MEMO

To: ElectroGas Malta
From: Atheendra Sreenivasan, Marin USA Inc.
CC: Kate Aplin, AECOM
Date: 8/3/2016
Project No: 27689-8-PO
Subject: Simulations and Results with modified Storm Mooring System

This memo should be regarded as an addendum to the Marin report No. 27689-8-PO , "Nautical and Risk Studies for the Delimara LNG Terminal in Marsaxlokk Port, Malta". The storm mooring system considered in report 27689-8-PO uses piles and clump weights. However, the client is considering an alternate mooring system that will use anchors and tri-chains. This memo gives the details of this new mooring system and the results in survival conditions of 50 and 100yr return environments.

1 STORM MOORING SYSTEM

1.1 Layout of Mooring Lines

On getting storm warnings, the FSU will change from jetty position to storm mooring position and be moored by 8 spread lines. The lines are grouped in 4 bundles of 2 lines each. The line length, components and azimuth angles are specified in Table 1 while the fairlead and anchor locations are specified in Table 2. The x and y locations for both fairlead and anchor are defined in the ship-fixed coordinate system. The z coordinate of fairlead and anchor is defined from vessel keel and water level, respectively.

The total line length, azimuth angles, fairlead and anchor locations are the same as before. However, instead of two chains (95mm top chain and 152mm bottom chain) with clump weights on the bottom chain, there are now three different chains and no clump weights (see Table 1).

Table 1: Mooring Lines distribution

	Anchor Radius	Line Length	Top Chain (95mm R4)	Tri-Chain	Bottom Chain (140mm R4)	Azimuth
	[m]	[m]	[m]	[m]	[m]	[deg]
L1	150.0	159.8	59.8	65.0	35.0	145.0
L2	150.0	159.4	59.4	65.0	35.0	155.0
L3	150.0	161.5	61.5	65.0	35.0	230.0
L4	150.0	161.5	61.5	65.0	35.0	240.0
L5	150.0	160.5	60.5	65.0	35.0	300.0
L6	150.0	160.3	60.3	65.0	35.0	310.0
L7	150.0	158.8	58.8	65.0	35.0	25.0
L8	150.0	158.8	58.8	65.0	35.0	35.0

Table 2: Fairlead and Anchor locations

	Fairlead Location			Anchor Location		
	x [m]	y [m]	z [m]	x [m]	y [m]	z [m]
L1	134.03	8.33	25.20	256.90	94.40	-12.80
L2	136.79	6.29	25.20	272.70	69.70	-14.80
L3	122.93	-14.78	25.20	219.30	-129.70	-19.40
L4	119.72	-16.10	25.20	194.70	-146.00	-19.30
L5	-138.11	-10.35	23.40	-213.10	-140.30	-13.80
L6	-140.03	-9.14	23.40	-236.50	-124.00	-13.90
L7	-141.77	6.12	23.40	-277.70	69.50	-16.90
L8	-140.95	8.54	23.40	-263.80	94.60	-15.50

1.2 Composition of Line

Each mooring line consists of three segments, which are (from anchor to fairlead) a 140 mm chain, Tri-chain and a 95 mm chain segment. The tri-chain consists of 127mm studless chain and two 133mm studlink chains. The properties of these different segments are given in Table 3. The three chains that make up the middle tri-chain segment were combined into an equivalent single chain for the time-domain simulations.

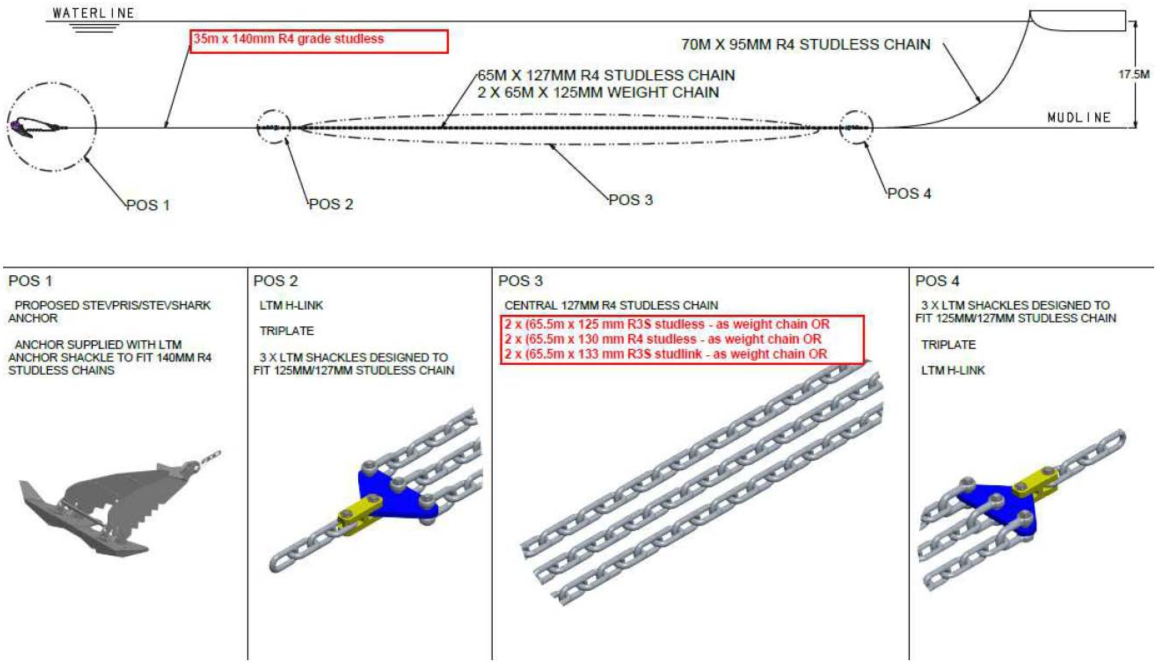

Figure 1: Proposed Spread Mooring System details

Table 3: Mooring Line Composition

Parameter	Top Chain	Tri-Chain		Bottom Chain
Diameter (mm)	95	127	133	140
Type	studless	studless	studlink	studless
Grade	R4	R4	R3S	R4
Weight in air (Kg/m)	179.6	321.0	387.4	390.0
Weight in water(Kg/m)	156.2	279.2	336.9	339.2
Axial Stiffness(kN)	771000.0	1377890.2	1526441.6	1674415.5
MBL (kN)	7682.0	13728.9	14697.2	16683.3

2 SIMULATION MATRIX

The simulations mentioned in Report 27689-8-PO were carried out for extreme wind for return periods of 5,10,25,50 and 100Yr return periods with associated sea, swell and current. Since the new modified spread mooring system is quite similar to the original mooring system, the simulations have been re-run only for the extreme environments with 50 and 100Yr return periods.

Table 4: Environments considered in the calculations

Case #	Return period	Wind		Penetrating wind sea			Local wind sea			penetrating swell			Current	
		Dir	Vw	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Vc
		[^{o}N]	[m/s]	[^{o}N]	[m]	[s]	[^{o}N]	[m]	[s]	[^{o}N]	[m]	[s]	[^{o}N]	[m/s]
4	50	0.00	23.90	187.00	1.11	9.96	341.00	0.68	2.81	193.00	0.58	10.50	196.00	0.09
5	100	0.00	25.90	190.00	1.31	11.72	341.00	0.75	2.90	193.00	0.58	10.50	196.00	0.10
9	50	30.00	23.80	188.00	1.05	12.80	4.00	0.55	2.84	194.00	0.59	10.60	197.00	0.09
10	100	30.00	25.20	190.00	1.16	13.61	4.00	0.59	2.90	194.00	0.59	10.60	197.00	0.09
14	50	60.00	22.07	190.80	1.42	11.36				194.00	0.59	10.50	217.00	0.08
15	100	60.00	23.09	190.80	1.53	11.83				194.00	0.59	10.50	217.00	0.08
19	50	90.00	20.38	179.00	1.92	10.63				192.00	0.54	10.00	180.00	0.09
20	100	90.00	21.13	179.00	2.08	11.02				192.00	0.54	10.00	180.00	0.09
24	50	120.00	19.79	180.00	2.39	10.03				192.00	0.49	8.80	160.00	0.14
25	100	120.00	20.43	180.00	2.52	10.32				192.00	0.49	8.80	160.00	0.14
29	50	150.00	21.05	181.00	2.92	10.60				192.00	0.34	9.30	171.00	0.08
30	100	150.00	21.85	181.00	3.08	10.95				192.00	0.34	9.30	171.00	0.08
34	50	180.00	19.21	181.00	2.79	9.20				192.00	0.37	9.10	158.00	0.06
35	100	180.00	19.96	181.00	2.95	9.45				192.00	0.37	9.10	158.00	0.06
39	50	210.00	19.62	184.00	2.42	9.87				192.00	0.53	9.20	359.00	0.21
40	100	210.00	20.67	184.00	2.61	10.32				192.00	0.53	9.20	359.00	0.22
44	50	240.00	20.68	192.00	1.97	10.02				193.00	0.59	9.90	340.00	0.18
45	100	240.00	21.43	192.00	2.07	10.33				193.00	0.59	9.90	340.00	0.19
49	50	270.00	24.50	190.00	1.53	12.30	269.00	0.87	2.86	193.00	0.62	9.70	329.00	0.20
50	100	270.00	25.40	190.00	1.63	12.82	269.00	0.91	2.90	193.00	0.62	9.70	329.00	0.21
54	50	300.00	24.30	190.00	1.58	14.74	292.00	0.86	2.87	193.00	0.56	9.20	307.00	0.19
55	100	300.00	25.00	190.00	1.69	15.89	292.00	0.89	2.90	193.00	0.56	9.20	307.00	0.20
59	50	330.00	23.60	190.00	1.07	9.82	320.00	0.76	2.57	193.00	0.62	9.40	193.00	0.13
60	100	330.00	24.40	190.00	1.15	10.59	320.00	0.79	2.60	193.00	0.62	9.40	193.00	0.13

3 RESULTS

3.1 Static Analysis

The storm mooring system is set up in aNySIM using line particulars described in Section 1. The fairlead and anchor locations are used as the input. The resulting pretensions and pretension angles for all 8 mooring lines are shown in Table 5.

Table 5: Pretension and pre-tension angle

Mooring Line	Pretensions(tons)		Fairlead Angle(deg)	
	Ballast	Loaded	Ballast	Loaded
L1	32.4	23.8	38.8	41.4
L2	33.6	24.0	38.5	41.3
L3	19.8	15.5	47.0	50.2
L4	19.5	15.3	47.2	50.3
L5	16.5	13.8	46.9	49.3
L6	17.2	14.1	46.1	48.7
L7	26.5	18.8	39.9	43.4
L8	28.5	20.2	39.0	42.2

Static load tests are run again in aNySIM to verify the stiffness of the mooring system. For the X and Y static load test, the ship is relocated to different distances from the origin position aligned with X and Y axis (positive X to South and positive Y to East). For the yaw static load test, the ship is rotated to different headings from the initial heading. The total restoring forces/moments are calculated for different locations/headings of the FSU. The load excursion curves (in x, y and yaw directions) from aNySIM are shown in Figure 2 to Figure 7. The two mooring systems have similar load excursion curves. They are virtually on top of each other for the first 5m (or deg) and diverge a little after that.

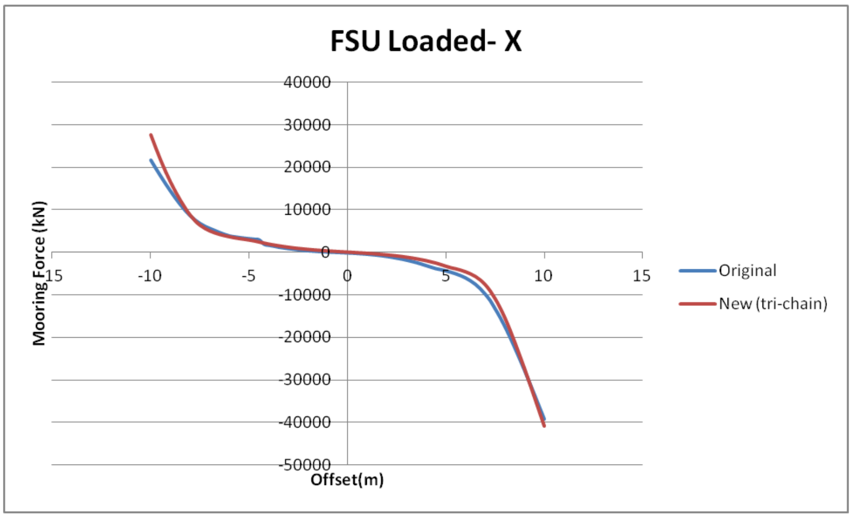

Figure 2: Load excursion curves in x direction – Loaded FSU

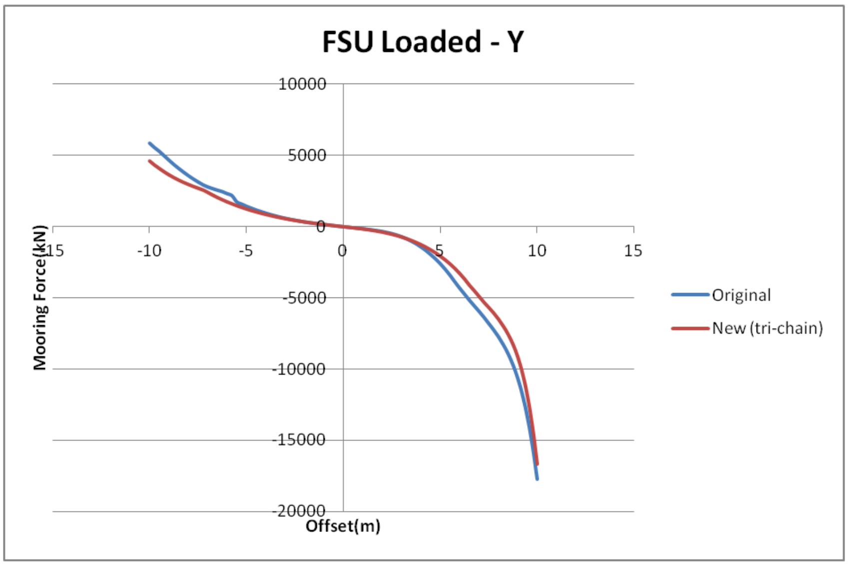

Figure 3: Load excursion curves in y direction – Loaded FSU

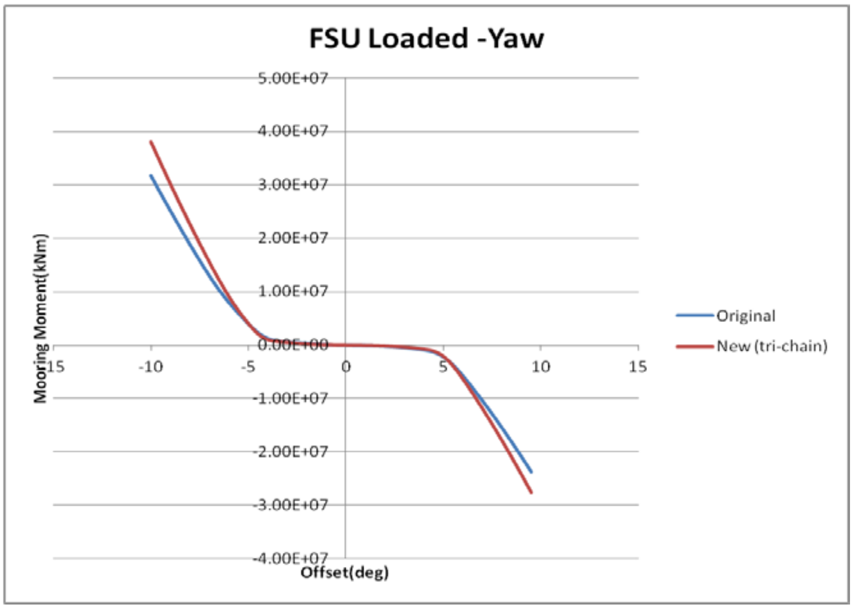

Figure 4: Load excursion curves in yaw – Loaded FSU

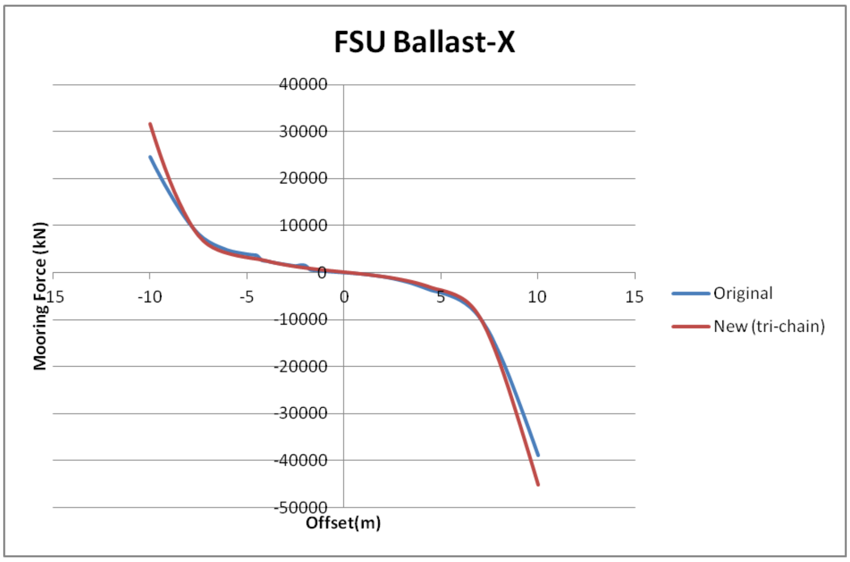

Figure 5: Load excursion curves in x direction – Ballast FSU

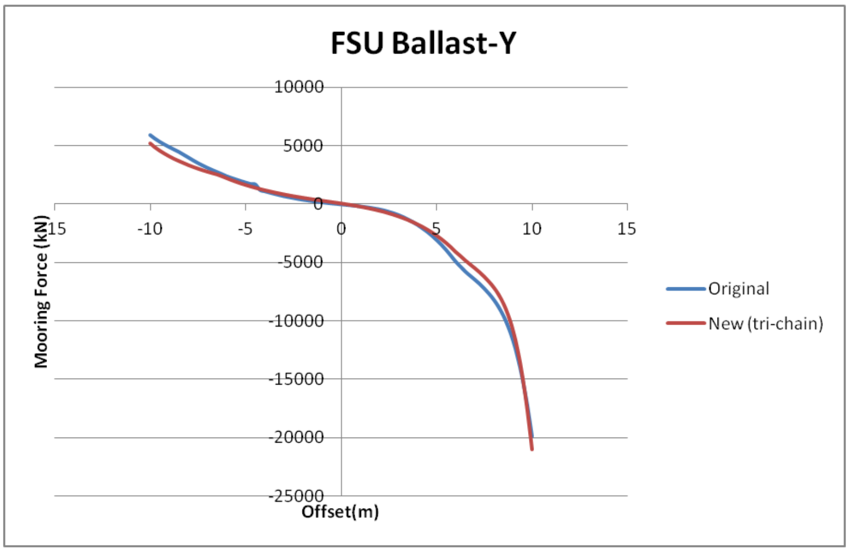

Figure 6: Load excursion curves in y direction – Ballast FSU

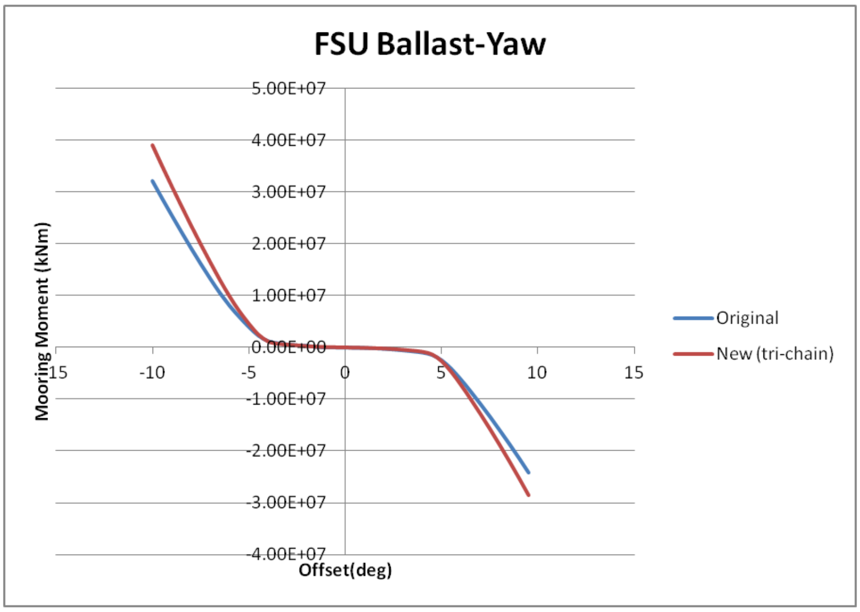

Figure 7: Load excursion curves in yaw – Ballast FSU

3.2 Simulation with extreme environments

The simulations are carried out for both the Loaded and Ballast FSU in all the environments shown in Table 4. For each environment, a 3.5 hours time domain simulation is carried out. All transient effect can die out in the first half hour of the run and the statistics is only based on the data of the last 3 hours of the simulation. The results of the mooring line tensions and FSU motions are discussed in this section.

3.2.1 Maximum Line tension and offset for different return periods

The maximum fairlead and anchor line tensions are shown for different wind angles and return periods in Figure 8 and Figure 9. It can be seen that higher line tensions are noticed when wind direction is close to beam on. The maximum fairlead line tensions out of all simulations is 3975 kN (405 tonnes) which occurs for the 100 yrs wind from 60^{o}N. This corresponds to 51.7% of the MBL for a 95 mm chain. The maximum line tensions for all simulated cases are tabulated in Table 6. Also shown in the table is the loading condition of the FSU for each tabulated maximum line tension.

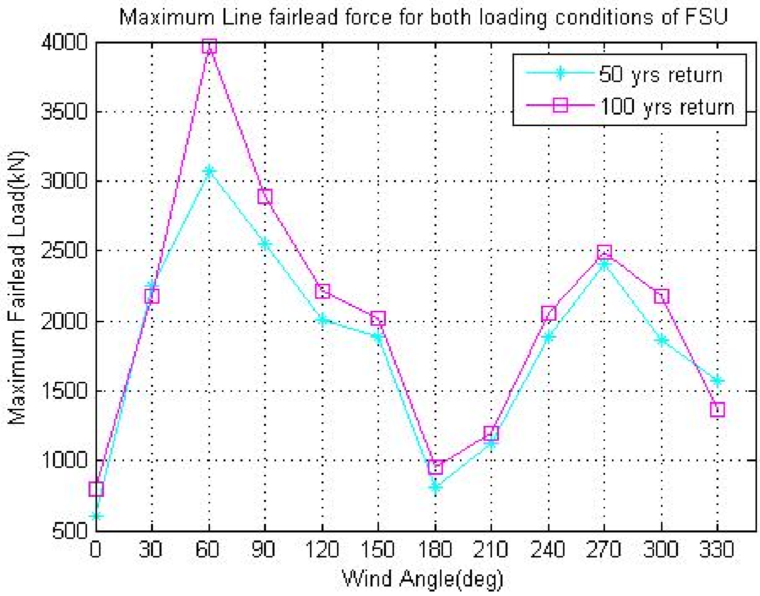

Figure 8: Maximum Fairlead forces for different wind angles (from North)

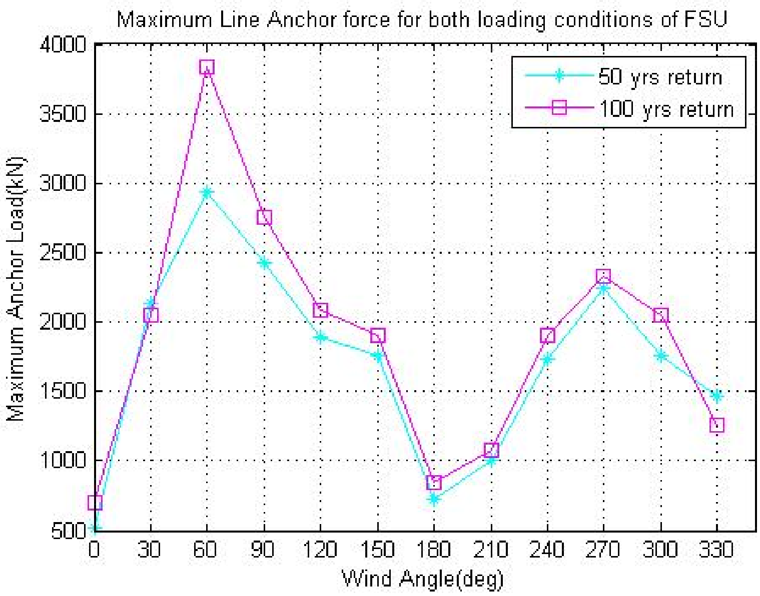

Figure 9: Maximum Anchor forces for different wind angles (from North)

Table 6: Maximum Fairlead/Anchor tension for different wind angles

Wind Angle (deg, from North)	Return Period(Yrs)					
	50			100		
	Tf(kN)	Ta(kN)	LC	Tf(kN)	Ta(kN)	LC
0	607	520	B	798	706	L
30	2255	2130	L	2175	2049	B
60	3071	2934	B	3975	3832	B
90	2556	2427	L	2889	2753	B
120	2013	1888	B	2216	2087	B
150	1888	1757	B	2023	1899	L
180	813	721	L	958	851	B
210	1120	1000	L	1198	1074	L
240	1887	1732	B	2058	1900	B
270	2410	2248	B	2494	2332	B
300	1865	1753	B	2178	2055	B
330	1569	1464	L	1362	1264	L
Max	3071	2934		3975	3832	
% MBL of 95mm Chain	40			51.7		

The most critical case (100Yr return wind from 60^{o}N,Ballast FSU) is looked into closer in this study. The maximum line tension (line 8) occurs at T = 9736 s. The time traces of the line tension, vessel Y motion, vessel yaw motion and wind speed are shown in Figure 10. It can be seen from the figure that the large line tension is due to the simultaneous occurrence of the large Y offset and large yaw offset.

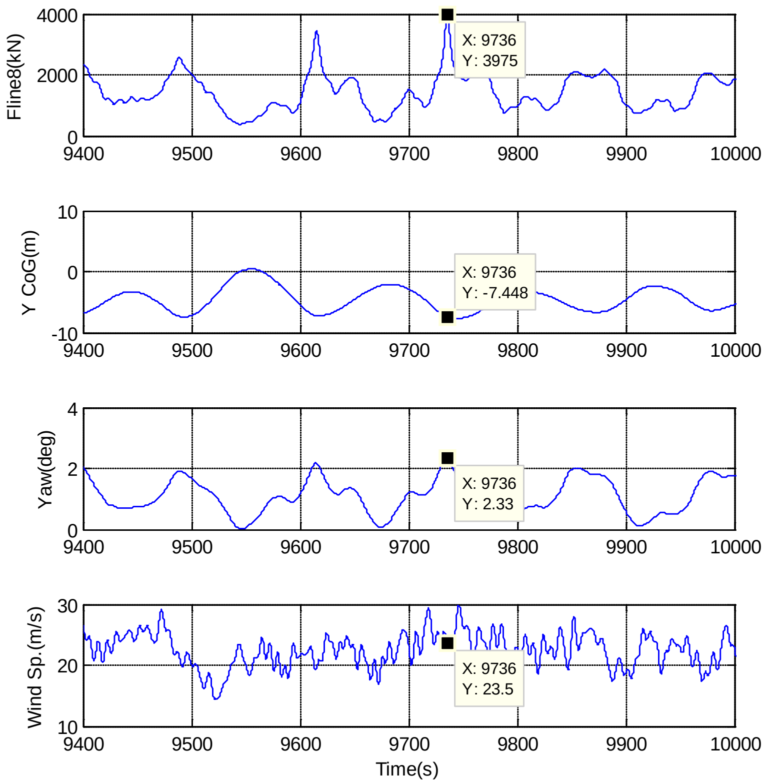

Figure 10: Time traces of most critical case (100Yr return wind from 60^{o}N,Ballast FSU)

In time domain simulations, the wind speed time trace is generated based on the specified energy spectrum and a wind seed number. Different wind seed numbers can lead to different wind time trace realizations. Therefore, another 4 simulations are carried out for the same case but with 4 different wind seed numbers.

The maximum line tensions for the 5 different wind seed numbers are shown in Table 7. The different wind speed time trace realizations have about 20% sensitivity effects on the final results.

Table 7: Maximum Fairlead tension of the most critical case for different wind seeds

Maximum Line Tension(kN)		
Wind Seed	Ballast	Loaded
1358	3975	3290
358	3573	2958
2358	2936	2867
4758	3041	3332
3172	3235	3189
Mean	3352	3127.2

The maximum horizontal offset are also calculated during each simulation and the maximum offsets for all cases are shown in Figure 11 and Table 8. The offset is defined as the horizontal distance moved by the CoG of the FSU from its initial starting position. Larger offset is noticed with beam on wind, and the maximum offset out of all cases is 9.5 m, which occurs in 100 yrs wind coming from 90^{o}N.

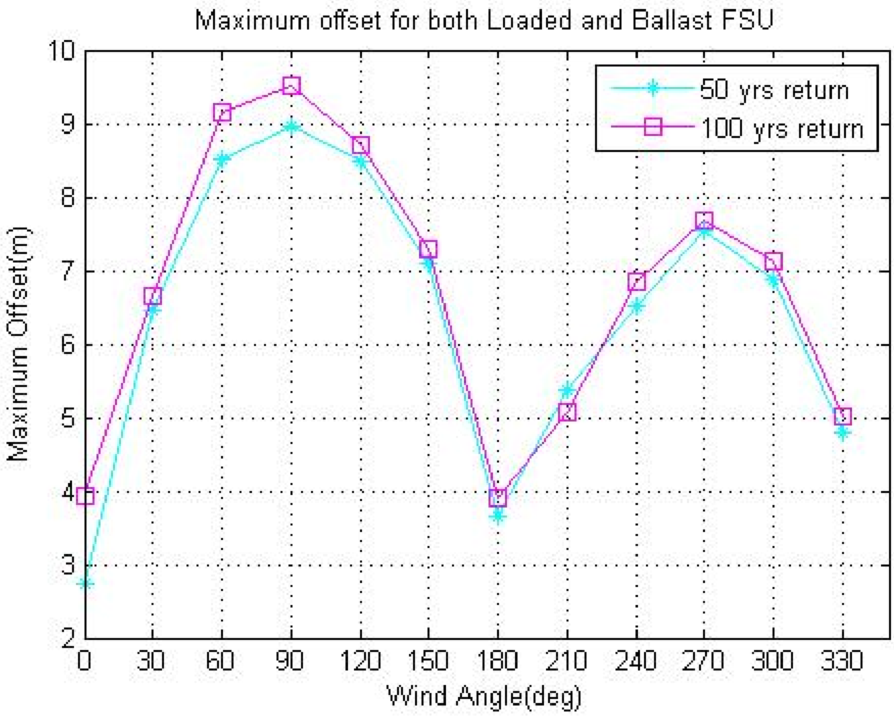

Figure 11: Maximum Offset for different wind angles (from North)

Table 8: Maximum Offset for different wind angles (from North)

Wind Angle (deg, from North)	Return Period(yrs)	
	50	100
	Offset(m)	Offset(m)
0	2.74	3.93
30	6.47	6.66
60	8.50	9.16
90	8.97	9.50
120	8.48	8.70
150	7.10	7.30
180	3.65	3.91
210	5.37	5.06
240	6.53	6.84
270	7.54	7.67
300	6.87	7.14
330	4.80	5.01

As noted in the previous report, the maximum line tension and offset occurs for winds coming from Easterly directions (around 90 deg in the results). This is due to the fact that the mooring lines on the portside of FSU (lines 1, 2, 7 and 8) have smaller angles w.r.t the centerline of the vessel, which leads to a softer system (less restoring capability) when the vessel moves towards West. This can also be confirmed in the mooring static test (Figure 3 and Figure 6), which indicate a much lower stiffness in Y when relocating the vessel to negative y locations (towards West).

3.2.2 Maximum line tensions for different mooring lines

The maximum tensions for different mooring lines are shown in Figure 12 and Figure 13. Line 8 is the most critical with a maximum tensions of 3975kN in the 100Yr wind environment. The maximum tensions in other lines are significantly lower.

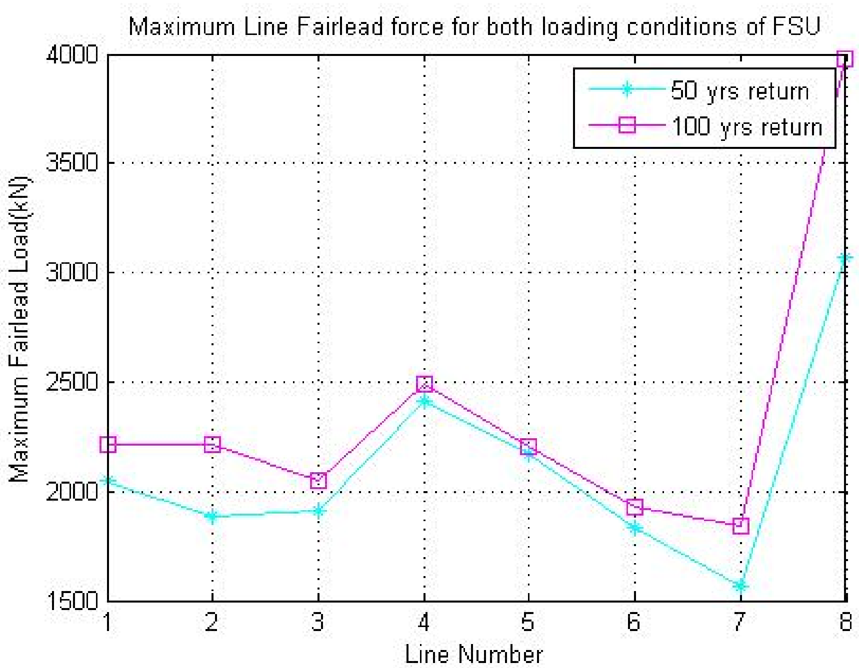

Figure 12: Maximum Fairlead forces for different mooring lines

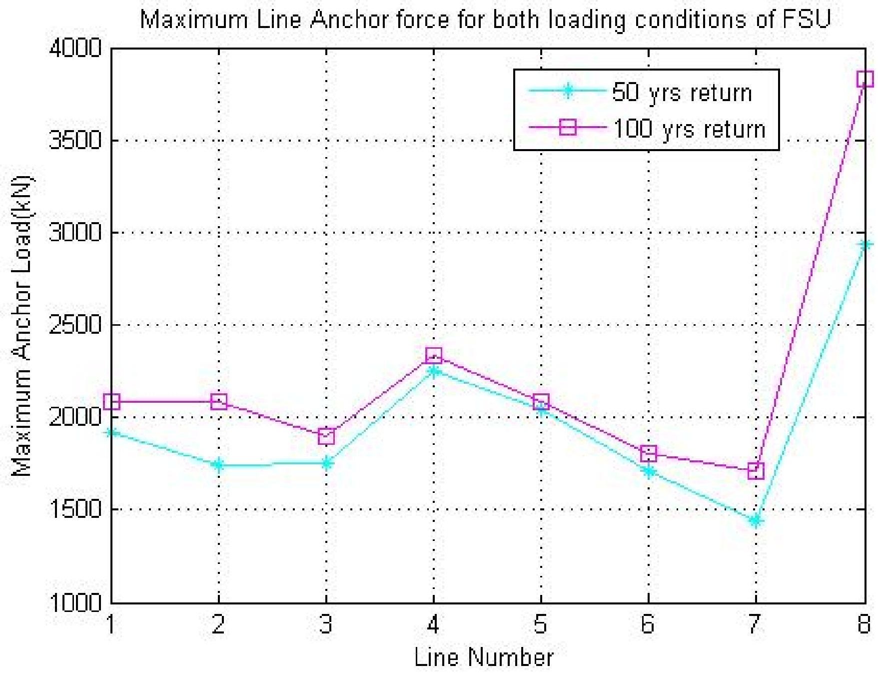

Figure 13: Maximum Anchor forces for different mooring lines

Table 9: Maximum Fairlead/Anchor tension for different mooring lines

Line Number	Return Period(Yrs)			
	50		100	
	Tf(kN)	Ta(kN)	Tf(kN)	Ta(kN)
1	2046	1919	2216	2087
2	1882	1747	2217	2080
3	1911	1757	2050	1893
4	2410	2248	2494	2332
5	2168	2046	2205	2085
6	1834	1716	1925	1808
7	1567	1442	1845	1712
8	3071	2934	3975	3832

4 CONCLUSIONS

A verification analysis was carried out for the updated storm mooring system of the Malta FSU. Two loading conditions (loaded and ballast) are considered and a total of 24 environmental cases (2 return periods and 12 wind directions with associated wave and current conditions) are analyzed for each loading condition. The following can be concluded from the study:

- The static load elongation curves are similar for the old and updated mooring systems.

- Higher line tensions and vessel offsets are noticed when wind direction is close to beam on, i.e., from 60^{o}N to 120^{o}N and from 240^{o}N to 300^{o}N.

- Higher line tensions and larger offsets occur for winds coming from Easterly directions (60^{o}N to 120^{o}N) when comparing to Westerly directions (240^{o}N to 300^{o}N). This is due to the fact that the mooring lines on the Eastern side have smaller angles w.r.t the centerline of the vessel, which leads to a softer system (less restoring capability) when the vessel moves towards West.

- The maximum fairlead line tensions out of all simulations is 3975 kN (405 tonnes) which occurs for the 100 yrs wind from 60^{o}N. The 3975 kN corresponds to 51.7% of the MBL for a 95 mm chain, which is within the usually adopted limit of 55% of the MBL. The same case was repeated for 4 other different wind time trace realizations. Different realizations can have about 20% sensitivity on the maximum line tensions.

- The maximum offset out of all simulations is 9.5 m, which occurs in 100 yrs wind coming from 90^{o}N.

- The maximum tensions for different mooring lines are also investigated. The line 8 (35^{o}N) is found to be the most critical line.

- The observed results are similar between the two mooring systems. The maximum line tension is now about 6% higher (3975kN vs 3537kN) and the maximum offset is 0.2m higher (9.5m vs 9.3m for the old system).