SUMMARY REPORT MARCO POLO JIP

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BACKGROUND

Tension Leg Platforms have proven their abilities for moderate water depths and are now being used for deep water and ultra deepwater. A number of issues in design, operation and inspection issues however still needed to be resolved. Such issues are:

- Actual wind (hurricane), wave and (loop) current conditions,
- Platform motions (LF, WF and HF),
- Tensions in tendons and risers,
- VIV behavior of tendons and risers (including effect of fairings and strakes),
- Extreme loads and fatigue life of the platform.

In the design stage, use is made of numerical analysis and physical scale model testing to derive the dynamic behaviour of the structure. However such models are restricted to specific aspects of the behaviour and also the input is schematised. Designers need to know the applicability and accuracy of their methods to make sure they are not missing out on certain physical phenomena, underestimating or over-conservative.

In 2004 the Marco Polo TLP has been installed in 4300 ft of water in the GoM. In order to collect data to resolve the above issues, the partners in the Marco Polo TLP project decided to install a monitoring system on the platform. In addition a Joint Industry Project was initiated to analyze the measured data and to validate the current design methods.

To this end MARIN instrumented Marco Polo during the outfitting phase. In May 2004 the monitoring system was commissioned and from June 2004 onwards data has been collected continuously.

Figure 1 Marco Polo Hull at Ingleside and on-site

1 INTRODUCTION

This document presents a general description of the Marco Polo Joint Industry Project. No results are presented as the project is still within her confidentially period.

1.1 Objectives

The Marco Polo JIP was aiming at the dynamic behavior of TLPs in operational and survival condition and the verification of design methods and numerical analysis to enable development of new TLPs for even deeper water.

1.2 Scope

As the project is of interest to all parties involved in deep water TLPs and as the results can be used for design, interested companies were invited to join the data analysis and evaluation of the results in a 3 year Joint Industry Project. This Joint Industry Project consisted of 5 Tasks:

Table 1 Scope Marco Polo JIP I

#	Task	Period
1	Instrumentation	2003-2004
2	Installation & Commissioning	2004
3	Monitoring	June 2004 - Nov 2007
4	Data analyses	Nov 2005 - Nov 2007
5	Design method verification	Nov 2005 - Nov 2007

More specifically the envisaged monitoring campaign was aiming at:

- Actual wind (hurricane), wave and (loop) current conditions,
- Damping in the stiff modes of motion,
- Platform behavior in loop current,
- VIV behavior of tendons and risers (including effect of fairings and strakes)
- Platform in hurricane conditions,
- Extreme loads and fatigue life consumption.
- Tensions in tendons and risers,

In 2007 the Marco Polo JIP was extended with two years. The corresponding scope is listed in Table 2.

Table 2 Scope Marco Polo JIP II

#	Task	Period
1	Monitoring	Dec 2007 - Dec 2009
2	Data analyses	Dec 2007 - Dec 2009
3	Design method verification	Dec 2007 - Dec 2009

The analyses was aiming at fatigue consumption by the tendons including the subjects as listed in phase 1.

1.3 Participants

The participants of the Marco Polo JIP I and the Marco Polo JIP II are listed in Table 3 and Table 4 respectively (in alphabetical order):

Table 3 Participants Marco Polo JIP I

#	Participant	#	Participant
1	ABS	7	Hess
2	Anadarko (Operator)	8	MARIN
3	BHPB	9	MMS
4	BP	10	Modec
5	Chevron	11	WorleyParsons Sea
6	Enterprise		

Table 4 Participants Marco Polo JIP II

#	Participant	#	Participant
1	ABS	5	Hess
2	Anadarko (Operator)	6	MARIN
3	Chevron	7	MMS
4	Enterprise	8	Modec

1.4 Progress meetings

Two yearly progress meetings were held in Houston, one meeting around the OTC time and one in the fall. MARIN has been the project manager of the project. During the progress meeting issues related to MMS Rules and Regulations, U.S. Coast Guard Regulations, etc. were discussed, as well as discussions on events that occurred during the past six months or any other measured event regarding the Marco Polo JIP that was of interest to the JIP participants.

The date and place of the Marco Polo JIP meetings are listed in Table 5 and Table 6.

Table 5 Meetings Marco Polo JIP I

#	Date of meeting	Location of meeting
1	November 29, 2005	WorleyParsons Sea office, Houston
2	May 16, 2006	Enterprise office, Houston
3	October 19, 2006	Anadarko office, Houston
4	May 3, 2007	BP office, Houston
5	December 18, 2007	WorleyParsons Sea office, Houston
6	May 22, 2008	MARIN USA office, Houston
7	December 11, 2008	ABS office, Houston
8	April 2, 2009	Anadarko office, Houston
9	November 16, 2009	Anadarko office, Houston

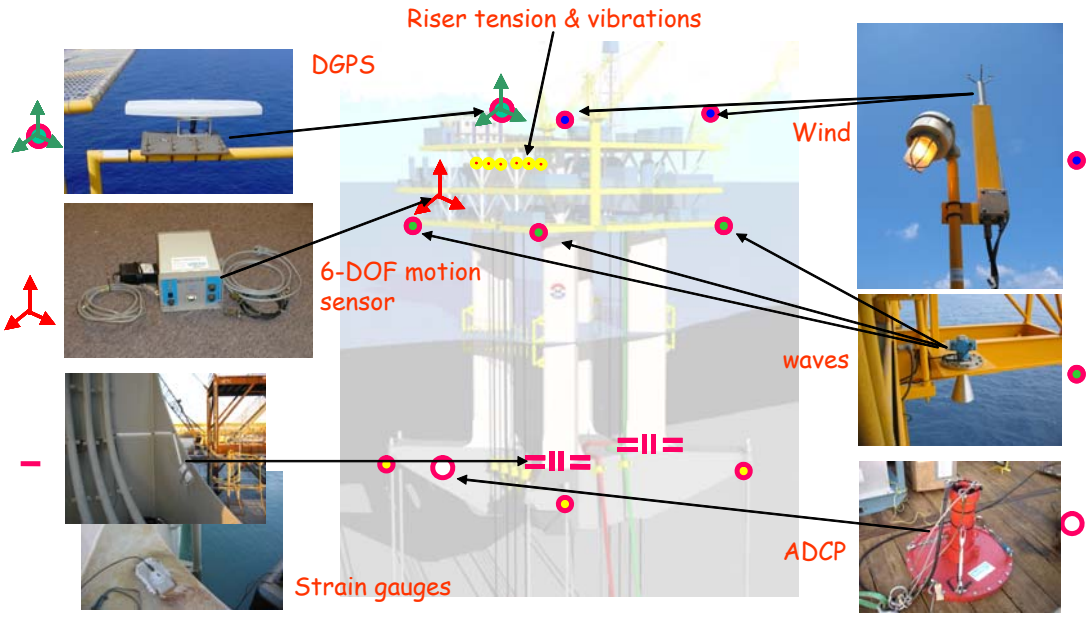
Table 6 Meetings Marco Polo JIP II

#	Date of meeting	Location of meeting
1	May 22, 2008	MARIN USA office, Houston
2	December 11, 2008	ABS office, Houston
3	April 2, 2009	Anadarko office, Houston
4	November 16, 2009	Anadarko office, Houston
5	May 5, 2010	Anadarko office, Houston

Results, reports and other relevant JIP information were made available from a dedicated website to participants only.

2 INSTRUMENTATION

The monitoring system comprises a dedicated control cabinet with the monitoring computer, signal conditioners, control and test switches and power supply including an UPS system. This main cabinet is installed in the control room on the SE corner of the production deck.



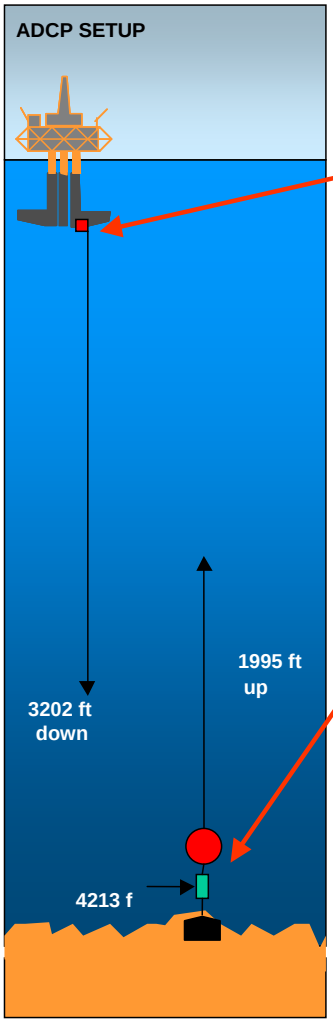
In this chapter a brief description is presented of the Marco Polo Monitoring System (MPMS).

The autonomous system comprises of a PC with hardware for the data acquisition and storage as well as visualization software to control the system. The PC is located in the control cabinet and connected to different sensor systems through serial connections and dedicated data acquisition hardware.

2.1 Current

During the outfitting phase a 75 kHz Self Contained Workhorse was installed at the bottom of the TLP, measuring the current 1995 ft downwards.

In July 2005 the current speed and direction monitoring was upgraded following the new MMS legislation. Now the current profile is measured over the full water depth column of 4300 ft. At the bottom of the TLP the 38 kHz Ocean Observer measuring the current over the top 3200 ft of the water column was installed. The 75 kHz Workhorse Long Ranger (which was initially installed at the bottom of the TLP) was placed in a subsea buoy system and moored to the sea floor. It was measuring the current upwards from the seabed over a height of 1995 ft. This subsea system was retrieved every 6 months to obtain the measurements.



Ocean Observer OO38 kHz

- **Mounted at 131 ft below water level**
- **Looking down**
- **First reading at 236 ft**
- **Total of 60 bins at each 52.5 ft**
- **Maximal reading at 3333 ft**
- **Data averaging of 20 min, 72 values each day**
- **Data automatically send to MMS/NDBC on daily bases**

Self Contained Workhorse 75kHz

- **Launched at bottom at 4213 ft**
- **Looking up**
- **First reading 4108 ft**
- **Total of 37 bins at each 52.5 ft**
- **Minimum reading at 2218 ft**
- **Data averaging of 20 min, 72 values each day**
- **Data stored locally**
- **Acoustic release must be used to recover buoy with sensor**
- **Maximum battery life 7 months**

Figure 2 ADCP setup

2.2 Wave height

The wave condition were monitored by means of 3 down looking level radars which are mounted on the East, South and West sides of the cellar deck. The radars record the wave elevations. A picture of the West mounted radar is shown in the left picture of Figure 3.

Figure 4 shows the wave radar locations highlighted on the general arrangement drawing of the cellar deck.

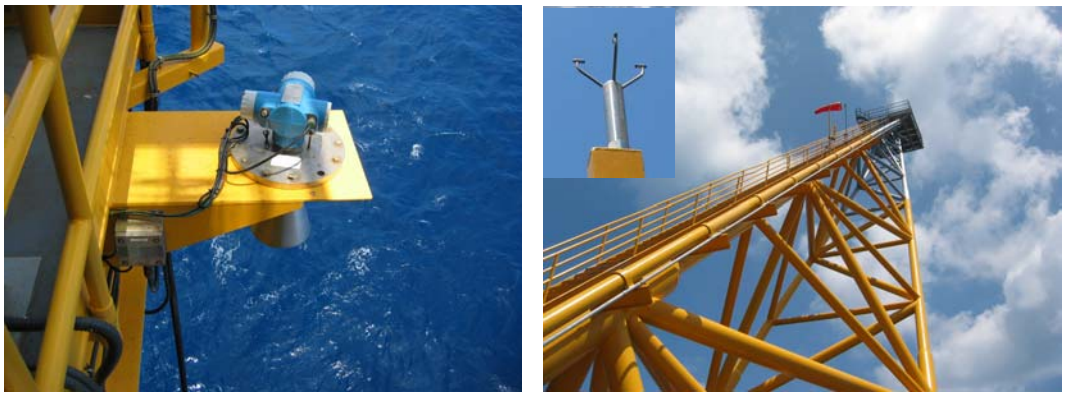


Figure 3 Photo level radar W3 and wind meter in flare

2.3 Wind

Wind speed and direction were measured by means of two solid state ultrasonic Wind Observer II wind meters. One wind meter is fitted on a light pole at the South West corner of the main deck. The second wind meter is located on the flare structure at approximately one third of the flare height. The wind meter in the flare is shown in the right picture of Figure 3.

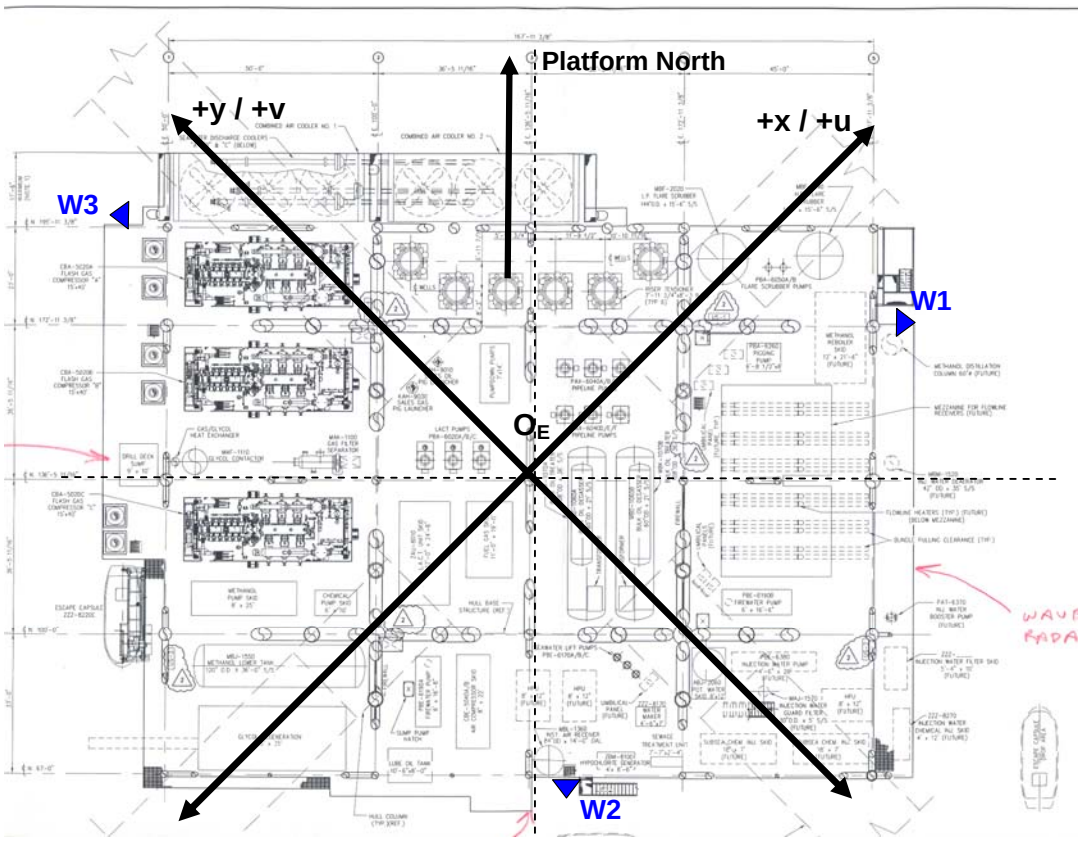


Figure 4 Cellar deck with wave radar positions

2.4 Tensions in risers and tendons

Tensions in six risers (# A up to # F) and four tendons (T1, T3, T5 and T7) were measured. The top tensions in the risers are retrieved from the OPT system. The tensions in the tendons are obtained by a serial link with the BBN TTMS system.

Figure 5 shows the riser tensioners.

Figure 5 Riser tensioners and accelerometer on riser

2.5 Riser vibrations

Accelerometers R1, R2, R5 and R6 are located on the upper section of risers # A, # C, # E and # F respectively to measure the vertical vibrations due to VIV (0.1 s – 3 s) . The risers are shown in Figure 5. An accelerometer on a riser is shown in the right picture of Figure 5.

2.6 Wave and low frequency motions of TLP

To measure the platform motions over the complete frequency range the platform was equipped with two systems:

- A dedicated motion sensor unit (MQK) with accelerometers and solid state rate gyros to measure the wave frequency (3 s – 20 s).
- A Vector Pro GPS system providing a high accuracy of the mean and low frequency horizontal motions (surge, sway and yaw) (10 s – 300 s).

The wave frequent accelerations and angular rates are measured with the MQK, located in the control room on the production deck. The MQK measures the motions in 6 DOF, it is equipped with 3 accelerometers and 3 solid state rate gyro's, as well as signal conditioning, filtering and processing. The direction of the x- and y-axis of the MQK corresponds with the direction of the u- and v-axis of the Marco Polo Platform Fixed coordinate system (O_P-UV).

The low frequent motions are measured with a DGPS, based on Space Based Augmentation Systems (SBAS). The differential correction is made by satellites, providing a high accuracy at all times. The DGPS is installed at the west side of the helicopter deck.

Figure 6 shows a comparison between measurements recorded by the MQK and DGPS.

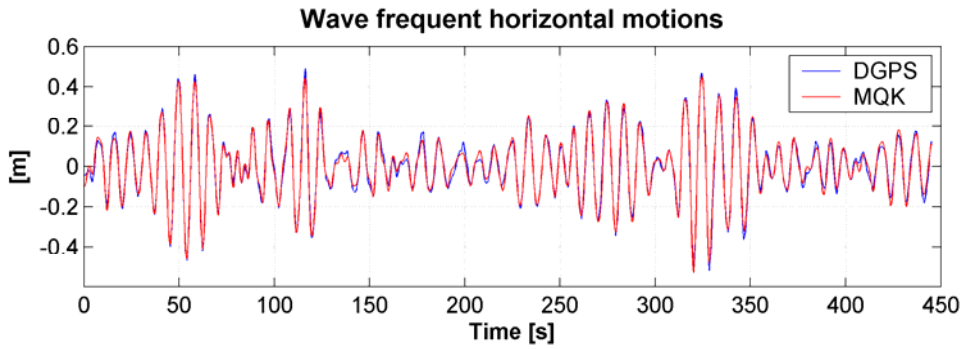


Figure 6 Comparison MQK sensor and DGPS sensor

2.7 Strain gauges

Eight strain gauges (S3, S4, S5, S6, S9, S10, S11 and S12) were installed in the horizontal and vertical inner gusset plates between the column (column # 1 and column # 4) and the top base of the tendon support structure. In Figure 7 the locations of the strain gauges are visualized in a sketch of the tendon support structure and columns.

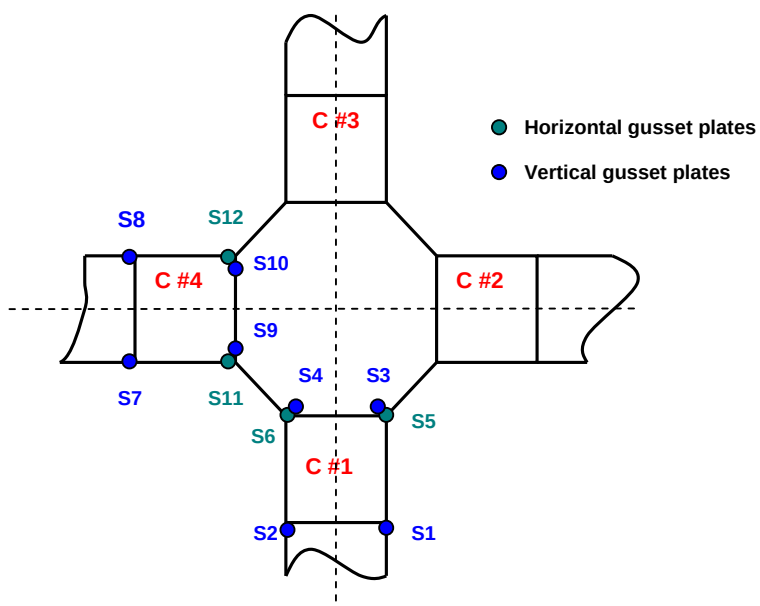


Figure 7 Strain gauge locations on gusset plates

Figure 8 shows pictures of strain gauges installed on a horizontal and vertical inner gusset plate.

Figure 8 Pictures strain gauges on horizontal and vertical gusset plates

3 MEASUREMENTS

3.1 Uptime MPMS

As part of the Marco Polo JIP data has been measured and logged by the Marco Polo Measurement System (MPMS) starting in June 2004 and ending in December 2007. An overview of the available data files is presented in Figure 9.

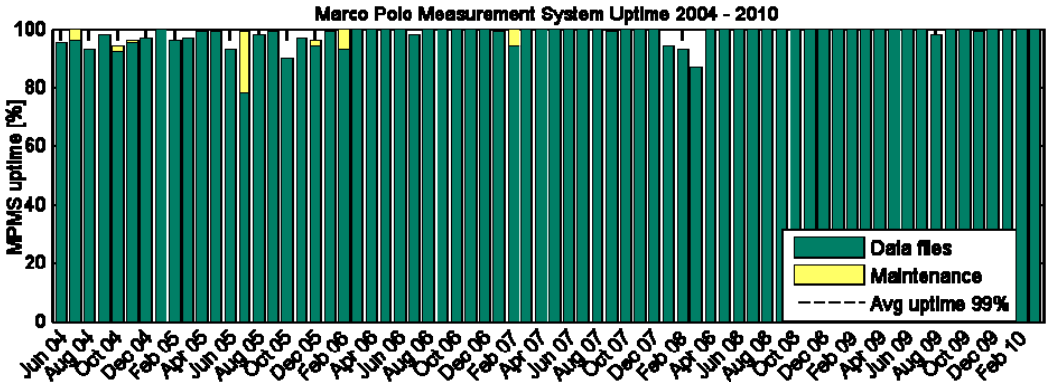


Figure 9 Uptime MPMS

Figure 9 shows the percentage of data files that are logged for each month over the 5½ year period. Also shown is the amount of data files that were lost due to measurement system shutdown (marked yellow) in order to perform maintenance to the system. The average uptime of the system is above 99%. Although the measurements started in June 2004, the actual kick-off of the JIP was only on November 29, 2005, when sufficient participants to the JIP were found. It can be observed that before this kick-off date a larger percentage of data is missing, due to the fact that only low level monitoring of the measurement system was performed, as the project funding was not completed yet. After the kick-off date almost 100% of the data has been successfully logged. This shows the importance of active monitoring of an offshore measurement system.

3.2 Current loop

Current loop has been monitored in January, February and March 2009 with a maximum velocity of 2.9 knots on February 22nd. Also high current velocities were measured during a current loop in July 2006. Throughout these events data has been recorded and detailed analysis of these and other events has been discussed in the following bi-annual progress meetings.

3.3 Hurricanes

During the Marco Polo JIP the TLP has encountered four major hurricanes (Ivan, Katrina, Rita & Ike) and one moderate (Gustav, Ida)

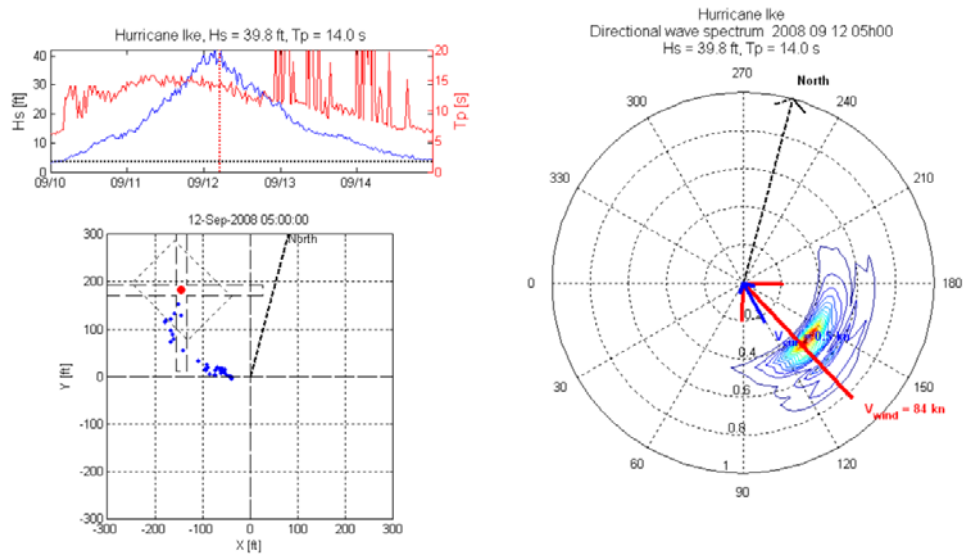


Figure 10 Hurricane Ike measurements

Table 7 shows an overview of all major and moderate hurricanes which were recorded by the Marco Polo JIP including the significant wave height and the minimal distance of hurricanes eye to the platform.

Table 7 Overview hurricanes recorded by Marco Polo JIP

#	Hurricane	Date	Minimal distance from MP [nm]	Hs [ft]
1	Ivan	2004-09-15	120	27.2
2	Katrina	2008-08-29	45	34.7
3	Rita	2005-09-23	60	40.5
4	Gustav	2008-09-01	130	23.4
5	Ike	2008-09-12	70	43.2
6	Ida	2009-11-09	95	18.2

4 DELIVERABLES

4.1 Monthly statistical reports

Monthly statistical reports were issued by the Marco Polo JIP. In Table 8 and Table 9 the reports issued during JIP Marco Polo I and JIP Marco Polo II as listed respectively.

Table 8 Monthly statistical reports JIP Marco Polo I

Month	19811-xx-TM	Month	19811-xx-TM	Month	19811-xx-TM	Month	19811-xx-TM	Month	19811-xx-TM
2004-06	13	2005-03	23	2005-11	07	2006-09	30	2007-06	40
2004-07	15	2005-04	24	2006-01	08	2006-10	31	2007-07	41
2004-08	16	2005-05	25	2006-02	09	2006-11	32	2007-08	42
2004-09	17	2005-06	26	2006-03	10	2006-12	33	2007-09	43
2004-10	18	2005-07	27	2006-04	11	2007-01	34	2007-10	44
2004-11	19	2005-08	02	2006-05	12	2007-02	36	2007-11	45
2004-12	20	2005-09	03	2006-06	14	2007-03	37		
2005-01	21	2005-10	04	2006-07	28	2007-04	38		
2005-02	22	2005-11	06	2006-08	29	2007-05	39		

Table 9 Monthly statistical reports JIP Marco Polo II

Month	19811-xx-TM	Month	19811-xx-TM	Month	19811-xx-TM	Month	19811-xx-TM	Month	19811-xx-TM
2007-12	46	2008-06	52	2008-12	58	2009-06	64	2009-12	71
2008-01	47	2008-07	53	2009-01	59	2009-07	65	2010-01	72
2008-02	48	2008-08	54	2009-02	60	2009-08	67	2010-02	73
2008-03	49	2008-09	55	2009-03	61	2009-09	68	2010-03	74
2008-04	50	2008-10	56	2009-04	62	2009-10	69		
2008-05	51	2008-11	57	2009-05	63	2009-11	70		

The specifications for the long term analyses are reported in:

‘Specifications data analyses Marco Polo Full scale measurements’, MARIN Report no. 19811-01-TM, January 2006

4.2 Design verification reports

‘Marco Polo JIP Stress verification’, Worley Parsons Sea Document 05329-RPT-HL-1003, 02/14/2008

‘Marco Polo JIP Global performance verification’, Worley Parsons Sea Document 05329-RPT-NA-1000, March 19, 2008

‘Marco Polo JIP Tendon and riser assessment’, Worley Parsons Sea Document 05329-RPT-TS-1001, March 21, 2008

‘Marco Polo design verification’, MARIN Report 19811-66-TM, October 2009

4.3 Short term analyses reports

‘Marco Polo Short term analysis, description of analysis method’, MARIN Report 19811-05-TM, November 2007.

‘Tendon fatigue analyses Marco Polo TLP’, MARIN Report no. 21537-01-HSS, October 2008.

4.4 Movies

Movies of the low frequency motions of the TLP (offset) and the environmental conditions during the hurricanes. On image of the video for hurricane Ike is shown in Figure 10.

4.5 Papers

‘Full scale monitoring Marco Polo Tension Leg Platform’, OMAE2007-29635, San Diego 2007, Radboud van Dijk and Henk van den Boom, MARIN

‘Effect of hurricanes on the cumulative fatigue life consumption of a GoM TLP’, OMAE2008-57856, Portugal 2008, Pieter Aalberts and Radboud van Dijk, MARIN, Weizhong Zheng, WorleyParsons Sea.

4.6 Presentations

The table below shows which topics were discussed during the JIP progress meetings. The results can be found in the presentations.

Table 10 Subjects discussed during bi-annual JIP progress meetings

#	Subject	2005-11-29	2006-05-16	2006-10-19	2007-05-03	2007-12-18	2008-05-22	2008-12-11	2009-04-02	2009-11-16	2010-05-10
1	Status MPMS & sensors	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Data qualification										
	- DGPS versus MQK		✓								
	- Waves		✓	✓	✓						
	- Bottom ADCP versus top ADCP			✓	✓						
	- Riser accelerations versus MQK			✓							
3	Long Term Statistics		✓	✓	✓	✓		✓	✓	✓	✓
4	Short term events	✓	✓	✓	✓	✓		✓	✓	✓	✓
5	Design verification										
	- Wind & current coefficients						✓			✓	✓
	- RAO motions and loads		✓	✓	✓	✓				✓	
6	Fatigue consumption					✓			✓	✓	
7	Loop current		✓						✓		✓
8	Hurricane wave conditions										
	- Ivan	✓	✓	✓	✓			✓	✓		
	- Katrina	✓	✓	✓	✓		✓	✓	✓		
	- Rita	✓	✓	✓	✓		✓	✓	✓		
	- Gustav							✓	✓		
	- Ike							✓	✓		
	- Ida									✓	
9	Hurricane wave distributions			✓	✓						
10	Analysis Extreme wave in model basin			✓							
11	Storm surge during hurricanes						✓				
12	Marco Polo radiated and diffracted waves			✓							
13	Tendons										
	- Global analyses		✓	✓	✓			✓			
	- Extreme response analysis				✓						
	- Tension & bending related to offset				✓						✓
14	VIV behavior of risers				✓				✓		✓
15	TLP offset and air gap			✓		✓	✓	✓	✓	✓	✓
16	Rita TLP Offset								✓	✓	
17	GoM earthquake		✓								
18	Summary of conclusions										✓

5 CONCLUSIONS

This section shows general conclusions only. Conclusions with respect to the aim of the project are not included as the project is still within her confidentially period.

● All objectives of the Marco Polo JIP were reached, the design methods were verified and the dynamic behavior of Marco Polo TLP in operational and survival condition were investigated in depth.

● The Marco Polo Monitoring System (MPMS) has been running properly during the monitoring campaign starting from June 2004. The average uptime was above 99%.

● Four major hurricanes were recorded with MPMS during the monitoring campaign.