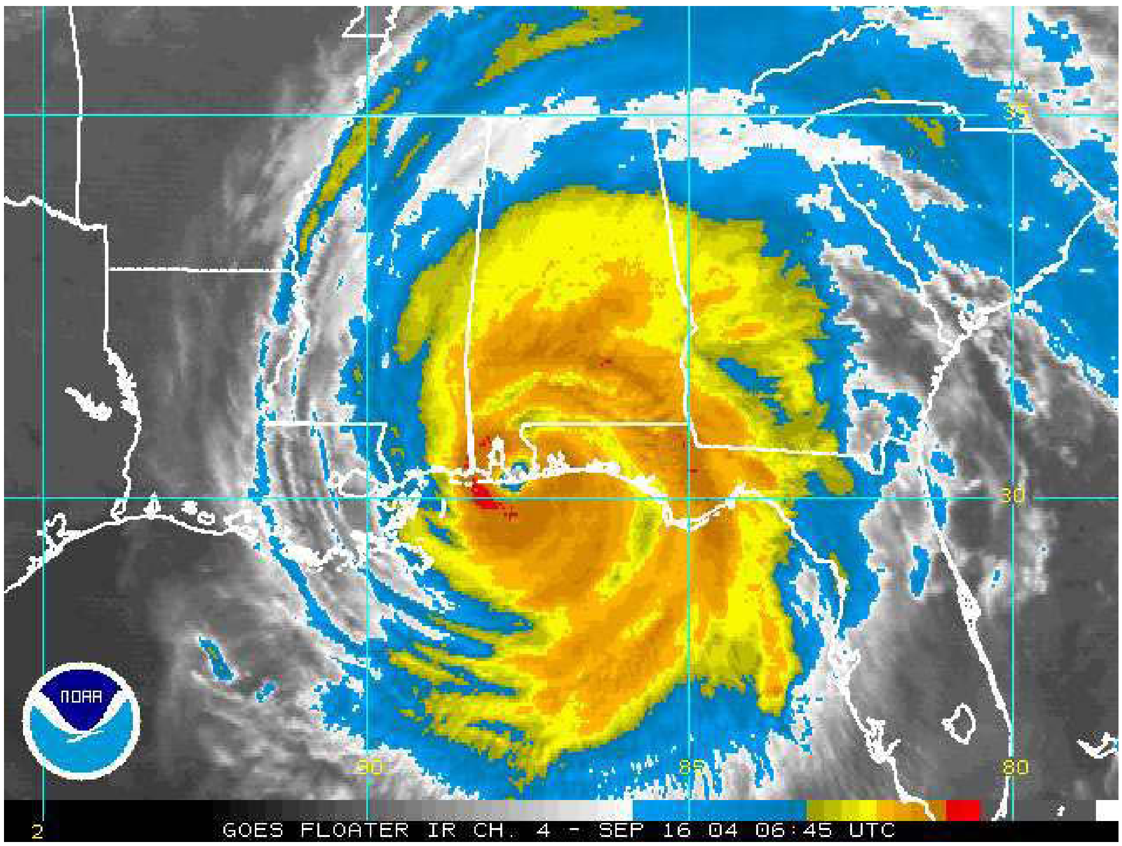
Offshore : Risk & Technology Consulting Inc.
Dr. Malcolm Sharples, Principal Author, Houston, Texas

Post Mortem Failure Assessment of MODUs During Hurricane Ivan

September 2004



Prepared for:

Minerals Management Service

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MINERALS MANAGEMENT SERVICE CONTRACT

Hurricane Ivan: MODU Investigation & Recommendations Sept 2004

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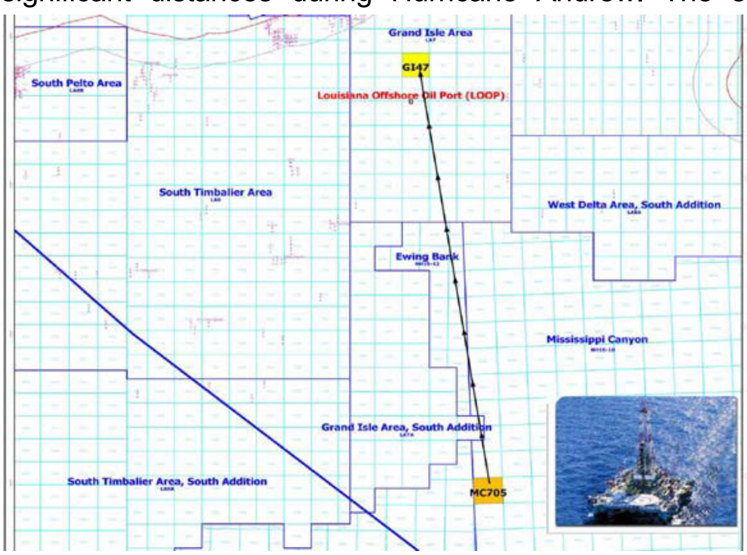
1.0 EXECUTIVE SUMMARY

MODUs in the Gulf of Mexico are a critical part of the infrastructure that brings oil and gas production to the marketplace. Industry standards that allow safe, and economic operations are important both to the community and regulatory interests. Appropriate verification of those standards is an on-going issue particularly because the events by which they can be calibrated such as hurricanes are rare events. A critical part of ensuring that the MODUs are both safe, and affordable is this verification of the criteria and methods used for structural integrity and stationkeeping through the resultant incidents in hurricanes.

In the aftermath of a hurricane there is a unique opportunity to reflect on the events that took place, to chronicle them, and give industry an understanding of their impact on the standards that the industry considers appropriate in maintaining an envelope of safety for MODUs. This study is similar to studies that were previously undertaken in the aftermath of Hurricane Andrew, and Hurricane Lili –sponsored by the MMS to chronicle failures and to seek recommendations from the lessons learned from the failures.

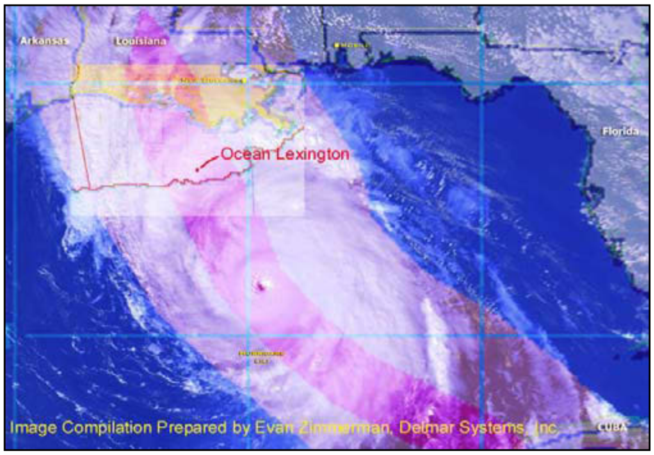
Hurricane Ivan in September 2004 tracked through a high-density corridor of MODUs in the Gulf of Mexico. Five semi-submersibles parted moorings and four left their original locations and were adrift. All but one jackup, the Ensco 64, survived the event. Additionally 7 platforms were destroyed, 33 had major damage and more than 119 minor damage. Some 162 pipeline segments were impacted 4 of which were by third parties. One 18” line had been moved by the storm some 1800 ft off location.

Hurricane Andrew in September 1992 similarly impacted the offshore MODUs in the Gulf of Mexico. In that hurricane 5 MODUs broke adrift and 2 fixed platforms were toppled as a result of the transit to the beach of one of those MODUs. The Zane Barnes, Zapata Saratoga, and Treasure 75 semi-submersibles all moved very significant distances during Hurricane Andrew. The storm snapped seven of the semisubmersible drilling unit Zapata Saratoga's eight anchor chains and drove the unit some 40 miles to the north until it was beached coming in close proximity to the LOOP (Louisiana Offshore Oil Port), facility en route. After breaking loose from its location, the Zane Barnes collided with 2 platforms as it was propelled by sustained winds of 140 miles per hour until it beached. The anchors from the Treasure 75 dragged along the bottom for approximately 4 miles and ruptured a



large Texaco pipeline spilling 2000 BBL of oil: this incident was one of the worst spills during Hurricane Andrew. In Hurricane Andrew there were 16 pipeline failures from MODUs, which drifted from their anchored positions during the storm: the damage occurring from the anchors or from the anchor chains of the drifting vessels. The majority of pipeline/flowline failures occurred on lines with sizes between 4” and 10” in diameter. One 20” oil line was damaged from the anchor of a drifting vessel, which resulted in significant release of oil into the sea. (Ref. 3).

Hurricane Lili in October of 2002 impacted the MODUs to a lesser degree than Hurricane Ivan. Two semisubmersibles broke moorings, the Celtic Sea and the Ocean Lexington, however only the Ocean Lexington came adrift. It drifted to the beach with no incident. Two jackups were destroyed. In the case of the Dolphin 105, the airgap was insufficient and breaking waves hit the main hull: the guidance offered, for 100-year deck elevations by API RP2A was insufficient for a breaking wave crest elevation in shallow water.



The Rowan Houston casualty resulted from an overload of the jackup well beyond its design load and well beyond what is standard industry practice in the Gulf of Mexico for siting the rig: generally a 10-year return period hurricane. Age did not appear to contribute to the incident, nor was there any contribution in degradation of the location from a close-by spud-can hole.

The loss in Hurricane Lili was more severe to the production structures: 17 steel jacket platforms damaged/failed and 120 pipeline segments were damaged, only one of which was attributed to a MODU: the Rowan Houston where the rig substructure went overboard and impacted a pipeline. Of the pipeline segments damaged, about 93% were small lines and 60% were associated with platform risers.

The various MODU owners and oil companies with casualties in Hurricane Ivan were very cooperative with divulging information, which was helpful to the study.

The incidents that occurred with MODUs in Hurricane Ivan led to no injuries, no major pollution and no platforms toppled. The semi-submersibles loss of the station keeping was due to very similar circumstances that led to the drifting of semi-submersibles in Hurricane Andrew, and Hurricane Lili.

The investigation into semisubmersible incidents led to the conclusion that the design criteria for the location had been exceeded: the combination of windspeeds, wave height and current were considerably higher than the API and other industry-used standard criteria. Overall it is not desirable to have a situation where semi-submersibles break adrift of their moorings and potentially impact other structures, particularly if those other structures are significant either in terms of oil & gas production or because of their use as part of the critical infrastructure.

Since Hurricane Ivan two further hurricanes have added to the list of damaged MODUs. In Hurricane Katrina in August 2005, five semisubmersible MODUs lost station, and two were listing. 1 semisubmersible MODU was stuck under a bridge. Four jackups became constructive total losses, and four more were damaged.

In September 2005, ten semisubmersibles were adrift with the advent of Hurricane Rita. Four jackups were destroyed and 6 jackups were adrift. Altogether some 69 platforms were also destroyed.

It was fortunate that in these incidents there were no collisions of major consequence.

While the incidents in Hurricane Katrina and Rita have not been part of this study, nor at the time of writing have they been subject to a complete investigation in a publicly available document, from what is known about the situation it would be expected that the conclusions of the Hurricane Ivan study would most likely be similar to the situations in Hurricane Katrina and Rita also.

A number of actions have been taken by industry, and the Minerals Management Service and with the cooperation of the USCG since Hurricane Ivan. The result, so far, has been two documents issued:

- API "Interim Guidance for GOM MODU Mooring Practice", Report by API RP 2SK WG
- API RP95J – "Gulf of Mexico Jackup Optimization during Hurricane Season"

Both these documents improve the situation and will reduce and perhaps prevent any further incidents of MODUs being adrift in hurricanes. Since it is not possible to guarantee no MODUs adrift these documents, adopted as practice, will make the risk as low as reasonably practical. Further guidance will be issued as a joint industry study on moorings during hurricanes continues its work.

This MMS sponsored post mortem assessment of the MODUs in Hurricane Ivan is an excellent method of promulgating the information to industry. It remains for industry in the various committees and standards organizations to react to this information. MMS's encouragement to share knowledge of these incidents and insights that result from the investigation is a critical part of encouraging the development of appropriate standards for the MODU industry. Such a pro-active initiative is reflective of MMS's concern for safety.

2.0 CONVERSIONS

Unit Conversion Chart			
Conversion Factors for Different Units of Measurements			
Quantity	SI Unit	Other Unit	Inverse Factor
Length	1 m 1 km 1 km	3.28 feet (ft) 0.54 nautical miles 0.62 mile	0.305 m 1.85 km 1.601 km
	1 nautical mile or n. mi.	1.151 miles	
Velocity	1 m/sec	1.94 kts	0.514
	1 cm/sec	.00194 kts	514.9
	1 m/sec	1.237 mph	0.809
	1 kts	1.1516 mph	0.868
Conversion Factors for Different Wind Durations			
	30-min Average	0.98 for 1-hr Average	1.02-for 30 min
	30-min Average	1.09 for 10-min Average	0.92 for 30-min
	30-min Average	1.24 for 1-min Average	0.81 for 30-min
	30-min Average	1.53 for 3-sec Gust	0.65 for 30-min
	1-min @ 10 m	1.1 for 1-min @ 20 m	0.91 for 1-min @10 m

3.0 LIST OF TERMS AND ABBREVIATIONS

The following words and phrases are used in this report have the meanings assigned below:

100-year Return:
The (storm/wind/wave/current) expected to be of this value once in every 100 years at this specific location.

10-year Return:
The (storm/wind/wave/current) expected to be of this value once in every 100 years at this specific location.

AHV:
Acronym for Anchor Handling Vessel

Airgap:
Distance between mean low water and the bottom of a hull or enclosed deck

API RP2I:
American Petroleum Institute Recommended Practice, Committee 2, on Inspection of Mooring Chain

API RP2SK:
American Petroleum Institute Recommended Practice, Committee 2, on Station Keeping

API RP95J:
American Petroleum Institute Recommended Practice, Committee 2, on Gulf of Mexico Jackup Optimization during Hurricane Season

BOP:
Acronym for Blowout Preventer

BS:
Acronym for Breaking Strength

Deepstar:
A Joint Industry funded project that developed wind, waves, and currents for some specific work being undertaken in deepwater. A letter was issued by the Deepstar Committee to discourage use of these values as a general guideline since they had not been subject to appropriate scrutiny.

Fairlead:
The device attached to a rig through which the chain or wire goes in departing from the vessel.

GOM:
Acronym for Gulf of Mexico

Hmax:
Abbreviation for the maximum wave height (In deepwater rough rule-of-thumb is 1.86 * Hs).

Hs:
Abbreviation Significant wave height. The average of the top 1/3rd of the waves.

Kt:
Abbreviation for nautical miles per hour

MLT:
Marathon LeTourneau - a designer of mobile jackups later known as LeTourneau.

MMS:
Minerals Management Service or the U.S. Dept of the Interior

MODU:
A type of vessel Mobile Offshore Drilling Unit

NOAA:
National Oceanographic and Atmospheric Administration

NTL:
Notice to Lessees – a notice by which MMS interfaces with lessees and the industry in general about regulatory items and changes.

OTC:
Offshore Technology Conference - annual conference with papers held in Houston on the first week of May each year

Pre-Set Mooring:
A mooring which has been set up on the seabed ready to hook up a MODU prior to the vessel actually arriving at location.

Purple Finder:
Pole Star's web-based service providing a way of automatically tracking vessel movements in real time. The system utilizes the GMDSS Sat-C terminal already installed on most ocean-going vessels, or specialized GPS-enabled satellite tracking terminals including Inmarsat D+, Mini C, and Iridium

ROV:
Acronym for Remote Operated Vehicle

SMDL:
Acronym for Subsea Methanol Distribution Line

SSHS:
Acronym for Saffir-Simpson Hurricane Scale

SSHS Category One Hurricane:
Winds 74-95 mph (64-82 kts or 119-153 km/hr). Storm surge generally 4-5 ft above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage. Hurricane Lili of 2002 made landfall on the Louisiana coast as a Category One hurricane.

SSHS Category Two Hurricane:
Winds 96-110 mph (83-95 kts or 154-177 km/hr). Storm surge generally 6-8 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings.

SSHS Category Three Hurricane:
Winds 111-130 mph (96-113 kts or 178-209 km/hr). Storm surge generally 9-12 ft above normal. Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Flooding near the coast destroys smaller structures with larger structures damaged by battering from floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 miles (13 km) or more. Evacuation of low-lying residences with several blocks of the shoreline may be required. Hurricanes Jeanne and Ivan of 2004 were Category Three hurricanes when they made landfall in Florida and in Alabama, respectively.

SSHS Category Four Hurricane:
Winds 131-155 mph (114-135 kts or 210-249 km/hr). Storm surge generally 13-18 ft above normal. More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 miles (10 km).

SSHS Category Five Hurricane:
Winds greater than 155 mph (135 kts or 249 km/hr). Storm surge generally greater than 18 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5-10 miles (8-16 km) of the shoreline may be required. Only 3 Category Five Hurricanes have made landfall in the United States since records began: The Labor Day Hurricane of 1935, Hurricane Camille (1969), and Hurricane

Andrew in August, 1992. Hurricane Camille struck the Mississippi Gulf Coast causing a 25-foot storm surge, which inundated Pass Christian. Hurricane Andrew of 1992 made landfall over southern Miami-Dade County, Florida causing 26.5 billion dollars in losses--the costliest hurricane on record. In addition, Hurricane Gilbert of 1988 was a Category Five hurricane at peak intensity and is the strongest Atlantic tropical cyclone on record with a minimum pressure of 888 mb.

UTC:
Coordinated Universal Time or UTC, also sometimes referred to as "Zulu time" or "Z", is an atomic realization of Universal Time (UT) or Greenwich Mean Time (GMT), the astronomical basis for civil time. Time zones around the world are expressed as positive and negative offsets from UT.

4.0 INTRODUCTION

Hurricane Ivan in September, 2004 tracked through a high-density corridor of oil and gas infrastructure in the Gulf of Mexico. A study was commissioned by the Minerals Management Service of the Department of the Interior (MMS) to chronicle the incidents that affected the infrastructure of oil and gas equipment: the specific task was to gather information, examine and review Mobile Offshore Drilling Units (MODUs) loss of stationkeeping ability during Hurricane Ivan. The study relies heavily upon the work of Oceanweather who carried out the meteorological hindcast (Ref. 1 & 2).

MMS had commissioned a study in the aftermath of Hurricane Andrew in 1992 (Ref 3). This study investigated failures associated with mobile offshore drilling units (MODUs) during intense Gulf of Mexico hurricanes. The study addressed jack-up units, drillships, drilling barges, and semi-submersible drilling units. The study also addressed mooring and abandonment procedures for units exposed to hurricane wind, wave, and current forces and provided recommendations for securing procedures for MODUs in advance and during hurricanes. The project used MODU failure and survival experiences from past hurricanes including Andrew, Betsy, Camille, Carmen, Hilda, and Juan to verify the securing procedures.

Additionally MMS had commissioned a study in the aftermath of Hurricane Lili in 2002 (Ref 4). The study reviewed information learned in Hurricane Andrew and added to it the information available from industry related to the Hurricane Lili experience.

At the time of Hurricane Ivan there were approximately 112 jackups in the Gulf of Mexico (compared to 142 jackups during Hurricane Lili) and 32 semisubmersibles (compared to 39 semi-submersibles during Hurricane Lili)). Of those only 3 jackups were impacted and only 1 of those became a constructive total loss. There was no loss of life or pollution associated with that event. Of the semisubmersibles in the Gulf of Mexico only 5 were impacted. Four left their general location and became adrift and 1 moved approximately 3000 ft, (including the distance moved within the mooring pattern) with some anchor drag.

A variety of sources were used to identify rigs that had potentially been impacted by the hurricane. Most of the information was obtained directly from drilling contractors, and oil companies involved, and some from the MMS files.

4.1 OVERVIEW OF IVAN AND MMS ANNOUNCEMENT:

In September 2004, Hurricane Ivan, a full category-4 storm, moved through the U.S. Gulf of Mexico (GOM) with extreme winds and large waves exceeding the 100-year design criteria of the facilities in its path. Of the more than 4,000 offshore oil and gas facilities and 33,000 miles of pipelines in Federal waters of the GOM, approximately 150 facilities and 10,000 miles of pipelines were in the direct path of Hurricane Ivan. The oil and gas industry submitted numerous damage reports to MMS. The range of damaged facilities included mobile drilling rigs, offshore platforms, producing wells, topside systems including wellheads and production and processing equipment, risers, and pipeline systems that transport oil and gas ashore from offshore facilities. The MMS received industry reports indicating that seven platforms were destroyed, six platforms had major damage, five drilling rigs had major damage and a substantial amount of oil and gas production remained shut-in because of damage to pipelines.

5.0 HURRICANE GENERAL INFORMATION:

Ivan was a classical, long-lived Cape Verde hurricane that reached Category 5 strength three times on the Saffir-Simpson Hurricane Scale (SSHS). It was also the strongest hurricane on record that far south east of the Lesser Antilles. Ivan caused considerable damage and loss of life as it passed through the Caribbean Sea. (Ref 5).

Ivan was declared a Tropical Storm on 3 September. Ivan continued on a generally westward motion south of 10°N latitude and steadily strengthened, becoming a hurricane on 5th of September centered about 1000 n mi east of Tobago in the southern Windward Islands. It intensified in a short period of time reaching its first peak intensity of 115 kts on 6 September. This made Ivan the southernmost major hurricane on record. Reports from the aircrew indicated that Ivan had strengthened to a strong category 3 (SSHS) hurricane as the center passed about 6 n. mi. south-southwest of Grenada. The eye diameter at that time was about 10 n. mi., and the strongest winds raked the southern portion of the island.

After passing Grenada Ivan reached its second peak intensity -- 140 kts and category 5 strength (SSHS) – by 6 am on the 9th September. As Ivan passed south of Jamaica it weakened to category 4 strength, but later intensified to category 5 strength a second time. Ivan reached its third peak intensity at 1800 UTC 11 September. However, Ivan only maintained its maximum intensity of 145 kts and category 5 status for 6 hours before it weakened back to a category 4 hurricane on 12 September.

Ivan fluctuated between category 4 and 5 as it passed through the Caribbean and into the Gulf and over the oil and gas facilities offshore Gulf of Mexico.
Ivan weakened only slowly and made landfall as a 105 kts hurricane (category 3). By this time, the eye diameter had increased to 40-50 n. mi., which resulted in some of the strongest winds occurring over a narrow area near the southern Alabama-western Florida panhandle border.

A storm surge of 10-15 ft occurred along the coasts from Destin in the Florida panhandle westward to Mobile Bay/Baldwin County, Alabama. There was also a possible record observed wave height of 52.5 ft reported by the NOAA Buoy 42040 located in the north central Gulf of Mexico, south of Alabama.

Figure 1: Location of buoy recording 52.5 ft significant wave height in Hurricane Ivan

Ivan caused extensive damage to coastal and inland areas of the United States. Portions of the Interstate 10 bridge system across Pensacola Bay, Florida were severely damaged in several locations as a result of severe wave action on top of the 10-15 ft storm surge. As much as a quarter-mile of the bridge collapsed into the bay. Thousands of homes the three-county coastal area of Baldwin, Escambia, and Santa Rosa were damaged or destroyed. Cleanup efforts alone in Escambia County resulted in debris piles that were more than three-quarters of a mile long and 70 feet high. In all, Ivan was the most destructive hurricane to affect this area in more than 100 years. Figure 2 and Figure 3 reference the track of Hurricane Ivan, and the wind observations in order to provide an overview, as posted by the National Hurricane Center (Ref 5).

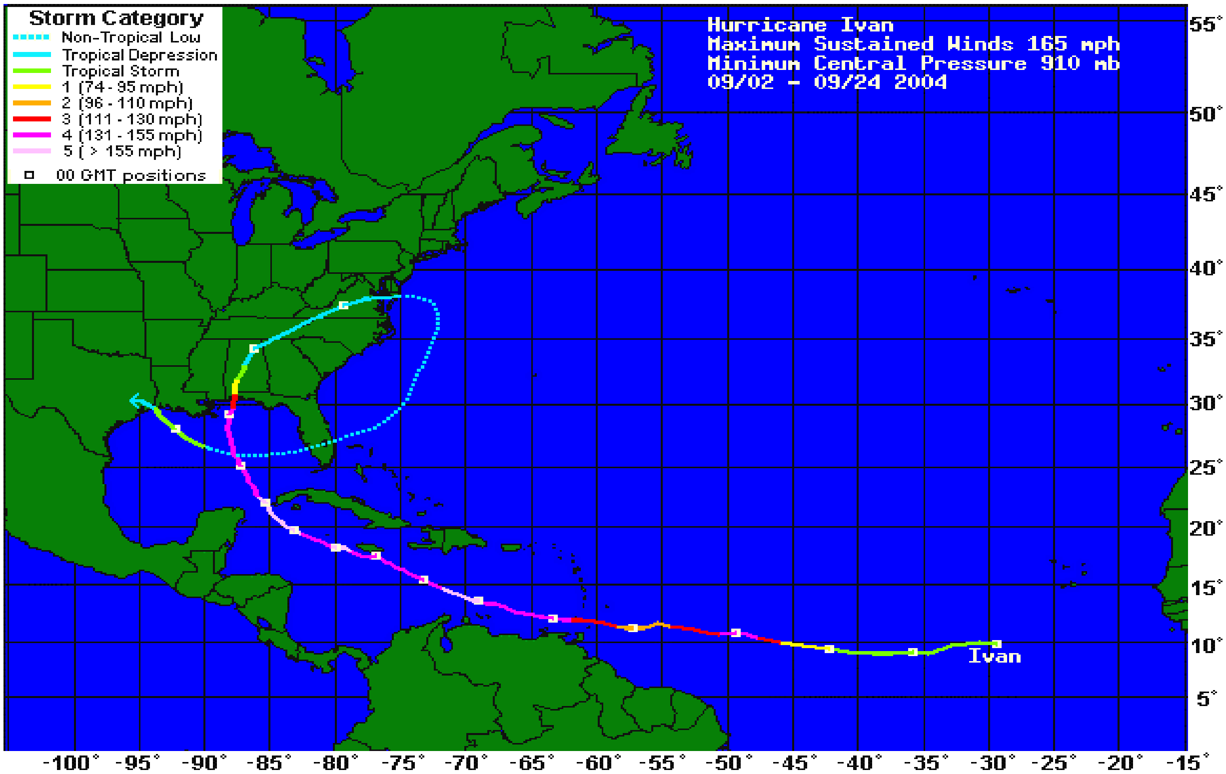


Figure 2: Track of Hurricane Ivan through the Caribbean and Gulf of Mexico

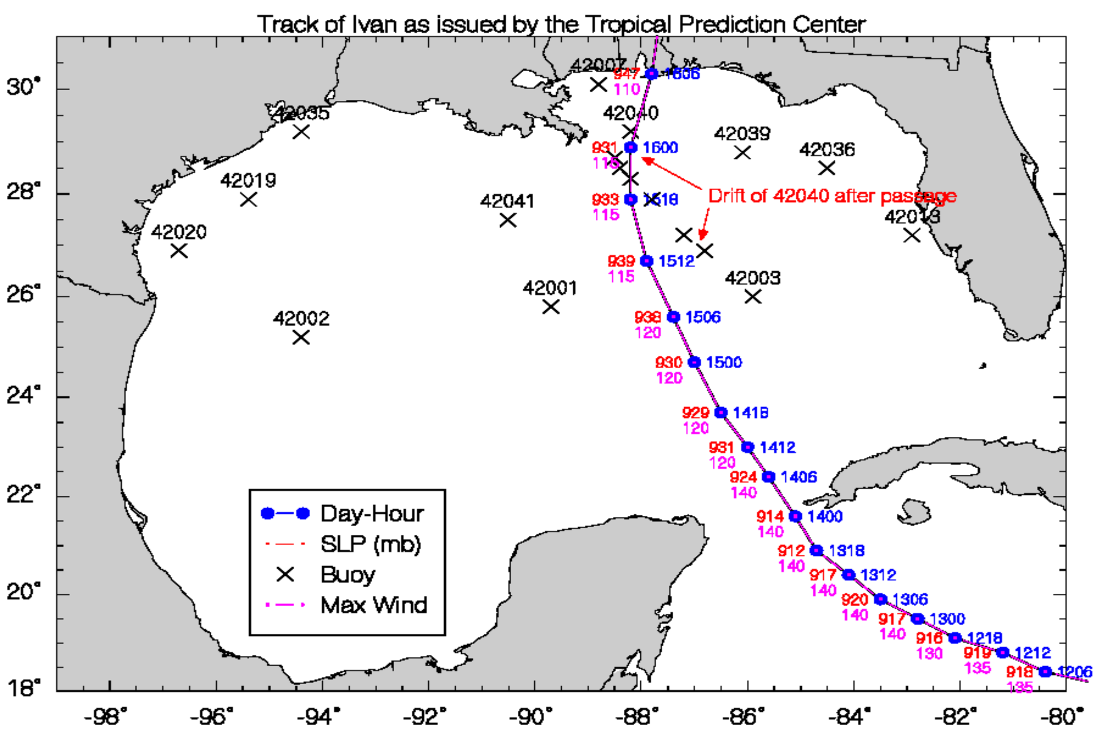


Figure 3 Track of Ivan (initial landfall only) in Northern Gulf with fix time (blue, GMT, Day-Hour format), central pressure (red, mb) and NDBC buoy locations (black).

Figure 4 references the wind observations in order to provide an overview, as posted by the National Hurricane Center (Ref 5).

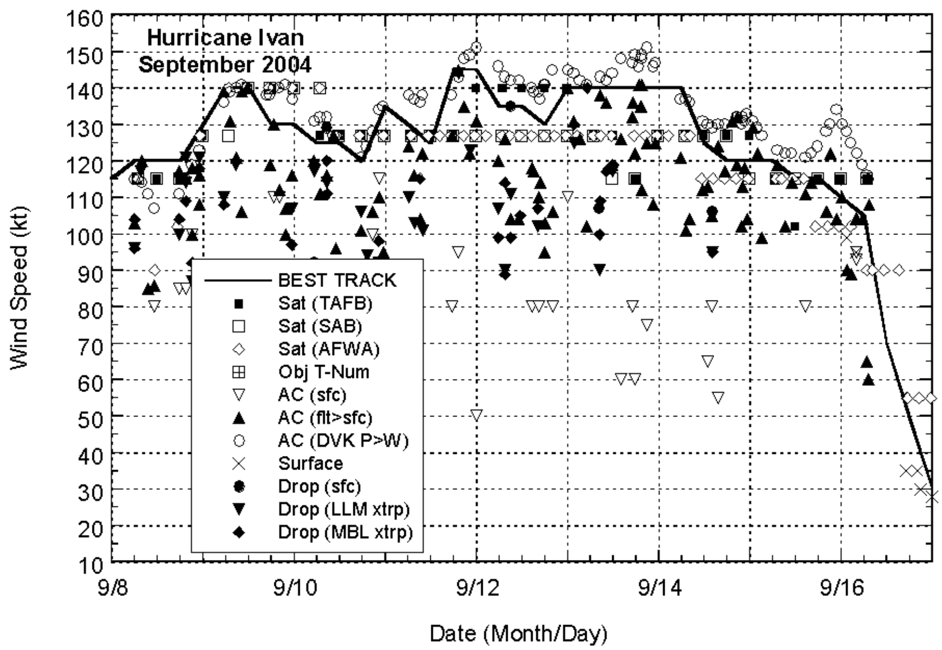


Figure 4: Selected Wind Observations for Hurricane Ivan

Note that the wind speed drops off prior to the time of landfall. This occurs quite often with hurricanes and has been the reason that in revising the metocean data, the industry has tended to discount the information from pre-1950's hurricanes where all that is known is the central pressure at time of landfall. Thus the predictions may have been underestimating the strength of hurricanes in the distant OCS areas, for the pre-1950s when Hurricane Hunter aircraft were dispatched to obtain better measurements in hurricanes.

Figure 5 references selected pressures for Hurricane Ivan in order provide an overview.

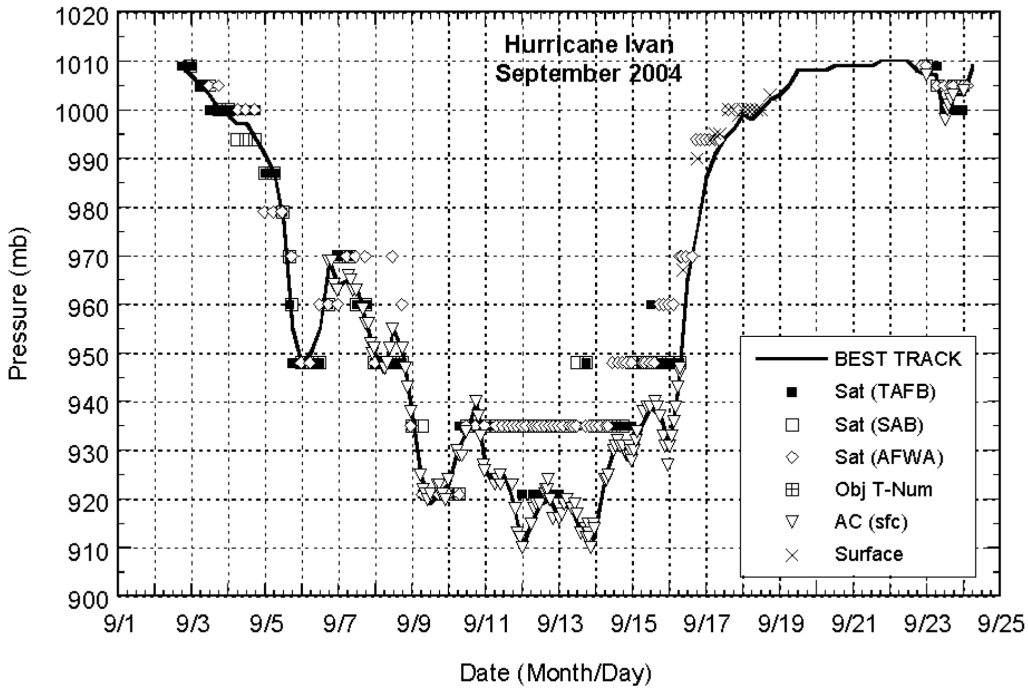


Figure 5: Selected Pressure Observations for Hurricane Ivan

Figure 6 shows the frequency and intensity of hurricanes throughout the season. Note that September when Hurricane Ivan occurred is the height of the most frequently severe hurricanes.

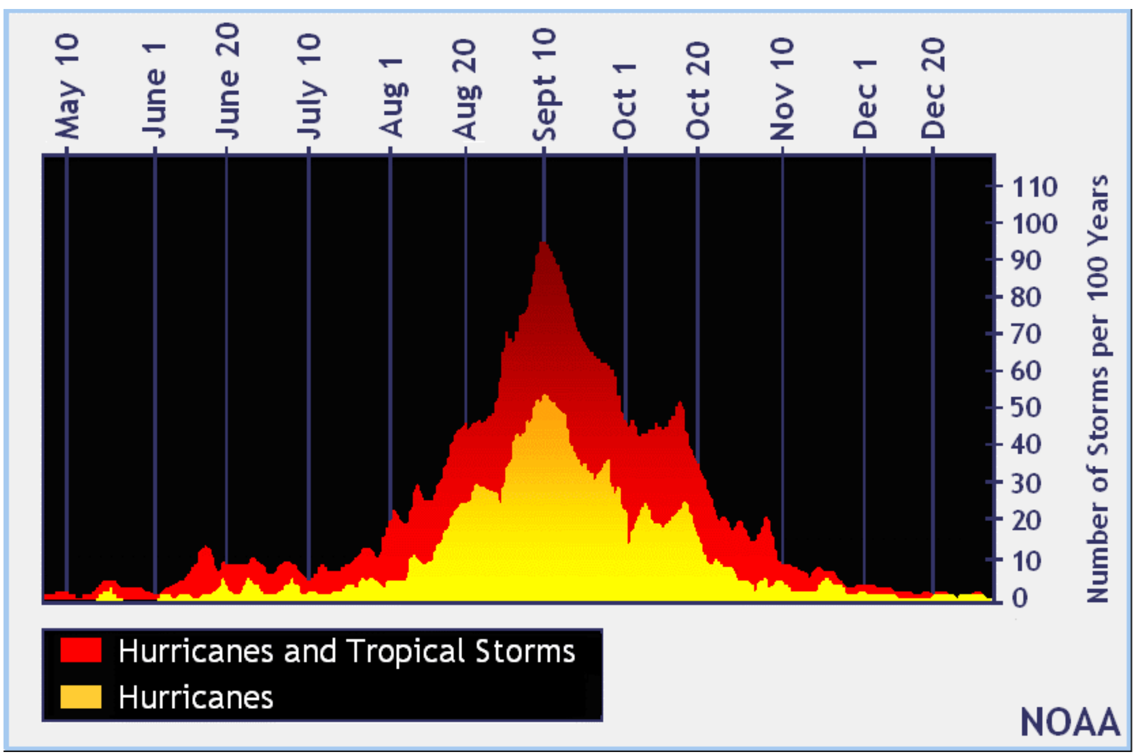


Figure 6: Showing Monthly Variances in Frequency of Intense Hurricanes and Tropical Storms

6.0 METEOROLOGICAL INFORMATION:

The performance measure of the MODUs is judged against industry criteria for metocean information compiled for design. The Oceanweather study (Ref 1) chronicles the information after the storm and this can then be compared to the design metocean information. It has been reported (Ref 6), that Ivan was said to be a 1/2500-year storm for wave heights and a 1/700 storm for windspeeds according to expert opinion (see also Ref 32).

Examining the information available for general design of semisubmersible moorings in the Gulf of Mexico Table 1 gives a comparison of Gulf of Mexico API figures for both 10 (Ref 7) and 100-year (Ref 8) period storms. Wind might represent typically 60% of the total mooring force and so is the most important parameter; currents following next in importance.

The values of the extreme winds, waves and currents have changed since Hurricanes Ivan, Katrina and Rita. A group of metocean experts has come together and is currently providing consensus criteria for new post-Rita values of extremes. Some preliminary numbers are shown in Table 1 – since they are still under discussion they should be taken with considerable caution, particularly in the values of currents.

The moorings of semisubmersibles were compared in this study to industry-used values as shown in Table 1, appropriate to the criteria in API RP2SK (Ref 9), which references either 5-year or 10-year data to be used as a minimum. Data from Deepstar (Ref 10) which is a well-known reference for deepwater technology is sometimes used. The Deepstar “high wave” values have occasionally been used for criteria on which to design moorings, but the high wave case is also a lower windspeed case and since waves and currents dominate the loads the high wind case values should be used for mooring design. The Deepstar Committee does not endorse the use of these criteria for design. Segments of the data were obtained from Ref 11, which gave other references to metocean conditions.

Data used by industry can vary. Other similar figures are quoted in Ref 12 as being appropriate to the Gulf of Mexico environmental characteristics. In previous studies of semisubmersibles the 10-year return period values obtained from different meteorological experts was noted to vary considerably (Ref 4).

It should also be noted that the reported windspeeds as “sustained winds” by NOAA are further defined as 1-min sustained average winds at the standard 10 m height (Ref 15).

QUOTE:

Dear Dr. Sharples,

Todd has referred your question to NHC's Office of Public Affairs for action.
The wind "speed" in our "Public Advisories" are maximum winds, represented as 1-minute average sustained.

Respectfully submitted,

Frank Lepore
Public Affairs Officer
National Hurricane Center
11691 S.W. 17th Street
Miami, FL 33165-2149

E-Mail: Frank.C.Lepore@noaa.gov
Frank.Lepore@noaa.gov
URL: http//www.nhc.noaa.gov
Telephone: (305)229-4404
Facsimile: (305)553-1901

Additionally:

Malcolm, I spoke to our Science Operations Officer (Dr. Christopher Landsea) and he said yes, it would be the standard 10-meter height.

Sincerely,
Christopher Juckins
Meteorologist / Webmaster
National Hurricane Center | http://www.nhc.noaa.gov
Tropical Prediction Center | nhcwebmaster@noaa.gov

UNQUOTE

								"Gulf of Mexico Metocean" IADC/SPE 74503			
Return Period (Years)	**API[1] 5**	**API[1] 10**	**Post Rita 10**	**API 100**	**Post-Rita 100**	**IVAN Max [4]**	**IVAN[2]**	**10**	**25**	**50**	**100**
Wind											
3-sec Average Gust (m/sec)		45.7		68.6							
1-min Mean @ 10m (mph)		82.9	91.9	124.4	140.6		**110**				
1-min Mean @ 10m (kts)	**63.0**	**72.0**	**79.8**	**108.0**	**122.1**	**124**	95.7	**70.0**	**80.0**	**87.5**	**95**
10-min Mean @ 10m (m/sec)											
Wave											
Significant Wave (m)		9.1	9.69	12.2	14.9	**16.8**	15.4	**7.9**	**9.6**	**10.9**	**12.2**
Significant Wave (ft)	**14.5**	**30.0**	**31.8**	**40.0**	**48.9**	55.2		**26.0**	**31.6**	**35.8**	**40**
Peak Period Tp (secs)		12.7	**11-14**	14.0	**13.4-16.4**	13.7		**13.0**	**13.4**	**13.7**	**14**
Maximum Wave (m)		14.6		21.3		31.3					
Maximum Wave (ft)		**48.0**		**70.0**		102.7	**94**				
Current											
Wind-driven Surface (m/sec)	0.26	0.93	1.08	1.00	1.75	**2.6**	2.8	**0.7**	**1.8**	**2.0**	**2.3**
Wind-driven Surface (kts)	**0.5**	**1.80**	**2.10**	**2.00**	**3.4**	5.10	**5.4**				

	DEEPSTAR	**DEEPSTAR**		**DEEPSTAR**	
Return Period (Years)	**5 (Ref 10)**	**10 [2]**		**100 [2]**	
1-MIN Mean@ 10 m (kts)	**50.0**	**68.0**		**99.2**	
Significant Wave (ft)	**20.0**	**26.0**		**40.0**	
Surface Current (kts)	**0.50**	**1.50**		**2.10**	

1. Source: MMS Study on Hurricane Andrew
2. Source: Noble Presentation: stated to be measured from Nakika Platform (Ref 5)
3. Source: Noble Presentation: stated to be from David Tein Consulting Engineers (Ref 5)
4. Source: Oceanweather; API Seminar - Ivan said to be 1/2500 year storm for wave; 1/700 year storm for wind.

Bold - Actual Values (Others are calculated values)

The current direction can be taken to be up to 30^0 clockwise of the wind
The wave direction can be taken to be up to 20^0 clockwise of the wind
Note: this information for Post-Rita values should be confirmed from the Interim Guidelines.

Table 1: Extremes compared to API values as reference points.

7.0 MODU POSITIONS IN RELATION TO HURRICANE IVAN TRACK

Figure 7 gives a graphic representation of the path of Hurricane Ivan showing the approximate extent of the hurricane force winds and the location of each of the MODUs in relation to the storm on the 15th of September at the time indicated. Also shown is the storm track. The Deepwater Nautilus was located to the east of the storm track. North of the Deepwater Nautilus the track goes through between the Noble Jim Thompson to the west of the track and the Ocean Star to the east. The Ocean America would be on the east side of the track and about the right distance to see the full impact of the eyewall: the most ferocious part of the storm. Todco's THE 200 was directly on the path. Figure 8 shows the MODUs of interest plotted on the map issued with the MMS NTL (Ref 16). The full NTL is given in Appendix A.

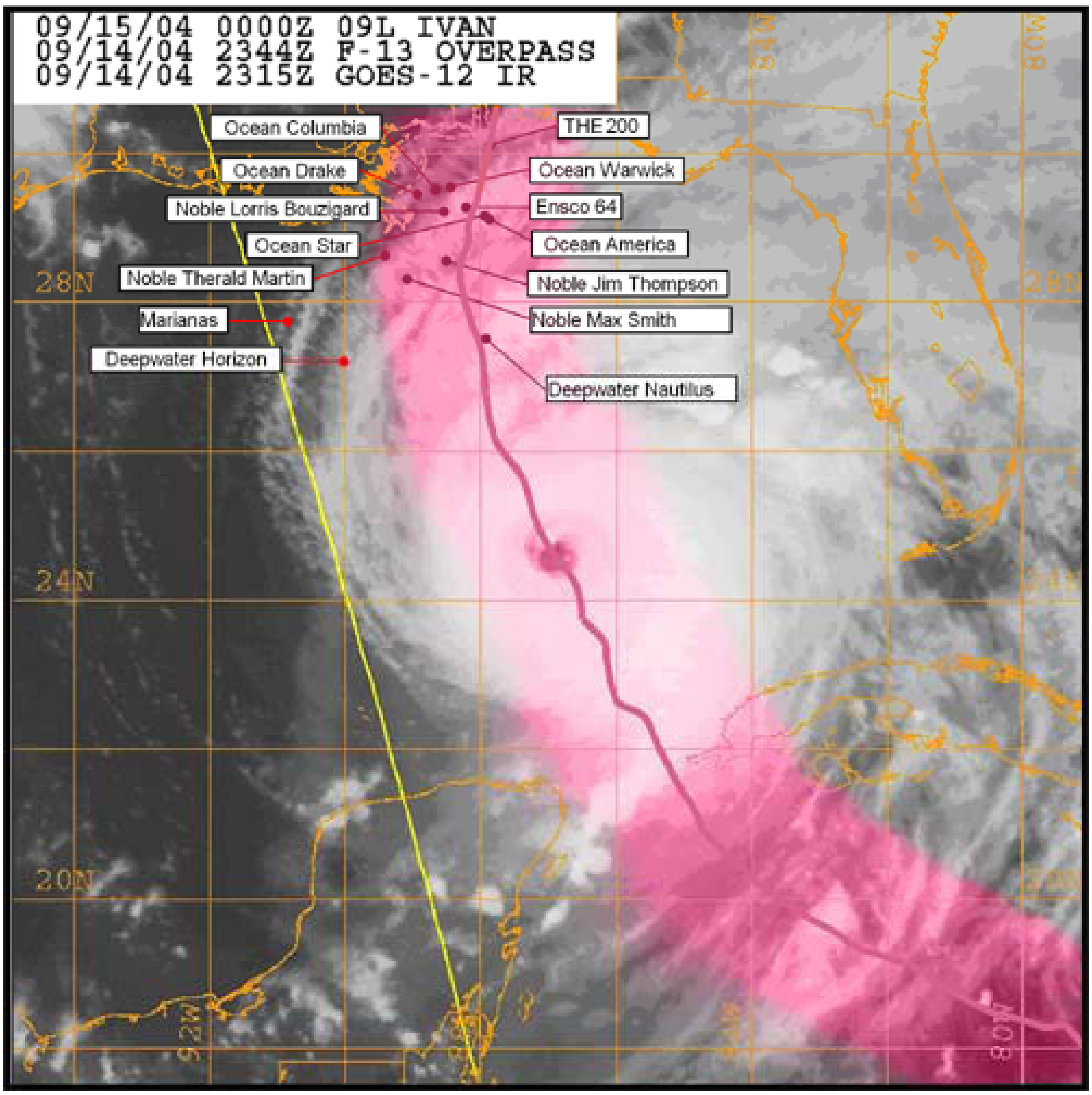


Figure 7: Location of MODUs Close by the Path of Hurricane Ivan

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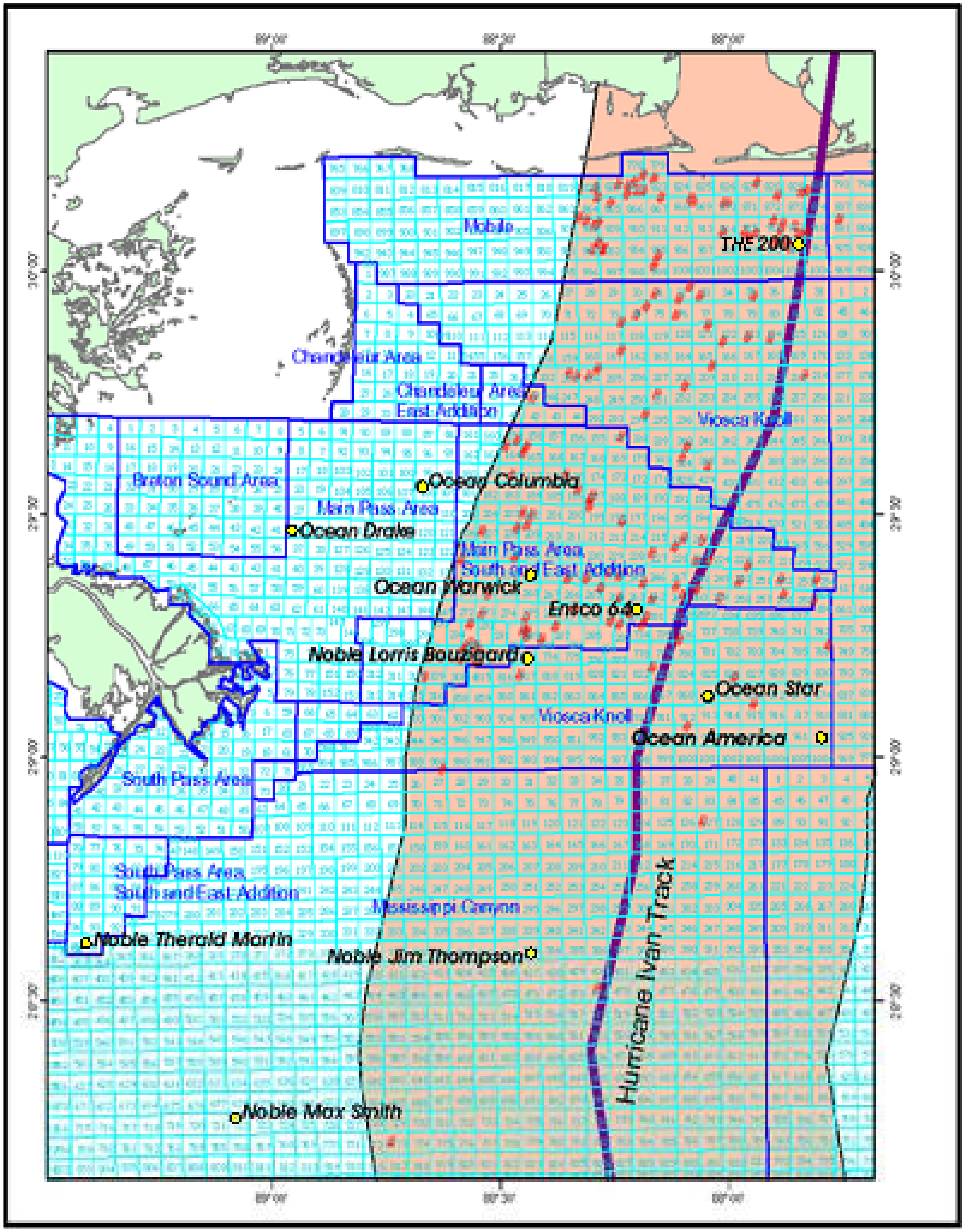


Figure 8: MODUS of Interest in Hurricane Ivan (excluding Deepwater Nautilus to the South of the Map).

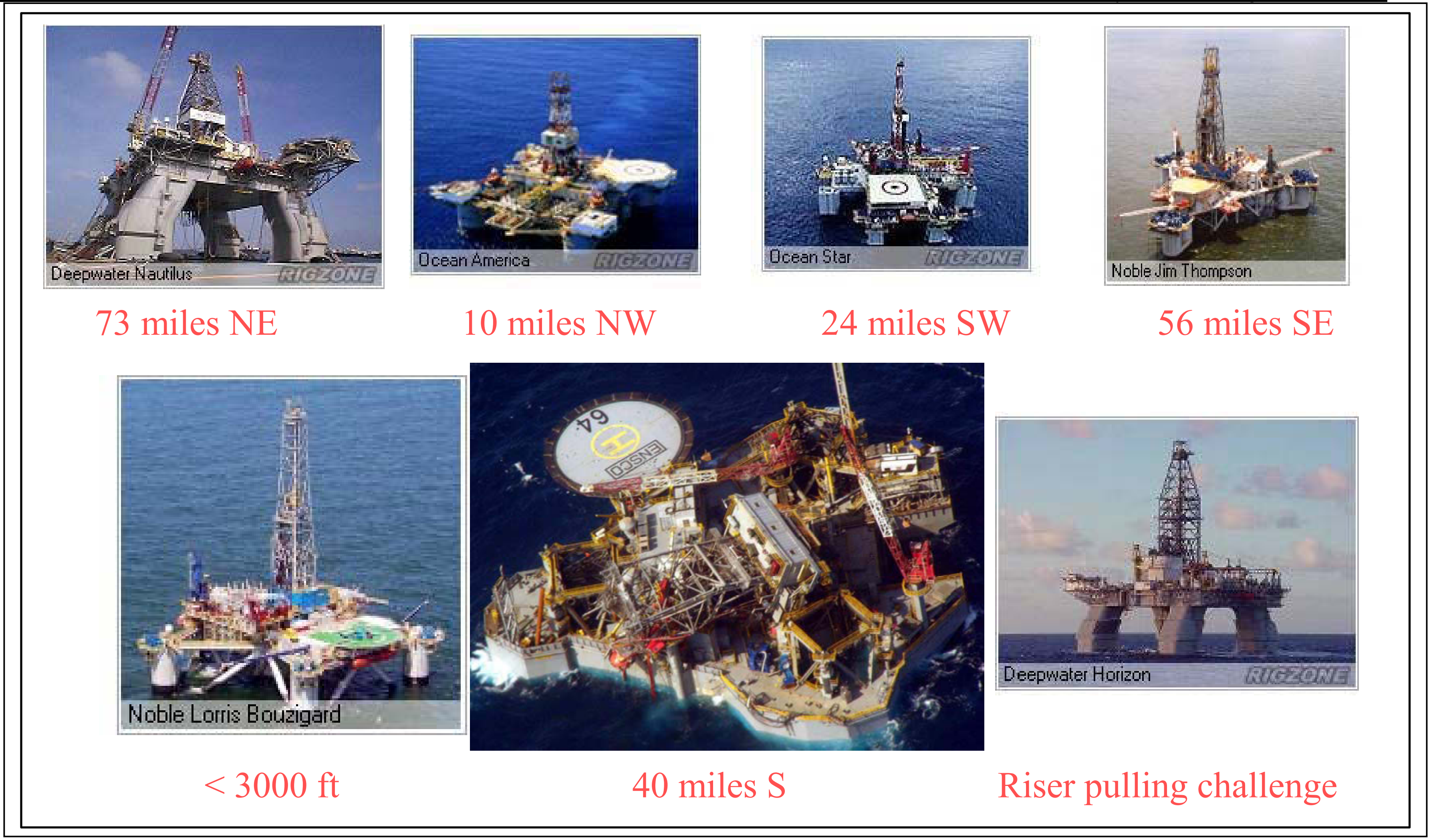


Figure 9: Hurricane Ivan MODU Mooring Issues

Figure 9 shows each of the MODUs that had stationkeeping issues. Note the Deepwater Horizon is self-propelled, and the Ensco 64 is a jackup. The other vessels depicted are semisubmersibles that are moored to their respective locations and where the moorings broke in Hurricane Ivan.

8.0 SEMI-SUBMERSIBLE MODUS: HURRICANE IVAN

The location designation for each semi-submersible, and mooring arrangements are described in Table 2 together with the results of any damage due to the hurricane's passage. Included are distances travelled for those that were unable to maintain station. Included in the list is the Noble Max Smith which weathered the storm with no issues. The Deepwater Horizon details are noted: it is self-propelled and thus the distance it travelled was in an attempt to lower the current on the riser that was hanging below the vessel. The vessel was at all times under command.

The study was not able to confirm the mooring arrangements, or the details of mooring failure of two of the vessels: Ocean Star and Ocean America.

Each of the vessels is described in subsequent sections with relevant information where known.

Table 3 describes each semi-submersible, the Name, Design, Builder, Year of Build, Oil Company whose lease the rig was on, the advertised waterdepth, the location, type of mooring, actual waterdepth at the location and the expected outcome based on the metocean data, also given in Table 3. The metocean conditions were obtained using the closest grid locations in the Oceanweather Report (Ref 1).

In no case are Loop currents accounted for. There is insufficient known about how they act to be able to hindcast them. They were not considered in this study nor in the figures derived from the Oceanweather data. The currents quoted are referenced based on information to hand. In some cases they are the vertically integrated current reported in the Oceanweather data. These are designated (1). In some cases where there was some confidence in the results by comparison to other sources, the APIRP2A profile was used. These are designated (2). And in two cases further more accurate information was available from studies carried out by the operator. These are designated (3).

At the top of the Table 3, the API 10-year values are quoted together with the Post-Rita preliminary 10-year data. In each case the wind, the wave and the current in the Post-Rita data have all increased from the previously used API 10-year values.

Table 4 gives the details of the semisubmersibles and compares the actual values to the 100-year pre-Ivan values. It should be noted in each case of the MODUs whose moorings broke the 100-year wind speed values were exceeded. If this was not sufficient, the additional load from increased currents would have strained the moorings beyond breaking. For the Noble Lorris Bouzigard, the combination of wind, wave and high current would have exceeded the combined total load from the 100-year condition predicted prior to the incident also has a high current acting and the 100 year conditions were exceeded with a combination of loads.

Operator	Rigname	Mooring Arrangements	Failure	Relationship to Eye	Travel	Oil Company	Other Damage If Reported	Location
Diamond	Ocean Star	8 pt mooring 10 MT Bruce Anchors 4350'-4600' 3-1/4" Chain out on each leg + 4300'-4800' 3-1/2" Wire out on each leg **NOT CONFIRMED	***Rig Wire (or Rig Chain) likely weakest link Wires on Legs 1-7 failed; (Wire: BS=1400 kips; Chain BP=1450 kips) #8 failed at insert wire on preset. #4 leg lost (anchor and chain) **NOT CONFIRMED***	***1.5 miles east***	***15 miles east; 24 miles west and concluded 1.5 miles east of original location; Passed close-by Marlin platform **NOT CONFIRMED***	Kerr McGee		Viosca Knoll 869 Nile 2
Diamond	Ocean America	Fitted Rig Equipment: 8 lines 3-1/4" x 4700' ORQ+20 chain, 3-1/2" x 5,600' wire, Bruce 10 MT MK-4 anchors **NOT CONFIRMED FOR THIS LOCATION	Rig Wire- near highest loading on the system: Most failures in wires at fairlead; Alleged that rig travelled to VK 917 and "anchor wire, cable, or other parts of the vessel struck and damaged components of the Canyon Express common System including a 2-7/8" methanol pipeline and an umbilical located in VK 825" ** NOT CONFIRMED	4.25 miles east	12 miles	Mariner Energy	On 12/09/2004, TOTAL E&P reported to the NRC a release of 234 bbls of Methanol into the GOM. Approximately 200' feet of mooring from the Ocean America was found. ALLEGED INFORMATION -NOT CONFIRMED	Viosca Knoll 962 Swordfish 2
Noble	Noble Jim Thompson	9 pt mooring - Preset Delmar with Suction Piles Rig wire 9000' 3-1/4" (BS=1150 kips) + Delmar wire 1560' 3-3/4"	#5, #3,anchor wires broken at fairlead. #4 rig wire was intact with all rig components the line having parted on rental wire 725 ft below buoys (2529' below keel) and was still attached to the 3 buoys which allowed it to surface; #6 wire found with the rig components hanging - having broken below the rig anchor line about 2993' below keel. #6 anchor wire had broken wires and rub marks 2400 ft out from rig. #1 rig wire was intact undamaged, the kenter link below the rig anchor components had parted. #7, #8, #9 anchor wires broken at fairleads; #2 had parted 632 ft out; 4 suction piles had padeyes broken	2.5 miles west drifted to 28 deg 19.9 north, 88 deg 3.7 west.	40 miles SE	BP	Starboard crane damaged when it came free from the cradled position and swung inboard. Wind damage to several pieces of equipment some of which had come loose. Fast rescue board damaged when freed from secured position. BOP inspection stump damaged. Satellite communications equipment severely damaged. Lifeboat davit stabilizer bar bent from motion of the boat in the storm	Mississippi Canyon 383 #K-1
Transocean	Deepwater Nautilus	8 Pt mooring 9.55' x 70' Suction Pile Anchor 3500' 3-3/4" HS Wire (BS = 1565) 7500' 160mm (5.8") polyester (BS=1760 kips); 50 kip foam submersible buoy; 500' 3-3/4" HS Wire (BS=1565 kips)	Rig wire - Weakest link at 1500 kips Line break order reported: #3; then #4 and #5; then #2, #6, #7, #1 in the rig wire. #8 dragging and was likely cut in the pile connecting wire on the deployment skid of the suction pile; Estimate of breaking load at 1 in 85 year storm level	17 miles east	73 miles NE	Shell		Lloyd Ridge 399 Cheyenne #1
Noble	Noble Lorris Bouzigard	10 pt Mooring incl. Technip Offshore 2 preset lines; Brissonneau & Lotz Anchor Winch; 8 & 12 MT Stevpris Drag Anchors 3" Wire; 3" Chain	#5, #6, #8, #9 failed at fairlead; #2 failed at intermediate point; #3, #4, #7, #10 dragged anchor	26 miles west	About 3000 ft	Stone Energy	BOP garage needed extensive repairs. 10 days for anchor recovery and redeployment Other than this weathered the storm well.	Viosca Knoll 773
Noble	Noble Max Smith		EVA 4000, 6 columns, converted submersible	47 miles west	N/A	Amerada Hess	None	Mississippi Canyon 722
DP Semisubmersibles Close By Hurricane IVAN								
Transocean	Deepwater Horizon	D.P.	BP Green Canyon Blk 743 Altantis DC-143	Away from Track	110+ east	BP	N/A	Green Canyon 743 Atlantis #DC 143

Table 2: Semisubmersible Mooring Arrangements and Results of Hurricane Ivan's Passage

Moored Semisubmersibles Exposed in and Close by the Path of Hurricane IVAN														
Operator	**Rigname**	**Design**	**Builder**	**Year Built**	**Oil Company**	**Capable Water Depth (ft)**	**Location**	**Station Keeping System**	**Actual Water Depth (ft)**	**Expected Outcome based on Information >**	**Max. Wind Speed 1-min (kts)**	**Current (kts) (see Note)**	**Sig. Hindcast Wave Ht. (ft)**	**Hindcast Max. Wave Ht. (ft)**
		10-Year Values									72	1.8	30	48
		Post Rita 10-Year									80	2.1	32	51
Diamond	Ocean Star	ODECO Ocean Victory Enhanced, 12 Columns	ex-Waage Drill II LITTON	1974	Kerr McGee	5500	Viosca Knoll 869 Nile 2	Rig Deployed Catenary	2410	Expected Break: Underwent Mooring line repairs 10/11/04.	109.2	2.0+(1)	49.5	85.8
Diamond	Ocean America	ODECO Ocean Odyssey, harsh environment, self propelled (4)	HYUNDAI	1988	Mariner Energy	5500	Viosca Knoll 962 Swordfish 2	Rig Deployed Catenary	4375	Expected Break: Underwent Mooring line repairs 10/11/04.	113.9	5.3(2)	53.3	92.0
Noble	Noble Jim Thompson	EVA 4000, 6 columns, converted submersible	ex-Transworld 72 NORTHROP GRUMMAN	1982	BP	6000	Mississippi Canyon 383 #K-1	Steel Semi-Taut	5730	Expected Break	100.0	3.9(3)	49.3	85.0
Transocean	Deepwater Nautilus	Reading & Bates RBS-8M	HYUNDAI	2000	Shell	8000	Lloyd Ridge 399 Cheyenne #1	Poly Insert Taut	8987	Expected Break: Underwent repairs until 10/04	110.9	4.1(3)	51.4	87.2
Noble	Noble Lorris Bouzigard	Forex Neptune & IFP Pentagone 85 Series	ex-DF 85 RAUMA-REPOLA	1973	Stone Energy	4000	Viosca Knoll 773	Catenary	465	Beyond design: Trouble Expected Underwent 3000' drift	95.0	3.6(2)	44.4	78.1
Noble	Noble Max Smith	EVA 4000, 6 columns, converted submersible	ex-Transworld 68 INGALLS	1980	Amerada Hess	6000	Mississippi Canyon 722	Catenary	3869	No problem	72.1	1.9(2)	41.3	72.8
DP Semisubmersibles Close By Hurricane IVAN														
Transocean	Deepwater Horizon	Reading & Bates Falcon RBS8D	HYUNDAI	2001	BP	N/A	Green Canyon 743 Atlantis #DC 143	DP	6830	Riser Retrieval Problems	50.4	2.0(2)	27.4	50.4
Note 1: (1) refers to vertically integrated current only. (2) Vertically integrated current plus adjustment based on API RP2A profile (3) Supplied data.														
Note 2: Total current does not account for the possibility of LOOP current interacting with the vessels.														

Table 3: Details of Semisubmersible Exposure during Hurricane Ivan - with API Design Conditions for Moorings Given.

Moored Semisubmersibles Exposed in and Close by the Path of Hurricane IVAN

									EXPECTED OUTCOME
Ocean Star	VK 869	2410	109.2 (108)	2.0+[1] (2.1)	49.5 (40)	85.8 (70)	API 100-Year: ( )	Expected Break
Ocean America	V 962	4375	113.9 (108)	5.3[2] (2.1)	53.3 (40)	92 (70)	API 100-Year: ( )	Expected Break
Noble Jim Thompson	MC 383	5730	100 (108)	3.9[3] (2.1)	49.3 (40)	85 (70)	API 100-Year: ( )	Expected Break
Deepwater Nautilus	LR 399	8987	110.9 (108)	4.1[3] (2.1)	51.4 (40)	87.2 (70)	API 100-Year: ( )	Expected Break
Noble Lorris Bouzigard	VK 773	465	95 (108)	3.6[2] (2.1)	44.4 (40)	78.1 (70)	API 100-Year: ( )	Expected Break: 3000' drift

Note 1: 100-year values in () under actual values

(1) refers to vertically integrated current only.
(2) Vertically integrated current plus adjustment based on API RP2A profile
(3) Supplied data.

Table 4: Details of Semisubmersible Exposure during Hurricane Ivan -Compared to API 100-year conditions. The Post-Rita 10-year conditions are also included for comparison purposes.

8.1 OCEAN STAR

Lloyd's List reported: London, Sep 20 -- A press release from Diamond Offshore Drilling Inc, dated Houston, Sep 16, states: Diamond Offshore Drilling Inc today reported that drill platform Ocean Star (19466 gt, built 1974 upgraded 1991) drifted from its moored location in the Gulf of Mexico at approximately 1700, Sep 15. However, a visual inspection of the unit by fixed-wing aircraft earlier today has confirmed Ocean Star is afloat with no apparent damage. A visual inspection by aircraft of four additional Diamond Offshore rigs operating in the path of hurricane "Ivan" also indicated no apparent damage. A visual inspection by aircraft of four additional Diamond Offshore rigs operating in the path of hurricane "Ivan" also indicated no apparent damage or pollution. All of the well operations being conducted by the rigs situated directly in the path of the storm had been secured and personnel evacuated in accordance with normal operating and safety practices prior to hurricane "Ivan" passing through the area. Ocean Star, which is being monitored via a satellite tracking mechanism, is currently situated approximately 12 miles from its pre-storm location, which was in 2,423 ft. of water in the Viosca Knoll area. The Company has notified and is cooperating with all appropriate regulatory authorities. The Company has initiated actions to re-board Ocean Star in order to restore power and further assess its condition prior to moving the rig back to its operating location. All of the Company-owned rigs in the Gulf of Mexico that were evacuated prior to the storm will be re-boarded as soon as practicable in order to recommence normal operations.

It is understood that the mooring analysis met the 10-year Deepstar (Ref 10) environmental data. It is also understood that as usual practice, the entire rig chain/wire moorings were carefully visually inspected when deployed.

Table 2 gives the information on the vessel and the best available information on the moorings. The results of the passage of the storm on the Ocean Star are shown in Table 3 including the extreme winds, waves and currents experienced. The actual data, obtained from the Oceanweather data is given, as well as the Post-Rita 10-year criteria. The Ivan Oceanweather data shows clearly that it exceeds the API 10-year criteria Pre-Ivan and Post-Rita. The factor of safety on breaking strength would have well been exceeded without the additional issue of double the current to which it was designed for use at this site. From calculations the expected outcome of the event is that the mooring would break. Table 4 tabulates the same information and makes the comparison to 100-year values. In each case of the rigs breaking their moorings the 100 year conditions were exceeded. On the 4 semisubmersible MODUs that drifted the 100-year wind alone was exceeded without a contribution from current or wave.

At the time of writing the information was not available as to the exact mooring configuration, nor the sequence of failure. The Ocean Star was only about 1.5 miles to the east of the storm track. A previous OTC paper (Ref 17), gave a chart of the track of the vessel after it broke loose. The distances to the production infrastructure can be noted.

There was no known report of damage as a result of the transit. Most of the wires were said to have broken below the rig fairlead near the highest loading point on the system. At least some lines were said to be pre-set and one line was rumored to have broken in the preset moorings.

None of the information on the Ocean Star has been confirmed.

8.2 OCEAN AMERICA

Lloyd's List reported: The semi-submersible drill platform Ocean Star and Ocean America (26692 gt, built 1989), which parted their mooring during the height of the hurricane, have both been moved to a shallow-water location where crews are working to replace anchor chain and wire lost during the storm. All necessary materials are on hand and estimated downtime for each rig is approximately 10 to 21 days, depending on weather and other conditions. Efforts to recover the lost anchor chain and wire are expected to commence as soon as weather and other conditions permits.

No information has been made available on the track or any damage which may have occurred as a result of the Ocean America breaking away in Hurricane Ivan.

Damage to a small methanol distribution line of the Canyon Express pipeline has been noted (Ref 18, 19) in the same general area but whether there was any interaction between the Ocean America and the methanol line has not been substantiated as fact.

If either the Deepstar (Ref 10) or the API standard metocean criteria (Ref 8) were used to design the moorings of Ocean America, by inspection from the data arising from the Oceanweather figures for wind, wave and current, it would be expected to exceed both the design condition and the break condition for the moorings. A 60% increase in wind load would result in a load of approximately 2.5 times that of design. With an additional doubling of the current it would be expected in this magnitude of hurricane to break from its moorings. It should also be noted that the wind speed, and thus the forces on the moorings of the Ocean America were higher than those of any other semisubmersible in the path of the storm and exceeded those, which would have been appropriate even for a 100-year design condition. This may also be a higher wind speed than has been experienced by any of the other semisubmersibles for Andrew, Lili or Ivan or other past hurricanes.

It should be noted that during Hurricane Andrew, the Ocean America was moored in 140 ft waterdepth in Ship Shoal 236, and maintained station even though the winds were reported to be 107 kts with a significant wave height of 33 ft as the eye passed over it.

Table 4 shows the data compared to 100 year design conditions and it shows that those conditions were exceeded.

None of the information on the Ocean America has been confirmed.

8.3 NOBLE JIM THOMPSON

Lloyd's List reported: London, Sept 22 -- A press release from Noble Corporation, dated Sugar Land, Texas, Sept 17, states: Noble Corporation reported that its semi-submersible drill platform Noble Jim Thompson (13720 gt, built 1982), contracted to BP America Production Company and on location offshore Louisiana at Mississippi Canyon block 383, was in the main path of Hurricane "Ivan". The unit had been secured and all personnel safely evacuated prior to the storm's arrival. The unit broke away from its mooring lines and has moved to Mississippi Canyon block 656, approximately 30 miles southeast from its original location. A Noble assessment crew of seven personnel safely boarded the unit by helicopter at approximately 10:00 today and has restored power and operating capabilities. The Company reports that the unit is level and stable and that the assessment team has commenced surveying its condition. The only damage of a significant nature is reported to be the starboard crane boom, based on the initial preliminary survey. One tug is in the process of securing the unit, and an anchor handling vessel is in route to assist. After towing lines establish connection with the unit, it will be towed to a shipyard in Mississippi to complete damage assessment and necessary repairs. The Company has not yet projected when the unit can return to operation.

The Noble Jim Thompson was moored at a BP location in Mississippi Canyon 383.

Coordinates at MC 383:

28^0 35' 54" Latitude
87^0 26' 07" Longitude

Waterdepth: 5725 ft

It was moored to the accepted 10-year API criteria with a 9 point preset, semi-taut steel mooring. The mooring arrangement consisted of 9 pt Preset Mooring (DELMAR) with Suction Piles:

- Delmar suction piles 9.55' x 70' or 12' x 60'
- 10,000 ft 3-5/8" rental wire
- 2-50-kip foam submersible buoys
- 200-1000 ft of 3-5/8" connecting wire
- 2600-3200 ft of 3-1/4" rig wire which was less than 3 years old

The total lengths of mooring lines should be noted to be in the order of 2 miles each leg. A typical mooring line configuration is shown in Figure 10 which gives an elevation view.

Detail 1 shows the attachment of a suction pile to the line; during the progressive failure these padeyes saw large angles (approximately $45^{0)}$ and consequently broke before the wires broke or the piles pulled out.

Detail 2 shows a Delmar subsea connector.

Detail 3 shows the submersible buoys.

Detail 4 shows a number of detailed mooring fittings to be deployed in the line along with the connector to the rig wire.

One item of note is the challenge of ensuring 100% quality performance for each of these mooring components.

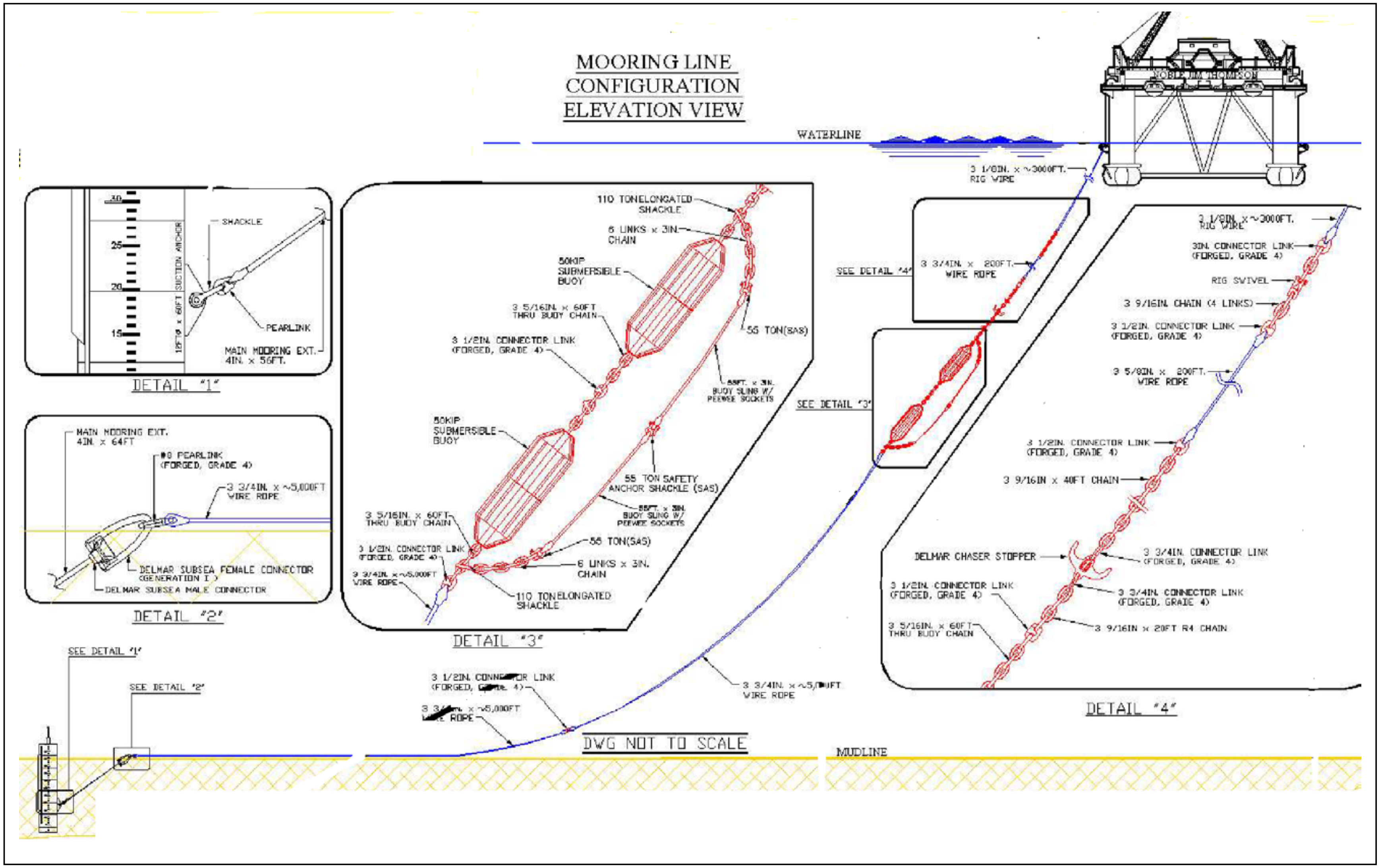


Figure 10: Mooring Line Configuration Elevation View

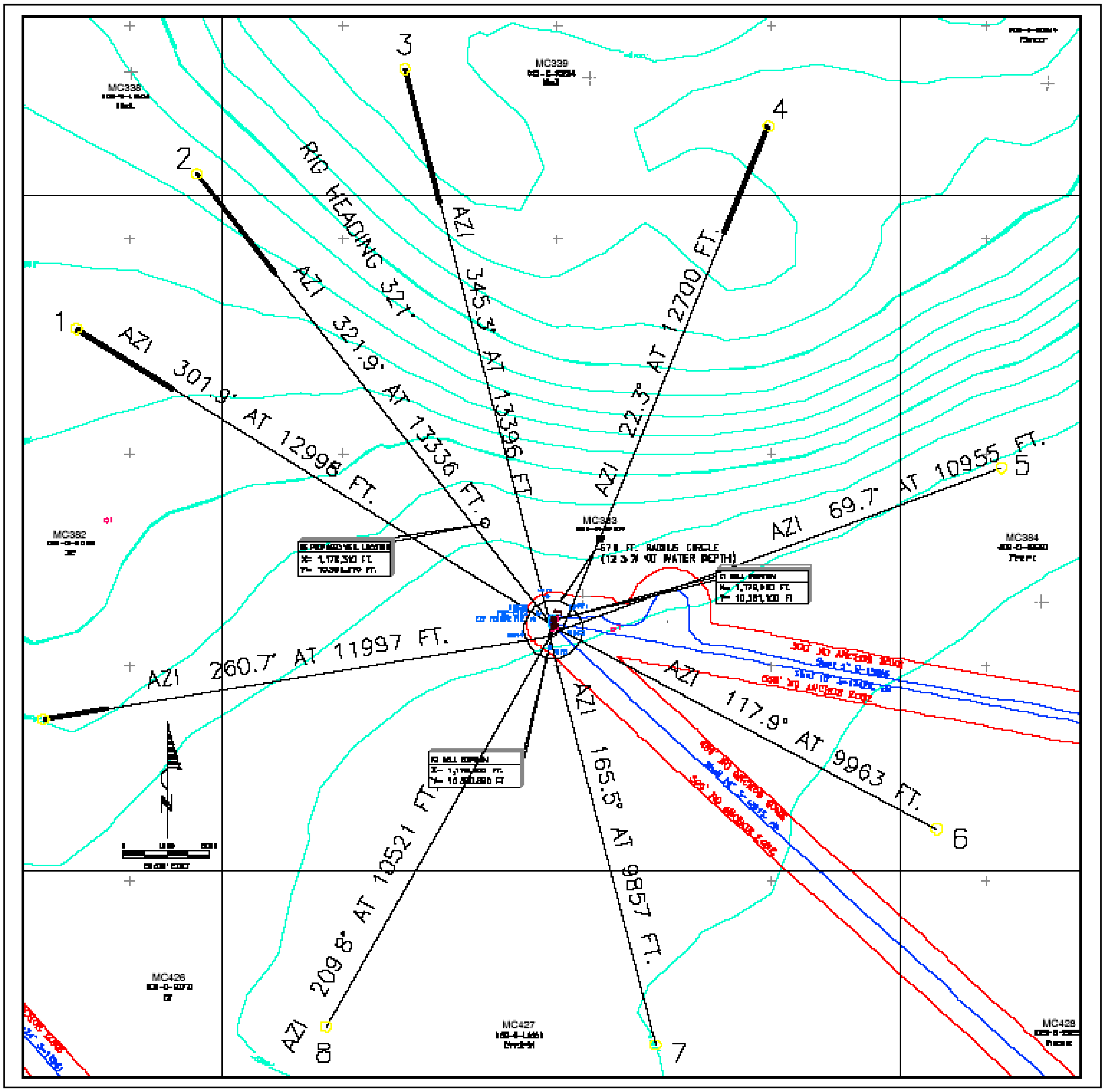


Figure 11: Noble Jim Thompson mooring pattern at MC 383

Figure 11 shows the mooring pattern at MC 383. Points of note are the pipelines. Arrangements of moorings over existing pipelines ensured that #6 would not impact if the hurricane winds came from the south. Different elevations to the north increases the complexity of the mooring design.

The information at failure was taken from References 21, 22 and 23. The maximum hindcast at the location were taken from the Oceanweather data (Ref 1).

The sequence of failure as determined from the position of the equipment after the rig departed the site can be visualized by following the sequence of diagrams below in Figure 12 in order from view 1 through view 6. The sequence starts in view 1 with the 1st line breaking, line #5. The second view shows the 2nd line breaking is #4, and so on. The vessel moved off to the south-west based on the way the mooring lines on location were found and thus the moorings would most likely have broken with the wind to the west prior to the eye passing by the location.

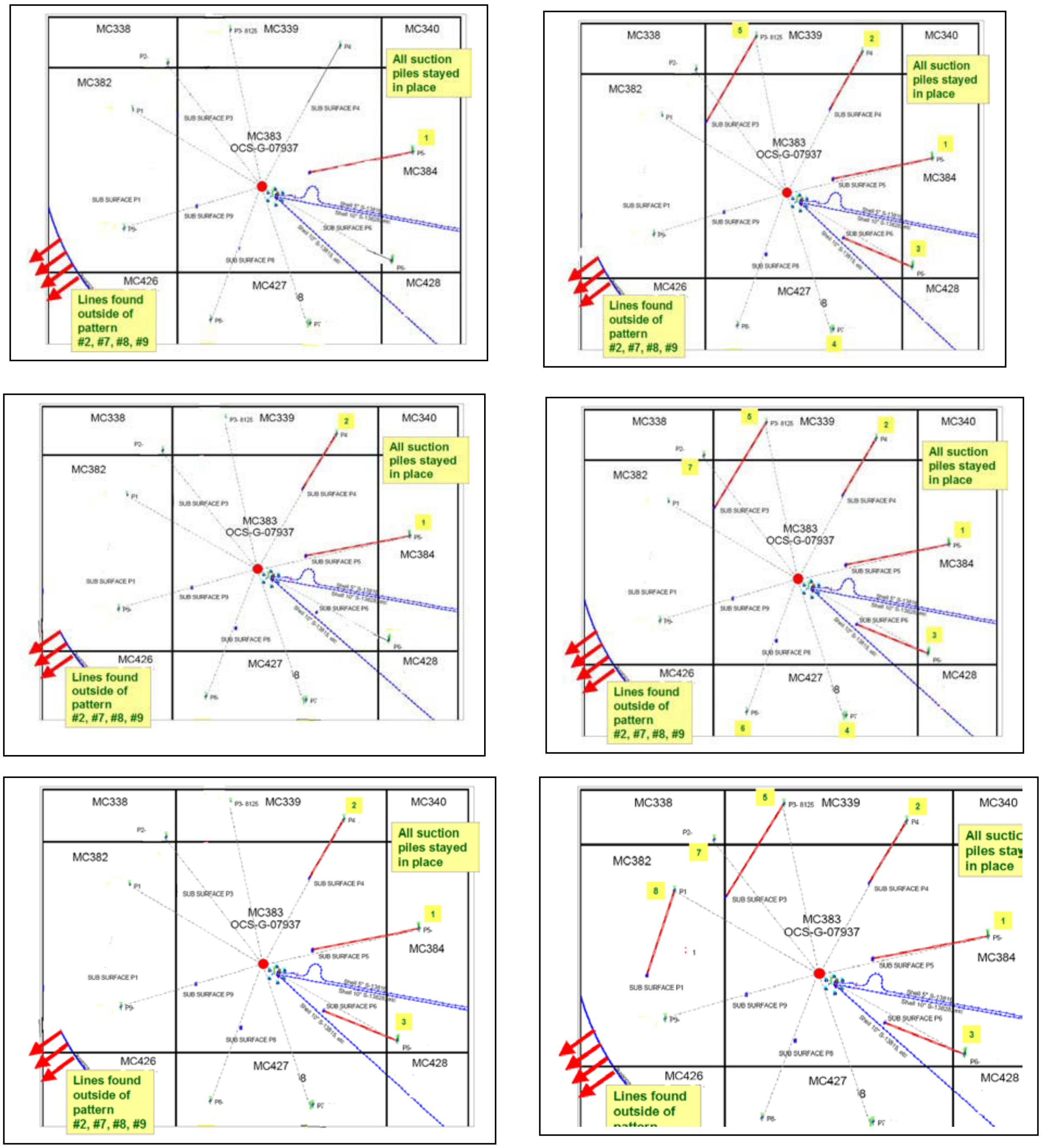


Figure 12: Showing the Most probable Line Sequence of Failure: Views 1-6 (Ref (21).

Line #	Item
5	3-1/8" wire –ENE line breaks first in the rig wire
4	3-5/8" wire NE line breaks next in wire below buoys
6	3-5/8" wire connecting wire is next
7	Suction pile pad eye due to angular load of about 45^0on padeye beyond designed condition
3	3-1/8" wire
8	Suction pile pad eye
2	Suction pile pad eye
1	Kenter link
9	Suction pile pad eye

Table 5: Sequence of Line Failure (Ref 21)

The storm center passed approximately 10-12 mi the east of the location of the Noble Jim Thompson which was working close by the Nakika location.

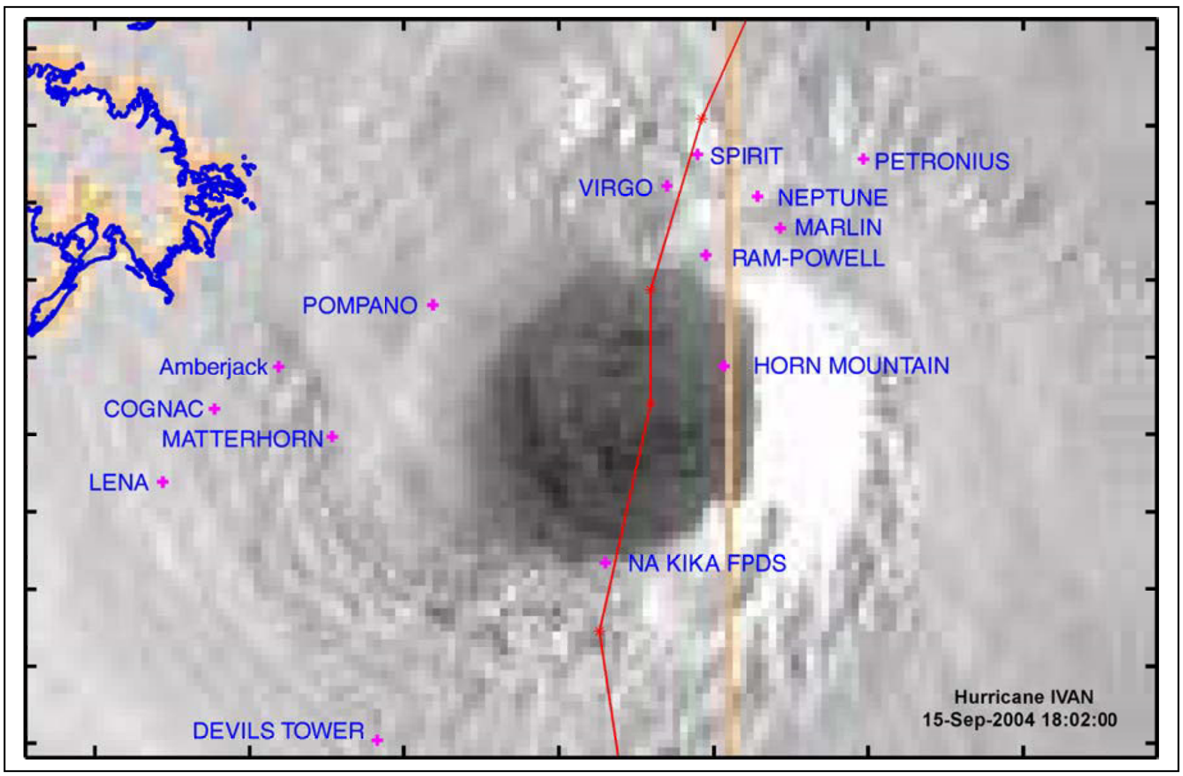


Figure 13 shows the eye of the Hurricane Ivan in relation to the Noble Jim Thompson which was working very close by to the Nakika position.

Once the 3 initial lines #5, #4 and #3 had broken the rig would have moved off location and then put a significant load out-of-plane on the padeyes of the suction piles, for which they are not traditionally designed. This would also be consistent with reported tangling of moorings around the rig after the event (Ref 22).

The damage to the rig was significant but it returned to work as soon as the repairs were complete and new mooring equipment procured. The damage can be summarized as follows:

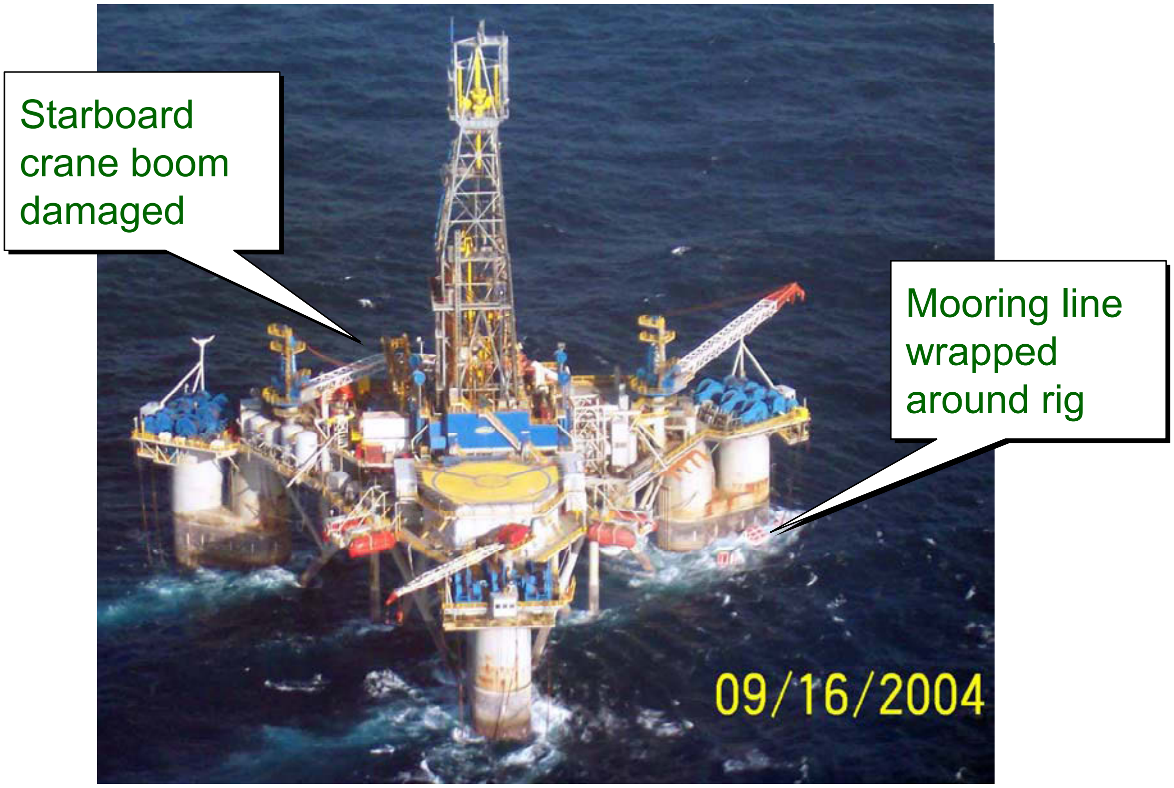


Figure 14: Noble Jim Thompson with damages noted.

- The Starboard crane came free from the cradled position and swung inboard and damaged itself.
- Wind damage to several service loops and control cables
- All the windows in the driller's shack were completely broken out or damaged.
- A set of tongs was found to have broken free from a securing rope and had been swinging freely during the storm. The tongs were swinging at a height that allowed them to contact the racking system control chair causing extensive electrical and structural damage.
- The windows in the anchor control room were damaged or missing. Some anchor controls and all radios were damaged.
- The fast rescue boat was severely damaged when it was freed from its pinned position and was contacting the rig structure as it moved with the motion of the rig.
- One of the lifeboat stabilizer bars was bent out from the motion of the rig in the storm.
- Crane windows were damaged and/or broken.
- Crane controls and radios were damaged
- The test stump used for inspection beneath the BOP storage area was severely damaged.

- All satellite dishes and the satellite tracking dome for the telephone system were all severely damaged.
- Ventilation louvers in the emergency room were blown out. Cradle and boom rest for one of the cranes was damaged.

Note that the windspeed increases with height by a factor of 10% every 33 ft in height increasing its ferocity at deck level and crane level.

The three first lines to break can be illustrated by the following diagrams:

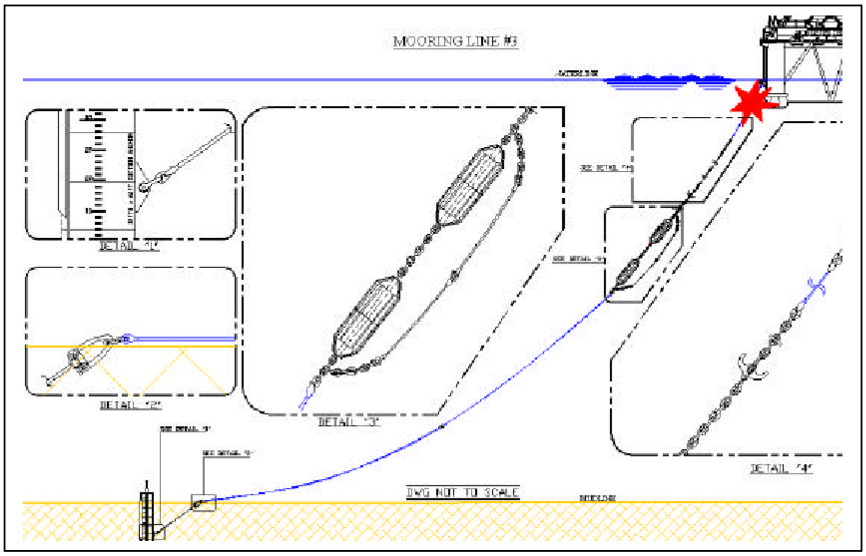


Figure 15 Illustrating the break position for line #5 near to the fairleader

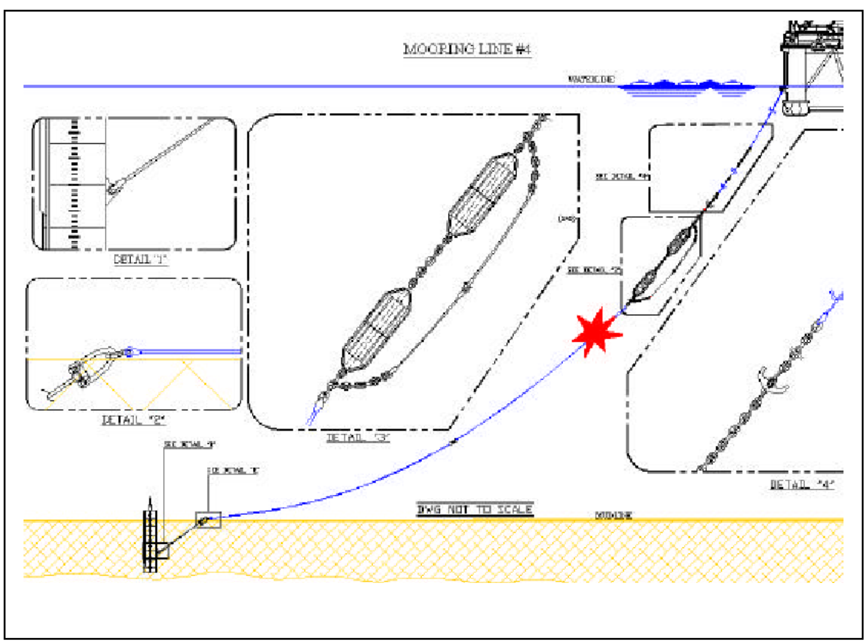


Figure 16 Illustrating the line #4 the 2nd line to break in the wire below the buoys

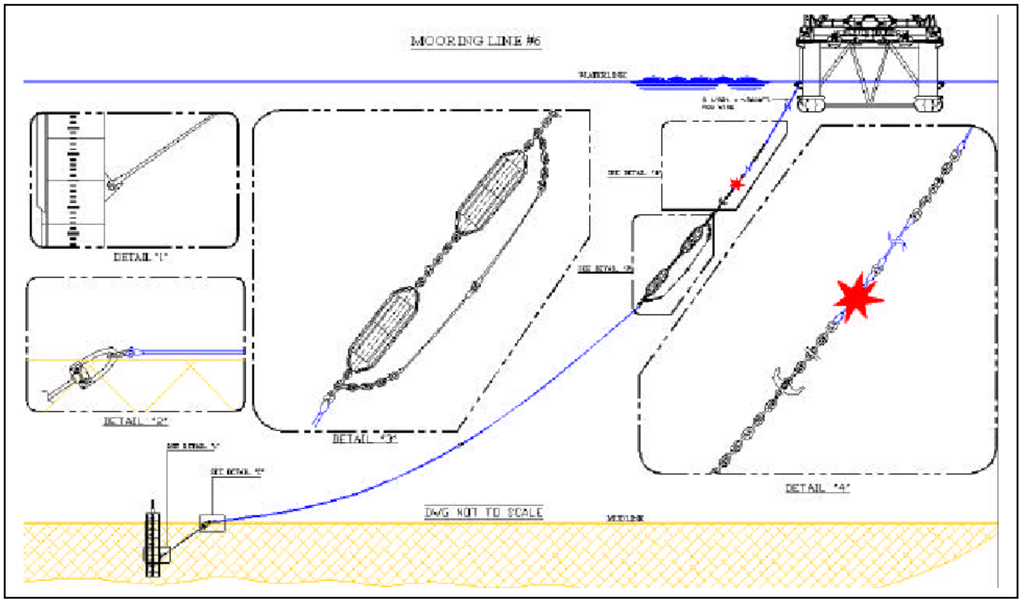


Figure 17 Illustrating the Break Point in 3-5/8" connecting wire Line #6

Figure 18: Shows the Damaged Padeye on the Suction Piles. The padeye angle was about 45^0 at the time of failure.

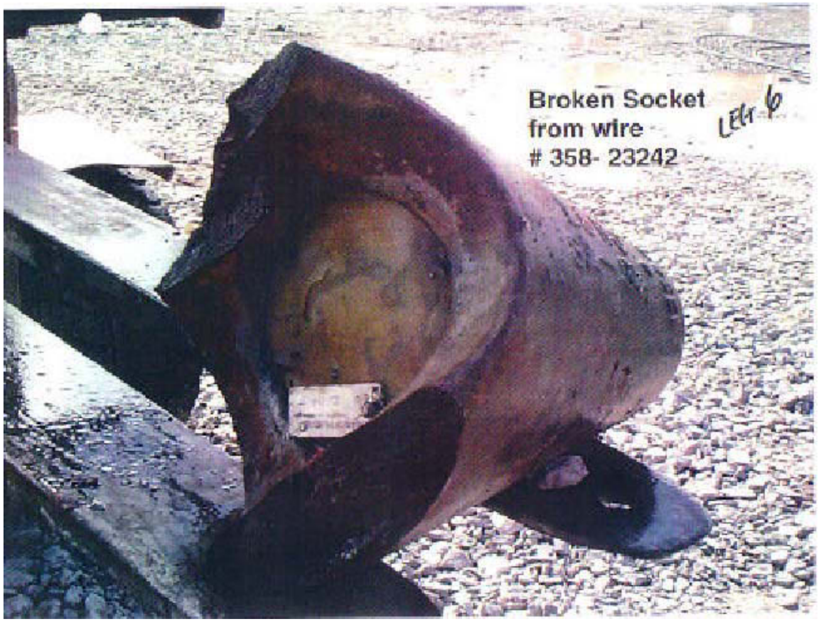


Figure 19: Broken socket from wire on Leg #6

After the breakages the vessel drifted off to the west before turning southeast and ended up 40 miles SE – with 3 wires below keel. (Ref 22).

The mooring components below the keel during the drifting consisted of:

- One length of 2500 ft of wire that was being buoyed up with the in-line buoys.
- One length of 500 ft of wire
- One length of 3000 ft of wire

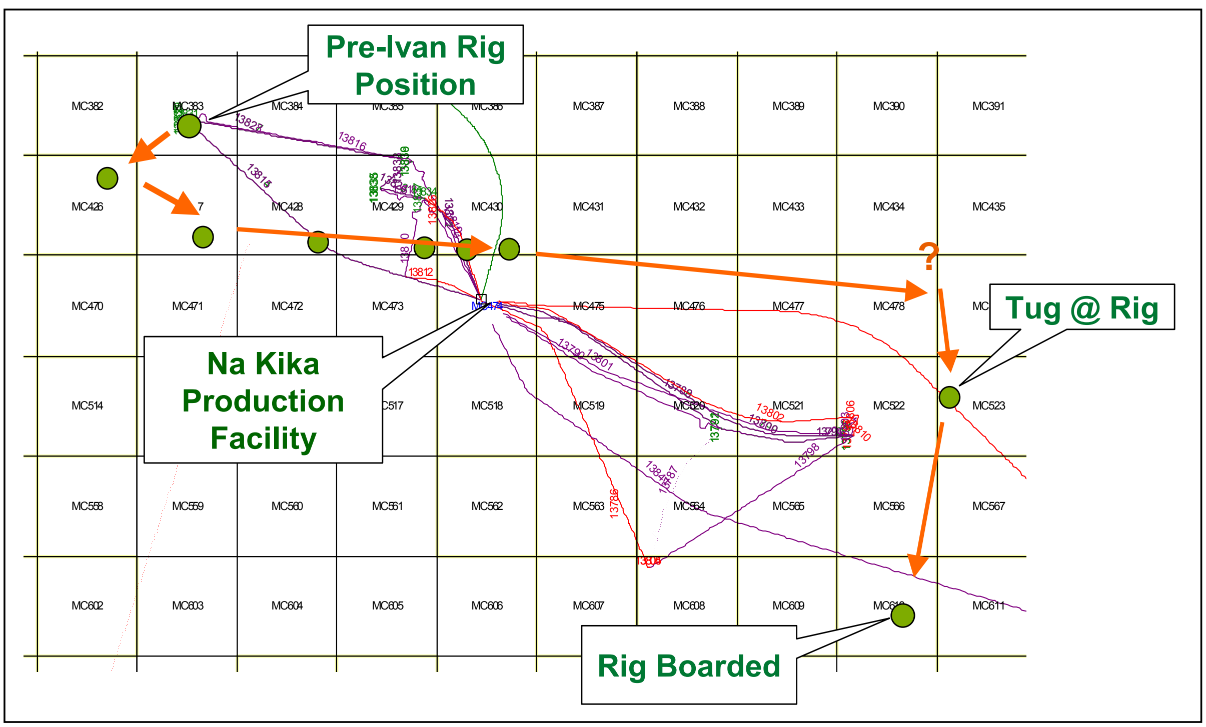


Figure 20: Possible Route of the Noble Jim Thompson after the Hurricane Broke the Moorings.

Figure 20 illustrates a possible route to that the vessel may have followed. The path was based on where mooring components were found, marks in the seafloor or from an indication where wire was drug across pipelines.

The wind, current and wave forces during the storm were well in excess of the design. Based on the timeline which was derived, the rig weathered the storm for some time prior to breaking just before the eye of the storm reached the rig. The rig saw 100-year (API) storm values based on the information derived from the Oceanweather hindcast (Ref 1). The Table 6 chronicles those values together with information on the API 10-year values. With the high current, combined with a wind speed more than 50% greater than design values the load would be expected to be more than double the design loads, exceeding the breaking values of the lines.

			Significant Wave Height (ft)
Best calculated extremes at failure	84.3	3.82	47.7
API- 10 Year pre-Ivan storm values	65	1.5	26
API – 100 year pre-Ivan storm values	108	2.0	40
Maximum hindcast in the storm	100	3.9	49.3

Table 6: Values of Wind, Wave and Current at location compared to API Values

Considering the magnitude of the storm the rig survived remarkably well and was back at work in a short period of time.

The vessel crossed:

- 4 large pipelines (one of them twice) with no damage (24”, 18” and 2@10”)
- 2 small pipelines with no damage (8” and 4”)
- 3 umbilical lines with damage to 2 of the 3.

The three buoys from Leg 4 were found trailing the free-floating rig and hitting each other at the surface. The buoys from Legs 7, 8, and 9 were found at the ocean floor below the free-floating rig at MC656 in 7100 ft of water, imploded by the rig wire and the pre-set wire was tangled up on both ends. Four small trenches, were identified on the seafloor heading to the southwest crossing Okeanos pipelines.

BP had pre-staged resources including boats, helicopters, ROVs, equipment, crews etc. prior to the storm. The response time from estimated failure time was impressively short:

- Within 24 hrs – rig spotted and tug arrived at rig

- Within 36 hrs - anchor handling vessel arrived at rig
- Within 48 hrs – tug secured rig.

The following "Take-Aways" from the incident may help future issues with semi-submersibles, moorings and hurricanes.

- With mooring lines tangled around the rig it is difficult to get the towline hooked up and get under tow. Hooking up towlines is more difficult if the cranes are damaged. Consideration should be given to a pre-rigged towing bridle easily deployable when necessary.

- Finding, locating and retrieving mooring lines after the incident turned out to be a chore that had to have careful planning and executing. Issues included handling knotted wires, and potential damage to ROVs and equipment, attempting to find the lines. There was also limited availability of this equipment.

- While not determined to be in any way an issue, some of the breakages remind us of how important it is to get the quality of the moorings right to ensure that when the moorings are strained, they can take their full component design load.

All mooring lines, mooring equipment and suction piles were located with the exception of one Kenter link.

Figure 21: Photos taken during the recovery process of the wire.

[Special thanks to BP and Noble Drilling for making available the details of a forensic evaluation and giving generously to the study of the photographs to allow a visual understanding of the results of the Hurricane Ivan passage]

8.4 DEEPWATER NAUTILUS

London, Sep 17 -- A press report, dated today, states: A drilling rig in the Gulf of Mexico is missing in the aftermath of Hurricane "Ivan". A spokesman for Houston-based Transocean says its 115-member crew was evacuated and the Panamanian flagged Deepwater Nautilus (built 2000) rig was secured before the storm hit, but there was no sign of it after "Ivan" passed. The Deepwater Nautilus is a mobile drilling platform with floats or pontoons that provide stability. The spokesman says aircraft and boat searches are under way.

London, Sep 20 -- A press report, dated Sep 16, states: Transocean, after a frantic search for drilling platform Deepsea Nautilus blown off location by Hurricane "Ivan," said late today it found the structure drifting along 70 miles from the well it had been drilling, upright and apparently undamaged. "We found it 70 miles off position. It appears to be in good shape, at least what we can see above the waterline," Transocean spokesman Guy Cantwell said. Cantwell said three boats were standing by Deepwater Nautilus, which had been safely evacuated ahead of the storm. "We expect to have people board it tomorrow. There's no danger of it running aground," he added. Transocean said the rig was anchored about 160 miles south of Mobile, Alabama, when the storm struck.

The Deepwater Nautilus, originally specially designed for deepwater service, was moored on location with suction piles, and prelaid moorings. The location was the Shell Cheyenne Well D in Lloyd Ridge Block 399. The location was in the SE corner of Block 399 and the moorings spanned into Lloyd Ridge 400 on the east, Lloyd Ridge 443 and 444 to the south. It was moored in an 8-point symmetrical mooring pattern with line #1 starting at the NE mid-quadrant. (Ref 25, 26).

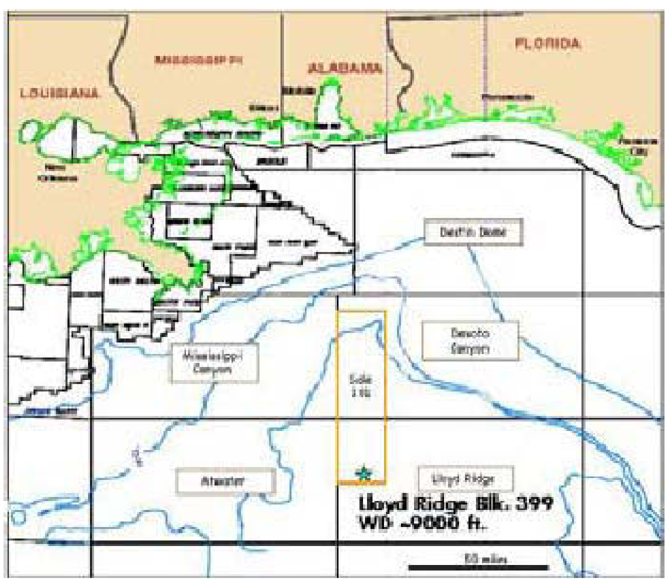


Figure 22 Illustrates the Deepwater Nautilus Location in Hurricane Ivan.

The rig's own mooring system includes 15,000 ft of high strength 3-3/4" wire with a breaking load of 1565 kips.

During the storm the eyewall of the hurricane passed directly over the Deepwater Nautilus with 1-min. sustained windspeeds of 111 kts gusting to 130 kts. and generating a maximum wave height of about 87 ft.

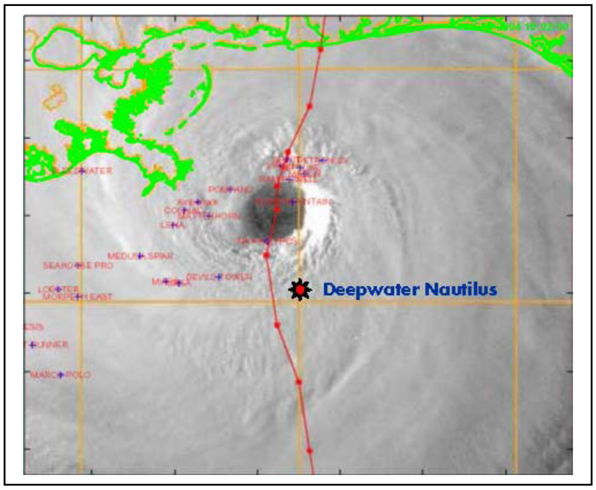


Figure 23: Deepwater Nautilus in relation to the eye of the storm and to the other significant production platforms in the area. The Nautilus was 17 miles to the east of the track in the most ferocious part of the storm.

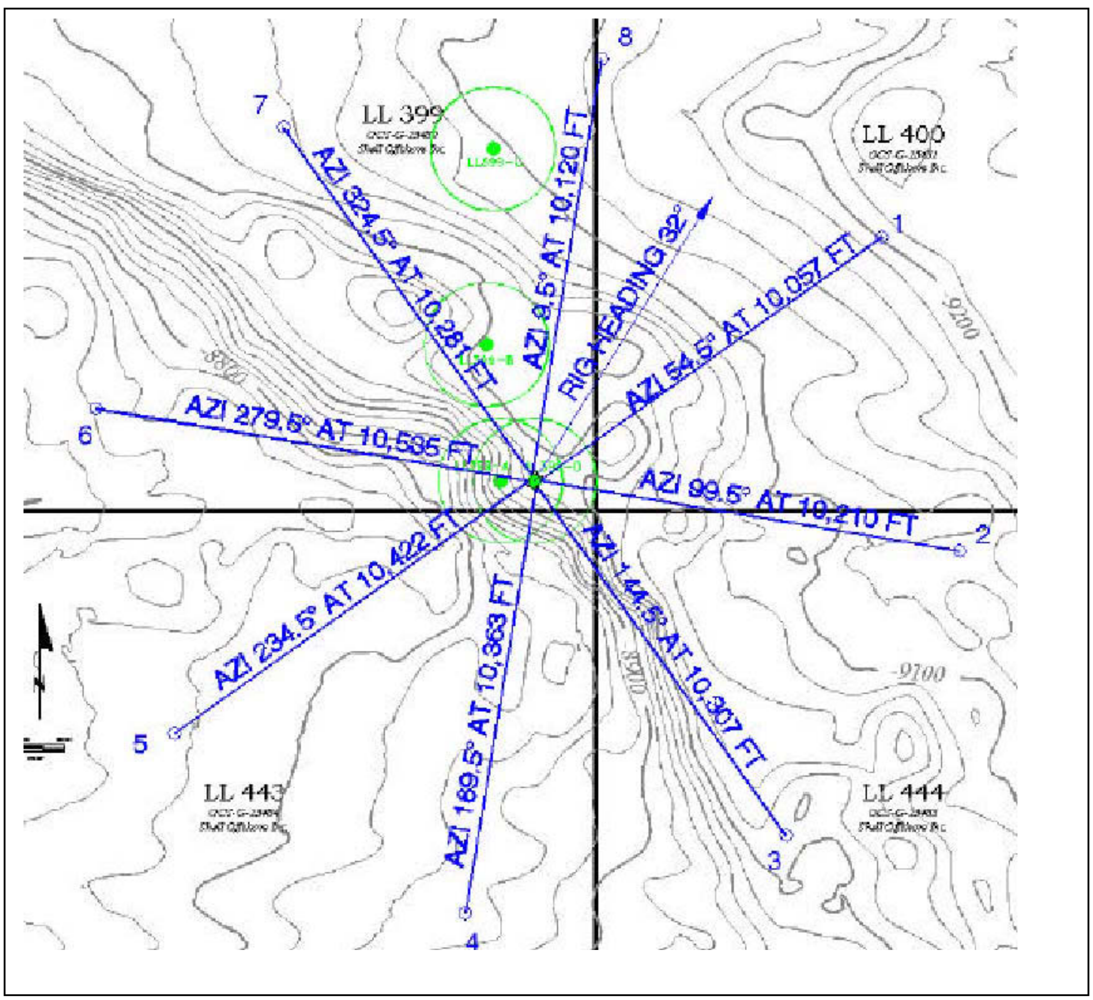


Figure 24: Mooring Pattern of Deepwater Nautilus at Lloyd Ridge 399

Note from the diagram above that the total mooring length of each of the 8 lines was approaching 2 miles.

At the time the storm passed the Deepwater Nautilus was 17 mi east of the track. It was moored on location with a 9 point mooring with preset 9.55 ft diameter and 70 ft long Suction Pile Anchors

Attached to each suction pile anchor was 3500 ft of 3 ¾" High Strength Wire with a breaking strength of 1565 kips. This transitioned to 7500 ft of 160 mm (5.8") diameter Polyester Rope with a breaking strength of 1764 kips. A Foam Submersible Buoy with Connection Hardware (Buoyancy = 50 kips, BS = 1854 kips) buoyed up the line: this also had the benefit of tending to buoy up the line end after failure. A further 500 ft of 3-3/4" High Strength Wire transitioned to the rig wire

The Rig wire was attached to this pre-set mooring with a length as needed (approximately +2000 ft.). This was 3 ¾" wire, with a specified breaking strength (BS) of 1498 kips.

The figure below shows the arrangement.

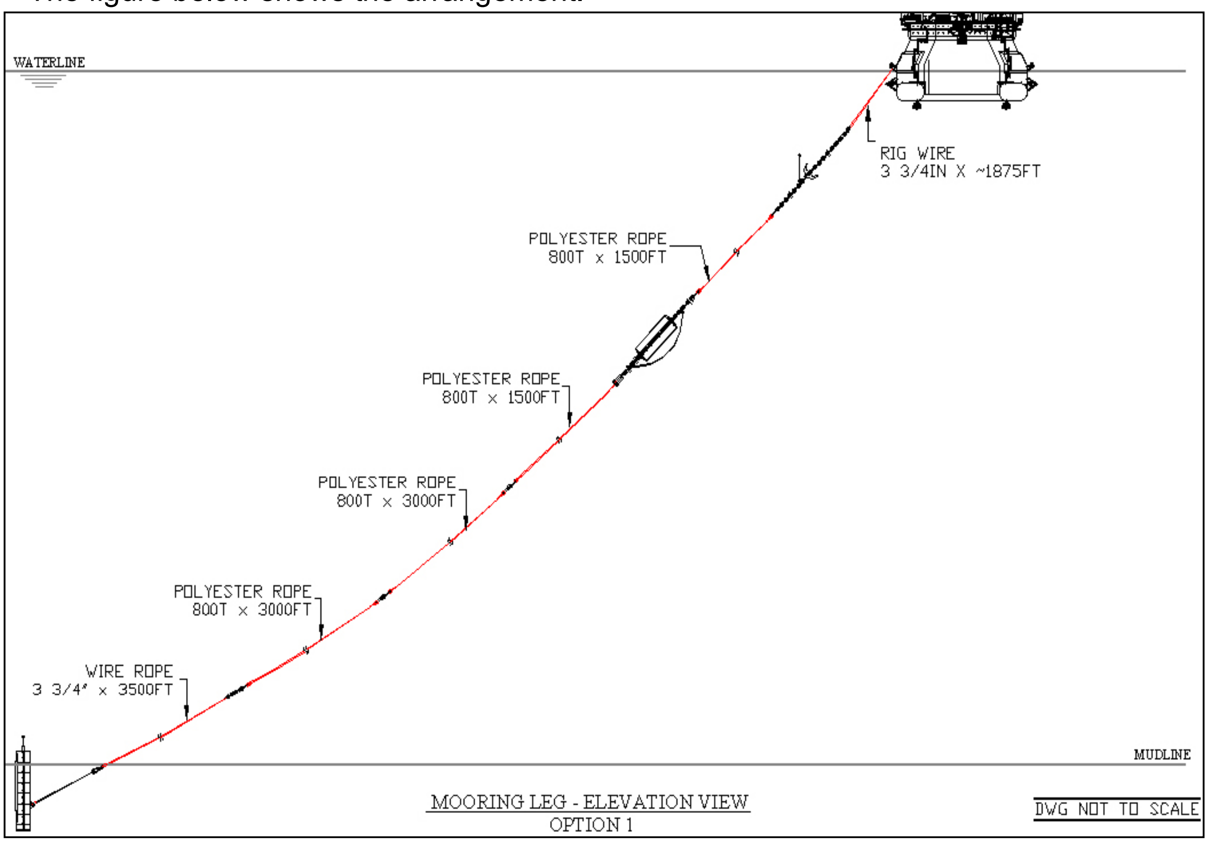


Figure 25: Mooring Line Elevation

Based on the sequence of the breaks and the direction determined by the lines on the seafloor after the incident the break must have occurred close to the time the storm center was on the same latitude as the Nautilus. A break at this time would allow the unit to move north propelled by the northerly winds on the east side of the storm.

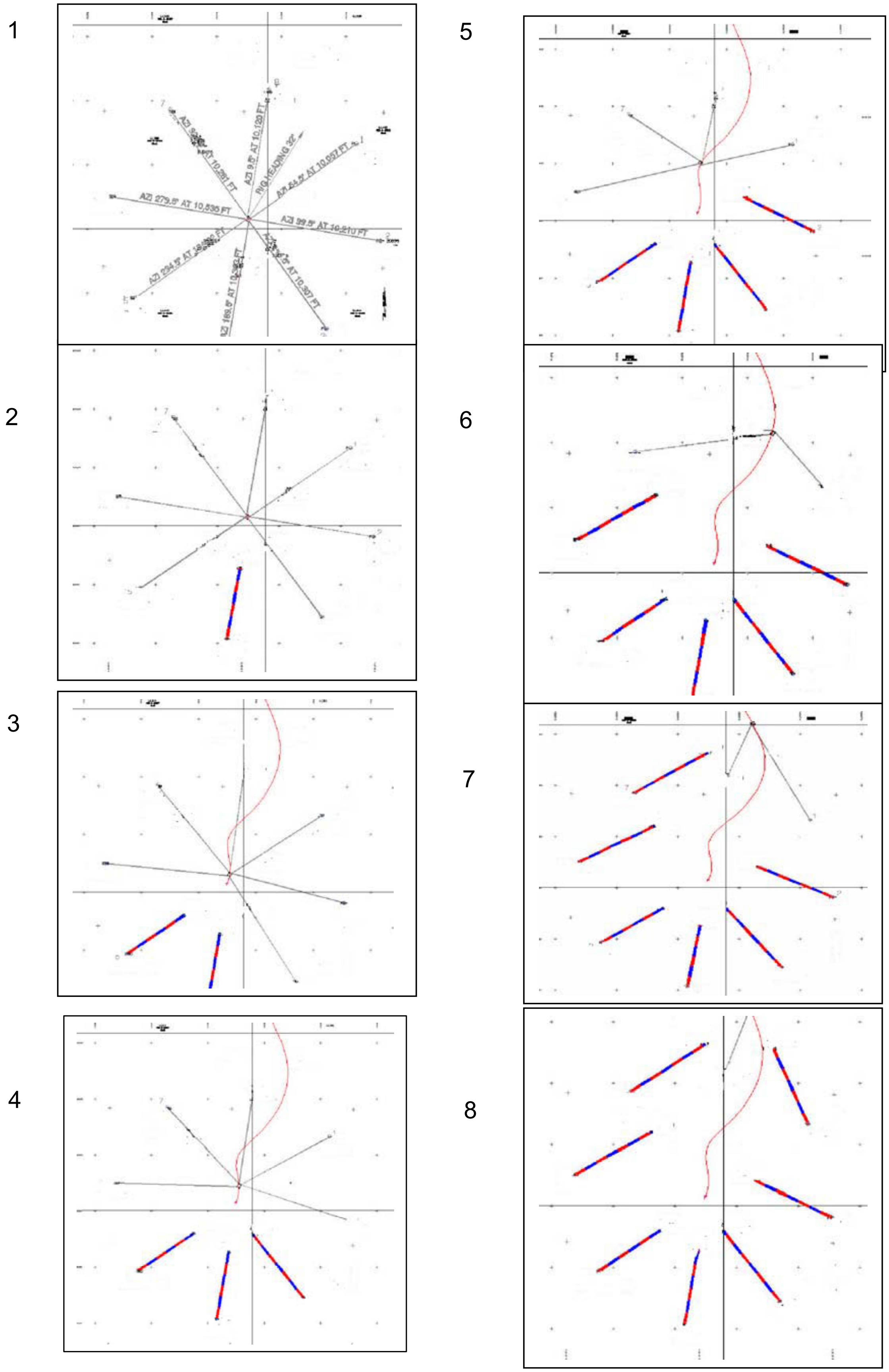


Figure 26: Sequence of Likely Mooring Line Failure – depicted as steps 1-8 (Ref 25)

While it is difficult to determine with exactness the time of the first break or the weather conditions, analysis has predicted that the Deepwater Nautilus did not part her moorings until the value of storm equivalent to an 85 year return period was upon it (Ref 26).

Later the location was subject to higher wind speeds and wave heights. The figures developed by Oceanweather indicate that at some point the metocean conditions would have reached an equivalent of a 100-year return period at this location.

Based on the interpretations from the equipment arrangement after the passage of the storm, together with calculations can determine the sequence of failure. The most likely first line to break was #3 first, as it was taking primary load from the SSE followed by #4 and #5 lines from the S and ESE. Thus initially the mmooring system failed at its designed weak point: the rig wire between the fairlead and the submersible buoy, followed by #2, #6, #7, and #1. Line #8 was reported to have likely been cut in the pile connecting wire on the deployment skid of the suction pile. The #8 mooring line was still attached at the time of recovery of the vessel, but the anchor had been left at location. The sequence is illustrated in Figure 26 following sequentially views 1 through 8.

The initial conclusion was that at the break point this represented something greater than an 85-year return period storm. Table 3 gives the complete listing of parameters of each MODU's location and weather hindcast values: a summary is provided here for the Deepwater Nautilus.

			Significant Wave Height (ft)
Best calculated extremes at failure	90.7	2.84	37.1
API- 5 Year Pre-Ivan values	63	0.5	14.5
Maximum Hindcast in the storm	110.9	4.1	51.4

Table 7: Values of Wind, Wave and Current at LL399 compared to API Values

In anticipation of potential issues Shell had arranged for Anchor Handling Vessels to be on standby for dispatch immediately after the storm. The vessels left on the 15th immediately after the storm had passed arriving on location on the morning of the 16th, and commenced the search for the rig that was found shortly thereafter. Fast action reduced the risk of further incident.

The Sequence of Events in the Deepwater Nautilus incident was as follows:

9/8/2004 Preparations commence for securing the rig for evacuation due to Hurricane Ivan. The entire riser was pulled.

9/12/2004 Rig ballasted to survival draft and then evacuated and secured

9/13/2004 Anchor Handling Vessels (AHVs) with anchor crews were dispatched to the Western Central Gulf Of Mexico shelf for possible operations after Ivan passes

9/15/2004 Anchor Handling Vessels (AHVs) with anchor crews were dispatched to the Western Central Gulf Of Mexico shelf for early start up of the Deepwater Nautilus after Ivan passes

9/16/2004 AHV arrived on location at 11:30 am and did not find the rig on location. The search for the rig commences and at approximately 4:00 pm the rig was located by aircraft 73 miles N. East of the original location.

At 6:15 pm AHV arrived at the rig and does a visual inspection with no major damage to report.

9/17/2004 Startup crew arrived at the rig and the tow bridle was attached to the tow vessel by 2:00 pm. #8 mooring line was found still attached (the only line attached) and recovered the line with an AHV. Rig was then undertow.

[Special thanks to Shell and Transocean for making available the details of a forensic evaluation and giving generously to the study of the photographs to allow a visual understanding of the results of the Hurricane Ivan passage]

8.5 NOBLE LORRIS BOUZIGARD

The Noble Lorris Bouzigard is originally a Pentagon 85 rig upgraded for deepwater service.


Noble Lorris Bouzigard

It was approximately 26 miles west of the storm, however, it experienced winds, waves and currents equal to almost a 100-year event rather than the 10-year event the moorings were designed to. While the forces on the unit were substantial, it is not obvious without significant calculations, soils data and further investigation as to whether it would be expected to fail. With a wind force equal to 1.7 times that for which it was designed one would expect trouble.

Trouble came from the hurricane in the way of 6 broken mooring lines and a movement of the rig approximately 3000 ft including the movement within the mooring pattern and some possible anchor drag. Since the anchors were designed to be drag anchors, it is not surprising that the unit survived without breaking, since dragging anchors allow the loads to re-distribute.

By visual examination the barge engineer stated that they were able to determine that #5, 6, 8, and 9 wires broke at the fairleaders. This led to the rig being able to pull the remaining anchors along with it due to the weather. After a short period the remaining anchors dug deep enough to offer enough resistance to stop the rig movement and also break the #2 wire. During this period the #3 managed to tie a loop in itself necessitating its being cut after the event.

			Significant Wave Height (ft)
API- 10 Year Values	72	2.0	49.5
Maximum Hindcast in the storm	95	3.6	44.4

Table 8: Values of Wind, Wave and Current at location compared to API Values

Table 4 gives the maximum wind, waves and currents and corresponding 10-year API criteria values. The wave crest reached up to do some damage to the BOP garage, which needed extensive repairs. Other than this the unit weathered the storm well and was back at work within about 10 days after the anchors were recovered and re-deployed.

8.6 NOBLE MAX SMITH

The Max Smith is an EVA-4000 semisubmersible owned by Noble Drilling Corp. It was originally constructed by Chicago Bridge & Iron, Ingleside, Texas, 1980. It was formerly the Transworld 68 and Noble Max Smith submersible.

The Noble Max Smith as shown in Figure 8 was approximately 47 miles to the west of the storm. The conditions there were somewhat in excess of the 10-year return period values used in mooring design. The Noble Max Smith had no apparent problem in maintaining location, nor was there any damage.

The item of interest here is that it confirmed for this storm that the required distance from the track before having issues was approximately 50 miles: the extent of the distance to avoid the ferocity of the storm in excess of the current mooring standard.

			Significant Wave Height (ft)
API- 10 Year Pre-Ivan Values	72	1.8	30
Maximum Hindcast in the storm	72	1.9	41.3

Table 9: Values of Wind, Wave and Current at location compared to API Values

8.7 DEEPWATER HORIZON

Deepwater Horizon is a Reading & Bates RBS 8D design semi-submersible drilling unit capable of operating in harsh environments and waterdepths up to 8000 ft (Upgradable to 10,000 ft). It is a 5^{th} generation rig, built by Hyundai Heavy Industries Shipyard, Ulsan, South Korea in 2001. It is Classed ✠ABS MODU and flagged with Panama. It has berths for 130 rated for S-61 helicopter, and dynamically positioned and can transit without tug assistance. Its design operating conditions are 29 ft Significant Wave @ 10 secs; Wind: 60 knots and current of 3.5 knots. Storm conditions are 41 ft significant wave@15 secs; Wind of 103 knots; Current of 3.5 knots.

The principal dimensions are:

Length 396 ft
Breadth 256 ft
Depth 136 ft
Operating Draft 76 ft
Variable Deck Load operating 8816 Tons.

ABS Class Notations:

✠A1, Column Stabilized Drilling Unit, ✠AMS, ✠ACCU, ✠DPS-3

Table 4 gives information about the location of the Deepwater Horizon in Hurricane Ivan and the meteorological information, which was reported from the Oceanweather study. There was no damage to the unit but a number of observations are made t present the anxiety which prevails until the storm was over.

			Significant Wave Height (ft)
Maximum Hindcast in the storm	50.4	2.0	27.4
Design: Capable Values	103	3.5	41
API 100-year	108	2.1	40

Table 10: Values of Wind, Wave and Current at location compared to API Values

Note: Loop current not addressed in the above figures.

Information on the Deepwater Horizon was reported in Ref 27. The Deepwater Horizon was located at Green Canyon Block 743 waiting on current in order to safely detach the riser from September 9th through September 11th. The rig experienced high currents of greater than 3.5 knots due to the migration of the Ulysses Western Front current across the location. When the time arrived, a disconnect was performed with 3.5 knot surface current running.

The planned move to the S/SW to find lower currents was hampered by the prevailing opposing current, of 2.6 knots. They were not able to drift with the current to the NE due to the proximity of the escarpment 2300 ft elevation within 2 miles. It was also not prudent to try to go to the SE or E because of the approaching path of the storm. Due to the high currents and ability to only move at 0.3 knots the rig remained in high currents. The movement was not hampered by the capability (HP) of the vessel but by the need to prevent severe oscillation of the riser and high bending and shear loads in the top of the riser. 44 personnel remained safely on board during the storm as they attempted to manoeuvre with the riser hanging. After the passage of Hurricane Ivan the rig had to move to the SE to find lower currents of 1.3 knots.

There were several “take-aways” from this incident. There is insufficient known about the Loop currents and the eddies that spin off to predict when they will occur and the combination with storms. Prior to this incident the industry had not recognized that the Loop current of any significance was likely to occur concurrently with a hurricane. The metocean advice given in either API RP2A or in ISO is silent on advice about how to best plan to take that into account.

Transocean offered some valuable advice to the industry in terms of do’s and do-nots in the API Workshop (Ref 27) in relation to riser management in deepwater. The advice which has been annotated by the author (in brackets) is given below:

- *DO - obtain credible site-specific data, including metocean and bathymetry. (this requires staying keenly aware if there are restrictions of movement on location with riser attached either because of shallower water to the north or an oncoming hurricane in another direction).*

- *DO – have a site-specific riser management plan (sometimes this may require disconnection well ahead of the storm – since it takes so many hours to pull the riser this requires conservative decisions even prior to the hurricane entering the Gulf of Mexico).*

- *DO – have a reliable means for sensing currents throughout the water column and for monitoring riser angles during operations. (MMS requires current measurements on production locations).*

- *DO NOT – unlatch BOP in any environmental conditions under which the riser cannot be retrieved. (The riser is more vulnerable to damage when it is disconnected and hanging freely).*

- *DO NOT – attempt to run or retrieve BOPs in high surface currents unless reliable current measurements through the water column indicate that riser angles can be managed within recommended limits (As time goes on the industry will have further more accurate software to help with decision analysis – for such crucial decisions on board requiring the quick solution to a complex mathematical problem).*

- *DO – Review and update T-time estimates on a routine basis during storm season to reflect changing operating and environmental conditions (such as high currents and well construction operations).*

- *DO – Maintain the ability at all times to manoeuvre a DP installation out of the path of a tropical storm environment to sufficient distance to protect personnel and equipment. This means allotting sufficient time to retrieve and stow the riser system onboard.*

While disconnecting and having the riser hang-off during a storm is not the best of situations there are ways to mitigate the risk while suspended. Transocean offered the following takeaways from their situation:

- *Pull in as much riser as possible. Shorter riser strings have shorter natural periods and less severe dynamic response.*

- *Properly support the marine riser as much as possible.*

- *Use of a landing joint (when possible) to increase the annulus around the riser in the diverter housing and prevent damage to buoyancy and peripheral lines.*

9.0 OBSERVATIONS ON SEMI-SUBMERSIBLE MODUS

In Hurricanes Andrew, Lili and Ivan, the storm that came through exceeded the existing industry criteria at the specified locations.

In the passage of a 100-year return period storm such as Hurricane Lili, or ones of larger, less frequent size, such as Hurricanes Ivan, Katrina and Rita, there may be expected consequences for a floating MODU in the path. While the breaking of a mooring is a very serious event at the stage of breaking, it has the potential of a major consequence: the final result will depend on its location, direction, speed of travel, components of the mooring system dragging along the seabed or through the water column, and any structure, (surface or subsea), along the route.

From an engineering point of view, there is an important balance between designing economically viable structures and those that will withstand any storm. The paper by Rechtin, Steel and Scales perhaps said it best when wrestling over a decision as to the appropriate return period to use for jackups (Ref 28).

> *The usual conservative engineering approach of taking "the worst condition possible" would mean designing against a catastrophic storm in which the loss of a platform would only be a minor incident in a regional disaster. But the structure resulting from such a design premise would be so heavy and expensive that it would be entirely uneconomical to operate. It would be carrying around weights and cost items which in all probability would never come into play during the life of the equipment or for a hundred years after it had been scrapped.*
>
> *On the other hand, it is possible to design and operate equipment which is economical and satisfactory to operate in moderate weather but which will be damaged by the first serious storm to such an extent as to wipe out all the previously hoped-for economy.*
>
> *Somewhere between these two extremes there must be a design criteria partly satisfying both the demands of safety and economy.*

There is also concern that it is not prudent to just increase size of mooring components or to change to different materials, about which our understanding is less. Such a move might make the moorings good in theory but ensuring that the components are consistently up to the standard to ensure they do not give way prior to their theoretical maxima is also a challenge not to be overlooked.

10. JACKUP MODUS: HURRICANE IVAN

Jackups have been used in the Gulf of Mexico since the mid-1950s and there has been notable success and few failures in that time. When hurricanes impact the infrastructure in the Gulf of Mexico they are often individually more powerful than the design conditions of individual rigs, so if the jackup is in the path within a 20-30 mile distance, of a hurricane of the magnitude of Hurricane Ivan it is likely to be adversely impacted. Because of the early warning contingency plans and the evacuation of personnel, there was no loss of life, and no significant pollution events. Very few jackups have been lost as a result of hurricanes considering the number that continually operate in the Gulf of Mexico. Either they are generally more robust than our conservative calculations methods predict, or the nature of our calculations either overestimates the loads or underestimates the strengths.

The practiced in the Gulf of Mexico has to been to site jackups to a 10-year return period storm (full population hurricanes), which is approximately equivalent to a 50-year sudden hurricane, to allow for full evacuation of the MODU prior to a major hurricane (Ref 29, 30).

The practice has also been to position the elevation of the jackup typically to a 100 year air gap (deck elevation). A minimum of 50 ft has been widely used, but the values of API RP2A are also often used.

In the case of Hurricane Lili one jackup was sited using the API RP2 A curve for deck elevation but it proved to be too low a value in shallow water where breaking wave crest elevations exceeded the norm (Ref 4).

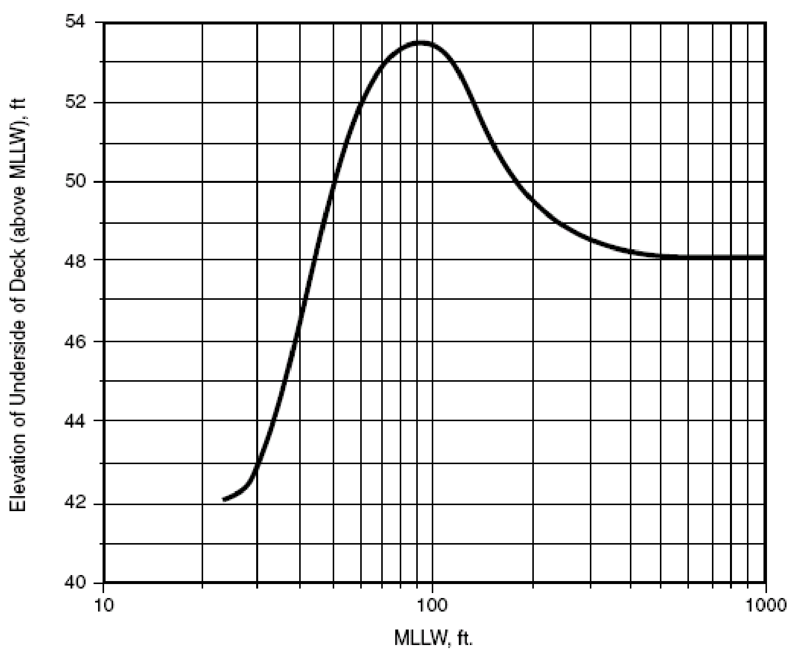


Figure 2.3.4-8—Elevation of Underside of Deck (Above MLLW) vs. MLLW, Gulf of Mexico, North of 27° N and West of 86° W

Figure 27: Deck Elevation from API RP2A (Ref 8).

For Hurricane Ivan 3 jackups were anticipated to be affected by the storm. Enquiries were made of others which would have been expected to survive. Their proximity to the storm made it useful to note for future reference that there was no damage or signs of distress. The details of the jackup MODUs upon which data was gathered are given in Table 11. Details of information on any results of Hurricane Ivan's passage are also given.

For some time now, the SNAME Gulf of Mexico Annex Committee with funding by some drilling contractors has been developing a more rational criteria to ensure that jackup designs can structurally withstand events to ensure safety of personnel during a the conservative anticipated evacuation period after a hurricane is declared and based on a 50-year "sudden hurricane" event. Recommendations from the work of this committee are being shared with industry (Ref 30). The committee is also in the midst of working with the API committee to develop an upgrade to the recommended air gap figures from which the jackup safety will benefit. The intention is to issue API RP95J for jackups as Interim Guidance for the Hurricanes.

The various jackups close to the storm are listed together in Table 12 together with a general view of their "likely capability".

The information as to the hindcast weather from the Oceanweather report (Ref 1) is given. In Table 12, the term "capability" is used as derived from the operating manuals, where available, and where not figures developed from previous papers and literature were used. Table 12 also shows the airgap and these have been provided based on the actual on-location airgap (where known), the API airgap, and a "required to survive" airgap figure. This latter figure is based upon the addition of the surge, wave crest elevation plus 6 ft for run-up (a figure often used by insurance warranty surveyors):

NAME	DESIGN	SITUATION ON LOCATION	FAILURE	COMMENT	TRAVEL
Ensco 64	MLT 53-S, Upgraded to 477' legs	Water Depth - 301' Leg Penetration - 75' all legs (approx.) Air Gap 46' Distance over Guides 52' Available Leg - 3' Preload 11,900 kips	All 3 legs failed; One leg length @100'; one leg length @65'; one leg completely gone. Legs laid over to the Northwest Derrick & Substructure laid over onto the pipe deck No apparent punch-through Well bent over and wellhead sheared off; Insured $65 million- Source: Upstream No pollution; Well was leaning at 16 deg.toward the west; Port and starboard legs are laying on each other;	Ivan's Eye passed 6 miles to the East of the location. Airgap insufficient on hindsight; Legs would have been overstressed regardless of airgap	40 Miles South of Location
THE 200	200-MC	Waterdepth 72' Air Gap 52'	No failure as such: Scour at forward end of approximately 6-8 ft. And at stern end approximately 4'. No other damage.	Mat rigs often slide or have scour issues in storms. This is a expected survival in "as new condition" but pressing the limits in view of the current. It was the one most directly in the path of the storm.	None
Ocean Warwick	Levingston 111 300' IC with 418' leg	Waterdepth 180' Airgap 50' Leg Penetration 27' all legs	Multi-node failures in 3 legs from levels 248-296' Starboard preload tank bulkhead buckled Wellhead impaled on hull All 3 jackhouses damaged Repairable - no losses overboard	Sufficient airgap; Legs would attract significant current forces; while it well exceeds the design the outcome is not unexpected i.e. significant but repairable damage	None
Ocean Columbia	MLT 82 SDC	Waterdepth 75' Leg Penetration 23'	None	No major damage expected based on Design vs Actual weather seen.	None
Ocean Drake	200-MC	Waterdepth 42' (Mat Rig)	Reported that wave action from the storm destabilized the drill site. No damage.	No major damage expected based on Design vs Actual weather seen.	None

Table 11: Jackup MODUs Exposed to Hurricane Ivan.

Operator	Rigname	Design	Builder	Year Built	Oil Company	Capable Water Depth (ft)	Location	Actual Water Depth (ft)	Capability	Max. Wind Speed 1-min (kts)	Current (kts) see Note 1	Max. Hindcast Max. Wave Ht. (ft)	Air Gap (ft)
Ensco	Ensco 64	MLT 53-S, Upgraded to 477' legs	MLT Clydebank	1973	Dominion E & P	350	Main Pass 280 #5 Penetration 75'	301	100 kts 45' waves, 0.0 kt current 88 kts, 40' waves, 1.5 kt current	100.6	3.3*	75.3	**46' Actual 48.5' API 61' RP95 Prop. 58' to have Survived**
Todco	THE 200	200-MC	Bethlehem Beaumont	1979	Palace Operating	200	Mobile 961	72	100 kts, 64' wave @ 15-16 secs 100 kts, 60' wave, 1.5 kts current	95.0	4.5	62.0	**52' Actual 53' API 50' RP95 Prop. 47' to have survived**
Diamond	Ocean Warwick	Levingston 111 300' IC	Levingston Orange	1971	Newfield Exploration	300	Main Pass 240 #1 Penetration 27'	180	100 kt winds, 60'waves, 1 kt current	91.9	3.8	66.0	**50' API 61' Proposed 52' to have survived**
Diamond	Ocean Columbia	MLT 82 SDC	MLT Brownsville	1978	Kerr McGee	250	Main Pass 108 Penetration 23'	67	88 kt winds, 40' waves, 1 kt current	80.4	4.6	33.2	53' API 48' RP95 Prop. 30' to have survived
Diamond	Ocean Drake	200-MC	Huangpu Shipyard China	1983	Chevron Texaco	200	Main Pass 30 (Mat)	43	100 kts, 64' wave @ 15-16 secs 100 kts, 60' wave, 1.5 kts current	71.6	2.7	41.0	47' API 48' RP95 Prop. 30' to have survived

Note 1: This is the current over the full depth with exception of Ensco 64 when the API profile was used and Surface current is reported.

Note 2: In shallow water < 50 ft the airgap is likely to be underestimated due to shoaling effects.

Comparison of 50-year sudden hurricane which is close to the quoted API 10-year for Comparison 72 kt wind, 1.8 kt current 48' Max Wave Height

Table 12: Results of Hurricane Ivan's passage on Jackups Exposed

10.1 ENSCO 64

Some of the first reports on the Ensco 64 came from Lloyd's List.

London, Sep 20 -- A press release from Ensco International Corp, dated Dallas Sep 16, states: Ensco International Inc announced today that one of the Company's jackup drilling platforms, Ensco 64 (5451 gt, built 1973, upgraded 2002) was directly in the path of hurricane "Ivan" and has sustained damage. The platform is now afloat in the U.S. Gulf of Mexico approximately 80 miles southeast of Venice, Louisiana. The platform was operating in Main Pass Block 280 for Dominion Exploration and Production Inc, and all personnel had been safely evacuated ahead of the storm. Appropriate regulatory agencies have been notified. A report of visual inspection from a fixed-wing aircraft has indicated Ensco 64 is floating approximately 40 miles south of its drilling location. Company personnel will be deployed to assess the extent of damage and determine appropriate remedial action to secure the platform as soon as practicable. The platform is insured for $65 million. Unless the rig is declared a total loss, Ensco anticipates the cost of repairs will be recoverable in excess of policy deductibles which are limited to $5.5 million. The Company also has received a preliminary report from a third-party of damage to the helideck on one of the Company's platform Ensco 25, which was adjacent to the path of the storm. The Company has commenced inspection and re-boarding operations of its Gulf of Mexico rig fleet and is unaware of any further damage at this time.


Figure 28: Ensco 64 jacked up on location

London, Oct 19 -- A press release from ENSCO International Inc, dated Dallas today, states: "In September, one of our Gulf of Mexico jackup rigs, Ensco 64, was severely damaged during Hurricane "Ivan". Platform rig Ensco 25 also sustained damage during the storm. We are still in the process of assessing the full extent of damage to both rigs. The contract on Ensco 64 was terminated in mid-September while the contract on

Ensco 25 reverted to a standby rate while repairs are undertaken over the remainder of 2004." (See issue of Oct 8.)

The location being drilled for Dominion was Main Pass 280 Well #5.

29 ^{0} 16’ 25.85” N
88 ^{0} 12’ 05.6” W

The location is shown on the chart below in a waterdepth of 301 feet.

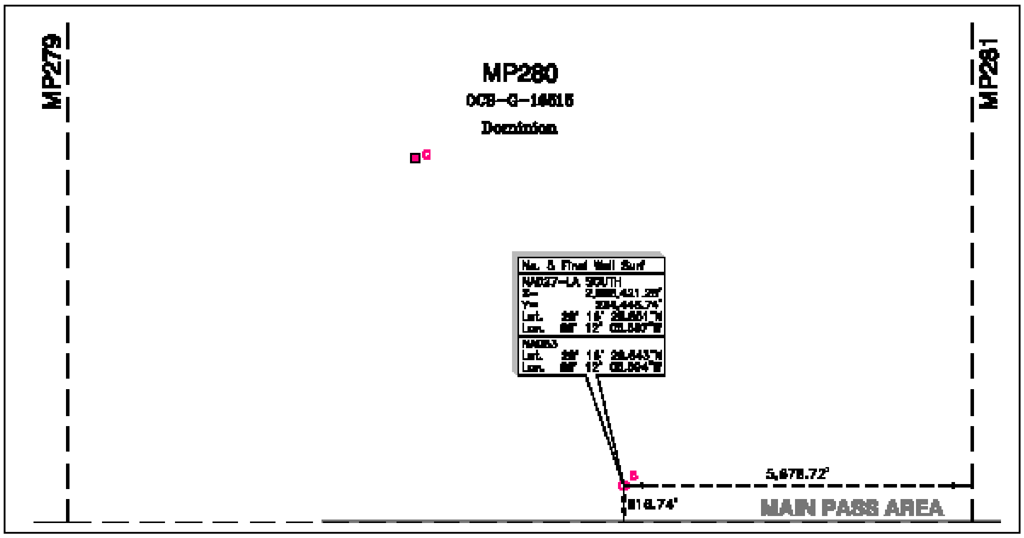


Figure 29: Location in Main Pass 280 Well #5.

ENSCO 64 owned by ENSCO International Inc. was a Letourneau 53 class slot jackup design built in 1973 at Marathon LeTourneau, Clyde Bank, Scotland, 1973 as the Penrod 64 a zero discharge rig (for environmentally sensitive area drilling).

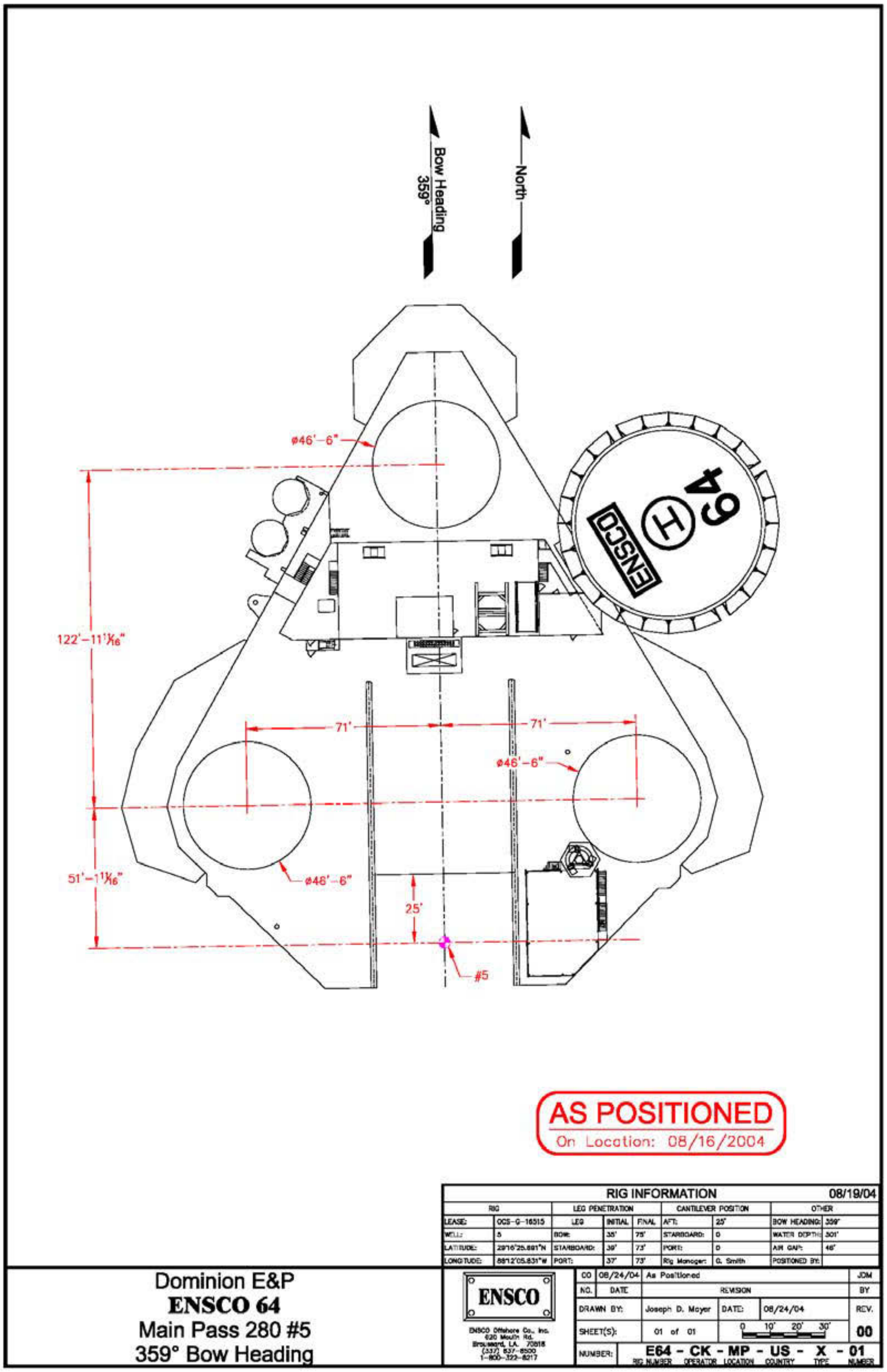


Figure 30: Ensco 64 Arrangements on Location

It had been upgraded to increase the leg length to 477 ft, reinforce the legs, and increase the preload capacity in order to increase the waterdepth capability of the rig. It was at its deepest waterdepth at this location based on the leg penetration. With 75 ft of leg penetration, this location was also on the limits of its leg length with little reserve (a couple of feet), to get higher (as can be seen in Figure 32).

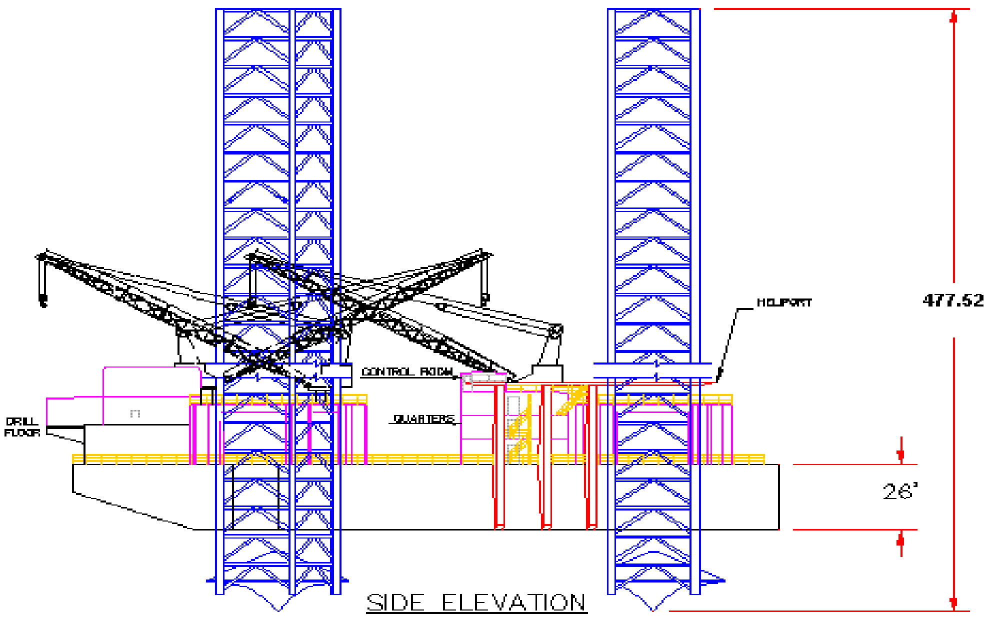


Figure 31: Side Elevation of ENSCO 64.

Principal Dimensions
Length between perpendiculars .... 231.00 ft
Length including sponson .... 248.00 ft
Width………..…………………………………………………………….200.50 ft
Width including heliport .... 241.33 ft
Depth of Hull …………………………………………………………..26.00 ft

Size of Slot:
Transverse .... 52.00 ft
Longitudinal .... 41.00 ft

Legs and Spud Cans
Length of Spud Legs…...…………………………………………………...477.52 ft
Bow to Forward Leg .... 40.89 ft
Longitudinal Leg Centers .... 122.97 ft
Transverse Leg Centers.. 142.00 ft
Diameter of Spud Can (across flats).. 46.00 ft
Length including sponson ……………………..……………………….248 ft.
Width ………………………………………………………………………..200 ft

Width including heliport ……………………………………………………..241.33 ft
Depth of Hull…………………………………..…………………………….. 26 ft
Size of Slot: Transverse 52 ft; Longitudinal 41 ft.

Main Pass 280 #5 well was a directional well that was being drilled by the drilling rig ENSCO #64. On September 12, 2004, operations were halted due to the approaching Hurricane Ivan. The well had been drilled to almost 6000 ft on day 21 since spud. The rig began evacuations procedures, which required laying down some excess drill pipe that was in the derrick, and in the hole. A storm packer was run in the hole and set at 850' with the drill bit at 4300 ft. The rig was skidded in and secured for the storm and all personnel were safely evacuated off the rig on September 13, 2004.

During the storm the hull sheared off the legs and into the water: the hull drifted off location and was later recovered. The drillfloor overturned. The rig was declared a Constructive Total Loss by Underwriters. After recovery, the main hull was hauled to Brownsville awaiting sale as scrap (or for rebuilding and refurbishment by others).

As the rig made its transit the following components were below the keel

- One leg @ 100 ft
- One leg @ 65 ft
- A third leg was completely gone.

The height of waves and thus whether the deck elevation was sufficient requires derivation of the heights and crest elevations in the hindcast storm at the specific site. Early indications were that this was an extreme hurricane, which themselves at this magnitude are quite rare. A science magazine article discusses the event:

Science 5 August 2005:
Vol. 309. no. 5736, p. 896
DOI: 10.1126/science.1112509

Extreme Waves Under Hurricane Ivan
David W. Wang,[*] Douglas A. Mitchell, William J. Teague, Ewa Jarosz, Mark S. Hulbert
Hurricane Ivan, a category 4 storm, passed directly over six wave-tide gauges deployed by the Naval Research Laboratory on the outer continental shelf in the northeastern Gulf of Mexico. Waves were observed with significant wave heights reaching 17.9 meters and maximum crest-to-trough individual wave heights of 27.7 meters (91 feet). Analysis suggests that significant wave heights likely surpassed 21 meters (69 feet) and that maximum crest-to-trough individual wave heights exceeded 40 meters (132 feet) near the eyewall.

The location arrangements were as follows:

Water depth 301 feet
Penetration for each leg: 75 ft, 75 ft, 75 ft
Air Gap 46 ft
Distance over Guides 52 ft

Total Leg Length required this location: (summation of above) 474 ft.

Length of Leg 477.52 ft

Reserve 3.52 ft above the upper guide

The following information gives the rig design capability and tabulates the hindcast conditions in the storm.

						Air G (ft)
Capability						
300	88	41	1.48	.65	75	50
300	100	44	0.0	0.0	75	50
328	88	40	1.51	.65	75	50
328	100	45	0.0	0.0	75	50
Actual Site Location at Main Pass #280						
301	100.6	75.3	3.0	3.0	25	46

Table 13: Hindcast conditions for Ensco 64 together with advertised capabilities

The airgap selected, 46 ft, would have allowed the jackup to weather most 100 year storms, and was close to that recommended by API RP2A for fixed platforms (Ref 8) at 48.5 ft.

By comparing the actual site conditions to those of the table below: the weather conditions caused the Ensco 64 to exceed even the 100-year load (API values).

				Bottom Current (kts)
API –10 yr Pre-Ivan	72	48	1.8	.9
API – 100 Yr Pre-Ivan	108	70	2.0	1.0

Table 14: Shows API criteria pre-Ivan

The Oceanweather hindcast developed the following figures for this location, and this added to the reserve of 6 ft, for contingencies and run-up brings the calculation for air gap as follows:

	Value (ft.)
Storm Surge	2.2
Crest Elevation	49.4
Subtotal	**51.6**
Reserve	6
Total	**57.6**

Table 15: Calculation of Hindcast Airgap

With an airgap of 46 ft based on the above, the storm crest elevation would have impacted the deck. Ensco 64 was stationed 6 miles to the west of the central path of the eye.

The wind, wave and current all exceeded the design by a large margin. An increase in current results in a decrease in capability as shown from the operating manual conditions showing the extreme design storms. A 1.5 kt current knocks the capability down by 12 knots of wind and 4 ft of wave. Doubling the current would further decrease the capability significantly. Thus Ivan imposed on the rig forces related to double the design wave height and this would take the jackup well past its ability to stand. Thus even by rare chance the rig did the wave crest impacting the hull bottom, it would be expected to fail regardless, based on normal wind, wave and current conditions as extreme as those of Hurricane Ivan.

Figure 32 follows:


64
H
ENSCO

The hull drifted off location and Figure 34 shows a photo taken of the unit after it drifted 40 miles south of location. At Main Pass 280, the bottom of the legs were found laid over to the northwest. The legs had to be removed before a drilling rig could be mobilized to attempt well bore salvage. The well was leaning about 16 degrees toward the west from below the mudline for one full joint, which appeared to be straight. The pipe was cut to about 50 ft above the mudline. All casings were collapsed about 6' above a collar on the 2nd joint above the mudline with an angle greater than 90 degrees. The drive pipe deck and tensioner were laying in the mud at the base of the drive pipe.

The wave height as measured at a nearby buoy was originally reported to be 83 ft. The legs parted below the rig and did not penetrate the hull. Only one tank took on water.

Figure 33: Photo showing the derrick collapsed.

Figure 34: Photo of Ensco 64, 40 miles south of location during recovery efforts.

Removal of the wreckage from the seafloor took place starting in December 2004. Some of the observations give some insight:

12/5/04:
All three small leg sections were found to actually be ¼ sections containing only 1 rack assembly and some K-braces. The length of the sections ranged from about 70 ft to 33 ft. The upper portion of the bow leg is essentially intact to 370 ft. At the 370 ft mark the A and C chords end and the b and D chords continue for about 66 ft but splay apart at the bend upwards with respect to the plane through C-D.

12/6/04:
Utilize the Rotech tool to continue excavation of the bow leg.

12/19/04:
Completed the survey of the starboard leg. The leg makes a 30 degree angle with the seabed. It is intact to between 410' and 420' mark after which the E and F chords shear away and the G and H chords continue to near their full length, bent and splayed. The leg is lying such that the F chord is the uppermost northern chord and the E-F plane is tilted so that E lies deeper than F. The tilt is 11.5 degrees. The chord marked with

lengths is the H chord. It is the lowermost southern chord and it enters the seabed at the 150 ft mark .The K braces appear intact right up to the break.

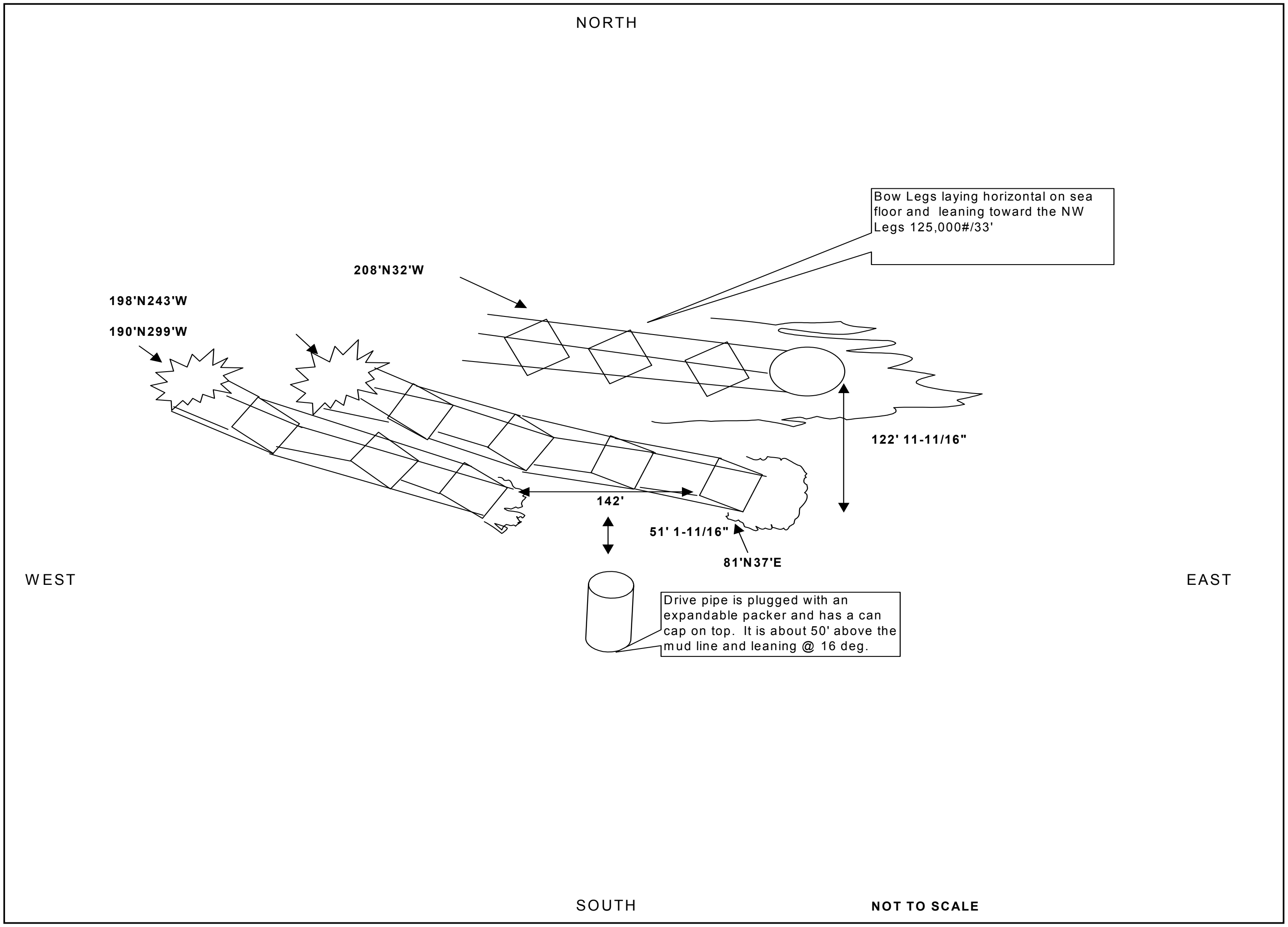


Figure 35: 3 legs of Ensco 64 on the bottom, after Hurricane Ivan Port and starboard legs are laying on each other. Bow leg has been excavated and spud can and leg laying horizontal on the seafloor. All small debris was removed from the sea floor.

As it transpired it took until 7th January 2005 to finally extract the bow leg, whereupon the focus of attention was shifted to the starboard leg.

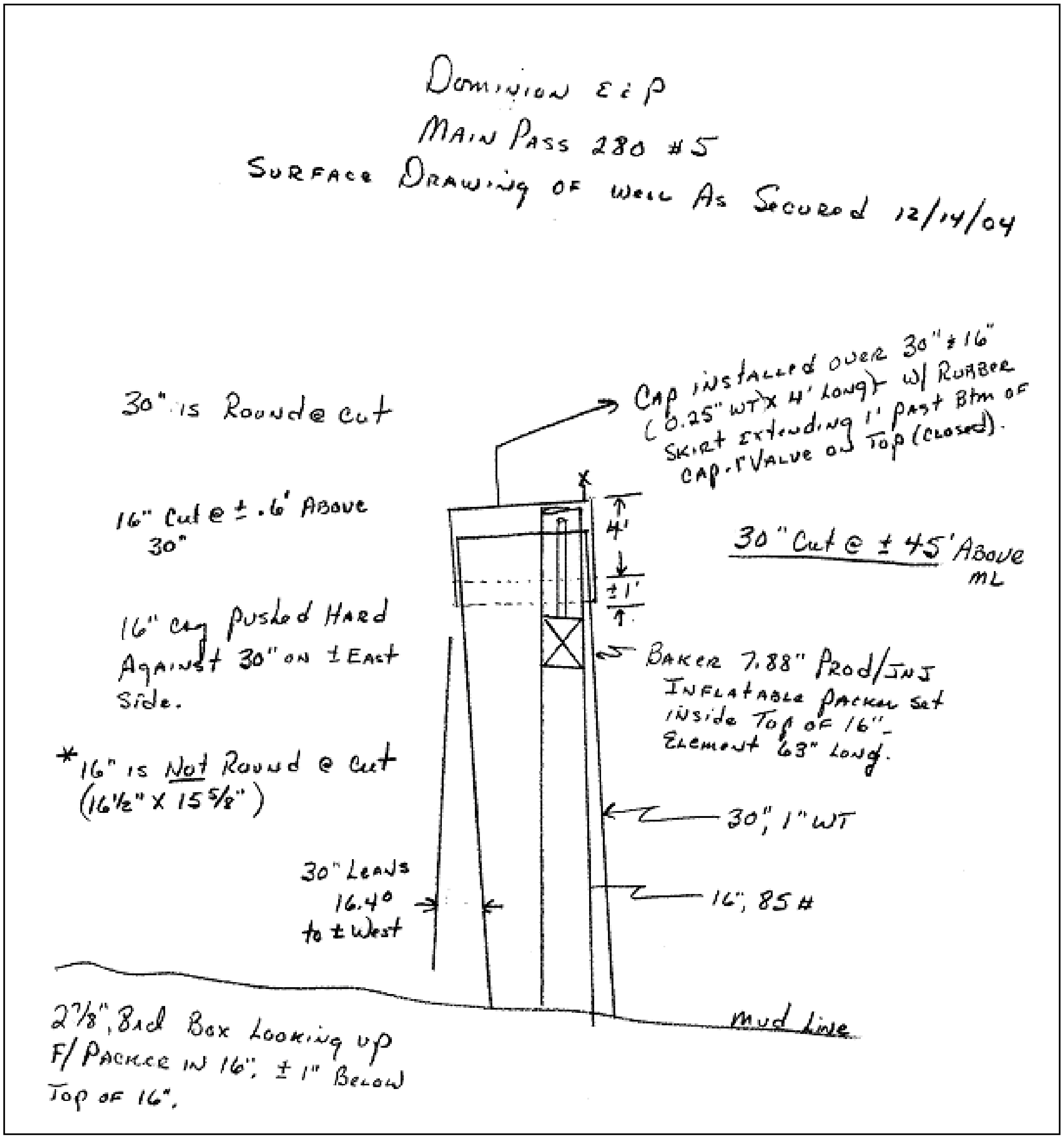


Figure 36: Well #5 after the incident.

Takeaways

ENSCO 64 came close to meeting the API criteria for fixed platforms; it would have taken an airgap much more than the historically used air gap in order to prevent the hull from being inundated with green water, a situation it is not designed for.

In previous years the information has not been available to the jackup community to allow assessment of airgaps, by using a Gulf-wide storm to model the wave crest elevations confidently (e.g. Oceanweather model). In the past the 50 ft "rule of thumb" was considered a sufficient airgap to avoid most 100-year events. As a result of this incident and those of the following hurricanes, Katrina and Rita, the jackup community has been made aware and has some new proposals as to recommended airgaps with water depths as contained in API RP95J.

[Special thanks to Dominion and Ensco for making available the details of a forensic evaluation and giving generously to the study of the photographs to allow a visual understanding of the results of the Hurricane Ivan passage]

10.2 THE 200

THE 200 is a Bethlehem 200 class cantilever rig, built at Beaumont, Texas in 1979. It was operating for Palace Operating Company. There were a number of this type of rig built by Bethlehem, many of which still work in the shallower waters of the Gulf of Mexico. Its operating capability is 200 ft and thus with an actual waterdepth of 72 ft its capability exceeded those values shown in the operating manual for deeper waterdepths.

Figure 37: Artist's Rendition of Bethlehem JU 200 Design

The jackup was built in 1979 of standard Bethlehem design. It was operating in 72 ft of water in Mobile Block 961.

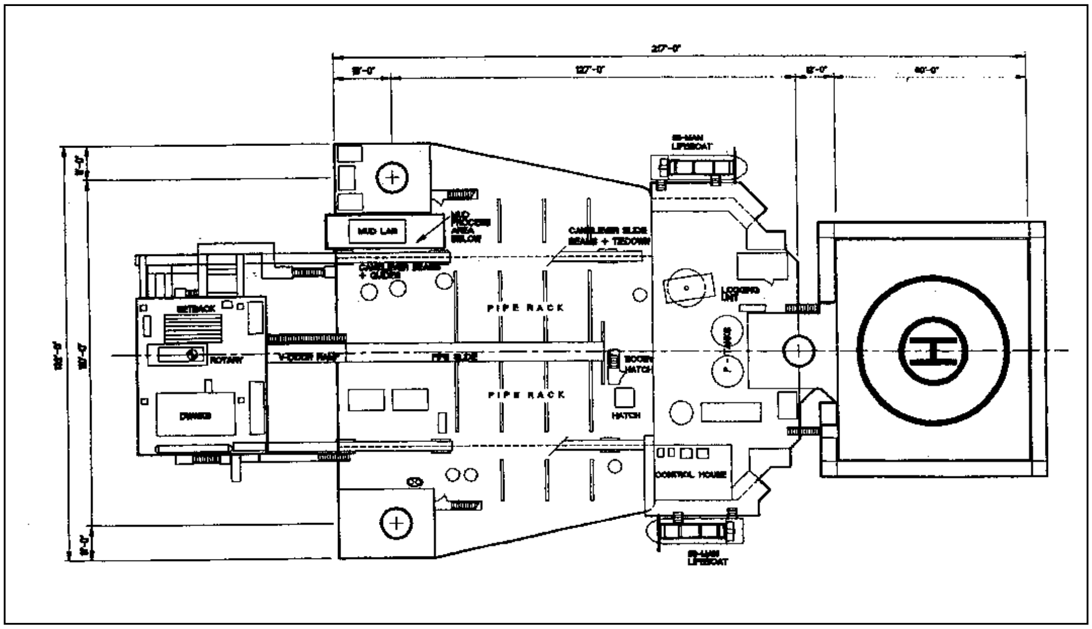


Figure 37: General arrangement view from above.

Main Dimensions

Length 157 ft
Breadth 132 ft
Depth 18 ft
Legs 3 @ 269 ft length
Cantilever Reach Transverse: 10 ft either side of centerline; Longitudinally: 45 ft either side of centerline
Operating Depth 200 ft (non-hurricane)
Accommodation – 50 persons
Mat 220 ft x 185 ft x 10 ft

The airgap, which would have been required based on the Oceanweather data, is 47 ft airgap. It had a 52 ft airgap so no inundation of the hull would be expected.

				Bottom Current (kts)
Capability				
200	100	64	0.0	0.0
200	100	60	1.5	0.0
Actual Site Location at Mobile 961				
72	95	62	4.5	4.5

Table 16: Showing THE 200 design capability and the Hindcast conditions in the storm.

The wind speed in Hurricane Ivan was close to that for which the unit was designed. Observing that the wave height decreased by 4 ft for an increase in current of 1.5 kt it can be judged that an increased current would further decrease the waveheight capability thus increasing the delta between the design and actual wave height at location. Based on this, the unit would be expected to survive, but require careful structural inspection since it would exceed the designed leg loads. The locations to be cautious about would be the leg at the lower guides and the mat-column connection Mat rigs often slide sideways in hurricanes (Ref 33, 36, 37) and thus it would not be unusual to find one loaded in excess of its design conditions to have some soil issues. This mechanism has often been thought to relieve the loads and allow survival in conditions above those of the design.

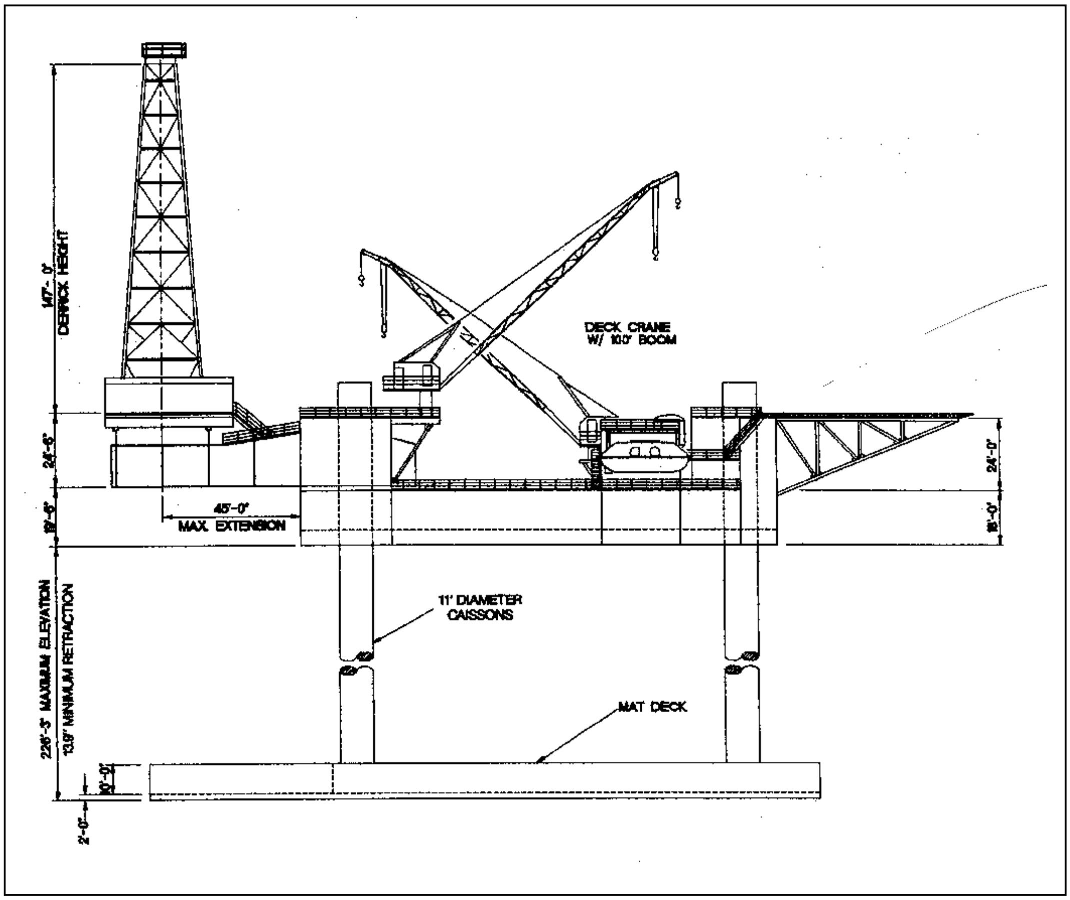


Figure 38: General Arrangement Elevation of THE 200

The following similar Bethlehem 200 Designs operating in the Gulf of Mexico.

		Build Date
		1982
		1983
		1981
		1981
		1982
		1981
		1981
		1981
		1982
		1981
		1981

Table 17: Bethlehem 200 Designs in the Gulf of Mexico

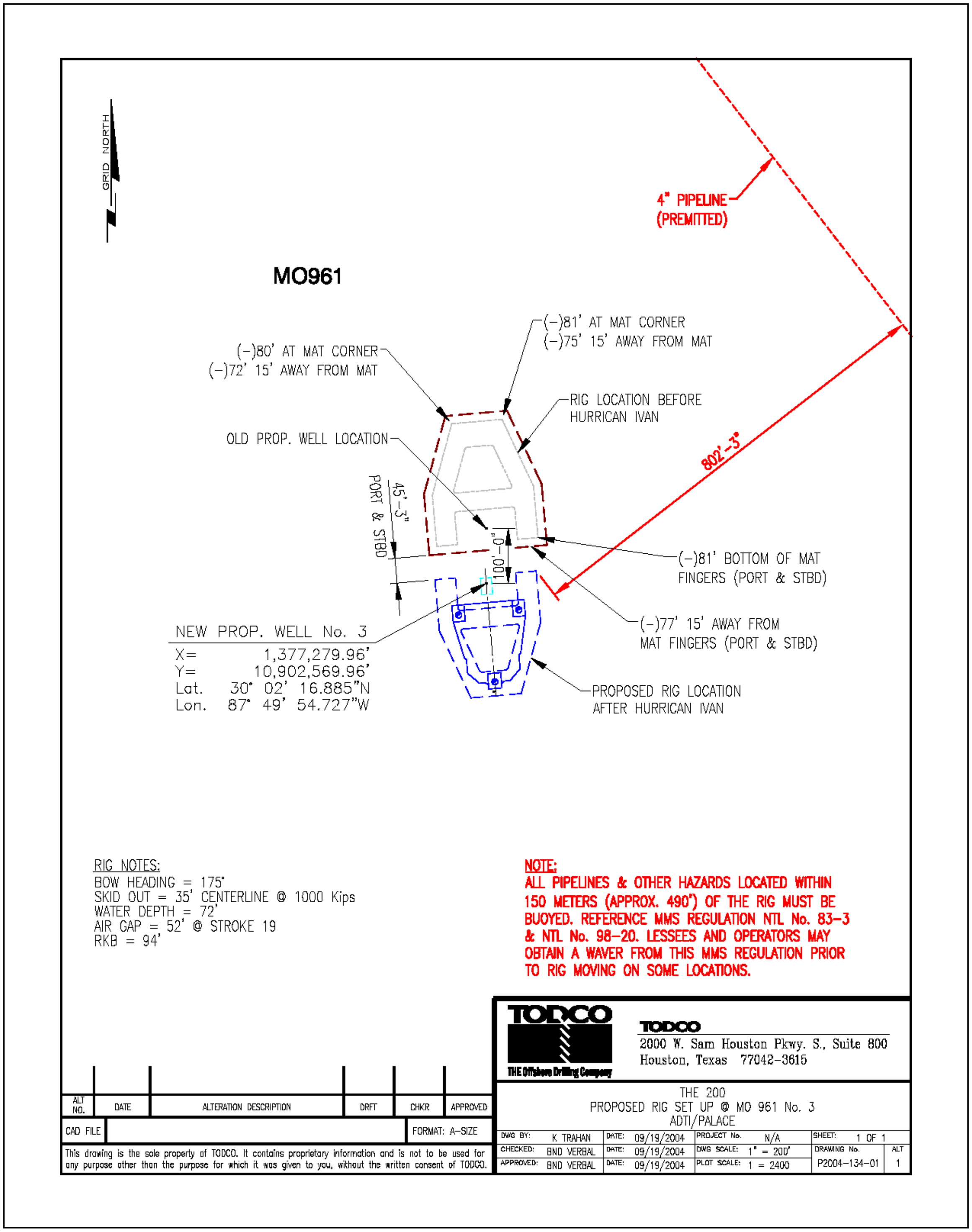


Figure 39: Showing area where THE 200 was set up and new proposed position since there is disturbed soil at the previous location.

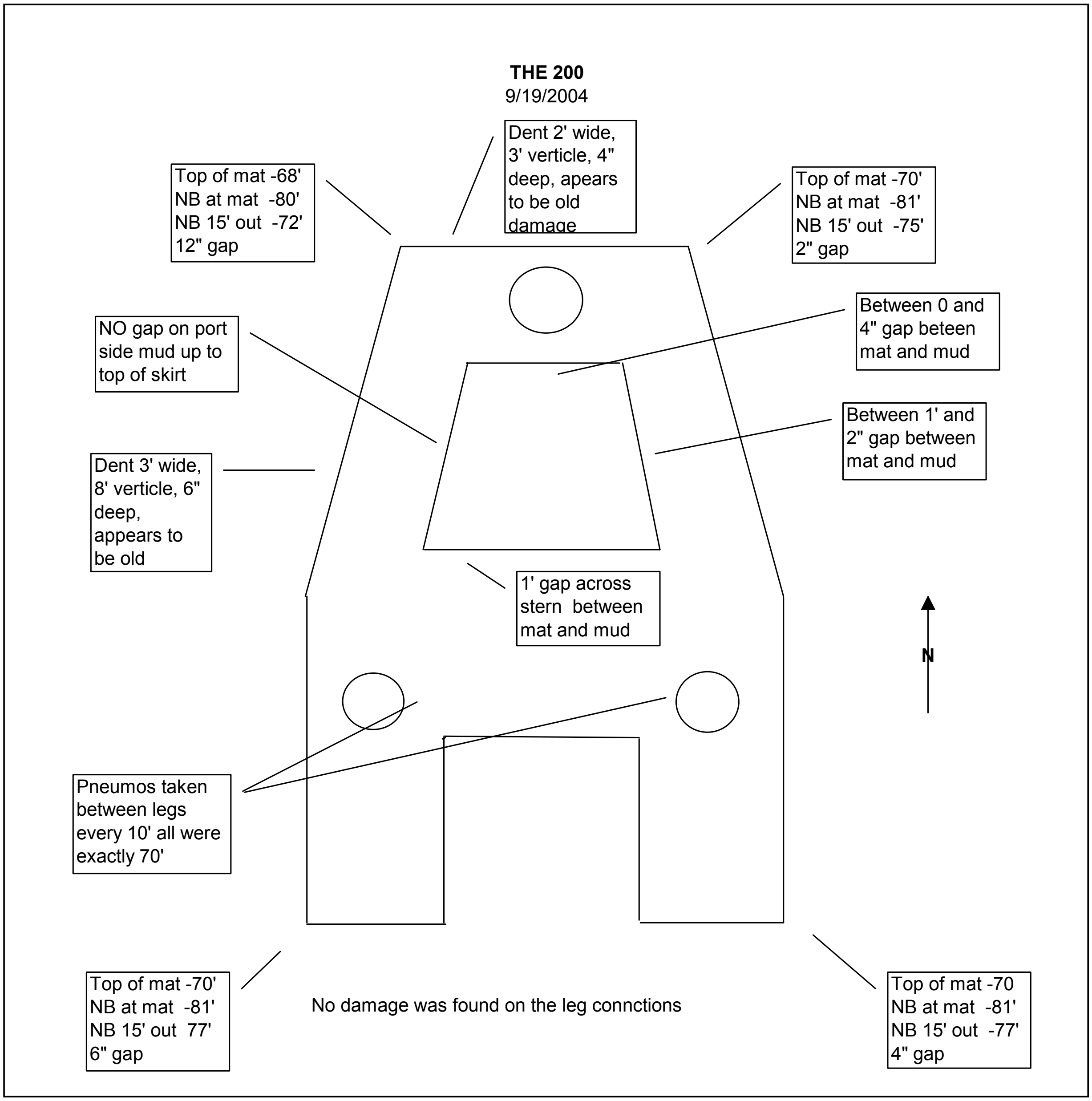


Figure 40: Sketch showing the situation at Location after Hurricane Ivan came through

THE 200 had no failures, and no issues resulting from a detailed structural inspection. Scour at the forward end of the mat of 6-8 ft and at the stern end of approximately 4 ft was the result of the passage of the storm causing the rig to be relocated for continuation of its work. Figure 41 shows the sonar scan of the area after the passage of the storm and lays out the position that the rig was to be moved to after the storm because of the unevenness of the soil, which had scoured under the mat. Figure 42 shows THE 200 after the storm. Note the effect of the high current on the legs of the unit.

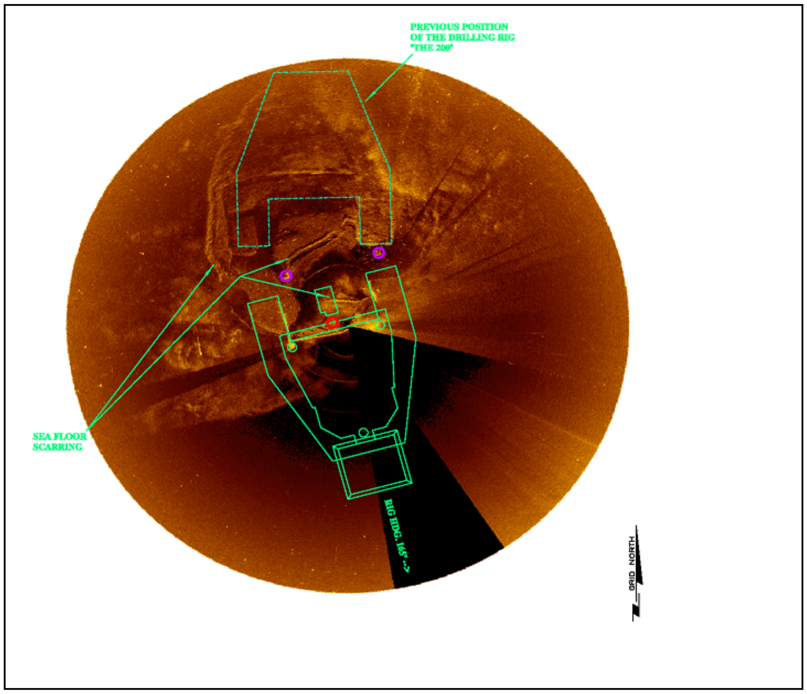


Figure 41: Fugro Chance Inc. Sonar Data on THE 200

Figure 42: THE 200 Photo taken After the Storm (note effect of currents on the legs)

10.3 OCEAN WARWICK

The reports from Lloyd's List indicated some damage.

London, Sep 22 -- A press release from Diamond Offshore Drilling Inc, dated Houston Sep 20, states: Diamond Offshore Drilling Inc today reported preliminary results of inspections on board five company rigs that were operating in the path of Hurricane "Ivan". Examination of drill platform Ocean Warwick (3621 gt, built 1971) revealed damage to the unit's legs and jacking system. Crews are currently making initial repairs before moving the rig to a shipyard to complete the inspection and perform any necessary work. Total downtime for Ocean Warwick cannot be determined until the inspections are complete.

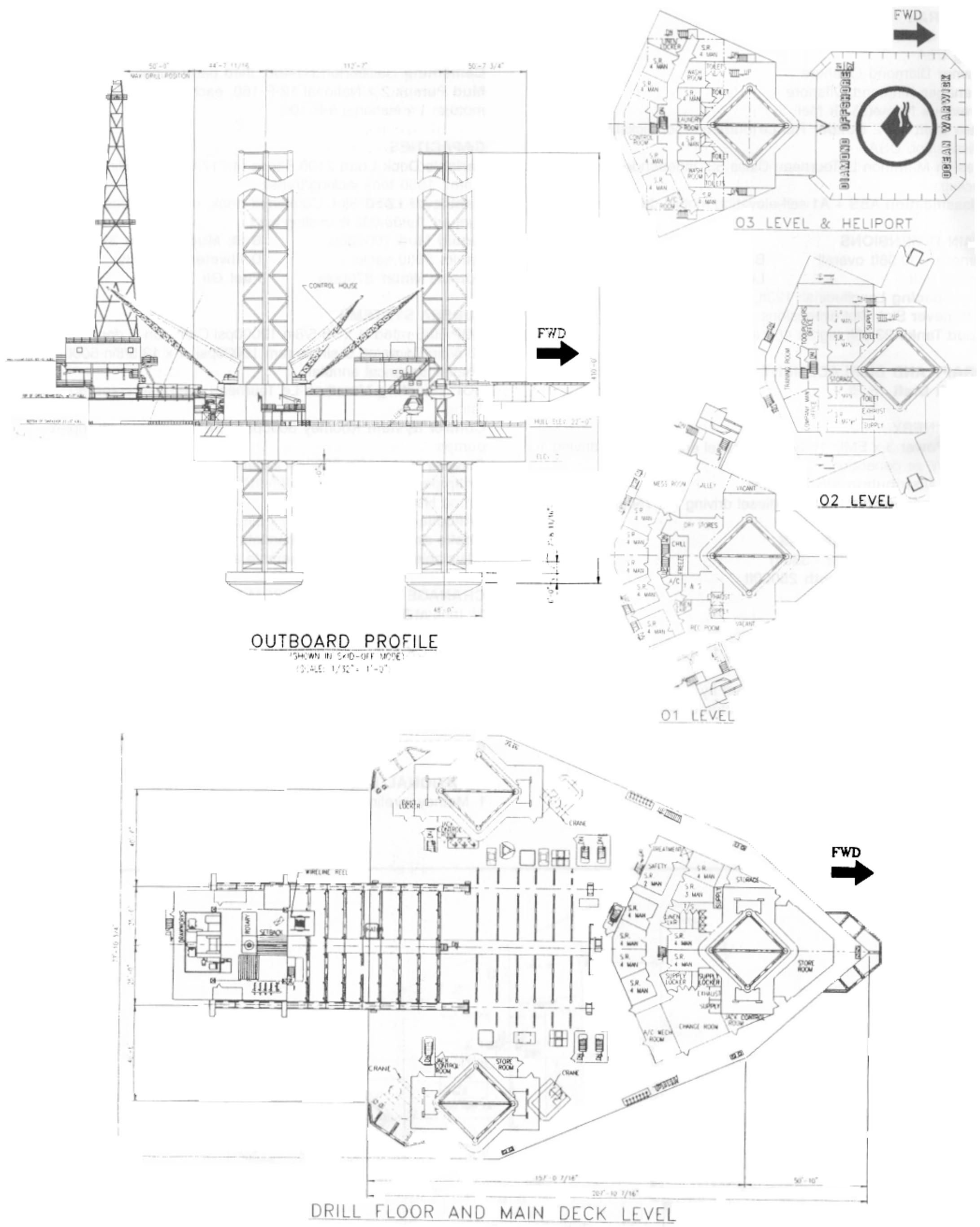
The Ocean Warwick is a Levingston 111 class jackup with 418 ft of leg. This was on of the "standard" designs in the early 1970s and several were built at Orange, Texas. The Ocean Warwick was constructed in 1971. It was in 185 ft of waterdepth and well within the waterdepth capability of the rig advertised as a 300 ft independent cantilever jackup.

Similar Levingston III Slot designs operating in the Gulf of Mexico are listed:

		Year of Build
Noble Gene Rosser	Noble Drilling	1977
Noble John Sandifer	Noble Drilling	1977
Noble Lewis Dugger	Noble Drilling	1975
Ocean Nugget	Diamond Offshore	1977
Ocean Summit	Diamond Offshore	1972
Ocean Warwick	Diamond Offshore	1971

Table 18: Levingston 111 Designs Operating in the Gulf of Mexico

Ocean Warwick (cont'd)



GENERAL
Name Ocean Warwick **Flag** USA
Owner Diamond Offshore **Manager** Diamond Offshore
Previous Name(s) Marlin No 6; Diamond M Warwick
Year Built 1971 **Builder** Levingston Shipbuilding Co, Texas, USA; 1998: Upgrade
Design Levingston 111-C, independent leg jackup
Classification ABS + A1 self-elevating drilling unit

MAIN DIMENSIONS
Length 208ft
Breadth 178ft
Depth 22ft
Legs 3 x 418ft
Leg Spacing Longitudinal: 130ft
Spud Tanks 48ft diameter x 6ft deep
continues on page 781

Figure 44: The Ocean Warwick was approximately 21 miles west of the storm track.

					Penetration (ft)
Capability					
300	100	60	1.0	0.0	25
Actual Site Location at Main Pass 240					
180	92	66	3.8	3.8	27

Table 19: Showing the Ocean Warwick approximate design capability and the Hindcast conditions in the storm.

Comparison of the actual to design conditions shows that the design condition would have been exceeded even based on a 1 kt current. With a 3.8 kt current, the capability would have been further decreased with the expectation of some minor structural damage.

The airgap would have to be 52 ft to have survived (6 ft reserve is included in this number) so based on customary practice of about 50 ft airgap there would be no expected inundation of the hull by waves. The loads were such that some damage to the legs might be expected, as was seen. It is understood that the airgap significantly exceeded any requirement and was in the 80 ft + range.

There were multimode cracks in all three legs from levels 248 ft to 296 ft. The starboard preload tank bulkhead buckled. The wellhead impaled on the hull. All three jackhouses were damaged. It would not be unusual to expect some damage to the jackhouses since this had been a chronic issue with Levingston 111 units, and thus would not be of major concern, except to say the cracks would need repairing.

10.4 OCEAN COLUMBIA AND OCEAN DRAKE–

Lloyd's List reported: Drill platform Ocean Drake (5990 gt, built 1983) experienced essentially no damage to the unit, but wave action from the storm destabilized the drill site, and the Company is currently working with the operator to develop a course of action. Drill platform Ocean Columbia was essentially undamaged and is proceeding to its next drilling location

Ocean Columbia and Ocean Drake were respectively 40+ miles and 50+ miles from the hurricane force winds. As shown on Figure 5, this was outside of the path of concern with MMS for fixed platforms. Areas inside the boundaries drawn on Figure 8 required an API Level II inspection for fixed platforms after the storm. This area is the area most likely to be where damaged MODUs are to be expected.

Reference to the metocean conditions compared to the design conditions indicates that no damage would be expected: and none was reported. It was stated in one report that for the Ocean Drake, the wave action from the storm destabilized the drilling site, which most probably means that there was some movement in the rig, or scour as is customary with mat supported drilling rigs (Ref 33).

11. ACTIONS SINCE HURRICANE IVAN ON FLOATING MODUs

Following Hurricane Ivan, the Offshore Operator's Committee at the encouragement of the MMS brought an extraordinary industry effort together to attempt to address the hurricane mooring issues prior to the 2006 hurricane season. An API Workshop was held on the Performance of MODUs and the following MMS questions were asked:

- Is the API RP 2SK Mooring Designs standard adequate?
- What are the assumptions used in performing risk analysis for mooring near infrastructure? Are they sufficient?
- Are the current mooring standards for anchors and synthetic mooring systems adequate?
- Are the current storm preparation and evacuation procedures adequate?
- Are the operators allowing enough time to properly secure and prepare?
- Are the recommended inspection schedules for mooring systems adequate

Source: API Presentation C. Oynes

Since Hurricane Ivan, Hurricanes Katrina and Rita have inflicted even more damage on the Gulf of Mexico infrastructure and the further reports of MODUs breaking adrift are significant.

A Joint Industry Study (Ref 34) was formed which has resulted in quick action on several items. A number of oil companies, drilling companies and equipment manufacturers joined together and pooled funds to allow a contractor to carry out studies, and the results are shared with the industry participants.

The metocean conditions have been re-examined and re-newed values of the 10-year and 100 year storms have been developed and promulgated to industry. New post-Ivan-Katrina-Rita metocean data will be available for variety of return periods and 4 separate areas of the Gulf of Mexico which have different levels of severity of the extreme storms. The 4 separate areas are:

- West of 94^0
- West Central 90^0-94^0
- Central 87^0-90^0 considered the "HOT SPOT" – with the most severe weather and the highest likelihood of severe hurricanes
- East of 87^0

An Interim Guideline has been issued as an API document to upgrade the criteria appropriate to mooring of semi-submersibles for the 2006 hurricane season. This criteria will be further developed and be part of a new API RP2SK issue in the near future. Some of the new requirements include:

- A minimum recommended windspeed of 64 kts
- 5-year return period eliminated except in special circumstances
- 10-year return period minimal without special circumstances
- All values for site-specific wind, wave and current should reflect the Post-Rita values.

- A new “risk ranking” tool is incorporated to allow an operator/drilling contractor to evaluate the risk at a specific site based on a number of factors including location, time-of-year, waterdepth, presence of pipelines, proximity of critical infrastructure and other important factors.

- Inspection requirements increased: Required use of documented API RP 2I (Ref. 31).

The recommendations of this new Interim Guideline will increase the required capability of mooring systems by a minimum of at least 40% for the 2006 hurricane season just based on changes in the metocean data. With the higher values being used for medium and high risk locations the results should be as low as reasonably practical. .

Overall it is not desirable for semi-submersibles to break adrift of their moorings and potentially impact other structures (Ref 35). The Joint Industry Study will lead to information for API to develop new criteria in API RP2SK which may be risk-based and may lead to a reduced risk to the critical infrastructure, from drifting MODUs during hurricanes.

12. ACTIONS SINCE HURRICANE IVAN ON JACKUP MODUs

Since Hurricane Ivan there have been two additional hurricanes: Katrina and Rita, which furthered the damage done to the jackup MODU structures in the Gulf of Mexico. MMS had a request out for White Papers in respect of Katrina and Rita with respect to jackups to compile the information and understand their failures.

A new API Recommended Practice RP95J has been developed for "Gulf of Mexico Jackup Optimization during Hurricane Season" with higher airgap requirements,

Additional features of the standard include:

- Recommendation for operator to provide soil and metocean information
- Recommendation for adherence to the operating manual requirements which would mean a more strict adherence to the design level requirements rather than the ultimate survival level of requirements
- Recommendation for additional airgap up to 61 ft.
- Satellite tracking requirement on abandonment for a storm.

This should increase the probability of survival of the jackup rigs by a considerable margin.

13. CONCLUSIONS AND RECOMMENDATIONS: FLOATING MODUs

The incidents that occurred led to no injuries, or major pollution, so far as we are aware.

There was one small pollution incident from damage to a 2-7/8" methanol line to the Canyon Express pipeline.

There were 2 umbilicals damaged to the Nakika floating production platform (Ref 22).

Design conditions were exceeded. Broken moorings were an expected outcome for every semi that broke its moorings and drifted based on a comparison between the design condition and the actual winds, waves and currents experienced in Hurricane Ivan.

Owners should remain ever-diligent about the quality control on mooring components. The enormous lengths of the mooring lines 2-3 miles each means it is very difficult to assure that every single component will be of robust quality without an extra-ordinary quality system backing up the equipment. Several items in the mooring systems are suspected of failing at loads below that anticipated: though in no case is it expected that the final outcome of the incidents would have been very different. Part of the standards to be developed will consider an enhanced quality system as applied to pre-laid and rig moorings (which may indeed already be practiced); since any analysis assumes that the equipment will hold the design loads of each component. A number of wires failed in areas where it might not be normally expected, and while no studies have been undertaken to our knowledge, there becomes a question about the "perfectness" of the equipment. Mooring lines are very expensive and the industry will have to be ever diligent about insisting on traceability of components, and record keeping as to their history. Reasonable discard criteria, in due course, will evolve.

There has been much discussion in the industry about calculation methods, and other input parameters to the analysis, including damping values used in the calculations. There is a research need to instrument some semi-submersibles in order to benchmark the mooring analysis assumptions and methodology. Operators should be encouraged to add instrumentation to gather this information.

14. CONCLUSIONS AND RECOMMENDATIONS JACKUPS

Both the jackups that survived and those that had failures including the ENSCO 64 which failed, was an expected outcome of the severity of the storm, and the design basis for the specific site on which the jackup was working. There should be no surprise as to the outcome.

The eye of Hurricane Ivan passed 6 miles to the east of the ENSCO 64. On hindsight there was insufficient airgap. Even the historically successfully used 50 ft storm level (rule of thumb), was insufficient. It is highly likely that even if the airgap had been sufficient that the ENSCO 64 would have had major damage from overload.

The 200, a mat supported jackup was directly on path and survived remarkably well. Mat rigs often have scour issues in hurricanes but rarely have any structural issues arising.

Provided Airgap is sufficient – Jackups are remarkably robust in hurricanes. An airgap to meet every location in “jackup normal operating areas”, for hurricane Ivan would have to be at least 56 ft to survive every potential jackup location in the storm.

Areas above 50’, for Ivan would have been:

- 87.3^0 - 88.5^0 long;
- 27.4^0 - 30^0 latitude

While there has been no incident with a jackup to alarm the industry, the new configuration of jackups are likely to be more prone to floating off and creating a hazard in the future.

It is recommended that the IADC and API committees working on new guidance for jackup rigs should additionally consider a section to identify critical infrastructure and additionally consider a higher return period storm for siting in close proximity to those critical structures.

To specifically decide whether the exact weather conditions will affect the site specific location, considerable details need to be known about the rig, and its loading during pre-load, variable load, current conditions at the rig etc. Since the results were obvious by inspection and engineering judgment, further analysis has not been undertaken since there is little to be learned without considerably more site-specific data, and particularly current information. As further information comes available it may be appropriate to identify likely candidates for further study. The information contained in this Report has been compiled with sufficient information that analysis will be possible in the future if desired.

Comparing the rig hindcast data to the API 10-year criteria (a general estimate of criteria close to the 50-year “sudden hurricane” values), it appears that the jackups, in general, performed better than their “agreed criteria”.

A search for improvements in safety and performance of jackup rigs is currently underway. There is no referenced study on the risk of jackups drifting after collapse. It is understood there are initiatives underway to bring these issues before the IADC jackup committee that has already had discussions concerning the need to address the question of an upgraded criteria when in proximity to critical infrastructure. Some discussion has been underway with developing a new JIP on the subject of jackup performance in hurricanes, and a way to ensure that critical infrastructure is accounted for. The work of the mooring JIP encouraged by the Offshore Operator's Committee should ensure that information of benefit should be disseminated and made available for use of the jackup community when completed.

15. REFERENCES:

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This work could not have been undertaken except for the special assistance and generous contributions of the drilling contractors and oil companies who offered their information and contributed to the study. In particular for the semi-submersibles: BP, Shell & Dominion as well as Transocean, Noble, and Diamond. For the jackups: Dominion, as well as Todco, and Ensco shared their information. Delmar’s reports released by oil companies were useful in compiling the information as were the insights of Evan Zimmerman. MMS provided information willingly. A number of individuals and organizations made helpful editorial comments. The study of Oceanweather reporting on the extent of the maximum winds, waves and currents, enhanced the understanding of the performance of MODUs.

This MMS sponsored post mortem assessment of the MODUs in Hurricane Ivan is an excellent method of promulgating the information to industry. It remains for industry in the various committees and standards organizations to react to this information. MMS’s encouragement to share knowledge of these incidents and insights that result from the investigation is a critical part of encouraging the development of appropriate standards for the MODU industry which is in-turn beneficial in protecting the oil and gas infrastructure. Such a pro-active initiative is reflective of MMS’s concern for safety.

APPENDIX A – MMS Notice to Lessees: Hurricane Ivan

OMB Approval Number: 1010-0050
OMB Expiration Date: January 31, 2006

UNITED STATES DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE
GULF OF MEXICO OCS REGION

NTL No. 2004-G18 Effective Date: October 4, 2004
Expiration Date: June 30, 2005

NOTICE TO LESSEES AND OPERATORS OF FEDERAL OIL AND GAS LEASES
AND PIPELINE RIGHT-OF-WAY HOLDERS
IN THE OUTER CONTINENTAL SHELF, GULF OF MEXICO OCS REGION

Damage Caused by Hurricane Ivan

The Minerals Management Service (MMS) Gulf of Mexico OCS Region (GOMR) is issuing this Notice to Operators and Pipeline Right-of-way Holders (NTL) pursuant to 30 CFR 250.103 and 30 CFR 250.106(b) and (c) to describe the inspections you need to conduct and the plans and reports you need to prepare because of the known and potential damage to OCS facilities caused by Hurricane Ivan when it struck land on September 16, 2004.

OCS Platforms and Structures

Pursuant to 30 CFR 250.912(a), you must periodically inspect OCS platforms and structures (platforms) in accordance with the provisions of American Petroleum Institute Recommended Practice 2A-WSD, Twenty-First Edition (API RP 2A-WSD), Section 14, Surveys.

Subsection 14.4.3 of API RP 2A-WSD requires that you conduct a Level I survey (above-water visual inspection) of the platform after direct exposure to a design environmental event (e.g., hurricane). Therefore, you must perform a Level I survey on all platforms that were exposed to hurricane force winds (74 miles per hour (mph) or greater) from Hurricane Ivan.

Subsection 14.3.2 of API RP 2A-WSD requires you to conduct a Level II survey (general underwater visual inspection by divers or remotely operated vehicle (ROV)) of the platform when the Level I survey indicates that underwater damage may have occurred. In addition, subsection 14.4.3 of API RP 2A-WSD requires you to conduct a Level II survey of the platform after severe accidental loading, such as a large object (e.g., boat landing, sump, staircase) being knocked loose and potentially causing structural damage to the platform as it fell to the seafloor.

Subsection 14.3.3 of API RP 2A-WSD prescribes a Level III survey (underwater visual inspection of areas of known or suspected damage) when a Level II survey detects significant structural damage.

In light of these requirements and the numerous reports of severe damage to platforms (both above and below the water line) along the path of Hurricane Ivan, the MMS GOMR has determined that you must conduct the following surveys:

Survey Level	Platform Category
I	All platforms exposed to winds speeds greater than 74 mph.
II	All platforms located within 35 miles of Hurricane Ivan's eye center storm track (see Attachment A of the NTL for a map of the described area).
III	All platforms that experienced wave loading on the deck and where Level II survey results prescribe Level III surveys.

Begin immediately to conduct the required surveys of the affected platforms. We encourage you to inspect first the older platforms located nearest the eye center storm track, and then gradually inspect those platforms toward the outer limits of the described area. Complete all inspections/surveys by May 1, 2005. Complete all work to correct any damage you find during a platform inspection before June 1, 2005.

Make every attempt to complete the required underwater inspections before you man any of the affected platforms. If it is operationally impractical for you to wait to complete the inspections before you man an affected platform, make sure that you:

a. Develop a detailed, comprehensive around-the-clock weather monitoring plan;
b. Comply with U.S. Coast Guard regulations regarding ingress/egress to the boat landing; and
c. Provide a 24-hour stand-by boat with full radio communications between the boat and the platform.

In addition, if your Level II or Level III surveys find structural damage, do not man the platform until you complete a structural analysis and perform any necessary repairs. Please be reminded that 30 CFR 250.900(e) requires you to obtain approval from the MMS GOMR before you make major repairs of any damage.

The MMS is currently working to obtain emergency approval from the Office of Management and Budget (OMB) to collect reports from you on inspections on the structures that are located in the area affected by Hurricane Ivan. After this approval is obtained, the MMS GOMR will likely issue an NTL that will require you to submit the following information:

a. A list of platforms affected by the hurricane;
b. An initial inspection plan for each platform;
c. A timetable that shows you will complete each inspection by May 1; and
d. Inspection reports.

These information collection requirements are very similar to those required by MMS GOMR after Hurricane Lili damaged OCS structures in the Gulf of Mexico (NTL No. 2003-G04).

OCS Pipelines

Pursuant to 30 CFR 250.1005(a), you must conduct inspections of pipeline routes at intervals and using methods prescribed by the MMS. Under this authority, and because of the numerous reports of severe damage to OCS pipelines along the path of Hurricane Ivan, the MMS GOMR hereby directs you to conduct the following inspections by May 1, 2005:

1. Pipeline Tie-in Inspections - Conduct an underwater visual inspection using divers or ROV, a scanning sonar processor, or a 500-kHz sidescan sonar in combination with a magnetometer to inspect each of your OCS pipeline tie-ins located within the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area). Design each inspection to determine whether any valves or fittings became exposed and to determine the extent of any damage, including damage to protective devices, mats, and sandbags.

2. Pipeline Riser Inspections - Conduct a visual inspection of the above-water portion of each pipeline riser located within the corridor between 89º 30’ W longitude and 87 º 30’ W longitudes (see Attachment B of this NTL for a map of the described area). If applicable, conduct this riser inspection in conjunction with the required platform Level I survey described above. Inspect the riser and riser clamps for damage. If this inspection indicates that damage may have occurred, conduct an underwater riser and pipeline inspection described in Item No. 4 below (if you are not already required to do so) to determine if the pipeline has been displaced or exposed.

3. Pipeline Steel Catenary Riser Inspections - Conduct an inspection using divers or ROV of the underwater portions of each of your OCS pipeline steel catenary risers located within the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area). Inspect the riser, vortex-induced vibration (VIV) suppression devices, and the connection point (flexible element, titanium stress joint, etc.) to the structure for damage.

4. Underwater Riser and Pipeline Inspections - Conduct a visual inspection using divers or ROV, a scanning sonar processor, or a 500-kHz sidescan sonar in combination with a magnetometer to inspect the underwater portions of each of your OCS pipeline risers and adjacent pipelines located in water depths between 200 feet and 500 feet within the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area). If applicable, conduct this riser and pipeline inspection in conjunction with the required platform Level II surveys described above. Inspect the riser and riser clamps for damage. Inspect the pipeline for evidence of displacement or exposure from the base of the riser along the entire length of the pipeline.

5. Remedial Action - If an inspection indicates (a) factors that could detrimentally affect the performance or integrity of pipeline valves and fittings at a tie-in, (b) conditions that could cause interference with navigation or other uses of the OCS, (c) riser or riser clamp damage, or (d) that a pipeline has been displaced, exposed, or damaged, submit a plan of corrective action, pursuant to the requirements of 30 CFR 250.1008(g), by mail to the GOMR Pipeline Section (MS 5232) or by e-mail to elizabeth.komiskey@mms.gov for approval within 30 days after completing the inspection. Within 30 days after you complete the work, submit a written report indicating that the repairs were performed as proposed, confirming the type and/or cause of damage, and including the results of any pressure tests by mail to the GOMR Pipeline Section (MS 5232) or by e-mail to elizabeth.komiskey@mms.gov. Complete all work requiring corrective action before June 1, 2005.

6. Additional inspections. If you suspect that Hurricane Ivan may have damaged a pipeline or related structure that is located outside the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area), conduct the appropriate inspections described in Items Nos. 1, 2, and 4 above and, as appropriate, submit a plan of corrective action as described in Item No. 5 above.

If you haven't already done so, perform a leak test before you return to service any pipeline located within the corridor between 89º 30' W longitude and 87º 30' W longitude (see Attachment B of this NTL for a map of the described area). Make sure that the leak test successfully tests the integrity of the pipeline. A successful leak test means no unobservable leakage during the test period. When you conduct a leak test, make sure that you use a stabilized pressure that is capable of detecting all leaks; use pressure gauges and recorders that are sufficiently accurate to determine whether the pipeline is leaking during the test; and conduct the test for at least two hours during daylight hours. For major oil pipelines, provide aerial surveillance of the pipeline route while you perform the test.

Paperwork Reduction Act of 1995 Statement

The Paperwork Reduction Act of 1995 (PRA) (44 U.S.C. 3504 et seq.) requires us to inform you that the MMS collects this information to carry out its responsibilities under the OCS Lands Act, as amended. The MMS will use the information to determine if the structural integrity of platforms and pipelines may have been adversely affected by Hurricane Ivan, if any damage poses a threat to continued safe operations or the environment, and, if so, whether to require correction action on damaged structures. Responses are mandatory. No proprietary data are collected. An agency may not conduct or sponsor, and a person is not required to respond to, a collection. There is no new reporting burden in this NTL. Reporting requirements in this NTL are per current regulations at 30 CFR 250 1008(g). The OMB has approved the collection of information and assigned OMB control number 1010-0050. Direct any comments regarding the burden estimate or any other aspect of this collection of information to the Information Collection Clearance Officer, Mail Stop 4230, Minerals Management Service, Department of the Interior, 1849 C Street, N.W., Washington, D.C. 20240.

Contacts

Please address any questions regarding platform inspections or reports to Mr. Tommy Laurendine of the GOMR Office of Technical and Structural Support by telephone at (504) 736-5709 or by e-mail at tommy.laurendine@mms.gov and questions regarding pipeline inspections or reports to Ms. Elizabeth Komiskey of the GOMR Pipeline Section by telephone at (504) 736-2418 or by e-mail at elizabeth.komiskey@mms.gov.

Chris C. Oynes
Regional Director

Attachments

APPENDIX B – OTC PAPER 18322 May 2006

APPENDIX C – OTC PRESENTATION PAPER 18322 May 2006

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