ASSESSMENT OF FIXED OFFSHORE PLATFORM PERFORMANCE IN HURRICANES ANDREW, LILI AND IVAN

January 2006

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Energo Engineering Project No.: E05114

Energo

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Andrew Konczvald
U.S. Department of the Interior
Mineral Management Service
Engineering and Research Branch
381 Elden Street, MS 4021
Herndon, VA 20170

Subject: ***MMS Project #549 – Final Report***

Dear Andrew:

Please find enclosed the final report of the Assessment of Fixed Offshore Platform Performance.

The report describes the Qualitative, Quantitative and Expert Panel portions of the project. In the Expert Panel section, recommendations are made for further evaluation, particularly given hurricanes Katrina and Rita that impacted the Gulf of Mexico fixed platform fleet following Ivan. The final report also contains the comments received on the draft submitted to the MMS in December 2005.

We appreciate the opportunity to work with the MMS on this interesting project and we look forward to working with you again in the future.

Sincerely,
Energo Engineering, Inc.

Robert E. Spong Jr.
Senior Consultant

Frank Puskar, P.E.
President

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ABBREVIATIONS

4-P	4 pile
4-P SK	4 pile w/skirt piles
8-P	8 pile
8-P SK	8 pile w/skirt piles
API	American Petroleum Institute
B-CAS	Braced caisson
C-TOWER	Compliant tower
FORM	First Order Reliability Method
MC	Mississippi Canyon Area Blocks
MMS	Minerals Management Service
MP	Main Pass Area Blocks
NTL	Notice to Lessees
OSTS	Office of Structural and Technical Support
OOC	Offshore Operators Committee
RP 2A	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, 21st Edition
RP 2A Section 17	Section within RP 2A 21st Edition that covers the assessment of existing platforms
SP	South Pass Area Blocks
TOPCAT	Template Offshore Platform Capacity Assessment Tools
VK	Viosca Knoll Area Blocks

TERMS AND DEFINITIONS

Saffir-Simpson Intensity Scale (SSI) – 1-5 category rating based on a hurricane's sustained wind intensity.

Forristall Distribution – A probabilistic distribution used to describe the maximum wave height during a storm

Bayesian Updating – A method used to update probabilistic distributions based on actual findings of samples

Bias Factor – A factor used to describe the ratio of actual capacity to calculated capacity

CONVERSIONS

1 foot (ft) = 0.305 meters (m)
1 mile (mi) = 1.609 kilometers (km)
1 knot (kn) = 0.514 meters/second (m/s)

EXECUTIVE SUMMARY

Background

Hurricane Ivan (Ivan) was a major hurricane that passed through the Gulf of Mexico on September 14 and 15, 2004, destroying and damaging numerous offshore oil and gas platforms. Ivan is one of several hurricanes that have damaged or destroyed platforms in the Gulf of Mexico during the last dozen years, the others being Andrew in 1992, Lili in 2002, and Katrina and Rita in 2005. These events provide a unique opportunity to determine the effectiveness of current structural design standards and MMS regulations and develop recommendations for changes, if any.

This document describes a project that used the results of Ivan to determine the current state of performance of API and MMS regulations in terms of the design of *fixed offshore platforms*. The project gathered Ivan fixed platform damage information into a database and evaluated trends, performed a quantitative assessment that compared analytically predicted platform damage to actual observed damage, and made recommendations for suggested studies of key fixed platform design issues. The focus of the effort was on wave-induced damage to the structural systems (foundation, jacket and deck), and not wind damage to topsides.

Approach

The work was accomplished in three tasks:

Qualitative Assessment. Data was gathered from the MMS as well as several operators on fixed platforms destroyed and damaged in Ivan. The data was reviewed and summarized into a database. The work also identified general trends such as number of platforms destroyed and damaged, age and water depths of the platforms destroyed, etc.

Quantitative Assessment. This provides a comparison of the platform's *actual* response to Ivan (destroyed, damaged or survived) versus what the load and resistance recipe in API RP2A would have predicted in terms of an *analytical* response. In other words, if a platform was destroyed in Ivan – would this have been predicted by RP2A? The results of this process for Ivan were compared to that of Andrew and Lili.

Expert Panel. This involved a "panel" of 13 experienced offshore structural engineers that reviewed the results of the above tasks, as well as general knowledge of hurricane damage to fixed platforms, and made recommendations for further study.

Results

Qualitative Assessment

The majority of the information used in the qualitative assessment was gathered from the Office of Structural & Technical Support (OSTS) of the MMS. Information was also obtained from the platform operators. This data comprised of post-Ivan inspection reports, structural assessments and repair reports as well as general information from the MMS platform database. The Ivan hindcast was also obtained through the MMS. This information was used to archive the damage and investigate trends as they related to the platform performance.

A total of seven fixed platforms were destroyed as a result of hurricane Ivan. One of the seven (MC 20A) was toppled by a mudslide, while the other six failures are thought to be attributed to the environmental loads (i.e., wind, wave and current) exceeding the capacity of the structures. The seven destroyed platforms are from the initial list provided by the MMS. Note that additional platforms may have been later decommissioned by the operator as a result of damage sustained from Ivan.

In addition to the seven destroyed platforms, there were a number of other fixed platforms that sustained varying degrees of damage during Ivan. Table E.1 presents a list of the fixed platforms that sustained damage during Ivan. Some of the damage and failures were not considered a surprise, since the many of the platforms that failed or sustained major damage tended to be older vintage facilities designed to lower environmental criteria than current design. These platforms generally have lower global strength characteristics (e.g., weaker joints, less robust bracing patterns, etc.) than platforms designed to existing industry practices. Additionally, these older platforms typically have lower topside deck heights which make them significantly more susceptible to wave-in-deck, which can increase the loads on the platform well over the platform’s ultimate capacity. However, the extent of topside damage both structural and non-structural (i.e., process equipment, safety systems, controls, etc.) on many of the platforms, both new and older vintage, indicated Ivan caused extremely large waves and associated wave crest heights, possibly larger then the hindcast predictions.

The fixed platform data indicated the majority of the platforms that failed or sustained major damage during Ivan were in water depths between 200 to 350 feet and had deck heights at or below the current API recommended practice new design deck heights. The resulting damage to the topsides included deck structure failures and deformations generally as a result of wave inundation. Wind damage was also observed on quarters and building structures. The damage to the jackets included jacket leg buckles and separations, bracing failures (e.g., parted and buckled members), joint failures (e.g., crushed joint cans and brace punch through) and conductor bracing failures. Specific observations are discussed in detail in the main body of the report.

Table E.1 – Platforms Damaged During Hurricane Ivan

No.	Area	Block		Operator	Water Depth (ft)	Year of Installation	Exposure Category	Deck Height (ft)	Structure Type	Damage Category (Note 1)
1	MC	20	A	Taylor Energy Company	475	1984	L1	49	8-P	destroyed
2	MP	98	A	Forest Oil Corporation	79	1985	L1	57.5	TRI	destroyed
3	MP	293	A	Noble Energy, Inc.	247	1969	L2	45	8-P	destroyed
4	MP	293	SONAT	Southern Natural Gas Company	232	1972	L2	42	4-P	destroyed
5	MP	305	C	Noble Energy, Inc.	244	1969	L2	46	8-P	destroyed
6	MP	306	E	Noble Energy, Inc.	255	1969	L2	46	8-P	destroyed
7	VK	294	A	Chevron U.S.A. Inc.	119	1988	L2	32	B-CAS	destroyed
8	MP	296	A	GOM Shelf LLC	212	1970	L2	46	8-P	major (D)
9	MP	277	A	El Paso Production Oil & Gas Company	223	2000	L2	50.3	4-P	major (D)
10	MP	279	B	Dominion Exploration & Production, Inc.	290	1998	L2	53.5		major (D)
11	MP	138	A	Newfield Exploration Company	158	1991	L2	55	4-P	major
12	MP	311	B	GOM Shelf LLC	250	1980	L2	39.5	8-P	major
13	MP	296	B	GOM Shelf LLC	225	1982	L2	49.2	8-P	major
14	SP	62	A	Apache Corporation	340	1967	L2	40	8-P SK	major
15	SP	62	B	Apache Corporation	322	1968	L2	44	8-P SK	major
16	SP	62	C	Apache Corporation	325	1968	L2	48	8-P SK	major
17	VK	900	A	Chevron U.S.A., Inc.	340	1975	L2	46.3	8-P	major
18	MP	281	A	Dominion Exploration & Production, Inc.	307	1999	L2	52	4-P	major
19	MP	289	B	Apache Corporation	320	1968	L1	45	8-P	major
20	MP	290	A	Apache Corporation	289	1968	L2	42	8-P	major
21	MP	305	A	Noble Energy, Inc.	180	1969	L2	45	8-P	major
22	MP	305	B	Noble Energy, Inc.	241	1969	L2	46	8-P	major
23	MP	306	D	Noble Energy, Inc.	255	1969	L2	46	8-P	major
24	MP	306	F	Noble Energy, Inc.	271	1978	L2	49	4-P SK	major
25	VK	786	A-Petronius	Chevron U.S.A. Inc.	1754	2000	L1	55	C-TOWER	major
26	VK	780	A-Spirit	Apache Corporation	722	1998	L1	49	4-P	minor
27	VK	823	A-Virgo	TOTAL E&P USA, INC.	1130	1999	L1	47	OTHER	minor
28	MP	261	JP	Williams Field Services - Gulf Coast Company	299	2001				minor
29	MP	298	B-VALVE	Southern Natural Gas Company	222	1972	L2	43	4-P	minor
30	MP	144	A	Chevron U.S.A., Inc.	207	1968	L2	62.2	4-P	minor
31	MP	252	A	Shell Offshore Inc.	277	1990	L2	50	4-P SK	minor
32	MP	280	C	Dominion Exploration & Production, Inc.	302	1998	L2	52		minor
33	SP	60	D	SPN Resources, LLC	193	1971	L2	49	8-P	minor
34	VK	989	A-Pompano	BP Exploration & Production Inc.	1290	1994	L1	55.8	4-P SK	minor

Note 1: Damage Categories: Destroyed – Complete Structural collapse of the platform, Major – Severe structural overload to the primary load bearing members, Major (D) – Major damage and later decommissioned, Minor – Some structural damage but generally to secondary structures.

Quantitative Assessment

The Bias Factor is a quantity which indicates the ratio between the true capacity of a platform to its predicted strength, as analyzed per API RP2A. If a platform survives after a hurricane, while API analysis predicted it should have been destroyed, this platform has a Bias Factor greater than 1.0. In this case it would imply that the API RP2A analysis recipe is conservative. The Bias Factor is computed with all known factors of safety (FS) in the API approach accounted for (i.e., the bias is in addition to normal FS).

Such an approach was previously used for Andrew and Lili, with resulting Bias Factors of about 1.1 and 1.25 respectively. The bias is about 1.15 when Andrew and Lili are combined. These results imply that API RP2A is doing a good job in terms of fixed platform design, with an inherent conservatism of about 15%.

For this study, the Bias Factor was recomputed considering Ivan, based upon six platforms – 2 destroyed, 3 damaged and 1 survived. The results are shown in Figure E.1. The combined jacket Bias Factor for Hurricane Ivan is 1.0, which means the prediction matches the observation almost exactly. The Bias Factor for Ivan was then combined with Andrew and Lily to determine a combined Bias Factor of 1.10 as shown in Figure E.1. Please note that the combined Bias Factor was calculated through a complicated process by calculating the combined likelihood function (for the three Hurricanes) first, and then perform numerical integration and curve fitting to obtain the combined Bias Factor, and not obtained through simply averaging the three individual Bias Factors.

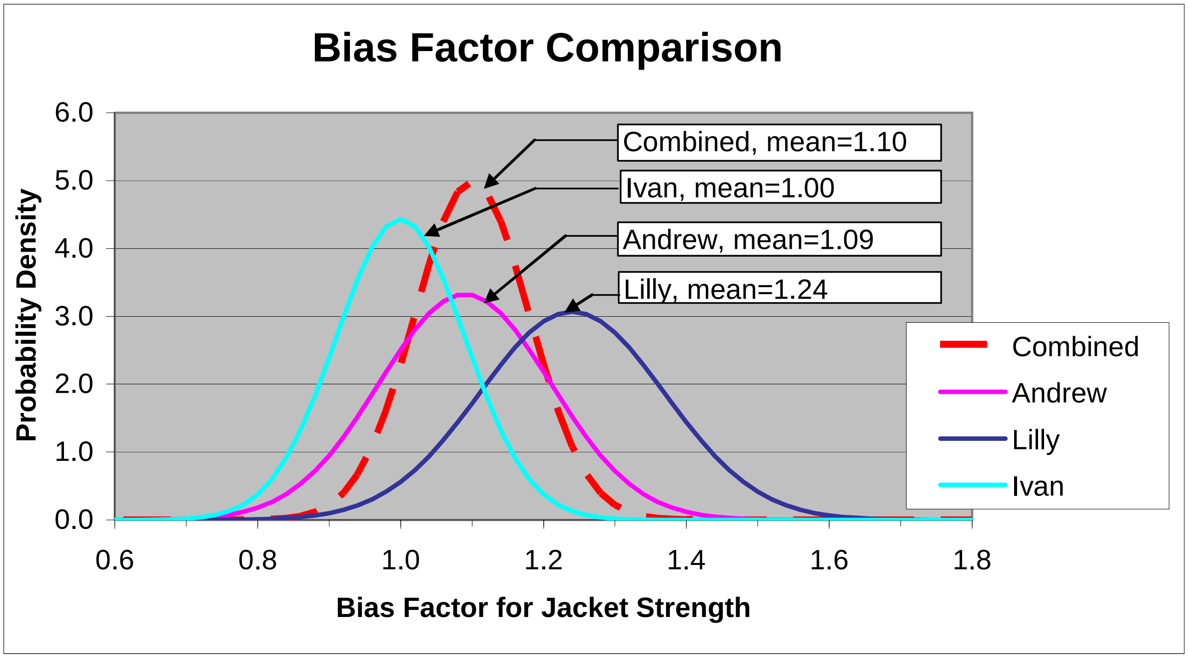


Figure E.1 - Bias Factor of Combined Results for Hurricanes Andrew, Lily and Ivan

The Ivan Bias Factor results are lower than for Andrew and Lili. However, it should also be noted that this result is the combination from the six platforms analyzed, with two platforms on the conservative side (>1.0) and four platforms slightly on the un-conservative side (<1.0). The lower Ivan results may be explained by the particular selection of these platforms, mostly damaged or destroyed. The inclusion of more platforms that survived Ivan, would increase the Bias Factor, but there was little information on survived platforms available to this study (most operators study damaged platforms and not those that survive). There is also a possibility that some of the damaged platforms had prior unknown existing damage that was not taken into account in the assessment. Hence the Ivan Bias Factor is believed to be conservative.

Overall, the Quantitative Assessment for Ivan indicates that the API RP2A fixed platform "recipe" has a Bias Factor of about 1.0. When combined with Andrew and Lili, the Bias Factor increases to 1.10. These results indicate that API RP2A is doing a slightly conservative job of predicting platform performance.

Expert Panel and Recommendations

The Expert Panel met on December 13, 2005 to review and discuss the above results. While the focus of discussion was related to Ivan, consideration for the effects of hurricanes Katrina and Rita were also considered in a generic manner since there has not yet been a similar proper study of these hurricanes. The key recommendations are as follows. The first two recommendations related to wave heights are considered the most important.

1. Investigate the possible changes to the minimum deck elevation curves for design of new platforms as contained in API RP2A Section 2, and for assessment of existing platforms as contained in Section 17.

> These are used to *establish fixed platform deck height.* Numerous platforms experienced wave-in-deck during Ivan as documented by damage observed to decks. Many of the platforms that were destroyed had wave-in-deck loading. It is a critical value because if the deck is high enough, above extreme wave crest elevations, then the platform has a good chance of surviving extreme conditions. The hindcast shows that in *some cases* waves were predicted to be in the deck, but in others, the hindcast indicates the waves were below the deck. There appears to be uncertainty about the elevation of wave crests in these extreme storms. This may be related to the height of the crest itself, the shape of the wave or wave crest, the kinematics at the crest, or other associated factors. These should all be addressed in a comprehensive study.

2. Investigate possible changes to the wave height curves in API RP2A used for designing new platforms as contained in Section 2 and for assessing existing platforms as contained in Section 17.

These are used to determine the required *platform resistance.* Although this is a different value than Item 1 related to deck elevation, the design wave height is one of the most critical factors that determine the overall platform resistance. The same set of issues that were identified for the deck elevation should also be considered here.

3. Investigate damage to secondary structural members such as conductor trays and riser clamps and provide design guidance.

Several of the platforms sustained damage to non-primary structure that resulted in considerable down time and costly repairs. Examples include conductor trays located near the waterline (e.g. -40 ft) that sustained cracks or fell-out, and sump caisson and riser clamps that failed. There is little design guidance in API or other industry standards for these secondary structures.

4. Investigate specifically the destroyed platforms in Ivan in order to understand how the failures occurred and how they could have been prevented.

Destroyed platforms can provide the most valuable information from an event like Ivan. There is little analytical data available on the destroyed platforms since there is little incentive by operators to evaluate these structures in a detailed manner to find out what went wrong. Almost all of the analytical evaluations are performed on platforms that were damaged in order to design repairs. .

5. Provide metocean instrumentation on fixed offshore platforms.

There is little to no metocean instrumentation on fixed platforms that provides data such as wave height, current and wind. Most of the existing instrumentation is on deeper water floating structures. Extreme wave characteristics may be different in the shallower water (<400 ft) region than for deep water. Such data would help verify some of the issues related to extreme waves. An example of simple low cost instrumentation is a video camera mounted on the platform that provides digital evidence of extreme seastates during hurricanes, including the crest elevations.

6. Investigate the apparent conservatism in pile foundation design and make recommendations for change to the design and assessment process, if any.

There have been few, if any, documented foundation failures due to hurricanes, although some have been “reported” for Katrina and Rita. Yet results of “pushover” analyses used to assess existing platform per API RP2A Section 17 indicate on a regular basis that the foundation system will fail first. This conservatism is also seen in new design, where deep piles are often required – yet they can be difficult to install since the soils are actually stronger.

It is recommended that additional study be conducted on the above items, with particular attention on the wave height issues. These studies should be funded by the MMS, API and industry (in the form of Joint Industry Projects). This work should be coordinated where possible with other studies underway or planned by API, OOC (Offshore Operators Committee) and others.

1.0 INTRODUCTION

1.1 Background

Hurricanes of large size that damage or destroy platforms have historically been infrequent in the Gulf of Mexico as shown in Table 1.1. However, in the last dozen years there have been several large hurricanes that have damaged or destroyed multiple offshore platforms. Hurricane Andrew was the first in 1992 and destroyed 28 platforms (excluding caissons). Hurricane Lili was the second in 2002 that destroyed or damaged 7 platforms. Hurricane Ivan was the third in 2004 with multiple platforms destroyed and damaged. Ivan was followed closely by Katrina and Rita in 2005, which damaged or destroyed approximately 114 fixed platforms (MMS, 2006). There were fortunately no life safety or environmental consequences with any of these events since the platforms were all evacuated prior to the hurricane and the platforms contained equipment with anti-pollution devices.

Table 1.1 - Historical Damage to Offshore Fixed Platforms from Hurricanes

No.	Hurricane	Year	Platforms Destroyed**	Industry Response
1	Grand Island	1948	2*	Limited number of platforms in service
2	Carla	1961	3*	
3	Hilda	1964	14*	Several operators start to use a 100 yr return period design wave
4	Betsy	1965	8*	
5	Camille	1969	3*	First API RP2A for fixed platform design
6	Carmen	1974	2*	
7	Frederic	1979	3	Wave load recipe provided in RP2A
8	Juan	1985	3	Assess-Inspect-Maintain (AIM) Joint Industry Projects for existing platforms
9	Andrew	1992	28	API RP2A Section 17 for assessment of existing platforms
10	Lili	2002	7	MMS sponsored studies
11	Ivan	2004	7	This study
12	Katrina	2005	46	MMS News Release #3418 (Jan. 19, 2006)
13	Rita	2005	68	MMS News Release #3418 (Jan. 19, 2006)
		Total	**194**	

* Based upon published reports at the time. Additional failures may have occurred but not reported.
** Fixed multi-leg platforms only. Does not include caissons. Most results are based upon MMS initial findings of destroyed platforms. Additional platforms may have been decommissioned later as a result of the hurricanes.

These types of incidents are unfortunate in terms of property damage and loss of production, but they provide a unique opportunity to provide the best guidance on the applicability of design codes. Hurricanes or storms that result in no damage, only validate design standards up to the level of loading imposed by the event, with the loading perhaps not as high as the design standard loads. However, events that cause structural damage and failures – like Andrew, Lili and Ivan – are the real tests to determine if design codes are adequate since damage occurred. Was it that the loads caused by the event were larger than the design standard and hence the damage was expected, or was the load lower than the design standard and the damage was unexpected? Was the damage a result of the structural resistance part of the standard?

With this in mind, the industry funded an extensive Joint Industry Project (JIP) to study the results of Andrew in 1992 [PMB, 1994; Puskar, et. al., 1994]. The JIP consisted of data gathering combined with a probabilistic Bayesian approach to determine in a quantitative manner how API is performing. A similar study was conducted in 2003 for Lili [Puskar, et. al., 2004], funded by the MMS.

This document describes a similar study for Ivan as performed for Andrew and Lili, including combining the effects of all three hurricanes. The effort also includes a specific set of recommendations for further work.

1.2 Approach

There were three parts to the study as follows:

1. Qualitative Assessment. Data was gathered from the MMS as well as several operators on platforms destroyed and damaged. The data was reviewed and summarized in a simple database. The work also identified general trends such as number of platforms destroyed and damaged, age and water depths of the platforms that were destroyed, deck heights vs. Ivan wave heights, API RP2A new design and assessment wave heights versus Ivan wave heights, and other useful information.

2. Quantitative Assessment. This provides a comparison of the platform's *actual* response to the hurricane Ivan (destroyed, damaged or survived) versus what the load and resistance recipe in API RP2A would have predicted in terms of an *analytical* response. In other words, if a platform was destroyed in Ivan – would this have been predicted by RP2A? A probabilistic Bayesian updating process was used, based upon an approach first used in 1993 for hurricane Andrew and repeated in 2004 for hurricane Lili. The prior Andrew and Lili studies show that there is about 15-20% conservatism inherent in RP2A once all known factors of safety are removed.

3. Expert Panel. This involved a "panel" of 13 experienced offshore structural engineers that reviewed the results of the above tasks, as well as general knowledge of hurricane damage, and made recommendations on potential further work. The intent was to make "top level" recommendations on further studies that should be performed, such as investigation of the RP2A minimum deck elevation and wave height curves once Ivan is considered. The intent was not to solve these issues within this project.

1.3 Project Team

The project was be managed by Energo Engineering. Mr. Frank Puskar was the Principal Investigator and led the Expert Panel. Mr. Puskar was also the Principle Investigator for the similar Andrew and Lili studies. Mr. Robert Spong of Energo led the Qualitative Assessment. Dr. Albert Ku of Energo led the Quantitative Assessment, assisted by Dr. Jin Wang. Other Energo staff assisted on the project as necessary.

The University of Texas (UT) at Austin also worked on the project via Dr. Robert Gilbert, assisted by Mr. Young Jae Choi. Dr. Gilbert is well known in the offshore community for his work in reliability, specifically foundations. Dr. Gilbert and Mr. Choi assisted primarily on the Quantitative Assessment, performing jacket and foundation capacity analysis using the TOPCAT program, assisting in global wave load computations, and reviewing the Bias Factor approach and results. Dr. Gilbert was also a member of the Expert Panel.

Mr. Kris Digre reviewed and commented on some of the project results as well as participated on the Expert Panel. Mr. Kris Digre is an industry consultant, previously with Shell, and was the API task group leader for the development of API RP2A, Section 17 in the early 1990’s for the Assessment of Existing Platforms.

Participating from the MMS where Mr. Tommy Laurendine, Mr. Andrew Konczvald, Ms. Fung Chan and Ms. Gwen Accardo.

The project was conducted from June to December 2005.

2.0 QUALITATIVE ASSESSMENT

The objective of this qualitative assessment is to archive fixed platform damage caused by Ivan in order to form a permanent record for MMS and industry archives. The information is used to investigate trends and gain better understanding of the performance of the fleet of platforms in the path of the hurricane.

2.1 Data Gathering

The majority of the information used in the qualitative assessment was gathered from Office of Structural & Technical Support (OSTS) of the MMS. This data comprised of fixed platform post Ivan inspection reports, structural assessments and repair report as well as general information from the MMS platform database. Note that the MMS platform database is a product of the MMS NTL 2004-G18 which required lessees to submit platform characteristics, production and manning that form the basis for the classification and assessment of existing platforms per the API RP 2A 21st edition. This information coupled with the post-Ivan submittals was used to investigate trends as they related to the platform performance. The Ivan hindcast was also obtained through the MMS [Oceanweather, 2005].

In addition to this data, information on the platform performance was gathered from published papers, conferences [API, 2005] and directly from several platform operators.

2.2 Storm Characteristics

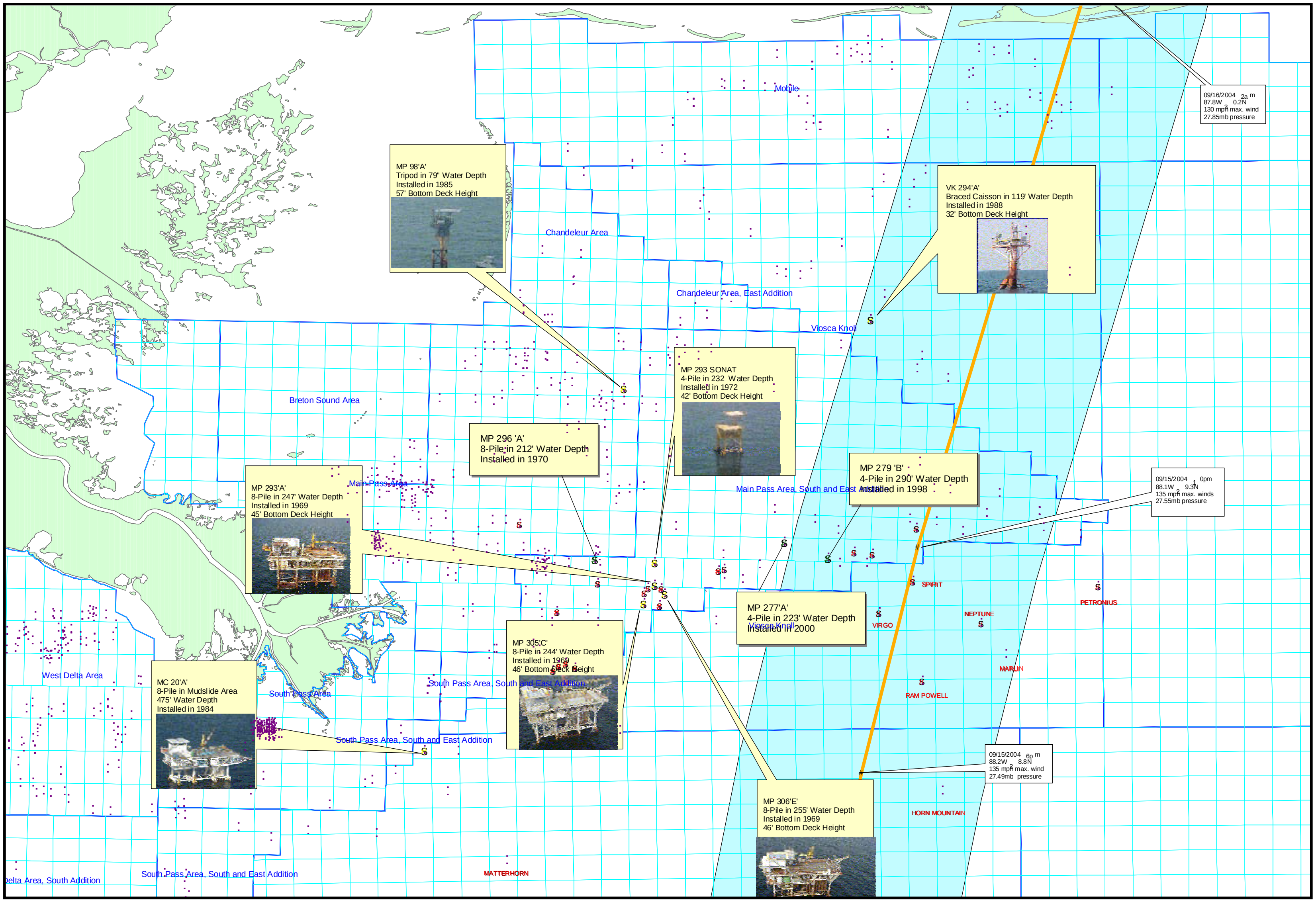
Hurricane Ivan developed off the west coast of Africa in late August 2004. By September 5th it was a hurricane about 1150 miles east of the southern Windward Islands. The hurricane strengthened running south of the Dominican Republic and passed within about 20 miles of Jamaica on the 11th and a similar distance from Grand Cayman on the 12th. When passing over the Caymans the sustained winds were approximately category 4 strength [NOAA, 2004]. Ivan then turned to the northwest running virtually unimpeded (i.e., did not pass over any large land mass) through the Yucatan channel on the September 14th. By the late afternoon on September 15th, Ivan was in the east-central Gulf of Mexico approaching the deepwater offshore oil and gas facilities. During this time, the hurricane was a Category 4 storm on the Saffir-Simpson scale, with maximum sustained wind speeds of 135 mph. The storm was also very large with an eye diameter between 20-40 miles and hurricane winds (i.e., greater than 74 mph) extending out approximately 100 miles and tropical storm winds out approximately 300 miles [NOAA, 2004]. Ivan tracked North-Northwest over the deepwater facilities in the Mississippi Canyon blocks and up into the Viosca Knoll (VK) and Main Pass (MP) block areas. The majority of the destroyed or damaged fixed platforms resided in the VK and MP block areas. Ivan continued its northerly track through the eastern edge of the Mobile block area, making landfall as a major hurricane with maximum winds of 130 mph on the early morning of September 16th just west of Gulf Shores, Alabama.

Figure 2.1 displays the storm track through the key offshore oil and gas blocks. Also shown in the figure are the fixed platforms that were destroyed during the hurricane.

The hurricane path tracked to the east of a densely populated region of fixed offshore platforms which were exposed to significant wind and waves. As a result of Ivan's intensity the waves were in many cases in excess of those used for the design of new structures. Many of the platforms in these regions were older vintage structures that were not originally designed to withstand the forces created by a hurricane of Ivan's magnitude.

However, it is important to note that even though damage and in some cases complete destruction of platforms occurred during hurricane Ivan, the advance warning of hurricanes allowed thousands of offshore workers to be safely evacuated from Gulf facilities prior to the storm reaching the area [Hurricane Readiness Conference, 2005]. There were also no significant environmental effects.

Figure 2.1 – Path of Hurricane Ivan through the MC, VK and MP Areas [Laurendine, 2005]



2.3 Fixed Platform Performance

A total of seven fixed platforms were destroyed as a result of hurricane Ivan. One of the seven (MC 20 A) was toppled by a mudslide, while the other six failures are thought to be attributed to the environmental loads (i.e., wind, wave and current) exceeding the capacity of the structures. The seven destroyed platforms are from the initial list provided by the MMS. Note that additional platforms may have been later decommissioned by the operator as a result of damage sustained from Ivan.

In addition to the seven destroyed platforms, there were a number of other fixed platforms that sustained varying degrees of damage during Hurricane Ivan. Some of the damage and failures were not considered a surprise, since the many of the platforms that failed or sustained major damage tended to be older vintage facilities designed to lower environmental criteria than current design. These platforms generally have lower global strength characteristics (e.g., weaker joints, less robust bracing patterns, etc.) than platforms designed to existing industry practices. Additionally, these older platforms typically have lower topside deck heights which make them significantly more susceptible to wave-in-deck, which can increase the loads on the platforms well over the platform’s ultimate capacity.

A summary of the platforms that were structural damaged is shown in Table 1.1. The table categorizes the damage into four categories that are defined as follows:

- Destroyed – Complete failure/structural collapse of the platform. Generally, for this category the platform is on the seafloor.
- Major – These platforms exhibited some evidence of severe structural overload which caused damage to the primary load bearing members (e.g., main bracing, jacket legs, topside structure).
- Minor – The platform has some structural damage due to the hurricane but the damage is generally to secondary structures which will not significantly reduce the platforms global capacity.
- No Damage – Platform had no structural damage.

Note that the damage categories relate only to the observed structural damage. The categories do not include those platforms that had severe non-structural damage (e.g., damaged equipment, cable tray, etc.) which would be considered major with regards to downtime and costs but does not influence the platforms structural capacity. Also, in some cases the platform was not destroyed but sustained major structural damage that was considered by the operator to be too costly to repair based on the economics of the development. In these cases, the platform was planned to be decommissioned (i.e., plug and abandon all active wells and remove the structure). Three platforms fell into this category and are denoted in Table 1.1 in the damage category by “major (D)”.

The list of damaged fixed platforms was provided by the MMS. This list was based on post-Ivan inspection and repair submittals to MMS by platform operators. Pompano and Petronius were added to the original MMS list.

The exposure category represents the three platform assessment classifications per Section 17 of API RP 2A. The category is dependent on the potential consequences of platform failure and it is dependent on variables such as platform production, oil storage, connecting pipelines, manning, etc. The category descriptions include:

- L1 – high consequence platform
- L2 – medium consequence platform
- L3 – low consequence platform

Table 2.1 – Platforms Damaged During Hurricane Ivan

No.	Area	Block		Operator	Water Depth (ft)	Year of Installation	Exposure Category	Deck Height (ft)	Structure Type	Damage Category (Note 1)
1	MC	20	A	Taylor Energy Company	475	1984	L1	49	8-P	destroyed
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7	VK	294	A	Chevron U.S.A. Inc.	119	1988	L2	32	B-CAS	destroyed
8	MP	296	A	GOM Shelf LLC	212	1970	L2	46	8-P	major (D)
9	MP	277	A	El Paso Production Oil & Gas Company	223	2000	L2	50.3	4-P	major (D)
10	MP	279	B	Dominion Exploration & Production, Inc.	290	1998	L2	53.5		major (D)
11	MP	138	A	Newfield Exploration Company	158	1991	L2	55	4-P	major
12	MP	311	B	GOM Shelf LLC	250	1980	L2	39.5	8-P	major
13	MP	296	B	GOM Shelf LLC	225	1982	L2	49.2	8-P	major
14	SP	62	A	Apache Corporation	340	1967	L2	40	8-P SK	major
15	SP	62	B	Apache Corporation	322	1968	L2	44	8-P SK	major
16	SP	62	C	Apache Corporation	325	1968	L2	48	8-P SK	major
17	VK	900	A	Chevron U.S.A., Inc.	340	1975	L2	46.3	8-P	major
18	MP	281	A	Dominion Exploration & Production, Inc.	307	1999	L2	52	4-P	major
19	MP	289	B	Apache Corporation	320	1968	L1	45	8-P	major
20	MP	290	A	Apache Corporation	289	1968	L2	42	8-P	major
21	MP	305	A	Noble Energy, Inc.	180	1969	L2	45	8-P	major
22	MP	305	B	Noble Energy, Inc.	241	1969	L2	46	8-P	major
23	MP	306	D	Noble Energy, Inc.	255	1969	L2	46	8-P	major
24	MP	306	F	Noble Energy, Inc.	271	1978	L2	49	4-P SK	major
25	VK	786	A-Petronius	Chevron U.S.A. Inc.	1754	2000	L1	55	C-TOWER	major
26	VK	780	A-Spirit	Apache Corporation	722	1998	L1	49	4-P	minor
27	VK	823	A-Virgo	TOTAL E&P USA, INC.	1130	1999	L1	47	OTHER	minor
28	MP	261	JP	Williams Field Services - Gulf Coast Company	299	2001				minor
29	MP	298	B-VALVE	Southern Natural Gas Company	222	1972	L2	43	4-P	minor
30	MP	144	A	Chevron U.S.A., Inc.	207	1968	L2	62.2	4-P	minor
31	MP	252	A	Shell Offshore Inc.	277	1990	L2	50	4-P SK	minor
32	MP	280	C	Dominion Exploration & Production, Inc.	302	1998	L2	52		minor
33	SP	60	D	SPN Resources, LLC	193	1971	L2	49	8-P	minor
34	VK	989	A-Pompano	BP Exploration & Production Inc.	1290	1994	L1	55.8	4-P SK	minor

Although a significant number of platforms sustained damaged, the majority of the facilities in the path of Ivan weathered the storm unscathed or with only minor damage. Figure 2.2 shows the percent breakdown of undamaged and damaged fixed platforms in the path of Ivan. The path of the storm is generally a 35 mile swath running out on each side of the hurricane center. The swath represents the approximate boundaries of the hurricane strength winds and was used to identify the special survey activities that were required by the MMS NTL No.: 2004-G18 issued in October of 2004. Some of the damaged platforms were outside of the 35 mile swath. These platforms are included in Table 2.1 and in the figures in this section.

Figure 2.3 shows the breakdown of the damaged and undamaged platforms with respect to there design vintage. From the figure, it is evident that the older designed platforms tended to sustain more damage than the new vintage platforms. This is not an unexpected observation, since each significant change in the design code was in response to learning from an environmental event (i.e., a severe hurricane). The code changes reduced the platforms susceptibility to wave in deck by requiring increased deck heights and also increased the capacity of the structure with stronger joints, more robust bracing, etc. The lessons learned from these experiences become apparent when a fleet of platforms is exposed to extreme environmental conditions such as what occurred during Ivan.

Figure 2.2 – Percentage of Damaged Platforms in Path of Ivan

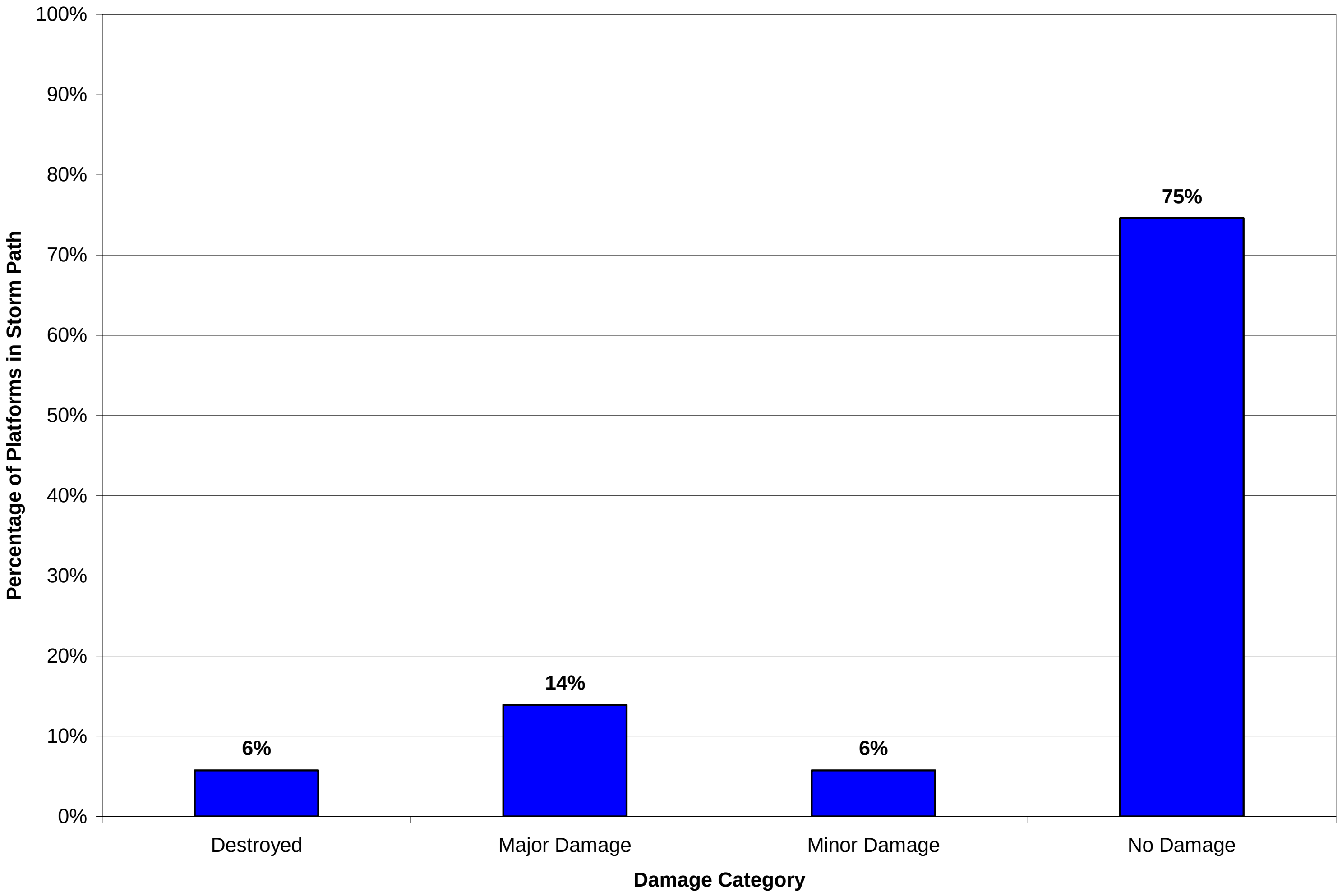


Figure 2.3 – Vintage of Fixed Platforms in Path of Hurricane Ivan

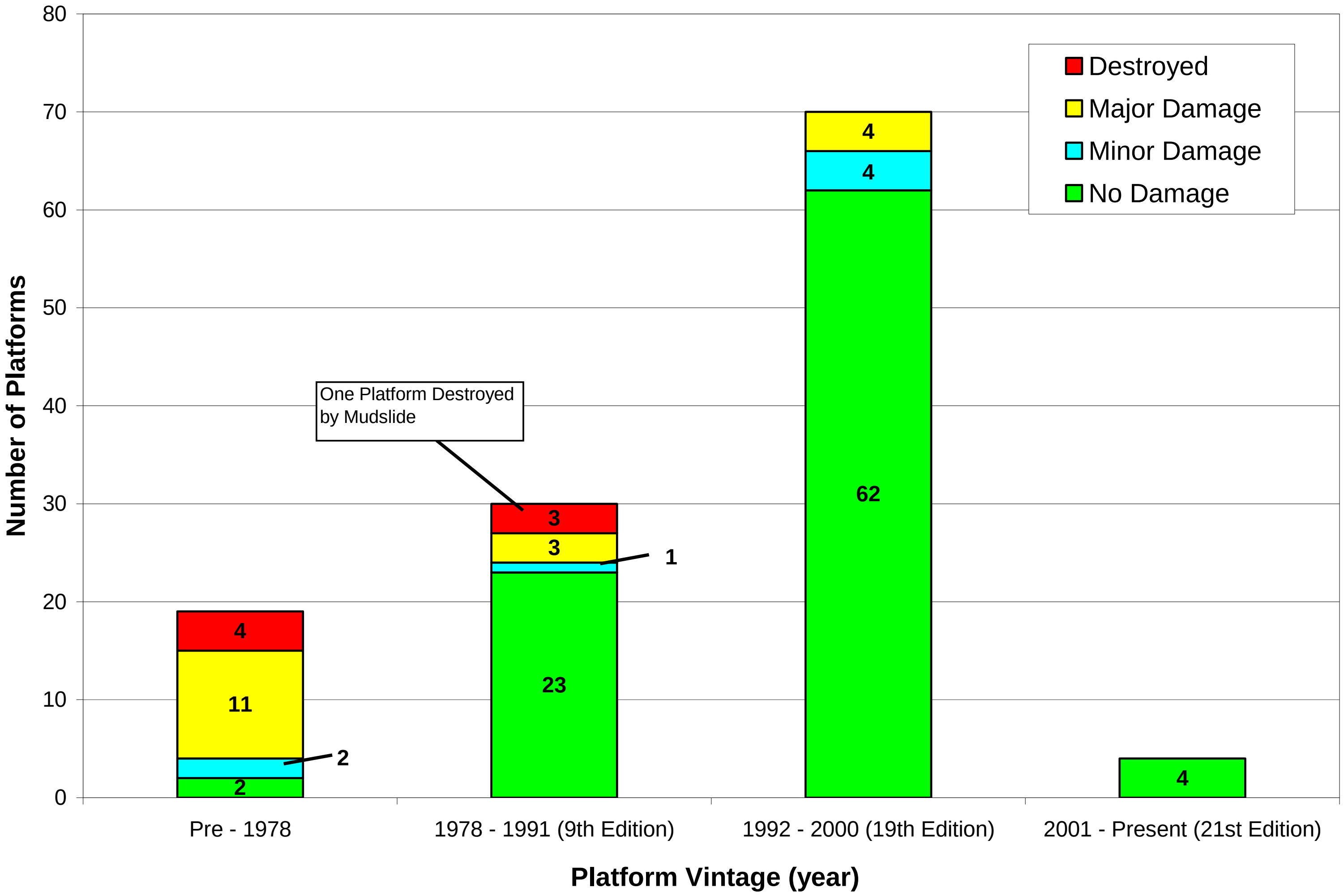


Figure 2.3 shows the majority of the platforms that failed or sustained major damage during Ivan were older vintage platforms. As mentioned above, these platforms were generally designed to lower environmental criteria and have lower global strength characteristics (e.g., weaker joints, less robust bracing patterns, less leg batter, etc.) than platforms designed to current industry practices. Additionally, these older platforms typically have lower topside deck heights which make them significantly more susceptible to wave-in-deck, which can increase the loading on the platform well over the platform's ultimate capacity.

To better understand the significance of the development of the platform design loads as well as the increase in loading that occurs when a wave inundates the deck of a platform Figure 2.3 was developed. The figure shows graphically lateral loads on a typical 8-pile fixed platform. It does not represent a specific platform that was damaged during Ivan. Instead it was developed for illustrative purposes to show why the older vintage platforms sustain more damage than the new vintage platforms. A 3-D image of the "generic" platform and the general characteristics are shown in Figure 2.4.

In Figure 2.3, the current API RP 2A 21st Edition design load recipe is taken as the reference value (i.e., 100%), and all other load cases are presented as a percentage of this value. For the older recommended practices, the wave loading recipes produce lower lateral loads or base shear on the platform. For this platform, the difference is between 10-20% lower lateral loads than the current design. Note that before the 9th Edition of RP 2A (1978), there was limited accepted industry-wide guidance on environmental loading for fixed platforms.

On the right side of the figure, the calculated lateral loads for Ivan are presented assuming a 90 foot wave. Wave heights such as these result in lateral loads which approach the platforms ultimate capacity (i.e., with all the inherent factors of safety removed). Typically this in the range of 1.6 times the design lateral load for a modern platform. When wave-in-deck is included the loads can be above 2 times the design load and in these cases failure may occur.

Note that the 90 foot wave is intended to be representative of Ivan wave heights based on damage observations on some of the platforms. There are discrepancies regarding the estimated wave heights based on post-storm wave-in-deck damage observations and the predicted wave heights based on the Ivan hindcast. These discrepancies are discussed later in the report in Section 2.5.

Figure 2.3 – Environmental Load Distribution

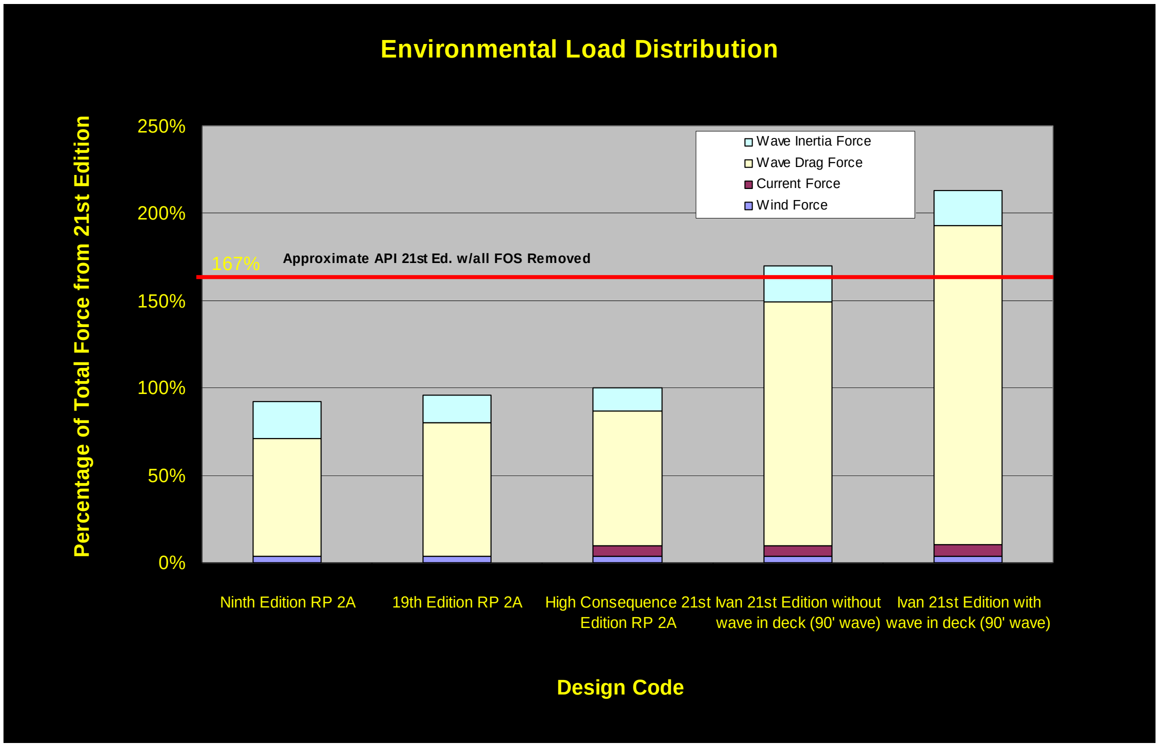
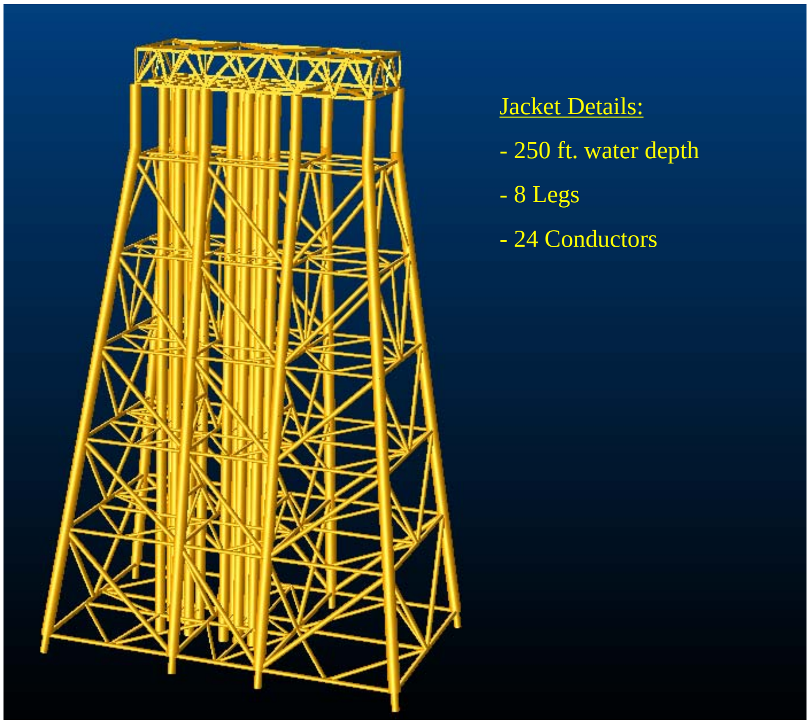


Figure 2.4 – "Generic" 8-Pile Platform Characteristics

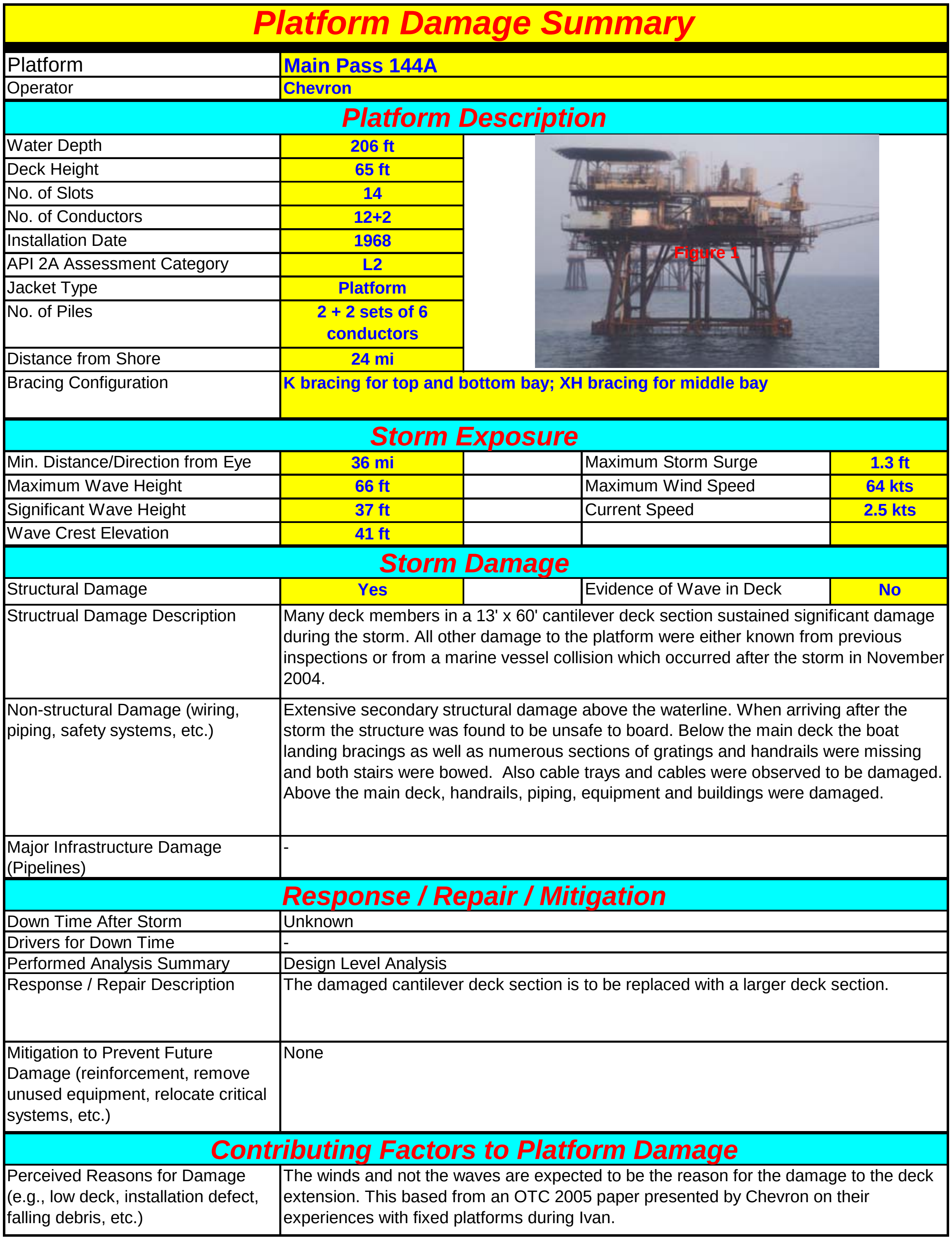


2.4 Platform Damage Summary

Where data on the platform characteristics and damage was available, summary sheets similar to the one illustrated in Figure 2.5 were developed on the platforms. The sheets provide details on the platform configuration, vintage, water depth as well as details on the observed damage. The sheets also have the predicted environmental conditions at the site, including the maximum current, wind speed, calculated wave height and wave crest, based on the hindcast data. Note that the maximum values presented in the sheets do not generally occur at the same time during the storm. These represent the maximums values pulled from the hindcast data over a specific duration of time (typically over a 2-3 hour duration).

The sheets also provide specific case studies on the observed damage, the response (i.e., assessment and repairs) and when indicated by the operator the perceived cause of the damage (e.g., wave, wind, etc.). The complete set of platform summary sheets is found in Appendix A.

Figure 2.5 – Example Platform Summary Sheet



Platform Damage Summary				
Platform	**Main Pass 144A**			
Operator	**Chevron**			
Platform Description				
Water Depth	**206 ft**			
Deck Height	**65 ft**			
No. of Slots	**14**			
No. of Conductors	**12+2**			
Installation Date	**1968**		Figure 1	
API 2A Assessment Category	**L2**			
Jacket Type	**Platform**			
No. of Piles	**2 + 2 sets of 6 conductors**			
Distance from Shore	**24 mi**			
Bracing Configuration	**K bracing for top and bottom bay; XH bracing for middle bay**			
Storm Exposure				
Min. Distance/Direction from Eye	**36 mi**		Maximum Storm Surge	**1.3 ft**
Maximum Wave Height	**66 ft**		Maximum Wind Speed	**64 kts**
Significant Wave Height	**37 ft**		Current Speed	**2.5 kts**
Wave Crest Elevation	**41 ft**			
Storm Damage				
Structural Damage	**Yes**		Evidence of Wave in Deck	**No**
Structrual Damage Description	Many deck members in a 13' x 60' cantilever deck section sustained significant damage during the storm. All other damage to the platform were either known from previous inspections or from a marine vessel collision which occurred after the storm in November 2004.			
Non-structural Damage (wiring, piping, safety systems, etc.)	Extensive secondary structural damage above the waterline. When arriving after the storm the structure was found to be unsafe to board. Below the main deck the boat landing bracings as well as numerous sections of gratings and handrails were missing and both stairs were bowed. Also cable trays and cables were observed to be damaged. Above the main deck, handrails, piping, equipment and buildings were damaged.			
Major Infrastructure Damage (Pipelines)	-			
Response / Repair / Mitigation				
Down Time After Storm	Unknown			
Drivers for Down Time	-			
Performed Analysis Summary	Design Level Analysis			
Response / Repair Description	The damaged cantilever deck section is to be replaced with a larger deck section.			
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None			
Contributing Factors to Platform Damage				
Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	The winds and not the waves are expected to be the reason for the damage to the deck extension. This based from an OTC 2005 paper presented by Chevron on their experiences with fixed platforms during Ivan.			

The following subsections summarize the observed platform damage. The subsections are broken into two categories: 1) topside damage and 2) jacket damage.

2.4.1 Topside Damage

The topside damage fell into two groups, wave-in-deck and wind.

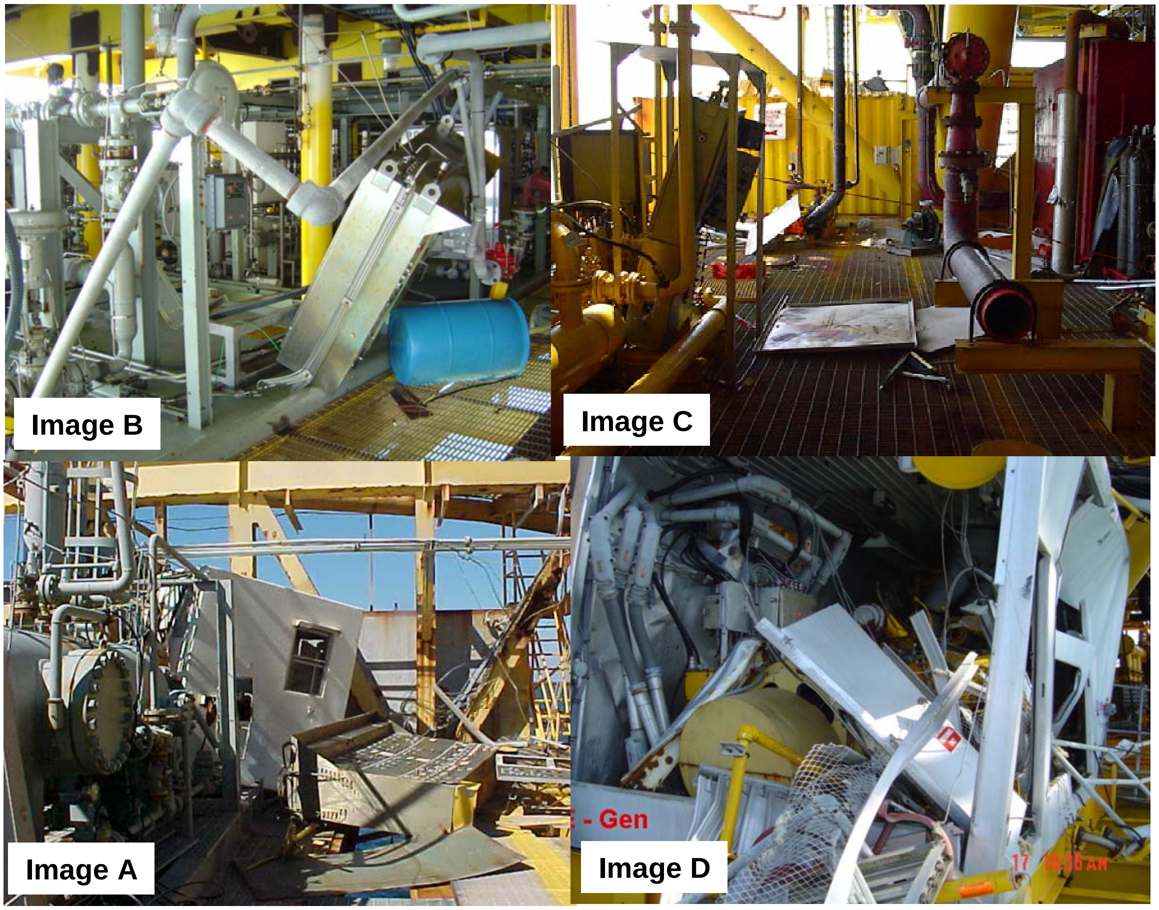
Wave-in-deck

The majority of the fixed platforms that sustained damage had evidence of wave-in-deck. The damage includes deflected structural members on the underside of decks and in many cases damage to equipment and support systems (i.e., piping, cable trays, etc.) on the lower decks. Wave inundation on the older vintage platforms with the lower decks is not necessarily a surprise, since for these platforms many sustained significant damage to the jacket structure as a result of the increased lateral loads which can exceed there capacity. However, some of the newer vintage platforms (1990's design) also experienced wave-in-deck. Although no major jacket structure damage occurred, significant non-structural damage was present which caused significant downtime and repair costs.

The structural damage to the topsides consisted of distorted lower decks (plating and support under deck structure), equipment foundation deformation, and in some cases destroyed equipment shelters on the lower decks.

Some of the more pronounced damage that occurred during Ivan was non-structural. This consisted of damaged facilities equipment (e.g., power controls, generators, etc.), cable trays, and support utilities all of which were located on the lower decks of the facilities. Also water in motor control buildings was observed on two of the platforms. Displaced or missing grating, handrails and stairs also hampered recovery efforts as these components needed to be fixed in order to address the equipment damage due to safety reasons. It was indicated that the non-structural damage associated with wave-in-deck resulted in the greatest contributor of downtime for the facilities. Getting the support and safety systems (power, fire water, etc.) up and running and the repair of safety critical items restricted the immediate and/or permanent manning of the facility, requiring work be done on a day-trip basis. Photos of some typical non-structural damage that occurred during Ivan are shown in Figure 2.6. Image 1 and 2 shows knocked over control consoles. Image 3 shows damaged fire water systems and Image 4 shows a damaged generator package.

Figure 2.6 – Typical Non-Structural Topside Damage Caused by Wave-in-Deck



One other observation regarding the wave-in-deck damage was the apparent wave and wave crest heights during Ivan. Many of the platforms that had evidence of wave in deck observed damage in the upper regions of the cellar deck. For example in the case of the Pompano platform, the deck damage was observed at an elevation of +63 feet above the water level. This equates to a postulated 105 ft maximum wave height when using present design calculation methods. This estimate is well above the hindcast estimates for maximum wave. For the Pompano location, the hindcast estimates put the maximum wave height at approximately 80 feet [O'Connor, 2005]. These sorts of discrepancies between the calculated wave heights based on damage and the hindcast estimates are highlighted in the Section 2.5. Although this report is limited to fixed platforms, Ivan caused wind damage on deepwater platforms (floating) that are not covered in this study.

Wind

Wind was also a contributor to some of the topside damage observed during Hurricane Ivan. One fixed platform (MP 144A) exhibited signs of topside structural failure due to wind loading. This included the failure of a light metal skinned structure and large deformation of a modular building wall as shown in Image A in Figure 2.7. The other noted failure attributed to wind was the temporary crew quarters on the Petronius compliant tower. The quarters and heliport toppled over toward the center of the platform under the wind loads. This damage is shown in Image B in Figure 2.7. Note that there is a separate MMS funded study looking specifically at this type of damage during Ivan.

Figure 2.7 – Examples of Ivan Wind Damage [Wisch, 2005]

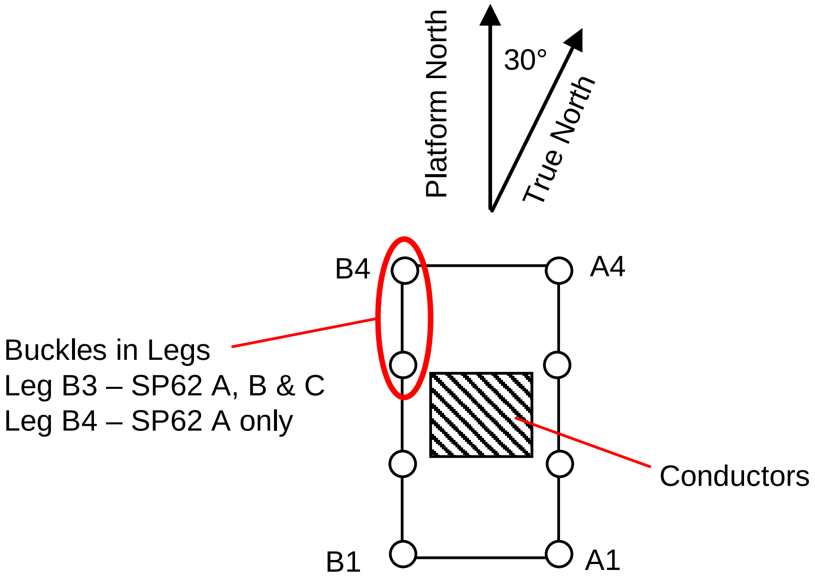
2.4.2 Jacket Damage (Underwater)

The majority of the underwater jacket damage was confined to the older vintage platforms. As mentioned in previous sections many of these platforms experienced wave-in-deck which resulted in the high loads on the jacket structure as well as the fact that many were designed to lower environmental criteria. Examples of the observed underwater jacket damage consisted of the following:

Local Jacket Leg Failures

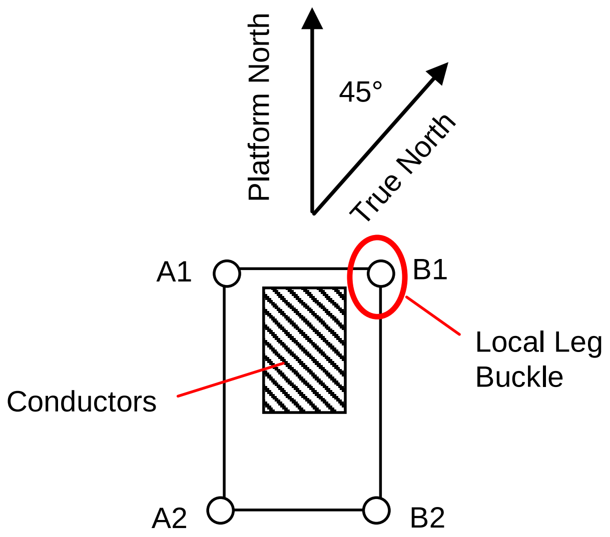
Local buckling was observed on four of the platforms that sustained major damage. Three of the platforms (SP 62 A/B/C) the platforms are very similar designs, installed in late 1960s in approximately 230 feet of water. All three have an 8 pile with 8 skirt piles configuration and are orientated in the same direction. The orientation is shown in Figure 2.8. During hurricane Ivan wave-in-deck was observed on all three platforms and local buckles were observed on the North/Northwest legs. The storm track of Ivan approached the platforms from the southeast. Hence it was the leeward side legs (legs under higher compression loading) that had the leg buckles.

Figure 2.8 – Platform Orientation of SP62 Platforms



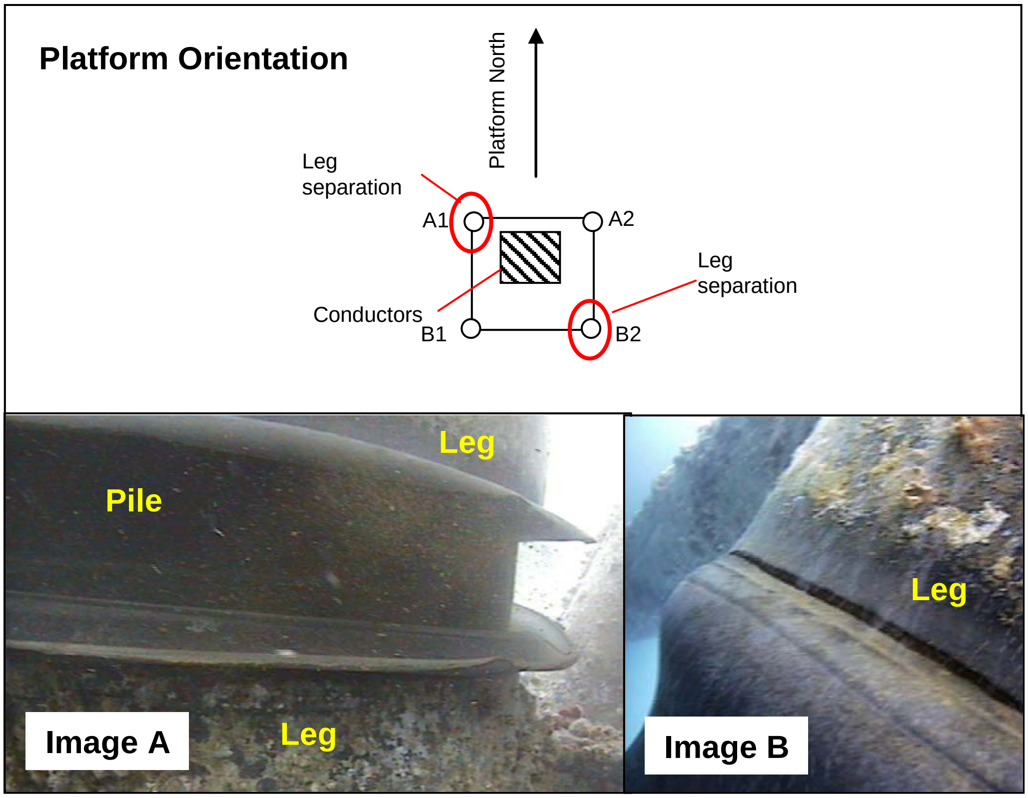
Another platform that sustained local leg buckling was MP 306F. This platform also sustained major damage to the main jacket bracing. The platform is a 4 pile with 4 skirt piles and there is no batter in the Row A and B direction. Rows A and B sustained major damage to the upper three bays of X-bracing. The platform orientation is shown in Figure 2.9. Similar to the SP 62 platforms, the buckled leg was on the Northern leg or leeward side of the platform with respect to the storm track.

Figure 2.9 – Platform Orientation of MP 306F Platform



MP 281 A sustained leg buckling and separation on the two diagonally opposed legs. The platform is a four pile platform and the A1 and B2 legs were observed to be separated. The X-bracing was also separated at two locations near the leg damage. The specific orientation was not shown in the documents but the inspection report shows the conductors to be on the north face of the platform. The orientation of the platform and photos of the observed damage are shown in Figure 2.10. Note that the wave action and subsequent movement of the platform caused the leg to expand outward at the both ends. Similar damage was seen in Lili [Puskar, 2004]. This is shown in Figure 2.10, Image B.

Figure 2.10 – Platform Orientation of MP 281 A Platform and Photos of Leg Damage



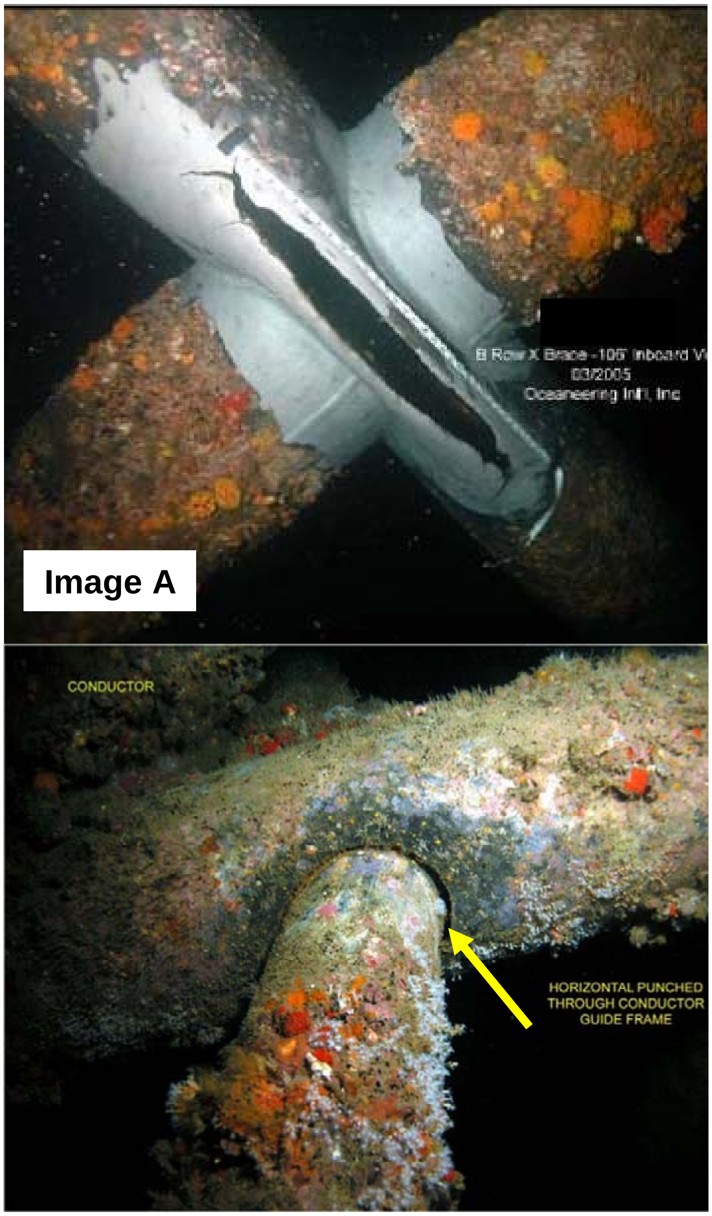
Joint Failures

Joint failures including cracks, punching and crushing, were observed on many of the platforms that sustained major damage. Some examples are shown in Figure 2.11. Image A shows a 24-inch diameter X-brace joint on MP 306 F platform that has been crushed under the wave loading from Ivan. The platform was designed in 1978. Since then, API RP 2A has incorporated improved joint designs formulations. In this case, a joint can (i.e., the thicker walled section of the through member) was present in the design. However, it was only marginally thicker than the connecting members and failed. The three upper bays on both the A and B rows (See Figure 2.9 for orientation) had similar joint failures. Also on the

A and B faces the legs are not battered as they are in rows 1 and 2. This was likely a contributing factor in the X-brace failures, since the braces must resist more loads in the non-battered direction.

Figure 2.11, Image B also shows an example of joint punching failure. The brace was pushed through the chord member. This was observed on a damaged conductor guide framing.

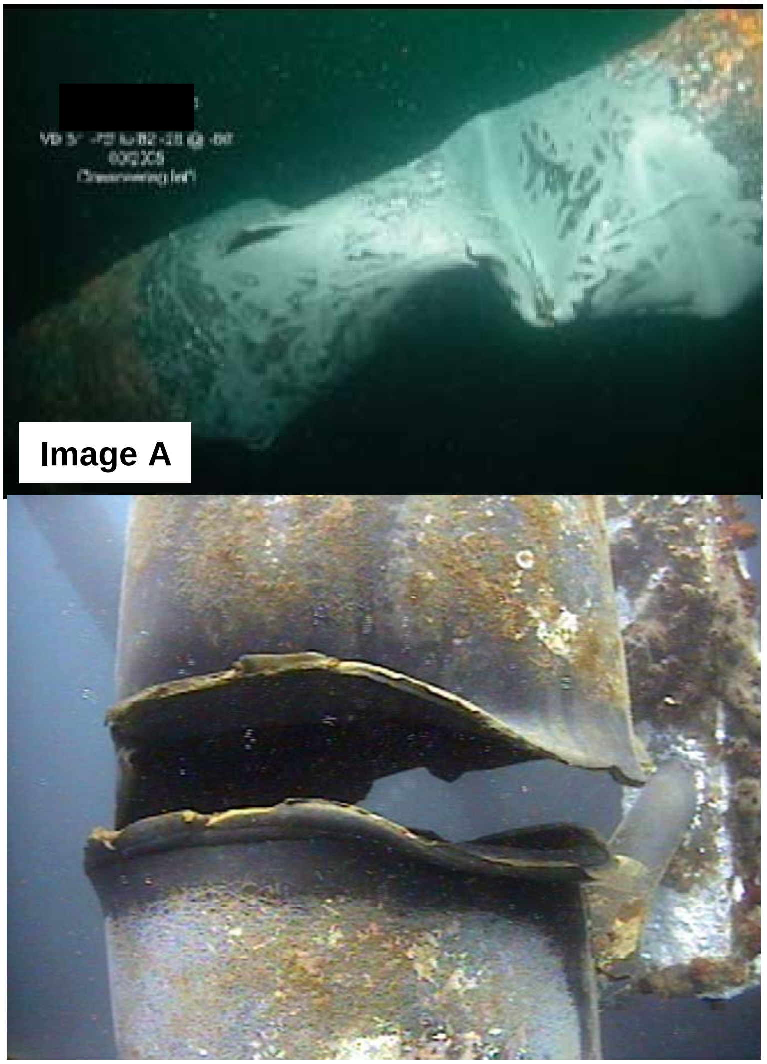
Figure 2.11 – Typical Joint Failures



Brace Failures

The majority of the platforms that were categorized as having major damage sustained jacket bracing failure. Most of bracing damage observed was local buckling of the bracing. One example is shown in Figure 2.12, Image A. The photo shows a 24” diameter X-brace that buckled locally near one of the connections. Note that in this photo the marine growth was not cleaned off, instead it popped off as the brace deformed. Marine growth that has popped off in this manner is often a clue during inspections that some form of damage has occurred to the member. Figure 2.12, Image B shows an example of a separated X-brace. The brace is 26-inch diameter x ½-inch wall thickness and the material yield strength is 50 ksi. Note the ends of the brace have been flattened out. This occurred after the brace separated as the brace ends came in contact by the back and forth motion of the jacket during the storm.

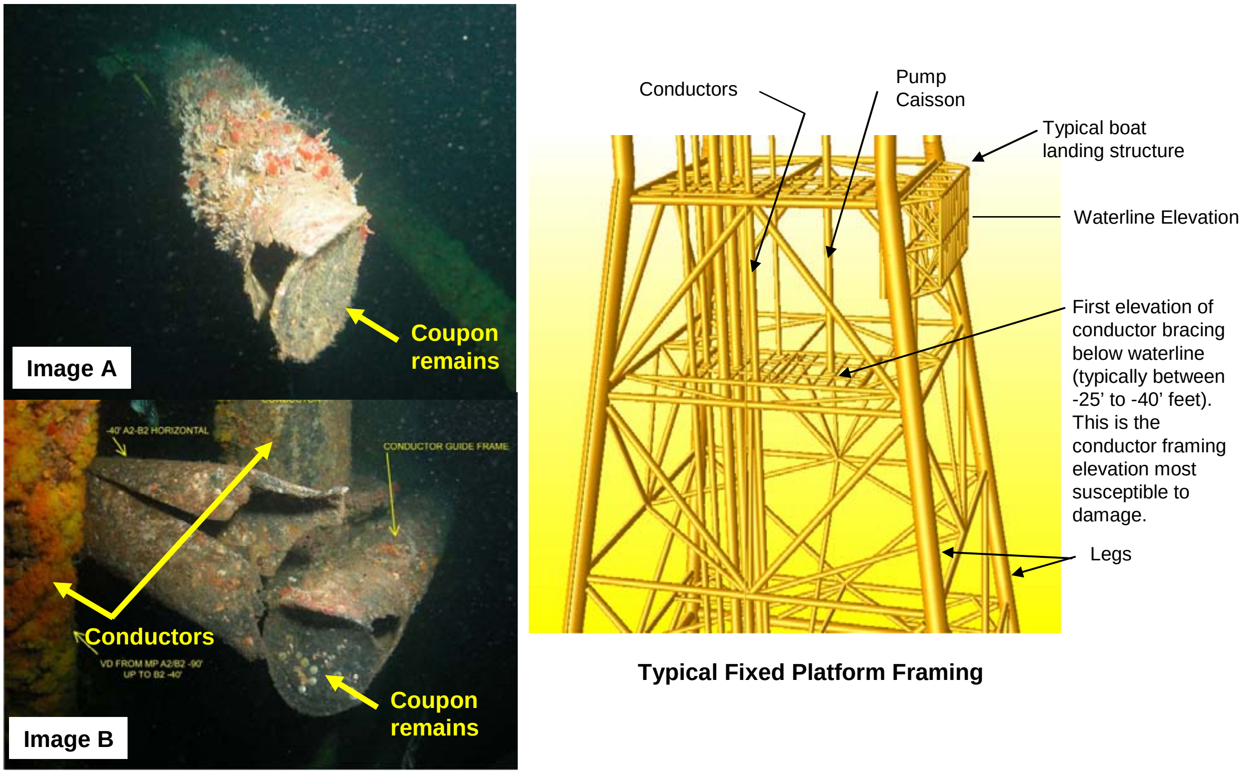
Figure 2.12 – Typical Bracing Failures


[redacted]

Fractured / Detached Conductor Guide Framing

This type of damage has been observed in many of the past hurricanes, Lili [ABS Consulting, 2004] and Andrew [PMB, 1993; PMB, 1996]. This is typically the result of fatigue damage due to the upward and downward loads as the waves run through the structure. In extreme storms like Ivan, these normally low-stress high-cycle fatigue issues become high-stress low-cycle fatigue that quickly escalates to this type of damage. The first conductor guide framing below the waterline on many platforms is between the -20 ft to -40 ft below the waterline and if not properly designed can be susceptible to this type of damage. Causes include the plating often found around the conductor guides that dramatically increases the vertical loading area (compared to say the tubular framing only), and the often lack of vertical support to the tray. This type of damage was observed on several platforms including, MP 305A, MP 305B and MP 306D. The first conductor guide framing is at -40 feet on these platforms. Typical damage is shown in Figure 2.13. Note in Figure 2.13, Image A, the steel coupon from the chord that remains on the end of the separated conductor guide brace. This type of separation is characteristic of a fatigue failure where the crack typically initiates at the top and bottom of the weld toe in the chord member and over time the crack propagates in the chord material and around the weld, eventually the brace completely separates from the chord.

Figure 2.13 – Typical Conductor Guide Damage



Typical Fixed Platform Framing

2.5 Data Comparisons

What should be the appropriate deck height for new design as well as for structural assessments of older vintage platforms is a hotly debated topic since Ivan as well as after Katrina and Rita. Figure 2.14 shows the deck heights of the platforms in the path of hurricane Ivan. When reviewing the figure there is a noted cluster of 200-350 ft water depth platforms with decks lower than the API RP 2A Section 2 (New Design Criteria) platforms that either failed or sustained major damage during Ivan. The majority of the platforms with decks above the Section 2 deck height criteria did not sustain major damage. One item to note in the figure is there are a number of deck heights which appear to be questionable since they are over 55 feet. The deck height data shown in the figure was obtained from the MMS platform database. It is suspected that some of these deck heights are the cellar deck top of steel or in some case the drill deck instead of the required cellar deck bottom of steel. However, the figure does indicate that for those platforms in the path of Ivan with deck heights at or above the API RP 2A Section 2 (new design) requirements generally did not sustain major structural damage.

Figures 2.15 provide comparisons between wave crests calculated from the Ivan hindcast and the latest design deck heights and platform deck heights, respectively. Based on the Ivan hindcast data, the wave crest elevations were generally found to be below the API Section 2 deck height criteria (New Design Criteria), and clustered around the API L1 Section 17 assessment criteria (Assessment Criteria for Existing Platforms). The figure tends to indicate platforms with deck heights at or above the current design criteria should not have seen any significant wave-in-deck. However, as mentioned in Section 2.4.1, observed deck damage on many of the platforms indicated wave heights may have been significantly higher than those predicted via the hindcast based on current long wave recipes.

Figure 2.16, the ratios between the Ivan hindcast crest elevations and the platform deck height are plotted. If the ratio is greater than or equal to 1, wave-in-deck should have occurred during the storm based on the Ivan hindcast estimates. The vintage of the platform and the damage category is also presented in the figure. Based on the hindcast data only a few of the platforms should have seen wave-in-deck. However, based on site observations of the damage to many of these platforms indicates that wave crests were higher than predicted via the hindcast.

In Figure 2.17, presents the same information as shown in Figure 2.16, but the platforms that observed wave-in-deck are indicated on the figure. The figure shows there are a significant number of platforms that sustained major damage and reported wave-in-deck but the calculated wave crests from the hindcast are predicted to be lower than the deck heights.

Figure 2.14 – Deck Heights of Platforms in Path of Ivan

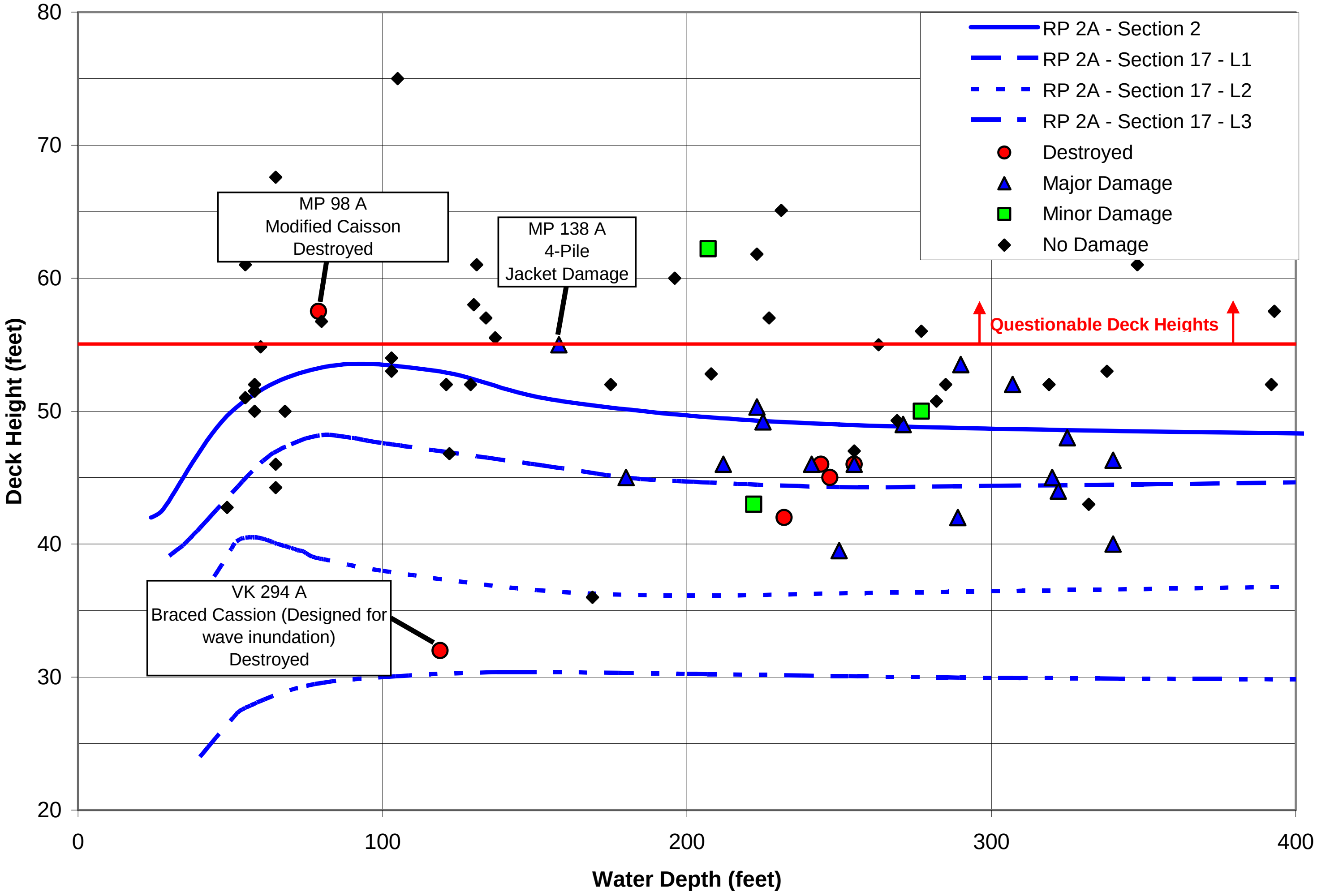


Figure 2.15 – Ivan Hindcast Maximum Wave Crests of Damaged Platforms

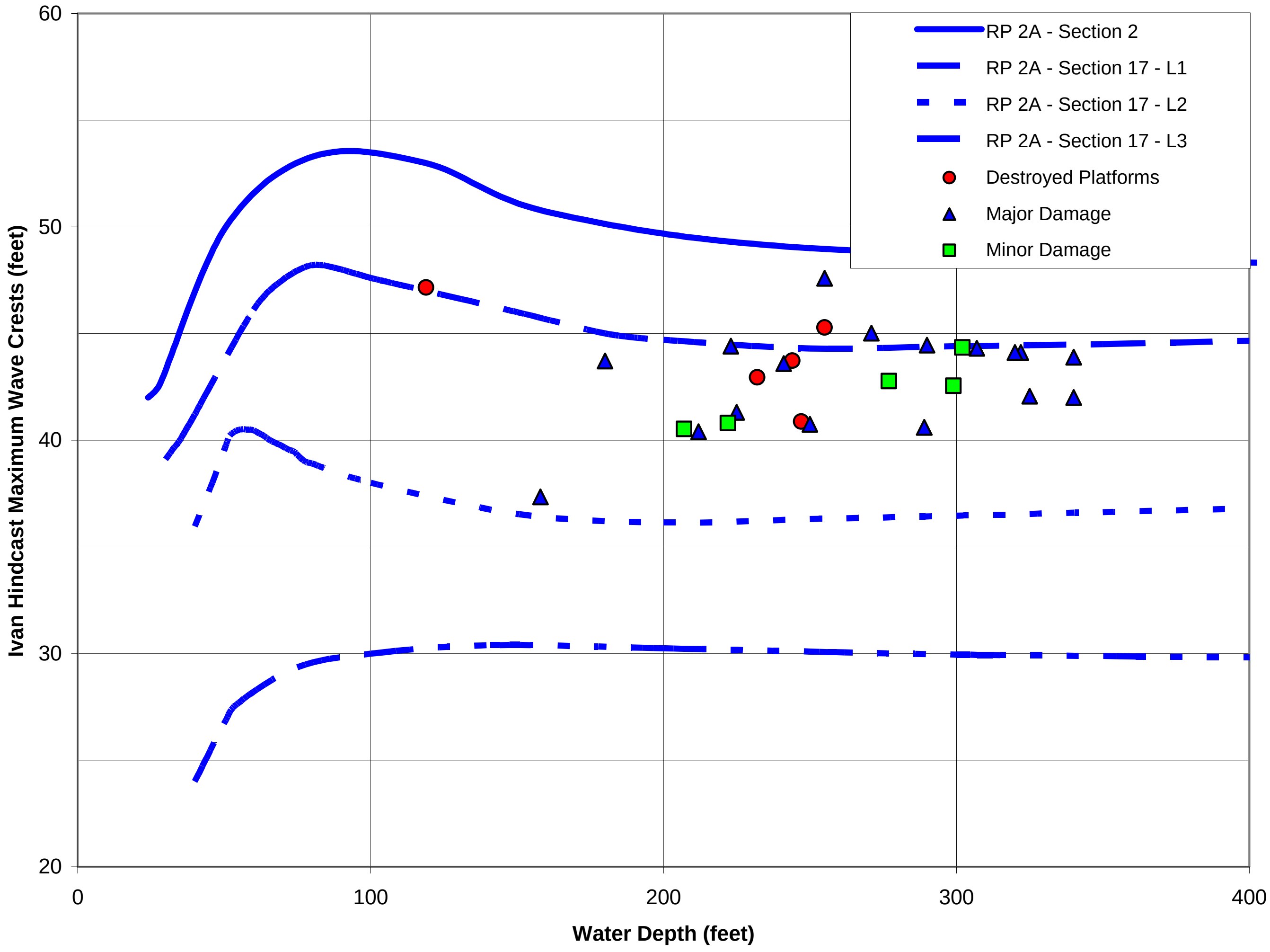


Figure 2.16 – Ratio of Ivan Hindcast Wave Crest versus Deck Heights

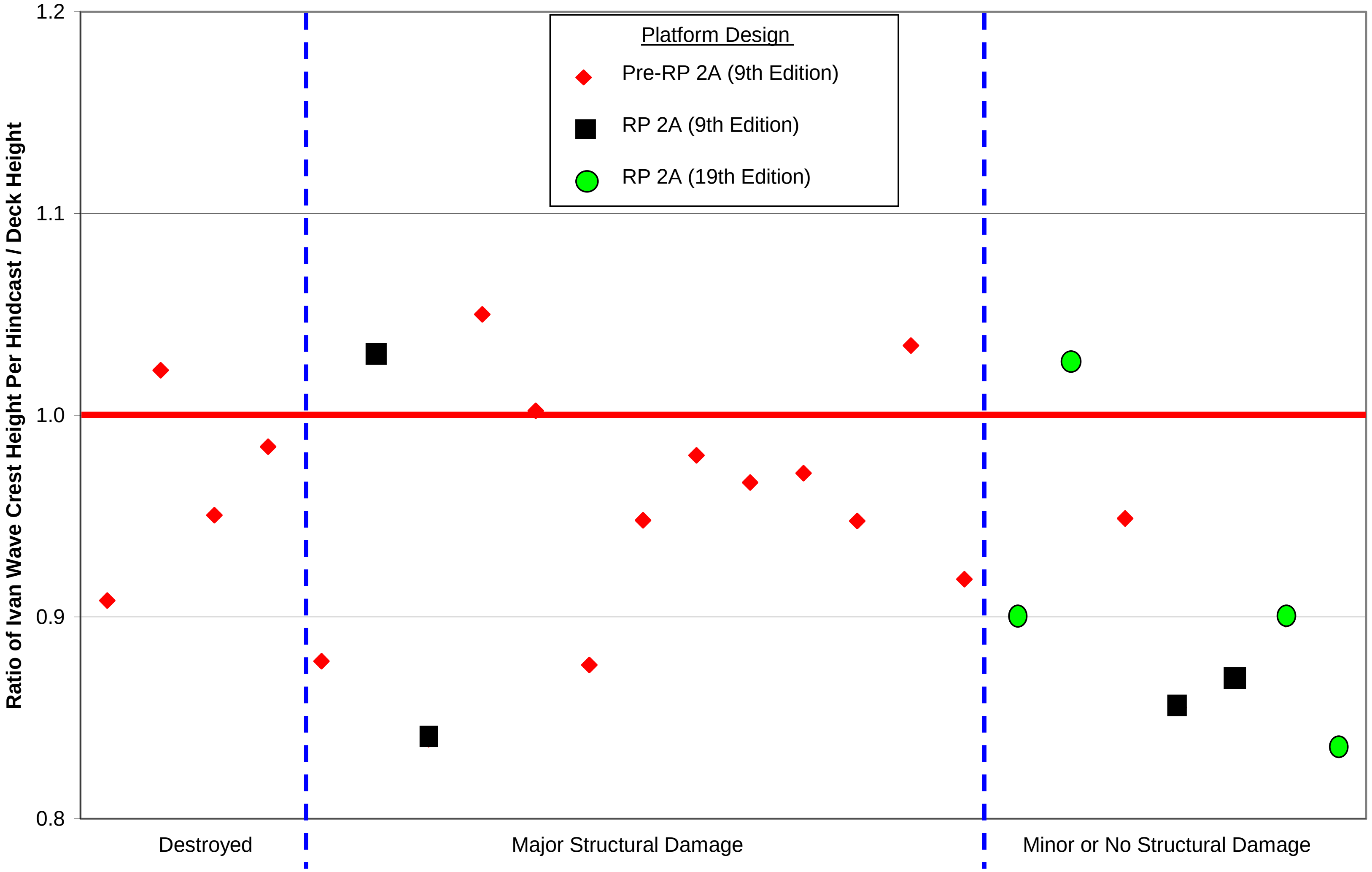


Figure 2.17 – Ratio of Ivan Hindcast Wave Crest versus Deck Heights

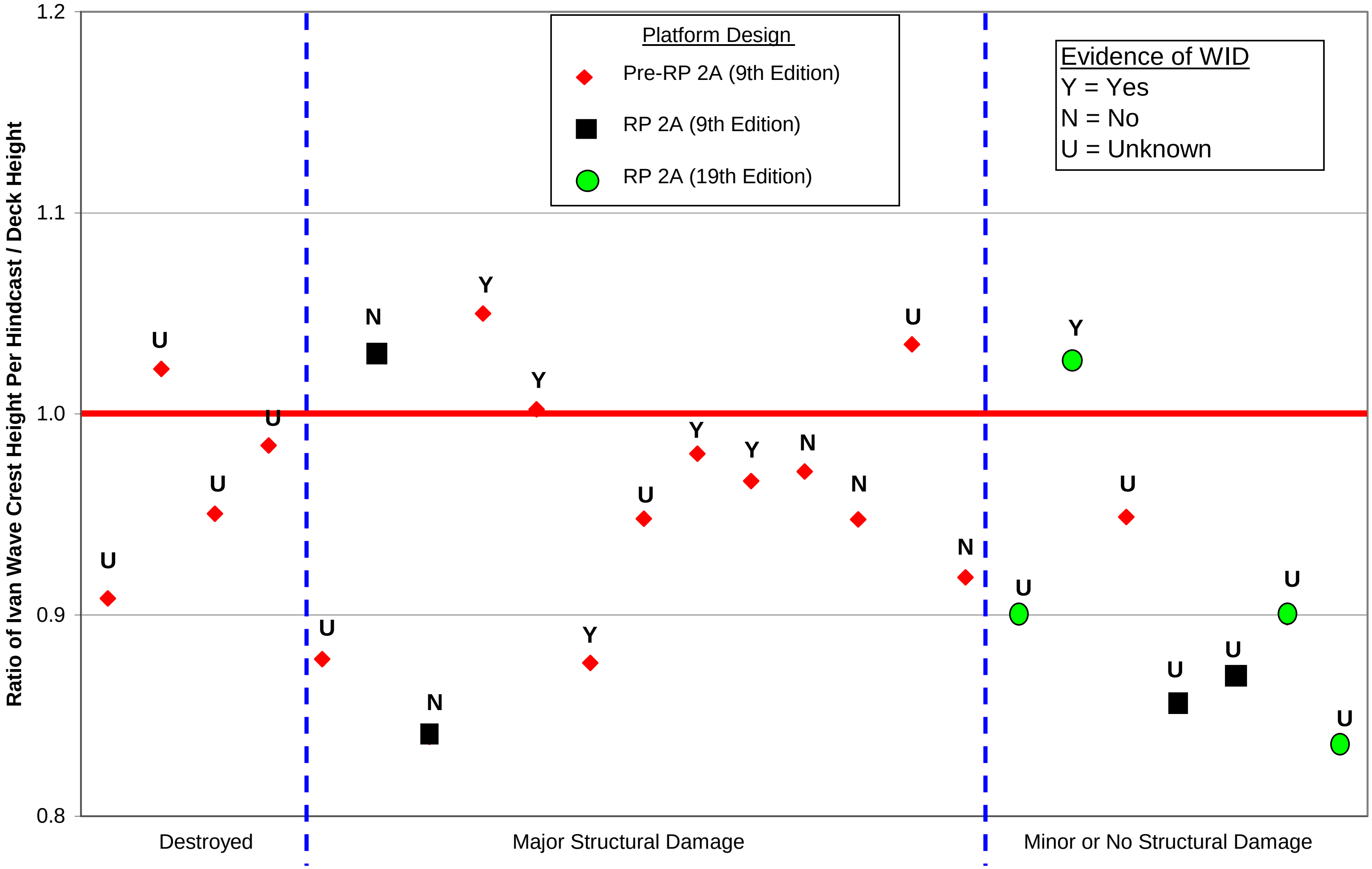


Figure 2.18 compares the API RP 2A design and assessment wave height curves to the Ivan hindcast data. The comparison indicates the maximum wave heights during Ivan based on the hindcast were generally in excess of the current API Section 2 wave height design criteria for new design. The figure indicates that it is likely that the platforms in the path of Ivan, particularly the older vintage platforms were exposed to loads in excess of there original design. The majority of the platforms survived due to the inherent safety factors in the designs. This was highlighted in the example shown in Section 2.3.

Note that when reviewing Figure 2.18 the hindcast maximum wave heights are generally above the new design wave height, but in Figure 2.15 hindcast maximum wave crests are in some cases below the new design deck heights. This occurs because the design deck height curves include an additional safety margin which enables the platform to generally survive waves larger than the “design” wave height. For example, in API RP2A Section 17, the deck height curves are based upon the “ultimate strength” wave height which is higher than the corresponding “design” wave height for a particular water depth.

Figure 2.19 shows the locations of the damaged platforms in relation to the seafloor bathometry. One important factor that stands out when reviewing the figure is the proximity of the damaged platforms to a significant drop in water depth. To the south the water depth drops from approximately 200 feet down to 1600 feet over a relatively short distance. Many of these platforms in this area experienced very high wave crests based on the observed topside damage. The high density of damaged platforms along this seafloor ridge may indicate some form of “shoaling” effect in which the wave crest heights were amplified as they approached the shallower waters of the shelf.

Figure 2.18 –Ivan Hindcast Wave Heights versus Design Waves Heights

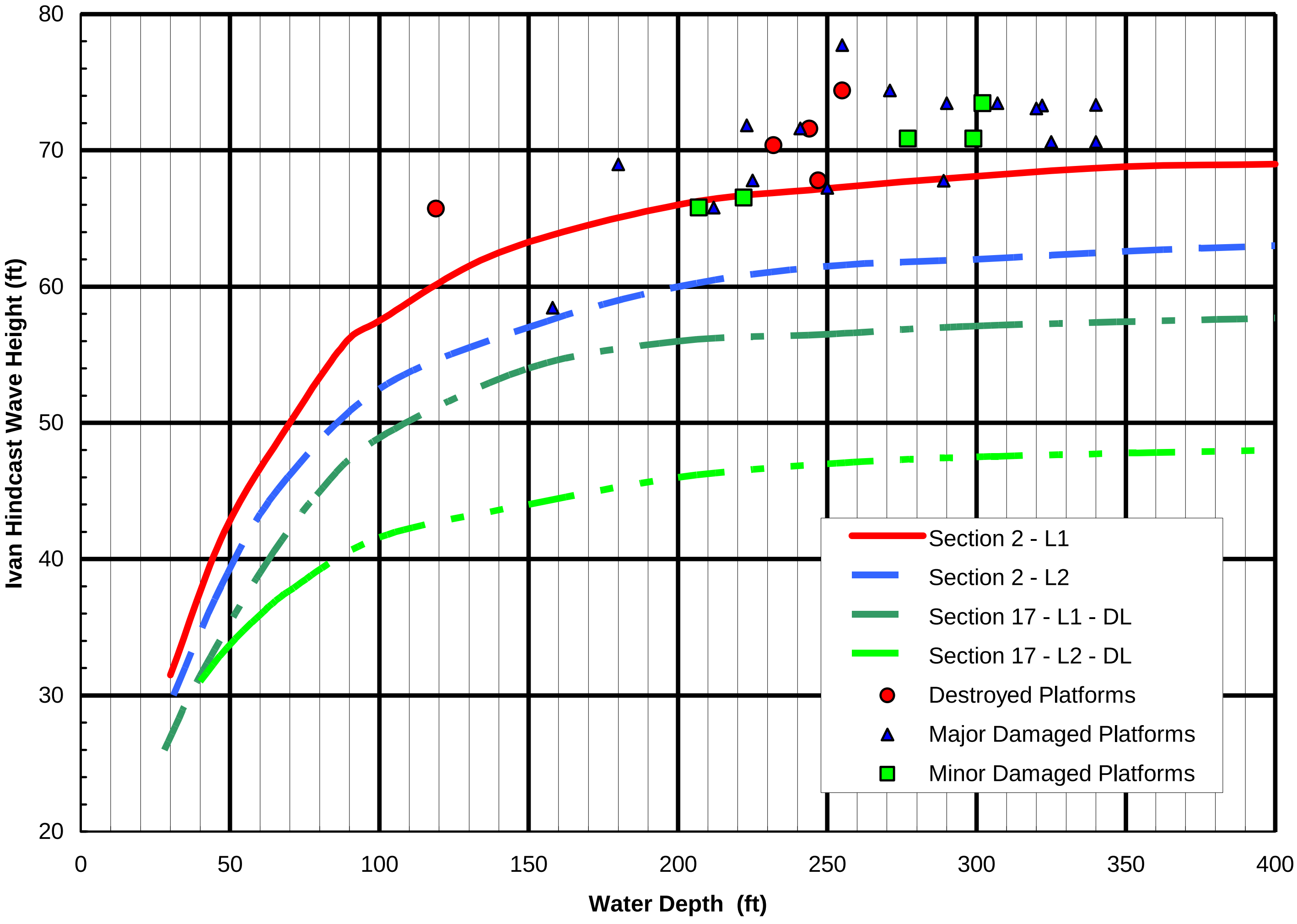
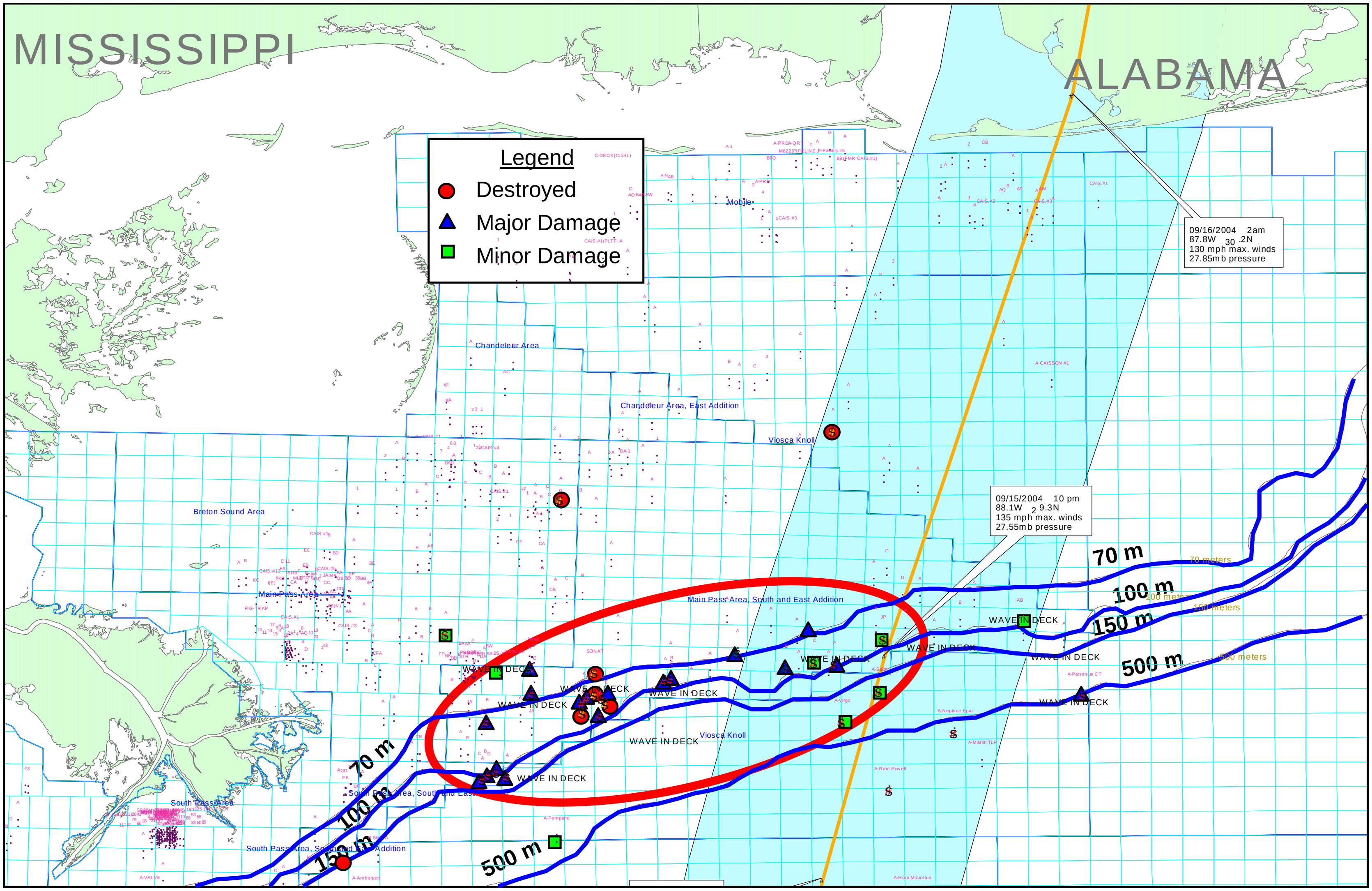


Figure 2.19 – Seafloor Bathometry and Location of Damaged Platforms



09/16/2004 2am
87.8W 30.2N
130 mph max. winds
27.85mb pressure

09/15/2004 10 pm
88.1W 29.3N
135 mph max. winds
27.55mb pressure

2.6 Ivan Recovery Effort

The resources necessary to initiate inspections, conduct repairs, procure equipment, etc. were stretched thin during the Ivan recovery effort [API, 2005]. Initially onshore housing and transportation were a constraint since many of the damaged offshore facilities could not be immediately manned for safety reasons (damaged safety systems, living quarters, power, etc.). Day-tripping (traveling offshore to facility, working during the day and traveling back to shore base at end of day) was the norm. During this time, cooperation and sharing of resources among companies occurred on a regular basis [API, 2005].

The recovery effort after hurricane Ivan was significant both in down-time (lost production) and costs. Some approximate repair costs and man-hours to complete the platform repairs are provide below. These estimates are from discussions during the 2005 Hurricane Readiness Conference - Facilities Breakout Session [API, 2005].

VK 823 Virgo Platform

- 135 days from manning platform to restart facility
- Approximately 75 personnel working on the repairs
- Approximate cost of $15 million

MP281A

- Estimated repair costs approximately $4 million

MP 252 Complex (2 platforms)

- $12 million budget

3.0 QUANTITATIVE ASSESSMENT

3.1 Bias Factors for Ivan

The quantitative assessment involves a probabilistic comparison of observed damage in Hurricane Ivan to analytically predicted damage for the same platforms. The analytical prediction is based upon the "recipe" contained in API RP2A for determining a platform's *load* and *resistance*. The intent is the following:

- How good is the load & resistance recipe in API RP2A?
- Does it predict the correct platform resistance?
- Does it predict the correct platform load?

These issues were also raised in 1992 during Andrew and a study was conducted via a Joint Industry Project [PMB, 1993; Puskar, et. al., 1994; PMB, 1996]. The Andrew work was used to help benchmark Section 17. The issue was further studied in 2004 for Lili via an MMS sponsored study [Puskar, et. al., 2004; ABS Consulting, 2004]. The same approach used for these studies was used here for Ivan.

Note that this is not a test of the adequacy of the API R2Ametocean design criteria. In fact the API RP2A metocean design criteria does not come into play in the quantitative study. The platform's resistance is determined according to API RP2A procedures for steel and pile/foundation design. The load that the platform experienced in Ivan is based upon the hindcast Ivan wave height and the API RP2A wave load recipe (with the Ivan hindcast maximum wave height at the platform site used instead of the API RP2A wind, wave height and current). These are then compared to see if the API approach would have predicted the actual platform performance in Ivan.

The Bias Factor is a quantity which indicates the ratio between the true capacity of a platform versus its predicted strength (as analyzed per API RP2A recipe). If a platform survives after a hurricane, while the ultimate strength analysis predicted it should have been destroyed, this platform has a Bias Factor greater than 1.0. In this case it would imply that the API RP2A analysis recipe is conservative. The Bias Factor can be mathematically written as:

$$\left[\frac{R}{S}\right]_{true} = B \cdot \left[\frac{R}{S}\right]_{computed} \tag{3.1}$$

in which R is the structural resistance capacity, and S is the maximum load induced during the Hurricane.

The Bias Factor is calculated via probabilistic analysis. This is because many quantities are best described by probabilistic variables during a hurricane. For example, the maximum wave height during a storm hour is best described by a probability distribution following a Forristall distribution. There are also uncertainties associated with hindcast data as well as platform capacity predictions. This probabilistic analysis is coupled with a “Bayesian Updating” technique to calculate Bias Factors from an assumed “prior” Bias Factor (assumed as 1.0 for jacket strength). Detailed formulations of the probabilistic Bias Factors and associated Bayesian updating can be found in Appendix A.

Three Bias Factors were considered: Bias Factor for jacket strength (B_j), Bias Factor for foundation lateral strength (B_{fl}), and Bias Factor for foundation axial strength (B_{fa}). In this Section the results are reported for the jacket strength Bias Factor B_j. More detailed results on the foundation Bias Factors can be found in Appendix B. Generally, the foundation Bias Factors are very conservative, in the range of 1.3 (30% conservatism).

Table 3.1 shows the capacity and load summaries for the six platforms used to determine the Ivan Bias Factors. For these six platforms, two were damaged (MP305 No.1 and SP62), three were destroyed (MP305 No.2, MP306 and MP293) and one survived without damage (SP60) during Ivan. Interestingly, the SP60 platform was damaged in a storm in 1998 and repaired using leg-pile grouting, which may have contributed to its ability to survive Ivan undamaged. The capacities for these platforms were divided into four categories: jacket damage, jacket collapse, foundation lateral failure and foundation axial failure. Also included in Table 3.1 is the *expected* maximum base shear for these platforms during Ivan based on the *expected* maximum wave height (approximately $\sqrt{3} * H_S$) and current from the hindcast (Oceanweather, 2004). The values in the table are for illustrative purposes only, with the actual calculations performed in a probabilistic manner, as noted above (i.e., the maximum wave height uses the Forristall distribution).

Table 3.1 - Six Platforms Analyzed for Hurricane Ivan

Platform	Category	Jacket Resistance Damage (kip)	Jacket Resistance Ultimate (kip)	Foundation Lateral Resistance (kip)	Foundation Axial Resistance (kip)	Max. Expected Base Shear (kip)*
MP305 No.1	Damaged	4,000	4,400	9,900	5,100	5,200
SP60	Survived	6,600	7,000	8,400	9,400	7,900
MP305 No.2	Destroyed	4,000	4,400	9,900	5,100	4,800
MP306	Destroyed	4,000	4,400	14,100	3,700	4,600
SP62	Damaged	7,300	8,500	17,700	8,600	5,900
MP293	Destroyed	4,000	4,400	9,900	5,100	4,500

* Without wave-in-deck force since hindcast waves did not reach the deck based on $\sqrt{3} * H_S$.

The jacket Bias Factors calculated for the platforms in Table 3.1 are shown in Figure 3.1. The "prior" Bias Factor is also shown in Figure 3.1 with an assumed mean value of 1.0 (no bias) and a COV (coefficient of variation) of 30% [PMB, 1994; PMB, 1996, ABS Consulting, 2004]. The MP305 No.1 platform has a Bias Factor of 1.18 after the Bayesian updating calculation. This is explained by comparing the capacity and the load values for this platform as listed in Table 3.1. For this platform, the maximum base shear during the Hurricane is 5,200 kips, while the ultimate resistance (collapse strength) of the jacket is 4,400 kips. This platform is therefore expected to be destroyed during Ivan, yet it only sustained a few damaged braces.

The Bias Factor for the SP62 Platform is calculated as 0.93, and can be explained similarly as described above. The maximum base shear during Ivan is predicted at 5,900 kips, with the ultimate resistance at 8,500 kips. This platform is therefore expected to survive during Ivan without damage, yet it sustained substantial damage. As a result, the Bias Factor is 0.93 and on the un-conservative side.

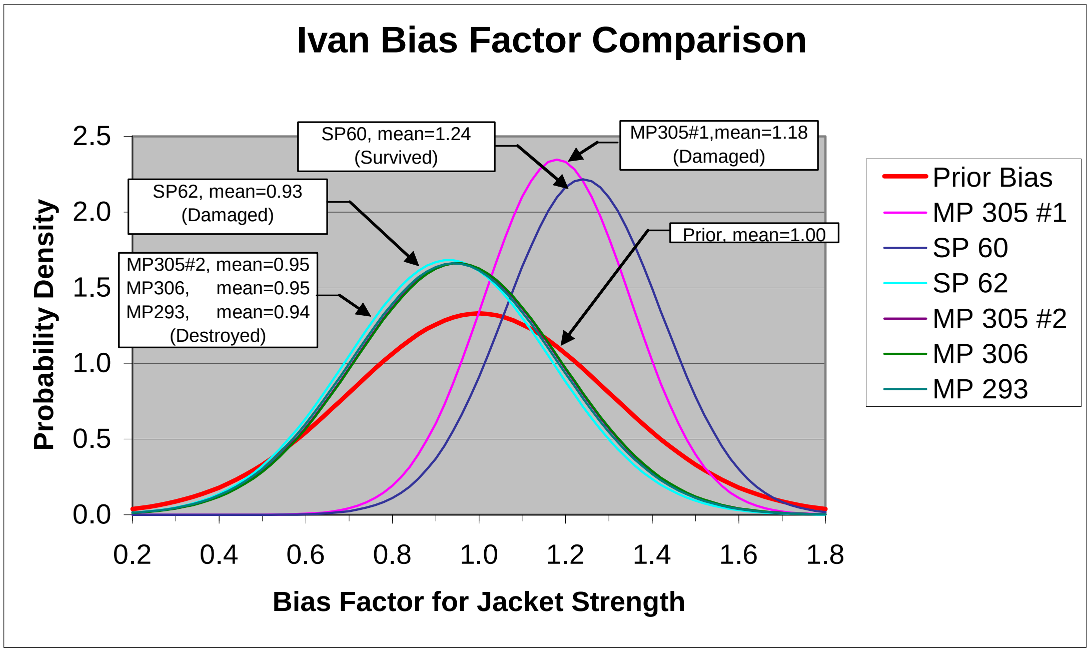


Figure 3.1 - Jacket Bias Factors for Six Platforms Analyzed for Hurricane Ivan

The Bias Factors for the six platforms analyzed can be combined into a single Bias Factor, as shown in Figure 3.2. The combined jacket Bias Factor for Ivan is 1.0, which means the prediction typically matches the observation almost exactly. Detailed information on Bias Factors (including foundation Bias Factors) for each of the platforms analyzed is presented in Table 3.2.

However, it should also be noted that this result is the combination from the six specific platforms analyzed, with two platforms on the conservative side (>1.0) and four platforms slightly on the un-conservative side (<1.0). It is therefore believed that these results are conservative. The lower Ivan results (compared to Andrew and Lili) may be explained by the particular selection of these six platforms, mostly damaged or destroyed. The inclusion of more platforms that survived Ivan, would increase the Bias Factor, but there was little information on survived platforms available to this study (most operators study damaged platforms and not those that survive). There is also a possibility that some of the damaged platforms had prior unknown existing damage that was not taken into account in the assessment. Hence the Ivan Bias Factor is believed to be conservative. There is also the possibility that the decrease in Bias Factor is due to the uniqueness of Ivan, particularly the observed high wave crest elevations as discussed in Section 2. The hindcast values may also come into play as discussed in Section 3.3. All of these issues point to need for additional studies like this with other hurricane data, like Katrina and Rita (see the recommendations in Section 4.3).

Overall, the Quantitative Assessment for Ivan indicates that the API RP2A fixed platform “recipe” has a Bias Factor of about 1.0. When combined with Andrew and Lili, the Bias Factor increases to 1.10 (See next section). These results indicate that API RP2A is doing a slightly conservative job of predicting platform performance.

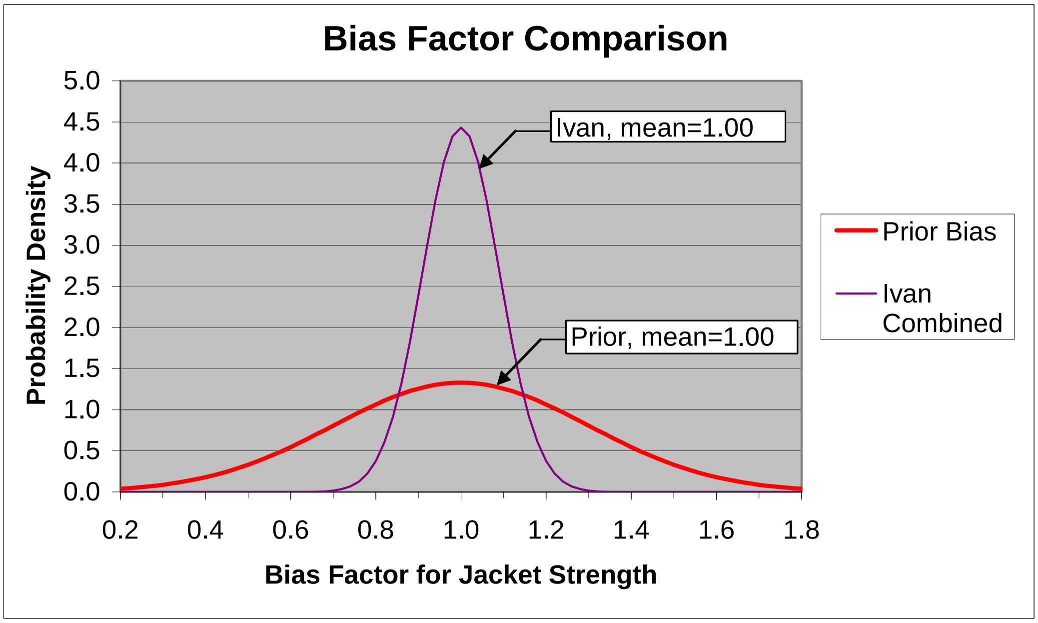


Figure 3.2 - Combined Jacket Bias Factor from Six Platforms Analyzed for Hurricane Ivan

Table 3.2 - Calculated Bias Factors for Jacket (B_j), Foundation Lateral Strength (B_{fl}), and Foundation Axial Strength (B_{fa})

			Mean	COV
MP 305 #1	Damaged	B_j	1.18	0.17
		B_{fl}	1.07	0.26
		B_{fa}	1.42	0.2
SP 60	Survived	B_j	1.24	0.18
		B_{fl}	1.14	0.2
		B_{fa}	1.37	0.2
MP 305 #2	Destroyed	B_j	0.95	0.24
		B_{fl}	1.08	0.29
		B_{fa}	1.37	0.2
MP 306	Destroyed	B_j	0.95	0.24
		B_{fl}	1.08	0.29
		B_{fa}	1.42	0.2
SP 62	Damaged	B_j	0.93	0.24
		B_{fl}	1.03	0.25
		B_{fa}	1.36	0.21
MP 293	Destroyed	B_j	0.94	0.24
		B_{fl}	1.07	0.29
		B_{fa}	1.36	0.2

3.2 Bias Factors for Ivan, Lily and Andrew Combined

The Bias Factors calculated for Ivan (6 platforms analyzed) can also be combined with previous results as analyzed for Andrew (9 platforms analyzed, [PMB, 2006]) and Lily (3 platforms analyzed, [ABS Consulting, 2004]). This is shown in Figure 3.3 in which Andrew has a Bias Factor of 1.09 and Lily has a Bias Factor of 1.24. After combining the three set of results the combined Bias Factor for jacket is 1.10.

It is important to note that the Bias Factor results are influenced by the number of platform analyzed and the behavior of platform versus expectations. For example, if a large number of platforms chosen has unexpected failures, then the Bias Factor will be lower. Due to these differences in the platforms chosen for these three different hurricanes, the Bias Factors obtained from these hurricanes should not be expected to match exactly. Rather, they compliment each other and the combined Bias Factor is more representative than their individual components.

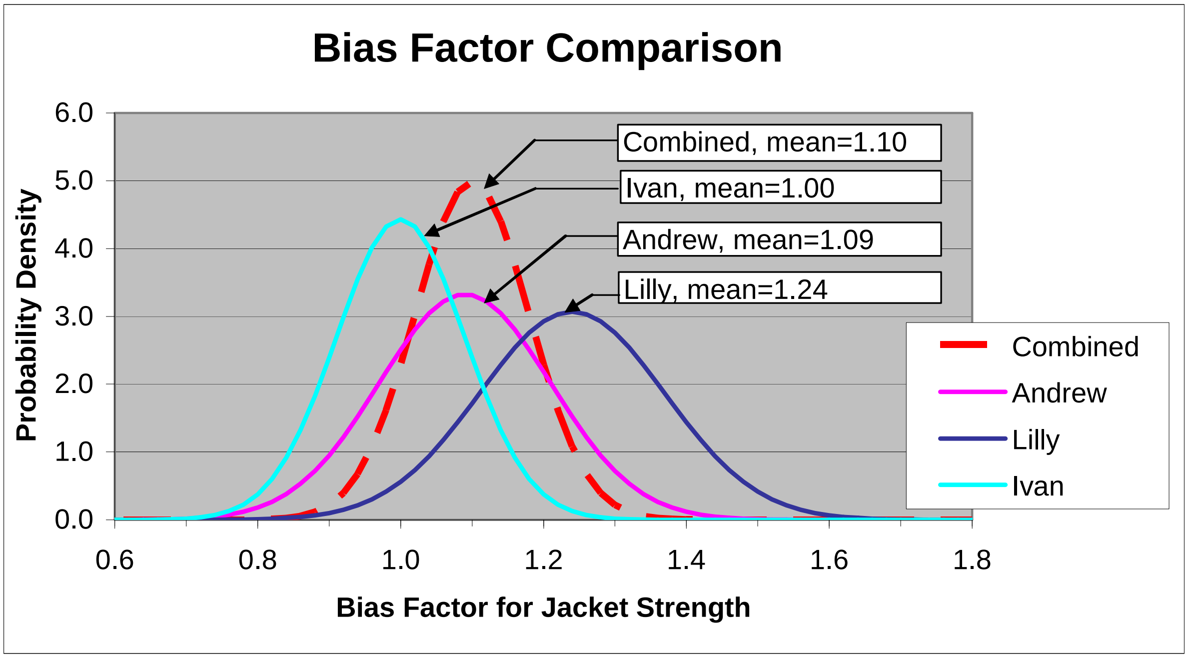


Figure 3.3 - Jacket Bias Factor of Combined Results for Hurricanes Andrew, Lily and Ivan

3.3 Sensitivity of the Bias Factor with Significant Wave Height

One issue raised during the Expert Panel meeting is that the actual wave heights occurring during Ivan appear to be larger than the hindcast values. For some platforms, evidence of wave-in-deck impact were observed yet the maximum wave height as calculated from hindcast data shows no such impact should have occurred (see the Qualitative Assessment in Section 2 for more detail).

To understand how much effect this has on the Bias Factors, a sensitivity was performed with the hindcast significant wave heights increased by 3 feet. As previously noted, the maximum wave heights used in the analysis are then computed using the Forristall distribution. Results are shown in Figure 3.4, in which the Bias Factor increases from 1.0 for the original hindcast to 1.14 for the increased hindcast (a 14% increase). This sensitivity study shows that the Bias Factor is relatively sensitive to the wave height input. It also indicates that this type of adjustment would increase the Ivan Bias Factor to a value that is more consistent with the values determined for Andrew and Lili.

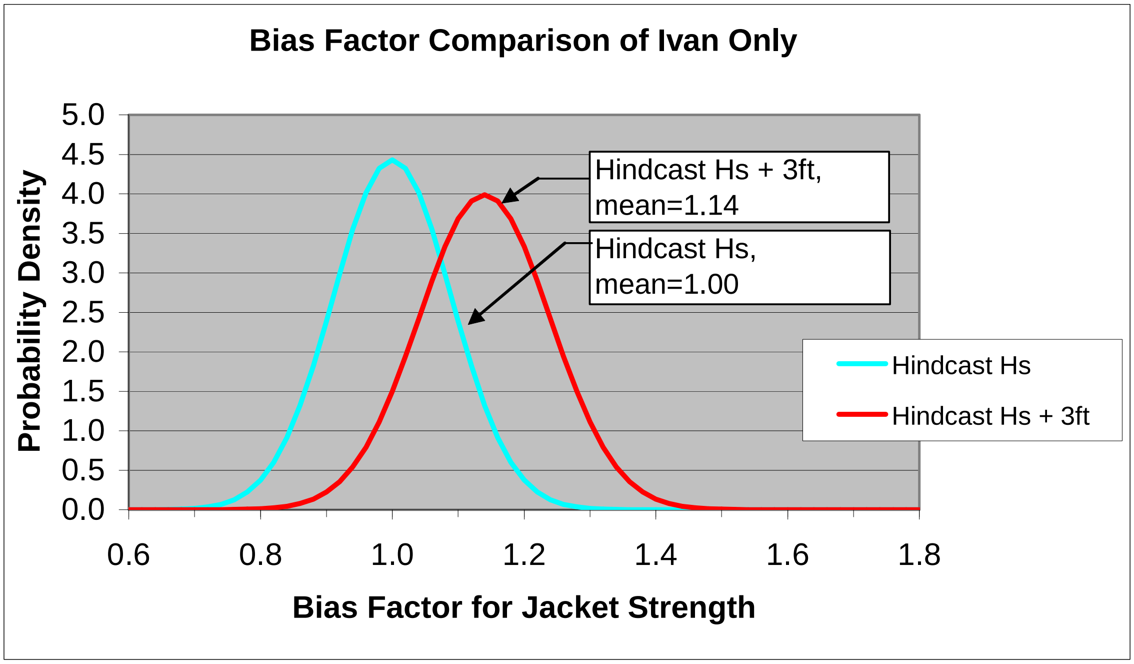


Figure 3.4 – Sensitivity of Ivan Bias Factor with Hindcast H_s Increased by 3 Feet

Also as a part of the sensitivity study, the combined Bias Factor from Hurricanes Andrew, Lily and Ivan was re-calculated using this increased wave height for Ivan (while wave heights for the other two Hurricanes are unchanged), with the results shown in Figure 3.5. The combined jacket Bias Factor is increases from 1.10 to 1.17.

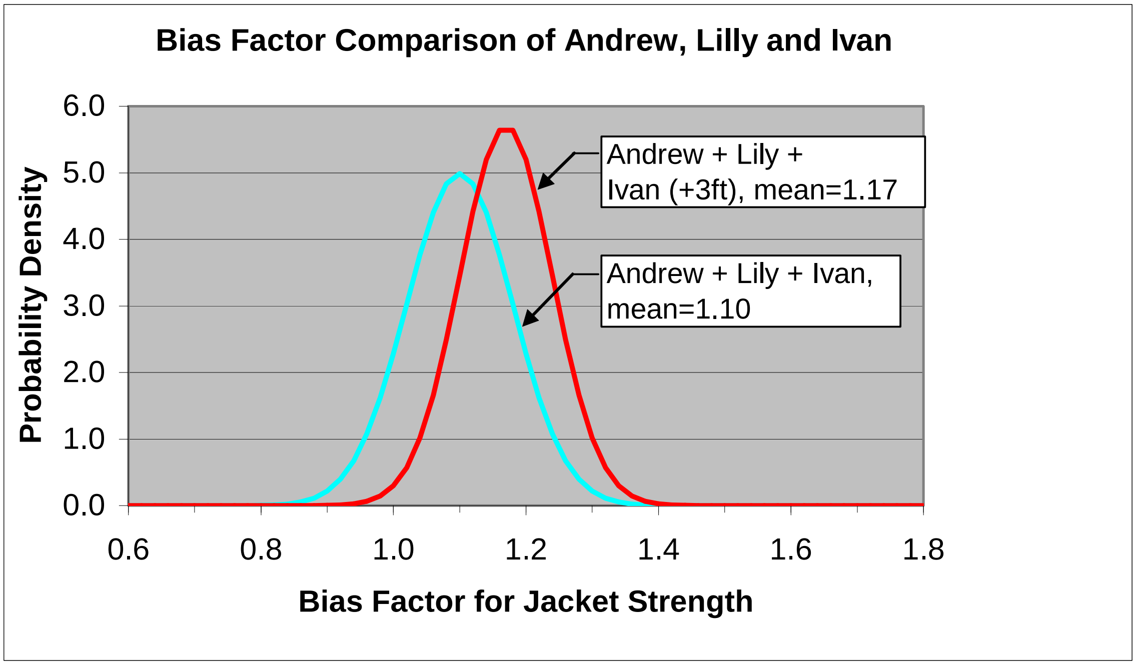


Figure 3.5 - Sensitivity of Combined Bias Factor with Increased Ivan Wave Height

4.0 EXPERT PANEL

4.1 Background

The meeting of the Expert Panel was held on December 13, 2005, at the Energo offices in Houston, Texas. The agenda for the meeting and the thirteen participants of the panel are provided in Appendix C.

The Expert Panel discussed a variety of issues, with most of the discussion focused on the damage and destruction of fixed platforms due to waves impacting the deck. General issues related to Katrina and Rita were also discussed, but not in detail since a similar study as described here has yet to be conducted for these hurricanes.

4.2 Recommendations

1. Investigate the possible changes to the <u>minimum deck elevation curves</u> for design of new platforms as contained in API RP2A Section 2, and for assessment of existing platforms as contained in Section 17.

> These are used to *establish fixed platform deck height.* Numerous platforms experienced wave-in-deck during Ivan as documented by damage observed to decks. Many of the platforms that were destroyed had wave-in-deck loading. It is a critical value because if the deck is high enough, above extreme wave crest elevations, then the platform has a good chance of surviving extreme conditions. The hindcast shows that in *some cases* waves were predicted to be in the deck, but in others, the hindcast indicates the waves were below the deck. There appears to be uncertainty about the elevation of wave crests in these extreme storms. This may be related to the height of the crest itself, the shape of the wave or wave crest, the kinematics at the crest, or other associated factors. These should all be addressed in a comprehensive study. Several items that should be considered in such a study include:
>
> a) API uses a specific design wave crest elevation (thought to be a 100 year return period condition) to establish the minimum deck elevation curves. Is this correct? Is a different return period wave height preferred?
> b) API uses an additional factor of safety or “air-gap” to increase the crest elevation. Is this air gap correct? Is a larger gap preferred? Should the crest elevation instead be based upon an “ultimate strength” wave of longer return period, say 500-1,000 years? Note that there are limits of platform deck heights due to reach and lifting constraints of installing crane barges, and this should be considered.
> c) The API RP2A wave height curves likely change once Ivan is included into the statistical database. Katrina and Rita will also influence the wave height.
> d) The data used to determine the API RP2A wave height curves divides the Gulf of Mexico into numerous sectors (about 25) for the statistical dataset. Is this correct? Every hurricane that comes into the Gulf impacts several of

these sectors (e.g. 4-6) as the storm moves to shore – is this considered? Should there be different wave heights in different regions (e.g., East, Central and West Gulf of Mexico)?

e) Is the hindcast correct? Although the hindcast (Oceanweather) has been benchmarked against buoy data, the field observations of deck damage indicate that the waves were higher than the hindcast predicts. Some of this may be due to issues associated with computing the maximum wave height from the hindcast significant wave height, or they may be associated with the significant wave height itself.

f) Are waves always long-crested as the theories state? We see considerable wave-in-deck damage that is localized to a small region of the deck. Does this affect the deck elevation criteria?

g) Are the statistics used to determine the maximum wave height from the significant wave height used by metocean experts correct? Numerous platforms have signs of deck damage yet the hindcast indicates the waves were not that high at the platform site. Perhaps the *significant wave height* is correct, but the extrapolation to the *maximum wave height* is incorrect.

h) Is the shape of the wave, particularly in the crest region, per the wave theories? Does the presence of the platform effect wave shape? Is there an effect caused by run-up of the wave near the platform legs (the physical evidence is inconclusive on this issue)?

i) There seems to be a large number of platforms destroyed and damaged near the shelf edge in about 300 feet of water (see Section 3). Is there a breaking wave phenomenon in these waters that needs to be accounted for when the waves are exceptionally high as in Ivan?

j) Existing Platforms (Section 17). These issues also affect the Full Population hurricane criteria of Section 17, and perhaps the Sudden Hurricane criteria. The Section 17 waves were derived on a consistent "force" basis, different than the API Section 2 wave heights used for new design. So this effort requires a different work set than for new design, although some of the new design issues associated with wave height characteristics are the same.

2. Investigate possible changes to the <u>wave height curves</u> in API RP2A used for designing new platforms as contained in Section 2 and for assessing existing platforms as contained in Section 17.

These are used to determine the required *platform resistance.* Most industry personnel understand that the basis for the Section 2 curve for design of new platforms is based upon a metocean condition at any site in the GOM. OTC 2005 paper Number 17740 [Cooper, et.al., 2005] indicates that when Ivan is included, the API RP2A new design wave height increases by about 3 feet in some water depths. Section 17 contains wave heights used for assessments, with the Full Population A-1 criteria partly based upon historical hurricane data like Ivan. Although the wave height curve is a different value than Item 1 related to minimum deck elevation, it is one of the most critical factors that determines the overall platform resistance. The same set of issues that were identified for the deck elevation should also be considered here. Of particular importance for this value is the inclusion of the Ivan (and Katrina and Rita) data into the process to determine the API RP2A L-1 platform design wave heights. The design wave heights for the Section 2, Consequence Based Design L-2 platforms may also have to be included in such a study. For existing platforms, the Full Population criteria is based upon specific target reserve strength ratios (RSRs) and not upon return period. It is not clear how changes to wave height will affect the Section 17 criteria (for example, if there is a change in the statistical wave data when Ivan is included), but it also needs to be included in the study.

3. Investigate damage to secondary structural members such as conductor trays, sump caissons, and riser clamps and provide design guidance.

Several of the platforms sustained damage to non-primary structure that resulted in considerable shut-in time and costly repairs. Examples include conductor trays located near the waterline (e.g. -40 ft) that sustained cracks or fell-out, and sump caissons and riser clamps that failed. There is little design guidance in API RP2A for these structures to ensure such problems do not occur. Some of these failures may be caused by pure strength overload during the hurricane, while some of the damage, particularly conductor trays located near the waterline, may be damaged by high stress, low cycle fatigue. These issues should be studied in more detail, with the intent of providing design guidance and also guidance on the ability to recognize where secondary structures on existing platforms may be vulnerable to such damage.

4. Investigate specifically the destroyed platforms in hurricane Ivan in order to understand how the failures occurred and how they could have been prevented.

There is little analytical data available on the destroyed platforms since there is little incentive by operators to evaluate these structures in a detailed manner to find out what went wrong. Almost all of the analytical evaluations are performed on platforms that were damaged in order to perform an assessment or design a repair. For Andrew, there was considerable analytical work performed on the destroyed platforms by the major operating companies of the time. This is not the case today. These destroyed platforms may provide the most valuable information from an event like Ivan. This can be a combination of qualitative and quantitative work, as performed here.

5. Provide metocean instrumentation on fixed offshore platforms.

There is little to no metocean instrumentation on fixed platforms that provides data such as wave height, current and wind. Most of the existing instrumentation is on deeper water floating structures. Extreme wave characteristics may be different in the shallower water (<400 ft) region than for deep water. Such data would help verify some of the issues related to extreme waves. An example of simple low cost instrumentation is a video camera mounted on the platform that provides digital evidence of extreme seastates during hurricanes, including the crest elevations.

6. Investigate the apparent conservatism in pile foundation design and make recommendations for change to the design and assessment process, if any.

There were no known foundation failures in Ivan, other than mudslides which are addressed in a separate study funded by the MMS. There have also been few, if any, documented foundation failures due in prior hurricanes. Most of the failures are in the jacket system. Yet results of pushover analyses indicate on a regular basis that the foundation system will fail first. The pile foundation conservatism was computed as part of the Andrew, Lili studies as well as this study for Ivan with quantitative assessments in the range of 30 to 40% conservatism. This conservatism is also seen in new design, where deep piles are often required – yet they can be difficult to install since the soils are actually stronger. Large diameter single caisson well head structures sometimes have a similar installation problem. This conservatism has been highlighted in several other industry studies. It is recommended to perform a study that takes all of this into account to update pile foundation assessment for new design and assessment of existing platforms. Such a study should account for the entire pile foundation design process – from soil sampling and laboratory testing to the pile-soil values used for design in order to identify conservatisms.

4.3 Other Comments

In addition to the recommendations, the Expert Panel made several other comments related to the study. These are summarized as follows.

1. The Bias Factor for Ivan appears lower than expected.

The computed Bias Factor of 1.0 for Ivan is smaller than determined for Andrew and Lili (Bias of 1.1 to 1.2). The Panel commented that this may be due to the selection of the particular platforms used. However, it may also be due to the unique characteristics of Ivan. It was suggested that the controlling platform that resulted in a significant reduction of the bias be removed from the data set (one of the participants familiar with this facility noted that this platform may have had prior damage which was not being accurately accounted for). It was also suggested that if the hindcast were to be smaller than actual, that this has an effect on the results and a case should be run with an assumed higher hindcast height (e.g., 3 ft). These extra cases were run and are described in Section 3.

2. This work and the recommended work should be coordination with other Industry studies.

There are several other ongoing or planned industry studies that can or should coordinate with this study or the proposed future studies. These include:

- Structural Integrity Management JIP (SIM JIP, MSL Services and Energo). Funded by industry as well as the MMS and API, this study is developing a new RP for existing fixed platforms, including Section 17.
- MODU Mooring Reliability JIP (ABS Consulting). This is investigating the performance of MODU mooring systems in extreme hurricanes and making recommendations for changes to API recommended practices for mooring design, particularly API RP2SK. There is a significant metocean task that can address some of the issues noted in this study.
- API Fixed Platform Studies (Studies pending). These are presently just getting underway. General topics to be addressed are Metocean, Data Gathering, Platform Assessment, Loads on Secondary Structures, and Communication with the Public.
- Resolution of Wave Crest Disparity During Ivan (Forristall Ocean Engineering). A JIP detailed investigation of the wave-in-deck issue.
- Wind damage to decks (Studies pending). Some of the damage reported for fixed platforms was specifically related to wind damage. Such damage was not the focus of this study. There are other on-going proposed MMS and API related studies of wind damage.

3. This work should be continued to include Katrina and Rita.

The MMS Ivan project was initiated prior to Katrina and Rita, that combined, destroyed over 114 fixed offshore platforms. Several of the platforms studied here for Ivan as damaged were later destroyed in Katrina or Rita. The procedures and results of the Ivan study should be extended to include these two hurricanes. In particular the computation of the Bias Factor would benefit from additional observations of observed platform survival, damage or destruction. Including Andrew, Lili, and Ivan these two hurricanes would increase the number of hurricanes used to judge API RP2A via the Bias Factor, which provides a much more meaningful comparison.

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Appendix A

Qualitative Assessment

Platform Damage Summary

Platform	**Main Pass 144A**
Operator	**Chevron**

Platform Description

Water Depth	**206 ft**
Deck Height	**65 ft**
No. of Slots	**14**
No. of Conductors	**12+2**
Installation Date	**1968**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**2 + 2 sets of 6 conductors**
Distance from Shore	**24 mi**
Bracing Configuration	**K bracing for top and bottom bay; XH bracing for middle bay**


Figure 1

Storm Exposure

Min. Distance/Direction from Eye	**36 mi**	Maximum Storm Surge	**1.3 ft**
Maximum Wave Height	**66 ft**	Maximum Wind Speed	**64 kts**
Significant Wave Height	**37 ft**	Current Speed	**2.5 kts**
Wave Crest Elevation	**41 ft**		

Storm Damage

Structural Damage	**Yes**	Evidence of Wave in Deck	**No**

Structrual Damage Description	Many deck members in a 13' x 60' cantilever deck section sustained significant damage during the storm. All other damage to the platform were either known from previous inspections or from a marine vessel collision which occurred after the storm in November 2004.
Non-structural Damage (wiring, piping, safety systems, etc.)	Extensive secondary structural damage above the waterline. When arriving after the storm the structure was found to be unsafe to board. Below the main deck the boat landing bracings as well as numerous sections of gratings and handrails were missing and both stairs were bowed. Also cable trays and cables were observed to be damaged. Above the main deck, handrails, piping, equipment and buildings were damaged.
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	The damaged cantilever deck section is to be replaced with a larger deck section.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	The winds and not the waves are expected to be the reason for the damage to the deck extension. This based from an OTC 2005 paper presented by Chevron on their experiences with fixed platforms during Ivan.

Platform Damage Summary

Platform	**Main Pass 311 B**
Operator	**Apache Corporation**

Platform Description

Water Depth	**246 ft**	
Deck Height	**52 ft**	
No. of Slots	**18**	
No. of Conductors	**15**	
Installation Date	**1980**	
API 2A Assessment Category	**L2**	
Jacket Type	**Platform**	
No. of Piles	**8 piles and 8 skirt piles**	
Distance from Shore	**19 mi**	
Bracing Configuration	**Long frame: XH for center bays; / for outer bays; Tran Frame: XH bracing**	

Storm Exposure

Min. Distance/Direction from Eye	**38 mi**	Maximum Storm Surge	**1.1 ft**
Maximum Wave Height	**67 ft**	Maximum Wind Speed	**61 kts**
Significant Wave Height	**38 ft**	Current Speed	**2.4 kts**
Wave Crest Elevation	**41 ft**		

Storm Damage

Structural Damage	**Yes**	Evidence of Wave in Deck	**No**

Structrual Damage Description	1. 6"L x 4"W x 2"D dent on a small vertical member (VM) on row A near the water line. 2. 1.5"W x 19.25"L crack at end of VM at the connection of X-brace veritcal diagonal. VM appears to have torn away from the X-brace resulting in a large crack near the weld, propogating outward along the length of the vertical diagonal. 3. 18"L x 18"W x 4"D dent on a HZ at the (-)46.5' elev. connecting leg B1 to leg A1. Notes in inspection report indicte that this is not anticipated to have been caused by the storm.
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	A design level assessment was performed on the post-storm condition (i.e. assuming damaged members cannot carry load) per RP2A 21st edition. Platform was found to pass the L2 sudden hurricane criteria. Based on assessment results, damaged members will be removed.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	The fact that the cracked member was at the end of the dented VM, may indicate that the cause of damage was due to impact, possibly boat or falling object.

Platform Damage Summary

Platform	**Main Pass 281 A**
Operator	**Dominion E & P**

Platform Description

Water Depth	**307 ft**
Deck Height	**52 ft**
No. of Slots	**9**
No. of Conductors	**6**
Installation Date	**1997**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**4**
Distance from Shore	**57 mi**
Bracing Configuration	**The platform has XH long frame and tran frame bracing.**

Storm Exposure

Min. Distance/Direction from Eye	**5 mi**		Maximum Storm Surge	**1.3 ft**
Maximum Wave Height	**74 ft**		Maximum Wind Speed	**75 kts**
Significant Wave Height	**41 ft**		Current Speed	**1.8 kts**
Wave Crest Elevation	**44 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Yes**

Structrual Damage Description	1. Two members were found to be flooded; VD A1(+)12' to A2(-)65' and VD A1(+)12' to B1(-)65'. 2. A2 jacket let has complete separation 360 degrees around the jacket leg at (-)58' level. 3. B2 jacket leg has complete separation 360 degrees around the jacket leg at (-)6' level. 4. VD A1(+)12' to A2(-)65' has a bulge 2' below the X-brace, a break at -47' level and another bulge at -64' level. 5. VD A1(+)12' to B1(-)65' has a bulge 1' below the X-brace, a break at the -40' area and a second bulge at the -62' level.
Non-structural Damage (wiring, piping, safety systems, etc.)	Some handrails and grating were missing. Some evidence of wave in deck under cellar deck (bent beams under deck).
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	The structure was re-analyzed with the same metocean criteria used in the original design which was based on the RP2A 19th Edition. Welded sleeves were provided for the cut-off VD's and clamps were provided for the jacket legs.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 296 B**
Operator	**GOM Shelf LLC**

Platform Description

Pre-Storm Platform Image Not Available

Water Depth	**225 ft**
Deck Height	**52 ft**
No. of Slots	**18**
No. of Conductors	**19**
Installation Date	**1982**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**8 Piles and 4 Skirt piles**
Distance from Shore	**24 mi**
Bracing Configuration	**Tran Frame: Rows 1 & 4: K bracing for bottom bay and XH bracing above it. Rows 2 & 3: XH bracing on one vertical half side and / bracing on the other.** **Long Frame: Bottom bay of both faces have XH bracing. Among the top bays, the center bay has XH bracing and the end bays have / bracing.**

Storm Exposure

Min. Distance/Direction from Eye	**35 mi**		Maximum Storm Surge	**1.2 ft**
Maximum Wave Height	**68 ft**		Maximum Wind Speed	**63 kts**
Significant Wave Height	**38 ft**		Current Speed	**2.4 kts**
Wave Crest Elevation	**41 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**No**

Structrual Damage Description	1. Damaged VD from B4(+)14' level to B3(-)62' level. It has 2" high x 6" wide bulge at the (-)39' level and another slight bulge near where it ties into the B3 leg. 2. Damaged VD from A4(+)14' level to A3 (-)52' level. It has a 1/4" high bulge at the (-) 40' level and another slight bulge where the member ties into the A3 leg. 3. Damaged HZ brace at the (-)62' level connecting leg B1 to leg B2. It has a slight bulge or ripple at about 20' from leg B1.
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	A design level assessment was performed on the post-storm condition (i.e., assuming damaged members cannot carry load) per RP2A 21st edition. Platform was found to pass the L2 sudden hurricane criteria. Two members were found to be overstressesed, and are going to be removed. These were only used to frame the skirt pile guide into the jacket
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 289 B**
Operator	**Apache Corporation**

Platform Description

Water Depth	**301 ft**
Deck Height	**45 ft**
No. of Slots	**18**
No. of Conductors	**16**
Installation Date	**1968**
API 2A Assessment Category	**L1**
Jacket Type	**Platform**
No. of Piles	**8 main piles and 4 skirt piles**
Distance from Shore	**39 mi**
Bracing Configuration	**Long Frame: All the bays have / bracing except the bottom end bays, which have a K bracing.** **Tran Frame: Rows 1&4 have K bracing for the bottom bay and / bracing for the ones above. Rows 2&3 have K bracing for the bottom row, XH bracing for the 2 bays above it and / bracing for the top 2 bays.**

Storm Exposure

Min. Distance/Direction from Eye	**20 mi**		Maximum Storm Surge	**1.2 ft**
Maximum Wave Height	**73 ft**		Maximum Wind Speed	**71 kts**
Significant Wave Height	**41 ft**		Current Speed	**1.8 kts**
Wave Crest Elevation	**44 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Yes**

Structrual Damage Description	1. An underwater inspection during September and October 2004 found five dented jacket braces. 2. A 26" diagonal brace on row B from leg 2 at the (+)10' level to leg 3 at the (-)42' level was found to have a midspan crack. 3. A VD from leg B2 at (-)98' level to leg B3 at (-)42' level had a dent 10"L x 8"W x 0.5"D at the (-)72' elevation. 4. A VD from leg B3 at (-)160' level to leg B2 at (-)98' level had a dent 11"L x 6"W x 1"D at the (-)155' elevation. 5. A VD from leg B3 at (-)160' level to leg B2 at (-)98' level had a dent 7"L x 4"W x 1"D at the (-)156' elevation. 6. A HD from midpt. of A1-A4 to midpt. of B1-B4 had a 10"L x 10"W x 2"D dent at 13.5' from row 4.
Non-structural Damage (wiring, piping, safety systems, etc.)	Four broken well conductors were found during the Level II underwater inspections.
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Ultimate Strength Analysis
Response / Repair Description	An ultimate strength analysis was performed in accordance with the API RP2A 21st edition using level I criteria. The 26" diagonal brace containing dents, holes and cracks was removed for the analysis to be consistent with the proposed repair plan. The dented members were checked for residual strength using an OTC paper on Residual Strength of Dent-Damaged Platform Bracing, and were found to be okay.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	Low deck - The deck was exposed to wave heights in exceedence of 90 feet (Ref: Report submitted to MMS by Operator, 24 Mar 2005).

Platform Damage Summary

Platform	**Main Pass 138 A**
Operator	**Newfield Exploration Company**

Platform Description

Water Depth	**158 ft**	
Deck Height	**55 ft**	
No. of Slots	**6**	
No. of Conductors	**Not Documented**	
Installation Date	**Not Documented**	
API 2A Assessment Category	**L2**	
Jacket Type	**Platform**	
No. of Piles	**4**	
Distance from Shore	**16 mi**	
Bracing Configuration	**A sea-horse type platform with XH bracing at the bottom bay on all four faces.**	

Storm Exposure

Min. Distance/Direction from Eye	**46 mi**		Maximum Storm Surge	**1.6 ft**
Maximum Wave Height	**58 ft**		Maximum Wind Speed	**59 kts**
Significant Wave Height	**33 ft**		Current Speed	**2.7 ft**
Wave Crest Elevation	**37 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Yes**

Structrual Damage Description	1. A diagonal brace on row 2 from the cellar deck (2A) to the main deck (2B) broke loose at the weldment on the cellar deck level. The brace is bowed. 2. A 24" major diagonal on row B from (-)7'-6" level to the (-)80' level had a 22"L x 9"W x 2"H dent at the (-)56' elevation. 3. A 16" HZ at the (-)80' level on row B from leg B1 to B2 had a 3"W x 12"L x 0.5"H hump close to leg 2.
Non-structural Damage (wiring, piping, safety systems, etc.)	A deck lean towards the west, which was already present before Ivan, had increased after the passing of Ivan. The cellar deck was subjected to wave inundation by Ivan. Handrail and grating on the cellar deck were damaged. Conductor guides for two wells at the top of the jacket broke loose and were missing. A caged ladder to the top of the jacket was missing.
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	1.The damaged brace in the deck level was replaced. The missing conductor guides were replaced with a full 360 degree doubler plate wrapping around the leg. 2. A dual brace clamp repair was done for the major diagonal brace damage. 3. The horizontal at (-)80' was repaired by welding a shear pup over the dent.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	Low deck - The cellar deck at the (+)54' level was inundated.

Platform Damage Summary

Platform	**South Pass 62 C**
Operator	**Apache Corporation**

Platform Description

Water Depth	**328 ft**
Deck Height	**47.8 ft**
No. of Slots	**18**
No. of Conductors	**18**
Installation Date	**1967**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**8 main piles and 8 skirt piles**
Distance from Shore	**19 mi**
Bracing Configuration	**Long Frame: All the bays have / bracing except the bottom end bays, which have a K bracing.** **Tran Frame: Rows 1&4 have K bracing for the bottom bay and / bracing for the ones above. Rows 2&3 have K bracing for the bottom row, XH bracing for the 3 bays above, and / bracing for the topmost bay.**

Storm Exposure

Min. Distance/Direction from Eye	**37 mi**		Maximum Storm Surge	**0.9 ft**
Maximum Wave Height	**71 ft**		Maximum Wind Speed	**60 kts**
Significant Wave Height	**40 ft**		Current Speed	**1.3 ft**
Wave Crest Elevation	**42 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Yes**

Structrual Damage Description	Two local buckles were found on a thin walled segment of jacket leg B3, at(-) 265' and (-) 276' levels. The buckles each protruded 1/4 inches from the legs original straight configuration.
Non-structural Damage (wiring, piping, safety systems, etc.)	None Documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	A design level analysis was performed on the structure per API RP2A 21st edition. The section of the jacket leg containing the beginnings of local buckling, and an adjacent HZ at the (-) 261' level which was found to be overstressed, were removed from the model. The analysis confirmed that the repair of the minor local leg buckling is unnecessary.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 290 A**
Operator	**Apache Corporation**

Platform Description

Water Depth	**288 ft**
Deck Height	**44 T.O.S**
No. of Slots	**18**
No. of Conductors	**18**
Installation Date	**1966**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**8 piles**
Distance from Shore	**38 mi**
Bracing Configuration	**Long Frame: Both the faces have / bracing throughout. Tran Frame: All four faces have K bracing in the bottom bay alone and / bracing all that way above it.**

Storm Exposure

Min. Distance/Direction from Eye	**22 mi**	Maximum Storm Surge	**1.1 ft**
Maximum Wave Height	**68 ft**	Maximum Wind Speed	**67 kts**
Significant Wave Height	**38 ft**	Current Speed	**1.8 ft**
Wave Crest Elevation	**41 ft**		

Storm Damage

Structural Damage	**Yes**	Evidence of Wave in Deck	**Yes**

Strucutral Damage Description	1. A VD from leg A1 at (-)50' level to leg A2 at (-)94' level had a dent 36"L x 23"W x 4.75"D at (-)74' elevation. 2. A VD from leg A1 at (-)150' level to leg A2 at (-)218' level had a dent 12"L x 20"W x 2"D at (-)169' elevation, a dent 44"L x 24"W x 3.625"D at (-)184' elevation and had a scrape 26"L x 3"W x 0.25"D at (-)190' elevation. In addition, at elevation (-)218' the manufactured weld seam had a crack along the seam. 3. VD from A2 to B2 has a 2"L x 2"W x 0.5"D pit at the cap of the weld, at the B2 leg (-)49' elevation. 4. VD from A1 to A2 has a 2"L x 2"W x 0.5"D pit at the cap of the weld, at the A1 leg (-)49' elevation. 5. A HD at the (-)218' elevation, from the mid points of A1-A2 to A2-B2 was damaged and required repair.
Non-structural Damage (wiring, piping, safety systems, etc.)	1. One of the J-tubes was found to be broken. 2. Movement was noted on 5 of the conductors. 3. A deck extension broke loose during the storm and damaged a lot of members during its descent. 4. All of the topside members were found to be in fair condition with moderate corrosion and moderate coating loss.
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	A design level analysis was performed on the structure per API RP2A 21st edition. Conservatively, 9 of the braces were either assigned zero axial strength or were removed from the analysis. Two of those nine braces were permanently removed as part of the repair plan. The platform was found to pass the Level-II environmental criteria.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**South Pass 62 B**
Operator	**Apache Corporation**

Platform Description

Water Depth	**322 ft**	
Deck Height	**44 ft**	
No. of Slots	**18**	
No. of Conductors	**18**	
Installation Date	**1968**	
API 2A Assessment Category	**L2**	
Jacket Type	**Platform**	
No. of Piles	**8 main piles and 8 skirt piles**	
Distance from Shore	**19 mi**	
Bracing Configuration	**Long Frame: All the bays have / bracing except the bottom end bays, which have a K bracing. Tran Frame: Rows 1&4 have XH bracing in the center of the bottommost bay and / bracing on both sides of the XH bracing. All bays above have / bracing. Rows 2&3 have K bracing for the bottom row, XH bracing for the 3 bays above, and / bracing for the top bays.**	

Storm Exposure

Min. Distance/Direction from Eye	**37 mi**		Maximum Storm Surge	**0.9 ft**
Maximum Wave Height	**73 ft**		Maximum Wind Speed	**63 kts**
Significant Wave Height	**41 ft**		Current Speed	**1.2 ft**
Wave Crest Elevation	**44 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Yes**

Structrual Damage Description	1. There was a 5"W x 42"L bulge on leg B3 at (-) 281' elevation.
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Design Level Analysis
Response / Repair Description	A design level analysis was performed on the structure per API RP2A 21st edition. The section of the jacket leg B3 between El. (-)260' and (-)289' containing the beginnings of local buckling, and an adjacent HZ at the (-) 260' level which was found to be overstressed, were removed from the model. The analysis confirmed that the repair of the minor local leg buckling is unnecessary.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**South Pass 62 A**
Operator	**Apache Corporation**

Platform Description

Water Depth	**340 ft**
Deck Height	**44.0 ft**
No. of Slots	**18**
No. of Conductors	**18**
Installation Date	**1967**
API 2A Assessment Category	**L1**
Jacket Type	**Platform**
No. of Piles	**8 main piles and 8 skirt piles**
Distance from Shore	**19 mi**
Bracing Configuration	**Long Frame: Both the faces have / bracing throughout. Tran Frame: Rows 1&4 have XH bracing in the center of the bottommost bay and / bracing on both sides of the XH bracing. All bays above have / bracing. Rows 2&3 have K bracing for the bottom row, XH bracing for the 3 bays above, and / bracing for the top bays.**

Storm Exposure

Min. Distance/Direction from Eye	**37 mi**	Maximum Storm Surge	**0.9 ft**
Maximum Wave Height	**71 ft**	Maximum Wind Speed	**60 kts**
Significant Wave Height	**40 ft**	Current Speed	**1.3 ft**
Wave Crest Elevation	**42 ft**		

Storm Damage

Structural Damage	**Yes**	Evidence of Wave in Deck	**Yes**

Structrual Damage Description	1. Three local buckles were found on the B4 leg at elevations (-)266' all around the circumference, at (-)274' from 6:00 to 1:00 and at (-)283' from 6:00 to 10:00. The width of the bulges vary along the circumference. 2. A buckle 4"W x 360 degrees was found in leg B3 at (-)294' level. The bulge extends 6" on the outboard side of the leg and 3" on the inboard side of the leg. 3. A buckle 3"W x 360 degrees was found in leg B3 at (-)289' level. The bulge extends 3" on the outboard side of the leg and 1.5" on the inboard side of the leg. 4. A buckle 3"W x 360 degrees was found in leg B3 at (-)278' level. The bulge extends 3" on the outboard side of the leg and 1.5" on the inboard side of the leg. 5. A dent 24"L x 10"W x 4"D was found on the HZ B1-B2 at (+)15' level, 10' from leg B1 at 3:00. 6. A dent 12"L x 8"W x 1.5"D was found on VD B1 at (+)15' to B2 at (-)30' level, 8' from Leg B1 at 12:00.
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Ultimate Strength Analysis
Response / Repair Description	An ultimate strength analysis was performed on the structure per API RP2A 21st edition. The locally buckled sections of legs B3 and B4 between elevations (-)265' and (-)299' were removed from the model. The analysis confirmed that the repair of the minor local leg bucklings was unnecessary.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 298 B-Valve**
Operator	**Southern Natural Gas**

Platform Description

Water Depth	**222 ft**
Deck Height	**43 ft**
No. of Slots	**None**
No. of Conductors	**4 Risers**
Installation Date	**1972**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**4**
Distance from Shore	**20.0 ft**
Bracing Configuration	**Both long frame and tran frame have KH type of bracing.**

Storm Exposure

Min. Distance/Direction from Eye	**39 mi**		Maximum Storm Surge	**1.3 ft**
Maximum Wave Height	**67 ft**		Maximum Wind Speed	**63 kts**
Significant Wave Height	**37 ft**		Current Speed	**2.7 ft**
Wave Crest Elevation	**41 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Unknown**

Structrual Damage Description	1. Crack on VD from leg B2 at (+)10' level to leg A2 at (-)29' level, 3' from leg B2. 2. Crack on HZ from leg B2 to A2 at (+)8' level, 8' from leg B2. 3. Dent on HZ from A2 to B2 at (+)8' level, 4' from leg A2. 4. Crack on VD from leg B1 at (+)10' level to leg B2 at (-)29' level, 2' from leg B1.
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	None Documented
Response / Repair Description	In all the cases, the damaged section of the member was cut out and a repair section was welded in its place.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 280 C**
Operator	**Dominion E & P**

Platform Description

Water Depth	**302 ft**
Deck Height	**52 ft**
No. of Slots	**Unknown**
No. of Conductors	**Unknown**
Installation Date	**1998**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**3**
Distance from Shore	**55 mi**
Bracing Configuration	**Unknown**

Storm Exposure

Min. Distance/Direction from Eye	**7 mi**		Maximum Storm Surge	**1.3 ft**
Maximum Wave Height	**74 ft**		Maximum Wind Speed	**75 kts**
Significant Wave Height	**41 ft**		Current Speed	**1.8 ft**
Wave Crest Elevation	**44 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Unknown**

Structrual Damage Description	1. One jacket member was damaged.
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	None Documented
Response / Repair Description	The structure was re-analyzed with the metocean criteria per API RP2A 21st edition.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 293 SONAT**
Operator	**Southern Natural Gas**

Platform Description

Water Depth	**226 ft**	
Deck Height	**45 ft**	
No. of Slots	**None**	
No. of Conductors	**None**	
Installation Date	**1972**	
API 2A Assessment Category	**Unknown**	
Jacket Type	**Platform**	
No. of Piles	**4**	
Distance from Shore	**30 mi**	
Bracing Configuration	**All the faces of the platform have K bracing for the bottom three bays and / bracing for the two bays above them.**	

Storm Exposure

Min. Distance/Direction from Eye	**29 mi**		Maximum Storm Surge	**1.1 ft**
Maximum Wave Height	**70 ft**		Maximum Wind Speed	**65 kts**
Significant Wave Height	**40 ft**		Current Speed	**2.0 ft**
Wave Crest Elevation	**43 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Unknown**

Structrual Damage Description	The platform was toppled
Non-structural Damage (wiring, piping, safety systems, etc.)	The platform was toppled
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Toppled
Response / Repair Description	The platform was salvaged as is and placed in an artificial reef area in main pass 132. All structure including pilings were removed to a depth of (-)15' below mudline.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Viosca Knoll 900 A**
Operator	**Chevron**

Platform Description

Water Depth	**340 ft**
Deck Height	**46 ft**
No. of Slots	**24**
No. of Conductors	**25**
Installation Date	**1975**
API 2A Assessment Category	**Unknown**
Jacket Type	**Platform**
No. of Piles	**8 Piles and 4 Skirt piles**
Distance from Shore	**22 mi**
Bracing Configuration	**Long Frame: The bottom end bays have XH bracing for one half and / bracing for the other. All other bays at other elevations have / bracing. Tran Frame: The bottom 3 bays on all faces have K bracing and the top two have / bracing.**

Storm Exposure

Min. Distance/Direction from Eye	**35 mi**		Maximum Storm Surge	**0.9 ft**
Maximum Wave Height	**73 ft**		Maximum Wind Speed	**61 kts**
Significant Wave Height	**41 ft**		Current Speed	**1.1 ft**
Wave Crest Elevation	**44 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Unknown**

Structrual Damage Description	1.The following members were found to be flooded: a. A HZ A4-B4 at the (-)80' level, has a linear indication at its mid point. b. VD from A1 and (-)32' to A2 at (+)12', was a repaired member. c. HZ A4-B4 at the (-)32' level was separated at the mid point of the member. There is a vertical gap of 5.75" between the centers of the separated members. 2. VD A4 at (-)32' level to B4 at (+)12' level is separated where it connects to leg A4 at (-)32'. Leg A4 has a hole 39.5"L x 24"W, resultant of the VD being torn from the leg and the VD retaining the coupon. A tear was noted on the A4 leg at 7:00 with the lip protruding 0.5". At this location, a 3" crack was also noted. 3. A dent 6.5"dia. x 1.5"D was found on HZ B4-B3 at (-)32' level 6' from leg B4 from 12:00 to 2:00. 4. A dent 12" dia. x 6"D was found on HZ A4-B4 at (+)12' level from 6:00 to 12:00. 5. A dent 12"L x 6"W x 4"D was found on HZ A4-B4 at (+)12' level, 7' from Leg A4 from 12:00 to 3:00. 6. A linear indication 21.5"L x 0.25"W was found on HD A4-B4 to B3 at (-)80' level from 6:00 to 12:00, on the node side of the weld. 7. A suspect visual indication was noted on weld 22/02 in the T.O.W HD A4-B4 to A3 at (-
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	None Documented
Response / Repair Description	1. Members below water line: Stress grouted clamps were designed for all damaged underwater jacket members. 2. Members above water line: Two permanent vetical posts were installed at the (+)12'-6" level to reduce the effective column length of members between column rows A1 and A2 and also between B3 and B4. Additionally a repair clamp for the (+)12'-6" elevation HZ was deisgned for load transfer in the horizontal member framing from row A to B. 3. Repair of tubular diagonals in the superstructure: Fabrication and repairs to the lateral bracing for the diagonals located in truss rows 3 and 4 framing from the production deck to elevation (+)23'-6" have been completed. Additional tubular members were designed and installed to provide out-of-plane support at the point of maximum eccentricity.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 279 B**
Operator	**Dominion E & P**

Platform Description

Water Depth	**290 ft**
Deck Height	**54 ft**
No. of Slots	**6**
No. of Conductors	**4**
Installation Date	**Not Documented**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**4**
Distance from Shore	**51 mi**

Pre-Storm Platform Image Not Available

Bracing Configuration	**The bottommost bay of all faces have XH bracing and all the other bays have / bracing.**

Storm Exposure

Min. Distance/Direction from Eye	**10 mi**		Maximum Storm Surge	**1.3 ft**
Maximum Wave Height	**74 ft**		Maximum Wind Speed	**75 kts**
Significant Wave Height	**41 ft**		Current Speed	**1.8 ft**
Wave Crest Elevation	**45 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**Yes**

Structrual Damage Description	1. The A1 leg has a buckle at the (-)90' level and is also broken and seperated at the (-)110' level.
Non-structural Damage (wiring, piping, safety systems, etc.)	1. Major damage to the production equipment on the cellar deck. 2. Damage to handrails, grating and stairs.
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	None Documented
Response / Repair Description	None documented
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 305 A**
Operator	**Noble Energy, Inc.**

Platform Description

Water Depth	**244 ft**
Deck Height	**45 ft**
No. of Slots	**24**
No. of Conductors	**Not Documented**
Installation Date	**1968**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**8 Pile**
Distance from Shore	**28 mi**
Bracing Configuration	**Long Frame: All the bays of both faces have / bracing.** **Tran Frame: All four faces have K- bracing on all the bays.**

Storm Exposure

Min. Distance/Direction from Eye	**30 mi**		Maximum Storm Surge	**1.1 ft**
Maximum Wave Height	**69 ft**		Maximum Wind Speed	**64 kts**
Significant Wave Height	**39 ft**		Current Speed	**2.2 ft**
Wave Crest Elevation	**44 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**No**

Structrual Damage Description	1. The storm disconnected the conductor tray and damaged several supporting secondary steel members at the (-)40' elevation. 18 anomalies were discovered at this level. A drawing has been provided showing the locations of all these anomalies. 2. A dent 18"L x 10"W x 2"D was found on a VD on row A from leg1 at (+)10' level to leg2 and (-)40' level, 20' from leg A2.
Non-structural Damage (wiring, piping, safety systems, etc.)	None documented
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Both Design Level and Ultimate Strength Analyses.
Response / Repair Description	1. A design level analysis was performed per API RP2A 21st edition, Section 17, using the L2 sudden hurricane environmental loading criteria. The damages in the structure were taken into account. 2. The analysis performed revealed some member and joint overstresses, and therefor an ultimate strength analysis was performed per API RP2A Section 17, based on L2 criteria. The analysis demonstrated the structure to be adequate for manning so that repairs could be made. 3.The conductor tray at the (-)40' elevation was repaired. 4. The platform in its repaired state was again subject to a design level analysis and to an ultimate strength analysis to confirm the adequacy of the repairs.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 305 B**
Operator	**Noble Energy, Inc.**

Platform Description

Water Depth	**241 ft**
Deck Height	**46 ft**
No. of Slots	**24**
No. of Conductors	**Not Documented**
Installation Date	**1968**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**8 Pile**
Distance from Shore	**28 mi**
Bracing Configuration	**Long Frame: All the bays of both faces have / bracing.** **Tran Frame: All four faces have K bracing on all the bays.**

Storm Exposure

Min. Distance/Direction from Eye	**30 mi**		Maximum Storm Surge	**1.1 ft**
Maximum Wave Height	**72 ft**		Maximum Wind Speed	**65 kts**
Significant Wave Height	**40 ft**		Current Speed	**1.7 ft**
Wave Crest Elevation	**44 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**No**

Structrual Damage Description	1. The storm disconnected the conductor tray and damaged several supporting secondary steel members at the (-)40' elevation. A total of 22 anomalies were found at the (-)40' elevation. A drawing has been provided showing the locations of all these anomalies. 2. A dent 12"L x 12"W x 2"D was found on HZ A1-A2 at (-)90' elevation, 7' from leg A1 from 12:00 to 10:00. 3. A linear indication 3"L x 0.375"W was found on HD B3/B4 to B4 at (-)243' elevation, 30' from the mid pt. of B3/B4 at 12:00. 4. A hole 1"L x 2.5"W was found on VD B3/A3 at (-)189' to B3 at (-)140', 19' from the mid point of A3/B3 at 9:00. 5. The VD A2 at (-)140' to A3 at (-)90', 5' from A2 is buckled from 7:00 to 3:00. 6. A dent 16"L x 8"W x 2"D was found on VD A3 at (+)10' to A4 at (-)40', 12' from leg A3 at 12:00. 7. A dent 9"L x 5"W x 1.5"D was found on VD B4 at (+)10' to B3 at (-)40', 20' from leg B4 at 12:00. 8. The weld on VM A1/B1 at (-)40' to A1/B1 at (-)90' is broken at the (-)40' attachment to the HZ. 9. A gouge 3"L x 0.25"W x 0.125"D was found on HZ B4-B3 at (-)90' level, 24' from leg B4 at 3:00. 10. Several dents 29"L x 13"W x 3.5"D were found on VD from B3 (-)40' to B3/A3 (-)90',
Non-structural Damage (wiring, piping, safety systems, etc.)	0
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Both Design Level and Ultimate Strength Analyses.
Response / Repair Description	1. A design level analysis was performed per API RP2A 21st edition, Section 17, using the L2 sudden hurricane environmental loading criteria. The damages in the structure were taken into account. 2. The analysis performed revealed some member and joint overstresses, and therefor an ultimate strength analysis was performed per API RP2A section 17, based on L2 criteria. The analysis demonstrated the structure to be adequate for manning so that repairs could be made. 3.The conductor tray at the (-)40' elevation was repaired. 4. The platform in its repaired state was again subjected to a design level analysis and to an ultimate strength analysis to confirm the adequacy of the repairs.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Platform Damage Summary

Platform	**Main Pass 306 F**
Operator	**Noble Energy, Inc.**

Platform Description

Water Depth	**293 ft**
Deck Height	**49 ft**
No. of Slots	**18**
No. of Conductors	**Not Documented**
Installation Date	**1977**
API 2A Assessment Category	**L2**
Jacket Type	**Platform**
No. of Piles	**4 Piles and 4 Skirt Piles**
Distance from Shore	**31 mi**
Bracing Configuration	**Long Frame: The center bay has XH bracing throughout, on both faces. The end faces have / bracing.** **Tran Frame: Both the faces have XH bracing, thoughout.**

Storm Exposure

Min. Distance/Direction from Eye	**27 mi**		Maximum Storm Surge	**1.0 ft**
Maximum Wave Height	**74 ft**		Maximum Wind Speed	**67 kts**
Significant Wave Height	**42 ft**		Current Speed	**1.5 ft**
Wave Crest Elevation	**45 ft**			

Storm Damage

Structural Damage	**Yes**		Evidence of Wave in Deck	**No**

Structrual Damage Description	Damage surverys following the hurricane revealed several anomalies to the platform in the upper four cross braces on row A & row B. Damage to the horizontal framing at the (-)28' and (-)75' levels were also discovered. A total of 22 anmoalies were discovered. The complete description of the anomalies, as well as drawings of the anomalies are available in the report.
Non-structural Damage (wiring, piping, safety systems, etc.)	0
Major Infrastructure Damage (Pipelines)	-

Response / Repair / Mitigation

Down Time After Storm	Unknown
Drivers for Down Time	-
Performed Analysis Summary	Both Design Level and Ultimate Strength Analyses.
Response / Repair Description	1. A design level analysis was performed per API RP2A 21st edition, Section 17, using the L2 sudden hurricane environmental loading criteria. The damages in the structure were taken into account. 2. Due to the damage revealed during the level III inspection, an ultimate strength analysis was performed per API RP2A section 17, based on L3 criteria. The analysis demonstrated the structure to be adequate for manning so that repairs could be made. 3. All the damaged cross bracing and horizontal framing of the jacket were repaired. 4. The platform in its repaired state was again subject to a design level analysis and to an ultimate strength analysis (L2 criteria) to confirm the adequacy of the repairs.
Mitigation to Prevent Future Damage (reinforcement, remove unused equipment, relocate critical systems, etc.)	None

Contributing Factors to Platform Damage

Perceived Reasons for Damage (e.g., low deck, installation defect, falling debris, etc.)	None noted.

Appendix B

Quantitative Assessment

B.1 Reliability Methodology
B.2 Random Variables and Bayesian Updating Definition
B.3 Printout of the Bias Factor Calculation Sheets

B.1 Reliability Methodology

The Bias Factor is defined as the ratio of the true safety factor to the computed safety factor. In term, the safety factor is defined as the ratio of structural resistance (R) to load (S). This can be written as

$$\left[\frac{R}{S}\right]_{true} = B \cdot \left[\frac{R}{S}\right]_{computed} \qquad \text{(B.1)}$$

Determination of the Bias Factor gives an indication of the accuracy of the computed (according to API RP2A Section 17 procedure) platform safety factor. A value of $B<1$ indicates that the computed platform safety factor is un-conservative, and a $B>1$ indicates that the computed platform safety factor is conservative.

A methodology was introduced in previous Andrew JIP studies to determine the Bias Factors for several chosen platforms that were either damaged or survived during Hurricane Andrew. This study follows a similar methodology.

Formulations

The first step in determining the Bias Factor is to compute the probability of platform failure. The conventional formula for computing the probability of failure is:

$$P_f = \int_0^\infty \left(1 - F_s(x)\right) f_R(x)\,dx \qquad \text{(B.2)}$$

where F_s is the cumulative distribution function for the load variable S, and f_R is the probability density function for the resistance variable R.

The load variable S is represented by the base shear (BS) on the platform, which in term can be expressed by the following equations:

$$BS = C_1\left[h + C_2 u\right]^{C_3} \varepsilon_o \qquad h<=h_d \qquad \text{(B.3)}$$

$$BS = \left[C_1 + C_4(h - h_d)\right]\left[h + C_2 u\right]^{C_3} \varepsilon_o \qquad h>h_d \qquad \text{(B.4)}$$

where h is the wave height (ft),
u is the current speed (knot),
h_d is the wave height which just hitting the platform cellar deck (ft),
C's are coefficients to be determined, and

ε_0 is a model uncertainty factor representing the accuracy in base shear equation.

The distribution of the wave height, *h*, is given by the Forristall distribution with the following form:

$$f_{H|H_s}(h|H_s = h_s) = \frac{\alpha 4^\alpha}{\beta H_s}\left(\frac{h}{H_s}\right)^{\alpha-1} \exp\left[-\frac{4^\alpha}{\beta}\left(\frac{h}{H_s}\right)^{\alpha}\right] \qquad \text{(B.5)}$$

in which $\alpha = 2.126$ and $\beta = 8.42$, and h_s is the significant wave height at a particular hour at the considered platform location from hindcast data.

The maximum base shear for a multi-hour, multi-directional storm can be written as

$$F_{MBS} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \prod_{hour\_j}^{Hours} \left\{ \int F_{BS}\left(x|H = h_s, U = u_j\right) f_{h|H_s}\left(h|H_{sj} = h_{sj}\right) dh \right\}^{Nj} f_{\varepsilon 1}(\varepsilon_1) f_{\varepsilon 2}(\varepsilon_2) d\varepsilon_1 d\varepsilon_2 \qquad \text{(B.6)}$$

F_{BS} is a log-normal cumulative distribution combined from equations (B.3), (B.4) and (A.5), N_j is the number of waves in a storm hour, and ε_1 and ε_2 are model uncertainties in the hindcast significant wave height and current data.

Similar to equation (A.2), the probability of failure for a given Bias Factor *b*, is

$$P_f(b) = \int_0^\infty \left(1 - F_s(bx)\right) f_R(x) dx \qquad \text{(B.7)}$$

Direct numerical integration on the above equation is not the most efficient way to compute $P_f(b)$. Rather, in the Andrew Phase 2 JIP study, a nested inner and outer loop FORM (First Order Reliability Method) method was used to determine this probability of failure.

Random variables are categorized by their appearance in either the inner or outer loop:

<u>Inner loop random variables, *Y*</u>

- Individual wave height, $H|H_s$.
- Model uncertainty factor in base shear calculation, ε_0.

Outer loop random variables X

- Capacity, R.
- Significant wave height, H_s.
- Current velocity, u.

The inner loop consists of the probability of failure based on a single wave. The limit state function for this inner loop is

$$g(Y, X; b) = bR - BS \cdot \varepsilon_0 \tag{B.8}$$

The limit state function for the outer loop can be written as

$$g(U, X; b) = U - \Phi^{-1}\left[1 - \left(1 - P_f(x, b)\right)^n\right] \tag{B.9}$$

Where U is an auxiliary variable (standard normal distribution with mean of 0 and standard deviation of 1), n is the number of waves in a storm hour. It can be theoretically shown that solutions from the nest reliability problem, Eqs.(B.8) and (B.9), are equivalent to the original failure probability definition, Eq.(B.7).

B.2 Random Variables and Bayesian Updating Definition

The random variables used in the analysis are listed in Table B.1, which are taken to be the same from Andrew Phase 2 JIP study.

Table B.1 – List of Random Variables

Variable	Distribution	Expected Value	COV
Capacity , R	Log-Normal	per analysis	0.15 for jacket capacity 0.20 for foundation lateral capacity 0.30 for foundation axial capacity
Individual wave height, h	Forristall	per hindcast	per formula
Hindcast error in Hs, ε_1	Log-Normal	1	0.1
Hindcast error in current, ε_2	Log-Normal	1	0.15
Wave to wave error in base shear, ε_0	Log-Normal	1	0.2 for wave below deck 0.25 for wave in deck

The Bias Factor b is further distinguished into a set of three Bias Factors (b_j, b_{fl} and b_{fa}), which represents the factors for jacket, foundation lateral capacity and foundation axial capacity, respectively. The reliability calculation calculates the failure probability for a specific set of Bias Factors (b_j, b_{fl} and b_{fa}). These reliability results are used to define the *likelihood function*, and then these likelihood functions are finally used in a Bayesian updating framework to estimate the probability distributions of b_j, b_{fl} and b_{fa}.

Depending on the degree of damage (damage/failure cases) or no damage (survival cases), the likelihood functions are defined differently. These are explained as follows, which are the same as used in the Andrew Phase 2 JIP study.

The platforms were grouped into five categories:

1. Survival – No damage, or only minor non-structural damage identified.
2. Damage, Type I – Known damage to the jacket, foundation is assumed intact.
3. Damage, Type II – Known damage, but not attributed specifically to jacket or foundation.
4. Failure, Type I – Known failure of the jacket, foundation assumed intact.
5. Failure Type II – Known failure, but not attributed specifically to jacket or foundation.

Specific definitions of likelihood functions for these five categories are described as follows:

Category 1 - Survival Cases

The likelihood function for the survival case is

$lb(b_j, b_{fl}, b_{fa} | survival) =$

P(base shear < jacket damage capacity AND *base shear < jacket foundation capacity)* (B.10)

Category 2 - Damage, Type I

$lb(b_j, b_{fl}, b_{fa} | damage1) =$

P(base shear is between jacket damage and collapse capacities AND *base shear < jacket foundation capacity)* (B.11)

Category 3 - Damage Type II

$lb(b_j, b_{fl}, b_{fa} | damage2) =$

P(base shear > jacket damage capacity AND *base shear > jacket foundation capacity)* (B.12)

Category 4 - Failure, Type I

$lb(b_j, b_{fl}, b_{fa} | failure1) =$

P(base shear > jacket collapse capacity AND *foundation capacity > jacket collapse capacity)* (B.13)

Category 5 - Failure Type II

$lb(b_j, b_{fl}, b_{fa} | failure2) =$

P(base shear > jacket collapse capacity AND *base shear > jacket foundation capacity)* (B.14)

Once an individual likelihood function is calculated (from nested FORM procedure as described earlier), a combined likelihood function is expressed as the multiplication of the individual functions.

$$lk(b_j, b_{fl}, b_{fa} | n\_observations) = \prod_{platform=1}^{n} \left[lk(b_j, b_{fl}, b_{fa} | observation) \right] \qquad \text{(B.15)}$$

Bayesian updating provided the posterior distribution of the Bias Factors. The prior distributions of the Bias Factors (f'_{B_j}, $f'_{B_{fl}}$ and $f'_{B_{fa}}$) are assumed as normal distributions with a mean value of 1.0 for b_j and b_{fl}, 1.3 for b_{fa}, and a COV of 0.3 for all three Bias Factors.

The joint prior distribution is the product of the individual independent prior distributions.

$$f'_{B_j,B_{fl},B_{fa}} = f'_{B_j} * f'_{B_{fl}} * f'_{B_{fa}} \qquad \text{(B.16)}$$

The posterior distribution is the multiplication of the prior and the likelihood functions.

$$f''_{B_j,B_{fl},B_{fa}}(b_j,b_{fl},b_{fa}) = f'_{B_j,B_{fl},B_{fa}}(b_j,b_{fl},b_{fa}) * lk(b_j,b_{fl},b_{fa} | n\_observations) \qquad \text{(B.17)}$$

The marginal posterior distributions, $f''_{B_j}(b_j)$, $f''_{B_{fl}}(b_{fl})$, $f''_{B_{fa}}(b_{fa})$ for the jacket, foundation lateral strength and foundation axial strength, respectively, can be obtained from the joint posterior distribution function with the other two variables integrated out.

Appendix C

Expert Panel

C.1 Expert Panel Makeup
C.2 Expert Panel Meeting Agenda
C.3 List of Meeting Attendees

C.1 Expert Panel Makeup

The Expert Panel reviewed and comment on the results of the study and made recommendations for further study. Panel members were provided with the key results of the study prior to the meeting. The group was kept intentionally small and of varied background in order to promote discussion and obtain diverse opinions.

The panel members were as follows including affiliation and expertise.

No.	Person	Affiliation	Expertise
1	Dave Wisch	Chevron, SC 2 Member	Major Operator, API/ISO Expert
2	Patrick O’Connor	BP, SC2 Chair	Major Operator, API SIM Chairman
3	Paul Versowsky	Chevron , SC2 Member	Major Operator, Large GOM fleet
4	Kris Digre	Consultant	Chair of original RP2A Section 17 Development
5	Mark Bruchman	Apache	Independent, large platform fleet
6	Steve Richardson	Dominion	Independent, moderate platform fleet
7	Pete Skrobarczyk	Mustang	Fixed platform designer, large firm
8	Barry Reed	Linder	Fixed platform designer, medium firm
9	Justin Bucknell	MSL, SC2 Member	Specialized consultant for platform assessments
10	Tommy Laurendine	MMS – New Orleans	MMS Chief Structural Engineer
	Others as part of the MMS study		
11	Frank Puskar*	Energo	Project Manager
12	Robert Spong*	Energo	Qualitative Evaluation
14	Bob Gilbert*	UT - OTRC	Academia

C.2 Expert Panel Meeting Agenda

MMS Ivan Fixed Platform Study
Expert Panel Meeting
December 13, 2005

Held at Energo Engineering
Houston, Texas

Topic	**Speaker**
11:00 Introductions	
11:05 Meeting Objectives	**Frank Puskar, Energo**

Objective is to review the project results with industry experts and solicit feedback in terms of recommendations to API for further work, if any, that may result improvements to industry practices.

11:15 Summary of Project Results – Qualitative	**Robert Spong, Energo**

Qualitative results include summary of the platform failures by type, water depth, estimated causes of failure, platforms with wave-in-deck, several "case histories", etc.

12:00 Lunch

12:30 Summary of Project Results – Quantitative	**Frank Puskar, Energo**

Quantitative results are based upon a probabilistic approach that investigates the "bias" contained in the APR RP2A design recipe, in terms of comparing actual to predicted platform performance (did it fail or survive the storm as predicted by RP2A?).

1:00 Open Discussion on Project Results	**All**

The Panel will be led through the observations of the work in order to provide a basis for open discussion and commentary, as well as begin to develop ideas for recommendations.

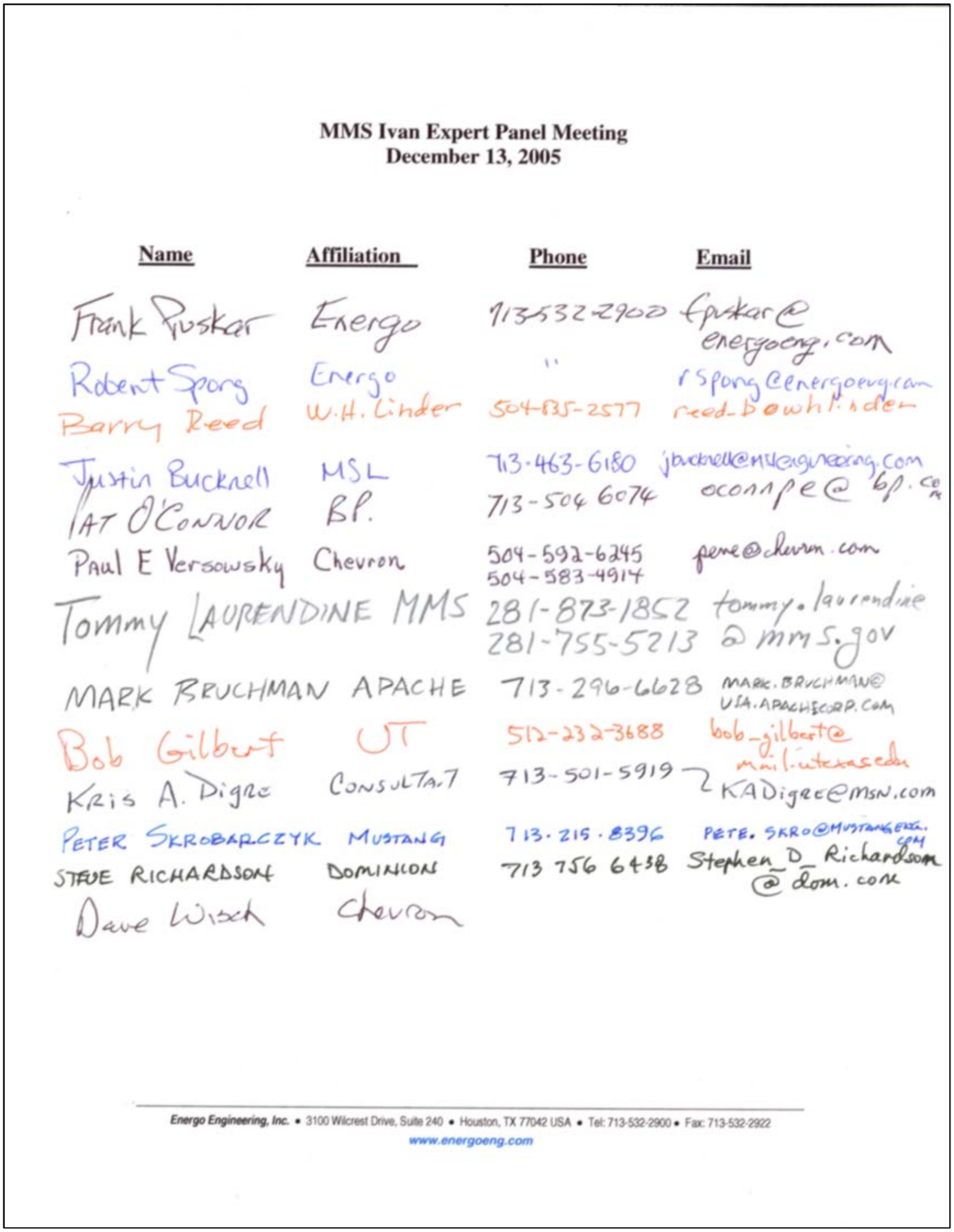
2:00 Break

2:15 Focus on Recommendations to Industry/API	**All**

Develop and summarize specific recommendations for further work to be performed by API, industry or the MMS (e.g., evaluation of minimum deck elevation requirements).

3:00 Adjourn

C.3 List of Meeting Attendees



MMS Ivan Expert Panel Meeting
December 13, 2005

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