Uncertainties in Mooring Analysis, Design, and Installation

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October 14 2020

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CONTENTS

A Analysis: Newtonian and Non-Newtonian Time Domain Programs (4 slides)

Results from ten commercially available time domain mooring analysis programs are compared in the SpinMoor™ and SpinTransit™ Studies. All analyses were performed by the software vendor or vendor appointed agents.

Surprisingly the majority of the time domain programs contain flawed implementations of Newton's Laws.

B Design: Differences Resulting from the use of Newtonian and Non-Newtonian Programs (5 slides)

To demonstrate the impact on the design of a passive turret moored vessel in squall conditions Newtonian and Non-Newtonian time domain solvers are compared for,

1. An individual simulation, i.e. for an initial vessel heading and squall direction
2. All 100-year return period load cases and squall realization, for intact mooring and maximum vessel draft
3. All intact cases for three vessel drafts and return periods between 1 and 1,000 years

C Installation: Pretensions, Load Sharing, and Impact on Strength and Fatigue Safety Factors (3 slides)

API RP 2SK Draft 4th ed. new requirements for the as-installed mooring to satisfy code criteria are reviewed
An example showing the impact of poor load sharing on strength and fatigue factors of safety is presented

A) Time Domain Mooring Analysis: Newtonian and Non-Newtonian Programs

In the SpinMoor™ and follow on SpinTransit™ Studies, organized by SeaSoft® Systems and ExxonMobil Upstream Integrated Solutions Company, vendors of time domain mooring programs submitted results for two highly simplified problems for which analytic solutions exist.

The SpinMoor and SpinTransit protocols call for:

1. A simple ship-shaped vessel
2. Elimination of all program and user specific “adjustable parameters”
3. Unambiguous initial conditions
4. A simple linear mooring, SpinMoor Study only
5. Simple constant lateral forcing, SpinMoor Study only

SpinMoor Participant Study: Revision 1 report was issued April 2020. Among the 10 commercially available time-domain mooring programs that simulated the SpinMoor,

- there exists a variability of order 100% (a factor of 2) in predicted offsets and turret loads,
- with estimates falling into two groups, one at each end of that range, and with an equal number of submissions, 5, in each group.

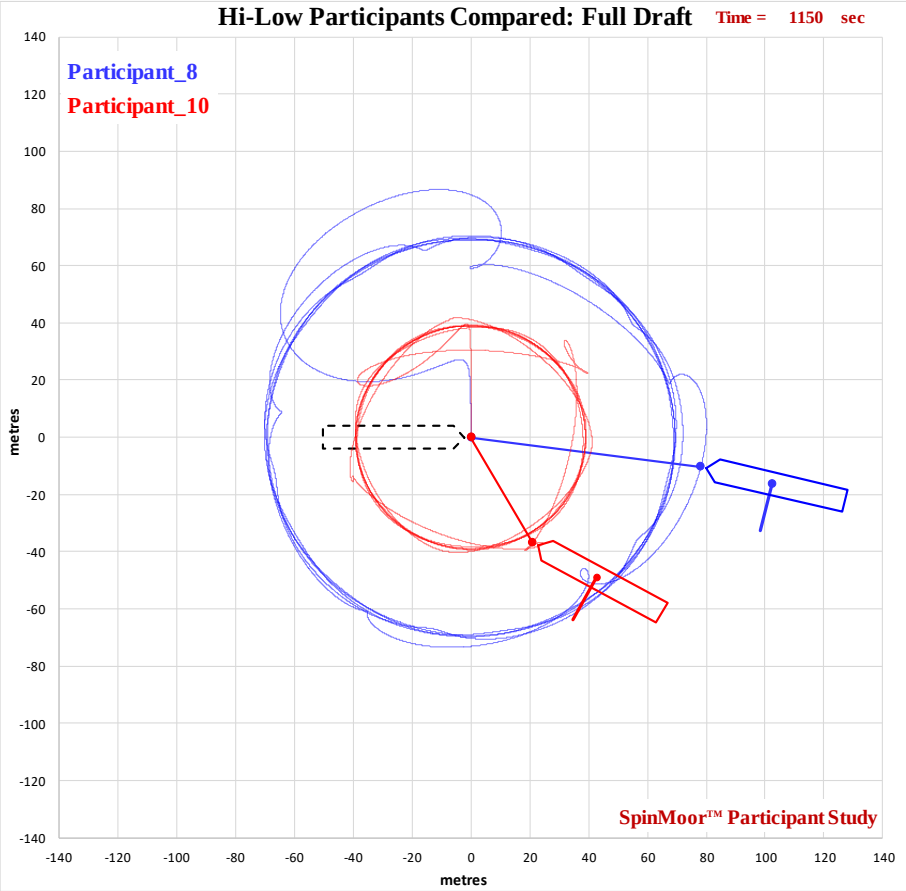
SpinTransit Participant Study, report was issued July 2020. Among the 9 commercially available time-domain mooring programs that simulated the SpinTransit,

- the 9 SpinTransit results fall into three qualitatively distinct groups, each group comprising 3 submissions.

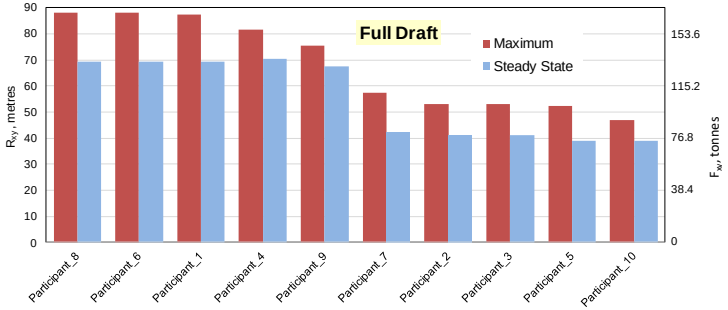
SpinMoor Participant Study: Revision 1, R.J. Hartman Ph.D. and D.W. Smith Ph.D., April 28, 2020.
https://www.seasoftsys.com/SpinMoor/SpinMoor_Study_Report_Rev1.pdf
SpinTransit Participant Study, R.J. Hartman Ph.D. and D.W. Smith Ph.D., July 9, 2020.
https://www.seasoftsys.com/SpinTransit/SpinTransit_Study_Report.pdf

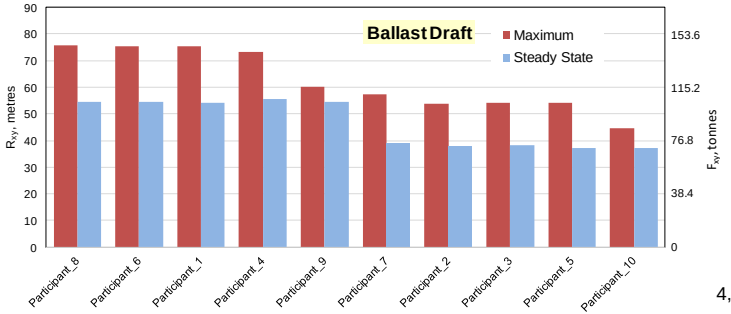
A) Time Domain Mooring Analysis: Newtonian and Non-Newtonian Programs

SpinMoor Participant Study



Participant Program	Full Draft						Ballast Draft					
	Maximum		*Steady State*				*Maximum*		*Steady State*			
	Rxy	Fxy	Rxy	Fxy	Period	Speed	Rxy	Fxy	Rxy	Fxy	Period	Speed
	m	tonne	m	tonne	sec	m/sec	m	tonne	m	tonne	sec	m/sec
Participant_8	88.0	169	69.3	133	1890	0.812	75.7	145	54.4	105	1127	1.278
Participant_6	87.9	169	69.2	133	1890	0.811	75.5	145	54.4	104	1127	1.278
Participant_1	87.5	168	69.2	133	1902	0.806	75.4	145	54.3	104	1128	1.277
Participant_4	81.5	156	70.4	135	2017	0.764	73.2	141	55.4	106	1132	1.278
Participant_9	75.6	145	67.4	129	2026	0.751	60.3	116	54.5	105	1127	1.279
Participant_7	57.5	110	42.3	81	1719	0.793	57.4	110	38.9	75	1051	1.277
Participant_2	53.0	102	41.2	79	1678	0.809	54.0	104	38.1	73	1048	1.277
Participant_3	52.9	102	41.2	79	1676	0.810	54.3	104	38.4	74	1049	1.278
Participant_5	52.5	101	39.1	75	1665	0.807	54.1	104	37.3	72	1043	1.278
Participant_10	46.8	90	39.0	75	1663	0.808	44.8	86	37.2	71	1043	1.277





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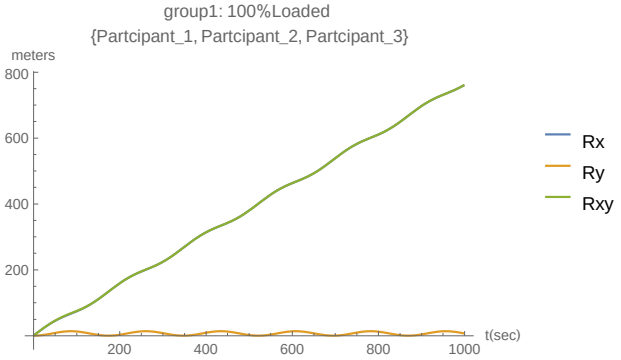
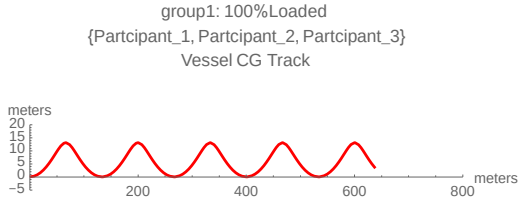
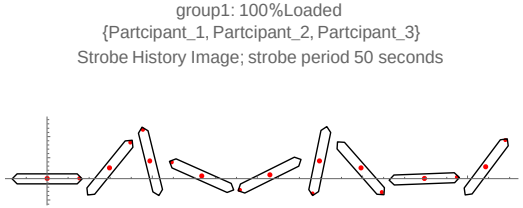
A) Time Domain Mooring Analysis: Newtonian and Non-Newtonian Programs

SpinTransit Participant Study

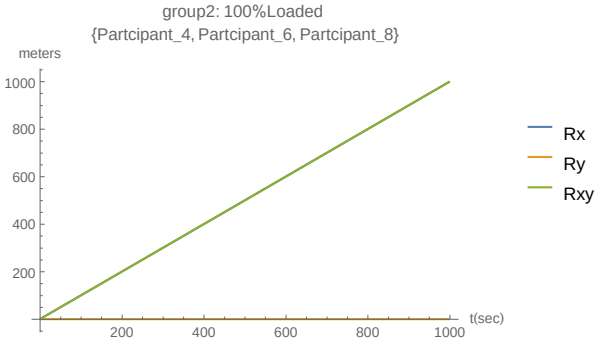
Newtonian Compliant Response: Group 1

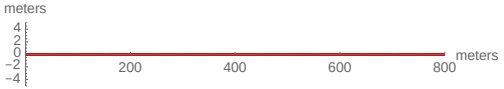


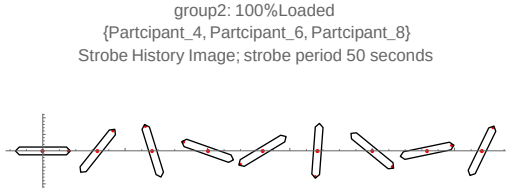




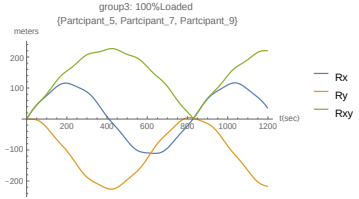
Newtonian Non-Compliant Response: Group 2

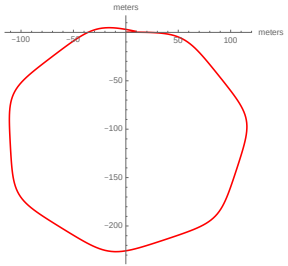


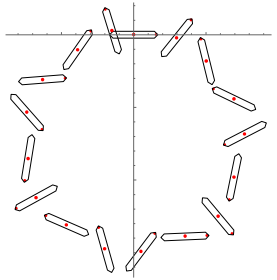




Newtonian Non-Compliant Response: Group 3





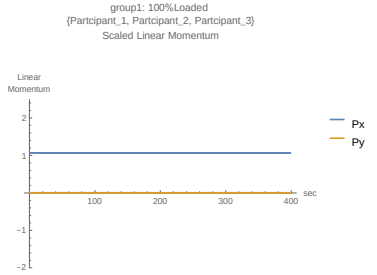


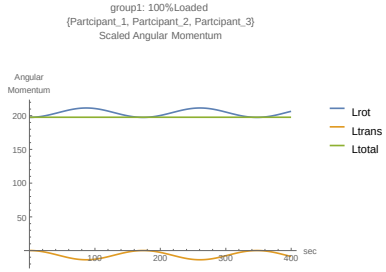
A Treatise on the Mathematical Theory of The Motion of Fluids, Horace Lamb, 1879; art. 117
Hydrodynamics, Sir Horace Lamb, Sixth Edition, pp. 174.

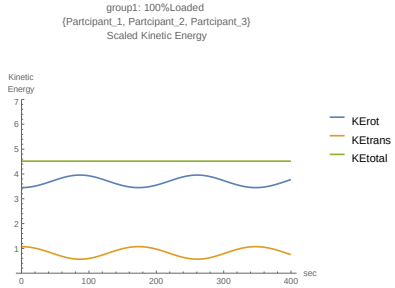
A) Time Domain Mooring Analysis: Newtonian and Non-Newtonian Programs

SpinTransit Participant Study

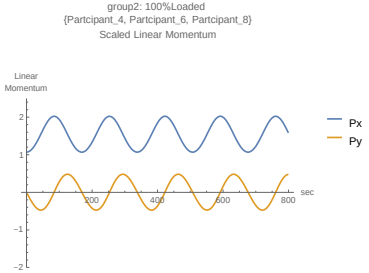
Newtonian Compliant Group 1 Momentum and Energy History

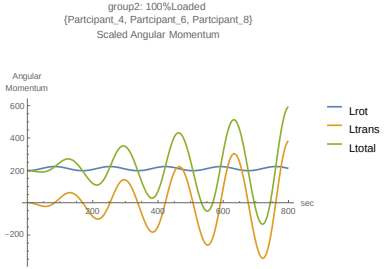


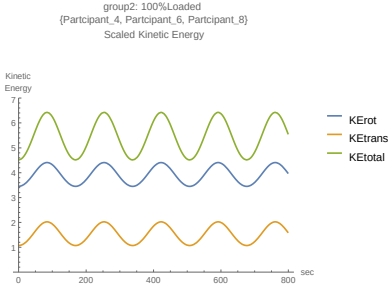




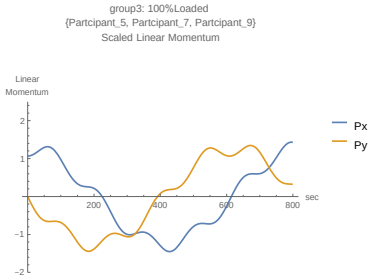
Newtonian Non-Compliant Group 2 Momentum and Energy History

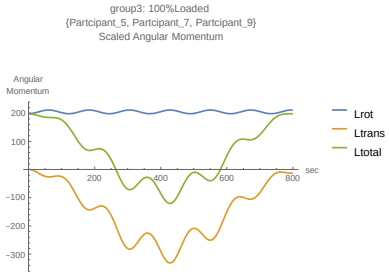


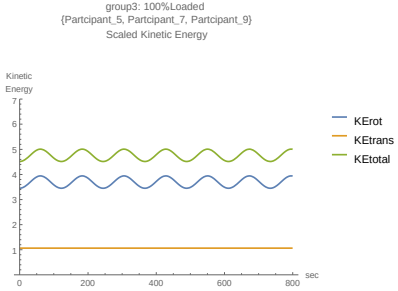




Newtonian Non-Compliant Group 3 Momentum and Energy History

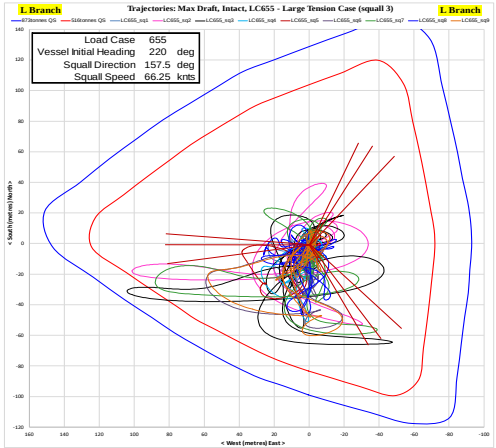


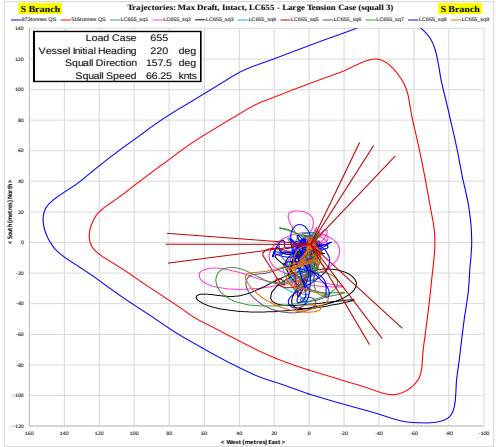


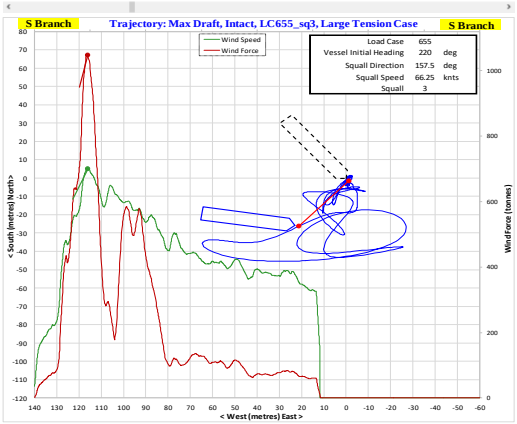


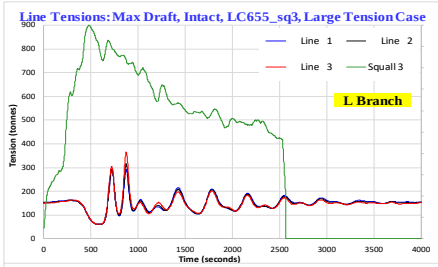
B) Differences in Design Values Resulting from Newtonian and Non-Newtonian Time Domain Solvers

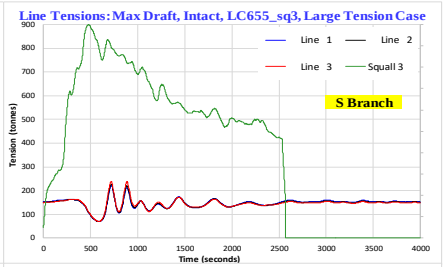
Squall Analysis Part 1: Comparisons for a Single Load Case: LC655 Maximum Tension

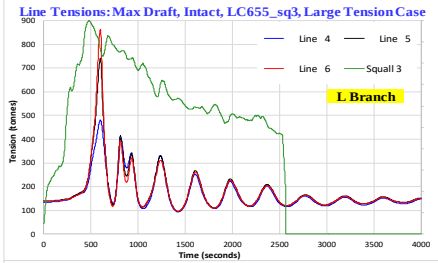


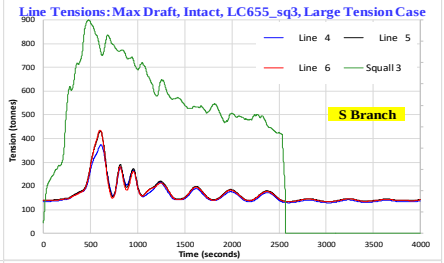


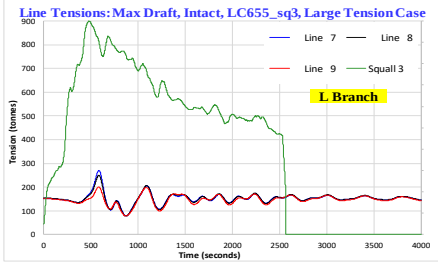


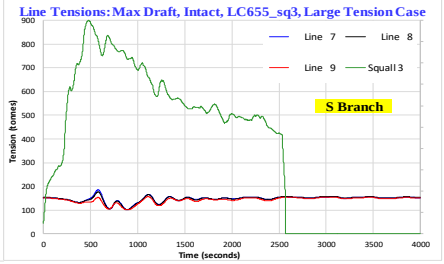








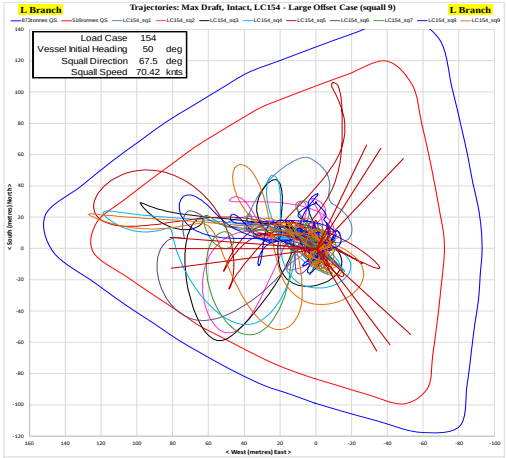


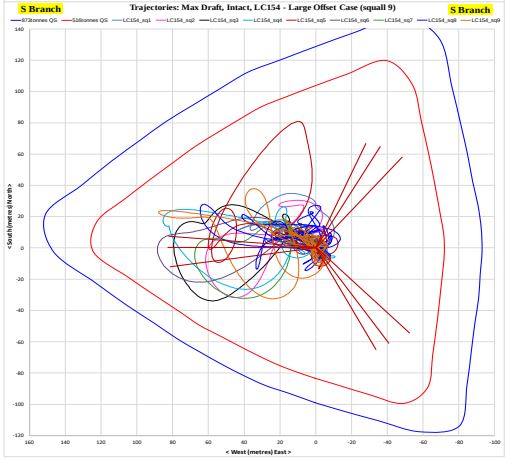


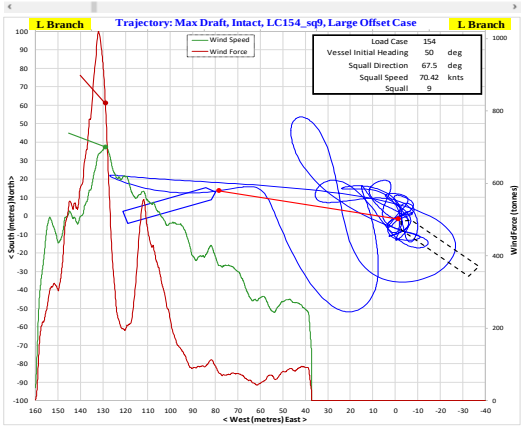
9 squall realizations for each Load Case, i.e. 9 simulations for each LC

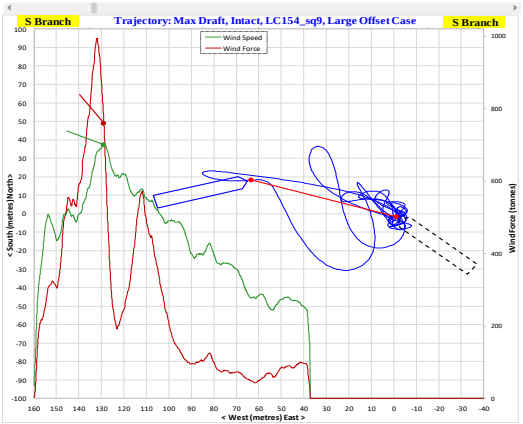
B) Differences in Design Values Resulting from Newtonian and Non-Newtonian Time Domain Solvers

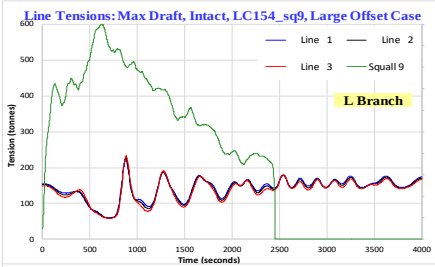
Squall Analysis Part 1: Comparisons for a Single Load Case: LC154 Maximum Offset

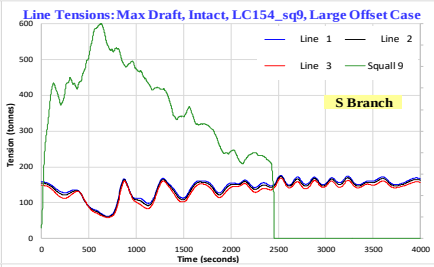


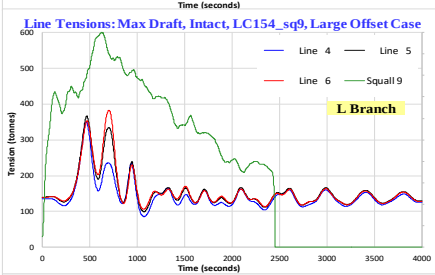


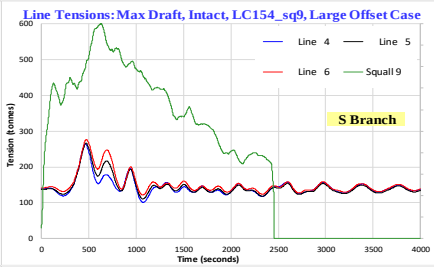


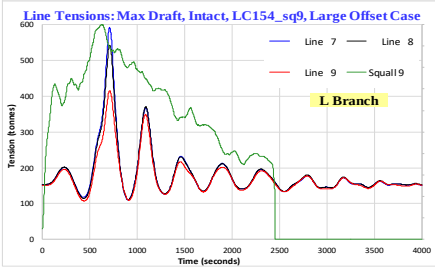


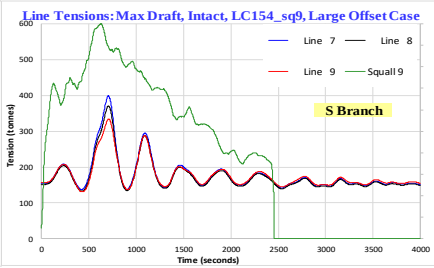












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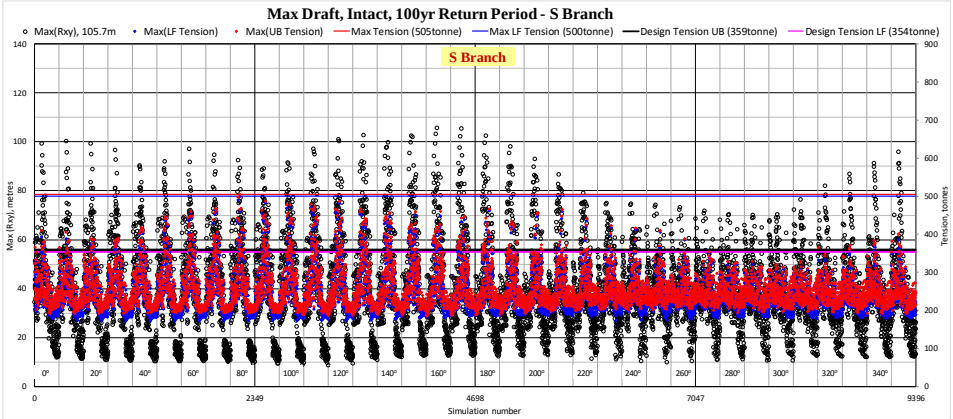
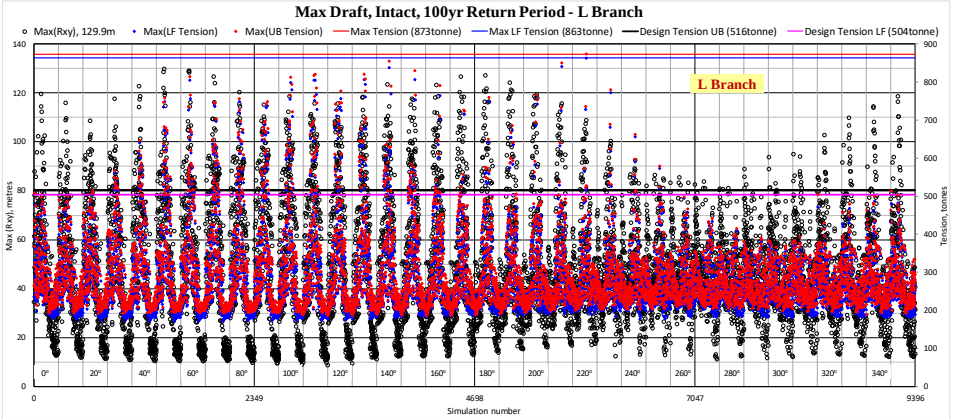
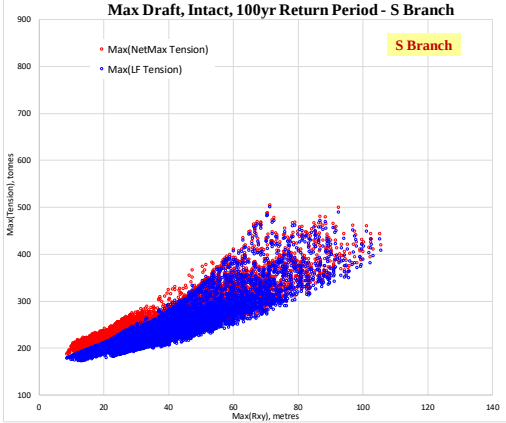
9 squall realizations for each Load Case, i.e. 9 simulations for each LC

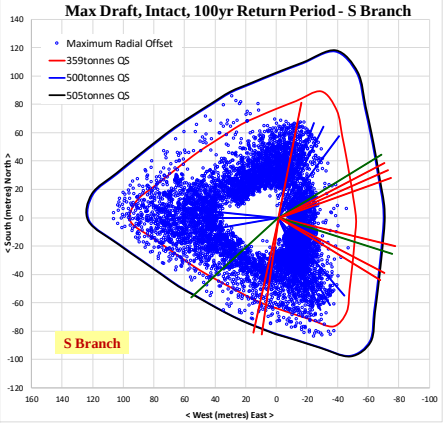
B) Differences in Design Values Resulting from Newtonian and Non-Newtonian Time Domain Solvers

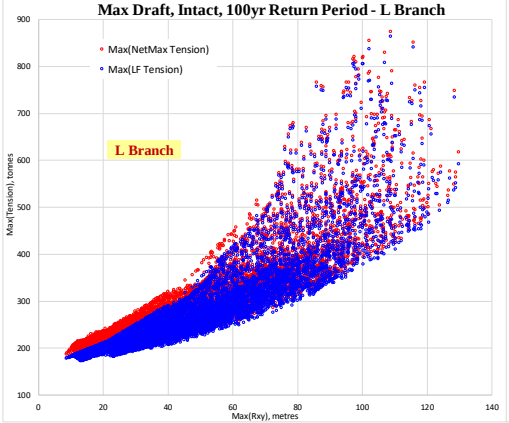
Squall Analysis Part 2: Comparisons of Intact Results for Maximum Draft and 100 Year Return Period Load Cases

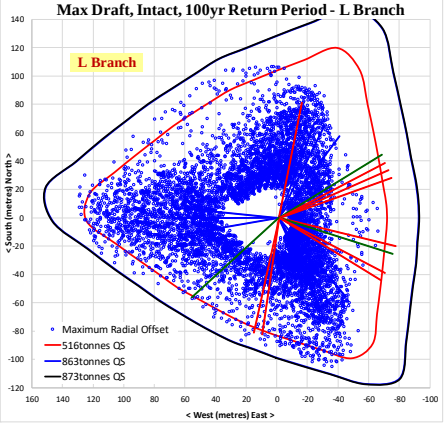










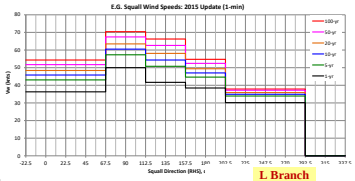


Maximum draft, intact mooring, 100-year return period: 1,044 Load Cases (29 squall directions x 36 initial vessel headings) and 9 squall realizations for each LC, i.e. 9,396 simulations for each return period and vessel and mooring condition.

ExxonMobil

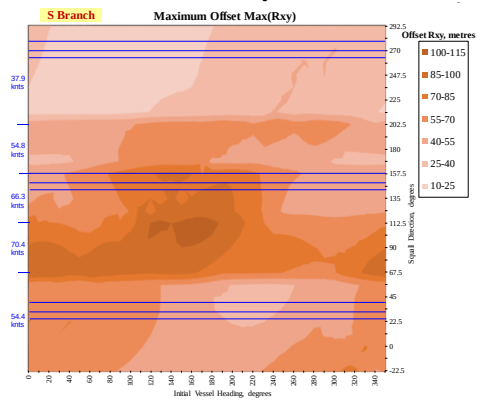
B) Differences in Design Values Resulting from Newtonian and Non-Newtonian Time Domain Solvers

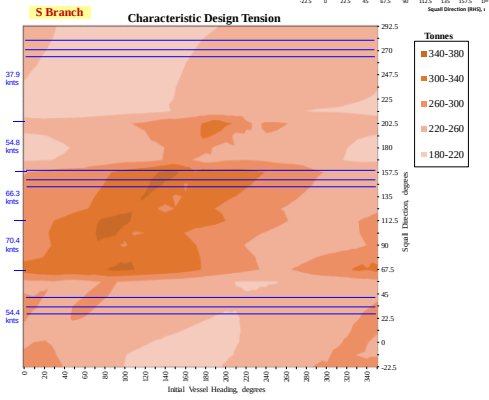
Squall Analysis Part 2: Comparisons of Intact Results for Maximum Draft and 100 Year Return Period Load Cases

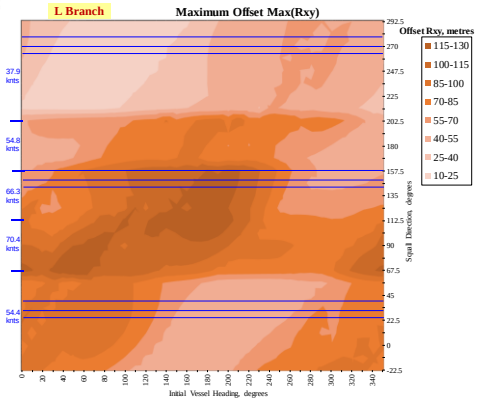


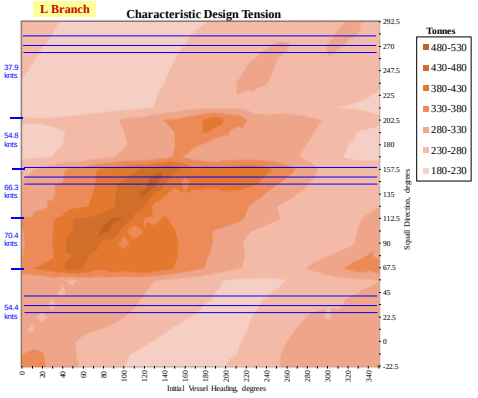
Max Draft, Intact, 100yr Return Period – S Branch; 9,396 Simulations

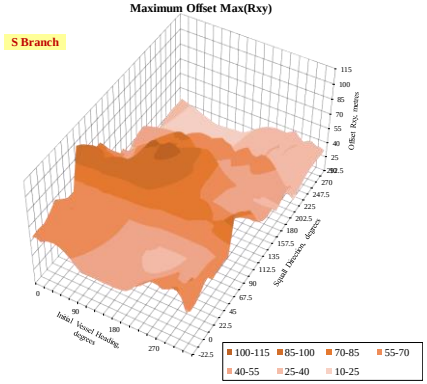
Max Draft, Intact, 100yr Return Period – L Branch; 9,396 Simulations

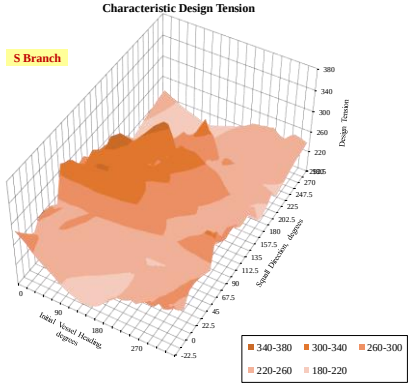


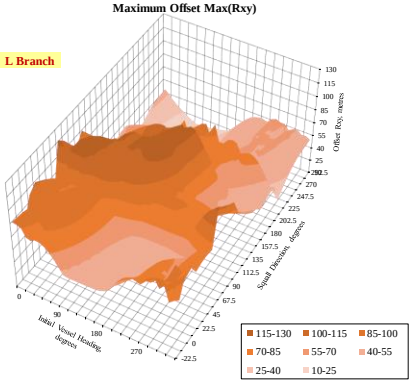


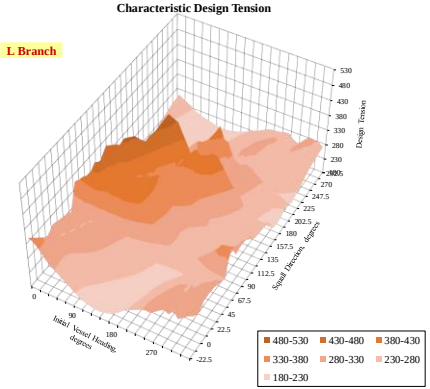












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B) Differences in Design Values Resulting from Newtonian and Non-Newtonian Time Domain Solvers

Squall Analysis Part 3: Comparisons of Intact Results for Three Drafts and 1 to 1,000 Year Return Period Load Cases

Max Draft, Intact: 1 to 1,000yr Return Periods - Small Branch

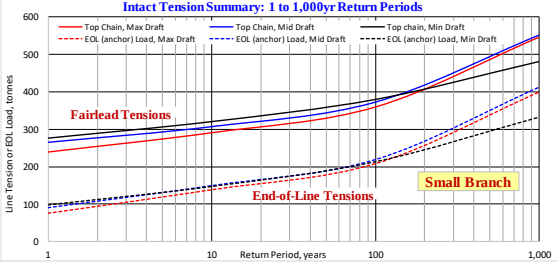
Return Period	Max. Turret Offset		Maximum Line Tensions						Maximum EOL (anchor) Load		Minimum Grounded Length	
	Tension Contour	Max all Rxy	Top Chain		SS-wire		Bottom Chain					
years	m	m	tonne	location	tonne	location	tonne	location	tonne	location	m	location
1	57	53	239	Line 8	211	Line 3	196	Line 3	75	Line 5	281	Line 6
10	76	79	290	Line 8	265	Line 5	251	Line 5	138	Line 5	209	Line 6
100	**95**	**106**	359	Line 5	334	Line 5	320	Line 5	208	Line 5	122	Line 6
1,000	131	131	545	Line 4	521	Line 4	507	Line 4	399	Line 4	0	Line 4 & 1 others

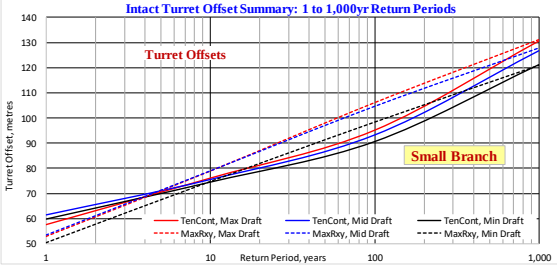
Mid Draft, Intact: 1 to 1,000yr Return Periods - Small Branch

Return Period	Max. Turret Offset		Maximum Line Tensions						Maximum EOL (anchor) Load		Minimum Grounded Length	
	Tension Contour	Max all Rxy	Top Chain		SS-wire		Bottom Chain					
years	m	m	tonne	location	tonne	location	tonne	location	tonne	location	m	location
1	61	54	266	Line 3	239	Line 3	224	Line 3	90	Line 5	248	Line 6
10	75	79	308	Line 8	281	Line 5	267	Line 5	149	Line 5	184	Line 6
100	93	105	373	Line 5	347	Line 5	334	Line 5	**218**	**Line 5**	99	Line 6
1,000	127	128	551	Line 4	528	Line 4	515	Line 4	411	Line 4	0	Line 4 & 2 others

Min Draft, Intact: 1 to 1,000yr Return Periods - Small Branch

Return Period	Max. Turret Offset		Maximum Line Tensions						Maximum EOL (anchor) Load		Minimum Grounded Length	
	Tension Contour	Max all Rxy	Top Chain		SS-wire		Bottom Chain					
years	m	m	tonne	location	tonne	location	tonne	location	tonne	location	m	location
1	60	50	276	Line 3	250	Line 3	235	Line 3	97	Line 5	236	Line 6
10	74	75	321	Line 8	293	Line 8	278	Line 8	147	Line 5	175	Line 6
100	91	98	**380**	**Line 7**	**354**	**Line 7**	**339**	**Line 7**	213	Line 4	98	Line 6
1,000	121	121	481	Line 4	457	Line 4	443	Line 4	333	Line 4	0	Line 4 & 2 others





All Drafts, Intact: Ratios of Large/Small; 225,504 Simulations

Return Period	Max. Turret Offset		Maximum Line Tensions			Maximum Anchor Load	Minimum Grounded Length
	Tension Contour	Max all Rxy	Top Chain	SS-wire	Bottom Chain		
years	L/S	L/S	L/S	L/S	L/S	L/S	L/S
1	116%	137%	106%	107%	107%	123%	92%
10	125%	130%	112%	114%	115%	141%	69%
100	**133%**	**123%**	**136%**	**139%**	**141%**	**169%**	
1,000	116%	120%	141%	143%	144%	155%	

Max Draft, Ratios of Large/Small

Return Period	Max. Turret Offset		Maximum Line Tensions			Maximum Anchor Load	Minimum Grounded Length
	Tension Contour	Max all Rxy	Top Chain	SS-wire	Bottom Chain		
years	L/S	L/S	L/S	L/S	L/S	L/S	L/S
1	123%	139%	115%	118%	120%	151%	85%
10	125%	130%	124%	126%	127%	151%	59%
100	133%	123%	144%	147%	149%	177%	
1,000	116%	120%	143%	145%	146%	159%	

Mid Draft, Ratios of Large/Small

Return Period	Max. Turret Offset		Maximum Line Tensions			Maximum Anchor Load	Minimum Grounded Length
	Tension Contour	Max all Rxy	Top Chain	SS-wire	Bottom Chain		
years	L/S	L/S	L/S	L/S	L/S	L/S	L/S
1	116%	123%	111%	112%	113%	134%	87%
10	119%	117%	117%	119%	120%	137%	66%
100	122%	112%	127%	130%	131%	150%	
1,000	110%	112%	119%	120%	121%	128%	

Min Draft, Ratios of Large/Small

Return Period	Max. Turret Offset		Maximum Line Tensions			Maximum Anchor Load	Minimum Grounded Length
	Tension Contour	Max all Rxy	Top Chain	SS-wire	Bottom Chain		
years	L/S	L/S	L/S	L/S	L/S	L/S	L/S
1	108%	112%	105%	106%	106%	115%	93%
10	107%	111%	105%	106%	106%	117%	86%
100	106%	109%	107%	107%	108%	116%	62%
1,000	107%	107%	111%	112%	112%	117%	

Max Draft, Intact: 1 to 1,000yr Return Periods - Large Branch

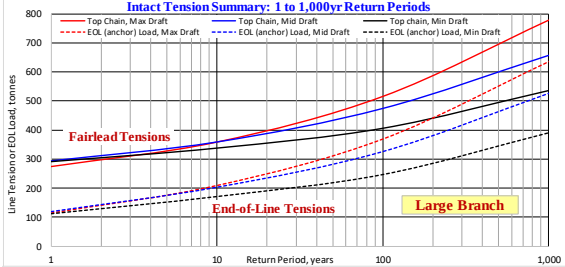
Return Period	Max. Turret Offset		Maximum Line Tensions						Maximum EOL (anchor) Load		Minimum Grounded Length	
	Tension Contour	Max all Rxy	Top Chain		SS-wire		Bottom Chain					
years	m	m	tonne	location	tonne	location	tonne	location	tonne	location	m	location
1	71	74	275	Line 1	249	Line 1	234	Line 1	114	Line 5	238	Line 6
10	95	102	359	Line 4	334	Line 4	320	Line 4	209	Line 4	124	Line 4
100	**126**	**130**	516	Line 4	491	Line 4	478	Line 4	369	Line 4	0	Line 4 & 2 others
1,000	151	158	778	Line 6	754	Line 6	742	Line 6	636	Line 6	0	Line 4 & 5 others

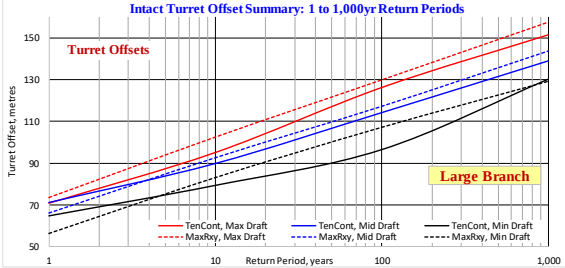
Mid Draft, Intact: 1 to 1,000yr Return Periods - Large Branch

Return Period	Max. Turret Offset		Maximum Line Tensions						Maximum EOL (anchor) Load		Minimum Grounded Length	
	Tension Contour	Max all Rxy	Top Chain		SS-wire		Bottom Chain					
years	m	m	tonne	location	tonne	location	tonne	location	tonne	location	m	location
1	71	66	294	Line 1	267	Line 1	253	Line 3	120	Line 5	216	Line 6
10	90	93	359	Line 5	334	Line 5	320	Line 5	204	Line 5	121	Line 5
100	114	117	475	Line 5	450	Line 5	437	Line 5	**326**	**Line 5**	0	Line 4 & 2 others
1,000	139	144	657	Line 4	635	Line 4	623	Line 4	525	Line 4	0	Line 4 & 5 others

Min Draft, Intact: 1 to 1,000yr Return Periods - Large Branch

Return Period	Max. Turret Offset		Maximum Line Tensions						Maximum EOL (anchor) Load		Minimum Grounded Length	
	Tension Contour	Max all Rxy	Top Chain		SS-wire		Bottom Chain					
years	m	m	tonne	location	tonne	location	tonne	location	tonne	location	m	location
1	65	56	291	Line 3	264	Line 3	250	Line 3	112	Line 5	220	Line 6
10	79	83	337	Line 8	310	Line 8	295	Line 8	171	Line 5	151	Line 6
100	96	107	**405**	**Line 8**	**379**	**Line 8**	**365**	**Line 8**	247	Line 4	62	Line 6
1,000	130	129	535	Line 4	511	Line 4	498	Line 4	390	Line 4	0	Line 4 & 2 others





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C) Installation, Pretensions, Load Sharing, and Impact on Strength and Fatigue Safety Factors

API RP 2SK, June 2020 Ballot Version – New Requirements on Acceptance Criteria of Installed Mooring System

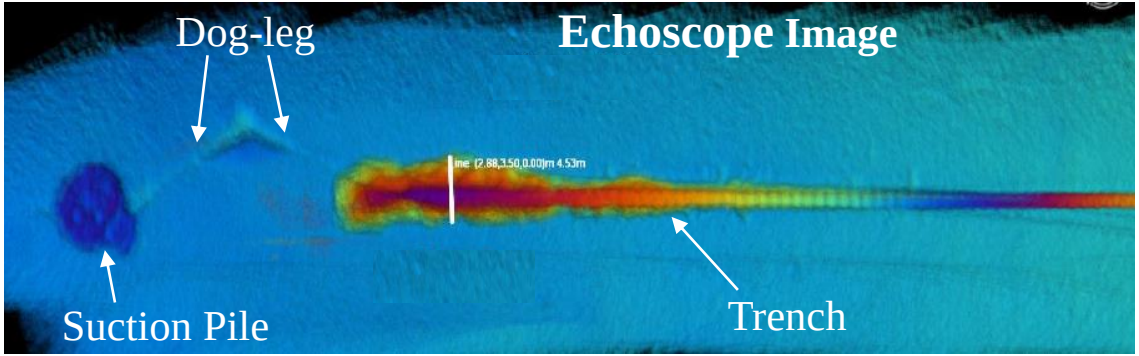
The owner or operator **shall** verify that the as-installed mooring system satisfies the design criteria for the conditions specified in this Code.

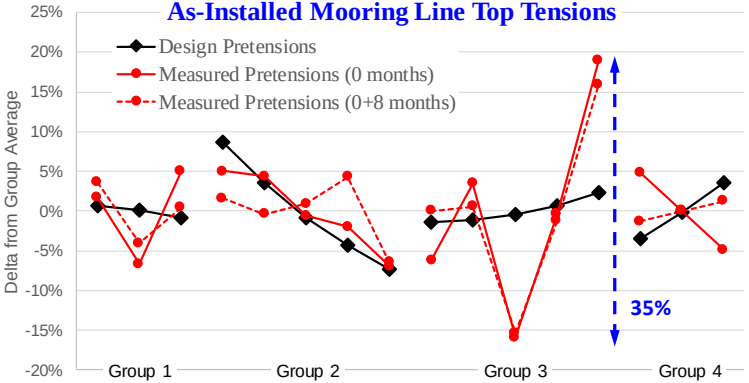
If the as-installed mooring system does not meet the design criteria, then appropriate plans **shall** be developed and implemented in a timely fashion to ensure that the design requirements are satisfied.

The owner **shall** develop, installation tolerances, procedures, and acceptance criteria to ensure that the installed mooring system satisfies the assumptions made in the design or site assessment.

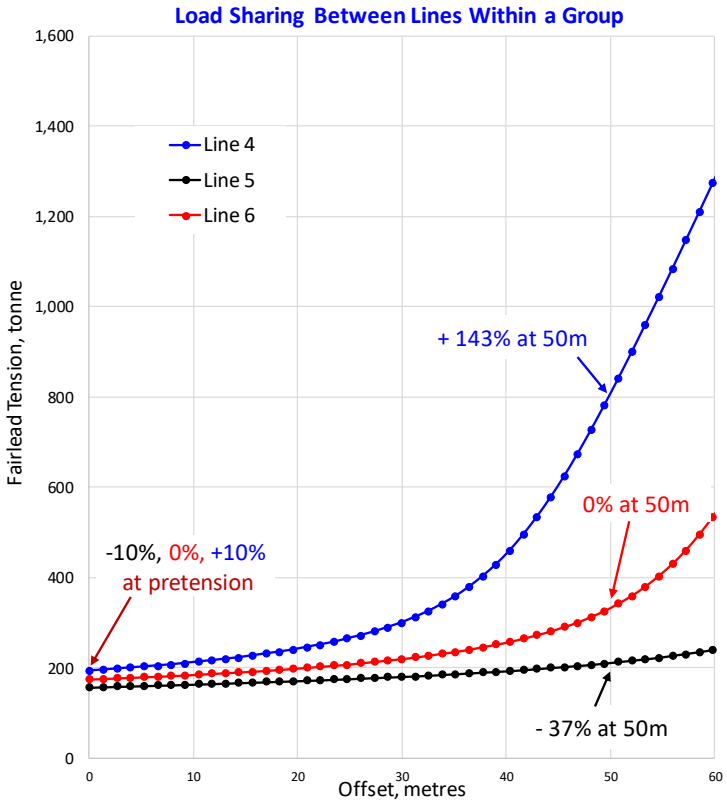
In particular, mooring line pretensions used in the strength and fatigue analyses **shall** be consistent with the installed pretension, this is especially important for mooring systems with grouped lines.

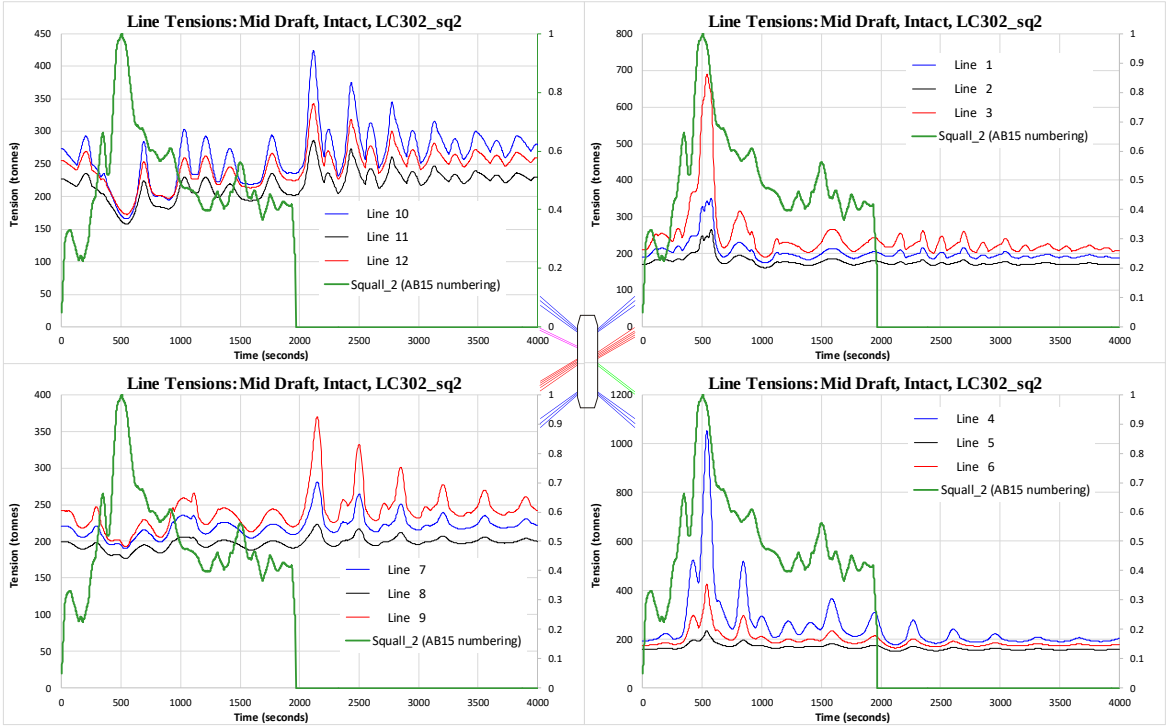
- If perfect load sharing between lines within a group is used for the strength and fatigue analyses, then the installation procedures and acceptance criteria **shall** ensure that the installed mooring system also has perfect load sharing.
- If the mooring system strength and fatigue analyses use, for example, a ±10% variation in pretensions, then the installation procedures and acceptance criteria **shall** also result in pretensions within a ±10% variation



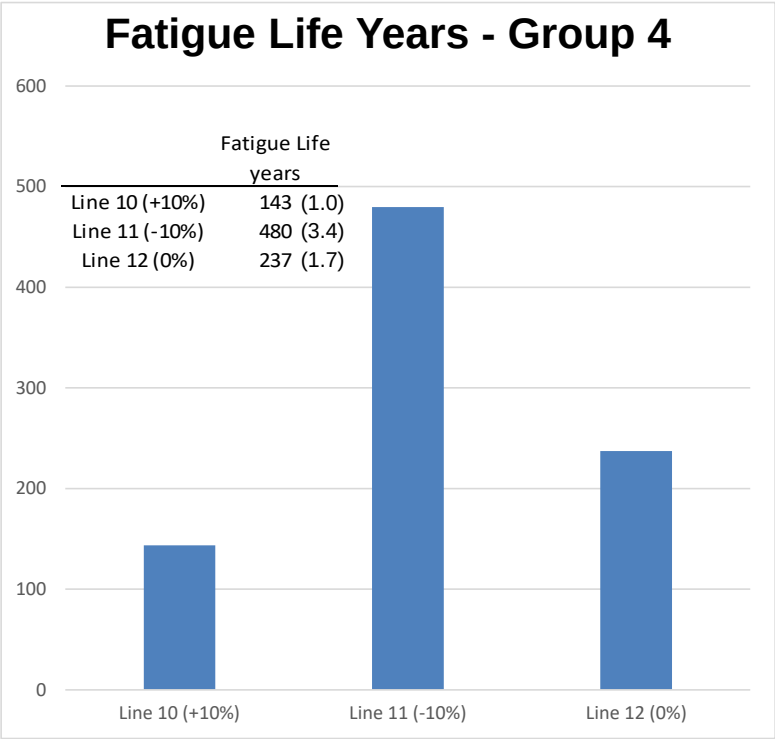


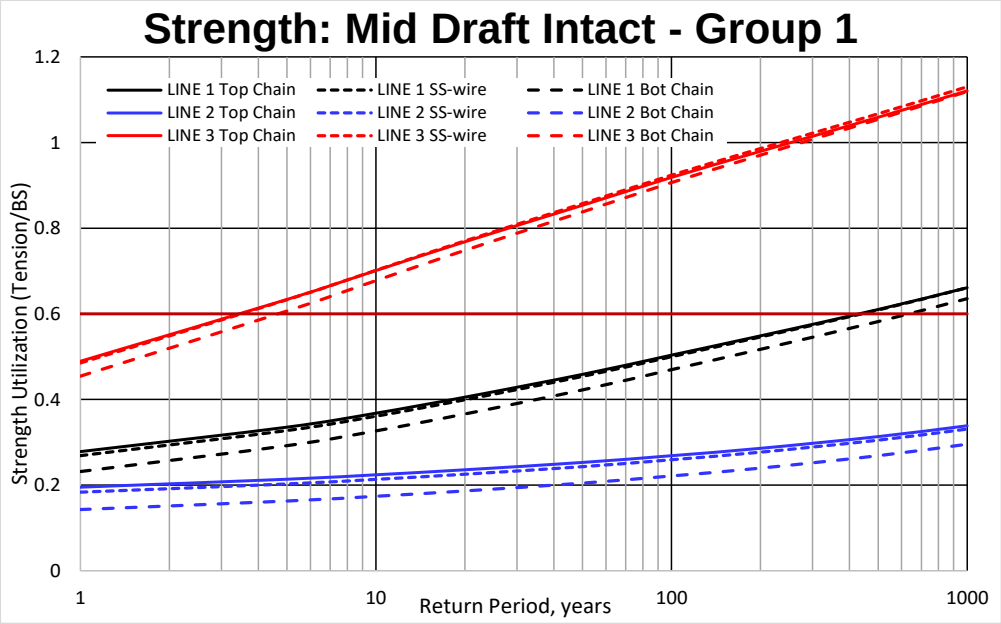
C) Installation, Pretensions, Load Sharing, and Impact on Strength and Fatigue Safety Factors





C) Installation, Pretensions, Load Sharing, and Impact on Strength and Fatigue Safety Factors





	Util. = 0.6 years	
Line 1 (0%)	400	(125)
Line 2 (-10%)	>1,000	(>312)
Line 3 (+10%)	3.2	(1.0)