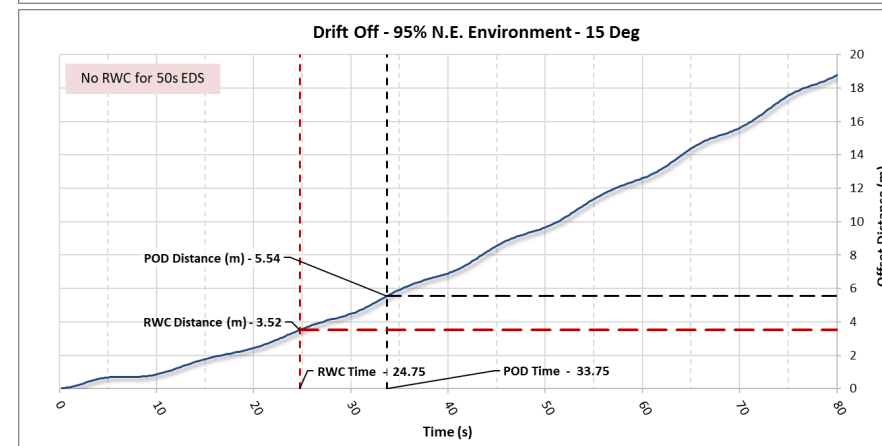
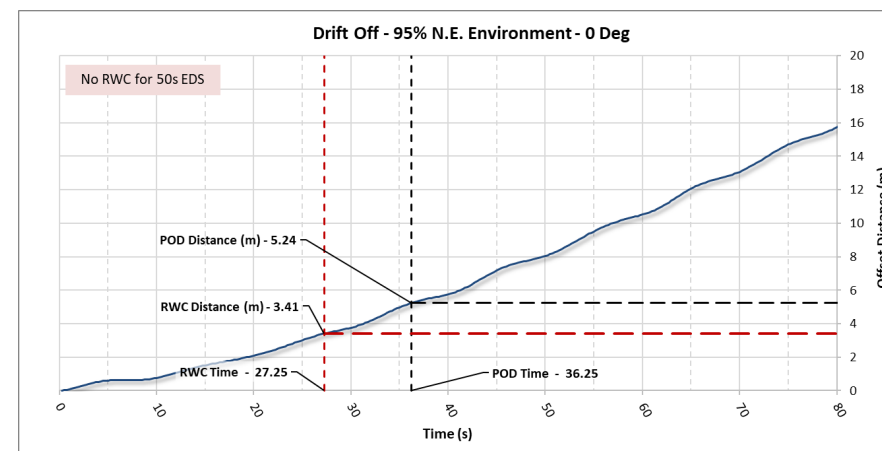
Results

Drift-Off (PRELIMINARY)

'Standard' BOP Stack

- Environment: 95% Non-Exceedence
- 9s EDS – K-BOS System Results:

Parameter	Unit	0 Deg	15 Deg	30 Deg
Limiting Criteria	-	BAP/BOP Connector	BAP/BOP Connector	BAP/BOP Connector
POD Time	s	36.2	33.7	24.7
POD Distance	m	5.2	5.5	4.2
POD % W.D.	%	4.90%	5.18%	3.96%
RWC Time	s	27.2	24.7	15.7
RWC Distance	m	3.4	3.5	2.2
RWC % W.D.	%	3.19%	3.29%	2.05%





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Results

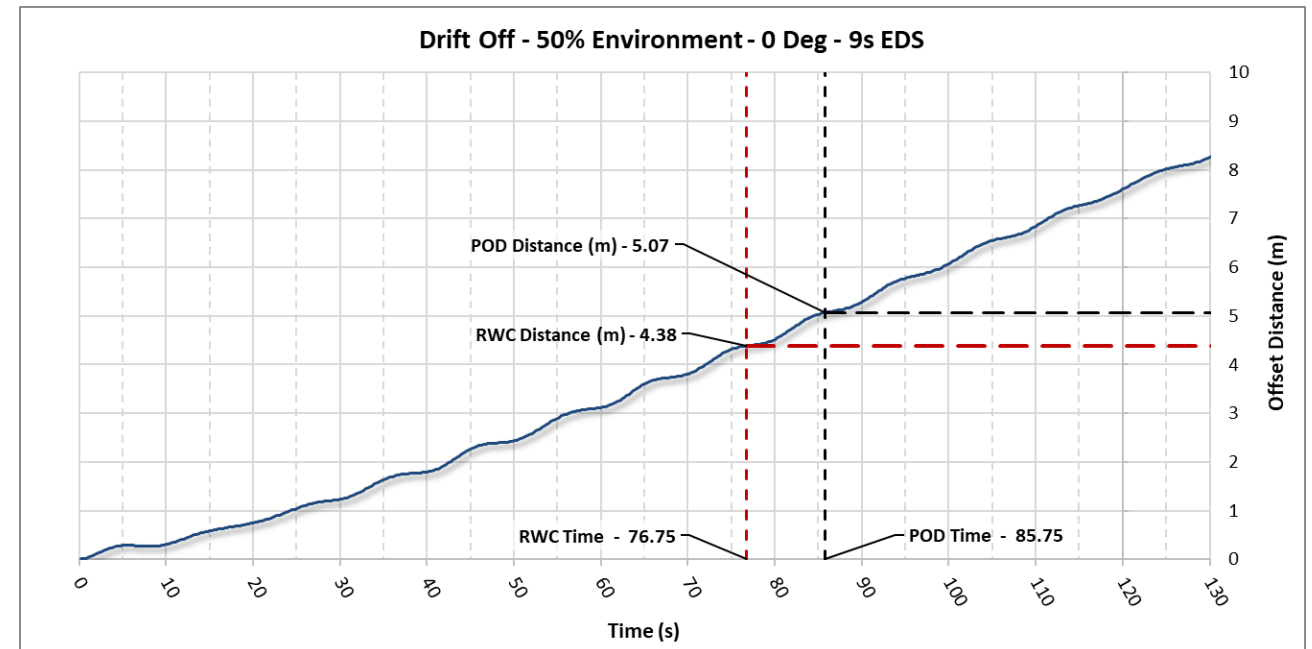
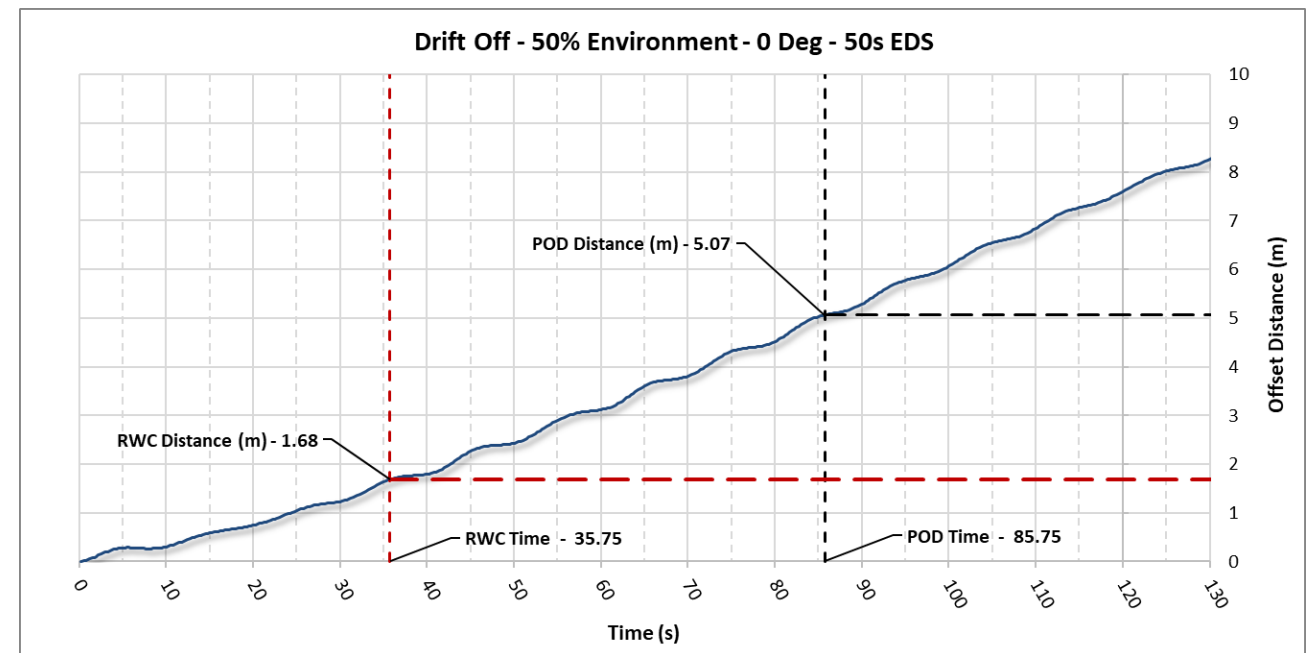
Drift-Off (PRELIMINARY)

'Standard' BOP Stack

■ Reduced Environment:

(50% of 95% Non-Exceedence)

- Wind Wave: $H_s = 1.5\text{m}$, $T_p = 8.8\text{s}$
- Wind: $V_{\text{wind}} = 5.72\text{m/s}$
- Current (Surface): $V_{\text{curr}} = 0.41\text{m/s}$





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Results

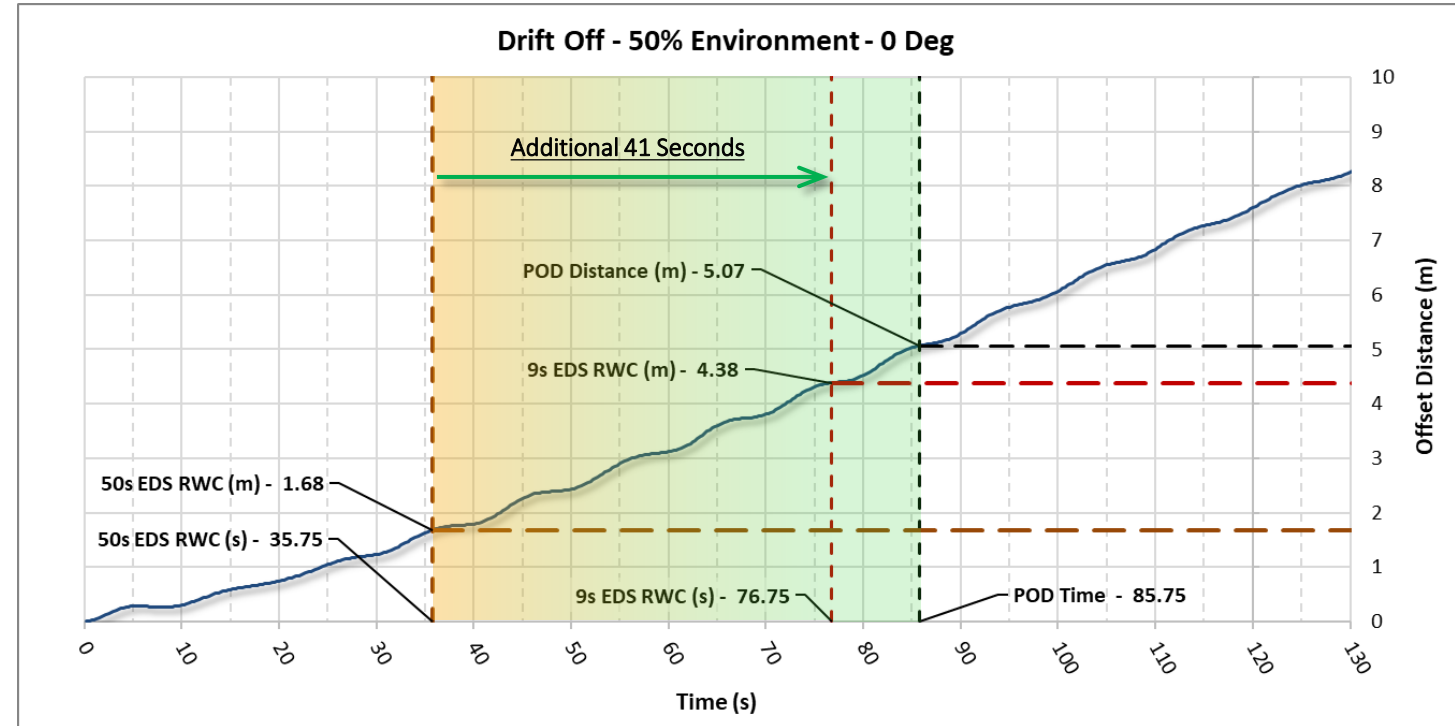
Drift-Off (PRELIMINARY)

'Standard' BOP Stack

- Reduced Environment (50% of 95% N.E.)
- 0 Degree Heading Results:

Parameter	Unit	50s EDS	9s EDS
Limiting Criteria	-	BAP/BOP Connector	BAP/BOP Connector
POD Time	s	85.7	85.7
POD Distance	m	5.1	5.1
POD % W.D.	%	4.73%	4.73%
RWC Time	s	35.7	76.7
RWC Distance	m	1.7	4.4
RWC % W.D.	%	1.57%	4.10%

- Time to RWC increased by 41s (115% ↑)
- Distance to RWC increased by 2.7m (160% ↑)





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Results

Drift-Off (PRELIMINARY)

Standard BOP Stack
(BAP Limit Removed)



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Results

Drift-Off (PRELIMINARY)

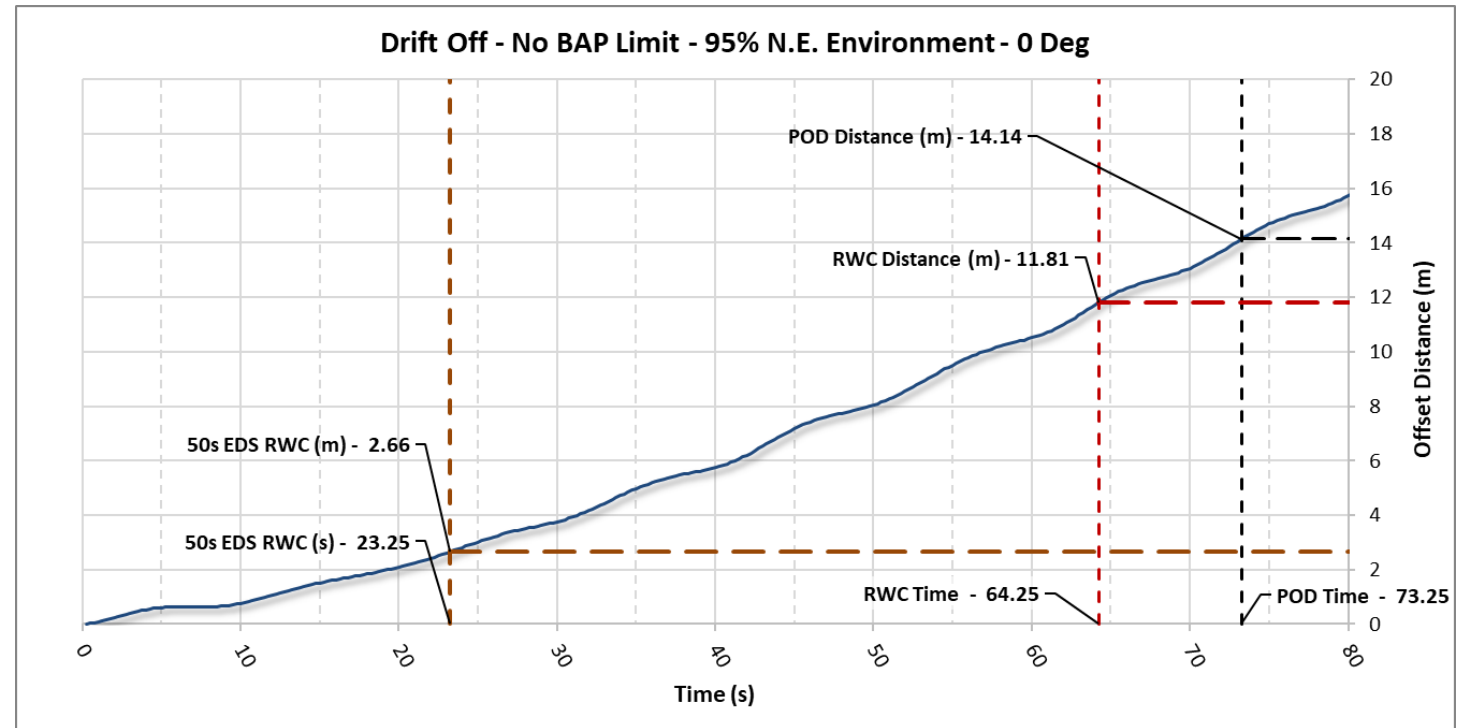
'Standard' BOP Stack

BAP Limit removed

- Environment: 95% Non-Exceedence, 0 Deg

Parameter	Unit	50s EDS	9s EDS
Limiting Criteria	-	UFJ Limit	UFJ Limit
POD Time	s	73.2	73.2
POD Distance	m	14.1	14.1
POD % W.D.	%	13.2%	13.2%
RWC Time	s	23.2	64.2
RWC Distance	m	2.7	11.8
RWC % W.D.	%	2.5%	11.0%

- Upper FJ Angle Limit (6 deg) reached first
- 9s EDS increases RWC Distance by 8.1m





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Results

Drift-Off (PRELIMINARY)

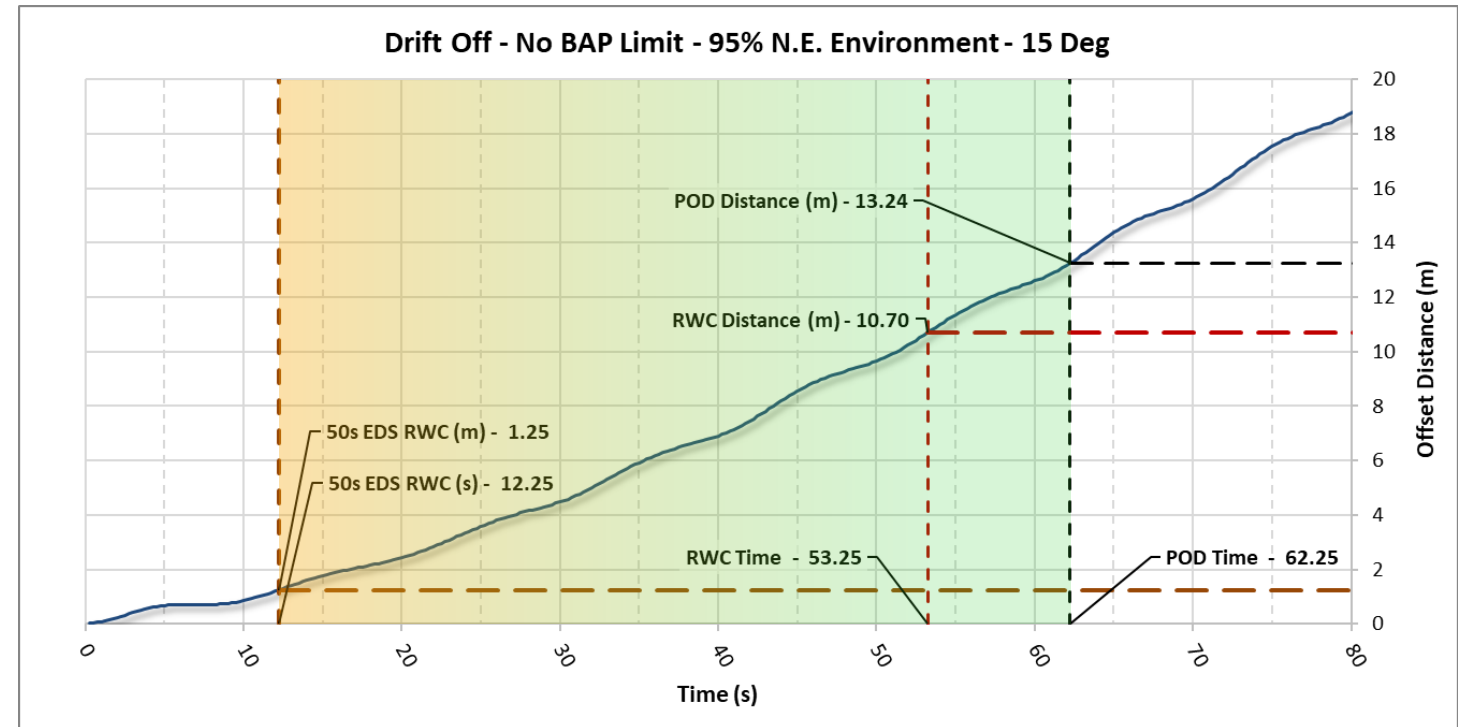
'Standard' BOP Stack

BAP Limit removed

- Environment: 95% Non-Exceedence, 15 Deg

Parameter	Unit	50s EDS	9s EDS
Limiting Criteria	-	UFJ Limit	UFJ Limit
POD Time	s	62.2	62.2
POD Distance	m	13.2	13.2
POD % W.D.	%	12.4%	12.4%
RWC Time	s	12.2	53.2
RWC Distance	m	1.2	10.7
RWC % W.D.	%	1.2%	10.0%

- Upper FJ Angle Limit (6 deg) reached first
- 9s EDS increases RWC Distance by 8.8m





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Results

Drift-Off (PRELIMINARY)

‘L-LITE’ BOP Stack



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Results

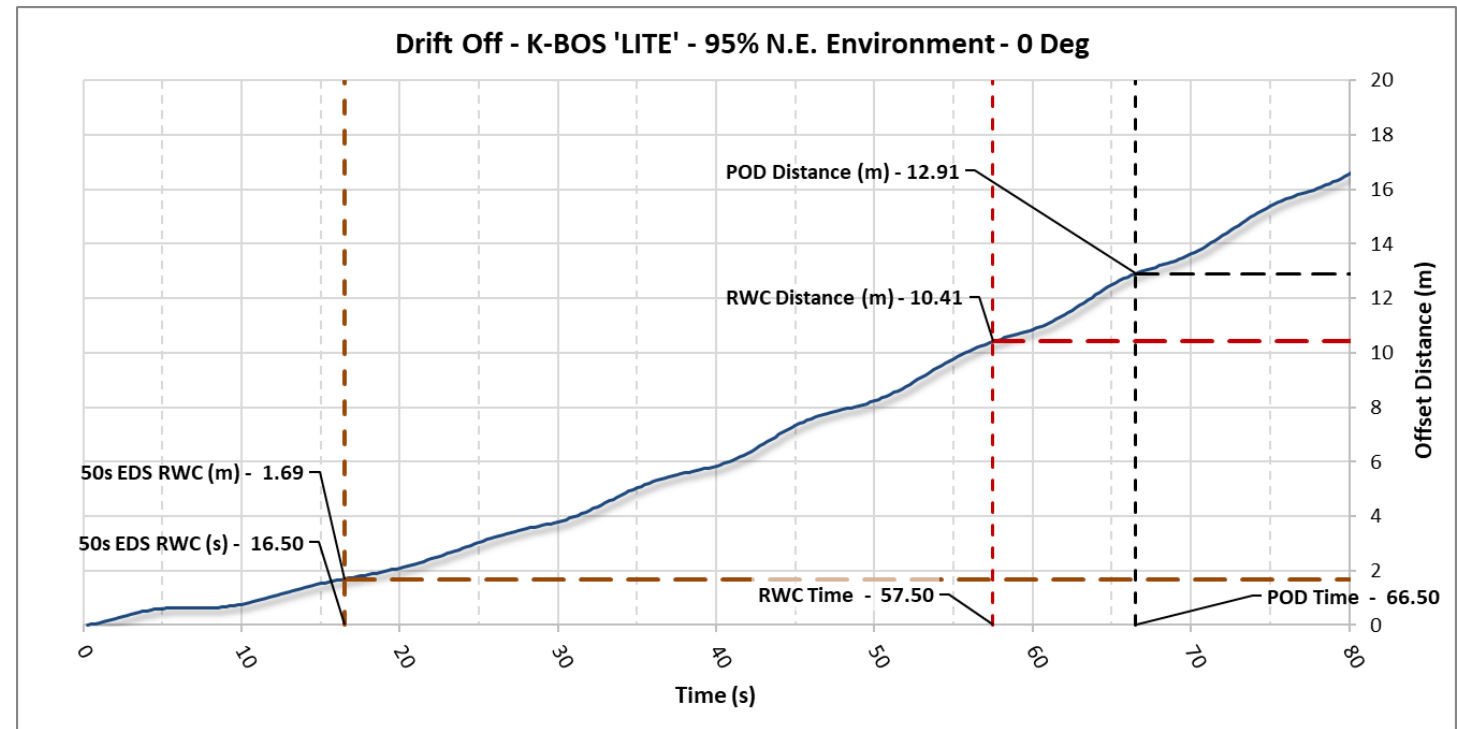
Drift-Off (PRELIMINARY)

'L-LITE' BOP Stack

- Environment: 95% Non-Exceedence
- 0 Degree Heading Results:

Parameter	Unit	50s EDS	9s EDS
Limiting Criteria	-	LFJ Limit	LFJ Limit
POD Time	s	66.50	66.50
POD Distance	m	12.91	12.91
POD % W.D.	%	12.07%	12.07%
RWC Time	s	16.50	57.50
RWC Distance	m	1.69	10.41
RWC % W.D.	%	1.58%	9.73%

- Lower FJ Angle Limit (6 deg) reached first
- 9s EDS increases RWC Distance by 8.7m





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Results

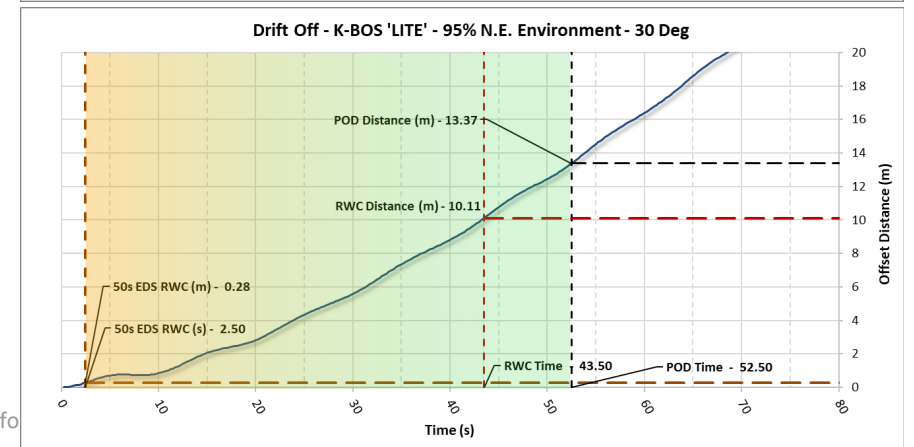
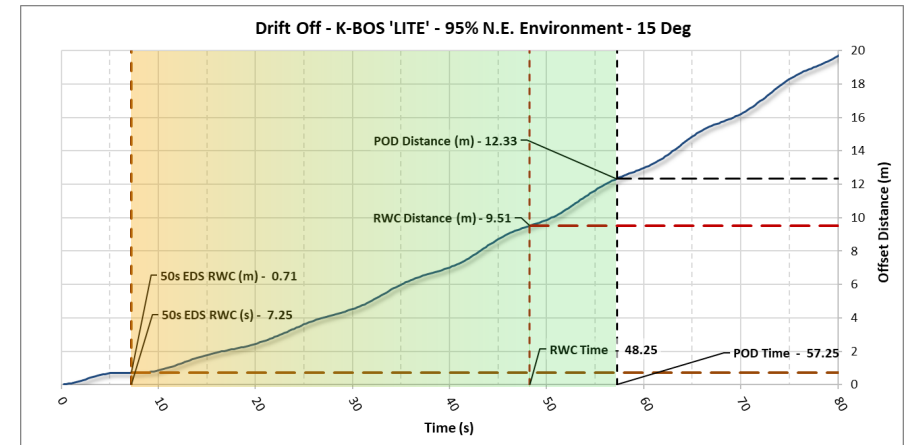
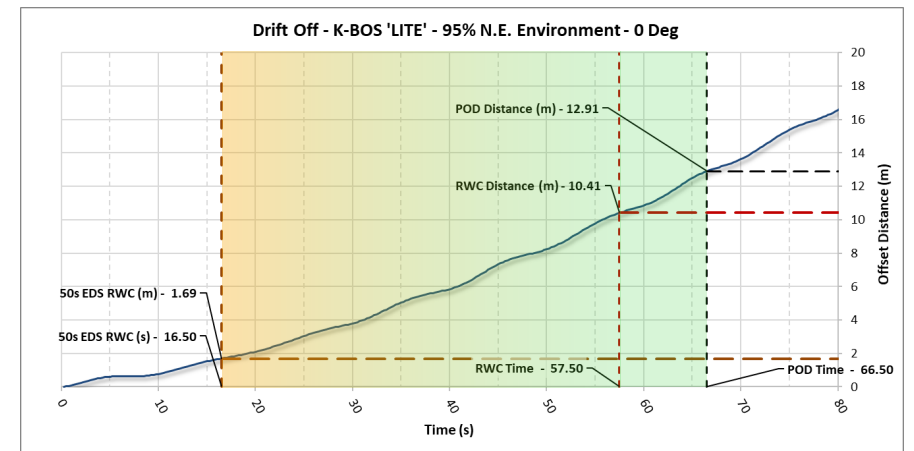
Drift-Off (PRELIMINARY)

'L-LITE' BOP Stack

- Environment: 95% Non-Exceedence
- 50s and 9s EDS Results:

Parameter	Unit	0 Deg		15 Deg		30 Deg	
Limiting Criteria	-	LFJ Limit		LFJ Limit		UFJ Limit	
POD Time	s	66.5		57.2		52.5	
POD Distance	m	12.9		12.3		13.4	
POD % W.D.	%	12.1		11.5%		12.5%	
EDS Time	s	50	9	50	9	50	9
RWC Time	s	16.5	57.5	7.2	48.2	2.5	43.5
RWC Distance	m	1.7	10.4	0.7	9.5	0.3	10.1
RWC % W.D.	%	1.6%	9.7%	0.7%	8.9%	0.3%	9.5%

- Lower FJ Angle Limit (6 deg) reached first generally
 - Upper FJ for 30deg vessel heading
- 9s EDS increases RWC Distance significantly (>8.0m)





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Results

Drift-Off (PRELIMINARY)

Standard vs. 'L-LITE' BOP Stack

Results

Drift-Off (PRELIMINARY)

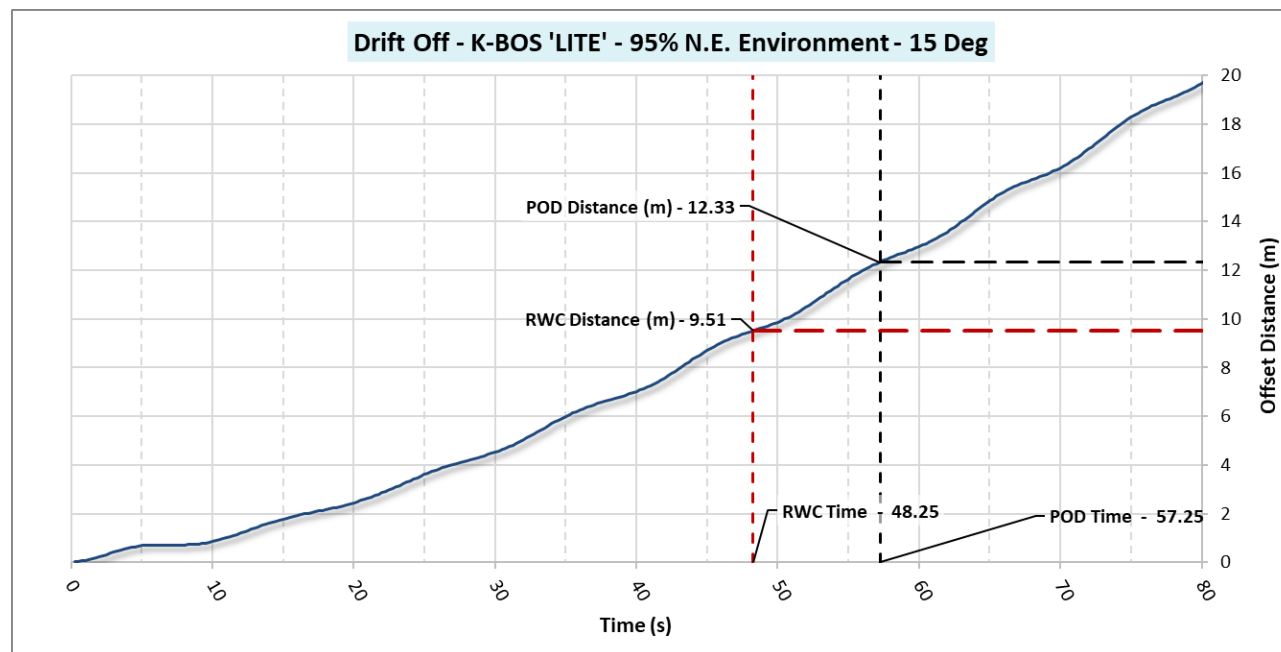
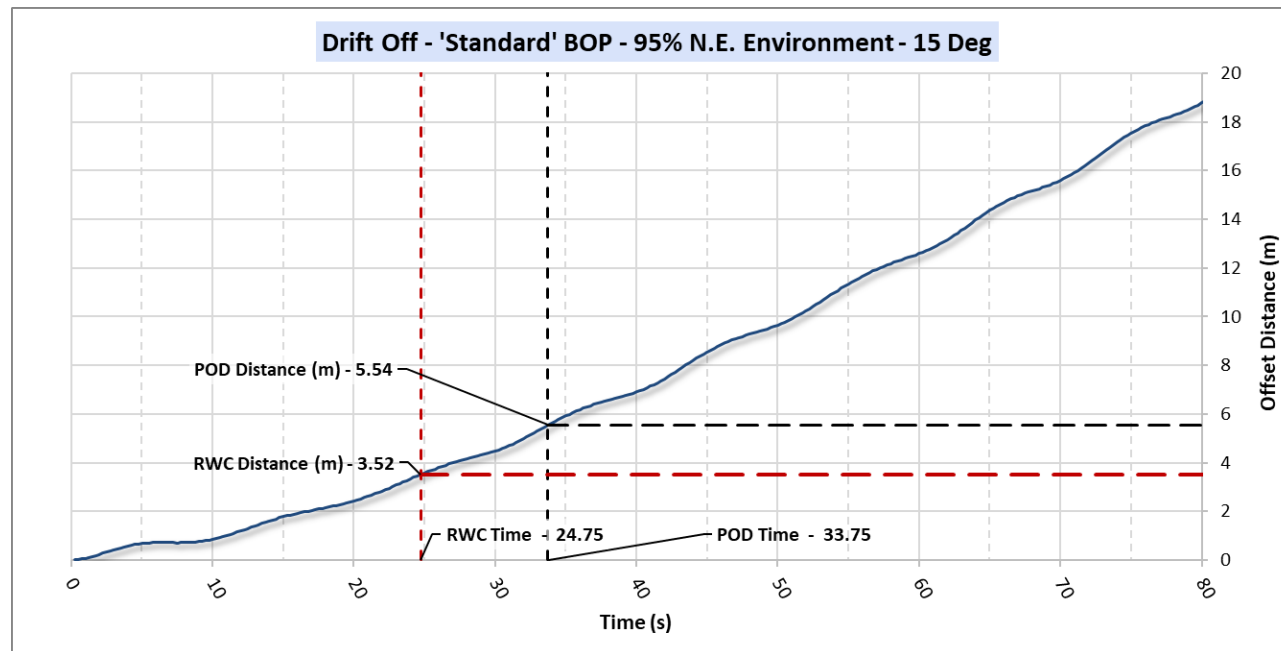
'Standard' vs 'L-LITE' BOP Stack

400t BOP Stack vs. 80t L-LITE BOP

- Environment: 95% Non-Exceedence – 15deg
- EDS = 9s

Parameter	Unit	Standard	L-LITE
Limiting Criteria	-	BAP/BOP Connector	LFJ Limit
POD Time	s	33.7	57.2
POD Distance	m	5.5	12.3
POD % W.D.	%	5.18%	11.5%
RWC Time	s	24.7	48.2
RWC Distance	m	3.5	9.5
RWC % W.D.	%	3.3%	8.9%

- Limiting component: BAP Connector → Lower FJ
- POD Distance increases from 5.5 to 12.3m (122% ↑)
- RWC Distance increases from 3.5 to 9.5m (170% ↑)



Results

Drift-Off (PRELIMINARY)

Drift-Off Summary Table



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Results

Drift-Off (PRELIMINARY)

Drift-Off Summary

- Environment: 95% Non-Exceedence – 15deg

Parameter	Unit	Base Case		BAP Limit Removed		L-LITE BOP Stack <i>(incl. BAP Limit)</i>	
EDS Time	-	50s	9s	50s	9s	50s	9s
Limiting Criteria	-	BAP/BOP Connector	BAP/BOP Connector	UFJ Limit	UFJ Limit	LFJ Limit	LFJ Limit
POD Time	s	33.7		62.2		57.2	
POD Distance	m	5.5		13.2		12.3	
POD % W.D.	%	5.2%		12.4%		11.5%	
RWC Time	s	0.0 (No RWC)	24.7	12.2	53.2	7.2	48.2
RWC Distance	m	0.0 (No RWC)	3.5	1.2	10.7	0.7	9.5
RWC % W.D.	%	0.0% (No RWC)	3.3%	1.2%	10.0%	0.7%	8.9%

- L-LITE BOP Stack results in slightly higher Lower FJ angle utilization, but significantly reduces wellhead bending loads



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Results

Operability (PRELIMINARY)

Operability Results



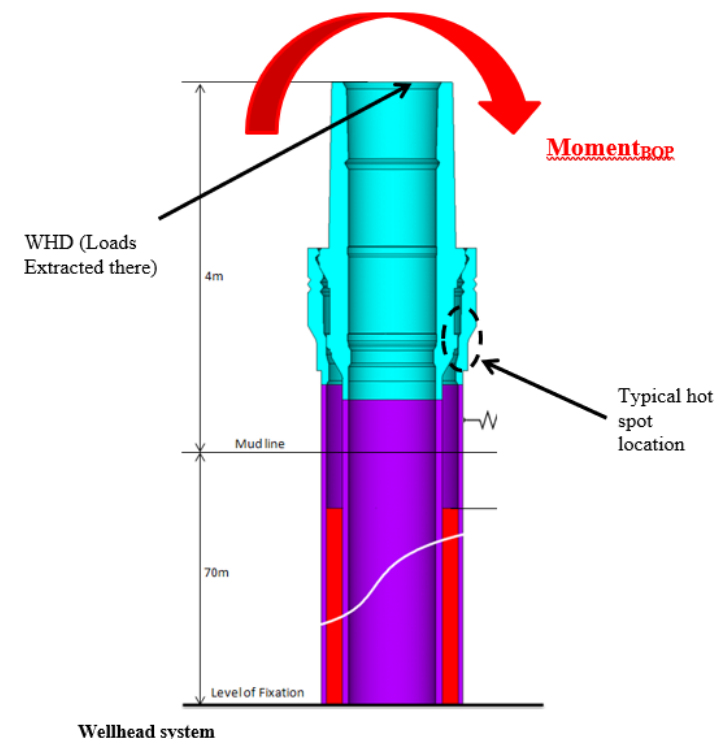
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Results Wellhead Fatigue (WHF)

Input

- Santos Basin Hs-Tp wave scatter for irregular waves including probabilities
- Wave 15 deg versus bow
- Rig type: drillship (DSME12000)
- Water depth: 107m
- Moment cycles are extracted at the top of the wellhead, as input to rainflow counting and fatigue damage calculation
- Using a typical MN curve (Wellhead Bending moment versus cycles)
- Compare relative fatigue damage for LITE BOP versus STANDARD BOP stack

Hs [m]	ALL YEAR - Hs-Tp Scatter Diagram for Santos Basin																					Probability [%]
	Tp [s]																					
	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
0.5	0.001	0.008	0.033	0.241	0.571	0.314	0.139	0.078	0.069	0.048	0.031	0.015	0.014	0.005	0.001	0.002	0.003	0.003	0.001			1.6
1.5	0.001	0.122	1.335	5.848	12.92	12.75	7.573	5.407	3.628	2.015	0.904	0.435	0.226	0.086	0.041	0.024	0.010	0.006	0.001			53.3
2.5		0.000	0.098	2.420	7.110	6.980	4.515	4.652	5.031	3.548	1.613	0.601	0.263	0.060	0.021	0.008	0.006	0.005	0.001	0.001	0.001	36.9
3.5				0.007	0.414	1.252	0.903	0.917	0.893	0.963	0.705	0.348	0.139	0.028	0.010	0.003	0.001	0.000				6.6
4.5					0.001	0.041	0.136	0.213	0.229	0.208	0.211	0.097	0.082	0.025	0.005	0.001	0.001	0.000				1.2
5.5						0.000	0.006	0.027	0.044	0.041	0.054	0.049	0.013	0.009	0.005	0.003	0.001					0.3
6.5								0.001	0.007	0.008	0.015	0.017	0.007	0.000	0.002	0.001						0.1
7.5									0.001	0.001	0.001	0.004	0.002	0.001	0.000							0.0
	0.001	0.131	1.466	8.516	21.02	21.34	13.27	11.29	9.90	6.832	3.534	1.566	0.746	0.216	0.085	0.042	0.021	0.013	0.003	0.001	0.001	100.0





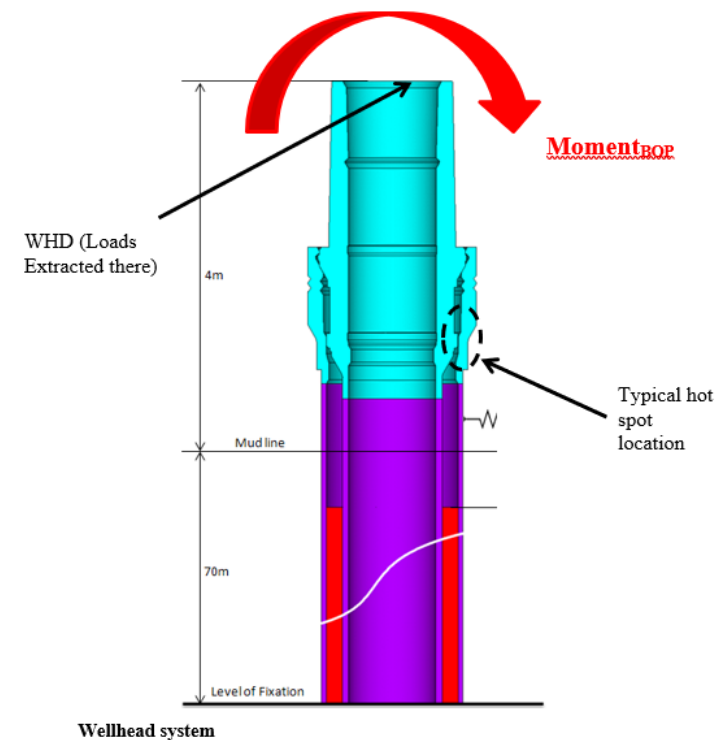
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Results Wellhead Fatigue (WHF)

Results - Max Bending Moment

- Max Bending Moment
- L-LITE BOP vs. STANDARD BOP
- Max Moment around half for most of the seastates (similar trend for Moment Standard deviation)
- Except for very low wave periods

Hs [m]	L-LITE BOP Max Moment versus STANDARD BOP (Moment LITE / Moment Standard -1) in %																					Probability [%]
	Tp [s]																					
	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
0.5	43%	-12%	-18%	-44%	-41%	-35%	-39%	-39%	-42%	-43%	-44%	-45%	-44%	-43%	-46%	-45%	-46%	-46%	-47%			1.6
1.5	71%	17%	-7%	-40%	-41%	-38%	-36%	-41%	-45%	-46%	-46%	-48%	-47%	-45%	-51%	-50%	-49%	-51%	-51%			53.3
2.5		30%	-11%	-35%	-36%	-38%	-36%	-41%	-45%	-48%	-47%	-48%	-46%	-46%	-51%	-51%	-49%	-52%	-52%	-50%	-54%	36.9
3.5				-32%	-30%	-38%	-39%	-42%	-46%	-48%	-46%	-48%	-48%	-49%	-52%	-52%	-51%	-53%				6.6
4.5					-25%	-39%	-43%	-43%	-48%	-49%	-46%	-47%	-49%	-51%	-53%	-53%	-52%	-54%				1.2
5.5						-42%	-45%	-44%	-50%	-50%	-46%	-47%	-51%	-53%	-54%	-55%	-53%					0.3
6.5								-46%	-51%	-51%	-46%	-47%	-52%	-54%	-55%	-56%						0.1
7.5									-52%	-50%	-45%	-47%	-52%	-54%	-56%							0.0
Prob [%]	0.00	0.13	1.47	8.52	21.02	21.34	13.27	11.29	9.90	6.83	3.53	1.57	0.75	0.22	0.08	0.04	0.02	0.01	0.00	0.00	0.00	





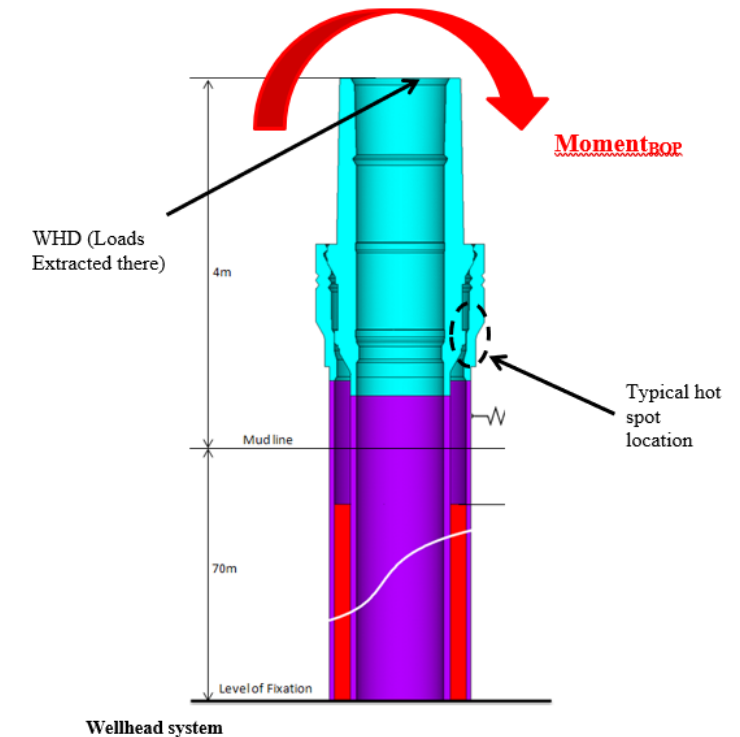
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Results Wellhead Fatigue (WHF)

Results - Max Bending Moment

- Max Bending Moment
- STANDARD BOP

Hs [m]	STANDARD BOP - Max bending Moment at Wellhead																					Probability [%]
	Tp [s]																					
	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
0.5	151	157	150	194	173	154	158	166	160	157	159	150	136	127	133	135	137	137	135			1.6
1.5	324	300	280	401	378	345	344	377	363	330	318	291	248	227	245	250	249	257	248			53.3
2.5		432	401	543	522	534	566	607	599	534	476	421	347	327	358	360	361	377	362	319	309	36.9
3.5				667	639	721	815	844	832	738	639	556	469	455	474	467	476	497				6.6
4.5					737	894	1054	1042	1051	940	808	689	618	602	593	585	598	623				1.2
5.5						1068	1276	1247	1249	1131	971	828	769	750	755	712	728					0.3
6.5								1454	1432	1312	1118	962	902	896	914	847						0.1
7.5									1578	1471	1261	1097	1003	1051	1075							0.0
Prob [%]	0.00	0.13	1.47	8.52	21.02	21.34	13.27	11.29	9.90	6.83	3.53	1.57	0.75	0.22	0.08	0.04	0.02	0.01	0.00	0.00	0.00	





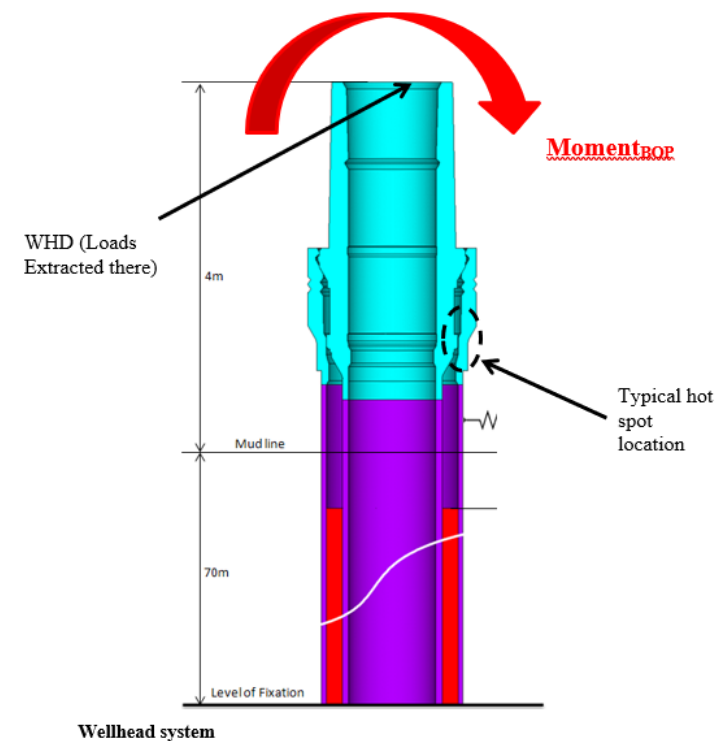
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Results Wellhead Fatigue (WHF)

Results - Max Bending Moment

- Max Bending Moment
- L-LITE BOP

Hs [m]	L-LITE BOP - Max bending Moment at Wellhead																					Probability [%]
	Tp [s]																					
	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
0.5	215	138	123	109	103	101	96	101	93	90	88	82	76	73	73	74	74	73	71			1.6
1.5	556	352	260	239	225	214	220	222	199	179	172	151	132	125	121	126	128	126	121			53.3
2.5		560	357	351	336	330	364	355	329	280	254	219	186	178	174	176	183	179	175	160	143	36.9
3.5				451	449	445	500	487	450	386	344	287	244	232	227	222	236	233				6.6
4.5					553	543	604	595	542	477	436	363	314	292	282	272	289	290				1.2
5.5						624	699	693	622	561	522	440	375	354	345	323	344					0.3
6.5								786	696	641	609	513	429	417	410	374						0.1
7.5									762	735	692	586	479	481	477							0.0
Prob [%]	0.00	0.13	1.47	8.52	21.02	21.34	13.27	11.29	9.90	6.83	3.53	1.57	0.75	0.22	0.08	0.04	0.02	0.01	0.00	0.00	0.00	





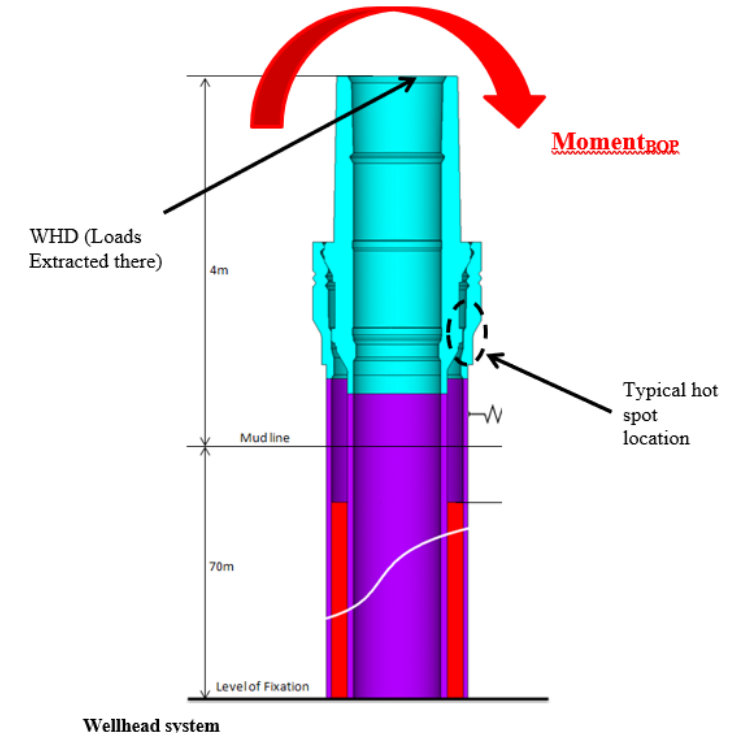
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Results Wellhead Fatigue (WHF)

Results – Fatigue

- Fatigue Damage calculated for L-LITE BOP vs. STANDARD BOP
- Probabilities for Santos Basin
- Moment cycles are extracted at the top of the wellhead, as input to rainflow counting and fatigue damage calculation
- Using a typical MN curve (Wellhead Bending moment versus cycles). Slope of $m=4$ or 5 (slope change at $1e+06$ cycles)
- Relative fatigue damage is 13 times higher for the STANDARD BOP (significant reduction with L-LITE for high wave periods)
- Similar or more damage with L-LITE BOP for very low periods (associated with low probability)

Hs [m]	Relative Fatigue Damage - STANDARD BOP / L-LITE BOP, in total = 13 times more damage)																					Probability [%]
	Tp [s]																					
	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
0.5	0.050	0.28	0.73	18	10	6	7	12	17	17	17	18	22	27	39	51	67	81	85			1.6
1.5	0.092	0.33	0.88	11	11	7	7	11	16	18	19	16	21	26	34	48	64	76	80			53.3
2.5		0.33	0.87	7	10	9	9	11	17	19	22	18	22	29	36	49	68	80	86	79	84	36.9
3.5				5	9	12	12	12	16	19	22	19	25	34	40	54	73	86				6.6
4.5					8	17	17	14	17	19	22	22	27	37	44	60	78	89				1.2
5.5						21	22	17	18	19	22	23	29	39	45	63	81					0.3
6.5								21	20	19	21	23	30	39	44	64						0.1
7.5									21	20	20	23	30	39	42							0.0
Prob [%]	0.00	0.13	1.47	8.52	21.02	21.34	13.27	11.29	9.90	6.83	3.53	1.57	0.75	0.22	0.08	0.04	0.02	0.01	0.00	0.00	0.00	





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References

Reference Documents:

1. Email from Petrobras (Magno Almeida da Silva), subject “RES: [EXTERNAL]Re: K-BOS Follow Up - 9-second EDS”, May 2, 2022



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