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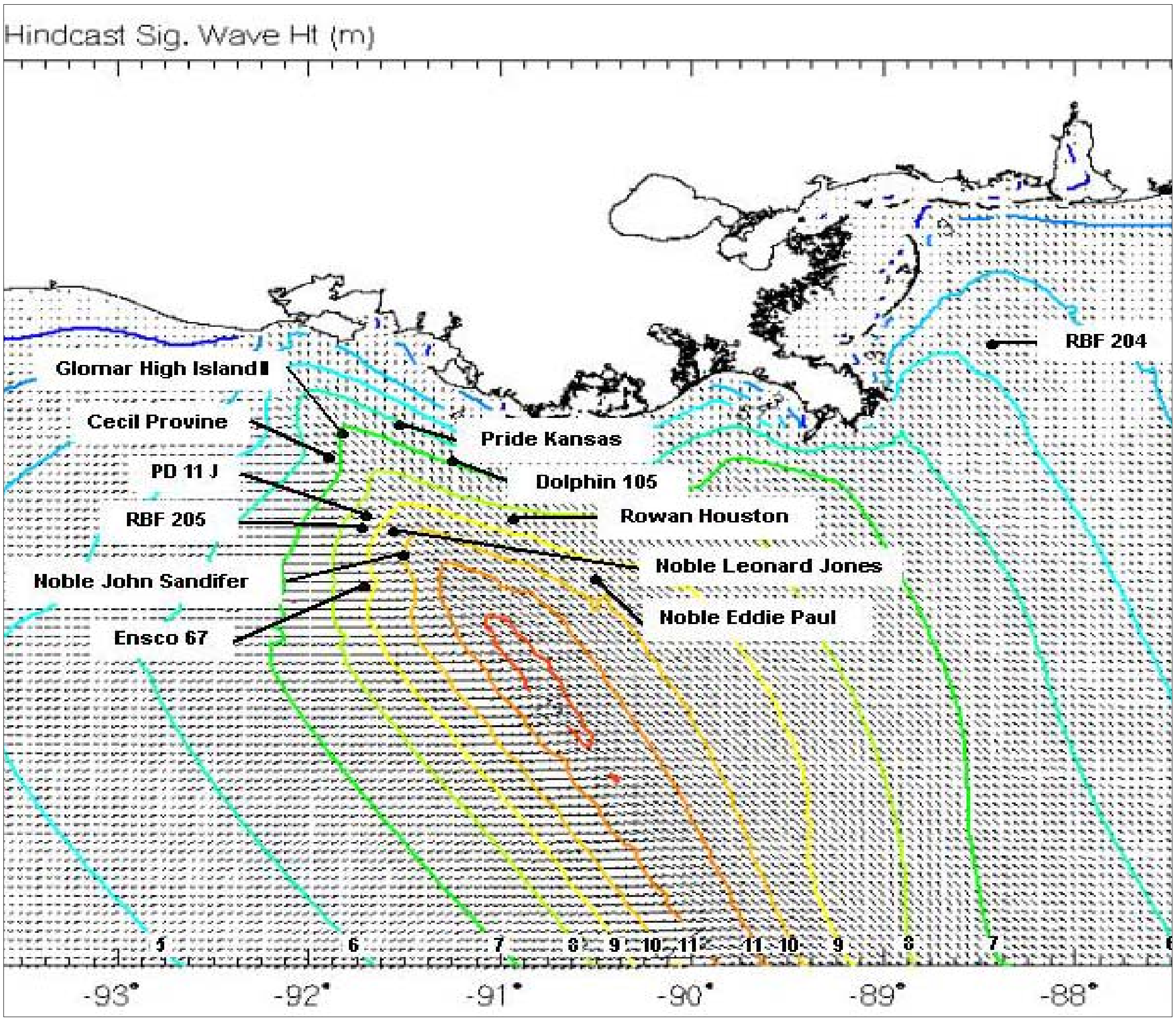
Post Mortem Failure Assessment of MODUs During Hurricane Lili

October 2002



Prepared for:

Minerals Management Service

MMS Order No.: 0103PO72450

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EXECUTIVE SUMMARY

MODUs in the Gulf of Mexico are a critical part of the infrastructure that brings oil and gas prospects to development. Industry standards that allow safe, and economic operations are important both to the community and regulatory interests. Appropriate calibration 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 was 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 is similar to a study that was previously undertaken in the aftermath of Hurricane Andrew –sponsored by the MMS to seek recommendations from the lessons learned from the failures. This study on Hurricane Lili takes into account the information in the report on Hurricane Andrew in coming to its conclusions and recommendations.

Hurricane Lili in October 2002 tracked through a high-density corridor of MODUs in the Gulf of Mexico. One semi-submersible parted moorings and drifted to the beach. Another semi-submersible broke some moorings but stayed on location. All but two jackups survived the event. Several jackups occasioned strong winds and high waves, which resulted in either no change or minor settlement in the foundations. One jackup noted a rotation in position even though the legs had significant penetration: such a phenomenon is noted for the record, and discussed, since in the future it may lead to some further understanding of the soil-spudcan interaction.

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. 19).

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

The incidents that occurred led to no injuries, no pollution and no other platforms toppled, by collision with the MODUs or pipelines, as had been the case in Hurricane Andrew. There are, however, lessons to be learned and insights that came from the investigation. The drifting of semi-submersibles after loss of the station keeping system was very similar to the drifting of semi-submersibles in Hurricane Andrew.

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 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. While the risk of a severe hurricane impacting a selected semisubmersible may be acceptable based on current criteria, the risk for a Gulf of Mexico hurricane setting one of the many rigs in the Gulf of Mexico adrift is substantially higher: and thus criteria acceptable to an owner may not be acceptable to a regulator. The comparatively higher consequences of exceeding the design load, gives rise to a very different approach of dealing with Gulf of Mexico than in the rest of the world, including evacuation at the on-set of a hurricane. It is recommended that the API Mooring Committee and/or the ISO TC67 SC7 committees take on the task of examining these incidents and the recommendations and come up with a more robust criteria either in terms of weather data to approve siting of the rig, or a practice of mitigation methods such as limiting movement of the rig should the primary mooring system fail.

The investigation into the jackups revealed that both jackups that collapsed did so under weather conditions, which were well in excess of the design loads. The jackups that failed brought to light several issues, which have only been given cursory attention in the standards developing within the jackup industry. This investigation highlights some areas to improve the standards.

In the case of the Dolphin 105 the deck height criteria recommended in API for fixed platforms in full population hurricanes would have been insufficient for this location. The rig owner could reasonably have expected to rely on this guidance. Recommendations are made to the API Committee to add a caution to its Figure Ref: 17.6.2-2b that the deck height in shallow water can be higher if breaking waves is considered. Caution about the higher crest height to wave height ratio for breaking waves could usefully be added to Marine Operating Manuals of jackups similar to this unit which are likely to be used in shallow water, where breaking waves are likely.

Additionally the loads imposed due to breaking waves were much higher than would have been predicted without specialist knowledge that a breaking wave could likely result from an extreme storm at this site. There would have been no warning in the

Marine Operating Manual for that effect to ensure the owner/operator could have predicted the need for either a higher air gap and the need to consider alternative action in evaluating the prudence of leaving the jackup on that location because of a potential exceedance of the design conditions. In general there is little guidance in the standard industry site-specific evaluation documents on breaking waves. It is recommended that the IADC Jackup committee and ISO TC67 SC7 take note and add a section to their guidance on this subject.

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.

While there are no lessons to be learned directly from the incident, it became apparent during that some gaps in knowledge/training could be usefully filled with items, which might prevent future incidents. There are no uniform ways to deal with the pre-existing spud can hole in evaluating the location for site-specific approval. Though it is stressed this was not a contributor in this case, there is no industry document to determine where experienced surveyors should inspect a jackup. Since all jackups have specific areas where inspection is proper, identifiable from historic issues or identifiable from analysis, surveyors inspecting the units could benefit from a “go-by” document identifying areas of concern.

Investigating all incidents led to the reporting that there were significant differences between the results from the hindcast companies regularly supplying metocean hindcast information. These same companies provide suitable criteria for the siting of MODUs. This leads to a reflection that determination of loads from these various sources can lead to widely different loads and thus widely different results and probabilities of failure. Such significant differences erode the confidence that a suitable uniform criteria is being applied in the industry for site-specific MODU locations. The difference in the “numbers” for the same event translates to a difference in approach of the organizations. Users of this data do not always understand the subtleties of interpretation of events and data between one metocean organization and another. Since this is such a significant issue it is recommended that the MMS consider sponsoring a Workshop, and/or sponsoring a “university” research project to investigate and evaluate the differences between methods used by the various suppliers of metocean data to the offshore industry for Gulf of Mexico – and promulgating that information in a clear form to assist the users in understanding the variability of the information provided. Such a study/workshop will allow the owner/operator to assess the implication of these differences on the safety of the MODUs they either own or operate. The strategy would be: that by getting the metocean experts in the same forum, and with discussion – effect a situation where the same results in terms of metocean parameters were being used uniformly by the hindcasters and site-specific assessment practitioners.

Understanding how MODUs react to severe weather events, whether we have calculation methods that reflect reality, and whether we can identify critical areas for inspection to give early warning that the unit may not achieve its maximum capacity (even though beyond design) are all important to the well-being of the Gulf of Mexico infrastructure. We live in a culture that does not easily accept, promulgating the results and insights into accidents and incidents, consequently it's not often one gets to know what the causes of an incident were and reflect on the results.

This MMS sponsored post mortem assessment of the MODUs in Hurricane Lili 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.

1.0 INTRODUCTION

MODUs in the Gulf of Mexico are a critical part of the infrastructure that brings oil and gas prospects to development. Industry standards that allow safe, and economic operations are important both to the community and regulatory interests. Appropriate calibration of those standards is an on-going issue particularly because they are calibrated on rare events such as hurricanes. 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 was 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 one that was previously undertaken in the aftermath of Hurricane Andrew –sponsored by the MMS to seek recommendations from the lessons learned from the failures. This study on Hurricane Lili takes into account the information in the report on Hurricane Andrew in coming to its conclusions and recommendations.

Hurricane Lili in October 2002 tracked through a high-density corridor of MODUs in the Gulf of Mexico. A series of studies 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: this document reports on the study on the Mobile Offshore Drilling Units. The specific task:

> ***To study the failures associated with MODUs during Hurricane Lili, gathering information on loss of station keeping of a semi-submersible MODU, collapse of 2 Jack-up MODUs and 3 other rigs that had settlement and possible related damage which could have resulted in (rig) casualties. Develop any recommended updates on criteria, review the Hurricane Andrew recommendations, and make recommendations for future mitigation action.***

The study relies upon the work of Oceanweather who carried out the meteorological hindcast (Ref. 1).

MMS had commissioned a study in the aftermath of Hurricane Andrew in 1992 (Ref 2). This study investigated historical failures associated with mobile offshore drilling units (MODUs) during all intense Gulf of Mexico hurricanes as far back the industry records go. 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 of 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. Reference is made to the Hurricane Andrew report in order to compound the learning available from these two major hurricane events.

At the time of Hurricane Lili there were approximately 142 jackups and 39 semi-submersibles in the Gulf of Mexico. Of those only 6 -7 jackups and 2 semi-submersibles were effectively impacted by Hurricane Lili, and only 3 with significant events. A variety of sources were used to identify potential rigs that had been impacted by the hurricane. Most of the information was directly from drilling contractors involved and from the MMS files.

Table 1: Hurricane Lili: Exposure of MODUs

Semis	Jackups
39 Semis in GOM	142 Jackups in GOM
2 Semis impacted	6 or 7 Jackups impacted
1 Significant event	2 Significant events
No Significant Consequence	3 Noticeable settlements

The image of Hurricane Lili compiled below is reproduced with the kind permission of Evan Zimmerman, Delmar Systems Inc. This figure gives a visual impression of the area of interest – and the original position of one of the semi-submersibles affected by Hurricane Lili is shown.

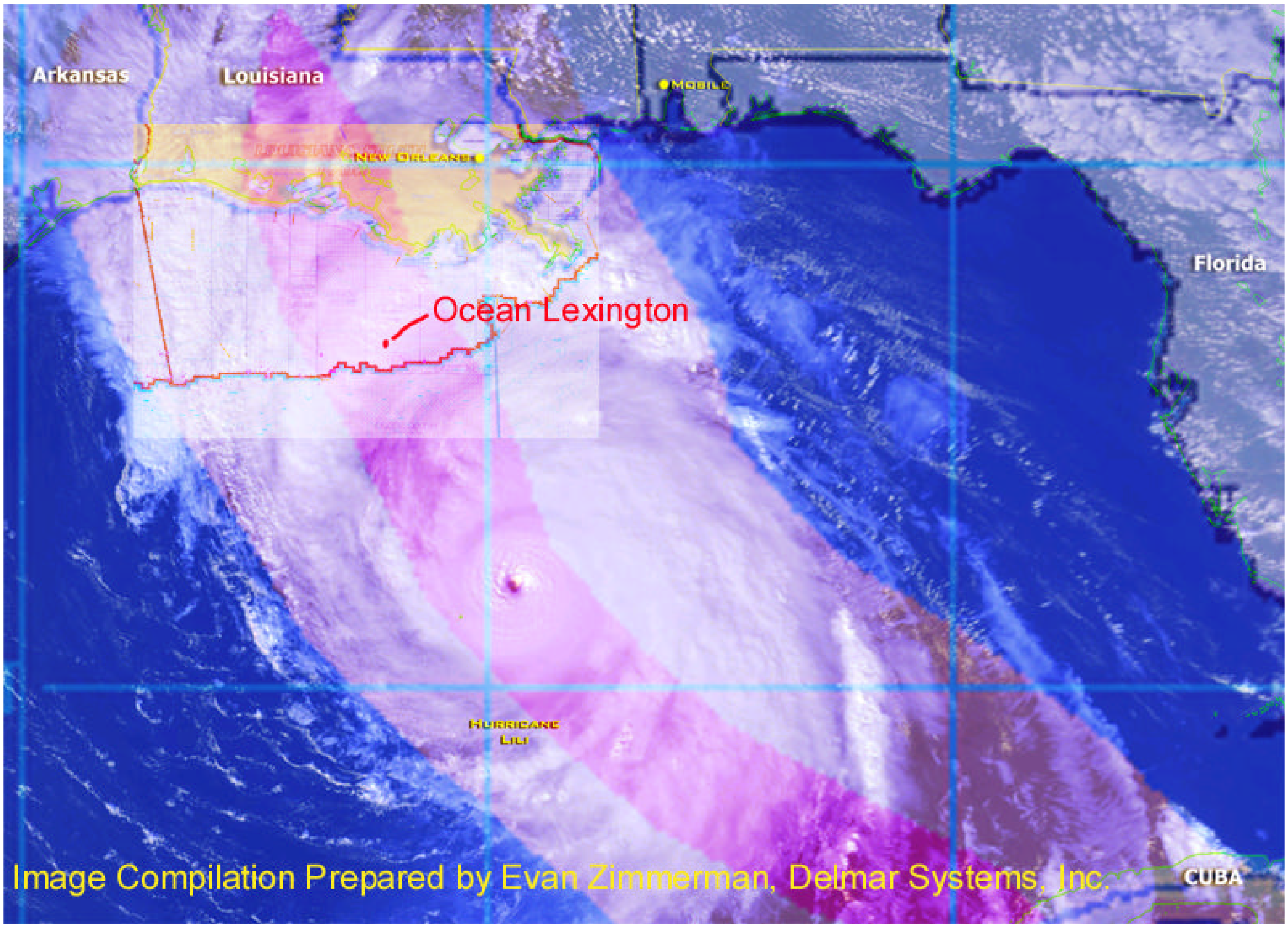


Figure 1: Image of Hurricane Lili Compiled by Evan Zimmerman, Delmar Systems Inc.

2.0 INITIAL REPORTS: HURRICANE "LILI"

The following are extracts from media reports of the hurricane chronicling its impact of the Gulf of Mexico coast and MODUs in particular. The media reports give a general overview of the storm and the nature of the widespread destruction that resulted. As indicated this hurricane had great impact on-shore based facilities and as well as offshore facilities. The media reports are given to provide the reader with a non-technical view of the story as it unfolded.

London, Sep 30 -- Following received from the Meteorological Office: Tropical storm "Lili" located near lat 19.4N, long 79.3W, at 0900, UTC. Position accurate within 30 nautical miles. Present movement toward the west-north-west or 290 deg at eight knots. Maximum sustained winds 60 knots with gusts to 75 knots. Radius of 50-knot winds nil nautical miles to southwest quadrant and 15 nautical miles elsewhere. Radius of 34-knot winds nil nautical miles southeast and 60 nautical miles elsewhere. Forecast for 1800, *UTC: Position lat 20.2N, long 80.3W. Maximum winds 65 knots, gusts 80 knots. Radius of 64-knot winds 15 nautical miles. Radius of 50-knot winds 30 nautical miles. Radius of 34-knot winds 60 nautical miles. Forecast for 0600, UTC, Oct 1, position lat 21.3N, long 82.3W. Maximum winds 70 knots, gusts 85 knots. Radius of 64-knot winds 15 nautical miles. Radius of 50-knot winds 30 nautical miles. Radius of 34-knot winds 60 nautical miles. (See issue of Oct 1.)*

London, Sep 30 -- A press report, dated today, states: "Lili", the storm that has forced thousands to evacuate in the Caribbean, was upgraded to a hurricane today, taking aim at the Cayman Islands and Cuba with strong winds and torrential rains. Flooding from the storm killed at least four people in Jamaica. By 1100, EDT, "Lili's" winds had strengthened to 75 mph, and its centre was near Cayman Brac in the Cayman Islands. Thousands of people evacuated their homes in eastern Cuba as "Lili "neared the coast. The storm was expected to reach the western part of the island by tomorrow. Hurricane force winds extended 15 miles outward from the centre, and tropical storm force winds were felt 105 miles away. The hurricane was drifting west-north-west at 10 mph, and the motion was expected to continue during the next day. In the United States, the National Hurricane Centre warned coastal residents from Texas to Florida that the storm could strike them by the end of the week, though it was too soon to tell where it would come ashore. Residents in the Cayman Islands were urged to stay indoors and off the roads. Government offices, some businesses and schools were closed. Strong winds reached the eastern island of Cayman Brac today, and a short at its power plant left half of its 1,200 residents without electricity. More than 200 people moved into shelters on Cayman Brac, and about a quarter of the 100 residents on nearby Little Cayman moved into a bunker-like shelter. In Jamaica, officials said flooding washed away several houses, damaged dozens of others and turned roads into muddy rivers. Winds toppled trees and power lines. Fire brigades rescued several dozen flood victims in trucks and took them to emergency shelters. Cuba issued a hurricane watch for Havana and the western provinces of Matanzas, Pinar del Rio and the Isle of Youth. Cuban officials said they would urge people in "Lili's" path to leave their homes in flood zones. In parts of eastern Cuba, more than 100,000 people had left their homes, Cuban media reported. Lili killed four people last week in St. Vincent and damaged about 400 homes in Barbados.

New York, Sept 30 -- Energy companies today began to evacuate workers from drilling platforms in the Gulf of Mexico, as a second major storm in two weeks bore down on the key oil and gas-producing region. The region's biggest producer, Royal Dutch/Shell Group's Shell Oil Co, and BP Plc and ConocoPhillips Corp. all started to move staff out of harm's way ahead of approaching hurricane "Lili". "We have taken off about 200 workers so far and we expect to remove more later today," said a Shell spokeswoman. BP said the company's exploration drilling operations are being suspended in both the shelf and deep-water areas of the U.S. Gulf of Mexico. "We will continue to monitor the storm and decide tomorrow what additional action is needed," said a BP spokesman. Gulf oil and gas operations are still recovering from last week's hurricane "Isidore" which forced oil firms to cut roughly 1.4 million barrels per day (bpd) of the Gulf's 1.5 million *bpd oil production capacity. That amounted to about 25% of a day's worth of U.S. oil consumption and nearly half of a day's worth of U.S. natural gas consumption, although "Isidore" ultimately caused little damage to oil and gas platforms. News of the fresh evacuations helped push crude oil futures prices in New York up nearly 20 cents in early trade to $30.73 a barrel. So far "Lili" has not made renewed cuts to oil and gas output, as the evacuated workers are "nonessential". "Lili" officially became a hurricane at 1500, UTC, today, reaching sustained winds of 75 miles per hour, the U.S. National Hurricane Center reported. Unlike "Isidore", "Lili" is moving on a direct path through the major U.S. oil platform area of the Gulf. "Isidore" took a less-threatening detour to Mexico's Yucatan Peninsula before heading toward U.S. oil platforms. It is projected to hit the heart of the Gulf of Mexico by Wednesday and approach the Gulf Coast's "Refinery Row" in Texas and Louisiana by Thursday. -- Reuters.*

London, Oct 2 -- Following received from Coast Guard San Juan, timed 1730, UTC: General cargo Fiona R.II (499 gt, built 1970), Guyana to St. Vincent, ETA St Vincent Sep 23, is reported overdue and presumed sunk during strong winds from hurricane "Lili. (See issue of Oct 3.)

London, Oct 2 -- Following received from Trinidad MRCC, timed 1735, UTC: General cargo Fiona R.II, cargo sand, is overdue and presumed sunk during hurricane "Lili." It sailed from Guyana at 1500, local time, Sep 22, bound for St. Vincent, ETA midnight Sep 23, and was last reported passing Tobago. Number of crew not known. The search is continuing.

London, Oct 3 -- Following received from the Meteorological Office: Tropical storm "Lili" located near lat 28.7N, long 91.7W, at 0900, UTC. Position accurate within 20 nautical miles. Present movement toward the north-north-west or 335 deg at 15 knots. Maximum sustained winds 105 knots with gusts to 130 knots. Radius of 64-knot winds 20 nautical miles west semicircle, 50 nautical miles to the north-east and 40 nautical miles to the south-east. Radius of 50-knot winds 90 nautical miles eastern semicircle, 80 nautical miles north-west quadrant and 40 nautical miles elsewhere. Radius of 34-knot winds 170 nautical miles north-east quadrant, 160 nautical miles south-east quadrant, 100 nautical miles south-west quadrant and 140 nautical miles north-west quadrant. Forecast for 1800, UTC: Position lat 30.7N, long 92.1W. Maximum winds 85 knots, gusts 105 knots. Radius of 64-knot winds 40 nautical miles east semicircle and 20 nautical miles elsewhere. Radius of 50-knot winds 75 nautical miles north semicircle,
90 nautical miles to the south-east and 40 nautical miles south-west. Radius of 34-knot winds 150 nautical miles north-east quadrant, 160 nautical miles south-east quadrant, 100 nautical miles south-west quadrant and 120 nautical miles north-west quadrant. Forecast for 0600, UTC, Oct 4, position lat 33.4N, long 91.0W, inland. Maximum winds 50 knots, gusts 60 knots. Radius of 50-knot winds 50 nautical miles east semicircle and 30 nautical miles elsewhere. Radius of 34-knot winds 75 nautical miles east semicircle, 50 nautical miles west semicircle.

London, Oct 5 -- A press report, dated Oct 4, states: Hurricane "Lili" ripped one offshore drilling rig from its moorings, sending it drifting for 45 miles, and capsized another as the *storm raced northward over the Gulf of Mexico toward Louisiana earlier this week. Houston-based Diamond Offshore Drilling Inc. reported today its semi-submersible drill platform Ocean Lexington, left its moorings and grounded in 35 feet of water off the Louisiana shore. The company, which believes "Lili" was still a Category 4 storm with winds around 140 mph when it hit the rig, is assessing damage. The U.S. Coast Guard reported no oil slick as a result. Elsewhere in the Gulf, drill platform Dolphin 105 (943 gt, built 1982) capsized during the storm, and the Coast Guard reported a "minor oil sheen." British Petroleum, whose U.S. exploration and development office is in Houston, deployed a response team to evaluate damage on its rig. Rigs in "Lili"'s path were evacuated, so no one was injured on the two affected rigs.*

London, Oct 5 -- A press report, dated Oct 4, states: Tropical Storm "Lili" spun out of Louisiana early today, leaving behind a trail of destruction, as residents contended with wind and flood damage and overnight power outages. "Lili" lost strength yesterday after coming ashore at Marsh Island as a Category 2 hurricane packing 100-mph winds. Officials said there were only a handful of injuries and no reported storm-related deaths along the Gulf Coast. Damage was widespread along coastal areas, with ripped-up roofing, felled trees, downed power lines, mud and debris littering the landscape. Water from four to eight feet deep swept across roads and into numerous houses in Pointe Aux Chenes. The driver of a National Guard truck used to rescue residents had no idea where the road was at some points. Guardsmen had to get out and walk through waist-deep water to guide him through. Many houses in the area were built above ground on pylons or pier foundations that minimised damage, but other homes were hit hard. A combination of storm surges and rain caused levees to fail at Montegut and Franklin, where floodwaters threatened hundreds of homes. "I'd say right now at least 75% of the town got water in it," said Spencer Rhodes, fire chief in Montegut, a town of 4,000 about 40 miles south-west of New Orleans. Rescue crews evacuated 500 to 600 Montegut residents who had failed to heed calls for evacuation. The situation was even worse in Grand Isle, the vulnerable barrier island community south of New Orleans. "Most of the island is under water," Police Chief Edward Bradberry said. Further west along the Louisiana coast, rural Vermillion Parish was spared flooding but ravaged by high winds that shattered windows, tipped mobile homes on their sides and knocked out power to all 19,800 homes in the parish, which covers 1,174 square miles. The entire parish had been under a mandatory evacuation order, and Robert J. LeBlanc, the parish emergency preparedness director, asked that no one return until late today so work crews would have time to clear roads of trees and telephone poles. "And if they do come back they must not expect to have power for a week to 14 days," LeBlanc said. Gusts as high as 92 mph in New Iberia hurled pieces of metal through the air and blew down a 50-foot-high sign at the Holiday Inn. In Rayne, west of Lafayette, tin roofing ripped from a lumber warehouse lay across neighbouring railroad tracks. President Bush declared a disaster in Louisiana, making communities that suffered from the storm eligible for federal aid. By the time "Lili" arrived, some 900,000 people had been ordered or advised to leave coastal Louisiana and 330,000 in far eastern Texas. Nearly 17,000 of them stayed at 98 emergency shelters. Col Jay Mayeaux of the Louisiana National Guard said there was no way to know how many evacuated. Thousands who took refuge in more northern parts of the state could not escape power outages, which affected hundreds of *thousands of customers from the coast north through Alexandria. Some residents in Lafayette were told they might be without power for five to seven days. Combined estimates of state and government utilities across the state said about 500,000 homes were without power last night.*

London, Oct 5 -- Following received from Coast Guard New Orleans, dated Oct 4: Coast Guard aircraft crews are surveying damage to coastal areas of Louisiana and Texas caused by Hurricane "Lili". Since the hurricane passed, Coast Guard helicopter crews have been patrolling the storm's course, looking for distressed mariners, stranded citizens, blocked waterways and environmental pollution. Crews from Coast Guard Air Station New Orleans launched their helicopters three hours after "Lili"'s eye made landfall and flew for more than 18 hours since yesterday afternoon. Multiple overflights of oil rigs in the Gulf of Mexico are being conducted for initial damage assessment. Two mobile offshore drilling units have already been assessed for damage: Drill platform Ocean Lexington broke its moorings at Ship Shoal Block 300 and was later reported aground at Eugene Island Block 123. It had drifted 45 miles north-northwest of its original location. No pollution was sighted by Coast Guard helicopter crews. The company's response team is scheduled to assess further damage this morning. Drill platform Dolphin 105 capsized while jacked-up at Ship Shoal Block 126, and Coast Guard crews reported a minor oil sheen. British Petroleum is deploying a response team this morning to assess further damage.

London, Oct 5 -- A press report, dated Oct 4, states: Rowan has completed an aerial survey of its 22 rigs in the Gulf of Mexico. All rigs appear to be undamaged, with the exception of drill platform Rowan Houston (4088 gt, built 1970), which apparently capsized and sank in approximately 105 feet of water in Ship Shoal Block 207, offshore Louisiana. The rig had been under contract to Anadarko. All appropriate regulatory agencies have been notified. The Company is in the process of conducting a thorough investigation to determine the cause.

London, Oct 5 -- A press report, dated Oct 4, states: Diamond Offshore Drilling Inc. reported that its semi-submersible drill platform Ocean Lexington (8609 gt, built 1976), as a result of Hurricane "Lili", parted its moorings. The rig drifted approximately 45 miles before apparently grounding in an estimated water depth of 35 feet offshore Louisiana. As a part of normal hurricane procedures, the rig and well were secured in anticipation of storm conditions. All personnel had been evacuated to shore base locations earlier in the week. The Company is in the process of conducting a detailed assessment of Ocean Lexington and any estimate of damages or related repairs is expected to take several days to complete. Indications are that Hurricane "Lili" passed directly over Ocean Lexington's location reportedly as a category 4 storm.

London, Oct 6 -- A press report, dated Oct 5, states: The plane sent out by Diamond Offshore Drilling after Hurricane "Lili" passed made the dismaying discovery that there was only empty water where the drill platform Ocean Lexington had been. It immediately launched a search, but the floating rig had been blown so far that the plane had to refuel *before it was found, said Lynn Charles a spokesman for the company. The rig was finally found 45 miles to the northwest, stuck on the bottom in water about 35 feet deep. The high winds and waves had apparently pulled apart the huge steel anchor chains that held the semisubmersible rig in place, Charles said. All of the crew had long since been evacuated. Closer to the Louisiana shore, Rowan Cos. spotted pieces of its jack-up drill platform Rowan Houston around 1100 yesterday sticking out of 105 feet of water, said Bill Provine, its vice president for investor relations. The eye of the storm passed within 10 or 12 miles of the Diamond Offshore rig, and wind gusts were thought to be between 145 and 160 mph, he said. "The wave action had to be tremendous." Equipment like this is designed to take a tremendous amount of stress, he said, but a direct hit by a Category 4 storm is something else. The Hurricane lost power as it hit the colder waters closer to shore. Originally, the rig was moored in 250 feet of water about 150 miles south of Morgan City, La. From the air yesterday, everything on the rig appears fine, Charles said. The unknown is possible damage below the water line. Rigs of this size, type and age are thought to be worth between $50 million and $100 million. In addition to bringing in divers, the company will pump air into the ballast tanks to float it off the mud, pull it away with boats and possibly take the rig to a shipyard for inspection. The potential damage was limited because before "Lili" hit, Ocean Lexington had been detached from the subsea well control equipment, the riser and the blowout preventer, all of which are undamaged. The Rowan rig was capsized and sunk by Hurricane Lili. The company's other 21 rigs in the Gulf appear to be undamaged. The 32-year-old rig, which was evacuated almost two days before the storm, was working for Anadarko Petroleum in Ship Shoal Block 207. It is too early to know the extent of damage, Provine said. Also in the Ship Shoal portion of the Gulf, Nabors Industries found one of its smaller jack-up rigs, used mostly for well workovers, flipped over on its side in 40 feet of water. The rig was working for BP. It had been prepared for the bad weather in the normal way by jacking the deck to about 40 feet above the water so waves could pass underneath, said Nabors spokesman Dennis Smith. This kind of rig has long legs that rest on the seafloor. The biggest offshore driller, Transocean, escaped damage to its deep-water rigs, including drillships, spokesman Guy Cantwell said. Its inland barges were also OK, and it is checking out the jack-ups this weekend.*

3.0 METEOROLOGICAL INFORMATION:

Hurricane Lili – National Hurricane Center Information

Hurricane Lili reached hurricane strength on September 30, 2002 in the northwest Caribbean Sea, and continued to gain strength until it reached Category 4 status late on October 2 out in the central Gulf of Mexico. A Category 4 hurricane on the Saffir-Simpson scale, Table 2, has maximum sustained winds between 132 and 155 mph. Lili's peak strength was 156 mph sustained near the ocean surface. Higher gusts of up to 165 mph were reported during the storm. Hurricane Lili was a Category 4 hurricane throughout her passage through the Gulf of Mexico, making landfall just west of Vermillion Bay as a Category 2 hurricane on October 3rd at 10 a.m. CDT.

The 145 miles per hour (125 kts) 1-min mean winds of Lili weakened toward the coastline to 100 miles per hour (86 kts) at the coast and continued to subside as Lili made landfall.

Table 2: Saffir-Simpson Categories of Hurricane & Characteristics

Category	Maximum Sustained Wind Speed (mph)	Maximum Sustained Wind Speed (kts)	Minimum Surface Pressure mb	Storm Surge (ft)
1	74 - 96	64 -83	> 980	3 – 5
2	97 - 111	84 - 96	979-965	6 – 8
3	112 - 131	97 - 114	964-945	9 - 12
4	132 - 155	115 - 135	944-920	13 - 18
5	156 +	136+	< 920	19+

Figure 2 references the track positions for Hurricane Lili, 21 September - 4 October 2002.

Figure 3 references the wind observations as posted by the National Hurricane Center (Ref. 3). Both these figures give an overall frame of reference.

Figure 2: Best track positions for Hurricane Lili, 21 Sept. - 4 Oct. 2002.

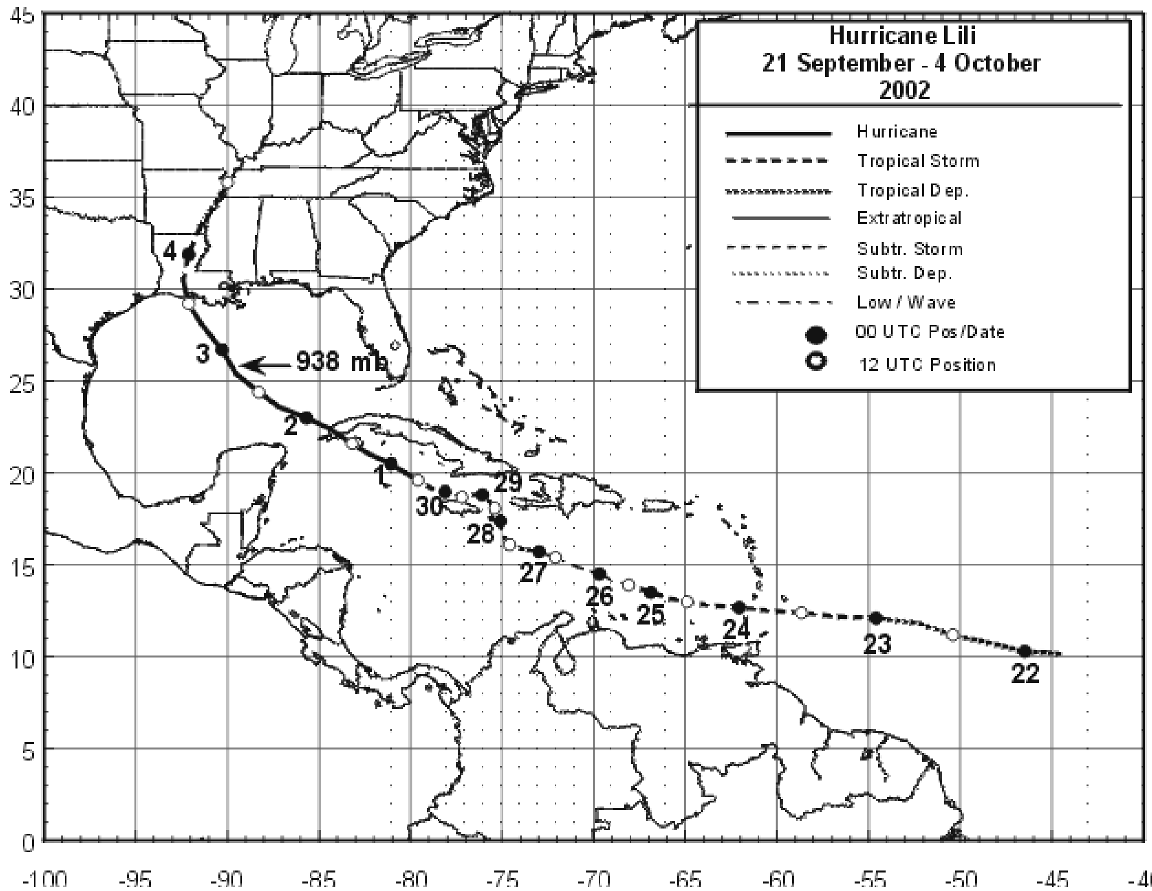


Table 3: Track Positions for Hurricane Lili

Date/Time	Position		Pressure	Wind Speed
(UTC)	Lat.	Lon.	(mb)	(kt)
	(°N)	(°W)		1-min Mean
02 / 0000	23	85.7	967	90
02 / 0600	23.6	87.2	954	100
02 / 1200	24.4	88.3	954	110
02 / 1800	25.4	89.5	941	120
03 / 0000	26.7	90.3	940	125
03 / 0600	28.1	91.4	957	105
03 / 1200	29.2	92.1	962	80
03 / 1800	30.5	92.4	976	60

Figure 3: Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Lili, 21 September - 4 October 2002.

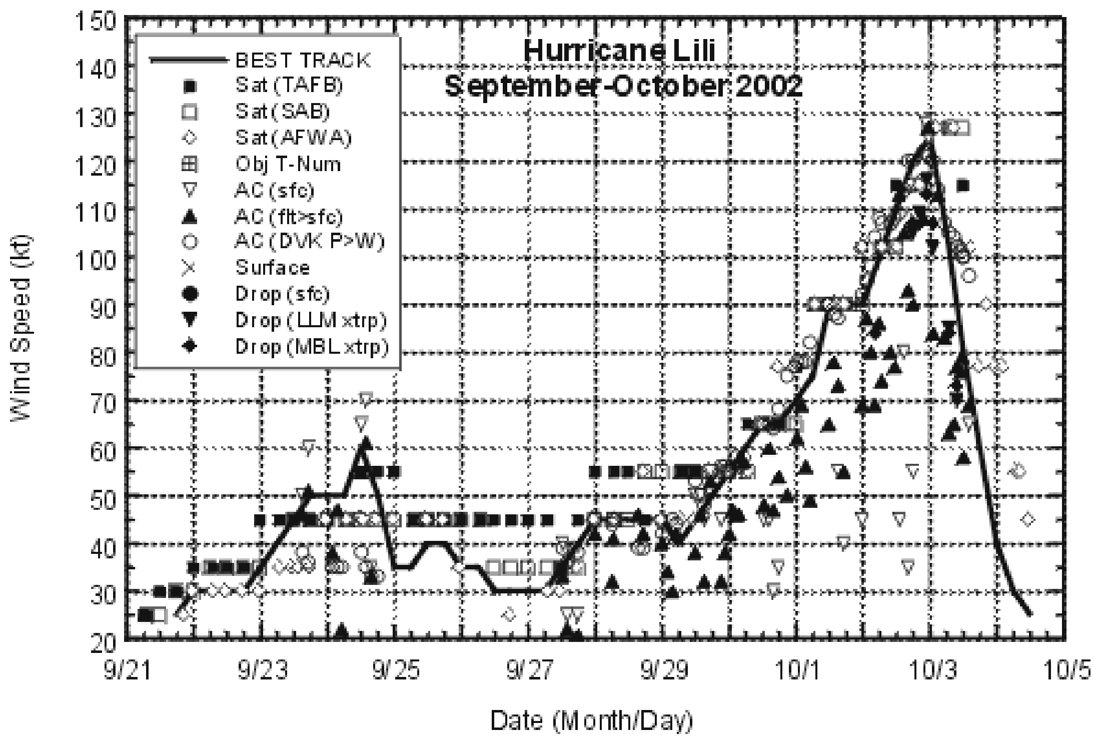
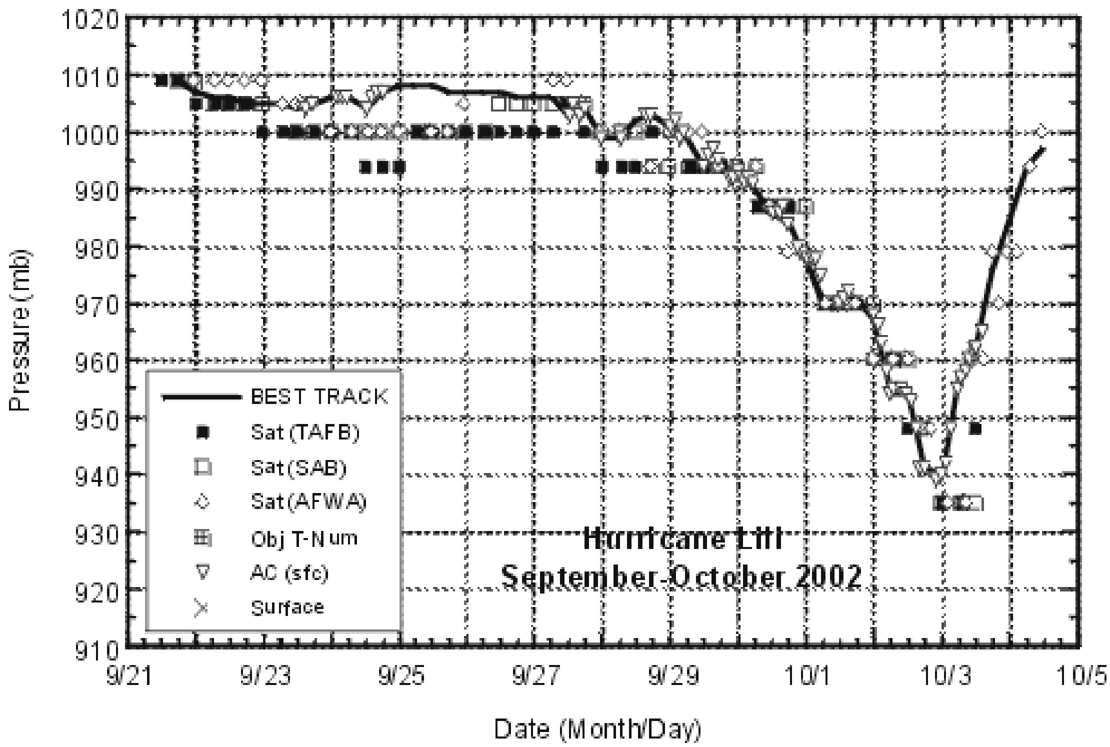


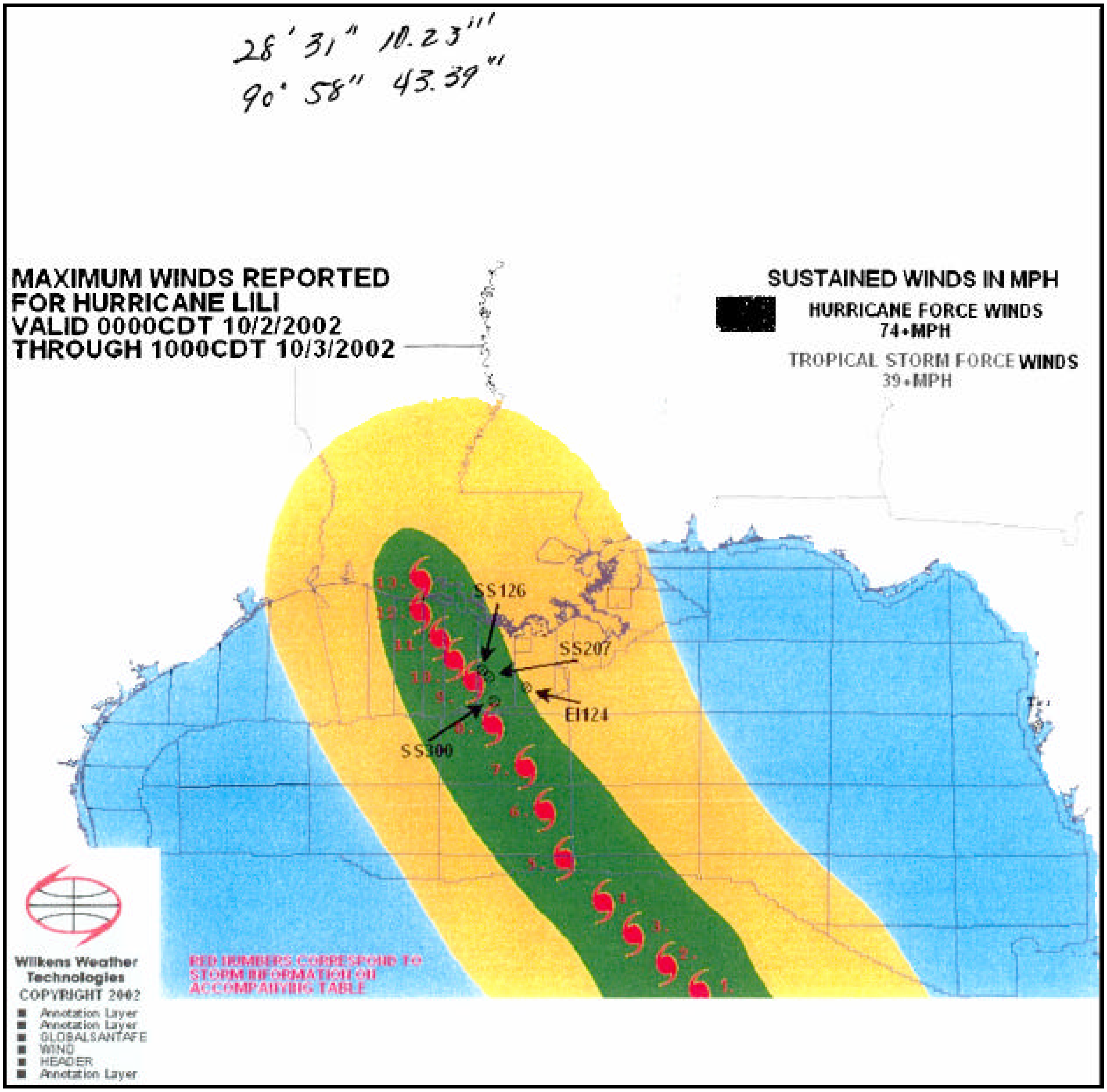
Figure 4: Selected pressure observations and best track minimum central pressure curve for Hurricane Lili, 21 September - 4 October 2002.



Hurricane Lili – Wilkens Weather

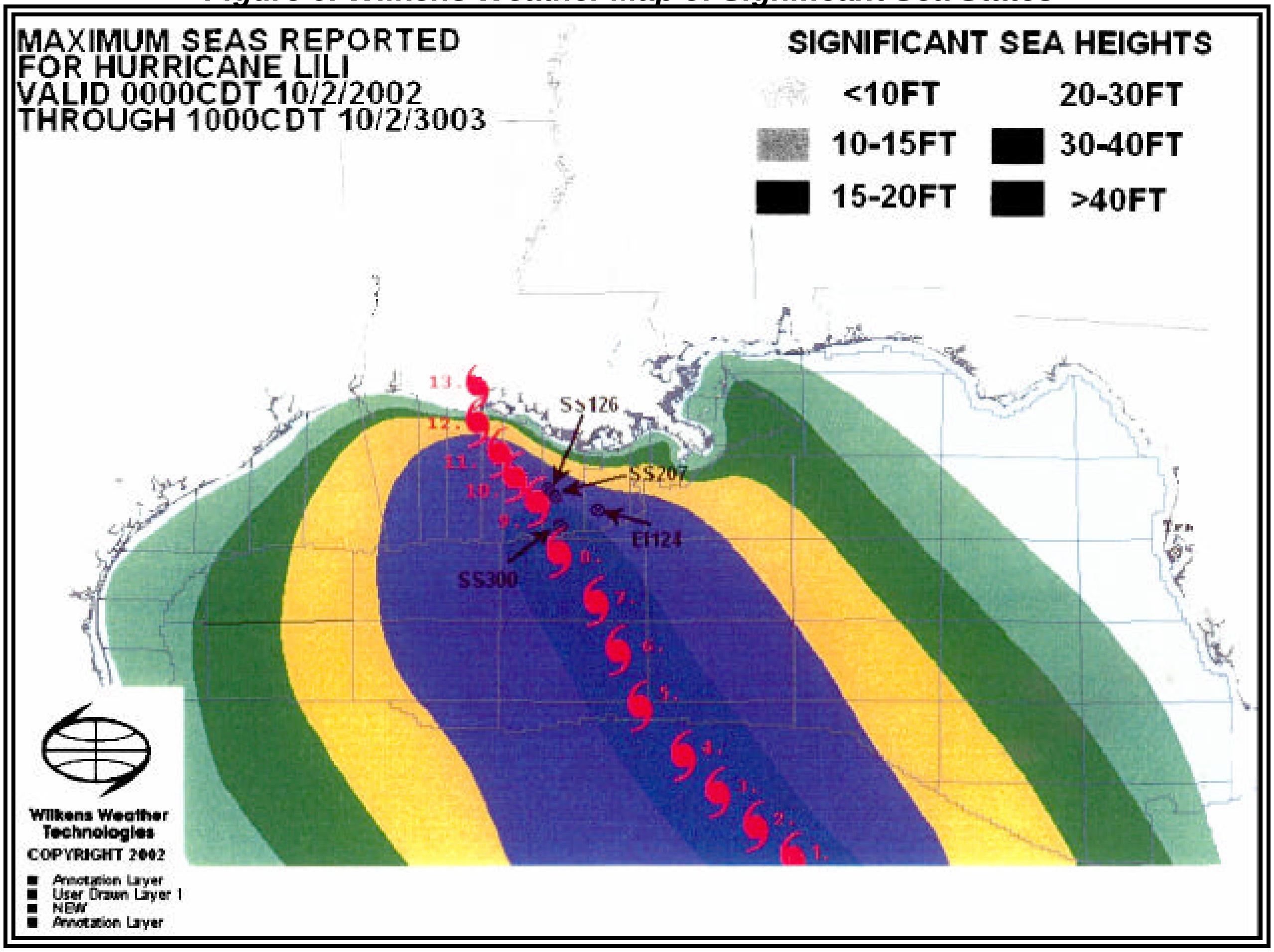
The general windspeeds were chronicled by Wilkens Weather, that produced their opinion of the extent of extreme winds in relation to some of the locations of interest to MODUs. Wilkens Weather Technologies is an independent commercial consultancy which does major weather forecasting for Gulf of Mexico and other offshore regions for oil companies, drilling contractors and others customers.

Figure 5. Wilkens Weather Map of Hurricane Force Winds



The extreme waveheights were also derived by Wilkens Weather and are shown in the figure below.

Figure 6: Wilkens Weather Map of Significant Sea States



Hurricane Andrew – National Hurricane Center Information

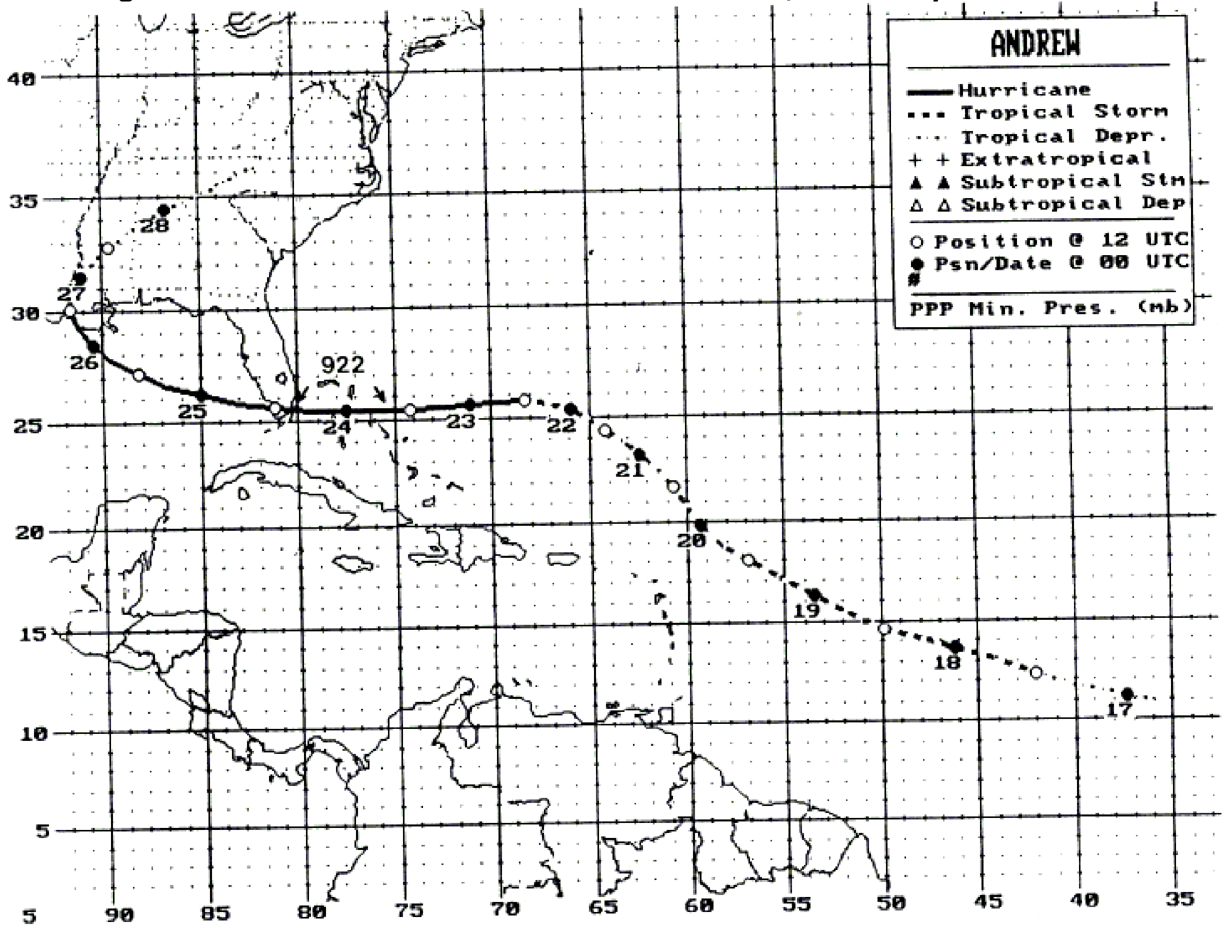
While Hurricane Andrew was one of the most damaging storms to offshore infrastructure in recent memory the wind speeds of Hurricane Lili, according to the National Hurricane Center, were somewhat higher during the transit through the Gulf of Mexico oilpatch.

.

The maximum sustained surface wind speed (1-min average at 10 meters [about 33 ft] elevation) during landfall over Florida were estimated at 125 kt (145 mph), with gusts at that elevation to at least 150 kt (175 mph). By the time Andrew reached the north-central Gulf of Mexico, the high-pressure system to its northeast weakened and a strong mid-latitude trough approached the area from the northwest. Steering currents began to change. Andrew turned toward the northwest and its forward speed decreased to about 8 kt. The hurricane struck a sparsely populated section of the south-central Louisiana coast with category 3 intensity at about 0830 UTC on the 26th. The landfall location was about 20 n mi west-southwest of Morgan City.

The track of Hurricane Andrew is shown on the Figure 7.

Figure 7: Selected track for Hurricane Andrew, 17-27 September 1992.



The figures for the windspeed and pressures for the area of interest are shown in the table below, though the windspeeds were higher offshore Florida

Table 4: Track Positions for Hurricane Andrew

Date/Time	Position		Pressure	Wind Speed
(UTC)	Lat. (°N)	Lon. (°W)	(mb)	1-Min Mean (kt)
25/0000	26.2	85	943	115
600	26.6	86.7	948	115
1200	27.2	88.2	946	115
1800	27.8	89.6	941	120
26/0000	28.5	90.5	937	120
600	29.2	91.3	955	115

Date/Time	Position		Pressure	Wind Speed
1200	30.1	91.7	973	80
1800	30.9	91.6	991	50

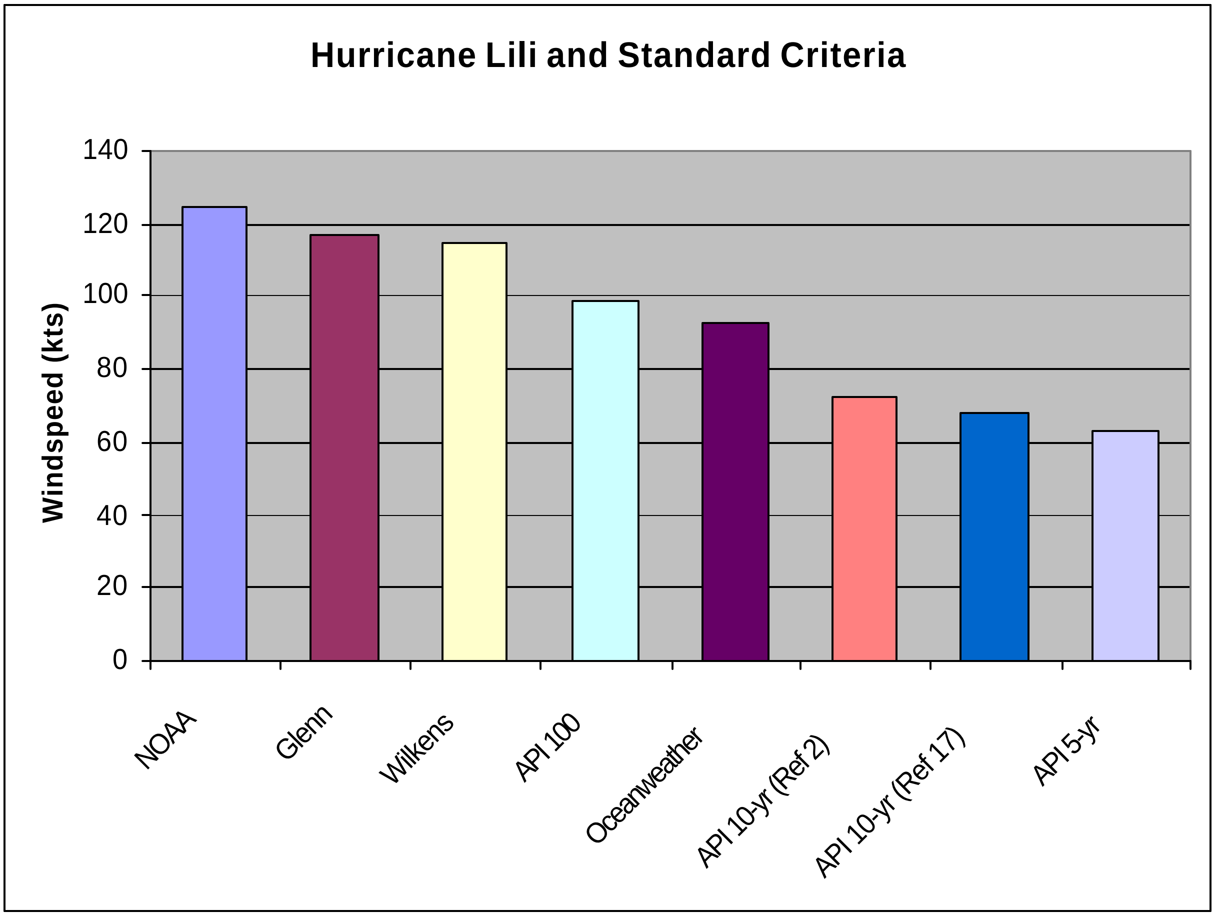
Hurricane Lili – Perspective of Hindcast Information and Current Criteria

In order to put the meteorological conditions in perspective Table 5 chronicles information from various sources concerning wind speed only. The table chronicles information meant for different purposes and thus does not purport to be a completely "apples-to-apples" comparison. Nevertheless it gives some interesting insights.

Table 5: Comparison of Wind Speeds in Hurricane Lili

Source	1-min wind speed (kts)	Highest at Location
5 Yr API (Ref 2)	63	Specific design
10 Yr API (Ref 17)	68	Deepwater – SEMI - TARGET VALUE
10 Yr API (Ref 2)	72	Specific Design
Oceanweather (Ref 1)	93	Worst in Storm
100 Yr API (Ref 17)	99	Deepwater
Glenn at Ship Shoal (Ref 4)	115	Specific (close to max)
Wilkens at Ship Shoal (Ref 5)	117	Specific (close to max)
NOAA (Ref 3)	125	Worst in Storm

Figure 8: Hurricane Lili and Standard Criteria



Observations can be made from Table 5.

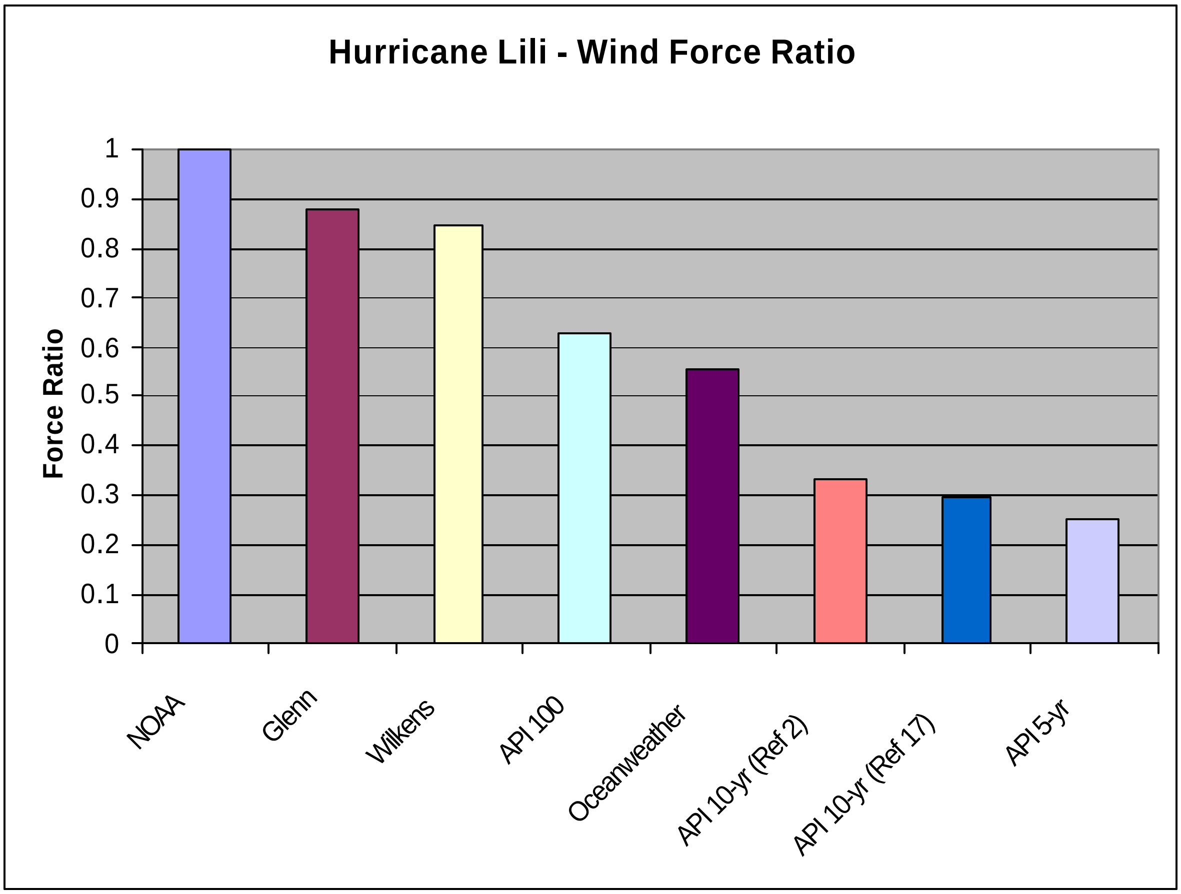
- Oceanweather chronicles a lesser windspeed from its hindcast than NOAA reports. Some of this may be to do with height above the sea. Oceanweather report at 10 m. above sea level. NOAA buoy wind information is said to be transmitted at 10 m.

- Adjustments may be necessary to observations. The wind at the buoy may be shielded by a high wave – so adjustments may be appropriate. There may be some unstated joint probability accounted for in some of these values and not in others, since the maximum wind may precede the waves in a rapidly moving storm: however such qualifications to the numbers, if they exist, have not been explicitly stated.

- Site-specific wind speeds in Ship Shoal reported by Glenn and Wilkens appear to be similar and in line with the NOAA data: site-specific data for locations near the track would be expected to be somewhat lower than the highest observed data.

- Wind forces on structures increase as the square of the velocity. It would be unlikely that a mooring developed to a 10-year API design standard would survive any reported wind values including the extreme value from Oceanweather (the lowest).

Figure 9: Hurricane Lili – Wind Force Ratio



The criteria generally used for jackup siting in the Gulf of Mexico is considered to be a 10-year return period storm for locations in the Gulf of Mexico. The wind speed generally associated with this event has been considered for a number of years to be 100 kts, (Ref: 20). Additionally ABS Rules call for 100-kts as the appropriate minimum design windspeed for unrestricted offshore service:

> *All units in unrestricted offshore service are to have the capability to withstand a severe storm condition wherein a wind velocity of not less than 51.5 m/s (100 kn) is assumed. In order to comply with a severe storm condition, all units are to show*

> *compliance with this requirement at all times or have the capability to change their mode of operation.*

Observations: Comparison to Hurricane Andrew

Hurricane Andrew had imposed major damage on the Gulf of Mexico infrastructure as indicated by the following media report:

> *London, May 12 – The outcome of hurricane "Andrew," which brought total insurance claims of $14.5 bn for property loss in Southern Florida, was "successful," said the US Mineral Management Service, which regulates the offshore industry. Of 2,000 structures – one-third platforms and the rest satellite installations – 49 were completely destroyed while 125 were left leaning and 122 sustained other damage. This was despite the fact that 800 of the structures were built before 1972. An MMS spokesman, detailing the results of a survey, said 393 of 10,000 lengths of pipeline in the affected area were damaged. Underwater surveys have found little more damage than surface inspections. Five drilling platforms were set adrift by the hurricane. Analysis of the damage by age showed 7.7% of pre 1966 structures were damaged, a good result in the view of MMS, and the rate for post 1975 structures was 2.6%, more than double that of 1966-75 buildings. Most pipeline damage was caused by the effects on platforms and satellites. Apart from the limited nature of damage to structures, the MMS measures success by the fact that 20,000 workers were evacuated without injury, that there was no loss of well control and that production was resumed remarkably quickly…….. This does not mean that MMS found no areas for concern. Pipeline spillage during start-up was a problem, probably because of the rapid build-up of renewed flows. Similarly, the amount of damage caused by drifting platforms is considered unacceptable." Lloyd's List 13/5/1993.*
>
> *Hurricane Andrew was one of the costliest hurricanes in Gulf of Mexico history. At least 249 of the 3800 offshore platforms were damaged by the storm, though there was no loss of life offshore, less than 500 barrels of oil spilled (with virtually no residual pollution therefrom), and production of oil and gas were minimally affected. (Ref. 26).*

As indicated above, the wind speeds and waveheights of Hurricane Lili (because the storm was slower moving) are expected to have been more severe than that of Hurricane Andrew for the Gulf of Mexico infrastructure had the paths been the same. Thus it is not surprising that there were breakaways of floating units, and some impact on the jackup MODU fleet as a result of Hurricane Lili.

Conclusion

Referring to Table 5, there are some significant differences in what is apparently the same "critieria" between the appropriate results of the hindcast analyses: this may be because of differences between the methods or philosophy used by Glenn, Wilkens, and Oceanweather in developing the hindcast windspeeds.

The windspeeds quoted from the National Hurricane Center are apparently the same definition (1-minute mean) as those developed by the Glenn, Wilkens and Oceanweather whose numbers are different.

These same commercial companies provide suitable criteria for the siting of MODUs: these differences lead to some confusion about the uniform risk that MODUs use to develop acceptability limits for stationkeeping and structural criteria.

The generally accepted criteria for siting MODUs relate to acceptance of a specified return period storm 5-year, 10-year, 25-year, 50-year. Generally 100-year criteria is used for Fixed Platforms and Floating Offshore Installations, 10-year criteria for jackup MODUs and somewhere between 5-Year and 10-year for MODU stationkeeping requirements depending on the circumstances. Table 5 indicates that there is a significant difference between how data is interpreted by different organizations for the same event leading to a conclusion that further insights are necessary as to the differences in methodology, philosophy and ultimately in the values that each organization specifies.

4.0 MODU LOCATIONS: HURRICANE LILI

In order to establish the locations of the MODUs related to the hurricane path, Figure 10 shows the locations of the known MODUs. These were defined from various sources in the Gulf of Mexico in order to identify the most likely candidates for study besides those that had volunteered the information of how close they were to the hurricane track.

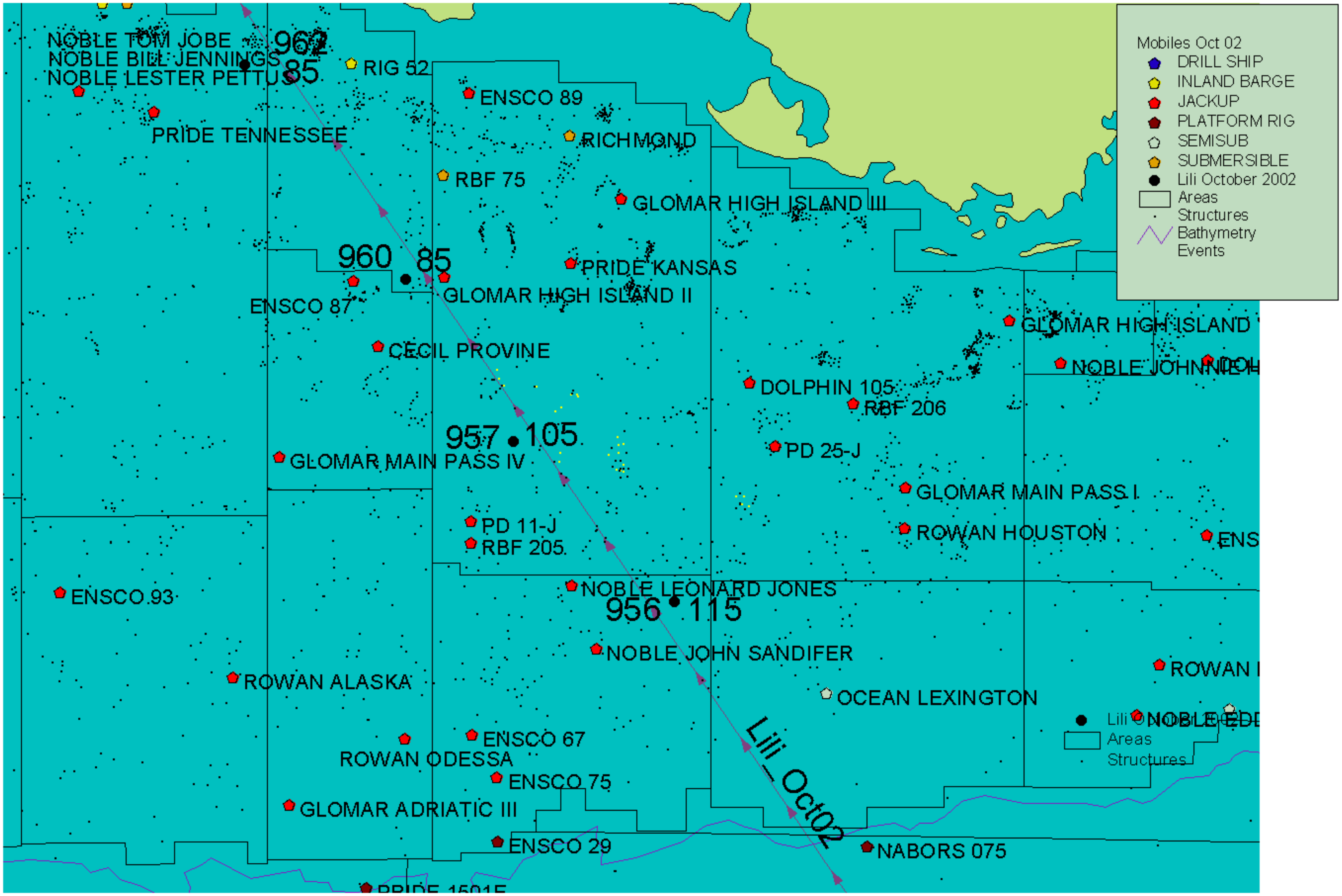


Figure 10: Approximate Positions of MODUs developed after Hurricane Lili's passage (Courtesy Matthews-Daniel)

5.0 SEMISUBMERSIBLE MODUS: HURRICANE LILI

The incidents of semisubmersibles in Hurricane Lili were as follows:

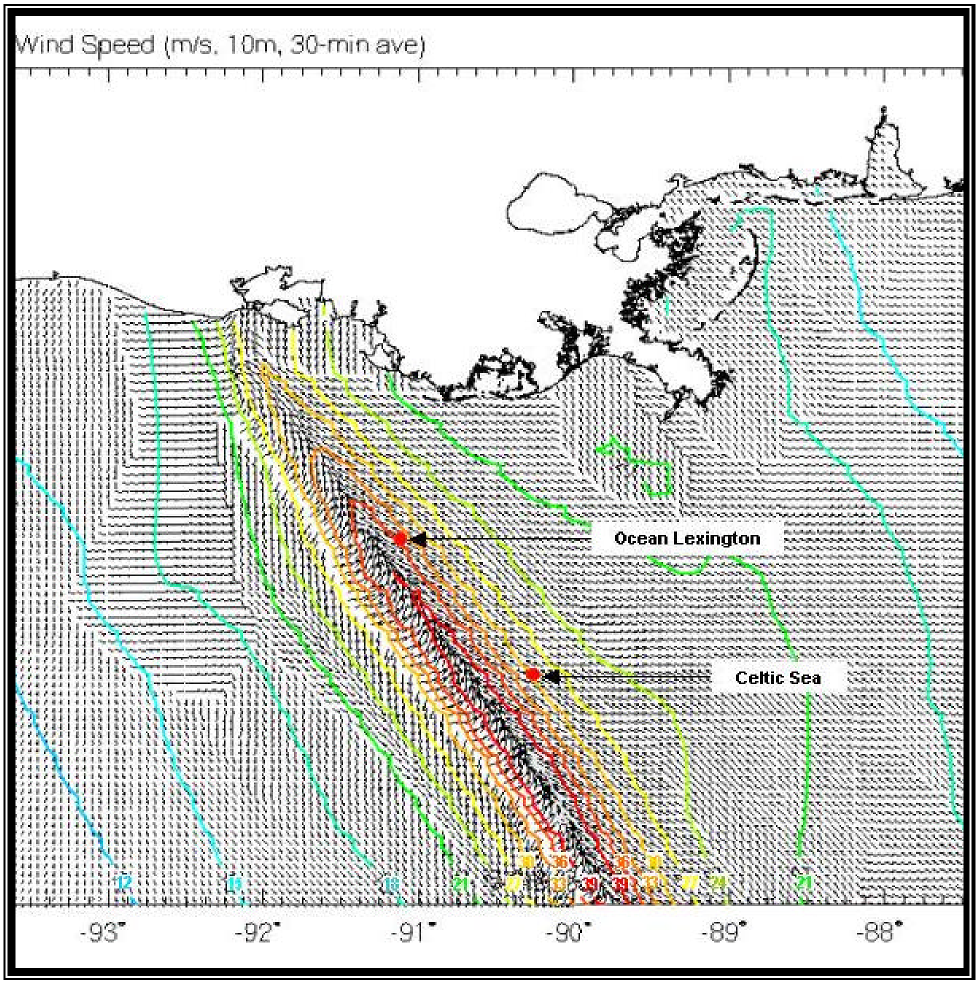
- Ocean Lexington – drifted free of the anchors and sailed 43 miles grounding off the coast of Louisiana without incident. The first break was in wire on a pre-deployed mooring.
- Glomar Celtic Sea – 6 of 8 mooring lines broke. The unit stayed on location, reconnected afterwards and went back to work.

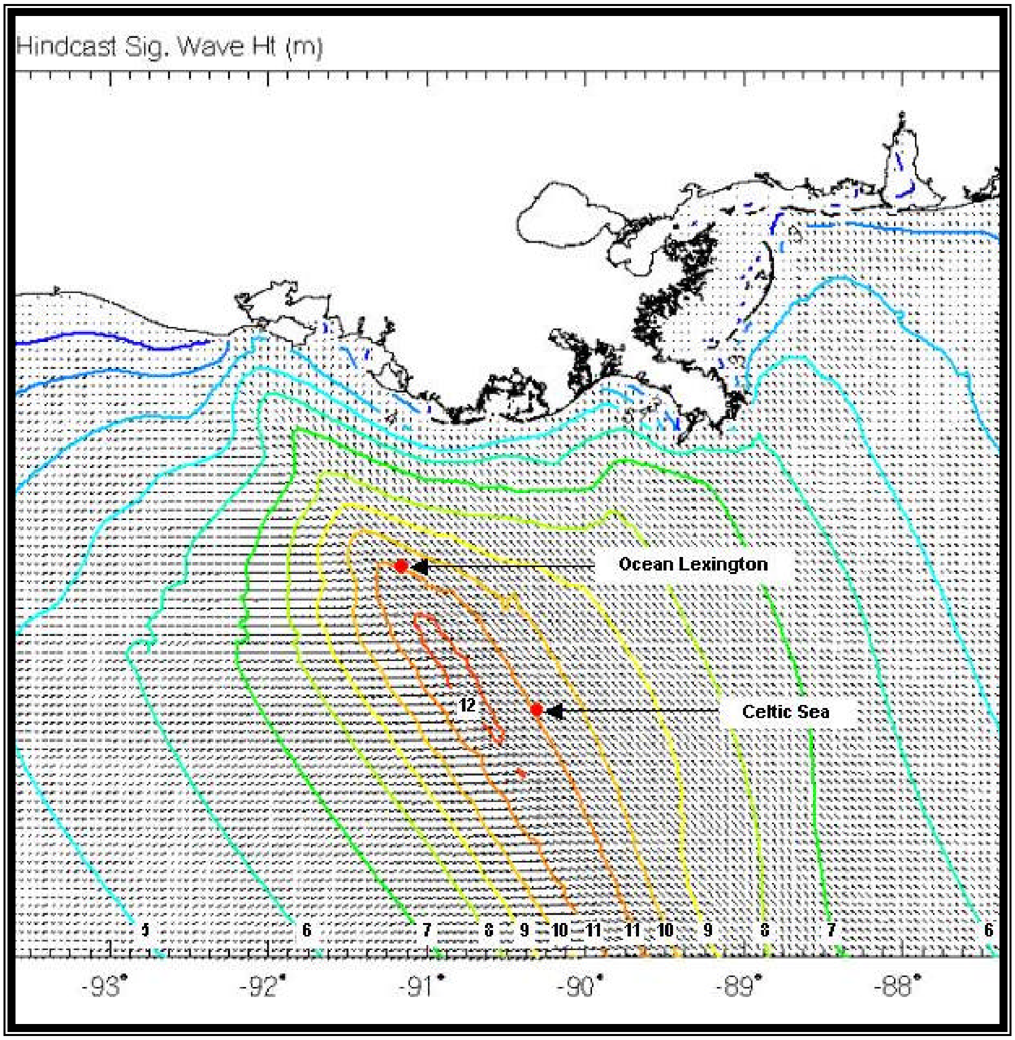
Table 6 gives the information about the semi-submersible rigs that had mooring breaks during Hurricane Lili. Figure 11 gives the wind and wave contours from the Oceanweather Report (Ref 1) with rig locations superimposed.

Table 6: Semi Submersibles Involved in Mooring Incidents: Hurricane Lili

Operator	Rigname	Design	Builder	Yr Built	Oil Co	Location	Water Depth (ft)
Diamond Offshore	Ocean Lexington	Zapata SS-2000	Avondale	1976	LLOG Exploration	Ship Shoal 300	257
Global Santa Fe	Glomar Celtic Sea	F&G L-907 Enhanced	Mitsui Tamano	1984	Chevron Texaco	Green Canyon 562	910

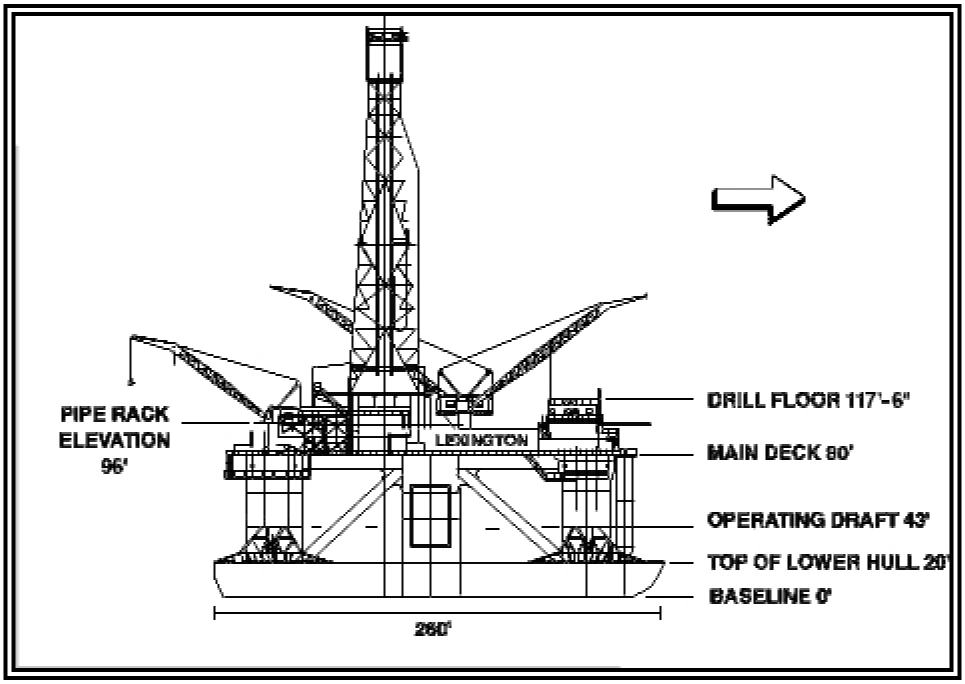
Figure 11: Locations of Rig in relation to Storm (Base Maps by Oceanweather-Ref. 1)





OCEAN LEXINGTON

Diamond Offshore Drilling Inc. reported that its semi-submersible, Ocean Lexington, located in Ship Shoal 300, parted its moorings. The rig drifted free leaving all anchors on the bottom and traveled NNW approximately 43 miles before grounding in an estimated water depth of 35 feet offshore Louisiana in Eugene Island Block 123. Hurricane Lili passed directly over the Ocean Lexington's location reportedly as a category 4 storm during the passage. While there were fixed structures in its path the Ocean Lexington avoided all of them arriving on the beach with no personnel injuries, no pollution and no collisions.



Ocean Lexington was blown off location and is believed to have drifted to the northeast. This is possible in view of the fact that the center of Hurricane Lili probably went over the semi-submersible. It probably was blown off location as the hurricane center moved by, with the winds suddenly shifting strongly into the southwest which could account for the initial movement to the northeast.

The initial mooring analysis was done by Delmar Technical Engineering Department and confirmed by Diamond Offshore Naval Architects. The mooring analysis met API RP2SK using the Deepstar II 10 year hurricane, high wave environmental data. The waterdepth within the anchor pattern was quite shallow at about 250 ft.

Two lines # 3 & # 4 were required to cross the Kerr McGee and Walter Pipelines. The anchors on these lines were placed shorter than normal to keep at least 500 feet away from a third Petrobras Pipeline. These two mooring lines were pre-layed with leased anchors and lines.

The configuration on location is shown below:

The configurations of the lines were as follows:

Lines 1,2,5,6,7,8 consisted of

- 775' 2-3/4" wire rope
- 2250' 2-3/4" ORQ+20 chain
- 40 kip Offdrill II Anchors

Lines 3 & 4 consisted of

- 500-feet 2-3/4” rig chain
- Chaser Stopper
- 500-feet 3-1/4” wire rope (EEIPS) for line #3 and 1000-feet for line #4
- 50-kip Submersible Buoy on buoy swivel
- 500-feet 3-1/4” wire rope (EEIPS) for line #3 and 1000-feet for line #4
- Inline Pipeline Swivel
- 1500-feet 3-1/4” chain (ORQ or greater)
- 15MT Bruce HHC Anchor

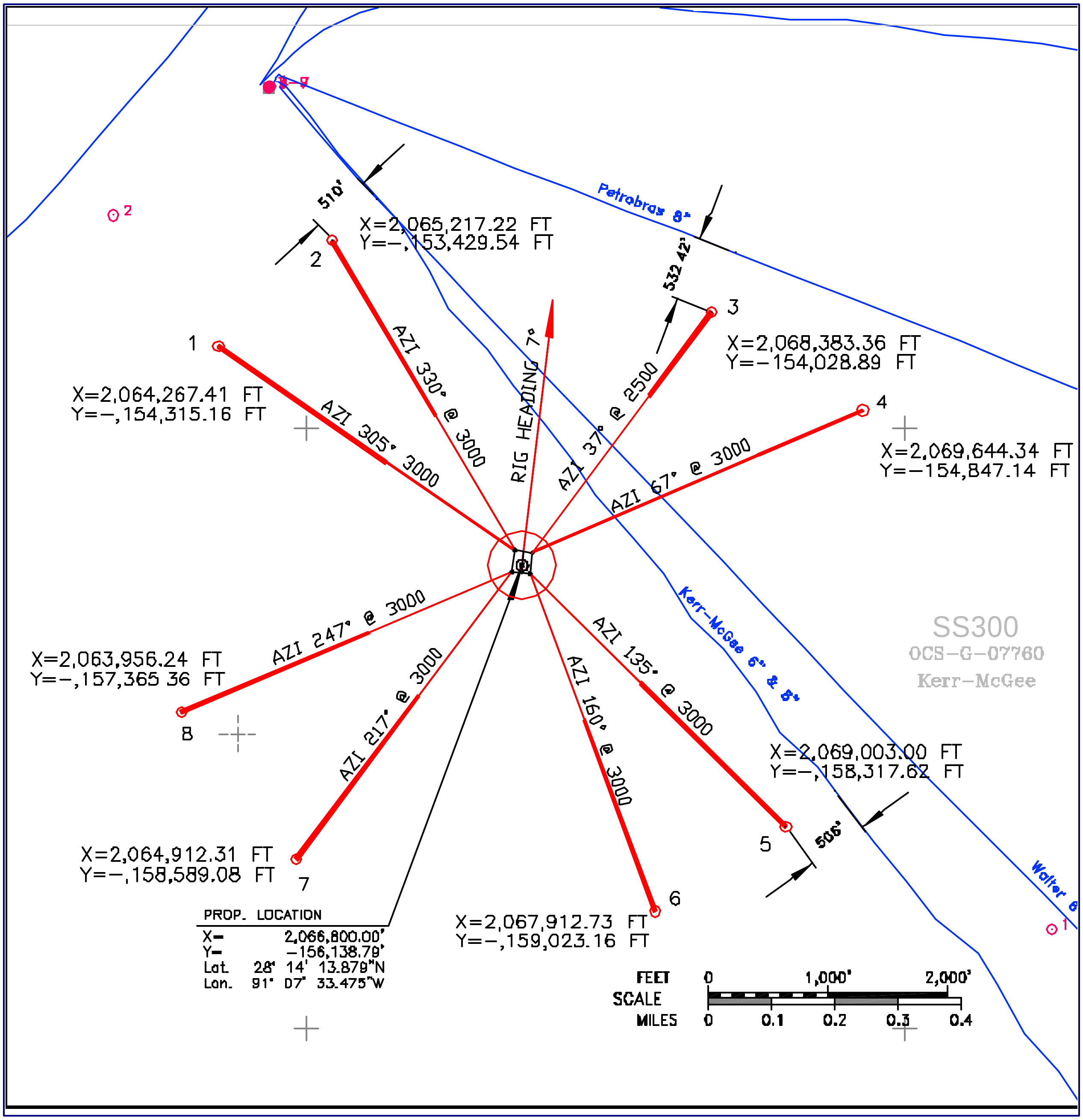


Figure 12: Configuration of mooring lines on Ocean Lexington.

The chain was at the fairlead on legs 3 and 4 and the wire was at the fairlead on the other legs. The pre-layed anchors were Bruce 15 mt. with high holding capacity and because of their characteristics it would have been anticipated they would have minimum drag: the appropriate solution for this site-specific location. The calculated strength of the preset moorings was designed to exceed the strength of the rig mooring components.

No. 3 leg failed in the first section of rental wire between the rig chain and the buoy as shown on the Figure 13.

No. 4 leg failed at or near the fairlead on the rig chain as shown on the Figure 14.

No. 5 leg failed in the rig wire about 500’ from the fairlead.

All other lines failed at or near the fairlead on the rig wires.

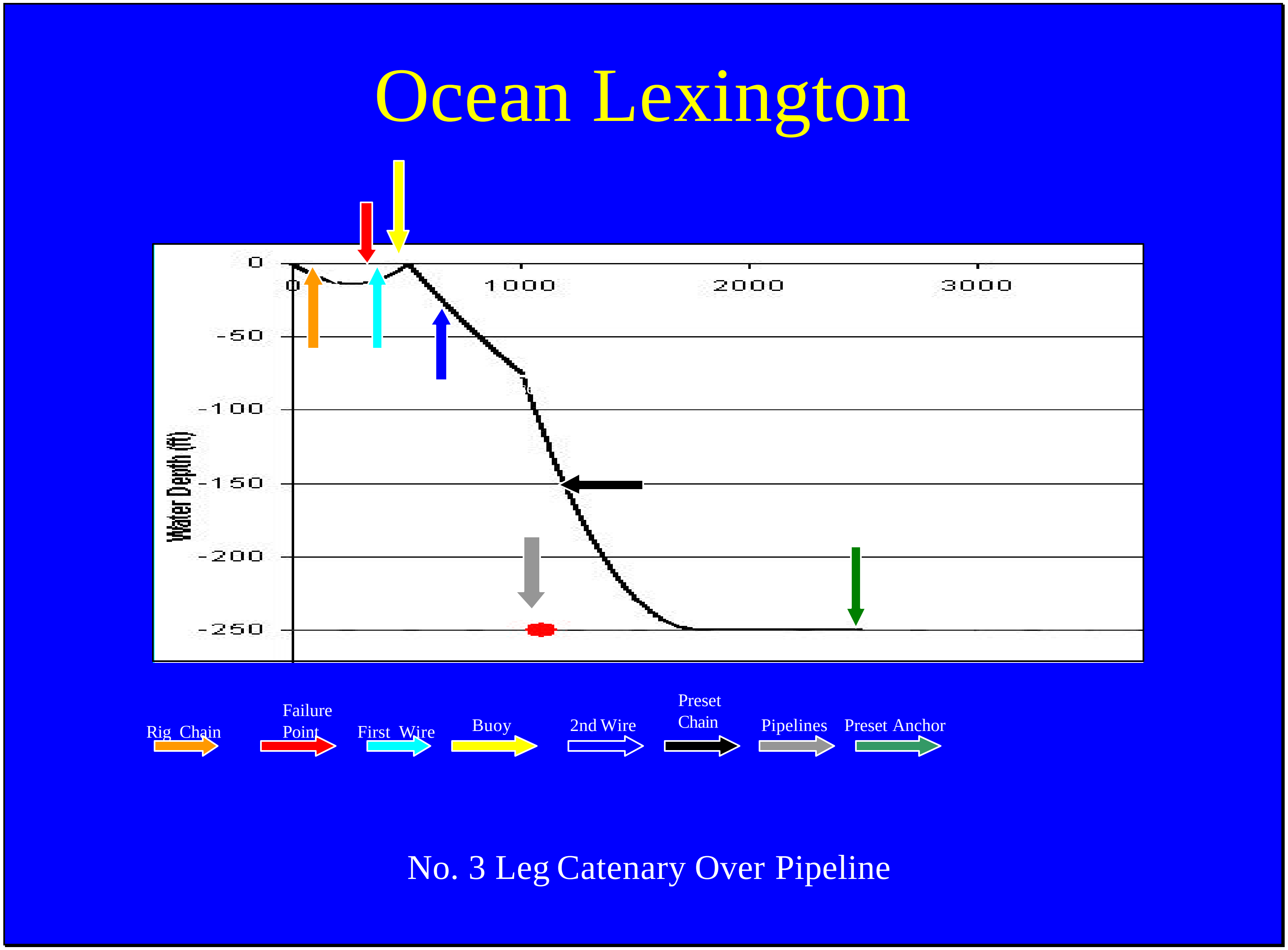


Figure 13: Showing location of Failure on Line #3.

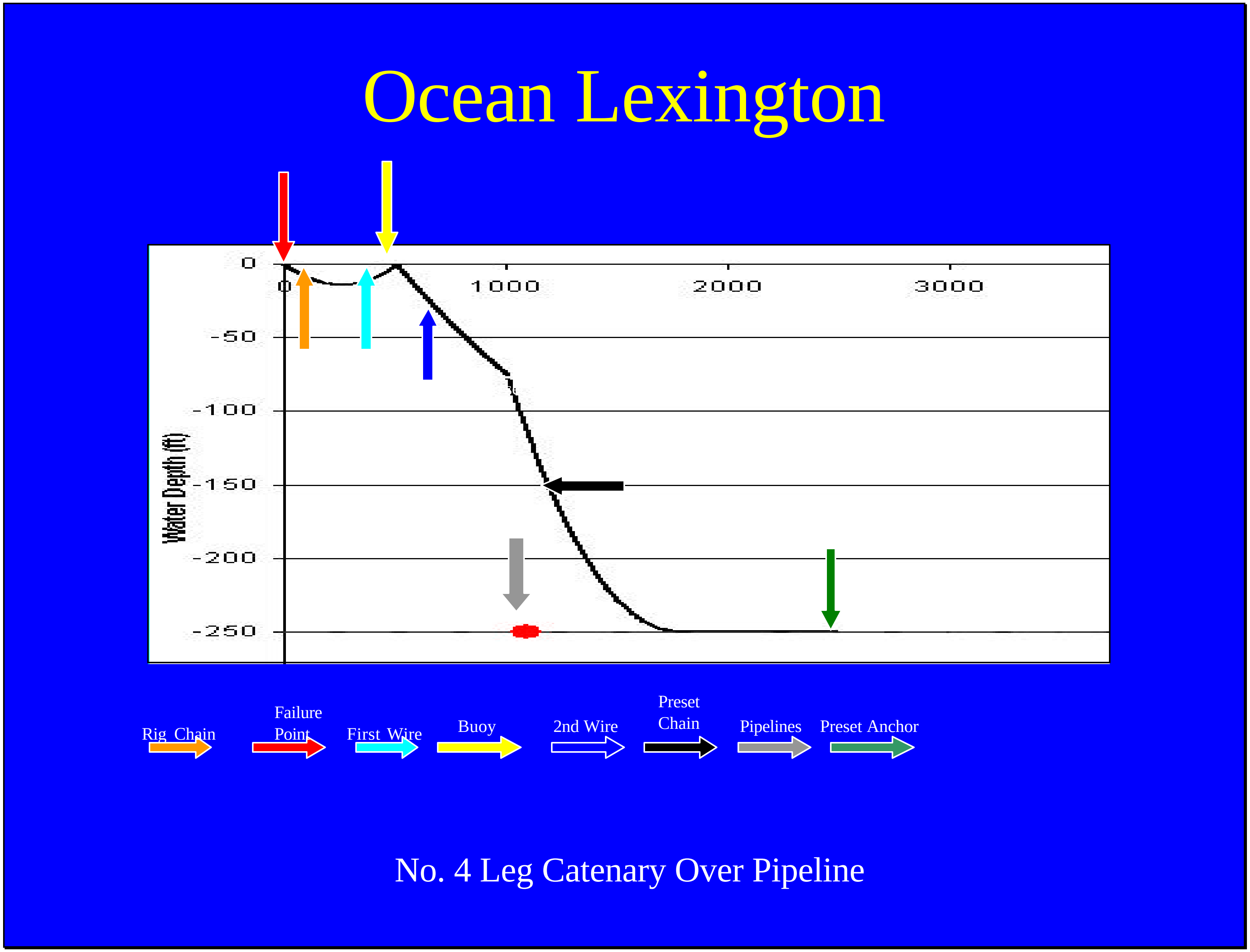


Figure 14: Showing location of Failure on Line #4

The mooring analysis met API RP2 SK (Ref 15) using 10-year hurricane high wave environmental data (Ref 17). The high wave data also constitutes the high wind case.

The entire rig chain/wire moorings were in like-new condition, under three years old and visually inspected when deployed.

Conclusions by Diamond were:

> The mooring configuration complied with industry standards (API R2SK) using Deepstar II Data for 10 year return, hurricane high wave condition.
>
> The calculated strength of the preset moorings was designed to exceed the strength of the rig mooring component
>
> - The buoys in the preset mooring systems succeeded in preventing any mooring components falling on the pipelines.
> - The strength of the storm as experienced at the location substantially exceeded the design criteria.

The fact of the matter is that the weather that the Lexington saw was above the design speed, for Oceanweather's results and also for each of the NOAA results and also for the Wilkens and Glenn data (not shown here). As it turned out – the difference between the design and actual at 87 knots would predict a breakage in a perfect line.

A brief comparison between API 10-year return and the weather hindcast result is shown in Table 7.

Table 7: Comparison of Anticipated and Actual conditions for Ocean Lexington

	Oceanweather	**API 10-Year (Ref 17) Target Design**	**API 10-Year (Ref 2)**	**NOAA**	**API 100-Year (Ref 17)**
Wind 1-min mean	87 kts	**68 kts**	72 kts	125 kts	99 kts
Sig. Wave Height	36 ft	**26 ft**	30 ft	-	40 ft
Current	1.9 kts	**1.5 kts**	1.8 kts	-	2.1 kts

Quite clearly, the data shows that the conditions for acceptance, the site-specific 10-year "Target Design" conditions at that location, were exceeded.

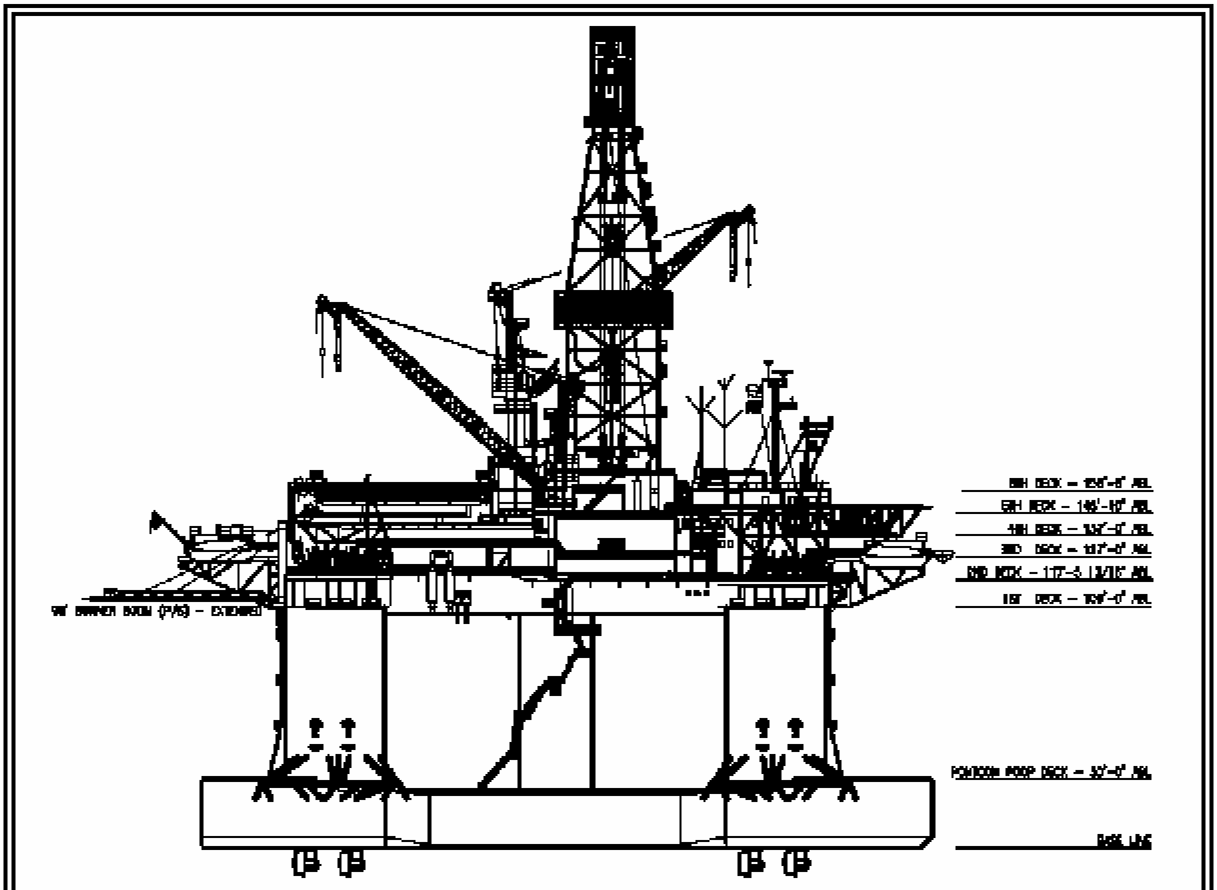
The API data was reference by the Mooring Code Joint Industry Study dated October 1995 (Ref 21) which used generic Gulf of Mexico data as follows:

Table 8: Historic Data used for Mooring Joint Industry Code

	100-year	10-year	5-Year
Wind 1-min mean	97 kts	72	63 kts
Sig. Wave Height	40 ft	30 ft	27 ft
Current	3.0 kts	1.8 kts	1.4 kts

GLOMAR CELTIC SEA

The Glomar Celtic Sea is a Friede & Goldman L907- Enhanced Semisubmersible and was drilling in Green Canyon 562 at the time of the Hurricane in 910 ft waterdepth, well within its advertised waterdepth capability of over 2200 ft. It was moored with 4500 ft 3" K4 chain; and 10,000 ft 3.5" wire. At the termination are 14.7 ton Stevpris anchors.



GSF CELTIC SEA

Glomar Celtic Sea reported that 6 of its 8 mooring lines broke in Hurricane Lili but it remained tethered to the seabed. One failure was about 700 ft from the end; the others were in the region of the fairleads. The rig was moored with Stevpris anchors, which moved somewhat on location even though these are high holding power anchors. There was evidence that they reached their maximum limits. There was additionally some minor damage to the accommodation recreation room, which had the deck plates and beams bent upward. This was unexpected and may have resulted from wave run-up on the column. Of the 6 mooring lines that failed, all but one failed near the fairlead. The comparison of anticipated and actual conditions is shown in Table 9.

Table 9: Comparison of Anticipated and Actual conditions for Glomar Celtic Sea

	API 10-Year (Ref 17) Target Design	**Wilkens**	**Oceanweather**	**API 10-Year (Ref 2)**
Wind 1 –min mean	**68 kts**	91 kts	72 kts	72 kts
Sig. Wave Height	**26 ft**	42 ft	36 ft	30 ft
Current	**1.9 kts**	-	2.1 kts	1.8 kts

Note: Significant Wave used here is considered to be the average of the highest 1/3rd waves. Conversion between significant and maximum wave is generally done through a multiplier of 1.86.

Given that the storm conditions were in excess of the "design" conditions, one should not be surprised that such a severe hurricane, this close to the location would result in a mooring failure. Further investigation was not apparently carried out by the drilling contractor. It might have been expected that even though the conditions exceeded the design that the unit in all probability might withstand these additional loads considering safety factors involved.

There was no further information available. Based on other historical incidents, there is no doubt that one must always remain diligent in the quality control of mooring system components to be assured that they will carry their breaking load when the time comes to put them to the ultimate test.

As noted above, it is also of note that there is a difference between hindcast data from two different experienced sources.

6.0 SEMI-SUBMERSIBLE MODUS: HISTORICAL INFORMATION

Worldwide, semi-submersibles have a long record of operations, which provide a great deal of historical information. Modern semi-submersibles have been operating successfully in the Gulf of Mexico since the early 1960s.

Hurricane Hilda affected the first semi-submersibles, Bluewater 1 and Ocean Driller, in 1964 shortly after commencing operations (Ref. 6). Hurricane Hilda capsized the Bluewater 1 and broke the moorings of “Ocean Driller” causing it to drift 15 miles. The Bluewater 1, the industry’s first semi-submersible, was some 100 miles to the east of the path taken by the eye of the storm. After the storm, the Bluewater 1 was found floating upside down in the middle of its moorings due to a structural failure caused by tornadoes spawned from the hurricane. The Ocean Driller located about 30 miles east of the path, broke two of nine chains and dragged the rest for 10 miles. A crew of 14 safely rode out the storm (Ref. 6). Industry practice in the Gulf of Mexico is to evacuate offshore rigs during hurricanes, and this was the only documented instance in the Gulf of personnel remaining onboard a semi-submersible during a hurricane of this strength.

The Bluewater 1’s mooring system actually held it on location after it capsized. There is strong evidence from the derrick being found 1 mile away that it was hit with a tornado. The derrick was found about a mile due north of the rig. The racked drill pipe was still chained together and about 1/2 mile due north. The other end of the rig, which had the machinery in a steel plate building, was completely intact. The two 72" beams, which supported the derrick, were twisted. Apparently the tornado went across the drilling end of the rig. Surveyors made several attempts to salvage it. Shifting ballast and having an armada of tugs try to pull it upright. After spending about $5 million in salvage and paying Bluewater $5.6 million, they towed it out into deepwater to sink it. John Mecom bought it at the last minute for $100,000. He moved it into shallower water and moored the upside down rig with only four mooring lines and only used two of the original three lengths of wire in each leg. A second hurricane Betsy same through the following summer. By that time they had cut off the Texas deck structure so only the four columns and hull remained. In Betsy the rig dragged the four anchors moved 14 miles across the Gulf and hit a newly installed West Delta platform in 300 ft of water. So in a bizarre historical way we can trace moorings breaking on semis-back to the first semi-submersible.

We have progressed the understanding of mooring systems considerably over the years. Bruce Collip, one of the Offshore Energy Center Pioneers honored with being the inventor of the semi-submersible wrote an early useful paper in 1968 on mooring system calculations. In 1982 the National Civil Engineering Laboratory carried out some helpful tests on a variety of anchors – leading to a better understanding of anchor holding power. The anchors have become progressively more efficient and have a higher holding power to weight ratio, but there are suggestions that as a design philosophy, the dragging of anchors, might be a useful avenue to explore.

Elsewhere in the world there have been mooring incidents of relevance. Historically the semisubmersibles were sited with mooring systems in the North Sea were capable of about a 10-year return period storm. In 1990 UK HSE commissioned a report which

> *"covered 30 incidents reported to the Department of Energy over the previous 10 years, starting with failures in a severe storm in November 1981. Of these 30 incidents 10 were in just two storms, the second being in November 1985. 20 of the failures occurred in relatively mild or moderate weather and were considered to be largely symptomatic of gross material defects in chain. In both of these storms a rig remained connected and the riser subsequently pulled the BOP off the well, though without serious consequences. The second review covered 9 mooring incidents which occurred in a single storm in December 1990. In 3 cases the riser was still connected at the time of line breakage, forcing the BOP to be disconnected in one case and breaking the riser in another."*

HSE commissioned a further report after two severe storms occurring in October 1991 and January 1992. (Ref. 23). The study observed:

> *"Although there have been significant improvements, particularly with chain, the number of incidents is still considered to be too high. When mooring failures occur too frequently the first concern is that there is insufficient margin of basic strength over predictably frequent high loads. One remedy is to increase this margin by applying higher design safety factors and thereby requiring higher line strength. Alternative explanations for failure are possible where such a remedy may not be completely effective, or perhaps be the most economical way to decrease failure incidence. For example, if the failures were due to detectable material defects in lines these can be avoided by better manufacturing practices, in-service inspection or handling. Additionally the incidence of extreme loads might be reduced by prudent active adjustment of lines and the use of vessel propulsion.*
>
> *A key question is thus whether the rating of mooring systems, particularly on some of the earlier rig designs, should restrict areas or season of operation. Earlier reviews revealed that gross material defects were responsible for many of the failures. Some operators emphasised that the operation and maintenance aspects of mooring were critical, and indeed it is clear that operational factors do have a significant effect in preventing failures and controlling severity in those cases where it occurs. This review seeks to add to the body of objective data on mooring failures to assist decisions on future policy regarding mooring regulations."*

In general the conclusion was that defects in the mooring systems in North Sea rigs caused them to fail at a lower than design load. There is no evidence of this in the current information we have on failures in the Gulf of Mexico, though one would always caution that with so many components, all of which have to hold their full design load, it is very important to be ever-diligent about the quality control in manufacturing and the in-service inspection of mooring components.

A number of Joint industry studies were developed to understand mooring components, these included:

1989-91 Wire Rope Endurance – where key investigators included C.R. Chaplin University of Reading, UK. Some of the publications are noted as follows:

Chaplin, C.R. The Prediction of Wire Rope Endurance for Mooring Offshore Structures - Interpretation and Recommendations Final Report of Joint Industry Study - distributed by Noble Denton and Associates, 1991.

Chaplin, C.R. & Potts, A.E. Wire Rope Offshore - a Critical Review of Wire Rope Endurance Research Affecting Offshore Applications Offshore Technology Report HMSO Publication OTH 91 341, 1991.

Potts, A.E., Chaplin, C.R. & Tantrum, N.R.H. Factors Influencing the Endurance of Steel Wire Ropes for Mooring Offshore Structures Proc. 20th Annual OTC, Paper No OTC 5718, May, 1988.

Chaplin, C.R. & Potts, A.E. Wire Rope in Offshore Applications - Review of 1985-1987 programme published by Marine Technology Directorate Ltd. (ISBN 1 87 553 01 2) February, 1988, pp160

1989-94 JIP on Fatigue Testing of Large Diameter Mooring Anchor Chains-Noble Denton.

1993-1995 Mooring Code JIS "Calibration of ABS, API, DnV, HSE(DEn), and NMD Mooring Design Codes for Floating Drilling and Production Platforms" (Ref. 21).

This JIS was under the auspices of the Floating Systems Criteria Subcommittee of the API with 17 sponsors. The risk of mooring failure component of this study involved the analysis of 261 mooring related incidents from which it was concluded that the among the causes of component failure the following was the order of likelihood:

- Chain break 55%
- Wire break 28%
- Dragged anchors 13%.

It was also stated that due to the wider use of chain mooring systems compared to wire mooring systems, the probability of breaking chain or wire mooring lines is approximately equal.

In 1996 the API published the second edition of API RP2SK Design and Analysis of Stationkeeping for Floating Structures. This document does not contain any specific wave heights and wind speeds but does refer to a criteria based on appropriate return periods. There is, however, a significant difference in the "return period storm" values hindcast by those professionals who regularly provide information for the industry. Additionally the meaning of the terms "away from" and "in the vicinity of" other structures is not well-defined in the API recommended practice where it specifies:

- Operations away from other structures – 5 year return period

- Operations in the vicinity of other structures – 10 year return period

There is a new edition of API due to be published in early 2005, however, the same provisions are understood to exist for mobile offshore drilling units in the new document. The general philosophy has been that mobile offshore drilling rigs have equipment, which necessarily must be light enough to be moved with the rig from place to place (the normal operation). Using higher strength moorings of similar weight has traditionally led to a less reliable mooring because of component material issues. Heavier moorings would decrease payload significantly and result in much less economical operation. To date, mooring failure has not become an issue since there have been only two collisions resulting from the breakaways to date. In view of the recent incidents in Hurricane Lili, it may be appropriate for the API Committee to review the information provided herein and from its members and re-evaluate the criteria that is appropriate for moorings of MODUs.

In 1990 the MMS Study on Hurricane Andrew (Ref 2), discussed in more detail in a following section of this report, reported information on two semisubmersibles – the Zapata Saratoga – and the Zane Barnes, both of which broke their moorings in Hurricane Andrew and drifted to the beach. The Zapata Saratoga made its way to the beach without incident, and the Zane Barnes impacted two small platforms on the way to shore. The Report following Hurricane Andrew examined the issue of whether there were safe stacking locations for semi-submersibles where, given a hurricane, and a breakaway, they would not impact the Gulf of Mexico offshore infrastructure. The conclusions included the following (Ref. 2):

- *Historically, semi-submersibles lack of exposure to hurricanes is the principal factor contributing to the small number of mooring failures.*

- *Given the assumption a mooring failure will occur, safe stacking locations are minimal due to the density of platforms in the Gulf. In general, a unit would have to be moored:*
  1. *Approximately 115 miles offshore in the Central Gulf region.*
  2. *In isolated areas such as off West Florida or East Texas.*
- *Vital structures in the Gulf should be designated that should a collision occur, severe environmental or financial risk would result. This would enable future risk studies that examine specific mooring locations to do so with greater precision.*

After Hurricane Andrew a further study was commissioned (Ref. 25) on the development of a computer program, which accepted rig-specific parameters, site-specific parameters and using a Monte-Carlo simulation predicted the likely breakaway in a specified hurricane, the path that the rig would take and the various collision scenarios. Specifically, the objective was to develop an analytical model to evaluate MODUs movements in response to the combined load effect due to hurricane winds, waves and currents and then use a Monte-Carlo simulation process to evaluate the probability of collision between the MODU and large facilities.

As part of the continuing interest in semi-submersible mooring systems by the UK Regulators, a recent study was commissioned in 2004 on the Design and Integrity Management of Mobile Installation Moorings (Ref. 26). In this report the design of semi-submersible moorings that operate in the UKCS were assessed against Codes, which are continually being modified and updated. The report reviews and compares current documents put forward by Class and Regulatory Bodies and provides guidance on individual features common to each of the Codes considered. Connecting links come under close scrutiny since many instances of line failure can be attributable to these items of equipment.

7.0 SEMI-SUBMERSIBLE MODUS: HURRICANE ANDREW

In September 1992, hurricane Andrew swept through the eastern portion of the Gulf of Mexico. Hurricane Andrew caused more damage to offshore structures than any other hurricane in history, but it was not this alone that has caused the concern. In most of the previous hurricanes responsible for extensive damage, individual platforms had failed, but there had never been the level of interaction between failures that there was during hurricane Andrew. In Andrew, there were platforms knocked over by drifting Mobile Offshore Drilling Units (MODUs), pipelines being moved by wave action, and possibly damaging attached structures; pipelines moved by MODUs dragging the seafloor as they drifted around; and major oil distribution systems threatened by floating equipment. One of the major areas of concern was that semi-submersibles were breaking adrift more readily than had been anticipated by the regulators, and industry. The number of semi-submersible failures relative to other types of MODUs during Hurricane Andrew is shown below in Table 10. The problem was not confined to the older units where the expectation of performance may have changed with time, but it was the new designs that were responsible for much of the damage and threats (Ref. 2).

Table 10: MODU Failures in Hurricane Andrew

Rig Type	In Gulf	Exposed	Moved
Jackups	91	28	1
Semi-submersibles	10	8	3
Submersibles	10	8	2

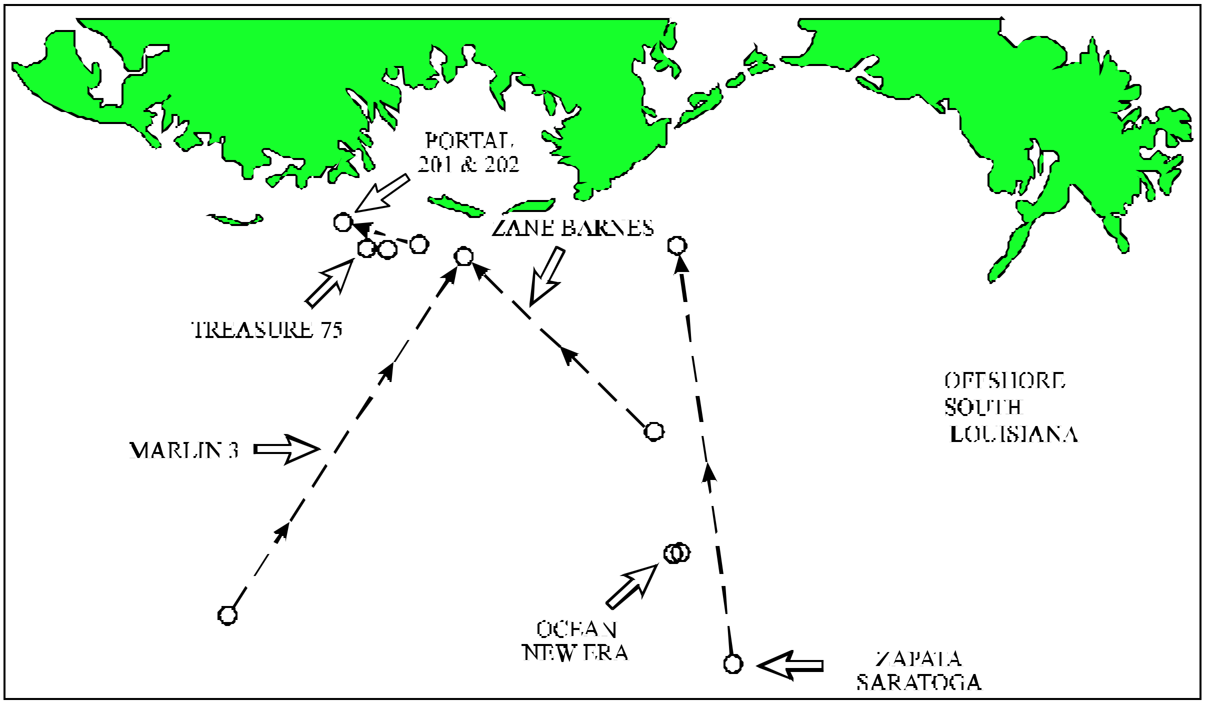
After Hurricane Andrew, MMS commissioned a study to evaluate the effects of the hurricanes, on semi-submersibles and this was reported in: "Evaluation of Securing Procedures for Mobile Offshore Drilling Units when Threatened by Hurricanes" MMS Report on Hurricane Andrew, 1992 (Ref. 2). As part of the study, past hurricanes of category 3 and above contained in the list in Table 11 were investigated with respect to the proximity of the path to semi-submersible positions. According to the Report, since 1964, only three hurricanes: Hilda '64, Elena '85, and Andrew '92, passed within 50 miles of any semi-submersible positions. In each of these hurricanes, storm induced failures resulted in semi-submersible MODUs becoming adrift. Since that time, only Hurricane Georges of September 1998 would come into the same category for investigation and, to our knowledge, no semi-submersibles were exposed or broke adrift, in that storm.

Table 11: Hurricanes Evaluated in Study

Name	Date	Cat
Hilda	Sept 1964	4
Betsy	Sept 1965	4
Camille	Aug 1969	5
Celia	Aug 1970	3
Edith	Sept 1971	5
Carmen	Aug 1974	4
Eloise	Sept 1975	3
Frederic	Sept 1979	4
Allen	Aug 1980	5
Alecia	Aug 1983	3
Elena	Sept 1985	3
Andrew	Aug 1992	4

In hurricane Andrew, three semisubmersible MODUs both experienced damage and inflicted significant damage on surrounding facilities. The Zane Barnes, Zapata Saratoga, and Treasure 75 all moved very significant distance during hurricane Andrew. The storm snapped seven of the semi-submersible drilling unit Saratoga's eight anchor chains and drove the unit some 40 miles to the north. The Zane Barnes broke loose from its eight anchors, drifted northwest some 30 miles, colliding with two platforms and allegedly several pipelines. Treasure 75, was ballasted on the seafloor with four anchors deployed prior to Andrew. By the time Andrew had passed, she had dragged along the bottom for approximately 4 miles and ruptured a large Texaco pipeline spilling 2000 BBL of oil. (Ref. 2). This incident was one of the worst spills during Andrew. The LOOP (Louisiana Offshore Oil Port) 36-inch diameter pipeline narrowly missed being snagged by the dragging anchors of one of these MODUs.

Figure 15 MODU Movement During Hurricane Andrew



The main conclusions of the Hurricane Andrew Report are repeated below for perspective:

- *Historically, semi-submersibles lack of exposure to hurricanes is the principal factor contributing to the small number of mooring failures in the Gulf of Mexico. With a greater exposure, there would almost certainly be a significant increase in the number of vessels that break loose, and a consequential increase in the number of structures damaged by the drifting semi-submersibles.*

- *A small amount of anchor drag can be beneficial in preventing mooring line breakage by allowing some redistribution of line loads, but it can be difficult to accurately predict when slippage will occur, especially given the variety of soil conditions that there are in the Gulf of Mexico. In some cases, the holding capacity of the anchors can be much more than would normally be expected using standard published data. The assumption of slippage, in the analysis, can then become dangerously un-conservative. Conversely, if there is too much slippage, then the unit can drift a significant distance and potentially damage other structures and/or pipelines.*

- *Mooring line failures can occur at tensions far below the catalog break strength of the mooring line. In chain, this may be due to either* *manufacturing deflects or handling damage; in wire it is normally due to age and handling. It is important to note that CBS for chain is the Catalog Break Strength, and NOT the Certified Break Strength. All chain is tested to a proof load of 70% CBS, but only 1% is tested to CBS, and some failures are allowed without rejecting the chain.*

- *Semi-submersibles can, and have, broken loose in winter storms, so hurricanes are not the only threat. The concern about winter storms is increased because there is a chance that the rig crew may not disconnect their riser quickly enough, thereby running the risk of pulling the BOP off the seabed, leaving an open hole and causing a major blowout. Indeed, the "OCEAN TRAVELER" did pull the BOP off the seabed in the 1983 winter storm in the Gulf, and the same thing has happened at least twice in the North Sea, although fortunately none of these incidents has led to a blowout.*

- *A working maintenance and inspection program is vital to preventing mooring line failures.*

Additionally it was noted that there is a serious issue of a shortage of full-scale data to verify the accuracy of the calculation methods.

Some of the recommendations are also noted:

- *If anchor drag is assumed in the mooring analysis procedure (API) to mitigate consequence of damage, further research is required to develop techniques that predict the ultimate holding capacity of anchors. More information than is presently now supplied, particularly with respect to the soils, needs to be known about the proposed operation site prior to mooring a unit in order to determine this capacity.*

- *There is a need to instrument some semi-submersibles in order to benchmark the mooring analysis assumptions and methodology. Instrumentation of FPSs currently in use in the Gulf of Mexico presents an excellent opportunity to gather this information. (Model test data is not as good as full-scale data since there are many inaccuracies associated with modelling an entire mooring system, especially with regard to second order effects).*

- *Vital structures in the Gulf of Mexico should be designated (e.g. those that would result in severer environmental or financial loss, should a collision occur). This would help facilitate future risk studies that could examine specific mooring locations with greater precision and insight.*

- *To improve future studies such as this, it is recommended that all MODU incidents and near incidents be investigated in detail so as to determine the factors contributing to the incident. This will allow the lessons learned to be shared within the industry. Also, a database should be established containing the results of these investigations to aid in calibrating industry standard practices and thus, reduce the probability of future failures.*

It appears there are many of the same fundamental issues that need to be resolved on mooring semi-submersible drilling units in the GOM during hurricane season as existed after Hurricane Andrew 1992. This will be amplified further in the conclusions to this report.

8.0 OBSERVATIONS ON SEMI-SUBMERSIBLE MODUS: FROM BOTH HURRICANE LILI AND HURRICANE ANDREW

Both in Hurricane Andrew and again in Hurricane Lili the storm that came through exceeded the present criteria for each of the semisubmersibles at their specified locations. It had been concluded from the Hurricane Andrew study that for semi-submersibles when they are within 50 miles of a severe hurricane, they have a likelihood of an incident (Ref 2).

The consequences of failure of a structure vary considerably, and as a result of the above comparison it seems likely in the passage of a 100-year storm, such as Hurricane Lili, that there will likely be major consequences to any floating MODU in the path.

From an engineering point of view, there is an important balance between designing economically viable structures and those that will withstand any storm. Had design been carried out to a higher 100-year level, the same argument would apply when a more severe storm came by, with a huge additional cost added to each and every location the unit drills in its lifetime, although, of course, the frequency of occurrence is less.

While the risk of an individual hurricane to each individual semisubmersible may be acceptable to each individual owner, the risk for MMS is based on any semisubmersible coming adrift in any hurricane to come through the Gulf of Mexico infrastructure. This risk for a Gulf of Mexico hurricane setting one of the many rigs in the Gulf of Mexico adrift is substantially higher: and thus criteria acceptable to an owner may not be acceptable to a regulator. The comparatively higher consequences of exceeding the design load, gives rise to a very different approach of dealing with Gulf of Mexico than in the rest of the world, including evacuation at the on-set of a hurricane. Likewise, as a result of further observations of behavior of MODUs in this study, and reflecting on lessons learned from Hurricane Andrew, it may be prudent for standards organizations, industry organizations such as IADC and rig owners, to reflect on the benefits from mitigation of consequences as part of their work on design criteria. This is explored further in the conclusions.

Table 12 chronicles the information on semi-submersibles near Hurricane Andrew compared to those of Hurricane Lili. API criteria are also noted. API criteria is based on the statistical chance of a severe storm occurring at a specific location in the time period specified and does not purport to protect the vessel against storms more severe. While the table clearly points to the fact that the criteria was exceeded it is interesting to note that in the case of the GSF Celtic Sea, the criteria was exceeded but not all the moorings broke- the unit stayed on location after some of the lines parted.

Table 12: Semi-Submersibles Near Hurricane Andrew Compared to those of Lili.

Rig	Type/	Size	Location	Condition	Water	Wind/Wave	Mooring System		Anchor
Name	**Generation**	**(LT)**			**Depth**	**Encountered**	**Chain**	**Wire**	**Type**
HURRICANE ANDREW									
Zane	Trendsetter	52843	Grand Isle	Stacked	167 ft	Wind = 90 kts	8 x 2000ft	9900 ft	33 kips
Barnes	4th Gen.		Blk 87			Hs = 38 ft	3 9/16" ORQ +20%	3 1/2"	Bruce F.F.
	Damage: Broke all mooring lines, drifted 30 nm						CBS 1600 kips	CBS 1400 kips	Mark III
Zapata	SS-2000	16490	Miss. Canyon	Drilling	845 ft	Wind = 98 kts	8 x 2500 ft	4500 ft	40 kips
Saratoga	2nd Gen.		Blk 705			Hs = 37 ft	2 3/4" ORQ	2 3/4"	Vicinay
	Damage: Broke 7 of 8 mooring lines, drifted 50 nm						CBS 889 kips	CBS 695 kips	Offdrill
Treasure	Unique	40313	South Pelto	Stacked	36 ft	Wind = 90 kts	8 x 6500ft	None	33 kips
No. 75	2nd Gen.		Blk 7			Hs = 28 ft	3" ORQ		Unknown
	Damage: Drifted 4 nm, dragged anchors across pipeline						CBS 1044 kips		
Ocean	Ocean N. Era	14670	Grand Isle	Drilling	255 ft	Wind = 113 kts	8 x 5200ft	None	22 kip
New Era	2nd Gen.		Blk 103			Hs = 41 ft	2 3/4" ORQ		Stevpris
	Damage: Anchors dragged 800 ft?						CBS 889 kips		
Ocean	Ocean Odessey	42842	Ship Shoal	Stacked	140 ft	Wind = 107 kts	8 x 3900ft	5600ft	22 kip
America	4th Gen.		Blk 236			Hs = 33 ft	3 1/4" ORQ+20%	3 1/2"	Bruce Mark IV
HURRICANE LILI									
Ocean	SS-2000		Ship Shoal	Drilling	250 ft	Wind = 86.7 kts	6 x 2250' 2.75" ORQ+20	6 x775 ft; 2-3/4"	6 x 40 kip Offdrill II
Lexington	2nd Gen.		Blk 300			Hs = 36.1 ft Curr. 1.9 kts	2 x 500 ft x 3.25" ORQ+	1000 ft x 3.25" 3-1/4"	2 x 15mt Bruce HHC
	Damage: Broke all mooring lines, drifted 45 nm								
GSF	F&G L-907 Enhanced		Green Canyon 562	Drilling	910 ft	Wind = 72.2 kts Hs = 36 ft Curr. 2.1 kts	4500 ft 3" chain;	10,000 ft 3.5" wire	14.7 ton Stevpris anchors
Celtic Sea	Damage: Broke mooring 6 of 8 lines, stayed on loc'n								
	API – Approx 10 year Return (Ref 2)					Wind = 72 kts	Sig. Wave = 30 ft		
	API- Approx 10 year Return (Ref 13) Hurricane High					Wind = 68 kts	Sig. Wave = 26 ft		

9.0 JACKUP MODUS: HURRICANE LILI

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. About one-third of the world's jackup fleet resides in the U.S. Gulf of Mexico and if Mexico is included in the statistics about 40% of the worldwide fleet is in the hurricane-prone waters of the Gulf of Mexico. The next most populous regions are S.E. Asia and the North Sea where www.rigzone.com chronicles about 8% in each location.

Structures are designed in-general for a specific return period storm. The premise is that the design storm will impact the rig once in the given return period. When a hurricane of the intensity of Lili, which exceeds the normal design parameters industry selects for the MODUs, comes into the Gulf of Mexico, the expected outcome is that there will be failure of those MODUs close to the hurricane path. Such a hurricane is not expected to return to that location, at that intensity, except at the frequency of once in the given return period.

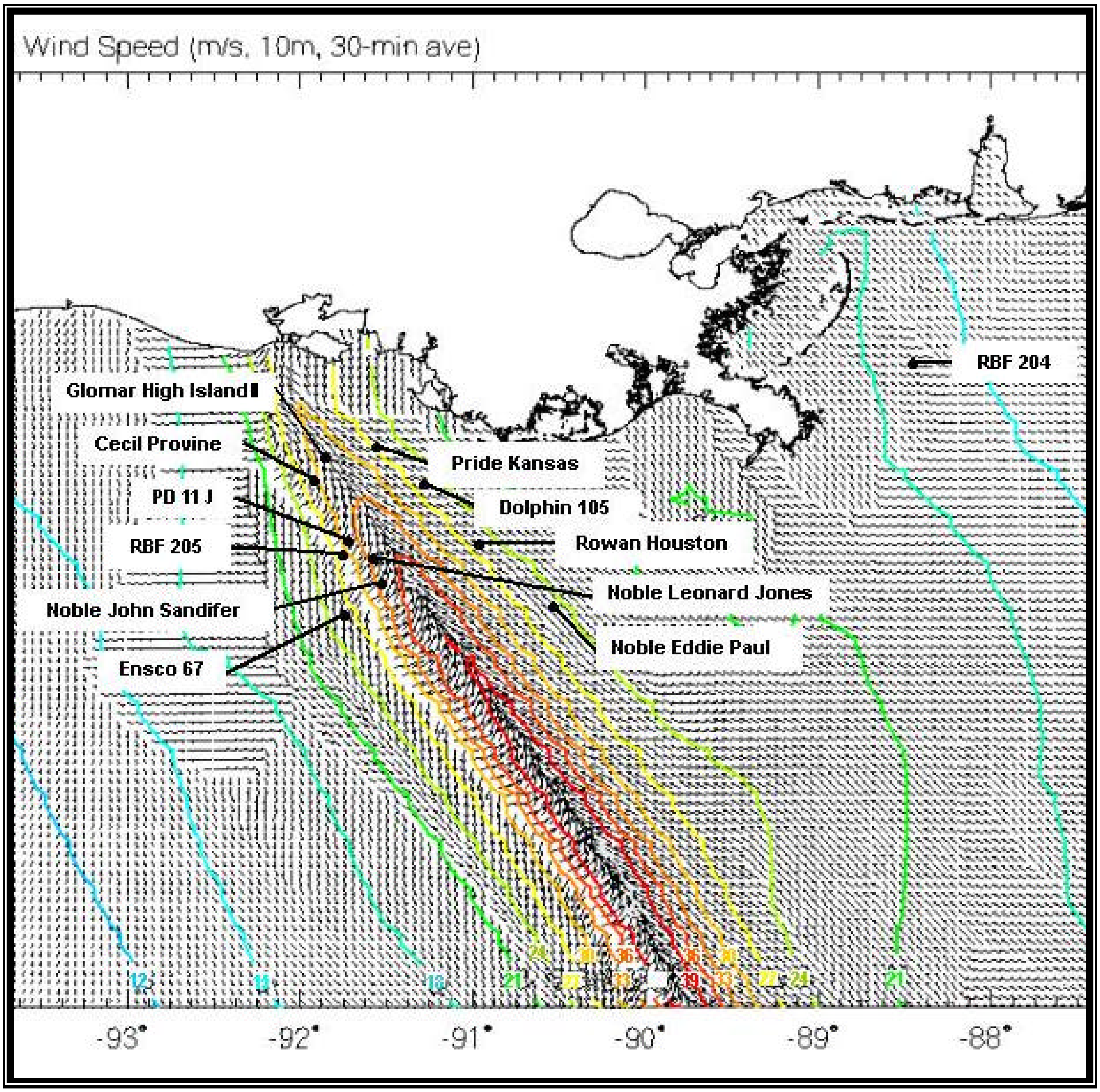
Unlike areas such as the North Sea where the 1000-year return storm is only a small amount higher than a 100-year return storm: this is not true of hurricane prone regions where the differences between 100-year return storm and 1000-year return storm are substantial. Clearly the rule-of-thumb varies with the storm and the situation, but if a jackup is in the path within a 35 east to 50-mile west distance, of a hurricane of the magnitude of Hurricane Lili it is likely to have a high chance of being adversely impacted. Because of the early warning contingency plans and the evacuation of personnel, there has been no multiple loss of life, no significant pollution events. Very few jackups have been lost as a result of hurricane weather exceeding the design conditions. There have been situations where the hurricane has toppled a rig, which had been placed on location without proper pre-load, for example, but none where the design loads had been exceeded. Indeed, the Nabors rig, which failed in Hurricane Lili, is rather unique because of this.

While the 10-year hurricane event has been generally used as a "design" condition (Ref. 7 and Ref. 12) for jackups, recently SNAME sponsored Gulf of Mexico Annex Committee with funding by a few drilling contractors has been developing a more rational criteria. The criteria is based on ensuring that jackup designs can structurally withstand events likely to occur prior to evacuation, to ensure safety of personnel during a reasonable evacuation period after tropical storm is declared. Recommendations from the work of this committee will be shared with industry in the near future. It is anticipated that this will not significantly change the waterdepths, which jackups operate in, but it will rationalize the criteria to provide a method for siting a jackup with an evacuation plan, for a sudden hurricane. It will not have an outcome that changes the probability of failure of the jackup, after evacuation, which is considered an "economic" decision.

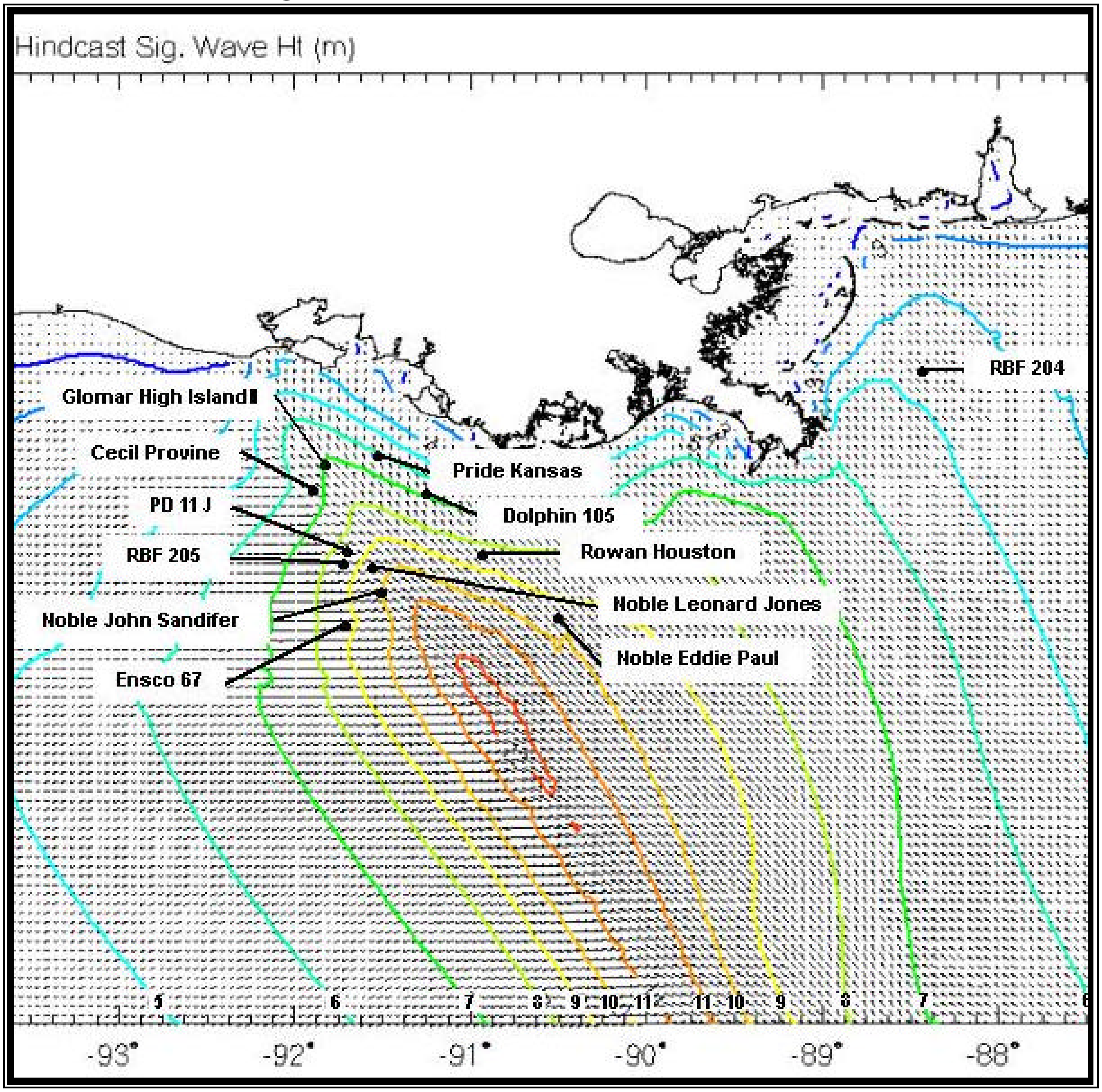
At the time of Hurricane Lili there were approximately 142 jackups and 39 semi-submersibles in the Gulf of Mexico. Of those only 6 -7 jackups and 2 semi-submersibles were effectively impacted by Hurricane Lili, and only 3 with significant events. A variety of sources were used to identify potential rigs that had been impacted by the hurricane. Most of the information was directly from drilling contractors involved and from the MMS files.

Figure 16: Rig Locations Related to Storm (Base Maps by Oceanweather- Ref. 1)

16 a. Wind Speed



16 b. Wave Height



The jackups affected by Hurricane Lili are chronicled in the following section:

Table 13: Jackup Rigs Affected by Hurricane Lili

Name	Date
Dolphin 105	Rig broke up at location. Hull drifted a short distance and sank. Mat turned over and buoyancy caused part to be above water.
Rowan Houston	Collapsed on Location. Legs remained at the location. Hull drifted a short distance and sank. Debris from structure derrick and part of leg around location and may have impacted a small in-field flowline.
Eddie Paul	Reported to have moved in storm a few feet and rotated slightly.
Leonard Jones	Slight increase in penetration one leg
John Sandifer	Bow Leg increased penetration to move the rig to a 2.8 degree tilt.
Ensco 67	Slight settlement

The information on location, details of jackup MODUs, and the derived wave heights, wind speeds and currents from Oceanweather's data is shown in Table 14.

Table 14 chronicles, names, locations, builders, age, oil company, the design waterdepth, and the likely capability compared to the interpolated data from Oceanweather's information. Thus for the Dolphin 105, working for BP in Ship Shoal 126 #B2, it had been designed to something like a 100 ft maximum waterdepth where the design wave eight was 43 ft together with an assumed surface current of 1.5 knots. The Oceanweather's interpolated wind speed was 65 kts, the wave height 43.3 ft and the current 4.3 ft. In the lesser waterdepth of 35 ft, it is not obvious just by inspection that this was overloaded by very much, and thus it is important to look for further contributors to the incident.

Likewise for the Noble Eddie Paul the design was for 50 ft waves and 100 kt winds but the hindcast wave was 61 ft which is quite a significant increase, however the waterdepth the rig is capable is 390 ft and thus it was not near the limitations of the legs. The judgement is that it was highly loaded but would not have been expected to exceed its limit.

Table 14: Jackups Exposed to Hurricane Lili

Operator	Rigname	Design	Builder	Year Built	Oil Company	Capable Water Depth (ft)	Location	Actual Water Depth	Likely Capability	Max. Wind Speed 1-min (kts)	Current (kts)	Max. Hindcast Max. Wave Ht. (ft)
Nabors	Dolphin 105	Penn Engineering 4-leg	Gonzales Marine, Miss.	1982	BP	100	Ship Shoal 126 #B2	35	100 ft @ 43' waves 1.5 kt current	65.0	4.30	43.3
Noble Drilling Corp	Noble John Sandifer	Levingston 111-C	Levingston	1975	Devon Energy (Sept)	300	Eugene Island 305	226 -56 ft Pen	100 kts wind, 60 ft seas, 1 kt current	81.9	2.20	59.2
Noble Drilling Corp	Noble Leonard Jones	Letourneau 53-C	Marathon Vicsburg	1972	BP	390	Eugene Island Blk 273	184 - 70 ft Pen	100 kt winds, 45 ft waves, 25 ft pen	80.7	2.20	56.8
Transocean	RBF 205	Bethlehem JU-200 MC	Bethlehem Beaumont	1979	Energy Partners	200	Eugene Island Blk 247	158	Typ 108 kt winds, 45 ft waves, 1 kt current	68.6		50.6
Transocean	RBF 204	Bethlehem JU-200 MC	Bethlehem Beaumont	1979	Llog Exploration	200	Main Pass 207	52	Typ 108 kt winds, 45 ft waves, 1 kt current	39.7		28.7
Parker Drilling	PD 11 J	Bethlehem 200 MC	Bethlehem	1980	Stone Energy	200	Euguene Island 243	185	Typ 108 kt winds, 45 ft waves, 1 kt current	74.7		50.0
Rowan	Cecil Provine	LeTourneau 116-C	Marathon Vickburg	1982	Remington O & G	300	South Marsh Is Blk 24	80	In 150 ft w.d. 52 ft waves, 100 kt wind, 1 knt current 50 ft Airgap 15 ft leg pen	69.8		40.3
Global Santa Fe	Glomar High Island II	LeTourneau 82-SD-C	Davie Shipbuilding	1979	Chevron Texaco	270	South Marsh Isl Blk 288 #CB-5ST	60		74.7		42.7
Ensco International	ENSCO 67	LeTourneau 116-C	Marathon Vicksburg	1982	Hunt Oil	350	Eugene Island Blk 355 #2	286	In 150 ft w.d. 52 ft waves, 100 kt wind, 1 knt current 50 ft Airgap 15 ft leg pen	63.8		52.5
Pride	Pride Kansas	Bethlehem JU-250 MC	Bethlehem Spore	1976	Ocean Energy	250	Eugene Island Blk 108	25	Typ 108 kt winds, 45 ft waves, 1 kt current	63.8		36.6
Rowan	Rowan Houston	Letourneau 52-S Hull #48	Marathon	1969	Anadarko	250	Ship Shoal 207	105	Overloaded by an approximate factor of 1.5-2	70.0	1.64	50.6
Noble Drilling Corp	Noble Eddie Paul	Letourneau 84-C ex Penrod 66	Marathon	1975	Apache	390	South Timbalier 295 #B-6	283 - 105 ft Pen	Typ. 50 ft waves, 100 kt wind, 1 knt current	60.2		61.0
									10- Yr API @ min. evacuated	72.0		45-56

NABORS DOLPHIN 105 MAT SUPPORTED JACKUP

This mat supported 4-legged Penn Engineering designed rig was found with the mat floating upside down piercing the ocean surface and the hull sunk some distance from the location. There was not sufficient information to determine the sequence of events from observed logs. The rig was within 15 miles of the central path of the storm in the quadrant producing the worst waves and winds. The design conditions were for a 43 ft wave, 100 kt winds with a 1.5 kt surface current. Although the design would likely have been exceeded by some hindcast wind and wave, the location in Hurricane Lili was subject to breaking waves of 43.3 ft which would have vastly increased the expected loads. The combination of this together with a 4.3 kt current hindcast by Oceanweather would have caused the rig to be well beyond its design capability. Additionally the wave crest elevation would most likely have impacted the hull.

Figure 17: Nabors Dolphin 105 on location working at a fixed platform.

The general arrangement of the jackup is shown in the diagram following:

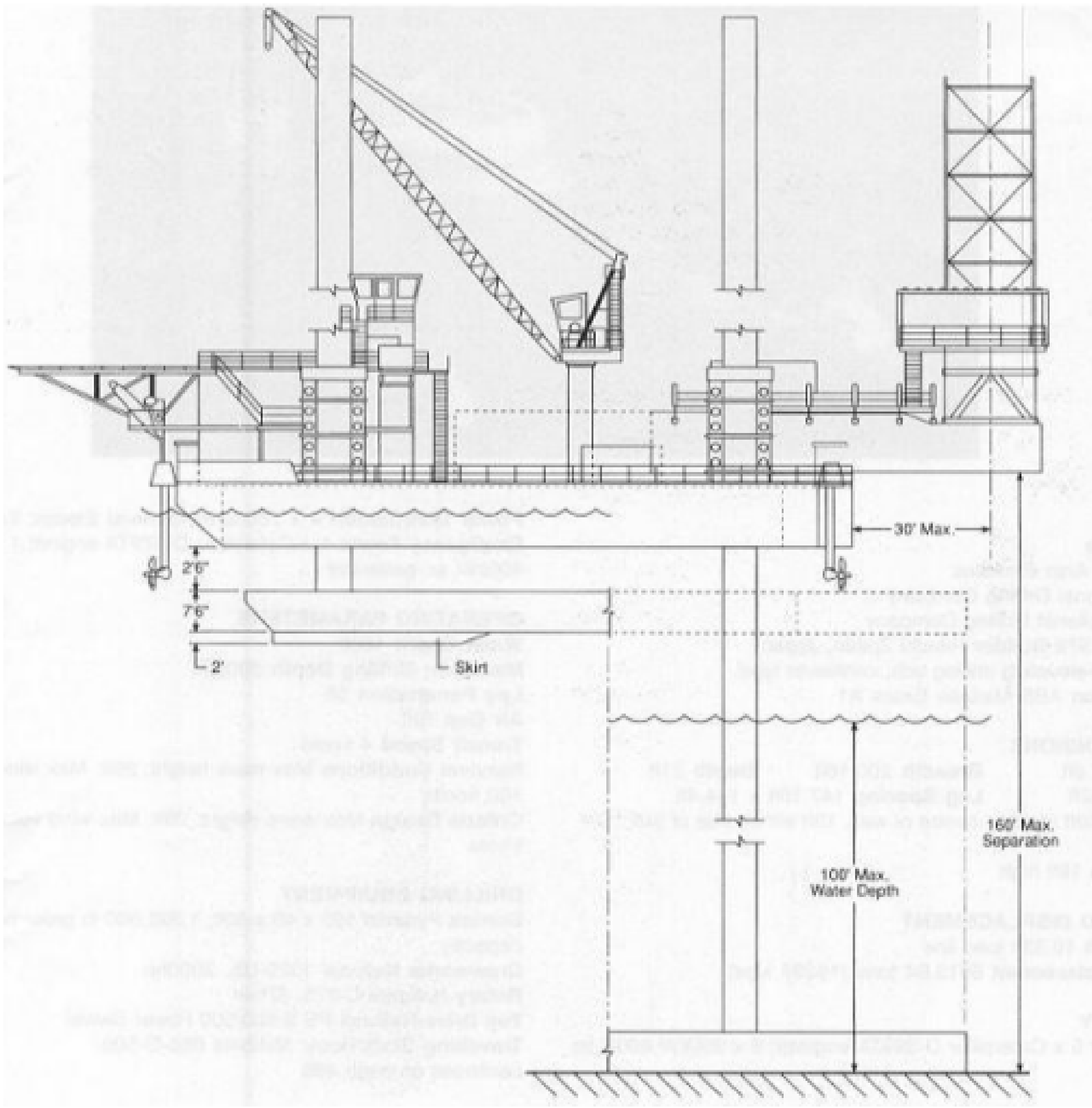


Figure 18: General Arrangement of Dolphin 105

The arrangements at location were as follows using the arrangements compared to the design conditions for comparison purposes.

Table 14: Location Arrangements of Dolphin 105

Item	Design	Ship Shoal 126
Water Depth	100 ft	35 ft
Wave Height	43 ft	43.3 ft
Wave Type	Normal	Breaking
Wind Speed	100 kts	65 kts
Current	1.5 kts	4.3 kts
Soil Type	Gulf of Mexico	Sand overlying soft clay

The rig capsized in about 35 feet of water during Hurricane Lili on 2 October in Ship Shoal Block 126, south of Morgan City, Louisiana. All personnel had been evacuated ahead of the storm. The Dolphin 105 was under contract to BP at the time of the accident. Nabors Offshore awarded wreck removal to specialists Bisso Marine a salvage contractor to remove the rig.

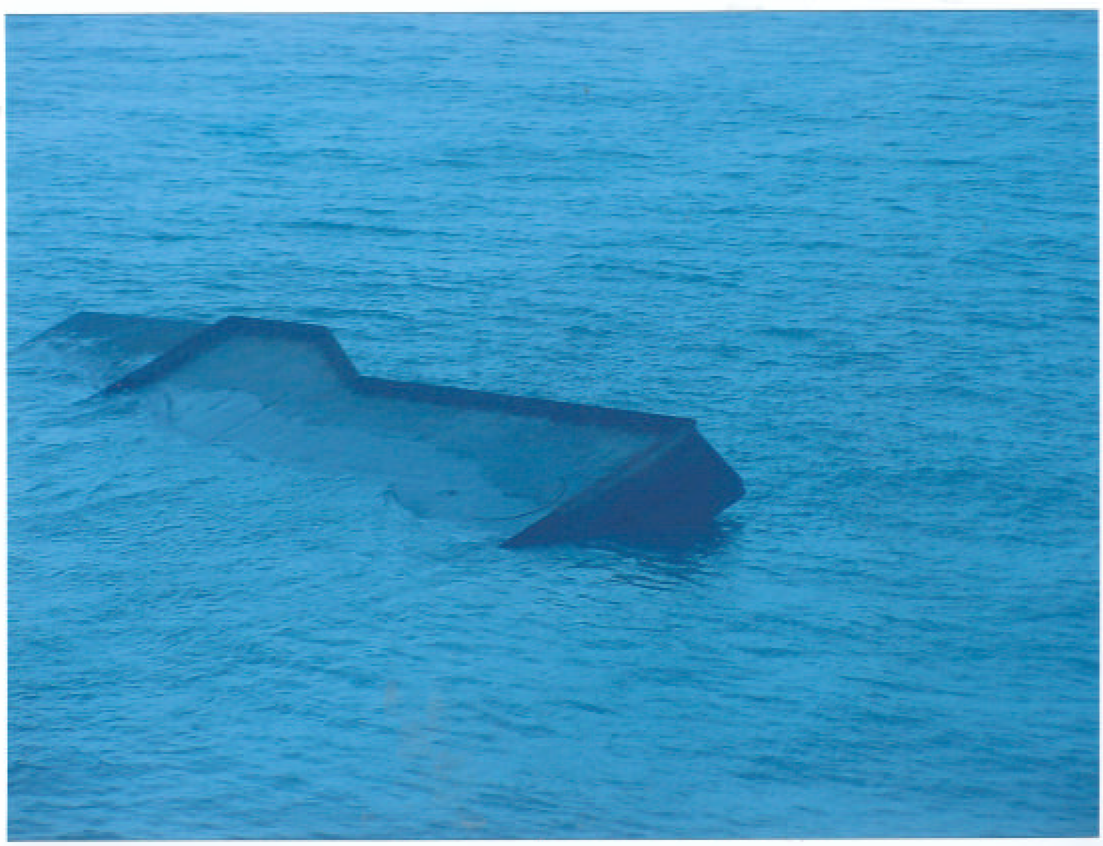


Figure 19: Mat of Dolphin 105 showing skirts protruding upward: indicating mat is upside down

The following are the general dimensions of the unit:

Length 120 ft
Breadth 92 ft
Depth 11 ft
Legs 4 x 183 ft long x 6 ft diameter
Cantilever Substructure: 26 ft clear, including cantilever beams
Maximum separation: 160 ft from mudline to bottom of cantilever
Mat: 128 ft x 128/144 ft wide bow/stern x 7.5 ft deep, 20 in. skirt

Capacities:
Variable Deck Load 1000 kips
Cantilever load 600,000 lb hook load at 30 ft off stern; capable of skid-off
Liquid Mud 400 bbls
Sacks 1500 sacs
Potable Water 710 bbls
Freshwater: 467 bbls
Bulk Mud 1310 ft^3 (1500 sacks)
Accommodation 30 berths + 3 berth sickbay.

The Report of owners is included:

Background:

Just prior to Hurricane Lili entering the northern Gulf of Mexico, the DOLPHIN 105 was temporarily moved from a well workover operation at nearby BP Well B-1 at Ship Shoal Block 126 to 28-49' N / 091-15' W, an area of "open water" approximately 1500 feet to the NNE of the B-1 well in approximately 35 feet of water. The rig was left bottom-bearing with the bow of the rectangular, barge-shaped upper hull oriented towards the north. The MODU was prepared for evacuation in accordance with its Marine Operating Manual and the approved Emergency Evacuation Plan (EEP). The drilling cantilever was skidded in to the stowed position and all loose gear secured or stowed. The rig was elevated to a 40' air gap and all personnel evacuated to shore.

On the morning of October 4, 2002, a fixed wing aircraft contracted by BP reported what appeared to be the wreckage of the DOLPHIN 105 broken into two widely separated sections. A later aerial survey confirmed the rig was broken into two major sections with the upper hull overturned and almost completely submerged near the rig's last secured position and the lower hull (mat) overturned and partially submerged approximately 1500 yards to the NNE of the upper hull.

The MODU was considered a total constructive loss by the various claim adjusters. The initial damage assessment by the salvage divers reported the mat was mostly intact with multiple minor insets and punctures throughout the *mat top. The four legs had been snapped off at various heights; one of the remaining leg sections was helping to hold the port side of the mat above the water. The upper hull was found to be partially buried in the sand/silt with only a small portion (approx. 5 %) of the hull visible above the water. Although underwater visibility was almost nil, the divers determined the upper hull to be broken into several large sections, some of which were loosely held together by the remaining intact steel plating. This was later confirmed during the wreckage removal phase when the sections were recovered with the salvage crane. A contracted seismic survey conducted in the days immediately following the capsizing showed a readily identifiable path or trench leading directly from the upper hull wreckage resting spot to the mat final resting spot. This bottom "scar" is consistent with the mat being swept or dragged by the hurricane's increased wind and seas.*

The weather data and hurricane tracking models developed by the National Weather Service indicate that Lili was most probably still a high Category 3 when its eye passed approximately 7 miles to the west of Ship Shoal Block 126 before rapidly diminishing just before hitting shore. Reports of sustained winds and combined tide/wave height in excess of 110 knots and 45 feet, respectively, were recorded just offshore of the rig's secured position. Any one of these conditions would have been in excess of the rig's severe storm design limitations.

The consensus of the independent marine surveyors and insurance investigators is that the DOLPHIN 105 was subjected to multiple extreme environmental conditions, each significantly above the vessel's severe storm design limitations. The severity of the damage to the upper hull is indicative of a vessel that was virtually lifted up and "body slammed" on the seabed rather than being merely toppled over by high seas and/or waves. The speculation is that most of the legs were broken during the initial capsizing and that the mat, along with the broken leg stubs, worked against the upper hull bottom until it finally broke free and was swept away.

The following is the location specific information on the rig:

Table 15 Dolphin 105 Rig Specific Information

Item	Design	Oceanroutes	Owner Analysis
Waterdepth (ft)	100	35	35
Wave Height (ft)	43	43.3	45
Wind Velocity (kts)	100	65	110
Current (kts)	1.5 (surface)	Not Determined	
Air Gap (kts)	40	Not Determined	40

It seems based on the report's description of how "broken" the rig was, that it is fairly likely that the hull was picked up by the waves i.e. the wave impacted the hull. It is appropriate to re-examine the airgap used, in view of this.

API RP2A Fig 17.6.2-2b (Figure 20) recommends a minimum deck height for fixed structures as approximately 40 ft for this water depth – the Dolphin 105 was within this recommendation.

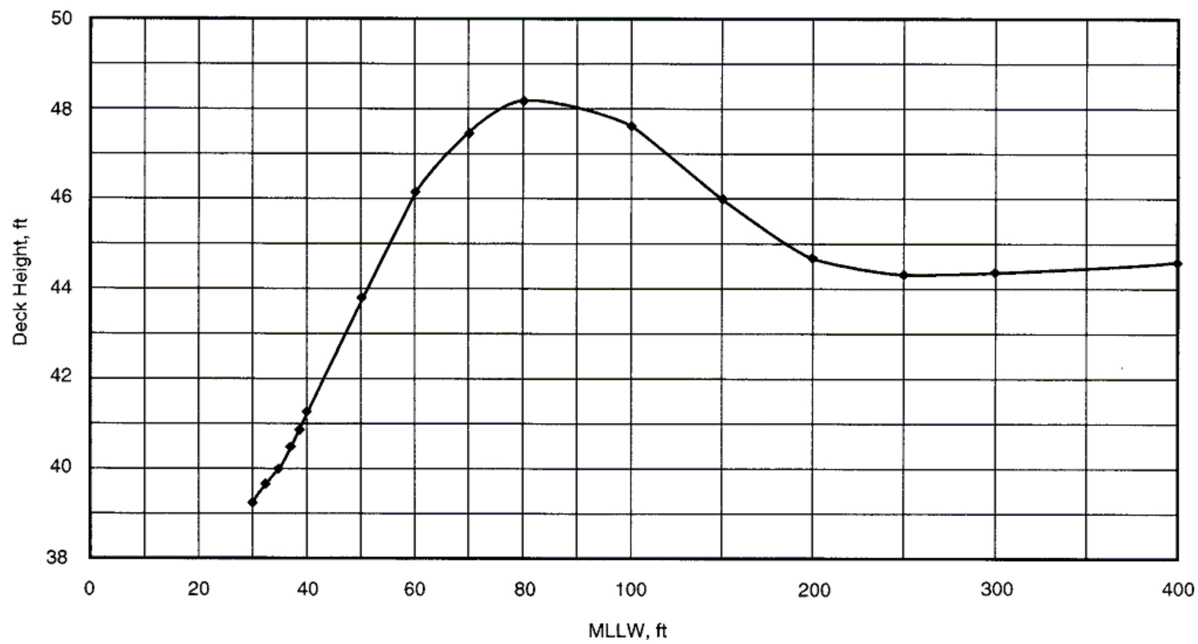


Figure 17.6.2-2b—Full Population Hurricane Deck Height Criteria

Figure 20: API Section 17 – Full Population Hurricane Deck Height Criteria

Historical A.H. Glenn hindcast data indicates typically 80% of the wave is in the crest elevation above still waterdepth for a breaking wave in similar waterdepths. A typical arrangement at location, assuming the wave heights applicable from Oceanweather is as follows:

Table 16: Calculation of Recommended Air Gap

Item	**Measure**
Highest Astronomical Tide	2.5 ft
Storm Surge	9.8 ft
Total Tide	**12.3 ft**
Crest Elevation above Still Water Line 80% of Wave Ht	34.6 ft
10% for wave runup	4.7 ft
Recommended Air Gap	**51.6 ft**

While the wave conditions in the hurricane exceeded the design conditions of the rig, very marginally (based on Oceanweather data) even so, one would not normally have expected a collapse for that reason alone. The calculations methods are relatively conservative and the general expectation is, that survival will exceed design by a comfortable margin. Review of the information leads to the conclusion that the rig was at the appropriate air gap as recommended by API RP 2A for the deck height of a fixed platform. Upon hindsight, had the owner jacked the rig to a 47-52 ft airgap then the outcome might have been that the rig survived. This figure is higher than the highest value given in the API chart (Figure 20). It is interesting to postulate the specific mechanism of collapse. The MODU was capable of a greater water depth; the rig might have slid as mat rigs often do in storms, penetrated one end and then been at an angle to the oncoming storm. With or without the sliding, the MODU would be unlikely to be able to withstand any substantial wave impact with the hull. Whether it slid sideways before the wave impacted the deck or afterwards is impossible to say.

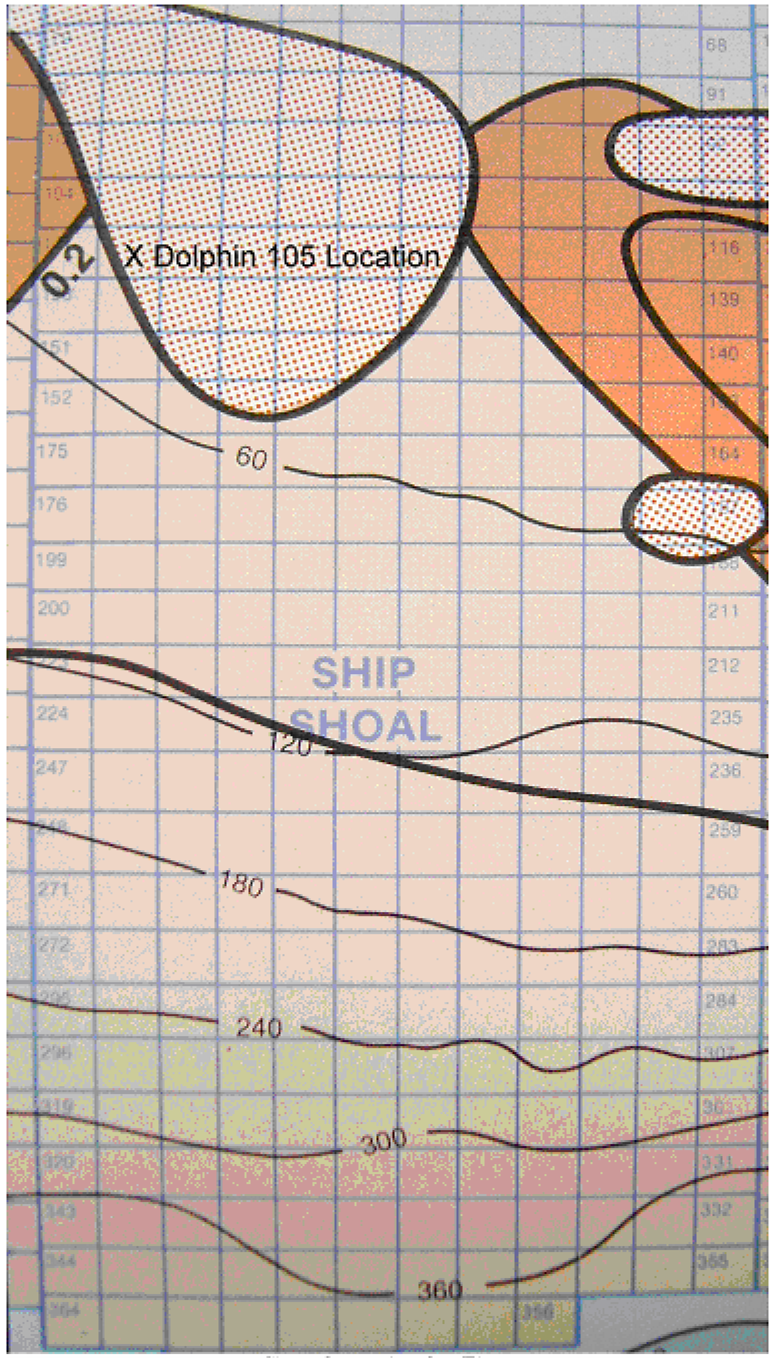
If such a rig is located, as this one, in the future, it would be recommended that the owner and designer consider a minimum 50 ft + airgap (which is above that recommended by API).

While the analysis above indicates the importance of determining the crest elevation at the site specific location, and an increase in airgap would have been an important factor in increasing the probability of survival, as will be seen further on in this analysis. It is believed that the result would have been the same: the additional loads caused by a breaking wave dramatically increase the horizontal forces on the unit and this is unlikely to have been considered in the design.

Information was obtained from a generalized Gulf of Mexico soils study, which is well outdated, but nonetheless indicates the general nature of the seafloor in the area. It was the only information that appeared to be available for this location.

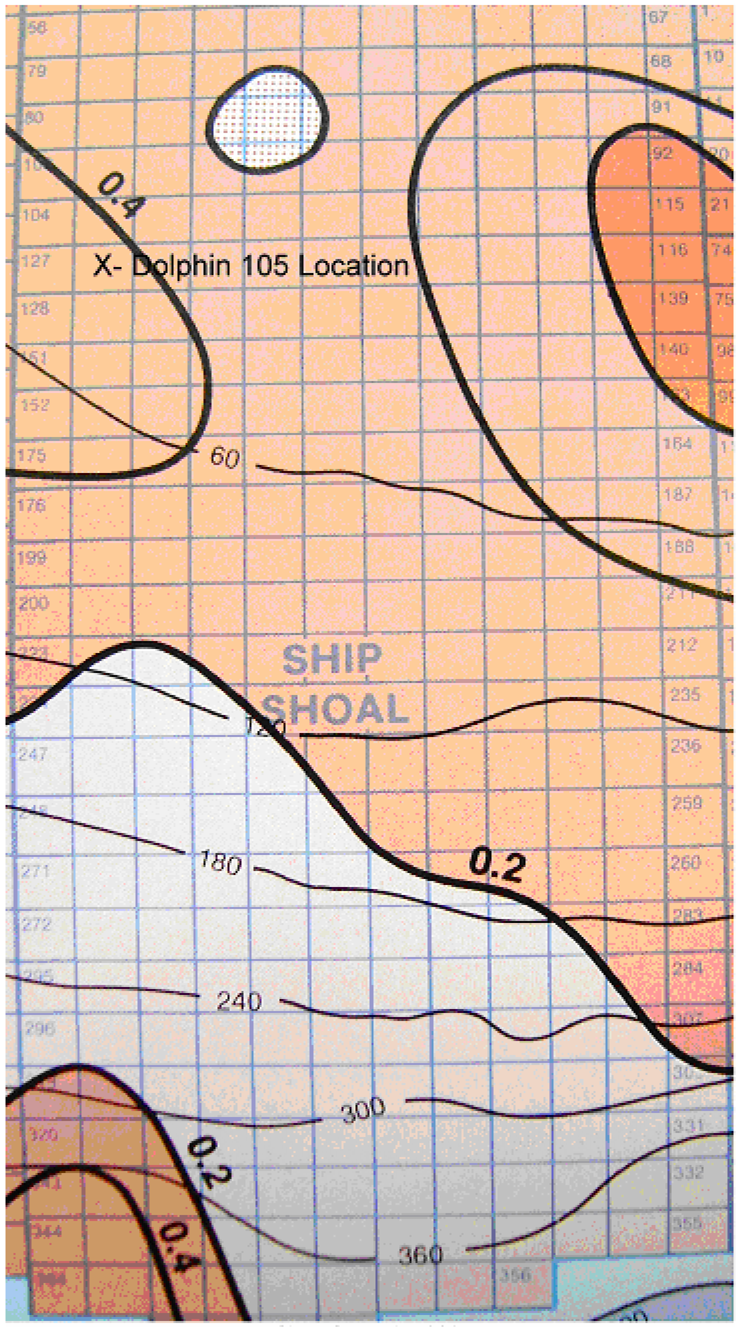
The soil shear strength at the seafloor is shown below. The location is granular material overlying very soft clay. At 10' depth the soil has a cohesive strength of 0.2 ksf and at a depth of 20 ft it has a strength of 0.4 ksf as shown in the diagram below. What is not known is how deep the granular layer is: all we know is that by the 10 ft depth the soils at the location are mapped as soft clay.

Figure 21: Soil Shear Strength at Dolphin 105 Location



Shear Strength – Sea Floor

Figure 22: Soil Shear Strength at Dolphin 105 Location



Shear Strength – 20ft

The propensity of the rig is to slide on the granular soils. It is most likely this would be exacerbated by potential scour from the breaking wave.

Calculations show that based on a 43.3 ft wave height, and a 40 ft water depth this is beyond the breaking wave index (Ref. 13, Section 8-10). Further calculations reveal that the breaking wave index, based on wave height and waterdepth parameters is independent of wave period. The additional load from current would effectively increase the celerity of the waves beyond those envisioned in the design.

Further comparison of approximate results compared to design shows the following:

Table 17: Comparison of Design to Breaking Wave

Item	Design	Ship Shoal 126
Wave Type	Normal	Breaking
Increased Wave Load above Design	1.0	4.9 times
Total Horizontal Load compared to Design	1.0	3.5 times
Resistance against 250 psf assumed design loading if shear is in cohesive soil	1.0	0.3
Resistance to calculated horizontal storm load if in sandy soil	Not known	0.20

While these are rudimentary calculations it is quite apparent that the hindcast wave in the given waterdepth resulted in a breaking wave situation. The forces increase dramatically when this occurs. Calculation methods for force were carried out using recommended methods in the Shore Protection Manual (Ref. 13) as the basis of the approximations of shallow water wave forces. More sophisticated methods should be used in order to refine the numbers: however it is believed this is sufficient for the purposes of this study. The calculation of the resistance of the mat against sliding used the methodology of Ref. 8 and Ref. 9. In order to make an assumption about the penetration depth (which is unknown), a conservative value such as a conservative site-assessor might use, of 7 ft including a 20" skirt was selected. While the calculations may be rudimentary it is readily apparent that with a factor of safety of 0.2 against sliding in sandy soil and 0.3 against sliding in cohesive soil that sliding would be an expected method of failure.

The experience of mat rigs, operating in the Gulf of Mexico since 1957 has been extensive. Some 90 units have been built and operated on soft soils. Mat supported rigs have survived many hurricanes with horizontal movements occurring from time to time. For the most part the experience has been successful. The rigs have been subject to fatigue issues with the leg-mat connections, and to sliding in storms.

Table 18: Historical movements of Mat Rigs in Hurricanes.

DATE yy/mm/dd	Rig Name	Incident	Surface Shear Strength (ksf)	Shear Str. @10 ft (ksf)	Shear Str @20-40 ft
641003	STORMDRILL 1	Slid 10' sideways in Hurricane HILDA	.06-0.1	0.1	0.4-0.6
650909	STORMDRILL 1	Slid 35' sideways in Hurricane BETSY	.06-0.1	0.56	0.4-0.6
650909	STORMDRILL 2	Slid 100' sideways in Hurricane BETSY- well destroyed	0.06	0.1	0.6
690817	TRANSWORLD 50	Slid 2' in Hurricane CAMILLE	Sand	0.4	1.7
800808	SALENERGY 1	Shifted position by Hurricane ALLEN			
800808	TELEDYNE 17	Shifted position due scour in Hurricane ALLEN			
800808	J STORM 7	Skidded due scour in Hurricane ALLEN -bent drive pipes & BOP			
800810	MR GUS 2	Slid in Hurricane ALLEN			
800810	SABINE 1	Damaged substructure & wellhead in Hurricane ALLEN			
800810	FJELLDRILL	Tilted during Hurricane ALLEN - drill caisson missing-leg cracks			
800811	HARVEY WARD	Capsized & sunk after mud slide in Hurricane ALLEN: legs sheared off			
830817	APACHE	Hit by supply boat during Hurricane ALICIA. Minor damage to bow leg			
890731	RANGER 6	Soil failure (tilted 3 deg onto the well) in Hurricane CHANTAL.			
920827	OCEAN PRIDE	Small oil slick after Hurricane ANDREW at South Timbalier 63			
920827	MARLIN 3 (SS263 Prod)	Legs collapsed in Hurricane ANDREW-drifted 50 miles and grounded in 17' Water depth: lost mat			
021002	DOLPHIN 105	Rig moved off location; mat upside down; hull at a distance	Granular	0.2	0.4

Reference to the Rechtin and Steele paper (Ref. 11) indicates that the figure of 150 psf was considered typical in the early design of mat rigs. Since the soil on this location is sand overlying soil of typically 200 psf it can be expected that the sideways force may well reach down to the underlying layers, depending of course, on how thick the area of granular deposit is. All we know is that the granular deposit is no more than 10 ft.: the Fugro information (Ref. 12) does not quantify the area in between surface and 10 ft any more accurately.

As the unit started to fail, one can well imagine that the leeward edge of the mat might "dig in". With the overturning moment on the unit, a breaking wave, possibly scour occurring at the same time and tripping over the leeward edge of the mat - one could expect the hull to have been impacted by the waves. With the hull moving while now afloat, the waves would impact the hull and be expected to "yank" the mat off location and it may be this impetus that caused the mat to overturn and be found bottom up, the legs having stayed intact long enough to trip the mat. Waves impacting the hull followed by a soil failure is the most likely initiating event.

Upon hindsight it is most probable that a detailed site-specific analysis ahead of time may have predicted the fact that the Dolphin 105 may have been overloaded at this location, had the storm of this magnitude been predicted. A cursory review (i.e. not site-specific, and from generally available literature (e.g. API) of the expected waveheights in 50 ft of water, however, would have led to the conclusion that no more than a 36 ft wave would have been expected in this typical waterdepth in the Gulf of Mexico based on a 10-year return period hurricane. Extrapolation of wave heights below 50 ft would have not warned about the potential for this being a breaking wave. Without a requirement for a site specific meteorological study coupled with a specific analysis taking into account a breaking wave scenario it is unlikely that the site would have been not been approved by most site assessors. It is unlikely the Operating Manual would have reflected the need to make any specific checks when the rig was in shallow water and subject to the possibility of a breaking wave.

It is interesting to note a comment in the 1957 paper of Rechtin, Steel and Scales related to this issue (over 45 years before Hurricane Lili), an early MODU designer, was evaluating this issue:

> *Remarks by Bramlette McClelland & John Focht (President and Chief Design Engineer, respectively McClelland Engineering Inc., Soil and Foundation Consultants, Houston Texas) "Since a single soil boring may cost from 10 to 15 thousand dollars or more, many operators fail to secure adequate information on foundation conditions. The dangers of this practice should be recognized. Even though a mobile unit may be designed for very weak soil, and may appear to have satisfactory bearing stability at the time of installation, its safety is not assured. ... In this connection, the writers would like to interpret more fully the authors' statement that the analysis of borings at the proposed site "is obviously not feasible for a mobile platform". It is assumed this statement refers only to the over-all design of a mobile unit and not to the installation of the unit on location. Installing of a mobile unit without information regarding the soil conditions at the site is the equivalent, on shore, of erecting a multimillion dollar*

> *structure which was designed by an engineer who had never seen the site nor had received any report of it.*

McClelland in 1979 (Ref.12) put out a very useful soils atlas of the Gulf of Mexico. To our knowledge this has not been updated since that time.

The main conclusion from the study of the Nabors Dolphin 105 is the following:

- Under the storm hindcast conditions, the deck height used from API (*API RP2A Fig 17.6.2-2b)* would have been insufficient for this unit's expected survival: the API data is based on 100-year full population hurricanes: a higher return storm than is generally used by MODUs.

- Under the storm hindcast conditions, the loads are so much higher than design that the structure was overloaded, primarily legs at the lower guide and at the mat.

- Under the storm hindcast conditions, the rig would have been expected to slide.

While the unit was operating in shallow water, the design did not take into account a breaking wave, nor is that a customary item to be included in rig designs.

The main recommendation arising from this interpretation is that the IADC group working on jackups, and the SNAME 5-5A panel, together with the ISO panel on jackups take heed of a need to comment in their recommended practice on the suitability of rigs to operate in areas where breaking waves are expected, and to include this as a typical check of the suitability of a jackup for a location.

It is recommended that the information of deck height experience from this unit be sent to the API RP2A committee for deliberation: since it is clear that *API RP2A Fig 17.6.2-2b* can be a misleading indicator to jackup rig owners who presume that using this deck height for the airgap of their units leaves them in a position of safety.

An additional recommendation to the MMS that consideration be given to discussions between government and industry for making information available of the type published in the McClelland study:

> *Strength Characteristics of Near Seafloor Continental Shelf Deposits of North Central Gulf of Mexico: McClelland Engineers, November 1979*

so that it is generally available for those carrying out site assessments. Since soil data is proprietary to the clients – the mechanism to have such information available is not clear. Nonetheless without more detailed site specific information: this document produced in 1979 does gives helpful general guidance. An update would be a welcome addition to the tools of site assessors.

ROWAN HOUSTON

The Rowan Houston was a Marathon LeTourneau design Class 52 jackup rig, built in Vicksburg, Miss, 1969, and converted in 1995 to a cantilever-type. It had some upgrades in 1997. The rated water depth is 250' and the drilling depth was 20,000'. It had quarters for 78 persons. The hull dimensions are 203' x 168' x 22'.

Figure 23: Rowan Houston on a Gulf of Mexico Location.

Initial Reports

One of the first report concerning rigs came in on October 6, 2002.

London, Oct 6 -- A press report, dated Oct 5, states: The plane sent out by Diamond Offshore Drilling after Hurricane "Lili" passed made the dismaying discovery that there was only empty water where the drill platform Ocean Lexington had been. It immediately launched a search, but the floating rig had been blown so far that the plane had to refuel before it was found, said Lynn Charles a spokesman for the *company. The rig was finally found 45 miles to the northwest, stuck on the bottom in water about 35 feet deep. The high winds and waves had apparently pulled apart the huge steel anchor chains that held the semisubmersible rig in place, Charles said. All of the crew had long since been evacuated. Closer to the Louisiana shore, Rowan Cos. spotted pieces of its jack-up drill platform Rowan Houston around 1100 yesterday sticking out of 105 feet of water, said Bill Provine, its vice president for investor relations. The eye of the storm passed within 10 or 12 miles of the Diamond Offshore rig, and wind gusts were thought to be between 145 and 160 mph, he said. "The wave action had to be tremendous." Equipment like this is designed to take a tremendous amount of stress, he said, but a direct hit by a Category 4 storm is something else. The Hurricane lost power as it hit the colder waters closer to shore. Originally, the rig was moored in 250 feet of water about 150 miles south of Morgan City. …..The Rowan rig was capsized and sunk by Hurricane Lili. The company's other 21 rigs in the Gulf appear to be undamaged. The 32-year-old rig, which was evacuated almost two days before the storm, was working for Anadarko Petroleum in Ship Shoal Block 207. It is too early to know the extent of damage, Provine said.*

RigZone – Offshore internet page reported as follows:

Rowan Companies, Inc. reports that apparently the Rowan Houston was involved in a collision resulting in the rig sinking. The Rowan-Houston was jacked up in 105 feet of water in Ship Shoal Block 207 adjacent to a production platform when the accident occurred. On October 1, the rig was secured and evacuated for Hurricane Lili, and the hull was 63 feet above the water. On October 4, portions of the rig, including the hull, were located approximately 1,750 feet northwest of the pre-storm location. Underwater surveys conducted on October 5 and 6 confirmed that the stern of the rig's hull was resting on the bottom of the Gulf of Mexico, with the bow elevated a approximately 30 degrees. The legs, which were severed below the hull, remain elevated at the original location. The port side of the hull near the bow is severely damaged, indicating a collision had occurred.

Currently, the company is formulating a plan for wreckage removal, investigating the cause of the collision and preparing for the anticipated litigation.

At the outset it appeared, in looking at the Rowan Houston damage that there had quite possibly been a collision with either an errant ship or possibly even with the Ocean Lexington since based on original location the Ocean Lexington could have passed close by the Rowan Houston location en route to the beach. Initial survey of the Ocean Lexington ruled out a collision based on the fact that there was no damage to the hull of the Ocean Lexington, nor were there any apparent errant vessels, which were damaged, and in port for repair. Further investigation of the damaged Rowan Houston, which took some time to accomplish, eventually led to different conclusions, which were not apparent in the immediate aftermath of Hurricane Lili. Rowan acted as a prudent uninsured in pursuing all possibilities in the initial stages of the investigation: to rule out possibilities, which would have been quickly obvious, had information been there related to those potential causes.

The news reported via 18 October 2002 came in confirmed:

Although Diamond Offshore's OCEAN LEXINGTON, which was located in Ship Shoal block 300 had broken loose from its moorings, Diamond stated that the results of an ROV survey conducted shortly after the OCEAN LEXINGTON was found indicated that the semi suffered only minor damage to a pontoon and displayed no signs of damage consistent with a vessel in collision.

The Rowan Houston collapsed during the storm. The collapse was to leeward, (starboard). The rig hull drifted off and in the process the substructure slid off the hull and was found on the sea bottom. The hull then drifted off to the north and was found a short distance away. As is often the case with accidents of this type, sorting out the facts and re-constructing the accident is not that easy. While Rowan spent considerable effort to make observations to determine the cause, there are still several possibilities that present themselves: the most likely of which agrees both with Rowan's conclusion, and that of our own independent analysis. The jackup collapsed in a rather unusual way and various impact marks on the leg, at first indicated there may have been an initiating collision event, which in hindsight, turned out not to be the case.

Figure 24 gives an overall view of each of the leg positions based on 105 ft waterdepth and a 63 ft waveheight.

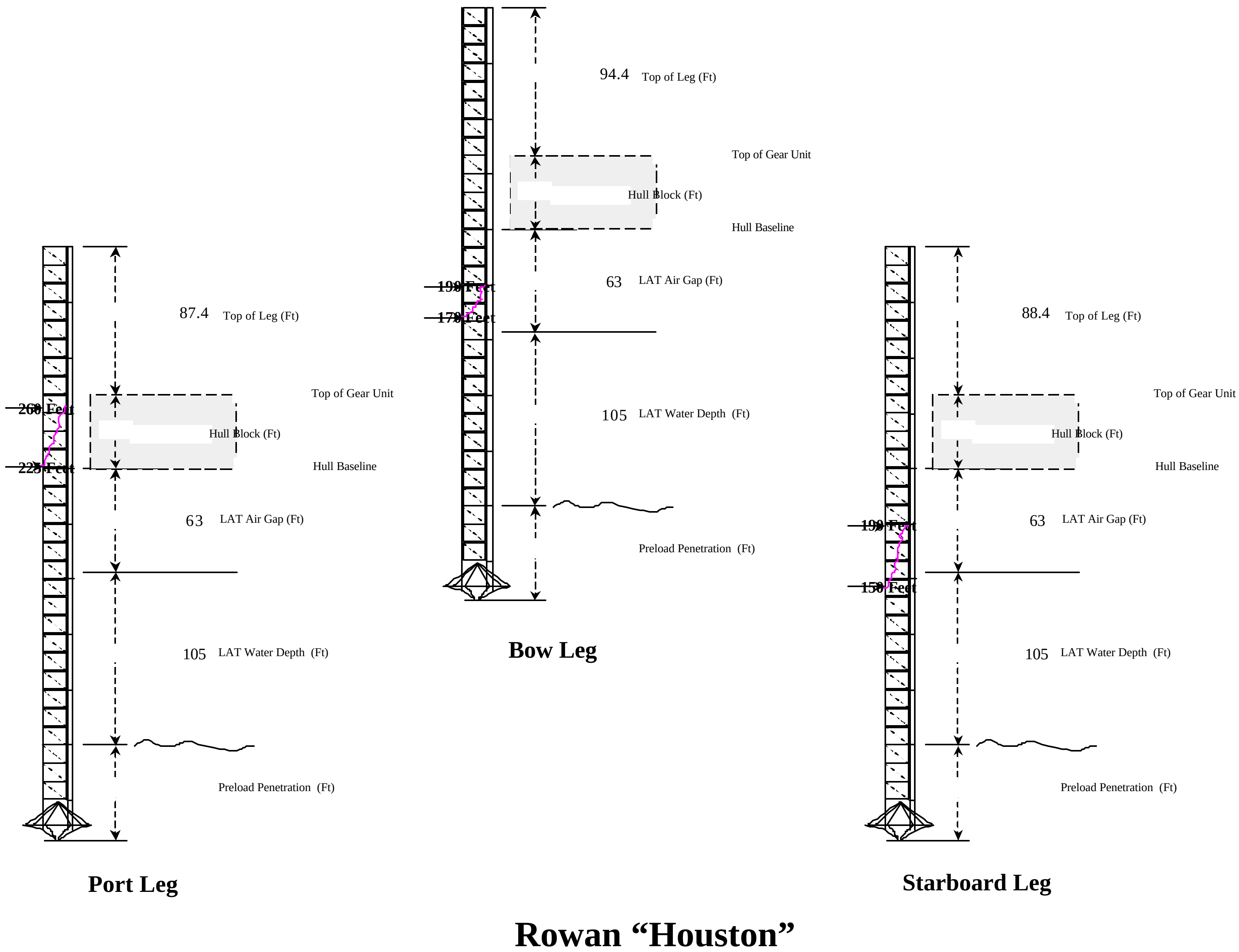
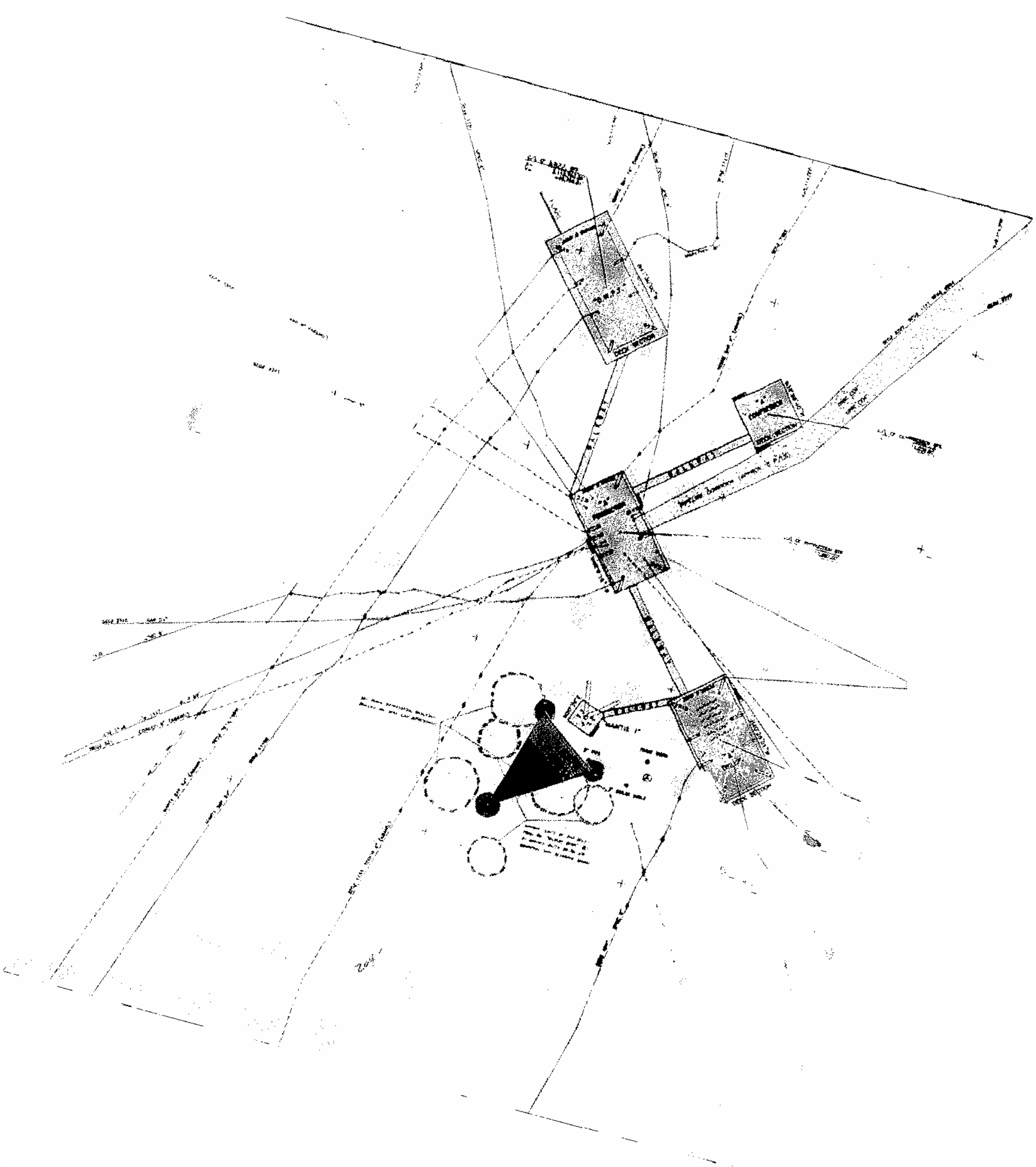


Figure 24: Location Arrangements: Rowan Houston

Figure 25: Leg attached to hull of Rowan Houston at Sunk Location 1600+ft NW of original location

Various "maps" of information became available, from observations at site and putting pieces of information together as they came available. The following 3 diagrams depict various aspects of the arrangements both before the incident and with maps of debris after the incident. The maps are not always to scale and the directions may not be consistent: however there appears general agreement to the extent necessary to make an assessment and come to an appropriate conclusion: so further backtracking to correlate the observations was not done.

Figure 26: Location Arrangements Rowan Houston



The figure above shows Rowan Houston basic leg holes in black and a black triangle is shown between the rig positions (this is not the shape of the Rowan Houston hull). This shows the probable orientation of the unit in relation to other spud can holes (dotted circles), which may have provided interference. The original drawing was constructed, prior to the casualty. The author has superimposed the image of the can spacing of Rowan Houston on this diagram: at the presumed location and direction. The direction of collapse is toward the top left corner of the page.

The following sketch provides some general idea of where debris may have been found, and the direction that the legs were pointing after the casualty and prior to retrieval.

Figure 27: Location Positions after the Rowan Houston collapse

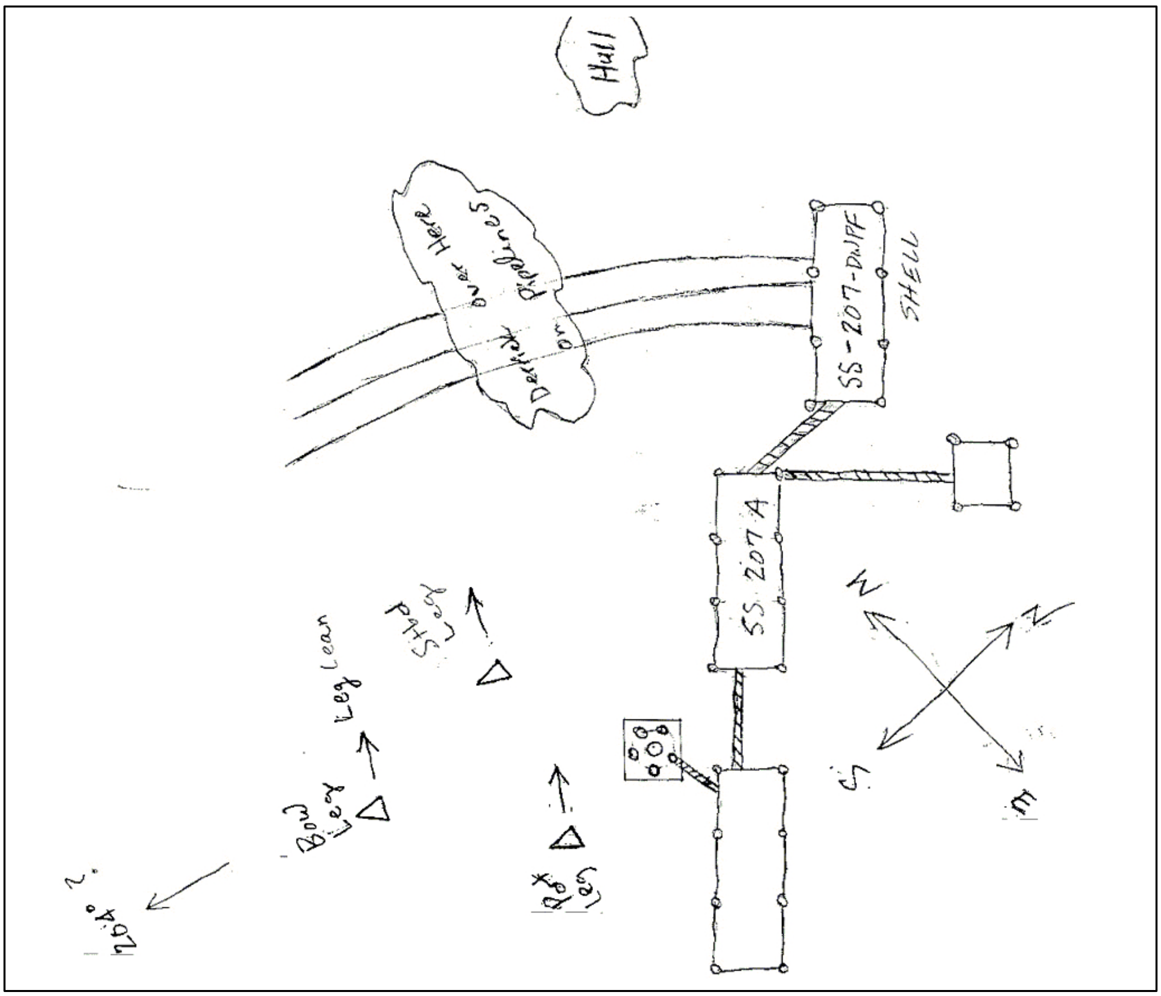
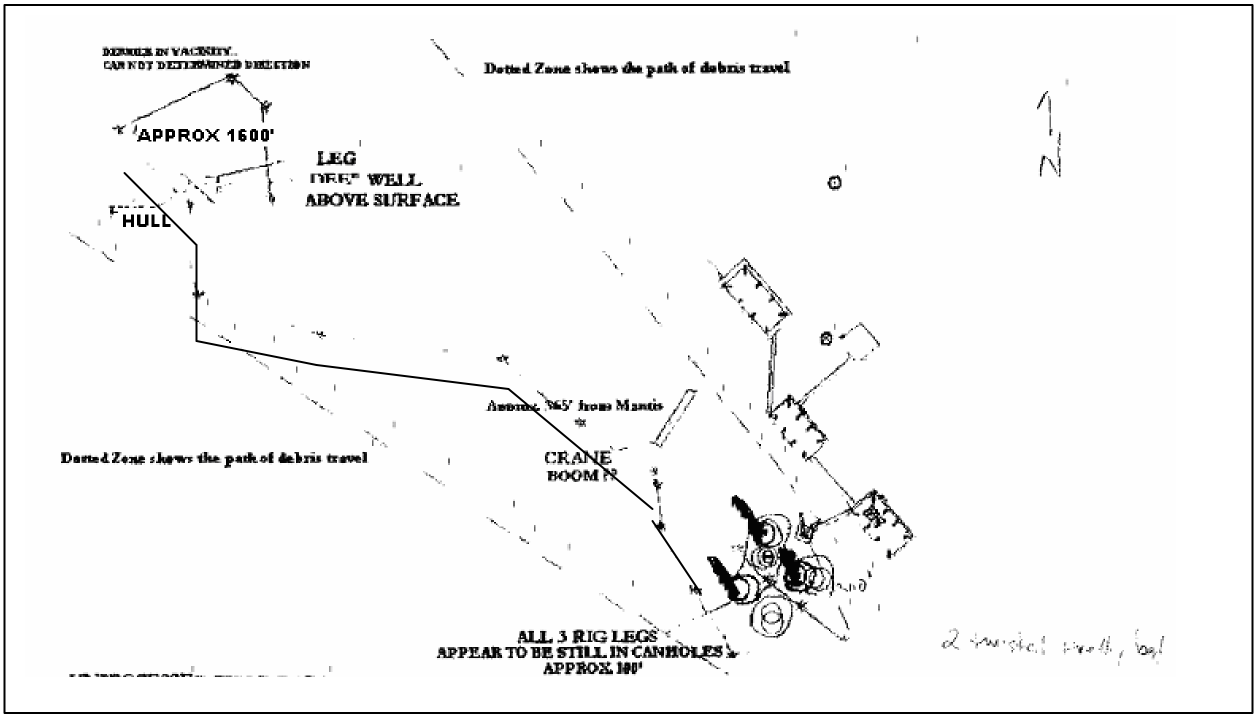


Figure 28: Path of Debris



The diagram above shows some of the debris path. The Hull was about 1600 ft off location to the NW. The legs had been severed and the bottom part remained on the original location. The crane boom is shown in relation to the rig about 365 ft from the platform. This view is very subjective and should only be relied upon for a general view of the area and situation.

Airgap Check

The situation on location was that the rig had been sited, and jacked up with full preload. The rig is designed in such a way that the full preload would have simulated the design storm conditions which might approximate to about a 10-year return period hurricane (in very general terms).

Table 19: Location Arrangements: Rowan Houston

Item	Glenn Hindcast
Waterdepth	105 ft
Tide & Surge	3.5 ft
Wave Height	54 ft (Oceanweather 50.6 ft)
Crest Elevation	36.8 ft
10% Reserve	5 ft
Recommended Air Gap	46 ft
API recommended Air Gap (100-year)	47.5 ft
Actual Air Gap	63 ft

Based on the above information the Rowan Houston had plenty of airgap to weather the storm. Impact from the storm on the hull at this level would be extremely unlikely since it was well above the recommended API recommended level for 100-year criteria of existing platforms in this waterdepth. Since the jackup was working over a platform, the airgap was higher than the minimum recommended from wave and tide considerations.

Design Check

The information in Table 20 shows the A.H. Glenn hindcast data compared to the Oceanweather data. Typical design information is not from an official source: it is typical of conditions used for designs of that timeframe: the Rowan Houston was upgraded in 1996/7 and thus the design conditions could be different from that depicted herein. It is believed that these conditions are representative, however, of an expected rig of this general type and vintage.

Jackups are wave dominant structures. As can be seen by inspection, the wave height occasioned in Hurricane Lili was greater than the anticipated typical design values by a significant amount: this combined with the addition of the current force would have been anticipated to overload the structure. An additional penalty on design is the larger penetration at this location compared to the design, as well as the increased airgap. General review of this information would leave little doubt that the anticipation would be that the unit would be significantly overloaded. An interesting note is that the typical design conditions are greater than those that would be used for a fixed platform being re-qualified under API Section 17.

The comparison between meteorological data that arose from different hindcast sources is shown in Table 20. What becomes clear is that there is a significant disparity between hindcast results of independent professional organizations. From the different weather data, we can infer different conclusions depending on the extreme data that is used. This is very important in the site specific approval, ahead of time, by all parties (owners, insurers, regulators), as to the acceptability of the MODU to be on the location. Without a uniform opinion of the actual results from a known storm after the event, one can well imagine the further disparity between predicted “return period” storms promulgated for the design event or the site-specific assessment event.

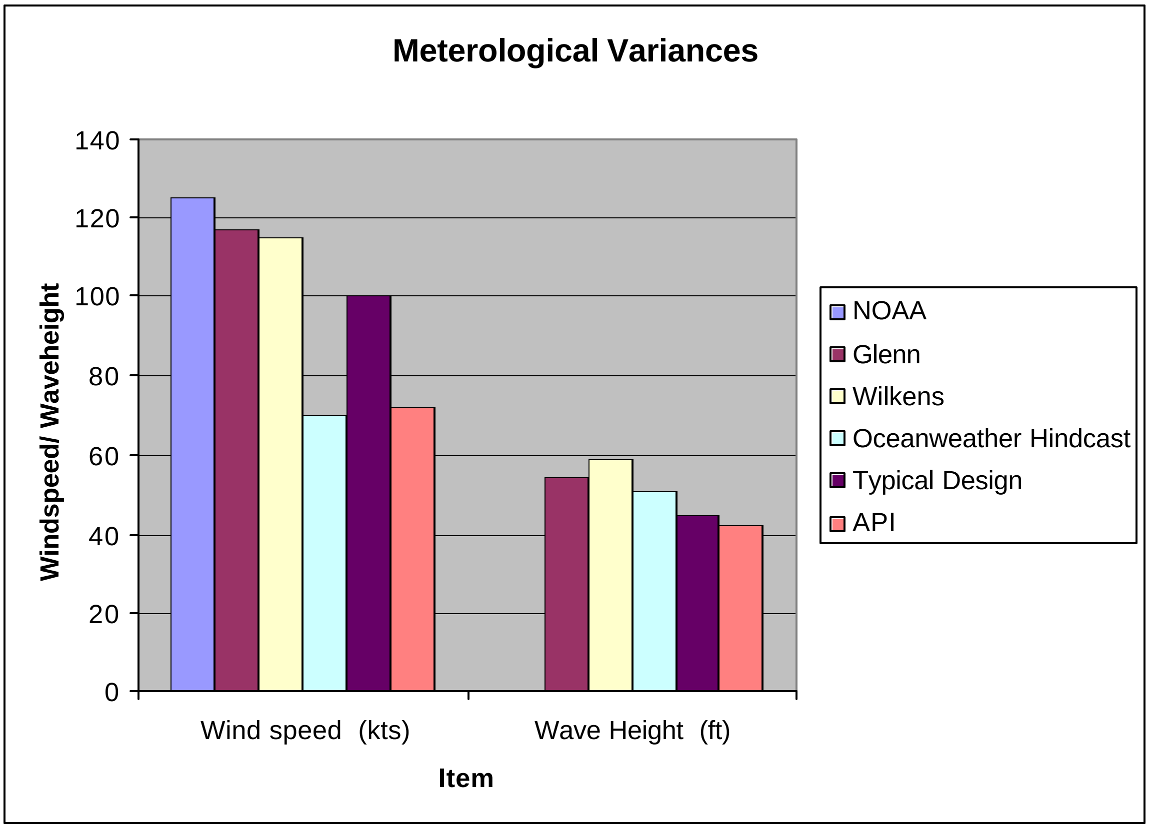
While the 1-minute wind speeds differ, it should be noted that Glenn recommends the use of a 1-hour wind speed for wind plus wave loadings. For wind only loading he recommends a 1-minute wind speed. Additionally Glenn recommends that wind speeds should be applied without change above the elevation of the maximum wave to the top of the structure (assumed to be up to 500 ft). While this lowers the effective force on the structure, it is not something, which is currently allowed for in the SNAME Recommended Practice when Glenn data is used.

Table 20: Comparison of Hindcast and Typical Design MODU Data

Item	Glenn Hindcast	Oceanweather Hindcast	Wilkens Hindcast	Typical Design	API	NOAA
HINDCAST						
Wind speed	87 kts (1-hr av.)	56.5 kts (30 min av.)				
Wind speed (1-min mean)	117 kts	70 kts	115 kts	100 kts	72 kts (10-year)	125 kts
Wave Height (ft)	54 ft	50.6 ft	59 ft	45 ft	42.5 ft (Sec 17 Sudden Design)	
Wave Period (peak spectral)	13.4 secs					
Current Surface	1.54 kts	1.64 kts		0.0 kts		
Current at 50%	1.07 kts					
Current @ bottom	0.24 kts					
OTHER						
Waterdepth	105 ft	105 ft		100 ft		
Penetration	(57 ft)	(57 ft)		(25 ft)		
Air Gap	63 ft	63 ft		50 ft		
	Recommends 1-hr wind with max wave			Note: with cantilever stowed		Maximum in storm

The information on wave heights and windspeeds is charted below in Figure 29. Oceanweather's hindcast is close to the API values but below the other practitioners' values.

Figure 29: Meteorological Variances with Hindcast and Design data from Table 20.



For reference some of the LeTourneau design criteria for triangular truss leg jackups is included in the following tables. Such values are typical of this manufacturer's designs at that time period and thus would be close the likely capability of the Rowan Houston.

Table 21: Typical LeTourneau Design Criteria

LeTourneau 150-44-C

Waterdepth	WaveHeight	Wind Speed
150 ft	44 ft	90 mph
150 ft	37 ft	100 kts
125 ft	47 ft	90 mph
125 ft	40 ft	100 kts

LeTourneau 82-SD-C

Waterdepth	WaveHeight	Wind Speed
250 ft	38 ft	100 kts
200 ft	42 ft	100 kts
150 ft	46 ft	100 kts
100 ft	47 ft	90 kts

Observations From Diver Survey

It was important at the outset to ensure that the divers recorded the depth at which the legs penetrated the mud, and the direction the legs were pointed in. The divers accomplished this.

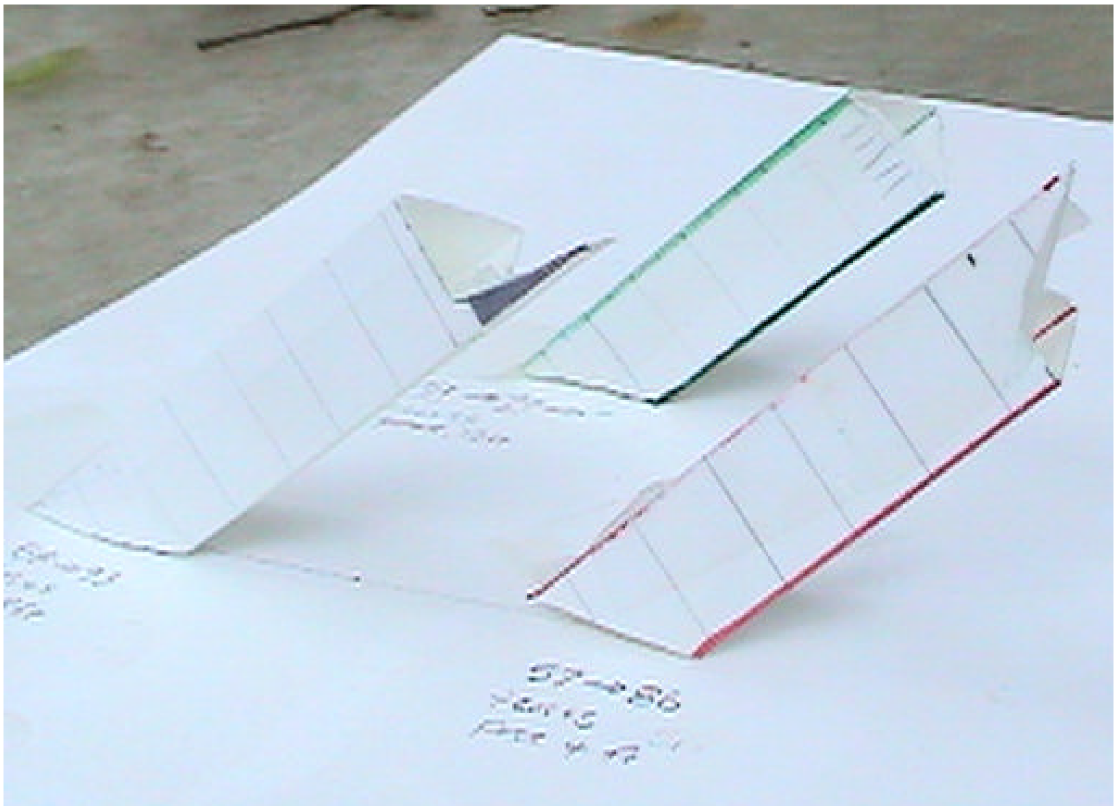


Figure 30: Small cardboard model of Rowan Houston's Legs

Figure 30 depicts the situation of the legs on location as surveyed after the incident. While this is a very early model and does not represent the final surveyed position, it was part of the analysis that led to the conclusion that there was no significant definable further penetration of the starboard leg. The divers located a leg depth indicator mark on one chord of each leg: and then moved around to the next chord using the closest horizontal brace as a reference. They then counted horizontal braces down to the mudline (and rack teeth between the lowest visible horizontal brace and the mudline). The penetration depth is then estimated knowing the elevation of the reference brace, the number of horizontal braces below the reference brace, and the number of teeth below the lowest horizontal brace. It was thus possible to use these observations to gain insight into the possible collapse mechanism.

As one example, the starboard leg that had been at 57 ft penetration was observed on average to be reading 86 ft and the leg was on an angle of approximately 45 degrees. If the leg had not penetrated further into the mud, but merely rotated on the tip of the can the reading should be: 57/sin 45^0 = 81 ft. The chord of the leg is approximately ½ a bay or 6 ft deeper putting the anticipated reading at the chord at 87 ft.

Table 22: Leg Penetrations on Location

Item	Port	Bow	Starboard
Original Penetration (ft)	58	51	57
Starboard Chord Final Penetration (ft)	115	90	97
Bow Chord Final Penetration (ft)	86	79	90
Port Chord Final Penetration (ft)	79	61	70
Average Chord Final Penetration (ft)	93	77	86
45^0 Angle	58/.707 = 82 ft.	51/.707=72 ft	57/.707= 81 ft
40^0 Angle	58/.643 = 90 ft	51/.643 = 79 ft	57/.643 = 89 ft
Leg Indicator chord	Stbd (inside)	Stbd (inside)	Port (inside)

The curiosity about the figures in Table 22 is that the port leg which was the least loaded, in theory, from wind wave and current appears to have been pushed deeper some 9 ft from what might have been "expected". Note, that this is a very "rough and ready" methodology in reasoning out the mechanism of failure: merely a point to note for future reference. One possible explanation is that as the hull collapsed it pulled over the port leg and the impact of the falling hull, pushed the port leg further into the soil; another explanation is that the angle of the leg to the bottom is different in one case from another: possibly the hull pushed the leg down when it collapsed, or possibly the angle estmations were subject to estimating error, since approximating the angle with poor visibility and by methods of depth gauges against the leg is fraught with potential sources of error.

Re-working the figures on the estimate of 40 degrees instead of 45 degrees gives much better correlation to actual.

The rudimentary model was useful early in the investigation in developing information to request of divers in order to determine what facts should be gathered so future analysis could determine the root cause.

The following diagram indicates the direction the legs were leaning:

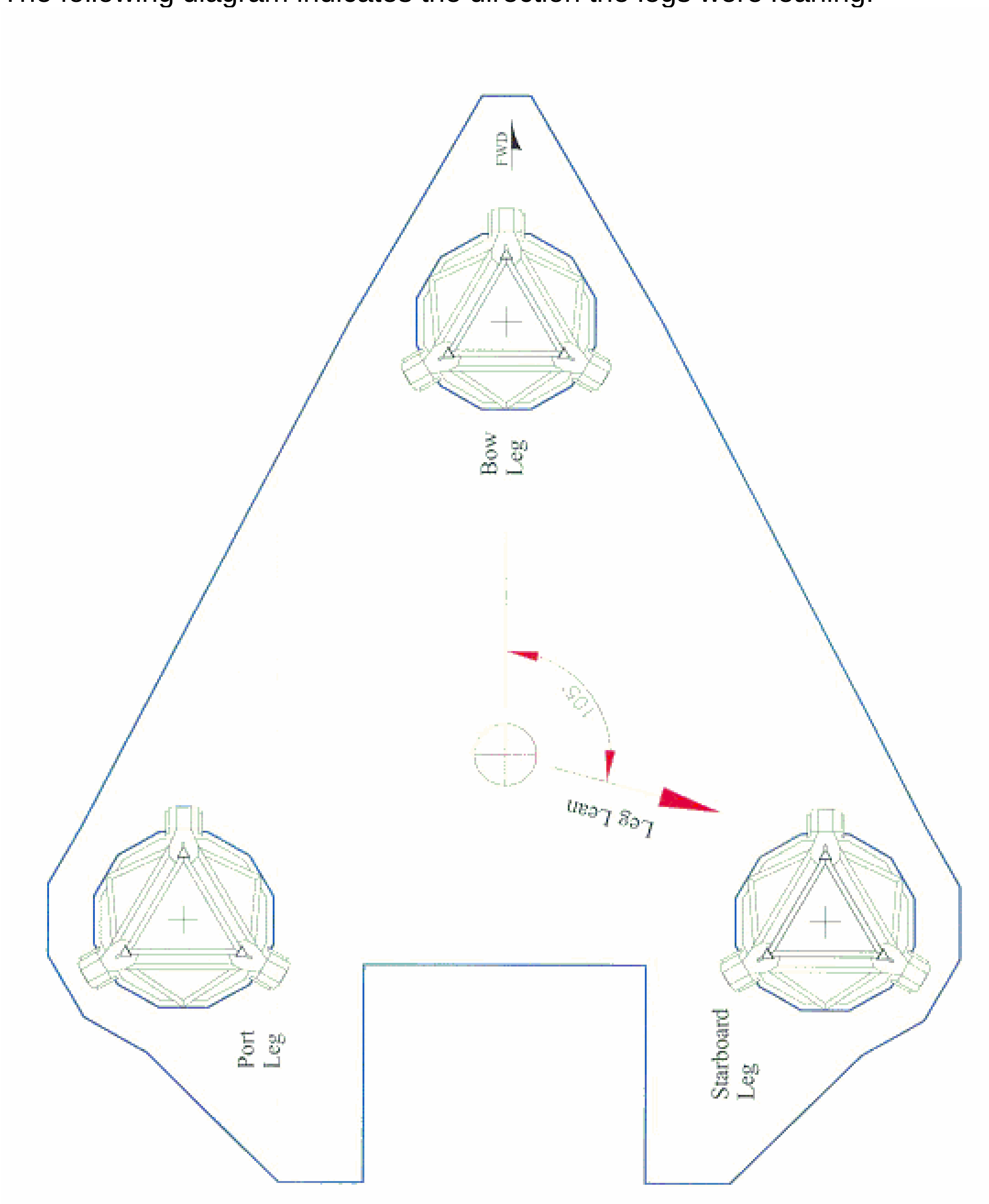


Figure 31: Plan View of Rowan Houston showing direction of leg leaning prior to failure.

Referring back to the example of the starboard leg: this "analysis" leads to one of two conclusions:

- The starboard leg penetrated further and then was pulled back to its original penetration level as the rig left location

- The leg rotated without further penetration.

While the first option is possible, the 2nd is, in the author's opinion, most likely. This would also mean, depending on the soil conditions, that it is likely that the preload value was not exceeded. This leads to a further conclusion:

- The mechanism of failure was not what we have seen in other failures of rigs in the past such as, for example the Penrod 61 in Hurricane Juan, where there was an overload, a penetration on the leeward leg, an increase in angle, and a collapse of the rig (and, in that case, failure of the crew which was on board, to jack the rig).

Reviewing of the soil information and the fact that there was an apparent footprint to the starboard side of the starboard leg – would lead to the fact that there may even have existed a pre-disposition to further penetration of the starboard leg: but it did not appear to happen.

The observation leads to the conclusion that some mechanism caused the rig to fail prior to the vertical load at the bottom of the leg significantly overloading the foundation

Further observations on the position of breakage in the legs are of importance in determining the likely mechanism of failure.

Item	Port	Bow	Starboard
Original Penetration (ft)	58	51	57
Leg Measure at Waterline (ft)	163	156	162
Leg Measure: Lower Guide (ft)	226	219	225
Leg Field Joint Location (ft)	190.7	190.7	190.7
Leg Field Joint Location (ft)	224.3	224.3	224.3

The Leg Field Joint indicates a field-welded joint. The leg sections of this type of rig are made in 3 bay lengths and then joined together by field-welded joints. These are noted since it was not initially obvious if these might have been a contributing factor: it turned out that they were not a contributor to the failure.

The Port Leg was broken mainly at the 225 ft level very close to the lower guide point, and an expected area where "crumpling" would be expected to occur based on the method that this rig resists bending moments with an upper and lower guide reaction.

The forces on location are greatest at the lower guide. The port side of the port leg was severed at (roughly) the 225 ft mark. The starboard chord of the port leg was torn above the 225 ft mark and parts of the chord extended to 260 ft., a distance well into the hull.

Figure 32: Small Cardboard Replica of Rowan Houston

The Starboard Leg was damaged starting mainly @ 150 ft level. The starboard face of the leg was broken at this point (see Figure 32 right-hand-side) and there are considerably more bracings broken from 150 ft to 190 ft. There was a hard bend @ 190 ft. The leg ends at 210 ft. The leg was leaning at a 45^0 angle.

The Bow leg was badly marked from the 170 ft mark upwards and the backplate was broken off the chord from 190 ft level upwards. The port side of the bow leg was missing from the 190 ft leg still attached to the hull. At 190 ft the backplate was bent over at 90 degrees to the horizontal and the vertical diagonal was pulled directly off the backplate

In order to visualize the situation on location a cardboard model was made of the legs, which was hoped to assist in visualizing what might have contributed to the mechanism of collapse. Figure 32 shows a cardboard replica of the rig. The green at the bottom of the legs indicates the amount of penetration of each of the legs (see also Figure 24). The waterline is shown as a blue horizontal line on the aft two legs. The break in the starboard leg represents the region of maximum distortion. This observation is important because had the starboard leg taken on further penetration, it would have been expected that the maximum bending moment and maximum distortion would be at the lower guide on the starboard leg, not further down, as is represented by the torn starboard leg.

Further examination was held when the legs were retrieved and examined in detail in the yard in Sabine Pass to which they were taken for examination.

During the various surveys the starboard leg was located lying on the seabed separated from the main hull which was some 1600+ ft to the N W of the original location. The leg had parted from the hull and rest of the leg in the seabed and the diver's observations was as follows:

> *"Jumped diver on 6" 204-A line at Production Platform and attempted to walk out to the Shell lines. 100 ft out encountered derrick debris and lost 6" line; diver moves west and intersected leg; Leg debris stuck in side of mat at top of leg. Followed numbering on Leg F/35 to 28 (Top of Jackhouse), Number 24 appeared below jackhouse on down to 21. Below 21 were several feet of twisted and peeled metal; diver also determined that all 3 chords of the leg are intact. The three jackhouses are in place and don't appear to be distorted, one jackhouse is on top of the mat. Moved buoy from jackhouse area to B/O leg."*

The fact that the geartrain was located attached to the leg chords, indicates that the geartrain to deck connection failed. While this is a critical area of design, the author is not aware that it has ever featured in a casualty of a LeTourneau or any other jackup design before. The rig was in Class and a Class survey had recently been carried out: the expectation would have been that the surveyor surveyed this area for any cracks or sign of distress: it is unlikely to have gone unnoticed.

While readings were taken of the leeward leg, it was not obvious that it penetrated further, (as seen in several other jackups in Lili). Measurements taken on location by divers appeared to coincide with what might be an expected depth of a leg that had swayed sideways without taking on further penetration. The state of the gear trains on the leg after the event lead to a suspicion that an initiating event may have been the jack foundation separating from the deck on the starboard side. This would also explain the damage to the leg at an area above the waterline but well below the lower guide, possibly an expected damage if the first action was that the hull descended the leg after the gear train-to-leg separation.

The rig was in Class with ABS at the time of the casualty and had been surveyed by the Class Society, and this survey would have been expected to included the jack foundations attached to the deck, so there is confidence that this area was not in distress prior to the storm.

The examination of the rig indicated that the legs were capable of their full capacity. The Figure 33 shows the bow leg, bow chord at approximately the 190 ft level showing that the chord experienced a full capacity overload.

Figure 33: Photo of bow chord of bow leg showing chord failed only after full capacity was reached.

Figure 34: Starboard leg recovered showing gear train still attached.

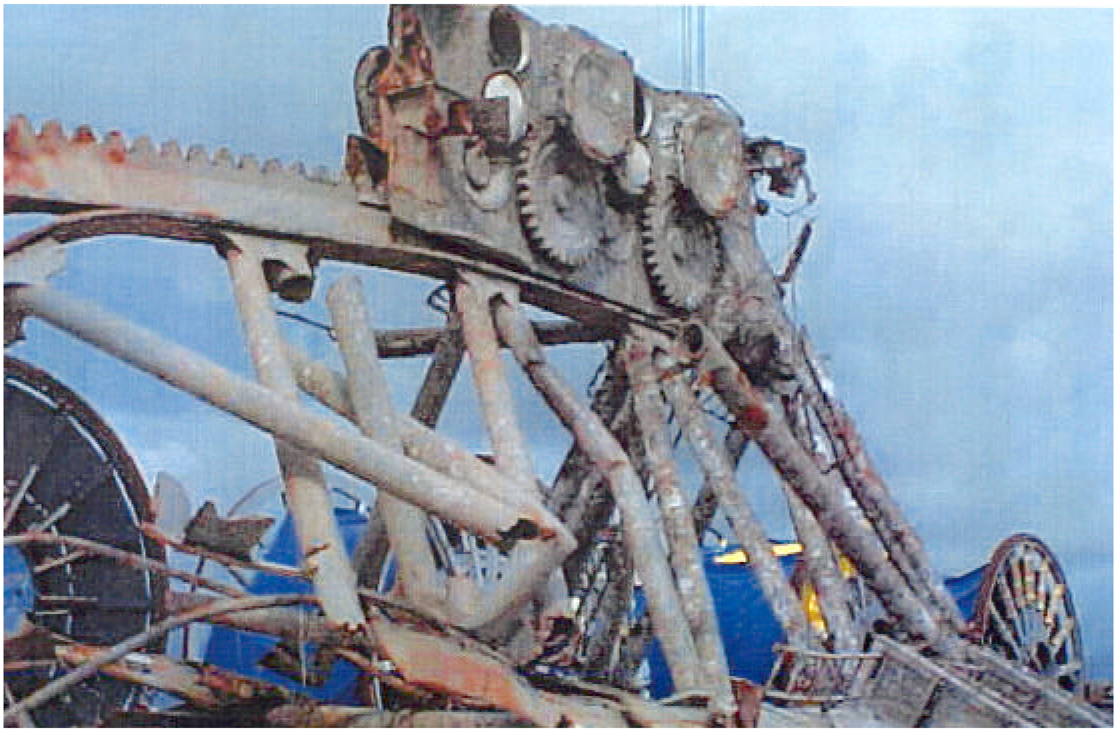


Figure 34 shows the gear train directly attached to the starboard leg. It is clear that the gear train-deck connection failed during the process. The failure of the gear train to deck connection while not an unexpected failure possibility (and this connection is part of the rig design), it has been general experience that this area has not been the first to fail in other rig accidents. Since the Rowan Houston was overwhelmed with the storm to such a great extent, and would not have been expected to survive, when compared to the design event – the initiating event is important only as a means to provide further guidance on another location on the rig to be ever-diligent about, during the inspection process.

Damage to the port forward corner had the characteristics of an external collision but on further reflection may have occurred as a result of collision with the bow leg impacting that part of the hull during the collapse.

Based on any of the Hurricane Lili meteorological hindcast data presented the Rowan Houston would have been expected to fail.

The summary of conclusions on the Rowan Houston casualty is as follows:

- the initiating event was the storm

- the jackup withstood the design event (10-year return period storm) and was overloaded by about a factor of at least 1.5 –2.

- we are able to have sufficient information to understand the failure, only because Rowan saw fit to gather key information immediately when they got onto location and chronicle where each of the pieces were, and carry out a forensic analysis.

- the elevating unit foundation connection to deck was, most probably, the first initiating event

- substructure and derrick possibly impacted the starboard leg, but at least moved to starboard and ultimately went over the side.

- to understand whether soil failure contributed it would be necessary to obtain soils information which was not available

While not directly related to this, during the course of consideration of ways to continue to enhance rigs and keep them capable of the very highest peak loads, it may be beneficial to have some guidance produced by the industry to alert surveyors of critical locations on a rig to be inspected and why, for the different types of rigs.

NOBLE JOHN SANDIFER, NOBLE EDDIE PAUL, NOBLE LEONARD JONES

The jackup rigs of Noble Drilling had some interesting observations. They are chronicled below.

Table 23: Observations on Noble John Sandifer, Noble Eddie Paul and Noble Leonard Jones

			Rig Location			Leg	Airgap	Water	Damage Descrition
Rig Name	Rig Class	OCS Block #	Longitude	Latitude	Bow-Head	Length		Depth	
			deg.min.sec	deg.min.sec	deg from N	(ft)	(ft)	(ft)	
Noble John Sandifer	111-C	Eugene Island 305	91.31.58	28.18.15	295*	426	67	226	Rig settled 2.8^0 down by the bow. Penetration was 56 ft Leg structural damage - Bow w/ broken members and chord damage. Portw/ structural damage to leg members. Stbd with minimal leg damage. Hull structural damage in way of the both longitudinal bulkheads requiring replacement of some sections due to buckling.
Noble Eddie Paul	Mod 84-C	So. Timbalier 295	90.32.16	28.11.43	185*	501	55	283	Penetration before storm- Bow - 108', Stbd - 105', Port-106'. Penetration after storm - Bow 110', Stbd - 112', Port - 106'. Rig inclined 1.8 deg to stbd with bow 0.9 deg high. Rig moved 3.8' aft and 5.6' to the stbd. Rig settled 5.0' on the starboard leg only. No leg or hull damage however, due to the movement of the rig in relation to the platform well, the rig legs had to be jetted free and relaxed, then jacked up and re-preloaded.
Noble Leonard Jones	Mod 53-C	Eugene Island 273	91.36.06	28.25.32	135*	501	85	184	Penetration before storm- Bow - 71', Stbd - 72.5', Port-72.5'. Penetration after storm - Bow 71', Stbd - 75', Port - 72.5'. Rig inclined 0.9 deg to stbd with bow 0.5 deg high. Rig moved 3.9' aft. Rig settled 2.5' on the starboard leg only. No leg or hull damage however, due to the movement of the rig in relation to the platform well, the rig legs had to be jetted free and relaxed, then jacked up and re-preloaded.

NOBLE JOHN SANDIFER

The Noble John Sandifer is a Levingston Class 111-C built by Levingston Shipbuilding Co., Orange, Texas in 1975 and converted in 1995. It has a water depth rating of 300 ft and a drilling depth of 25,000 ft. The hull dimensions are 208' x 178' x 23' with a spud can diameter of 48.00'. The legs are 426' in length. The quarters have a capacity for 80 persons. It was formerly Diamond M Gem, Loosbrock Comet and Gulfstar.

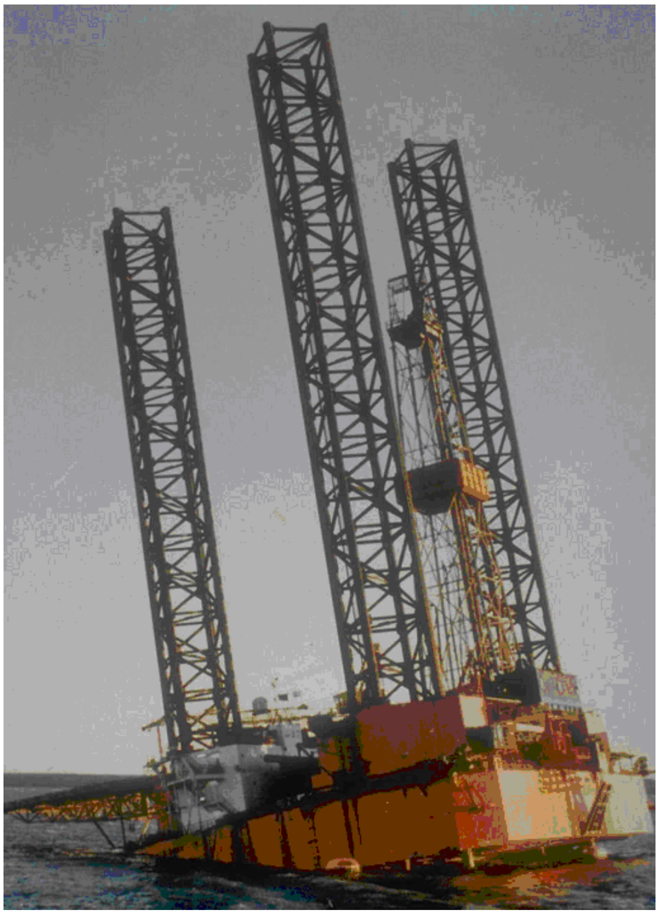
Figure 35: Noble John Sandifer

The Noble John Sandifer was 2.8 degrees down by the bow after the storm. Minor structural damage included cracked members and chord damage in the bow leg, port leg and slight damage in the starboard. There was some minor impact to the hull longitudinal bulkheads indicating some impact or possibly storm run-up on the legs. This hull type is particularly resilient to having the hull at an angle, but the loading was quite extreme.

The Levingston rig type is very resilient to settlement, and one leg penetrating more than another. As an example of this the photo in Figure 36 shows the Rio

Colorado (same rig type) after a major bow leg settlement offshore Argentina. There was virtually no damage even with this huge uneven penetration (which resulted from a punch-through).

Figure 36: Rio Colorado rig photo to illustrate the robustness of the Levingston III design to leg settlement.



NOBLE EDDIE PAUL

Noble Eddie Paul is an Independent Leg Cantilever Rig Design: LeTourneau Class 84-S with a Rated Water Depth: 390 ft and a Drilling Depth: 25,000 ft It has quarters for 74 persons. The hull is 247' x 200' x 26' with a spud can diameter of 46’. The legs are about 477’ in length. It was constructed by Marathon LeTourneau, Vicksburg, Miss, 1975, and converted in 1995. It was formerly the Penrod 66.

Figure 37: Noble Eddie Paul

The Noble Eddie Paul was in 283 ft waterdepth with about 105 ft of leg penetration into the soil. After the storm careful measurements were made. The leeward leg was down by 7 ft, and bow by 2 ft. The rig was reported to have moved 3.8 ft aft toward the platform and about 5.6 ft sideways, rotating about 5 degrees and was down to starboard 1.8 degrees with bow .9 deg high. There was no hull damage. The movement was pronounced enough to cause the rig to have to relocate on the platform in order to reach the wells after the event that were reachable before the event. The rig legs were jetted free and relaxed. The rig was then jacked up and re-preloaded.

It is difficult to see how such a horizontal move could have taken place with the reported penetration. Typical of platforms is the fact that they are worked over by a variety of rigs. One possibility is that there was a complex interaction with the footings of a previous rig that had been on site. It is clear that a further enquiry into the action that resulted could be an interesting activity and may shed some further interesting light on how jackups behave. There have been other occasions where jackups behaved differently than expected. One example is a jackup in Hurricane George that “danced” across the seabed rotating 20 degrees.

The rig was within 25 miles the worst quadrant of the storm, saw the worst 35-yr return period storm with a 1.0 load factor, the unity check exceeded >1.5. The site assessment would have failed a 10-year return period check, yet the jackup MODU saw no signs of distress. This leads to the conclusion that our current understanding on calculation methods is conservative and perhaps not as clear as was thought. It does however point to a need to continue to assess the incidents as they occur since this is the only means to learn more about the calculation methods that can ensure safety. Study of situations like this can lead to better understanding of rig capability: the same may be true here – and further research may be appropriate.

NOBLE LEONARD JONES

The Noble Leonard Jones is a Marathon LeTourneau Class 53- jackup built by Marathon LeTourneau, Vicksburg, Mississippi in 1972 and converted in 1998. It has a rated water depth of 390 ft and a drilling depth of 25,000 ft. The hull dimensions are 247' x 200' x 26', Spud can diameter 46'. It has quarters for 92 persons. The legs are about 477' in length. It was formerly the Penrod 62 and the Coral Sea.

Figure 38: Noble Leonard Jones

The Noble Leonard Jones was on location in 184 ft waterdepth with 72 ft of penetration at the time of Hurricane Lili. The starboard leg penetrated an extra 2.5 ft giving a rig inclination of 0.9 degrees to starboard with the bow 0.5 deg. high. The rig moved 3.9 ft aft. Such an incident is not unexpected but shows that the rig may have exceeded the level to which it was preloaded by some small amount. There was no leg or hull damage. The only consequence was that the legs had to be jetted free, and the rig jacked up on the location and preloaded again.

ENSCO 67

Ensco 67 is a Marathon LeTourneau design, Class 84 jackup similar to the Eddie Paul. It settled 6" to starboard. It has a rated water depth of 380'. The hull is 247' x 227' x 26'. It was constructed by Marathon LeTourneau, Clydebank, Scotland, 1976 and was formerly the Penrod 67.

This minor settlement is of no consequence.

OTHER JACKUPS

Jackups other than the ones chronicled above, appeared to have suffered no issues. RBF 204 is a mat supported jackup that had been reported as leaning, however no further information was obtained, and this is thought to be not significant since it was so far from the storm. Mat units often shift a little in hurricanes (Ref. 8-10).

10.0 OVERVIEW OF JACKUP MODUS IN HURRICANE LILI

The various jackups close to the storm are listed together in Table 14 together with a general view of their "likely capability". Figure 16a gives the wind contours, and Figure 16b the wave contours from the Oceanweather Report (Ref 1) with rig locations superimposed. In Table 14, the term "likely capability" is used because no site-specific studies were done to arrive at these numbers. It is a general "experience" number arrived at by engineering judgment from involvement in various analyses over the years. 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 as well as the soils data at the prescribed location. This tabulation was used to identify the most likely candidates for further study and to present an overview of "what happened" and was it expected to happen i.e. to see if the general understanding of rig capability resulted in performance of the jackups as expected. As can be generally seen from the table the likely capability was likely to cause the jackups directly in the path to be compromised. Their performance seems to be as expected. Comparing the rig hindcast data to the API 10-year criteria (a general estimate of criteria), it appears that the jackups, in general, performed better than their "agreed criteria".

- The Dolphin 105 appears to be just outside the limits of likely capability: thus leading to the recommendation to have the standards warn the interested parties that in shallow water breaking waves can significantly affect the result.

- The Rowan Houston was clearly expected to be overloaded based on existing information about the design and approval criteria

- The Noble John Sandifer would be expected to be close to but not exceeding its limits. A small penetration would be an expected outcome.

- The Noble Leonard Jones was close to its limits if not over – and the additional penetration would not be unexpected.

- The Noble Eddie Paul was close to its limits, if not over – and the additional small penetration would not be unexpected. Though this cannot be inferred from the material presented in Table 14, any rotation would be unexpected.

While in the case of the rigs affected by Hurricane Lili, all appear have realized their full design potential, during the course of the investigation, discussion of which areas of the different rigs become critical first brings to mind that the development of a document to identify to surveyors critical areas of the various different rig types in the Gulf of Mexico with a reason as to why they are recommended to be inspected at those critical locations, would be a useful tool. Such a document would preserve a knowledge base of historically sensitive areas. To our knowledge no such document currently exists.

The overall conclusions on jackup MODUs in Hurricane Lili were that:

- Both jackups that collapsed, the Dolphin 105 and the Rowan Houston withstood their expected design loads

- There is a big difference among hindcasts derived from hurricane information, which impacts data generally used for acceptability of a specific jackup MODU on a location.

- The settlement issues are "interesting" but most probably the rigs exceeded their preload design loads by a small margin.

11.0 JACKUP MODUS: HISTORICAL

The first jackups were used in the oilfield in the 1950's. A landmark paper by Bethlehem Steel Corp chronicled the methodology of jackup analysis (Ref 11). The documentation of a method, by which calculation could verify the safety of the jackup MODU, was a significant step in providing justification for approval by owners, classification and insurance warranty surveyors. Figure 39 shows one of the first jackups designed by R.G. LeTourneau and built by the LeTourneau Company in 1958; it was a triangular platform with 3-trussed legs. Each leg had a full-length gear rack to engage the pinions of the elevating mechanism. The rack was driven by 7 electric motors equipped with electromagnetic brakes.

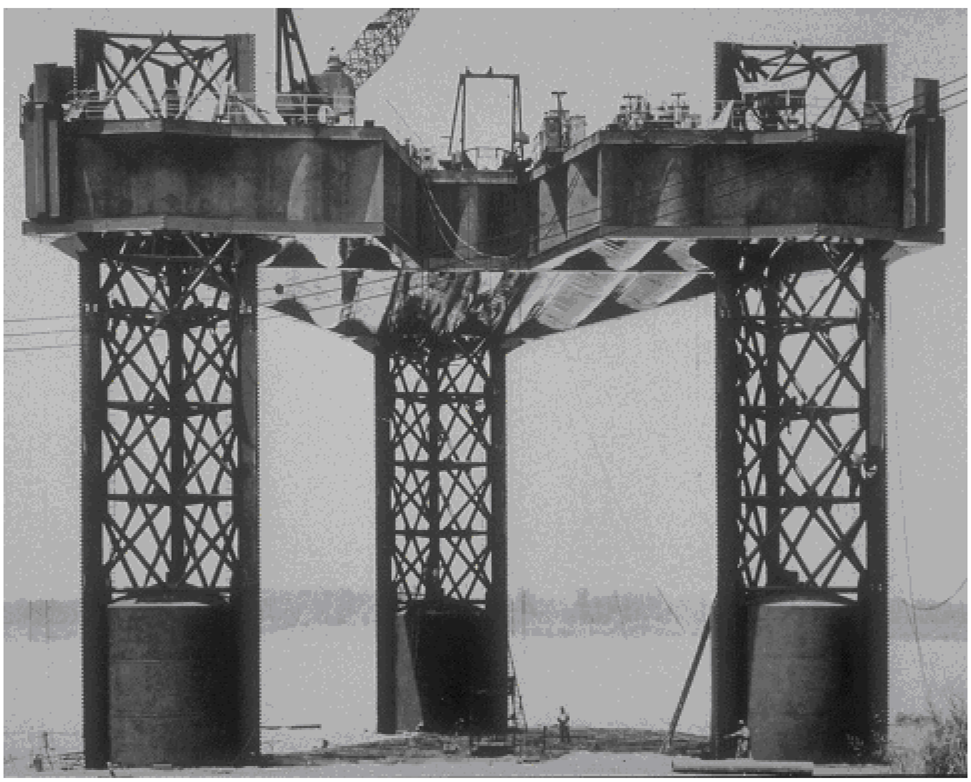


Figure 39: "Scarabeo" the 9th LeTourneau Jackup 1958

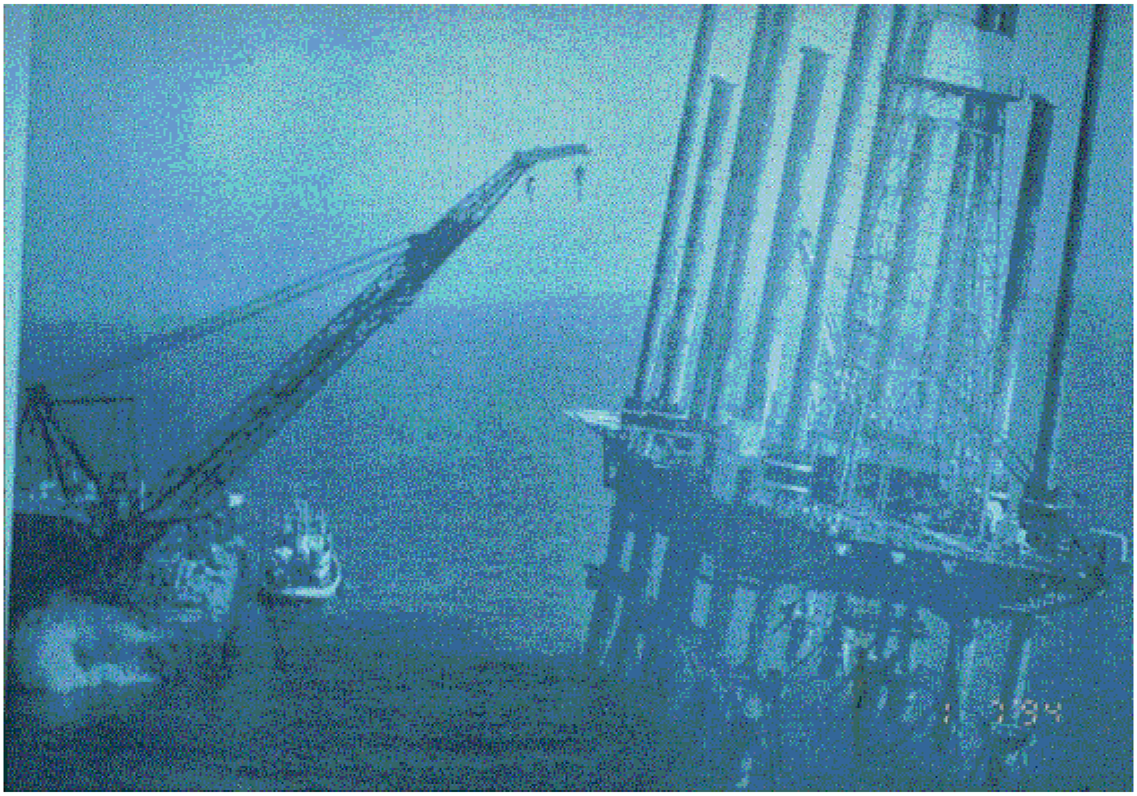
The next step in the process of safety was to codify the Rules for jackups. This was done in the 1968 ABS Rules for MODUs. The purpose was primarily to establish a suitable standard which could be accepted by foreign coastal states for operations of jackup MODUs in the coastal state's waters as jackups moved from the Gulf of Mexico to other areas of the world, including the North Sea.

Mr Louie was the first jackup built to class Rules in 1958 prior to the issuance of the class MODU Rules.

Figure 40: Mr Louie First Jackup built to Class Rules.

A series of issues arose over time with preload issues and in 1972 the ABS Rules incorporated preload. Prior to that time, when jackups occasioned major storms, settlements were a problem.

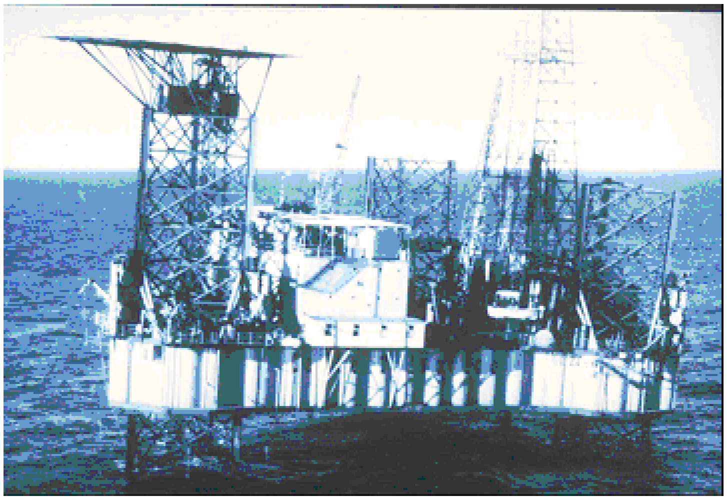
Figure 41: Mr Gus settled on location – prior to preload requirement



Settlement either from additional leg penetration or from scour and other "foundation related issues" was not uncustomary, and was not considered to be a failure event. The addition of a preload requirement minimized the risk of further penetration in storms.

Certainly the early days of settlement of footings triggered preload requirements that are universal today.

Figure 42: North Sea jackup after a storm with additional penetration at the stern.



A recent incident involving preload limitations was the collapse of the Penrod 61 in Hurricane Juan. The bow leg had insufficient preload capability for the resulting storm, took on extra penetration, which was not responded to by personnel on board. The result was a continuing settlement until the rig collapsed.

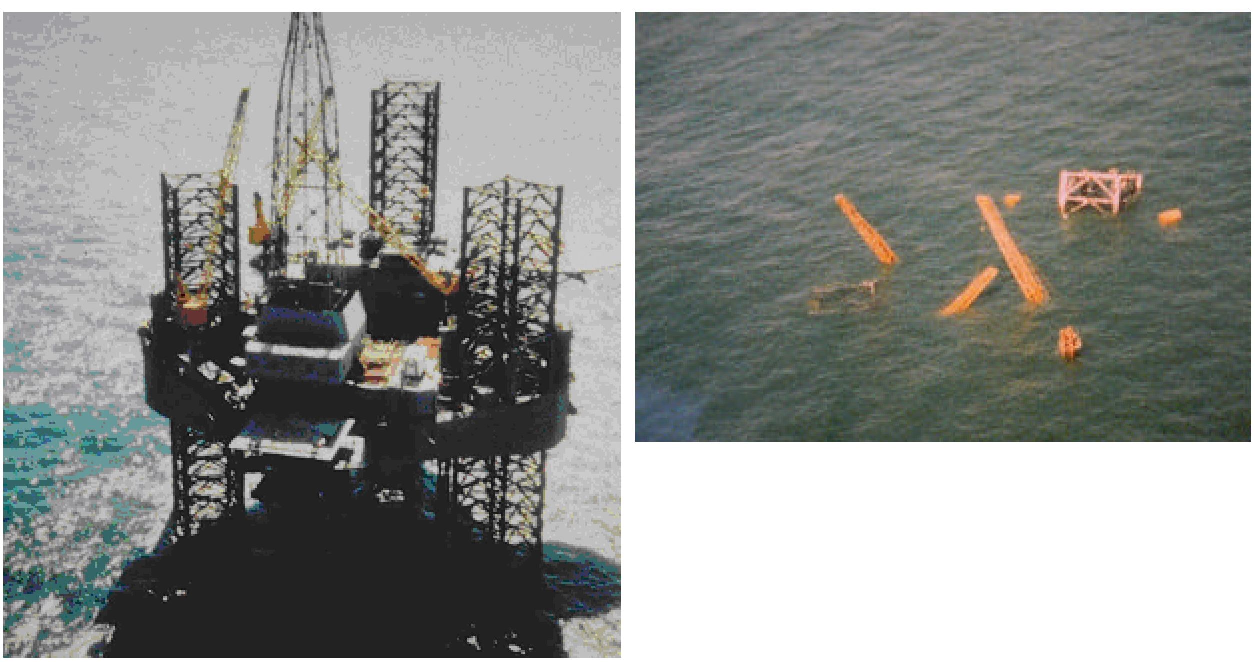


Figure 43: Penrod 61 – "before" & "after" Hurricane Juan

The *"PENROD 61"*, when it collapsed in hurricane Juan, drifted north and ran into the manned sister vessel the *"PENROD 60"*. It is fortunate that it did not cause the *"PENROD 60"* to collapse, which could have led to a heavy loss of life. Having collided with the *"PENROD 60"* the unit then drifted a considerable distance before sinking in shallow water.

The next step in the analysis of jackups did not occur until about 1986 when as a result of oil company concern about jackups and a lack of uniformity of application of site-assessment principles, Shell headed up an initiative to develop a methodology for approval of site assessment methods. The initiative started as a Joint Industry Study project propelled over concern with dynamics in the North Sea deeper water depth rigs. As a result of that initiative, dynamics was added to the generally accepted methods of analyzing jackup rigs by about 1990 together with accounting for the additional load in the legs as a result of the deflection of the rig (the so-called P-Delta effect).

In 1990 the MMS study on Hurricane Andrew chronicled the successes and failures to date in jackup MODUs in the Gulf of Mexico, putting the issue of potential failure in hurricanes in perspective. The study on Hurricane Andrew revealed that the rigs acted much as would have been anticipated and the lesson was that the current methods of calculation predicted the resulting incidents (or lack of them).

In 1994 the SNAME 5-5A Site assessment guideline was first published. This was the first codified method of site assessment which layed out in immense detail the calculation method for assessment of independent leg jackup MODUs for application at a particular site. While this was a very detailed document there was no guidance on the development and acceptance of meteorological data (a key ingredient), nor was it the intention of this document to give guidance on the selection of that information. The same year a group of drilling contractors started meeting together to attempt to move forward the standards by which jackup MODUs could be judged in a "balanced" way, worldwide, and particularly in the North Sea and Gulf of Mexico areas. These are referred to in this document as the IADC Jackup Committee. A further initiative was to take the SNAME 5-5A document and move it toward an ISO standard under the auspices of ISO TC67 (offshore), SC-7 (offshore structures), WG7 (working group on jackups). The SNAME 5-5A document continues to evolve as does the work with ISO TC 67 SC7 WG7.

While continued improvements have been made to the calculations methods, there have not been any incidents to offer many further insights in the calibration process.

In 2003 work was commenced on this study on the results of Hurricane Lili. to have a look at the casualties and decide if there were any lessons to be learned. One of the interesting things we've learned from the incidents is that for the most part jackup calculation methods are conservative, even for the older rigs which survive up their full design capacity. As a result of these studies, we have found the methods of analysis used in general for MODUs are both conservative and robust.

Whilst there were problems, from time to time, with these early rigs, since the late 1970s, though there have been improvements in the calculation methodology there have been no incidents that would dictate a major changes in regulation or recommended practice related to the jackup MODU calculation methods. There are a variety of jackup MODUs operating today. In the 1980s the photo in Figure 44 depicts the variety on-hold in Sabine Pass waiting for the industry to return to health.

Figure 44: Jackups in Sabine Pass circa 1985.

12.0 JACKUP MODUS: HURRICANE ANDREW

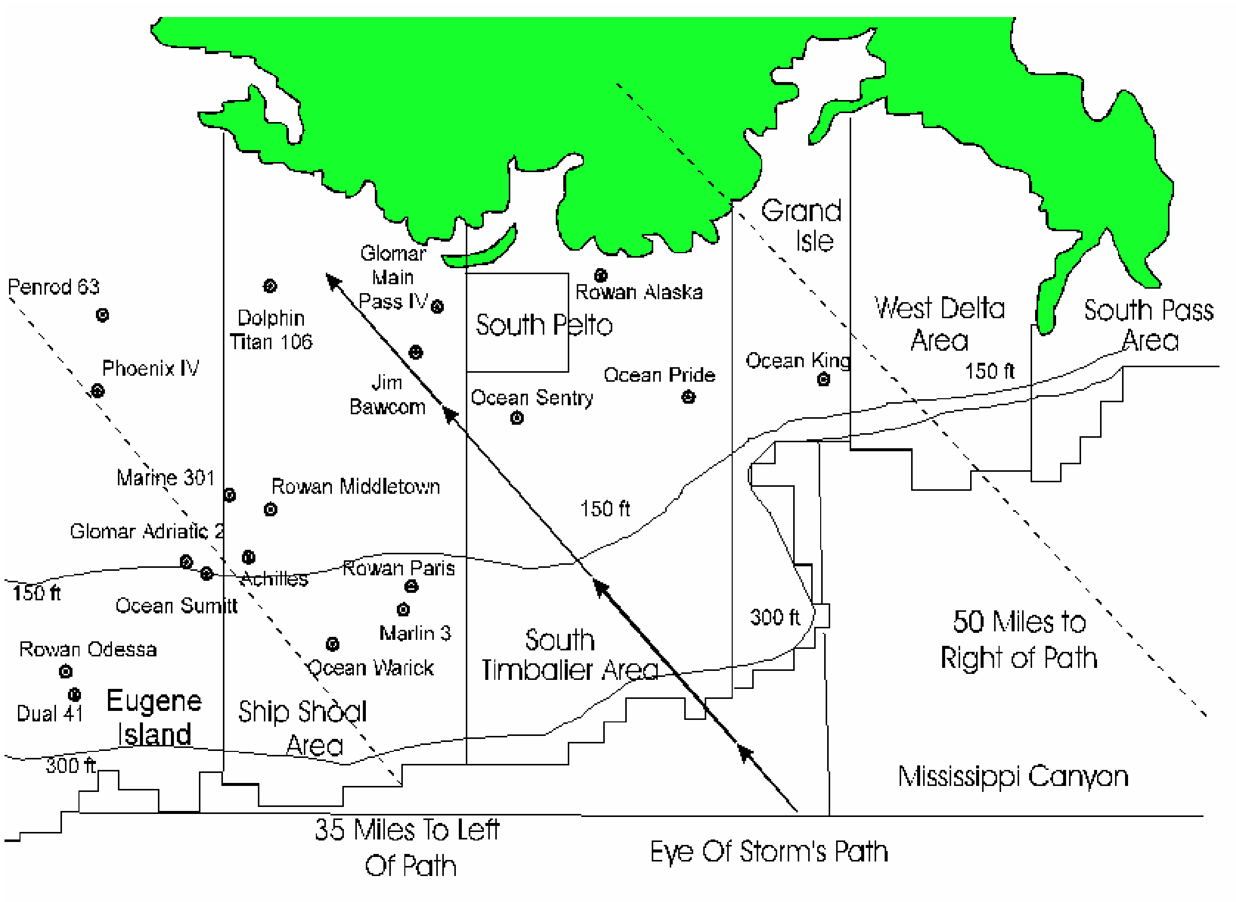


Figure 45: Jackup MODU Exposure in Hurricane Andrew.

Figure 45 depicts the path and the locations affecting the various MODUS in Hurricane Andrew-a Category 4 Hurricane.

Much of the information below is paraphrased from the MMS Report (Ref. 2).

There were a total of 18 Jackups exposed in Hurricane Andrew. Of those 18, 9 had no issues; on 4 equipment was damaged; on another 3 there was minor soil settlement much as occurred in Hurricane Lili and 2 jackups – Marlin 3, collapsed in 100 kt winds and 55 ft waves. It was working in 180 ft waterdepth – and the Dolphin 106 collapsed in 16 ft waterdepth.

Andrew went directly over a large number of jackups. Figure 45 shows the general area of expected damage 50 miles to the east 35 miles to the west: the area of most exposure. . Marlin 3 was the only jackup which came adrift and sailed to the beach. The Table 24 is extracted from the report on the Hurricane (Ref. 2) giving the rig name, type, waterdepth, distance and direction to the storm and the estimated maximum weather encountered.

Table 24: Jackup Results from Hurricane Andrew

Name	Type	Water Depth (ft)	Distance to Storm (Side Relative to Storm)	Estimated Maximum Weather Encountered
Marlin 3	Beth 265	180 ft	15nm (Left)	Wind 100 kts
Damage: Leg collapsed, drifted 50 nautical miles, lost Mat				Wave 55 ft
Dolphin Titan 106	Pen 100	16 ft	5nm (Left)	Wind 100 kts
Damage: Collapsed and derrick fell on platform heliport				Wave 32 ft
Jim Bawcom	Beth 250	36 ft	5nm (Right)	Wind 110 kts
Damage: Slide 50 feet over well head				Wave 40 ft
Penrod 63	Let 82-SD	42 ft	20nm (Left)	Wind 80 kts
Damage: Structural damage				Wave 35 ft
Ocean Summit	Lev III	155 ft	25nm (Left)	Wind 80 kts
Damage: Leaned onto platform				Wave 45 ft
Glomar Adriatic 2	Let 116-C	145 ft	25nm (Left)	Wind 80 kts
Damage: Lost BOP & drive pipe				Wave 45 ft
Ocean Pride	Beth 250	96 ft	22nm (Right)	Wind 100 kts
Damage: Small oil slick				Wave 60 ft
Rowan Paris	Let 116-C	165 ft	15nm (Left)	Wind 106 kts
Damage: Leg Settled				Wave 55 ft
Ocean King	Let 116-C	142 ft	38nm (Right)	Wind 95 kts
Damage: List a few degrees				Wave 50 ft

.Marlin 3 shown in Figure 46, after the incident – was overloaded by the hurricane that exceeded the design criteria – but not by much (Ref 2).

While the Marlin 3 figures concluded that it was above its limitations - there was a strong suspicion that the reason it did not survive arose from the multiple repairs to the trussed legs which had cracked and been troublesome to keep intact over time.

Figure 46: Marlin 3 After Hurricane Andrew and Prior to Scrapping.

The nine jack-ups that received various amounts of damage were located in water depth of 180 feet or less. All were well beneath their maximum operating water depth.

The jack-ups that were in deeper water and closer to their maximum allowable water depth were located on the left or weaker side of the hurricane path and 35 nautical miles or more away. These saw significantly reduced wind and wave forces than those rigs closer to the storm. The closest deep water jack-up was the *"OCEAN WARWICK"*, a Levingston Class III, located in 240 feet of water depth and 35 nautical miles on the left side of the hurricane path. This rig encountered a significant wave height of 25 feet and maximum 1 minute wind speeds of 83 knots. These environmental conditions were much less than those to which the rig was designed and it seems quite reasonable that this rig did not receive significant damage. Other deep water jack-ups were the *"DUAL 41"*, a F&G Mod II, and the *"ROWAN ODESSA"*, a Let 116, that were approximately 50 nautical miles on the left side of the hurricane path and in water depth of 260 feet and 248 feet respectively. These rigs encountered a significant wave height of 20 feet and maximum wind speed of 65 knots: these conditions were much less the values to which the rigs were designed.

If Hurricane Andrew had taken a different path such that the rigs in deeper water rigs saw environmental conditions closer to the peak conditions, the number of rigs damaged, and the extent of that damaged, could have been very different. Most of the deep water rigs were still within the maximum allowable water depths, but since the worst of Hurricane Andrew avoided these rigs, it is therefore not reasonable to use the fact that most of these rigs escaped damage to validate their water depth limits. As discussed above, the real operating limits of jack-ups are harder to define, based on modern calculation techniques, as site-specific factors, such as seabed conditions, play such an important role in a jackup's suitability. Those jackup MODUs that have collapsed in hurricanes have normally been due to factors that could have been easily predicted prior to the passage of the storm (e.g. lack of preload on the *"PENROD 61"* and *"DIXILYN FIELD 81"*) but there have been few units that have been exposed to close to their design conditions, and properly tested.

The structural capability of Bethlehem rigs is close to their physical water depth limits based on leg length. For Bethlehem designs their limits are more affected by the soils present at the site than by any other single factor. There have been many Bethlehem rigs that have slid during hurricanes and damaged the well. The *"HARVEY WARD"* was lost during a mudslide in Hurricane Allen. Many Bethlehem units are used to workover fixed platforms. They are often used because they can span any footing holes left by other, independent legged units. They are susceptible to moving in a hurricane and impacting the platform/wells they are working over.

The commonly accepted weather criteria for the operation of jack-ups is a 10-year hurricane. This is in contrast to modern fixed platforms, which are currently designed to a 100-year hurricane (although many of the older ones were designed to significantly less). A commonly quoted justification for the use of the 10-year hurricane data is that the consequence of a jack-up loss is less than that of a fixed platform loss (Ref 2). While this criteria evolved over the years it was well put by Rechtin and Scales (Ref 11)

> "*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."

The MMS Report (Ref. 2) concluded that there are certain jackup MODUs that are frequently used in water depths well beyond their limits, and others operate close to limits that were calculated on a, probably, unconservative basis. In addition, there are a large number of mat supported units, mostly designed and built by Bethlehem, that are very prone to sliding. There is additional reference in the MMS Report to the uncertainties that accompany the analysis of a jackup on a specific site in the Gulf of Mexico. These are tabulated in Figure 47.

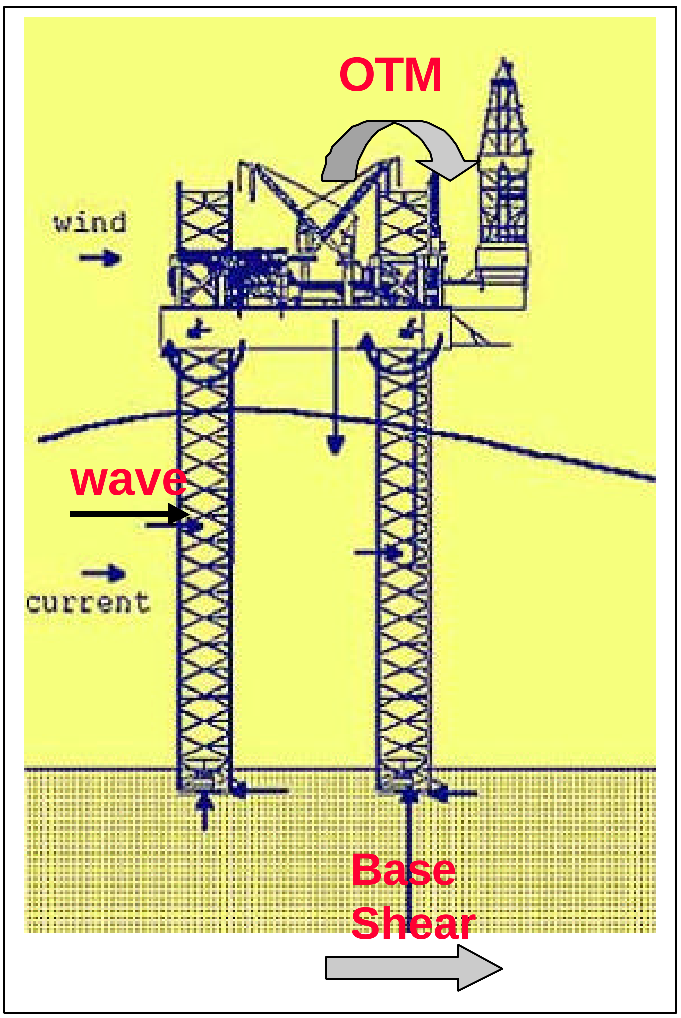


Figure 47: Site Assessment Uncertainties

Uncertainties

? Met Data
? Soil Data
? Soil Restraint w/spud can holes
? Above at Extremes

Checks

? Airgap & Leg Reserve
? Overturning
? Leg Stress
? Preload
? Safety Factors on above

The conclusion of the Hurricane Andrew sponsored work is that

- all the rigs reacted as predicted and there were at least no substandard methods of calculation.

- It may well be advantageous to ensure that jack-up operations are assessed in more detail in future by utilizing an accepted code.

- There should be some unified and consistent way of ensuring that jack-ups do not operate outside their areas of capability particularly when operating over or in close proximity to production platforms. Helpful to this task would be that Drilling contractors should be given the facilities within the operating manuals to ensure that they can maximize their jack-ups' survival capabilities by being informed of the critical failure mechanisms, and the optimum condition in which to leave the unit.

13.0 HURRICANE ANDREW CORRELATION JACKUPS

Comparing the issues of jackup MODUs in Hurricane Andrew and those in Hurricane Lili.

- Many of the jackups in Hurricane Lili were exposed in deeper waterdepths closer to, or in excess of their design capability. This was not the case in Hurricane Andrew where generally the rigs were in shallow water.
- There appeared to be no issues which would cause the jackup MODUs to fail in conditions below their capability, as was suspected in the case of Marlin 3 in Hurricane Andrew.
- The settlement as rigs exceed their preload capability is of interest, but there is little to be learned from this.

Two uniform conclusions from both studies is that

- all the rigs reacted as predicted and there were at least no substandard methods of calculation.

- It may well be advantageous to ensure that jack-up operations are assessed in more detail in future by utilizing an accepted code.

The report on Hurricane Andrew highlighted that a major problem concerns the definition of the 10 year hurricane to be used in the Gulf of Mexico and the significant differences that exist among the values quoted by different consultants, and used by many rig assessors (ref 2). The report also noted that the level of 10-year return period hurricane used is similar to the level of the 100-year sudden hurricane as defined by the API RP2A Section 17 for re-qualification of existing platforms.

A key criteria for jackup MODUs is that they be abandoned prior to the on-set of a hurricane which the jackup cannot withstand: this is the basis for the new criteria being evolved by the IADC Jackup Committee.

The assessment of jackups as to whether they are acceptable at a particular location is subject to many uncertainties. Some of those include soil uncertainties, meteorological data uncertainties, dynamics, and the contribution of foundation footprints. The one that impacts the safety most is probably the meteorological data uncertainties and it appears those are the most likely ones to be able to be unified.

14.0 CONTINUING ISSUES WITH JACKUPS: AVAILABILITY OF SOIL DATA

During the course of review of Hurricane Lili incidents, there were no issues related to a soil failure. Soils issues were examined, and even though none related to these particular incidents it drew attention to the fact that future incidents may be connected with soil failure or lack of being able to predict the soil situation prior to the jackup MODU going onto location.

Shell in a recent paper at City University on jackups evaluated a number of methods for ensuring the necessary control measures are in place so that risks associated with structural and/or foundation failure are managed effectively. A remark on the site data availability is of note:

> *The timely collection and collation of the site data in advance of the rig-on-site date, can represent a real challenge and needs to be slotted into the rig move sequence as early in the process as possible. Spud can penetrations achieved by other rigs at the intended site can provide valuable insights in to the application of soils data, particularly for locations where only limited bore hold data is available, but do not guarantee the safety of subsequent rigs.*

While not a factor in any of the Hurricane Lili incidents it is of note in passing that it is often difficult to obtain soil data at a particular proposed jackup location, in a timely manner. Locations are often decided with a short time fuse, and retrieving information from the lease owners' files is often a difficult task. As rig designs more toward a more "wave transparent" configuration there will be an increasing propensity for leg damage on jackups going onto location where soils data is unknown.

It is interesting to note a comment in the 1957 paper of Rechtin, Steel and Scales related to this issue (over 45 years before Hurricane Lili):

Remarks by Bramlette McClelland & John Focht (President and Chief Design Engineer, respectively McClelland Engineering Inc., Soil and Foundation Consultants, Houston Texas) "Since a single soil boring may cost from 10 to 15 thousand dollars or more, many operators fail to secure adequate information on foundation conditions. The dangers of this practice should be recognized. Even though a mobile unit may be designed for very weak soil, and may appear to have satisfactory bearing stability at the time of installation, its safety is not assured. ... In this connection, the writers would like to interpret more fully the authors' statement that the analysis of borings at the proposed site "is obviously not feasible for a mobile platform". It is assumed this statement refers only to the over-all design of a mobile unit and not to the installation of the unit on location. Installing of a mobile unit without information regarding the soil conditions at the site is the equivalent, on shore, of erecting a multimillion-dollar structure, which was designed by an engineer who had never seen the site nor had received any report of it.

One document available commercially in 1979 was the McClelland study on Soils for GOM, specifically McClelland Engineers "Strength Characteristics of Near Seafloor Continental Shelf Deposits of North Central Gulf of Mexico" Report No 0178-043, November 1979. This document was sold at "reasonable" cost to operators, drilling contractors and site assessors and provided a very reasonable basis for evaluation in those areas where there was no other retrievable data. An update of this document would be very useful in general terms for the jackup industry. While some may argue that the data is not enough and may lead to site specific data not being made available, a update of this could be quite a useful item.

It is recommended that MMS hold a discussion with IADC/ and Operators on the issue of availability of soil data for GOM locations and come to at least an understanding of what information would be helpful to have available in a forum so that drilling contractors could retrieve information on soil, rigs that have been on the location previously, and information on the soil penetration of those jackup MODUs.

It is recommended that industry and/or MMS encourage Fugro/Mc McClelland (Ref. 12) and explore the possibility of re-issuing the Gulf of Mexico soil atlas updating, that which was provided in the mid 1980s.

15.0 CONTINUING ISSUES WITH JACKUPS: OLD SPUD CAN HOLES

One of the items, which was considered in the case of Rowan Houston, but was NOT a factor in the collapse was the presence of pre-existing spud can holes.

In site assessments there is currently no accepted theoretical way to consider these items or their affect on the foundation integrity. When a Jackup MODU is removed from a drilling location its spudcans leave holes in a pattern known as a footprint in the seabed. When another jack up rig (often with a different footprint to the previous rig) moves onto the location there is often a tendency for the spudcans of the new rig to move into the footprints of the previous rig(s). The adverse movements caused by the spudcan-footprint interaction can in-theory result in:

- Damage to the rig
- Incorrect positioning of the rig
- Lost time getting onto location, and sometimes getting off location

The propensity of a rig to have issues with an existing spud can holes depends on the type of rig and how easily the leg "bends" into the hole; the resistance of the leg to rack phase differences (where one chord of a leg moves vertically with respect to another); and a number of other factors.

A recent Joint Industry Project has been trying to come up with a guideline on how to evaluate the effect of spud can holes, however the results are not yet in the public domain. The following diagram indicates the issue:

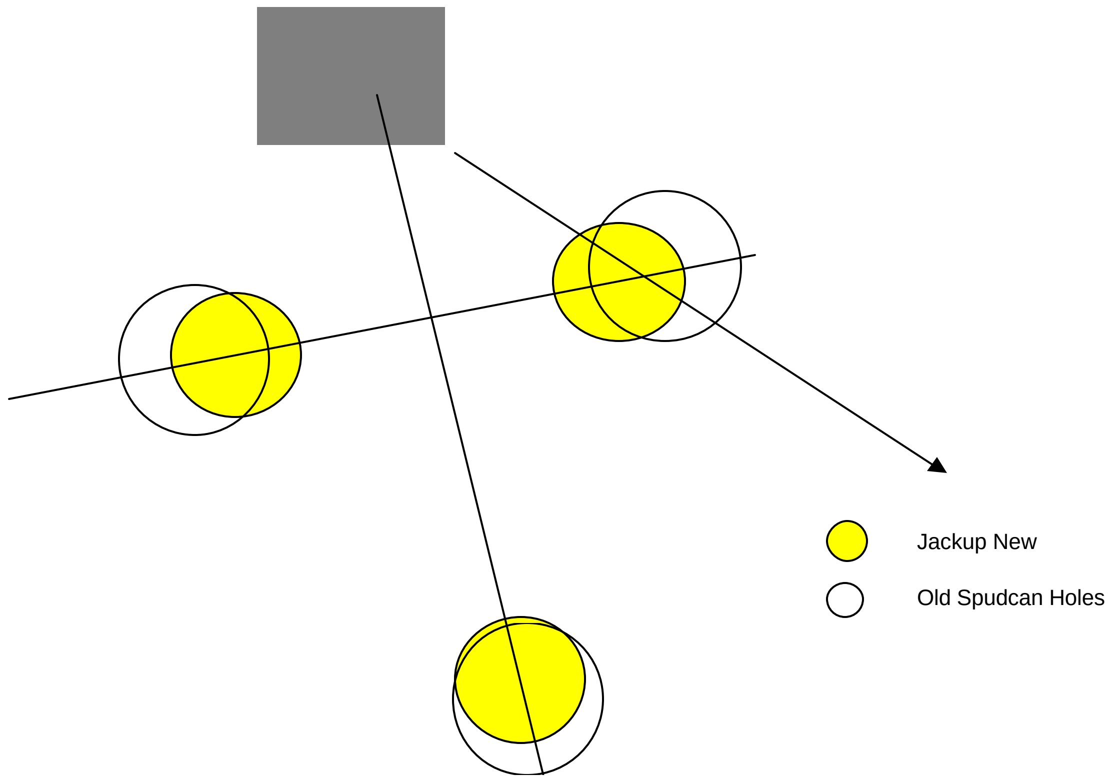


Figure 48: Spud Can Footprints of Jackup going on location with Old Spudcan Holes, alongside a platform (striped area).

As can be seen in the Figure 48 above, certain footprints do not match those of rigs, which may have been on location previously. The following illustration Figure 49 shows a variety of popular rig types, some 3 legged and some 4 legged with footprints superimposed. It must also be kept in mind that the average bearing pressure of the spud cans varies considerably also exacerbating the problem. If a spud can with a higher bearing requirement is on the platform ahead of the latest rig then it may turn out that the spud can holes are also deeper than that which would have been appropriate for the later rig. The result of several rig footprints of different size over the same platform gives a visual image of the issue.

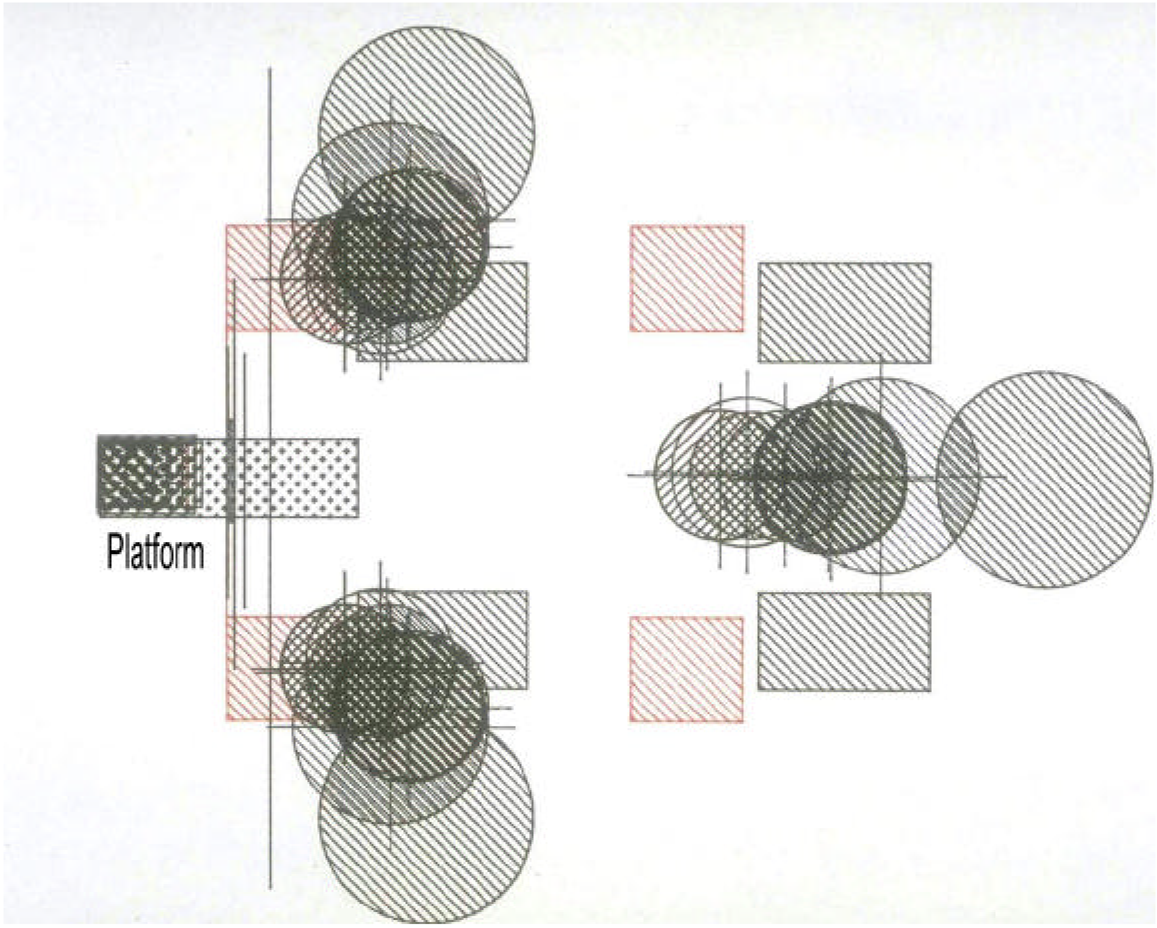


Figure 49: Illustration of Multiple Jackup MODU Footprints Superimposed on Each Other for a Target Platform.

While, as indicated this was not an issue with the rigs in Hurricane Lili as far as we were able to determine, it was indeed one of the issues that was closely scrutinized. One cannot help but observe that disclosure of soils information at jackup sites would enhance the ability of a drilling contractor in ensuring jackup MODU safety on location. For used sites: how previous rigs at that location have impacted the soil would also be helpful. It transpires that it is often not easy for drilling companies to obtain soils information for platforms they are bidding to work over. A method of making this information generally available would be helpful. There appears to be no obvious mechanism to make such a voluntary practice evolve, though the site is regulated through the lessee.

Global Maritime Consultants has been involved in a JIP on the subject of reducing the occurrence of problems associated with Jack-up spudcan-footprint interactions by publishing a Best Practice Guideline. Figure 50 illustrates a finite element approach to the evaluation of the spud can/soil interaction with old spud can holes – referenced at www.globalmaritime.com

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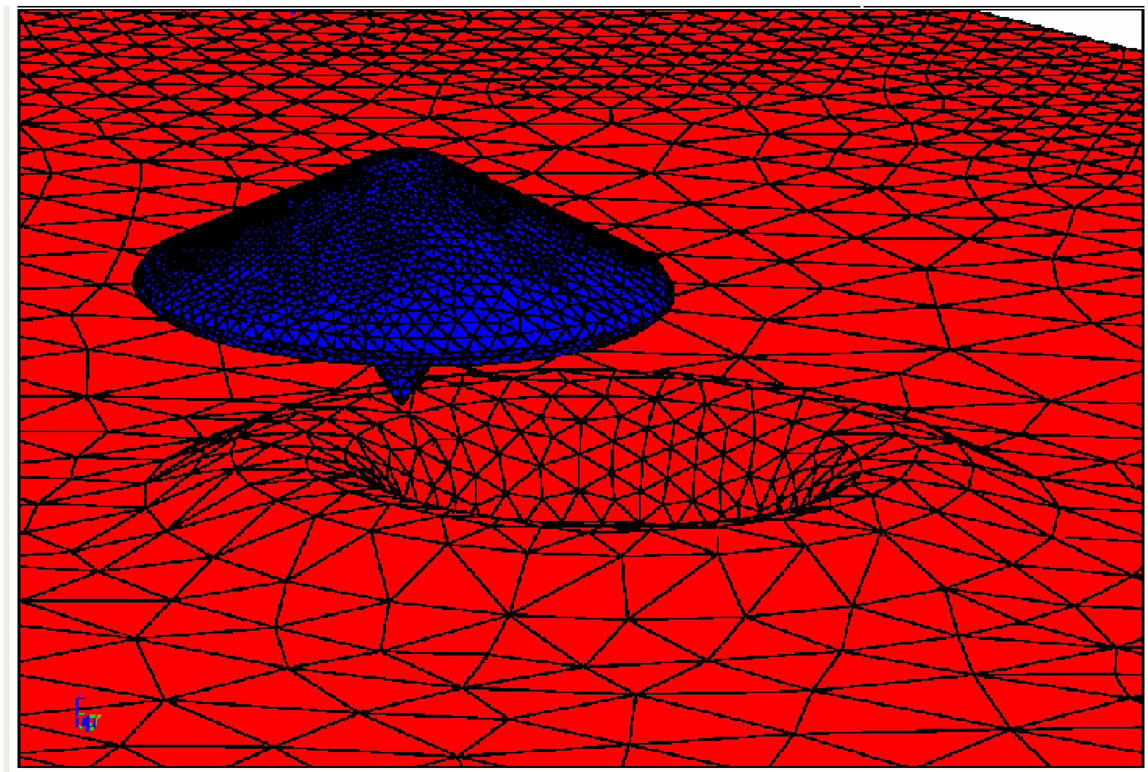


Figure 50: Illustration by Global Maritime Consultants of Spud Can Interaction

The bearing strength of a sample of jackup rigs while jacking varies from about 3 ksf to over 6 ksf. The maximum installed bearing pressure varies from about 3.5 ksf to over 10 ksf. The anticipated penetration therefore could double depending on the rig type used and soil (assuming a linear soil depth profile).

There have been various methods of dealing with the issue have been suggested and some tried:

- Filling in the Spud can holes with sand/ gravel
- Using a modified mat rig to cover the holes
- Schedule same footprint rigs to come back – or abandon the location in favor of a similar footprint rig.
- Schedule higher bearing capacity rigs than those that were there before.

Depending on rig type, these have had limited success.

The trend to go for “wave transparent” rigs that take the bending moment of the leg out with rack chocks exacerbates the problem of getting onto location. While we have not seen these issues in explicit terms in the Gulf of Mexico to date, it is well to anticipate them. The issue is explored in a recent paper by Foo, Quah, Wildberger and Vazquez where it states:

> *Old footprints created by jack-up spudcans can be an obstacle to the successful installation of a jack-up on site. These have been shown to cause diagonal and horizontal braces on the leg to buckle, thereby increasing the cost of the overall jack-up operation on site. The above discussions suggest that if the foundation characteristics allow the leg structure to slide into an old footprint, the structural strength/stiffness of the jack-up legs will not be the predominant factor in determining whether structural damage will occur.*
>
> The authors go on to recommend an addition of a device for measuring the RPD (Rack Phase Difference).

It is recognized that the general result of the spud can holes is a delay getting on location while the rig “reams” and “reworks” the holes (i.e. driving the leg up and down until the hole is large enough to take the leg of the latter rig without horizontal pressures. This is not generally a concern of safety but one of economics. Nevertheless it is considered prudent to investigate the phenomenon further and MMS may be able to sponsor a program to enhance the understanding of the issue.

It is recommended that MMS explore the issues in some further depth and request the IADC to make a recommendation as to how a regulator might proceed in this area to make the information available and thereby enhance jackup MODU safety.

Additionally it is suggested that some further research could be explored by inviting a Research paper on this subject.

References Specifically on the Subject of Jackups and Spud Cans:

David A. Geer, S. Douglas Devoy and Vladimir Rapoport
Effects of Soil Information on Economics of Jackup Installation, OTC Paper 12080 – May 2000.

Exxon Production Research Co.; U. of Cambridge, Effect of Jackup Spud Cans on Piles OTC 6467 – May 1990.

Fugro-McClelland Ltd.; BP Intl. Ltd., Potential Effects of Jackup Spud Can Penetration on Jacket Piles, OTC 5762 - May 1988

MARSCO Inc.; Matthews-Daniel Co.; MS Benbow & Assocs.; Huthnance; Soil-Structure Interaction During Preloading of Jackup MODU's in Different Soil Conditions, OTC 7531 May 1994

Syminex, Rig Jacking on Soft Soil Foundations: Improvements in Safety and Speed by Monitoring Leg Loads OTC 4408 – May 1982.

Carrington Tim., Hodges Bill, Aldridge Tom, Osborne J. and Mirrey J., Jack-Up Advanced Foundation Analysis by Automatic Re-meshing (Large Strain) FEA Methods, Ninth International Conference: The Jack-Up Platform Design Construction & Operation 2003, London, England.

Foo, K.S., Quah, M.C.K., Wildberger P., and Vazquez J.H., Spudcan Footprint Interaction and Rack Phase Difference (RPD), Ninth International Conference: The Jack-Up Platform Design Construction & Operation 2003, London, England.

16.0 CONTINUING ISSUES WITH JACKUPS: IN-SERVICE INSPECTION KNOWLEDGE

During the course of the investigation we were mindful of the age of the rig fleet and conscious of the importance of commenting as to whether this was a factor in the incidents. From the data gathered it was concluded that age was not a factor in the collapse of either of the jackup MODUs that were total losses. All engineering calculations carried out assumed as-new material and thicknesses and conclusions reached were not factored in any way for age.

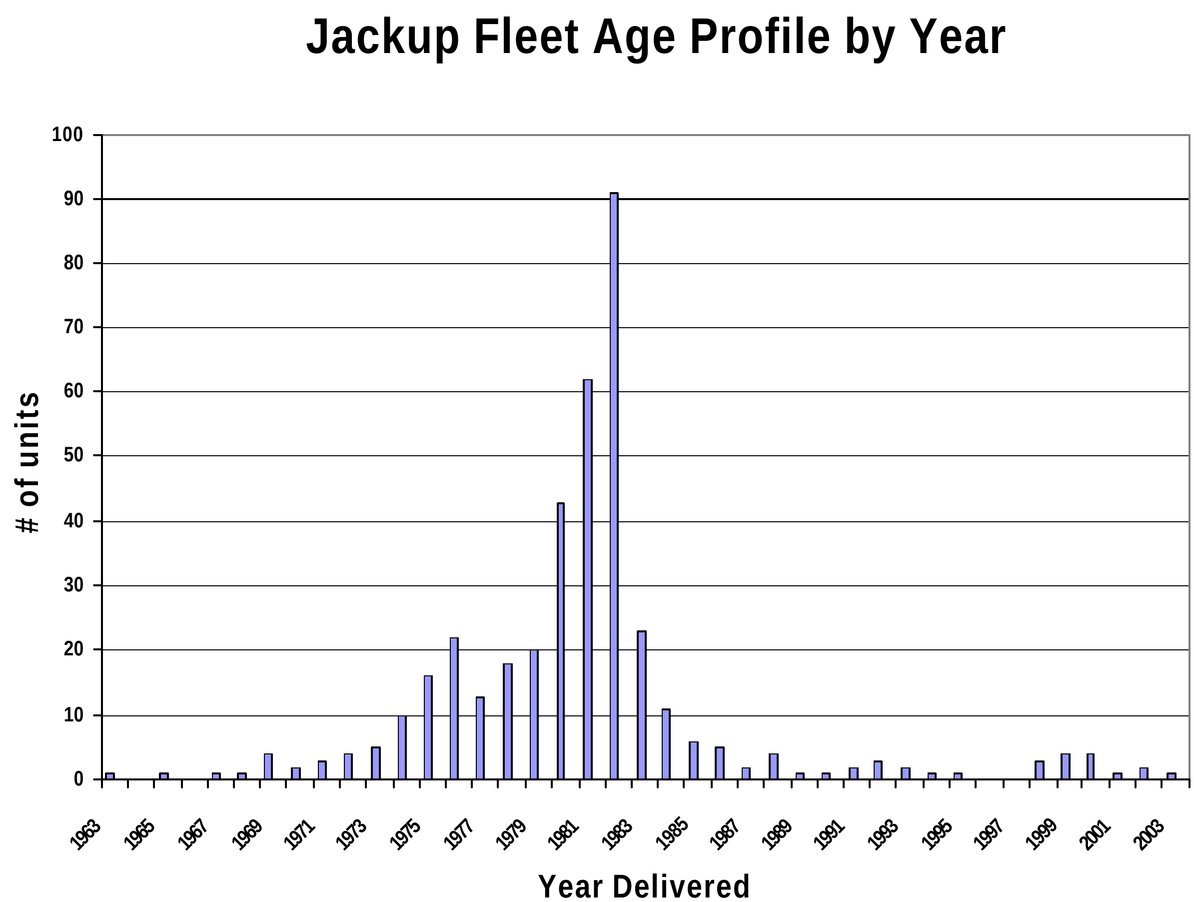
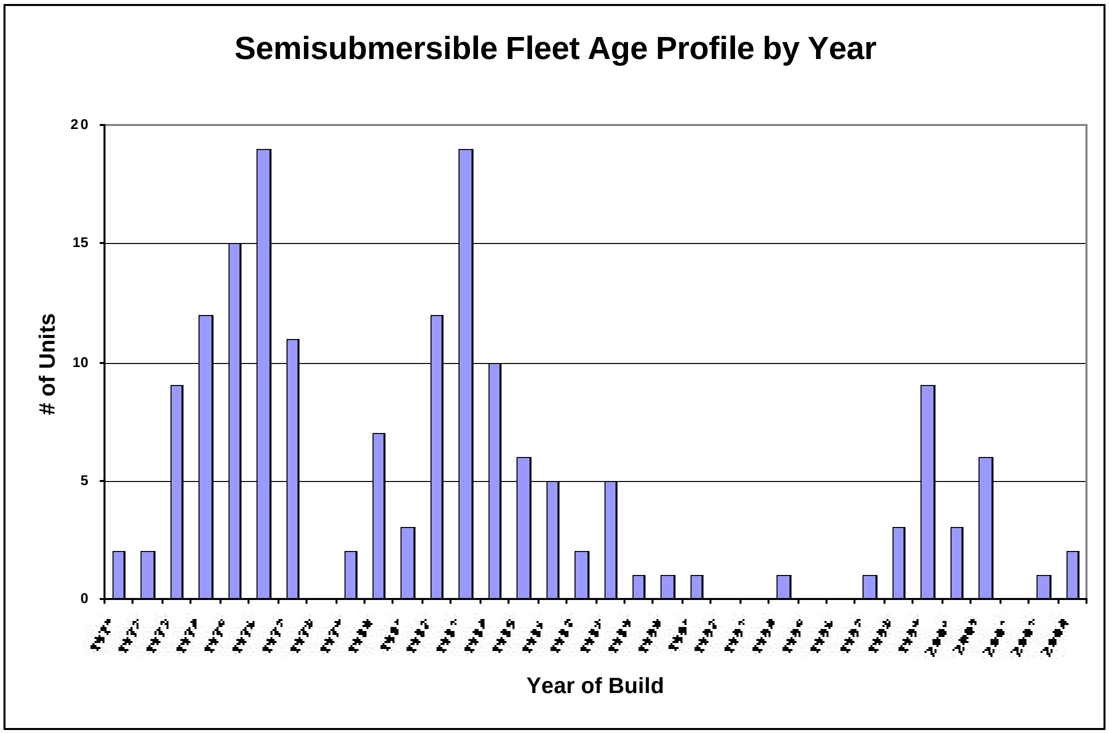


Figure 51: Jackup Fleet Age Profile by Year.

Reflecting on the issue of jackups and semi-submersibles the age profile is shown in Figures 51 and 52.

The distribution of Semi-submersibles is not too unsimilar to those of jackups, but there are fewer of them than of the jackups.



Based on Ocean Shipping information.

Figure 52: Semisubmersible Fleet Age Profile by Year

While not an outcome of the study incidents, during the course of consideration of ways to continue to enhance rigs and keep them capable of the very highest peak loads, the age profile was taken into account.

In reflecting on the issue, and in discussions with experts in the industry, it was generally acknowledged that the issue surrounds the disparity between the age of the surveyors/inspectors and the age of those personnel in the industry that have experience of the various rig “issues” of the past. The legal processes and the general wish to not highlight the potential issues hamper the promulgating of information on incidents, accidents and potential issues in our industry. As the age of the personnel in the industry increases, and as the incidents pass further from the corporate memory it is of importance to ensure that new personnel have a adequate handbook for inspection of jackups in particular. It is argued that class societies know where to “survey” rigs but their “survey” is stated not to be a substitution for owner’s inspection. Even within the class societies the “instructions” as to where to look on a jackup generally appear to lack specificity and we have been unable to unearth any document which gives advice on the critical parts of jackups and what is critically important to check. For example: a typical inspection by a surveyor might call for inspection of the thickness of legs at the waterline: an area of much less importance than the inspection of the legs between the guides at the anticipated operational location, or the generally used leg towing position. As a result of the Rowan Houston casualty, though re-iterating that it was NOT a factor – a prudent surveyor would add the area of the jack case to deck connection as a critical area to be inspected on all future rigs.

Likewise, it is well known for mat-supported rigs that the mat-column connection is a key area, which has caused casualties in the past. This area is generally still recognized as being of importance and we would anticipate that most rig inspectors would today be aware of this: but as the events of the Ranger 1 which caused this issue to be elevated fade from memory – this crack prone area could be an issue in a future incident.

It is thus one of the recommendations from this study that MMS give some consideration to encouraging the industry to develop a guideline of critical areas to inspect on jackups and make this guideline generally available for surveyors and inspectors. It may be that the class societies can be persuaded to cooperate in the writing of this document.

Figure 53: Independent Leg MODU Areas of Inspection Interest

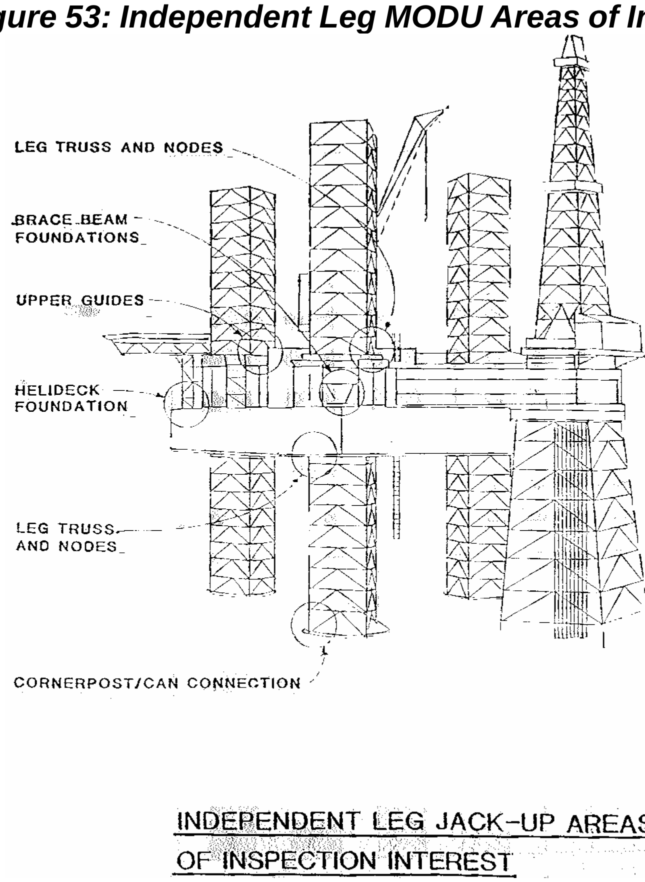
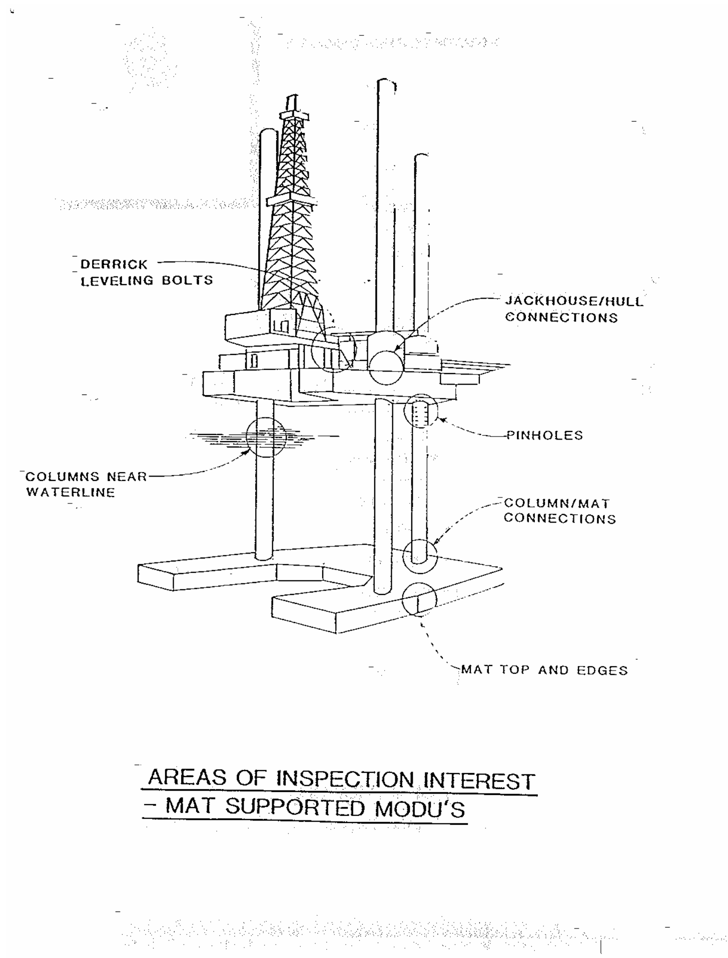


Figure 54: Mat Supported Rig Areas of Inspection Interest



For example this document might chronicle some of the past incidents and provide an on-going updated location to log the experience.

Mat Rigs – Mat/Column connection issues arose from several rigs experiencing fatigue issues at the connection point. General advice on inspection is to carry out a diligent magnetic particle inspection of the connection points at a minimum at each underwater survey (every 5 *years). Documented incident related is the Ranger 1 USCG Report circa 1980.*

Truss Leg Rigs powered on 2 of 4 chords or 1 of 3 chords (Named). Generally fatigue is not included in the design of truss leg rigs for tow situations. Inspection before and after tows should take place, particularly for these units where the diagonals take a reversal of loading at each cycle when un-powered chords are part of the design. Examples should be named.

Jacking Pinholes in tubular leg rigs – due to vortex induced vibration the area at the corner of pinholes at the upper guide during tow need to be inspected after tow since this is the critical area where the first fatigue cracks may appear. Pinholes 5 bays above the upper guide have been susceptible in the past. Makes and models should be named*.*

Rigs without rack chocks – Upper and Lower guide areas in operation are areas of high stress and should be checked in areas at the upper and lower guide for the tow position; the upper and lower guide for the operation condition; including both legs and watertowers. The guide itself should be checked to ensure there are no cracks in the guide attachment to the hull

.

While the above are intended only as examples, it would be anticipated that such a document would chronicle the incidents and accidents where inspection could play a useful part. It may also be appropriate to ask designers to contribute, as designs evolve to ensure that critical areas can be pinpointed on new designs. The document would be of most value if only critical areas are highlighted: and while this is not meant to restrict inspection/survey it is meant only to highlight and enhance the knowledge of individual inspectors/surveyors that may not be familiar with the peculiarities of the design.

17.0 CONCLUSIONS AND RECOMMENDATIONS: GENERAL

A great deal of information was developed as a result of this study and the promulgation of the information will be very helpful to the committees developing MODU standards for the Gulf of Mexico. Detailed investigations are very helpful in understanding appropriate levels of safety in standards, and should be conducted after all hurricane exposures in order to verify criteria and learn more on preventing future damage. All MODU incidents should be reported and the information made generally available: ideally reports should go to the regulator through a standards organization. This requires that the incidents be investigated. It is only by investigating failures and distribution of the information that the reliability of systems can be understood, and consequently improved.

Investigating all incidents led to the reporting that there were significant differences between the results of the hindcast companies regularly supplying metocean hindcast information. Determining failure mechanisms without uniform agreement on the meteorological data, which forms the basis for loading, leaves uncertainty in the process. These same companies provide suitable criteria for the siting of MODUs. This leads to a reflection that determination of loads from these various sources can lead to widely different loads and thus widely different results and probabilities of failure. Such significant differences erode the confidence that a suitable uniform criteria is being applied in the industry for site-specific MODU locations. The difference in the "numbers" for the same event translates to a difference in approach of the organizations. Users of this data do not always understand the subtleties of interpretation of events and data between one metocean consulting organization and another. Since this is such a significant issue it is recommended that the MMS consider sponsoring a Workshop, and/or sponsoring a "university" research project to investigate and evaluate the differences between methods used by the various suppliers of metocean data to the offshore industry for Gulf of Mexico use – and promulgating that information in a clear form to assist the users in understanding the variability of the information provided. Any attempt to itemize and rationalize differences, and get the issues into the domain of users of the information would be helpful. Such a study/workshop will allow the owner/operator to assess the implication of these differences on the safety of the MODUs they either own or operate. The strategy would be: that by getting the metocean experts in the same forum, and with discussion – effect a situation where the same results in terms of metocean parameters were being used uniformly by the hindcasters.

18.0 CONCLUSIONS AND RECOMMENDATIONS: FLOATING MODUs

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 standard criteria. While the risk of a severe hurricane impacting a selected semisubmersible may be acceptable to an individual owner based on current criteria, the risk of a Gulf of Mexico hurricane setting one of the many rigs in the Gulf of Mexico adrift is substantially higher: and thus criteria acceptable to an owner may not be acceptable to a regulator. The incidents that occurred led to no issues: no injuries, no pollution, and no other structures knocked down, or pipelines dragged.

Overall it is not desirable for semi-submersibles to break adrift of their moorings and potentially impact other structures. While the API mooring committee has developed good standards which continue to improve with time, there is a need to examine how, if loads recommended are exceeded, as happens in a severe hurricane event, whether there is a method of afterwards controlling the movement of the unit to minimize potential damage.

It is recommended that the API Mooring Committee and/or the ISO TC67 SC7 committees take on the task of examining these incidents and the recommendations and come up with a more robust criteria either in terms of weather data to approve siting of the rig, or a practice of mitigation methods such as limiting movement of the rig should the primary mooring system fail.

In discussion with several engineers in this investigative process, some interesting ideas developed. There was some agreement that a small amount of anchor drag can be beneficial in preventing mooring line breakage by allowing some redistribution of line loads, but it can be difficult to accurately predict when slippage will occur, especially given the variety of soil conditions that there are in the Gulf of Mexico. In some cases, the holding capacity of the anchors can be much more than would normally be expected using standard published data: the assumption of slippage, in the analysis, can then become dangerously un-conservative. Conversely, if there is too much slippage, then the unit can drift a significant distance and potentially damage other structures and/or pipelines. So far as we are aware, little research has been done on optimising mooring systems for semi-submersibles while allowing anchor drag. Little also has been done in the way of designing anchors so that in the extreme event they would drag and hold rather than hold in such a way as to allow the lines to break.

If anchor drag is assumed in the mooring analysis procedure to mitigate the consequence of damage, further research is required to develop techniques that predict the ultimate holding capacity of anchors. More information than is presently supplied, particularly with respect to the soils, needs to be known about the proposed operation site prior to mooring a unit in order to determine this capacity. Not only are the site specific soil conditions rarely known with sufficient accuracy, but also the analytical model available for predicting holding capacity in various soil conditions is not yet adequately developed. The advent of suction pile and high holding power anchors which result in a zero capability of the rig to resist drifting in the event of a failure, necessitates a re-thinking of the design standards.

Some designers, in the past, contended that an optimal design should have the anchor weaker than the anchor wire or chain thus there would always be a case of the anchor dragging prior to line failure. This worked well in the highest loaded semi-submersible in Hurricane Andrew (Ref. 2). The optimal relationship between line load and anchor capability is not well developed. For example, it would be interesting to know what the results would have looked like for those semi-submersibles that have broken adrift in past hurricanes, had the anchor lines been strong enough to preclude failure by the failed component remained intact and the next weakest component failed.

It is recommended that the API mooring committee investigate and recommend not only the design conditions of the rig to weather hurricanes, but also characteristics of the mooring system to prevent full stationkeeping failure with resultant "drifting" should those loads be exceeded. Several ideas come to mind including: deploying a device to slow down the unit and prevent drifting; decreasing the recommended holding capacity of the anchors in the code; further development of anchors, and perhaps even remote deployment of an anchor. This would be a suitable research project for sponsorship by MMS and/or other agencies: the above ideas could usefully be explored by funded studies.

Over the years, the API Stationkeeping RP has provided continuing recommendations for better security against semi-submersibles mooring failures in winter storms. Regulatory authorities should continue to support this development. After hurricanes and information coming available on any issues arising, API should consider the criteria in relation to the incidents and use them as an opportunity to improve the recommended practice.

As part of the recommendation above to investigate all MODU incidents, anchor drag incidents should be investigated as well as mooring line failures should be investigated. This is particularly important since it leads to an opportunity to fill the gap in knowledge about how anchors perform during high loads, how they ultimately fail and as such will consequently lead to improvements to current design practice

Several other observations are of note that came out of the Hurricane Andrew investigation that could be usefully re-iterated here:

- There is a need to instrument some semi-submersibles in order to benchmark the mooring analysis assumptions and methodology. MMS should consider how to encourage operators to add instrumentation perhaps on the FPSs since they present an excellent opportunity to gather this information.
- Vital structures in the Gulf of Mexico should be designated (e.g. those that would result in severe environmental or financial loss, should a collision occur). This would help facilitate future risk studies that could examine specific mooring locations with greater precision and insight. For example the "proximity to other structures" in API could be afforded a better definition related to where semi-submersibles are anchored.

In suggesting that API further study the incidents and continue to develop standards, it is particularly suggested that mitigation techniques other than increasing the criteria be investigated, since an increase in criteria will merely move the issue to a slightly less probability of occurrence, and not necessarily prevent future drifting of semi-submersibles in hurricanes. Since increasing the criteria would lead to larger moorings, possibly pre-deployed moorings, which may very well have its own issues, the recommended solution probably involves limiting the consequences of failure.

19.0 CONCLUSIONS AND RECOMMENDATIONS JACKUPS

Understanding how MODUs react to severe weather events, whether we have calculation methods that reflect reality, and whether we can identify critical areas for inspection to give early warning that the unit may not achieve its maximum capacity (even though beyond design) are all important to the well-being of the Gulf of Mexico infrastructure. We live in a culture that does not easily accept, promulgating the results and insights into accidents and incidents, consequently it's not often one gets to know what the causes of an incident were and reflect on the results. For jackups all storm damage and severe settlement events should be reported on and made available to the jackup community as a means to a better understanding of the structural behavior of jackups.

The ideal method of reporting is voluntarily through a standards committee such as through the IADC/ SNAME group working on the Gulf of Mexico regional annex.

Individuals in companies are often reluctant to go through a reporting process. While we have had excellent cooperation from a number of companies: there needs to be a way to release information in accidents and incidents without causing undue distress. One possibility is for the MMS to meet with industry to decide how best the incidents can be examined on a routine basis.

There is no evidence that age of the rigs was a factor in the incidents. The practice of evacuating jackups in the Gulf of Mexico is appropriate.

The jackups performed well, and while a few cracks resulted in one or two rigs, jackups are very redundant and can handle these generally well. Caution is recommended, however, and continued diligence about the condition of the rigs. One item that may be of assistance to ensure uniformity of survey is for a basic manual to be developed clearly showing critical parts of jackups, by type that should be inspected to enhance the ability of rigs to maintain their very maximum capability.

A mechanism needs to be worked out for soil data to be available for rigs going onto used drilling locations. The issue of whether the development of a guideline on how to go about assessing used locations and the impact of historical footprints on rig capability would be a useful idea, should be deliberated by industry. Both these issues should be sent to the SNAME committee on jackups and API Committee 2, for their consideration.

The meteorological information provided in the visual form that Oceanweather has provided it for their study, is commendable. It puts in perspective the very narrow area that is exposed during the 100-year event, and gives confidence to the notion that potential for accedence of design conditions for a jackup are very limited in extent when one of these hurricanes comes through the Gulf of Mexico.

The results of hindcast information obtained for this study indicate wide variance in the results by the meteorological consultants often used by drilling contractors and oil companies. Some more understanding of the difference in results would be desirable. The variance makes it very difficult to determine after the fact, the root causes of any accident. Likewise site-specific determination of the likelihood of a jackup to survive a storm is likewise at variance, depending on whose meteorological criteria is used. Further study of the differences between the techniques used by the various meteorological consultants and promulgating this information could be useful for the community as a whole.

The criteria to which rigs in the Gulf of Mexico have generally been capable of is about a 10-year return period storm. Efforts are underway to derive a more rational criteria related to the structural strength required in order to ensure the jackups safely provide for abandonment prior to the on-set of hurricane conditions, in case the resultant storm is greater than that for which the jackup is designed. This research work is under development by the Gulf of Mexico Jackup Sub-Committee of SNAME funded by a small group of IADC drilling contractors. This is an excellent industry project, and deserves the support of regulators.

The investigation into the jackups revealed that both jackups that collapsed did so under weather conditions, which were well in excess of the design loads. The jackups that failed brought to light several issues which have only been given cursory attention in the standards developing within the jackup industry making jackup owners aware of the issues.

In the case of the Dolphin 105 the deck height criteria recommended in API for fixed platforms in Full Population Hurricanes would have been insufficient for this location. The rig owner could reasonably have expected to rely on this guidance. Recommendations are made to the API Committee to add a caution to its Chart Ref: 17.6.2-2b that the deck height in shallow water can be higher if breaking waves are considered. Caution about the higher crest height to wave height ratio for breaking waves could usefully be added to Marine Operating Manuals of jackups similar to this unit which are likely to be used in shallow water, where breaking waves are likely.

Additionally the loads imposed due to breaking waves were much higher than would have been predicted without specialist knowledge that a breaking wave could likely result from an extreme storm at this site. There would have been no warning in the Marine Operating Manual for that effect to ensure the owner/operator could have predicted the need for either a higher airgap and the need to consider alternative action in evaluating the prudence of leaving the jackup on that location because of a potential accedence of the design conditions. In general there is little guidance in the standard industry site-specific evaluation documents on breaking waves. It is recommended that the IADC Jackup committee and ISO TC67 SC7 take note and add a section to their Guidance on this subject.

The Rowan Houston was on a location where a deeper penetrating jackup had been located previously with a somewhat different footprint close by. While readings were taken of the leeward leg, it was not obvious that it penetrated further. Measurements taken on location by divers appeared to coincide with what might be an expected depth of a leg that had swayed sideways without taking on further penetration. The state of the gear trains on the leg after the event initially led to a suspicion that an initiating event may have been the jack foundation separating from the deck on the starboard side. Calculations showed that this was the most plausible mode of failure consistent with the observations and that the load would have exceeding the design by a good factor. The conclusion that this was not a pre-mature failure of the jackhouse/hull interface is supported by the fact that the rig was in class and had been surveyed by the class society, ABS, and the survey had included the jack foundations attached to the deck. Damage to the port forward corner took on the characteristics of a collision but on further reflection it was apparent that it occurred as a result of the bow leg impacting that part of the hull during the collapse. If the jack foundation parting from the deck was the initiating factor for failure, it is a unique failure. The author is not aware of this type of failure being the initiating event for collapse in any other rig of this type. While this is not an unexpected failure possibility in that this connection is part of the rig design, it has been general experience that this area has not been the first to fail in other rig accidents. Since the Rowan Houston was overwhelmed with the storm to such a great extent, and would not have been expected to survive, when compared to the design event – the initiating event is important only as a means to provide further guidance on another location on the rig to be ever-diligent about during the inspection process.

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. While there are no lessons to be learned directly from the incident, it became apparent during that some gaps in knowledge/training could be usefully filled with items, which might prevent future incidents. There are no uniform ways to deal with the pre-existing spud can hole in evaluating the location for site-specific approval. Though it is stressed this was not a contributor in this case, there is no industry document to determine where experienced surveyors should inspect a jackup. Since all jackups have specific areas where inspection is proper, identifiable from historic issues or identifiable from analysis, surveyors inspecting the units could benefit from a "go-by" document identifying areas of concern.

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21.0 ACKNOWLEDGEMENTS:

This work could not have been undertaken except for the special assistance and generous contributions of the drilling contractors who offered their information and contributed to the study. In particular for the semi-submersibles: Diamond, and Global Santa Fe; for the jackups: Rowan, LeTourneau, Noble and Nabors that shared their information. The study of Oceanweather reporting on the extent of the maximum winds and waveheights so the issue could be seen visually, enhanced the understanding of the casualties.

This MMS sponsored post mortem assessment of the MODUs in Hurricane Lili 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 – OTC PAPER

APPENDIX B – OTC PRESENTATION

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MINERALS MANAGEMENT SERVICE CONTRACT

Hurricane Lili MODU Investigation & Recommendations Oct 02

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