Reliability vs. Consequence of Failure for API RP 2A Fixed Platforms Using API Bulletin 2INT-MET

FINAL REPORT
March 2009

Prepared for:

U.S. Department of the Interior
Minerals Management Service
Engineering and Research Branch
381 Elden Street
Herndon, VA 20170

Prepared by:

Energo Engineering
3100 Wilcrest Drive, Suite 240
Houston, Texas 77042

MMS Project No.: 609
Energo Engineering Project No.: E08129

Disclaimer

This report has been reviewed by the Minerals Management Service and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Service, nor does mention of trade names or commercial products constitute endorsement or recommendation for use

Table of Contents

ABBREVIATIONS

API	American Petroleum Institute
Bul	API abbreviation for Bulletin
BOS	Bottom of Steel
BS	Base Shear
CBD	Consequence Based Design
COR	Contracting Officer's Representative
cov	Coefficient of variation
FORM	First Order Reliability Method
HEAT	API Hurricane Evaluation and Assessment Team
Hmax	Maximum wave height for return period (e.g., 100 yr) used for design
LF	Load Factor
MMS	Minerals Management Service
MWL	Mean Water Level
NTL	Notice to Lessees
NA	Not Applicable
OOC	Offshore Operators Committee
OSTS	Office of Structural and Technical Support
PE	Professional Engineer
pf	Probability of Failure
RP	Return Period
RP2A	API Recommended Practice 2A for Planning, Designing and Constructing Fixed Offshore Platforms, Working Stress Design, 21st Edition
RSR	Reserve Strength Ratio
Section 17	Section within RP 2A 21st Edition that covers the assessment of existing platforms
WID	Wave-in-deck
WD	Water Depth
SC2	API Subcommittee No. 2 on Offshore Structures
2DG	API Bulletin 2INT-DG, *Interim Guidance for Design of Offshore Structures for Hurricane Conditions*, May 2007
2EX	API Bulletin 2INT-EX, *Interim Guidance for Assessment of Existing Offshore Structures for Hurricane Conditions* May 2007
2MET	API Bulletin 2INT-MET, *Interim Guidance on Hurricane Conditions in the Gulf of Mexico* May 2007

TERMS AND DEFINITIONS

Air Gap – The distance between the crest of the wave and the bottom of steel of the cellar deck.

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.

Cellar Deck –Platform deck with the lowest elevation.

Coefficient of Variation (cov) – a normalized measure of dispersion of a probability distribution, and is defined as the ratio of the standard deviation to the mean.

Load Factor (LF) – The ratio of the platform capacity to the applied metocean load.

Reserve Strength Ratio (RSR) – The ratio of the platform capacity to the 100 yr return period metocean base shear for the platform.

Wave-in-Deck – Large loading on offshore platform caused by the wave crest hitting the cellar deck structure and associated topside equipment. The large loading is caused by a combination of the high crest kinematics and the high drag coefficient of the general flat–shaped deck girders, plating, etc. of the deck.

CONVERSIONS

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

1.0 EXECUTIVE SUMMARY

Background

In May 2007 API issued Bulletin 2INT-MET (2MET) *Interim Guidance on Hurricane Conditions in the Gulf of Mexico* that divided the Gulf of Mexico (GOM) into four regions each with different metocean conditions. The regions are the East, Central, West Central and West. The Central has the most significant increase in metocean conditions from the prior API published metocean conditions contained in API RP 2A (RP2A), with the 100 yr return period maximum wave height (Hmax) in 1000ft of water increased from 70ft to 92ft. The other regions have metocean conditions much closer to the existing RP2A guidance. The larger metocean conditions in the Central are driven primarily by proximity to the summertime loop current that feeds hurricanes with warm water, increasing hurricane intensity and size.

At the same time, API also issued Bulletin 2INT-EX (2EX) *Interim Guidance for Assessment of Existing Offshore Structures for Hurricane Conditions* and Bulletin 2INT-DG (2DG) *Interim Guidance for Design of Offshore Structures for Hurricane Conditions*, which provide procedures for using the hurricane conditions contained in 2MET for the associated type of platforms. In October 2007 the Minerals Management Service issued Notice to Lessees (NTL) No. 2007-G26 and NTL No. 2007-G27 which essentially implemented 2DG and 2EX, respectively.

The 2MET metocean conditions vary by water depth and the changes in wave height, wind, current and storm surge are not always consistent. In some cases it is not clear if the updated conditions result in a larger or a smaller resultant load on a fixed platform compared to the prior RP2A conditions. It is also not clear how the reliability of fixed platforms varies for each of the four GOM regions.

Objectives

The key objective of this project was to determine the reliability of typical Gulf of Mexico fixed platforms for 2MET versus RP2A. Since RP2A provides the current basis for historical performance of GOM platforms, the comparison provides a basis to determine if 2MET provides the same or improved reliability compared to RP2A.

An additional objective was to compare platform reliability in each of the four 2MET regions. RP2A contained a single set of metocean conditions for all regions whereas 2MET contains four regions. This comparison will show if platform reliability changes according to region.

The reliability comparisons were performed for high, medium and low consequence platforms, as defined by RP2A, considering new platforms as well as existing platforms.

Approach

Two reliability methods were used for the study. The first was the Generic Method that used the Reserve Strength Ratio (RSR) of a platform along with wave height to determine probability of failure (pf) in a hurricane. The RSR is defined as the ratio of the platform capacity to the 100 yr return period metocean base shear for the structure. The Generic Method was used to determine the variation of pf between the four 2MET regions, by water depth and compared to RP2A. Note that a platform's reliability is equal to (1 – pf). The second was the Detailed Method which used actual GOM platform configurations to determine the pf. The Detailed Method also included the effect of deck elevation which is a critical factor in determining platform survival in extreme waves, should the wave crest impact the deck.

Results and Key Conclusions

The key results and conclusion are summarized as follows.

1. Compared to RP2A, the 2MET criteria for all types of platforms (L1, L2, A1, A2, etc.) show an equal or lower pf across all of the 2MET regions. In other words, 2MET results in offshore platforms that have the same or slightly better reliability than RP2A.

2. For platforms with RSRs on the order of 1.7, representative of new design API L1 high consequence platforms, the pf is about the same in all four of the 2MET regions with the pfs on the order of $7x10^{-4}$. A higher RSR will result in a lower pf. The 1.7 RSR is the estimated minimum RSR for a new platform designed to RP2A 21st Edition using working stress design methods. See Figure 1.1.

3. For platforms with RSRs on the order of 1.2, representative of existing high consequence A1 platforms, the pf is highest in the West Central compared to the other regions. The West Central pf is about 5 to $6x10^{-4}$, and is also about the same as RP2A. The other regions have a pf of about 3 to $4x10^{-4}$ or a reduction of about 1.5 to 2 compared to the West Central. The 1.2 RSR is the estimated minimum RSR for A1 platforms in the GOM [Krieger, et.al., 1994]. The higher pf in the West Central is driven by the steeper slope of the Hmax curve as a function of return period compared to the other regions. The large number of destroyed platforms in the West Central in recent hurricanes is perhaps explained in-part by the higher pf in this region, although other factors such as the number of exposed platforms and the vintage of the platforms in the West Central also influence the number of destroyed platforms [Energo, 2007]. See Figure 1.2.

4. The pf decreases by an order of magnitude with an increase in RSR from 1.2 to 1.7. An RSR of 1.2 is the approximate RSR for existing high consequence A1 platforms and an RSR of 1.7 is the expected minimum RSR of new platforms designed to RP2A. Hence, new design L1 platforms are generally an order of magnitude (i.e., 10 times) more reliable than the minimum API standard for existing A1 platforms. This helps explain why there have been only a few L1 failures in recent hurricanes compared to numerous A1 platforms.

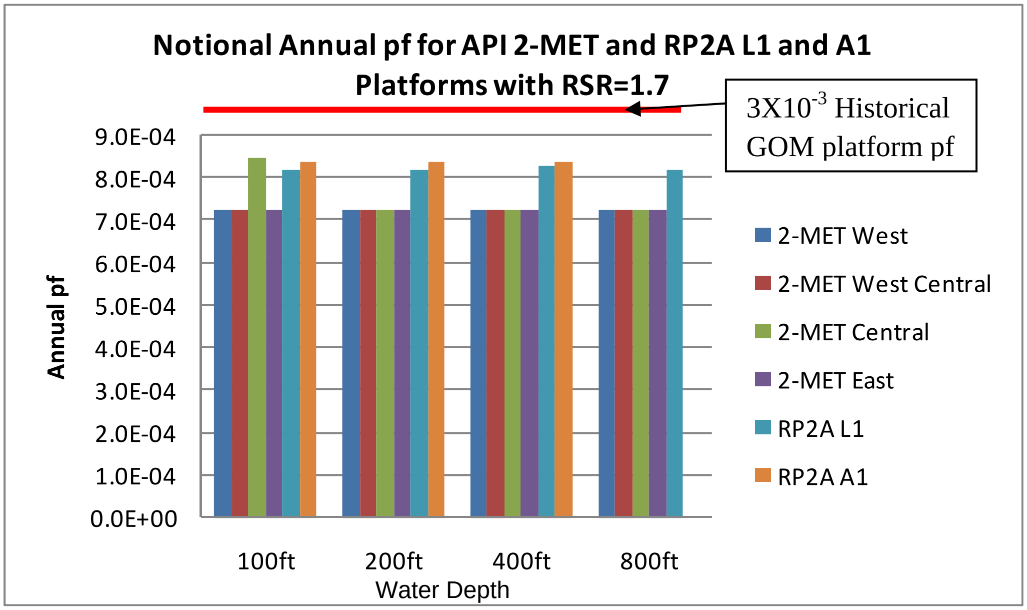
5. The "old" RP2A L1 minimum deck elevation results in a higher pf compared to the "new" 2DG recommendations (i.e., wave crest + 5ft air gap + 15% of crest height). This helps explain the large amount of wave-in-deck (WID) damage observed in recent hurricanes since most of these platforms had deck elevations based upon RP2A recommendations (or less in some cases). The historical API method of establishing the deck elevation based upon the 100 yr wave crest elevation plus a 5ft air gap results in a different pf for the various 2MET regions. This is due to the different slope of the Hmax curve in each region. An alternative recommended approach is to establish the minimum deck elevation based upon a given return period, such as a 1000 yr wave. This will result in a constant probability of not having WID across all of the GOM regions. This will also ensure that if the wave heights and associated hazard slopes of the regions are revised by API in the future, then the probability of not having WID will still be the same. The specific return period needs to be developed based upon further study beyond the scope of this effort.

6. The historical pf of GOM platforms for hurricane conditions is approximately $3x10^{-3}$. Generally, it is difficult to directly compare historical pfs, which are based upon *actual* statistics, to computed or *notional* pfs, based upon technical studies like this since there is additional uncertainty in the notional pfs due to the computational process. However, comparisons can be made to provide an approximate relationship as well as establish trends. Hence a comparison of historical pf to the pfs computed in this study for 2MET is as follows:

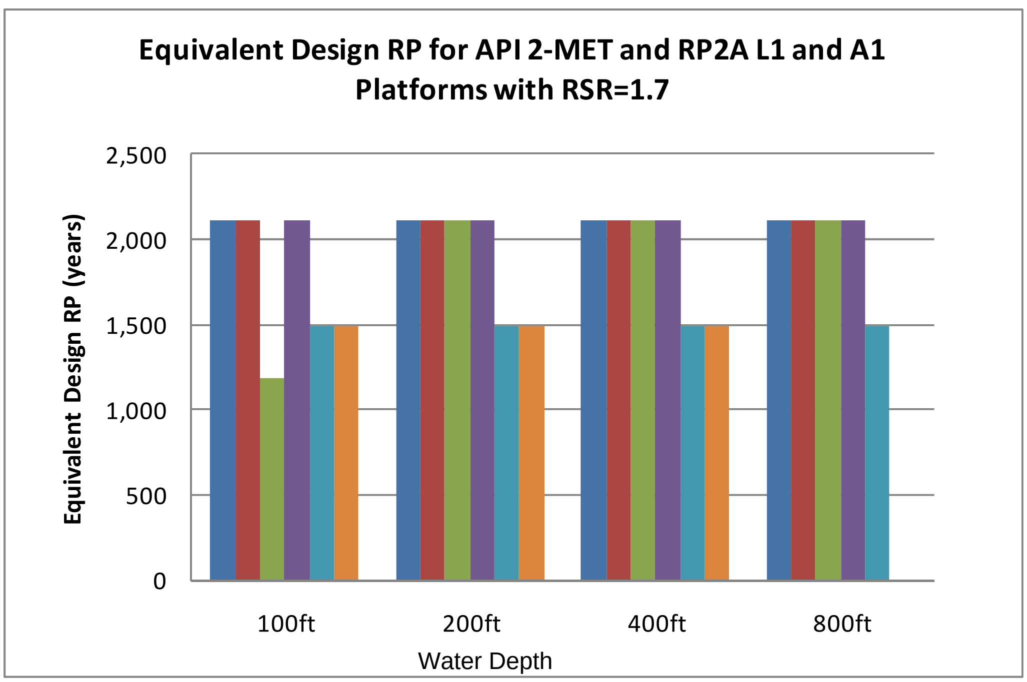
    - The estimated pf for new design L1 high consequence platforms, which typically have a minimum RSR of 1.7, is about $7x10^{-4}$. This is an order of magnitude lower pf than historical, as should be the case for new design platforms. A new design platform with a RSR higher than 1.7, achievable with structural design features such as X-bracing and thicker member and joints, will have an even lower pf.

    - The estimated pf for existing A1 high consequence platforms, which typically have a minimum RSR of 1.2, is about 3 to $6x10^{-3}$. These pfs are about the same as or slightly higher than the historical pf. Note that the 1.2 RSR is the 2EX target for high consequence existing platforms and results in a pf about the same as historical performance.

- The estimated pfs for existing L2, A2, L3 and A3 low and medium consequence existing platforms is in the range of 10^{-2}. This explains why many of the observed failures in recent hurricanes have been platforms with lower RSRs typical of these types of platforms.

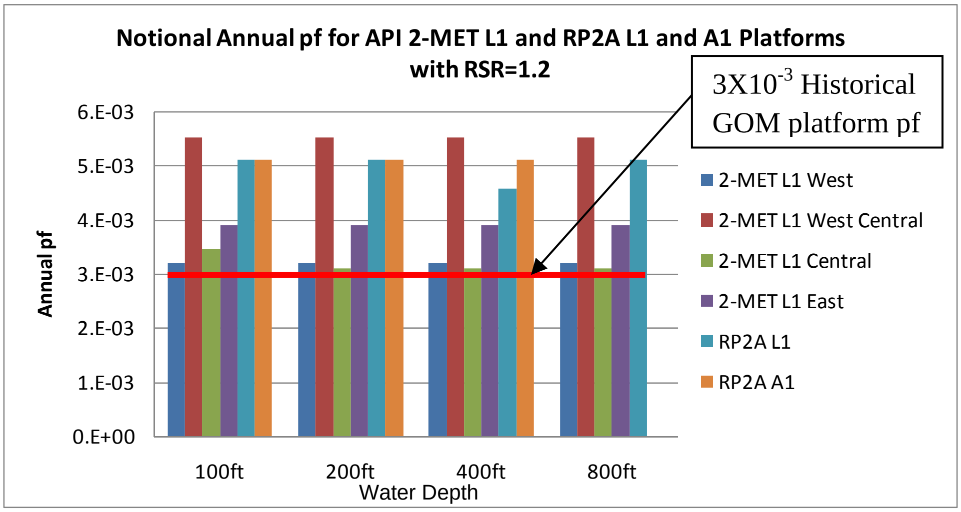


a. Probability of Failure (pf) Format

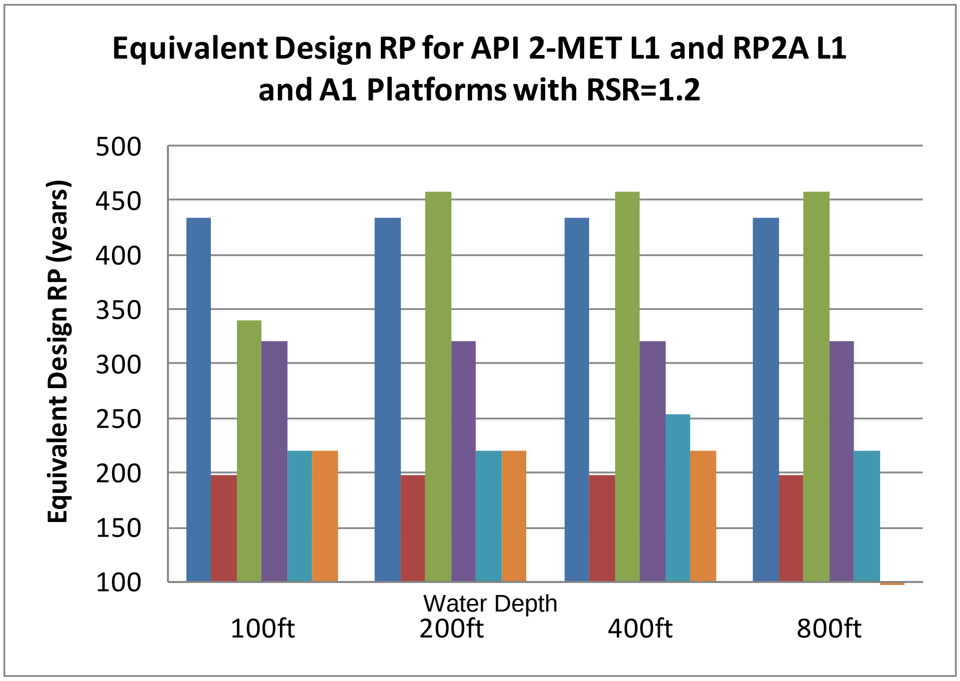


b. Equivalent Return Period Format

Figure 1.1 pf and Equivalent Return Period for RSR=1.7, L1 and A1 Platforms



a. Probability of Failure (pf) Format



b. Equivalent Return Period Format

Figure 1.2 pf and Equivalent Return Period for RSR=1.2, L1 and A1 Platforms

2.0 INTRODUCTION

2.1 Background

In May 2007, the American Petroleum Institute (API) issued three interim bulletins for the Gulf of Mexico (GOM) as follows:

- API Bulletin 2INT-MET (2MET) – *Interim Guidance on Hurricane Conditions in the Gulf of Mexico*.
- API Bulletin 2INT-DG (2DG) – *Interim Guidance for Design of Offshore Structures for Hurricane Conditions*.
- API Bulletin 2INT-EX (2EX) – *Interim Guidance for Assessment of Existing Offshore Structures for Hurricane Conditions.*

Bulletins 2DG and 2EX provide assessment and design guidance for the updated set of hurricane conditions contained in 2MET. In October 2007 the Minerals Management Service issued Notice to Lessees (NTL) No. 2007-G26 and NTL No. 2007-G27 which essentially implemented 2DG and 2EX, respectively.

2MET provides an updated set of hurricane conditions and divides the GOM into four regions, East, Central, West Central and West, as shown in Figure 2.1, with the largest increase in conditions occurring in the Central, located generally south of the Mississippi delta. For example, the very deep water (>1,000ft) 100 yr return period maximum wave height (Hmax) increased from 72ft as defined in API RP 2A 21st Edition (RP2A) to 92ft in 2MET bulletin. There is also a Transition Area between each region where the metocean conditions are to be linearly interpolated between those in the adjoining regions. The transition results in a more realistic ramp-type change in metocean conditions compared to a step-type change if there was no transition.

The metocean conditions within each region vary by water depth and the changes in wave height, wind, current and storm surge are not always consistent between regions. In some cases it is not clear if the updated conditions result in a larger or a smaller resultant load on a fixed platform compared to the prior RP2A conditions. For example, the wave height may be lower, but the surge is higher, or the wave height is higher but the current is lower.

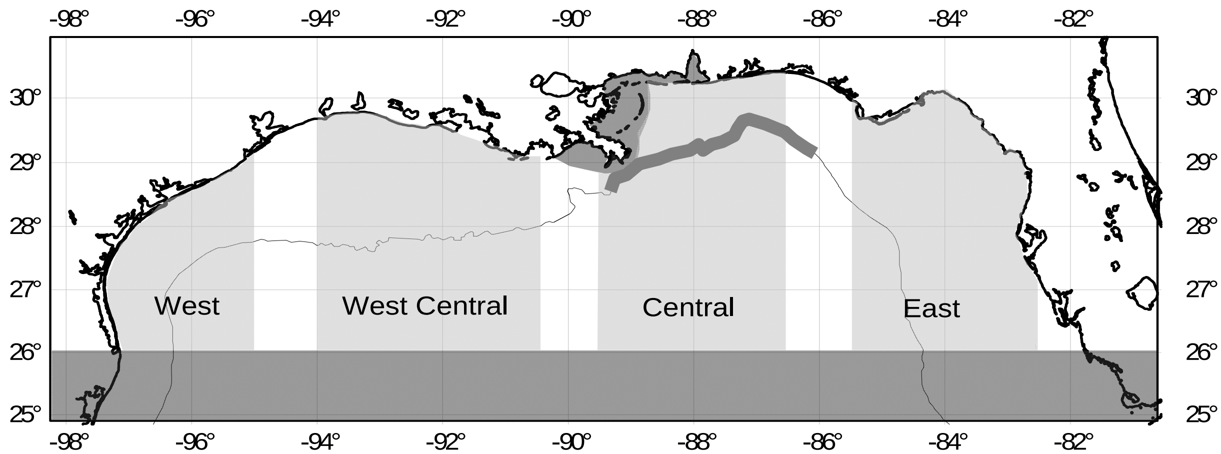


Figure 2.1 Gulf of Mexico Metocean Regions per API Bulletin 2INT-MET
The gray zone is the primary region. The white zone in-between is the transition region.

2DG and 2EX provide engineering procedures to be used in conjunction with the updated metocean conditions, for design of new platforms and assessment of existing platforms, respectively. 2DG recommends a minimum 100 yr condition for High Consequence platforms, 50 yr for Medium Consequence and 25 yr for Low Consequence. Note that the Low Consequence platforms were previously designed to a 15 yr return period in RP 2A.

2DG also contains specific recommendations for cellar deck elevation (measured to Bottom of Steel (BOS)) that accounts for a typical 5ft air gap above the 100 yr wave crest and also an additional allowance of 15% of the crest elevation to account for local wave effects. There is an option to neglect the 15% additional elevation if the deck structure and equipment in way of such a crest are designed for local wave loads.

The above indicates that the bulletins result in changes in metocean design conditions according to:

1. GOM Region – East, Central, West Central and West,
2. Water depth – shallow (<75ft), intermediate (200ft) and deep (400ft+),
3. API Exposure Category – High (100 yr), Medium (50 yr) and Low (25 yr),
4. 100 yr wave crest elevation to establish deck height.

The above factors lead to different reliability for a platform depending upon the region it is located in, water depth, its exposure category and deck elevation. The complement of the platform reliability is the platform probability of failure (pf), which for this document is defined as the annual probability the platform will fail. The pf is computed by a complex relationship but is essentially the likelihood that the loading acting on the platform will exceed the platform structural resistance. Figure 2.2 shows the pf in a conceptual format. The platform resistance and the metocean load are defined by a mean and then a variation about the mean of possible other values, otherwise known as a probabilistic distribution. The width of the distribution is in general terms the amount of uncertainty from the mean. In this document, the uncertainty is defined by the Coefficient of Variation (cov), a common statistical parameter used in reliability computations, defined as the ratio of the standard deviation to the mean of a distribution. A platform will fail in cases where the load exceeds the resistance, as shown in Figure 2.2 where a load value from the upper tail of the load distribution is larger than a resistance value from the lower tail of the resistance distribution. Factors of safety are used in design codes to ensure that the means of the load and mean of the resistance are far enough apart such that there is very low probability that the tails of the distributions overlap.

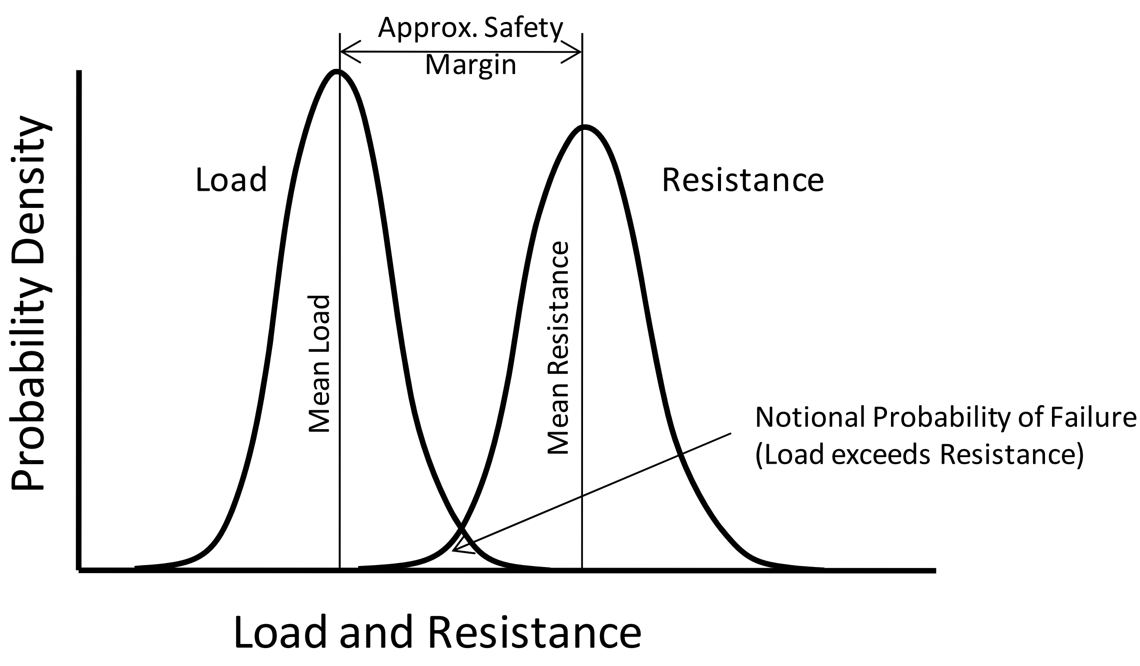


Figure 2.2 Showing Conceptually the Determination of the Probability of Failure (pf)

This document describes a study to determine the *reliability* of typical GOM platforms given the variations in metocean region, water depth, API exposure category and deck elevation as noted above. This information will be beneficial to determine how the reliability of platforms varies across the GOM using 2MET as well as how it compares to RP2A. Comparisons will also be made between the reliability data determined and historical performance of GOM fixed platforms, and other fixed platforms located worldwide.

2.2 Objectives

The key objective of this project was to determine the reliability of typical Gulf of Mexico fixed platforms for 2MET versus RP2A. Since RP2A provides the current basis for historical performance of GOM platforms, the comparison provides a basis to determine if 2MET provides the same or improved reliability compared to RP2A.

An additional objective was to compare platform reliability in each of the four regions. RP2A contains a single set of metocean conditions for all regions whereas 2MET contains four regions. This comparison will show if platform reliability changes according to region.

The reliability comparisons were performed for high, medium and low consequence platforms, considering new platforms as well as existing platforms.

This information will be beneficial to determine if the designated API return periods, RSRs and other pertinent design information for the various types of platform are acceptable. The goal is to understand the reliability of different types of fixed platforms based on location, water depth and consequence. Input to API for development of future guidelines will also be a result of this project.

2.3 Project Team

The project was executed by Energo Engineering, Houston, Texas. The Principal Investigator was Mr. Frank Puskar. Mr. Puskar was also the Principal Investigator for the Energo Ivan and Katrina / Rita studies. Mr. Puskar has 25 years of offshore structural engineering experience and is a PE in Texas, Louisiana and California. The reliability portions of the project were lead by Dr. Albert Ku. Dr. Ku has 12 years of offshore engineering experience and is a PE in Texas. Dr. Ku was supported by Dr. Beiqing Huang. Mr. Sean Verret led the data gathering portions of the study related to benchmarking. Other Energo staff assisted on the project as needed.

The project was executed as an MMS TA&R Project No. 609. The key participants from the MMS were Ms. Lori D'Angelo (COR) and Ms. Fung Chan Hassenboehler (OSTS).

The project was conducted from February 2008 to March 2009.

3.0 RELIABILITY METHODOLOGY

This section presents the key aspects of the reliability methodology used for the project. There are two reliability methods used.

The first is the *Generic Method* that uses generic platform information, such as water depth, location and platform strength measured as the Reserve Strength Ratio (RSR) to determine the platform reliability. The RSR is defined by API as the ratio of the platform ultimate strength to the 100 year return period metocean base shear for the platform in that region. Standard closed form probability calculations are used to determine the platform reliability. This allows a quick and easy comparison of platform reliability across the 2MET regions as well as to the "old" API RP2A 21st Edition criteria.

The second is the *Detailed Method* that uses specific platform information to determine the platform reliability. This information is the same as the Generic Method, but adjusted for a specific platform configuration based upon ultimate strength analysis and extreme condition metocean analysis. This information is then used to determine the platform reliability using a similar approach as used by Energo in prior studies of the performance of GOM platforms in hurricanes [Energo, 2006 & 2007]. These prior studies established a "Bias" factor based upon reliability that measured how well RP2A predicts platform performance based upon observed performance of fixed platforms in hurricanes. The Bias studies used an inherent method for determining platform reliability as part of determining the Bias factor. For this project, the reliability method has been extracted and used to compute the platform reliability for the Detailed Method. The advantage of the Detailed Method is that it accounts for factors such as wave-in-deck (WID) loading and currents that cannot be captured in the Generic Method

3.1 API GOM Metocean Regions

The recent Metocean criteria as contained in 2MET partitioned the Gulf of Mexico (GOM) into four regions: West, West Central, Central and East. Various design parameters (maximum wave height (Hmax), wind speed, current, etc.) are given in 2MET. The wave heights are a focus here since waves control design of fixed platforms. Previous to 2MET, API provided a single set of wave heights applicable for the entire GOM as contained in RP2A and as shown in Figure 3.1 as a function of return period and water depth, developed based upon information contained in Petrauskas, et.al., 1994. The wave heights are shown for four different water depths—100ft, 200ft, 400ft and 800ft—representing shallow to deep water depth. The similar 2MET wave heights for each of the four regions plus RP2A are shown in Figure 3.2. The 2MET wave heights are large for the Central Region compared to RP2A (e.g., 92ft vs. 70ft for 1000ft WD) but are about the same for the other regions. Although the East region is not currently being developed with offshore developments, it has been carried along for the Generic Method since it is relatively easy to incorporate for completeness.

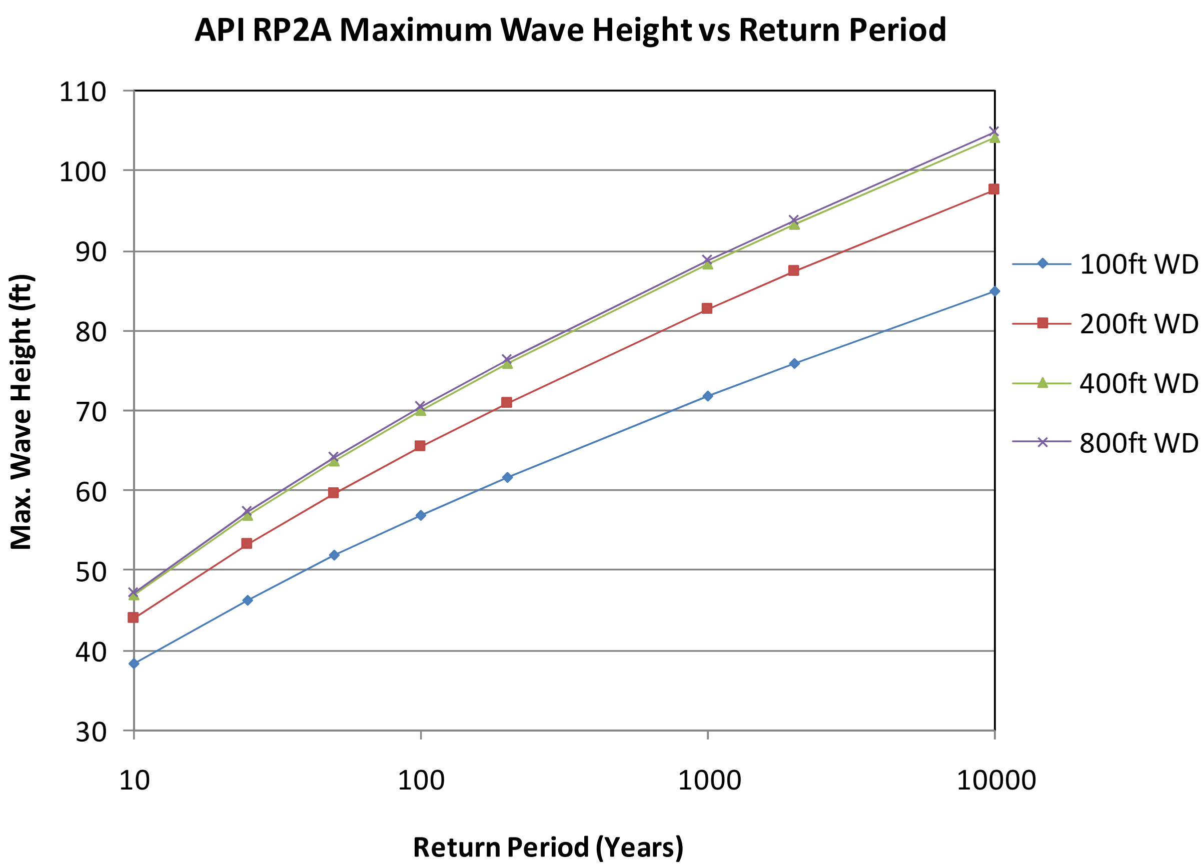


Figure 3.1 Approximate Wave Height vs Return Period for API RP 2A 21st Edition
(after Petrauskas, et.al., 1994)

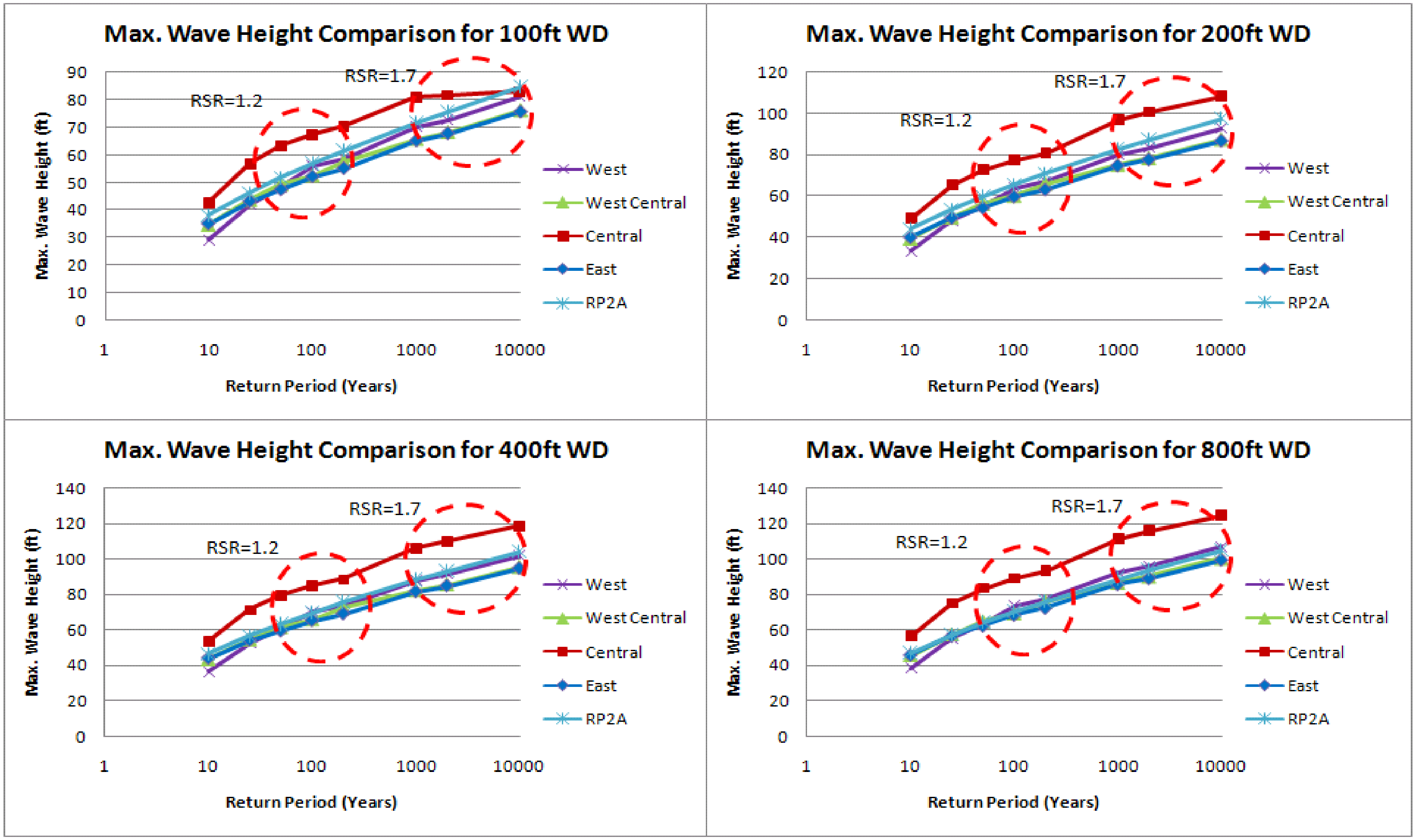


Figure 3.2 Maximum Wave Height Distribution in Four Zones in 100ft, 200ft, 400ft and 800ft Water Depth (WD) [2MET], Return periods relevant to determining the pf for RSR=1.2 and RSR=1.7 are shown with red dashed circles

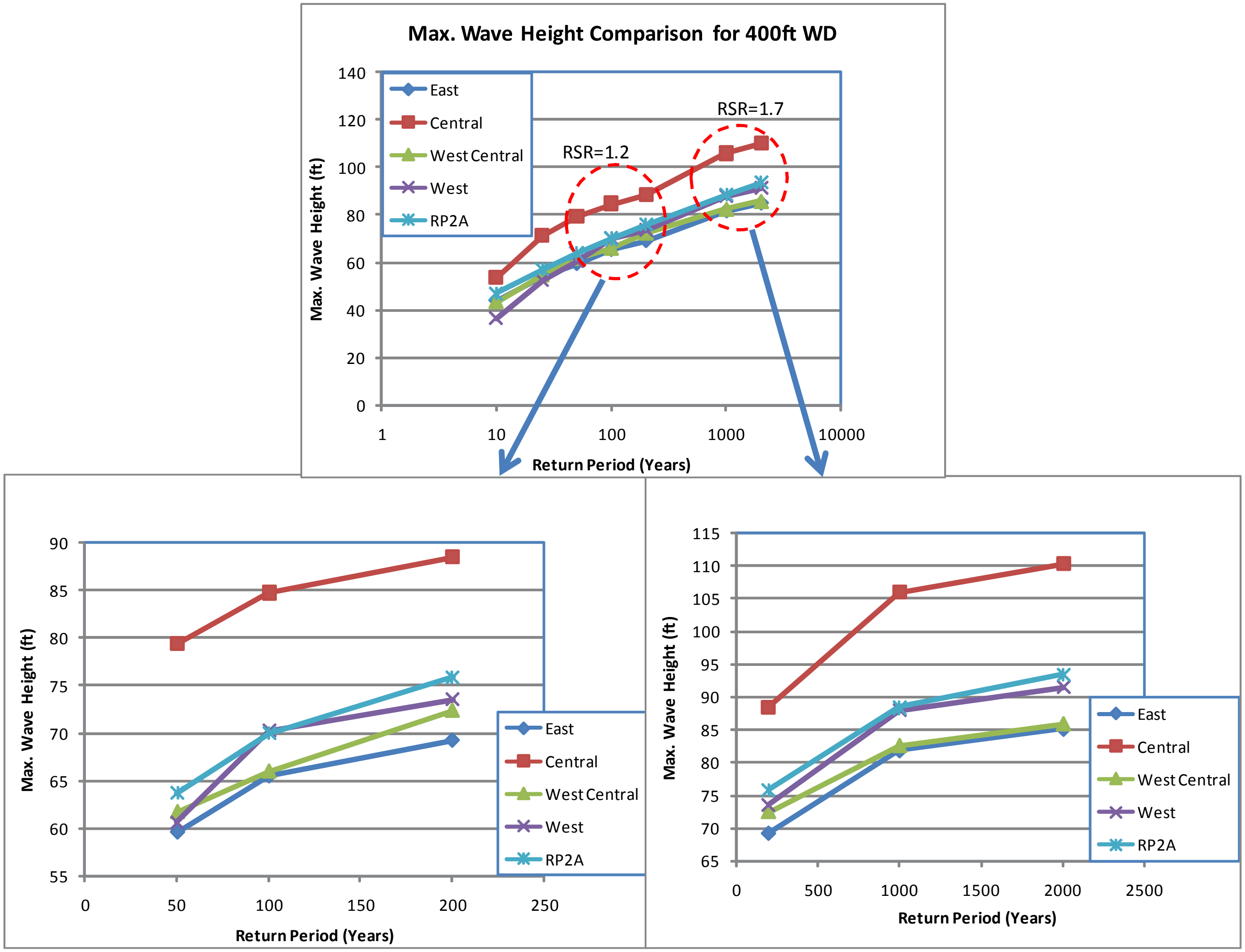


Figure 3.3 Enlargement of Wave Height Distribution for 400ft Water Depth (WD) for RSR=1.2 and 1.7
Note the steeper slope for the West Central Region (Green) in the range of RSR=1.2 and WD>100 ft

Figures 3.1 and 3.2 show that the wave heights in RP2A and 2MET increase with water depth, as expected. The general trend or "slope" of the wave height curves are approximately the same for the various water depths considered, except for the 100ft water depth Central. This curve flattens at extreme return periods (1000+ yr) due perhaps to the shallow-water effect which limits wave height.

Local variations of these slopes are important to defining platform reliabilities, and these variations and their effect on platform reliability are addressed in this study. These changes are difficult to see in Figure 3.1 due to the large return period scale used on the horizontal axis. Figure 3.3 shows the local slope variations in the 400ft water depth data for RP2A and 2MET by focusing on the RSR=1.2 (around 100 year) and RSR=1.7 (around 1000 year) regions. 1.2 is the approximate RSR for API A1 High Consequence GOM platforms as defined by RP2A Section 17 (Section 17). The performance of *existing platforms* with A1 categorization is critical and is therefore a focus of this study. As noted later, based upon results of reliability analysis, return periods in the range of 100 years tend to govern the reliability of platforms with an RSR of 1.2, and that is why there is interest in the slope of the metocean curves near this return period. Likewise, a *new platform* designed to RP2A will have and RSR in the range of 1.7 to 2.0 or more, depending upon configuration (4 pile or 8 pile), bracing scheme, pile penetration, etc. Using the minimum RSR of 1.7, return periods in the range of 1000 yr tend to govern the reliability of these platforms, and there is interest in the slope of the metocean curves near this return period. Appendix A shows similar plots as Figure 3.3 for water depths of 100ft, 200ft and 800ft.

Figure 3.3 shows that for an RSR of 1.2 the slope of the metocean curve (between 100-yr to 200-yr) is highest for the West Central region, followed by RP2A, Central, East and then West. For an RSR of 1.7, RP2A is slightly higher with all of the 2MET regions having about the same slope. The slope of the "hazard curve" (wave height in this case) is important for any reliability analysis, whether it is waves, winds or earthquakes. The slope is used to determine the incremental increase in hazard that will at some point fail the platform. If the slope is high (steep) then for a small increase in return period there is large increase in wave height. If the slope is low (shallow) then for a small increase in return period there is a small increase in wave height. The GOM has a relatively steep metocean hazard curve compared to other worldwide offshore areas, for example the North Sea. In the North Sea there is only about a 3ft to 7ft difference between 100 and 1000 year wave heights. In the GOM, the difference is about 20ft to 25ft for RP2A or 2MET.

Interestingly, the MODU Mooring Reliability Joint Industry Project [Stiff, 2009; Ku, et.al., 2009] determined that the slope of the 2MET wind curves governs reliability because MODUs are controlled by wind, similar to wave height controlling fixed platforms. Hence there is precedence for the different slopes of the metocean hazard curves controlling platform reliability according to the 2MET region. This study will determine if a similar difference exists between 2MET regions, using wave height as the factor controlling the design of fixed platforms.

3.2 Generic Method

The annual probability of failure of a platform can be written as follows:

$$p_f = H(R)\exp\left(\frac{1}{2}\left(k_1\delta_R\right)^2\right) \qquad \text{Equation (1)}$$

where R is the ultimate capacity of the structure, $H(R)$ is the cumulative probability at which the platform fails, k_1 is the "slope" of the environmental load, and δ_R is a measure of the uncertainty of the structural ultimate capacity. The random variables involved in the above equation are listed in Table 3.1.

Table 3.1 Random Variables Used for Platform Global Base Shear

Random Variable	***Type of Distribution***	***Mean Value***	***Coefficient of Variation (cov)***	***Comments***
Maximum wave height (*H*)	Log-Normal	(see comments)	(see comments)	Mean value and cov are determined based on local wave slopes in 2MET in the region of platform capacity
Platform Ultimate Capacity Uncertainty (δ_R)	Log-Normal	1.0	10% (Puskar, et.al., 1994)	To be multiplied to the platform ultimate capacity as predicted from strength analysis

This equation has found wide applications in structural engineering reliability. Examples include the ISO seismic code ISO 19901-2 [ISO, 2004], and the general theory has been described by Cornell for the offshore industry in 1995 [Cornell, 1995].

Generally, publications, and even this study, focus on the more "positive" sounding platform reliability versus the "negative" sounding probability of failure (pf). This is true for example in the title of this study. However, most reliability computations and technical studies determine the pf and then compute the reliability as (1 - pf). pf is used in this document.

Embedded in Equation (1) is the expression for the platform global base shear, which is assumed to have the following form for the Generic Method:

$$F = cH^{\alpha} \qquad \text{Equation (2)}$$

where F is the platform base shear, c is a proportional constant (does not need to be calculated in the Generic Method since it cancels out during derivations), H is the maximum wave height and alpha is a proportional constant, assumed to be 2.0, which implies that the wave loading on the platform is proportional to the wave height squared. This relationship is generally well known in the industry and has wide applications, with examples found in Petrauskas, et.al., 1994 and in De, 1995. It is generally accepted that for drag-dominated jacket platforms, the alpha parameter is in the range of 1.8 to 2.2 (taken as 2.0 for this study). This simplified base shear equation has been the basis for prior GOM platform reliability studies [Puskar, et.al, 1994; ABSC, 2004; Energo 2006 & 2007].

For the Generic Method the only platform-specific factor needed to define the reliability is the RSR. The rest of the variables are related to the metocean loading, which is assumed to be about the same for all platforms as described by the alpha factor. In comparison, the Detailed Method described below includes other platform-specific factors such as current loading and wave-in-deck loading. The Generic Method provides a quick and easy way to run many cases in order to compare reliability between platforms with different RSR and in different GOM regions with different water depths. As shown later the Generic Method provides a reasonable match to results using the Detailed Method.

For the Generic Method, sensitivity studies to determine the platform reliability can be performed by varying the following parameters:

- Wave height in RP2A and the four different 2MET regions.
- Water depth
- RSR

Section 4 details the various cases studied and the resulting platform reliabilities for the Generic Method.

3.3 Detailed Method

The Detailed Method uses the same form of pf computation as described for the Generic Method, Equation (1). However, a more sophisticated base shear relationship, compared to Equation (2), is used to determine the load acting on the platform that includes additional information about the metocean loading characteristics for the platform. The relationship is described by the following equation:

$$F = [C_1 + C_4(H - h_d)](H + C_2 u)^{C_3} \qquad \text{Equation (3)}$$

In this equation, H is the maximum wave height as in Equation (2), h_d is the smallest wave height with a crest that will reach the bottom of the cellar deck and *u* is the current. There are also four C coeffictients used to describe the metocean load acting on the platform. In order to apply Equation (3), the platform-specific C coefficients (C_1, C_2, C_3 and C_4)) need to be determined first. The C_1 term is a general term for the overall platform shape (4 leg vs 8 leg, etc.) the C_2 term is for current, the C_3 term is similar to the alpha term used in Equation (2), and the C_4 term is for WID loading. The ability to capture WID is important in regions with a steep hazard curve like the GOM since it is likely that extreme waves will impact the deck at some point in the reliability computations. This relationship can be used for both existing and new platforms. This more complicated base shear equation has also been the basis for prior platform reliability studies used to determine the platform "bias factor", e.g. Puskar, et.al, 1994; ABSC, 2004 and Energo 2006.

Figure 3.4 shows how the C factors are computed. A series of increasing wave heights are run past a 3D computer model of the platform and the resulting base shear (BS, or force (F) per Equation (3)) is plotted as a function of wave height as shown in Figure 3.4. The resulting nonlinear curve has a relationship as described by the lower left hand equation of Figure 3.4 using C_1 to C_3 factors. At the point where the increasing wave height impacts the platform deck, h_d, there is a rapid increase in wave loading with increasing wave height as shown by the increase in the slope of the base shear curve. Once this occurs, the C_4 factor is introduced, as shown by the right hand equation of Figure 3.4, in order to obtain a better fit to the base shear relationship. These curves which capture the platform shape "details" are then input into the structural reliability process, replacing the more "generic" curve as described for the Generic Method, Equation (2). Additional details on development of these types of curves are contained in Energo, 2006.

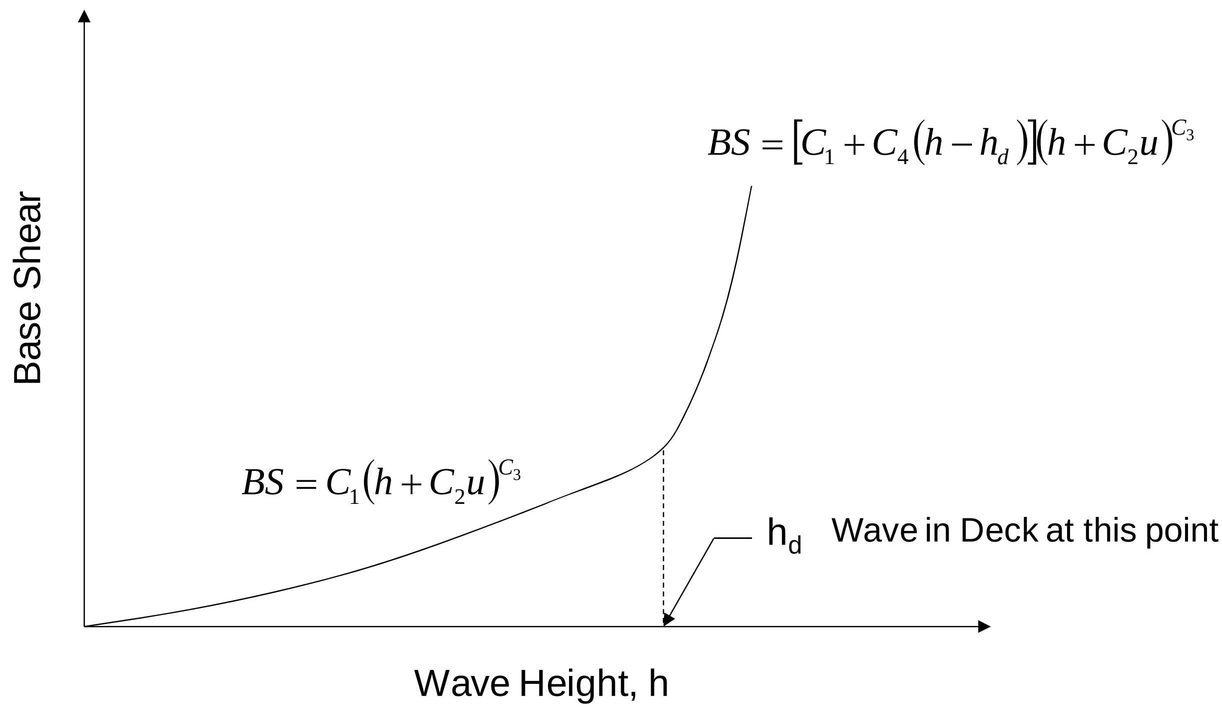


Figure 3.4 Typical Relationship for a Fixed Base Platform Accounting for WID Loading

The random variables used with the Detailed Method are the same as in Table 3.1, with the two main random variables being wave height and platform capacity. The current is determined according to its corresponding return period based wave height as given in 2MET. The uncertainty of the current is implicitly considered by way of its relationship to maximum wave height at various return periods, as given in the 2MET. The maximum wave and associated current speed have been considered, in which a current reduction factor has been applied as suggested in 2MET. The factors C_1, C_2, C_3 and C_4 are assumed to be deterministic. The uncertainties from these factors are of 2nd order effect, and can be neglected in the reliability studies of this project. The Detailed Method is consistent with the Generic Method when these factors are considered deterministically.

The pf for the Detailed Method is solved using a more sophisticated First-Order-Reliability-Method (FORM) approach that Energo and others have used on prior GOM hurricane loading projects [ABSC, 2004; Energo, 2006 & 2007].

For the Detailed Method, sensitivity studies to determine the platform reliability can be performed by varying the following parameters:

- Wave height in RP2A and the four different 2MET regions.
- Water depth
- RSR
- Deck height (wave-in-deck effect)
- Effects of current loads

The first three parameters are the same as the Generic Method. Section 5 describes the various cases studied and the resulting platform reliabilities for the Detailed Method.

4.0 PLATFORM RELIABILITY – GENERIC METHOD

Section 3.2 described the technical approach for the Generic Method. This method is described as generic since the only platform-specific detail needed is its RSR. This section provides results for a range of cases studied by varying the RSR, the water depth, and the location in the GOM. Section 4.1 provides an example case to show how the results are computed.

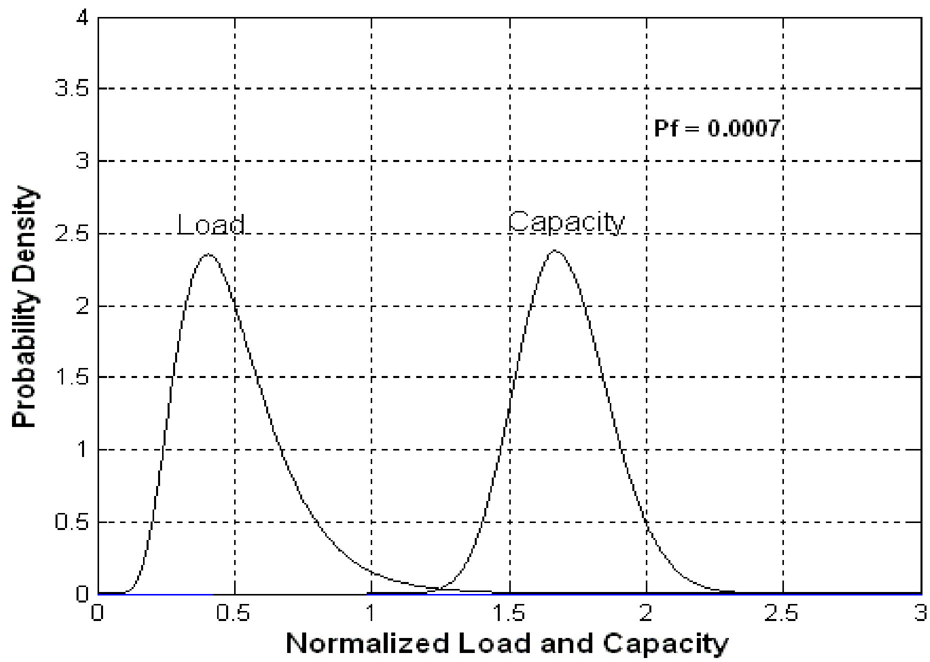
4.1 Example Platform Reliability

An example case using the Generic Method was run and the detailed probability distributions plotted in order to more fully illustrate the approach used to develop the results shown in Section 4.2. The basic equations used for determining the pf and base shear are defined in Section 3.2. The random variables used for the reliability calculations are defined in Table 3.1.

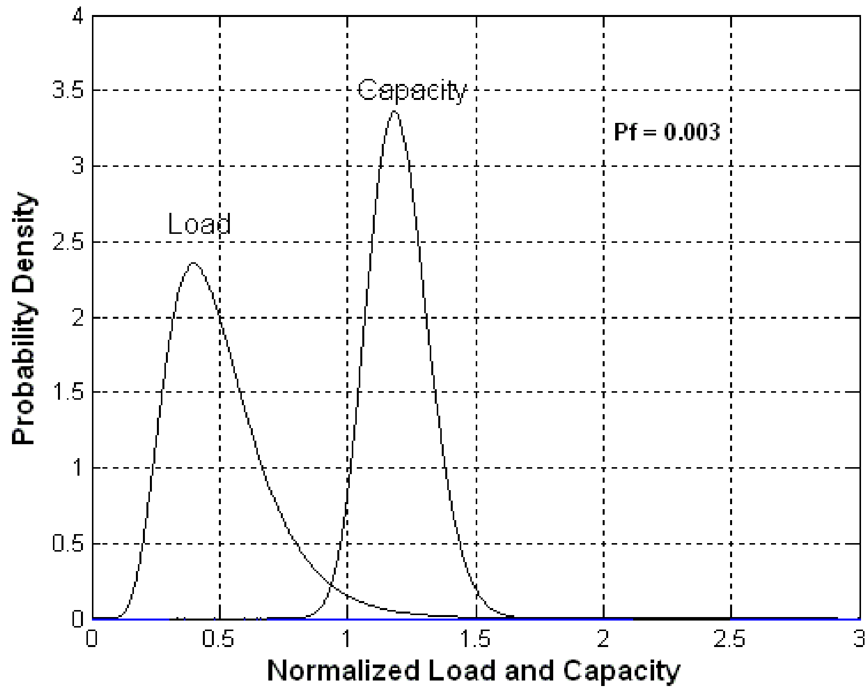
The example case involves a platform located in the Central Region with a water depth of 400ft. Once this is determined, the only value needed to determine the pf (or the platform reliability) for the Generic Method is the RSR. Two RSRs were used for this example, RSR=1.7 and RSR=1.2. Figure 4.1 shows the results, including the actual load and capacity (also sometimes called platform resistance) distributions, which are comparable to the generic case shown in Figure 2.2. The horizontal axis shows the normalized load or capacity, and the vertical axis shows the probability density (likelihood of having a load or capacity of that magnitude). Note that the load and capacity are normalized by the 100-yr metocean base shear load. This is because the RSR is defined as the ratio of the platform capacity to the 100 yr load for the platform site, making it a convenient measure for these types of studies. Note that many detailed platform capacity studies using advanced 3D structural analysis develop the RSR as one of the critical outputs.

Figure 4.1a shows the case of RSR=1.7 with a resulting pf measured as the annual probability of failure of 0.0007, or $7x10^{-4}$. This is a reasonably low pf for a GOM platform. Note that the distributions have a large separation and there is only a small amount of overlap of the tails of the load and capacity distributions. This leads to the low pf.

Figure 4.1b shows the case of RSR=1.2 with a resulting pf of 0.003, or $3x10^{-3}$. This is an order of magnitude larger than that for the RSR=1.7 case. Note how the load distribution has not changed from the RSR=1.7 case. The change in pf is due to the shift of the capacity curve to the left resulting in a substantial increase in the overlap of the load and capacity curves and a significantly increased pf for this case. The capacity distribution is narrower since the cov is held constant at 10%. The cov is defined as the ratio of the standard deviation to the mean, and since the mean of the 1.2 RSR case is smaller than the mean of the 1.7 RSR case, the distribution is more narrow. This example shows the dramatic effect that the RSR has on the pf.



a. Load and Capacity Distributions and pf for RSR = 1.7



b. Load and Capacity Distributions and pf for RSR = 1.2

Figure 4.1 Example Generic Method for RSR =1.2 and 1.7

4.2 Generic Method Results

Results were developed for the Generic Method by varying the RSR of a platform and then varying the location of the platform within the 2MET regions. This is intended to show how the reliability of the platform changes across regions – even though the platform has the same RSR. The pf was also determined for RP2A in order to compare to the pfs for the various 2MET GOM regions with the single GOM region defined by RP2A.

The Generic Method was used to evaluate a range of variables per the following:

- Location – East, Central, West Central and West
- API RP 2A Category – L1, L2 and L3
- API RP 2A Section 17 Category – A1, A2 and A3
- Water Depth – 100ft, 200ft, 400ft and 800ft, representing fixed platforms from shallow to intermediate to deep water
- Reserve Strength Ratio (RSR) – 2.0, 1.7, 1.2, 1.0, 0.8 and 0.6. The RSR is defined as the ratio of the platform ultimate capacity to the 100 yr return period L1 load for the platform location. The range of RSRs evaluated for each category was selected based upon typical platform strengths for that category (e.g., 2.0 to 0.8 for L1 and A1).
- Load Factor (LF) – 2.0, 1.7, 1.2, 1.0, 0.8 and 0.6. LF is defined as the ratio of the platform ultimate capacity to the load for the exposure category of interest (e.g., L2, A2, etc.) at the platform location.

Figures 4.2 to 4.8 at the end of this section show results in bar-chart format. Appendix B provides the corresponding results in numerical format in tables that correspond to the figures. Results are discussed below.

Comparison of L1 and A1 Platforms with RSR = 1.7

Figure 4.2 shows results for an RSR of 1.7 considering L1 and A1 platforms. An RSR of 1.7 is the minimum expected RSR for a new design fixed platform per RP2A. RP2A wave height data for A1 platforms is limited to 400ft WD hence there is no A1 plot for 800ft WD and therefore is assumed to be the same as the 400ft WD for this study. Figure 4.2.a shows these results as a function of annual pf and 4.2.b shows the same results as a function of equivalent annual return period. The return period is equal to the inverse of the pf. The following discussion of these figures is based upon the two key variables shown in the figures – Location and Water Depth.

- Location – Variation between 2MET Regions. The pfs are approximately constant for the four MET regions, with a value of about 7 to $8x10^{-4}$. The equivalent return periods are approximately 1,500 to 2,000 yrs. As discussed later in Section 7, these are reasonable return periods for high consequence platforms – new design or existing.

- Versus RP2A - The RP2A L1 and A1 results show a slightly higher pf than any of the 2MET regions, meaning that the 2MET wave heights result in slightly better platform performance for an RSR of 1.7.

- Water Depth. The pfs are approximately constant for all water depths, even though the wave heights differ for each water depth. This is because the 100 yr base shear denominator of the RSR serves to normalize the load and exemplifies why the RSR is a good design standard or code variable since it is well behaved. The constant pf also indicates that the slope of the wave height hazard curve for each region is about the same for RSRs in the range of 1.7. Also see Figure 3.3 and associated discussion.

<u>Comparison of L1 and A1 Platforms with RSR = 1.2</u>

Figure 4.3 shows results for an RSR of 1.2 considering L1 and A1 platforms. An RSR of 1.2 is the estimated minimum RSR for A1 platforms in the GOM [Kreiger, et.al., 1994]. For an L1 platform, this would represent the RSR of an existing RP2A 21st edition designed platform located in the Central Region per 2EX, or an unusually low RSR for a new design platform for any of the other regions. Figure 4.3.a shows the results as a function of annual pf and 4.3.b shows the same results as a function of return period. The results are much different than Figure 4.2 with the pfs varying between regions as described below.

- Location – Variation between 2MET Regions. There are considerable variations between the 2MET regions. The highest pfs are in the West Central, followed by the East, West and Central (even though it has the highest waves). The difference in pfs is due to the variation in the slopes of the wave height hazard curves for each region in the range of RSR=1.2 as shown in Figure 3.3. The pfs range from 3 to $5.5x10^{-3}$ with equivalent return periods ranging from 200 to 450 yrs. The pfs are about an order of magnitude lower than those for RSR=1.7 as shown in Figure 4.2. This shows the improvement in platform reliability when increasing the RSR from 1.2 to 1.7. This change in RSR does not seem large but the impact on pf is significant. As discussed later, these pfs for existing platforms are in the range of historical experience in the GOM for hurricane failures.

- Versus RP2A – The RP2A L1 and A1 pf values are about the same as the West Central and higher than any of the other 2MET regions for an RSR of 1.2

- Water Depth. The pfs are approximately constant for all water depths, even though the waves heights differ for each water depth. As described in the Figure 4.2 discussion, this is indicative of the normalizing effect of the 100 yr return period base shear used to calculate RSR.

High Consequence Platform Comparison

Figure 4.4 shows results for L1 and A1 platforms considering RSRs of 2.0, 1.7 and 1.2. The vertical scales for each of the figures are the same so that the effect on pf can be seen on a relative basis. The figures on the left hand side show the pf and the associated figures on the right hand side show the equivalent return period. An RSR of 2.0 would be considered to be a well designed platform with robust framing such as X-bracing as well as a robust foundation. RSRs of 1.7 and 1.2 have been previously shown in Figures 4.2 and 4.3 respectively. The figures show the significant decrease in pf as a function of increasing RSR. The figures also show the trend from generally the same pf in all of the 2MET regions for the higher RSRs to differing pfs between the regions for an RSR of 1.2.

Figure 4.5 shows additional results for RSRs of 1.0, 0.8 and 0.6. These results are shown at the same vertical pf scale and are shown separate from those of Figure 4.4 since there is an order of magnitude increase in the pf. These represent lower strength platforms with pfs in the range of $1x10^{-2}$ or an equivalent 100 yr or less return period. There are few variations between the 2MET regions and RP2A for an RSR of 1.0 and larger variations for an RSR of 0.8, due to the slopes of the hazard curves at low RSRs.

Medium Consequence Platform Comparison

Figure 4.6 shows results for medium consequence L2 and A2 platforms considering a *Load Factor* (LF) of 2.0, 1.7, 1.2 and 1.0. The LF is defined as the ratio of the platform capacity to the applied metocean load, i.e., L2 or A2. Hence the LF as used here is defined as the platform capacity divided by the L2 or A2 metocean base shear for that region. This is much like the RSR, except the denominator is the L2 or A2 condition base shear instead of the 100 yr condition base shear. L2 platforms are designed to a 50 yr return period. A2 platforms have no designated return period since they are based on a sudden hurricane condition [Kreiger, et. al., 1994]. As with Figures 4.4 and 4.5, the vertical scales for each of the figures are the same so that the effect on pf can be seen on a relative basis. The results show a significant increase in pf when going from an LF of 2.0 to 1.0, with overall pfs in the range of $1x10^{-3}$ to $1x10^{-2}$. These pfs are an order of magnitude higher than the better performing L1 and A1 platforms. This is as expected given the lower return periods for medium consequence platforms such as 50 yr for L2. Note that the low pf for LF=2.0 for 100ft WD is due to the flat slope of the Hmax curve at high return periods, since the extreme wave will break in this shallow water.

Low Consequence Platform Comparison

Figures 4.7 and 4.8 shows results for low consequence L3 and A3 platforms. L3 platforms are designed to a 25 yr return period for 2MET and a 15 yr return period for RP2A. A3 platforms have no designated return period as previously discussed for A2 platforms, although it is expected to be in the same range as the L3 return period. The figures are only shown to 100ft WD since these types of platforms are limited to shallow water. These results show relatively high pfs on the order of $1x10^{-2}$ to $1x10^{-1}$. The 2MET pfs are lower than the RP2A pfs primarily due to the higher 25 yr return period used for 2MET compared to the 15 yr return period for RP2A. API elected to increase the return period of L3 platforms for 2MET in order to improve performance of these low consequence platforms.

4.3 Generic Method Conclusions

The above results show some interesting trends and observations. The key conclusions from the generic method are as follows.

1. Compared to RP2A, the 2MET criteria for all types of platforms (L1, L2, A1, A2, etc.) show an equal or lower pf across all of the 2MET regions. In other words, 2MET results in offshore platforms that have the same or slightly better reliability than RP2A.

2. For platforms with RSRs on the order of 1.7, representative of new design API L1 high consequence platforms, the pf is about the same in all four of the 2MET regions with the pfs on the order of $7x10^{-4}$. A higher RSR will result in a lower pf. The 1.7 RSR is the estimated minimum RSR for a new platform designed to API RP2A 21st Edition using working stress design methods. See Figure 4.2.

3. For platforms with RSRs on the order of 1.2, representative of existing high consequence A1 platforms, the pf is highest in the West Central compared to the other regions. The West Central pf is about 5 to $6x10^{-4}$, and is also about the same as RP2A. The other regions have a pf of about 3 to $4x10^{-4}$ or a reduction of about 1.5 to 2 compared to the West Central. The 1.2 RSR is the estimated minimum RSR for A1 platforms in the GOM [Krieger, et. al., 1994]. The higher pf in the West Central is driven by the steeper slope of the Hmax curve as a function of return period compared to the other regions. The large number of destroyed platforms in the West Central in recent hurricanes is perhaps explained in-part by the higher pf in this region, although other factors such as the

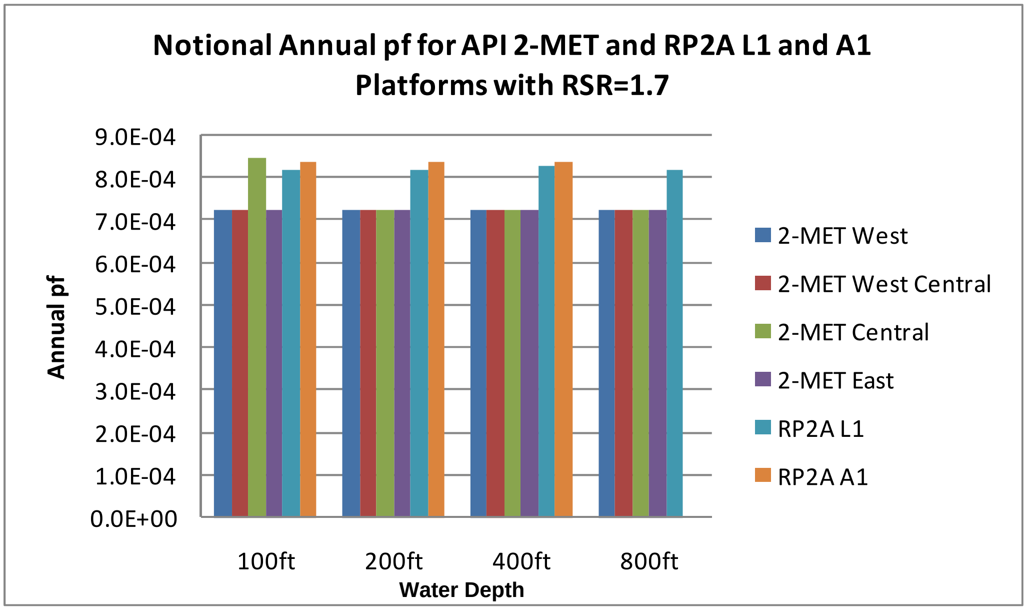
number of exposed platforms and the vintage of the platforms in the West Central also influence the number of destroyed platforms [Energo, 2007]. See Figure 4.3.

4. The pf decreases by an order of magnitude with an increase in RSR from 1.2 to 1.7. An RSR of 1.2 is the approximate RSR for existing high consequence A1 platforms and an RSR of 1.7 is the expected minimum RSR of new platforms designed to RP2A. Hence, new design L1 platforms are generally an order of magnitude (i.e., 10 times) more reliable than the minimum API standard for existing A1 platforms. This helps explain why there have been only a few L1 failures in recent hurricanes compared to numerous A1 platforms.

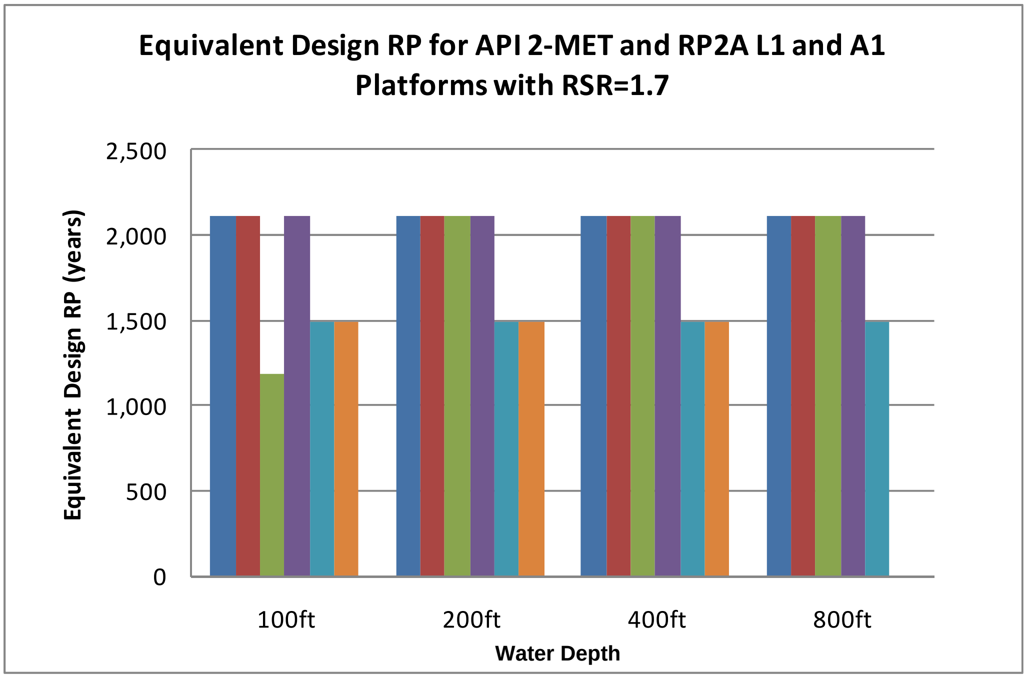
5. Medium Consequence L2 and A2 platforms have pfs in the range of $1x10^{-3}$ to $1x10^{-2}$. See Figure 4.6

6. Low consequence L3 and A3 platforms have pfs on the order of $1x10^{-2}$ to $1x10^{-3}$. See Figures 4.7 and 4.8.

The Generic Method uses wave height and RSR to determine platform reliability. The results have provided a good overview of the differences in reliability between 2MET regions and RP2A as well as platform Exposure Category (e.g., L1, A1, L2, etc.). An important factor that is too detailed to include in the Generic Method is deck elevation since extreme waves that impact the deck cause a sudden increase in platform loading and possible onset of failure. The effect of deck elevation is discussed in the next section for the Detailed Method.

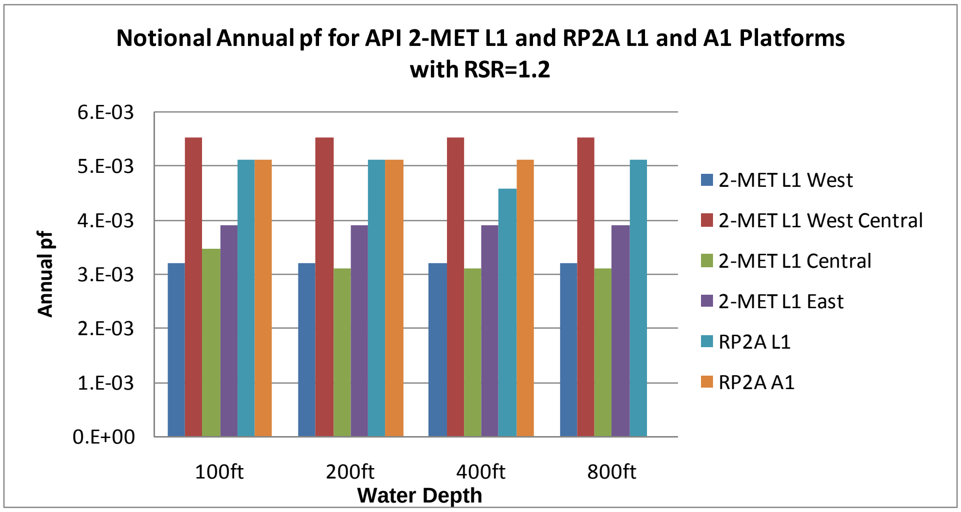


a. Probability of Failure (pf) Format

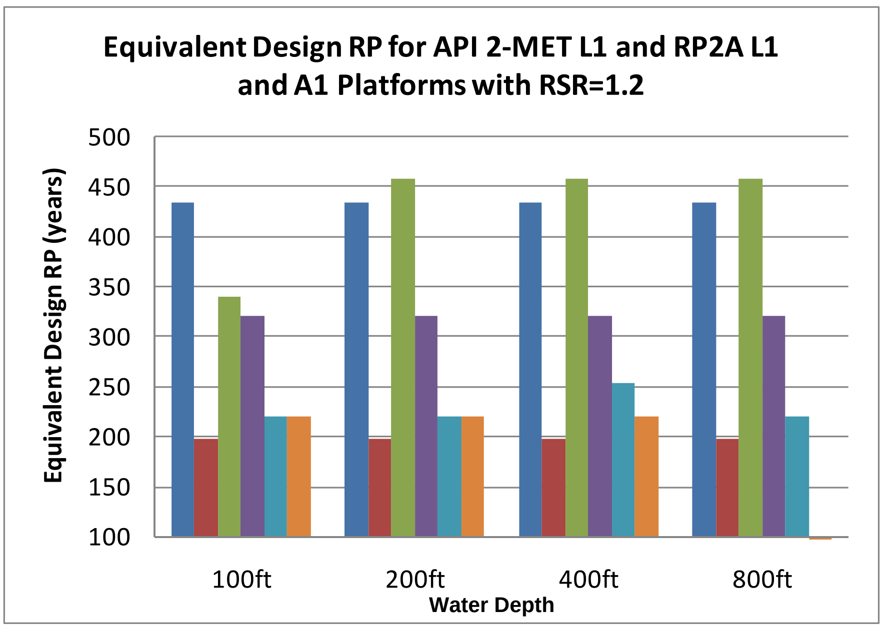


b. Equivalent Return Period Format

Figure 4.2 pf and Equivalent Return Period for RSR=1.7, L1 and A1 Platforms



a. Probability of Failure (pf) Format



b. Equivalent Return Period Format

Figure 4.3 pf and Equivalent Return Period for RSR=1.2, L1 and A1 Platforms

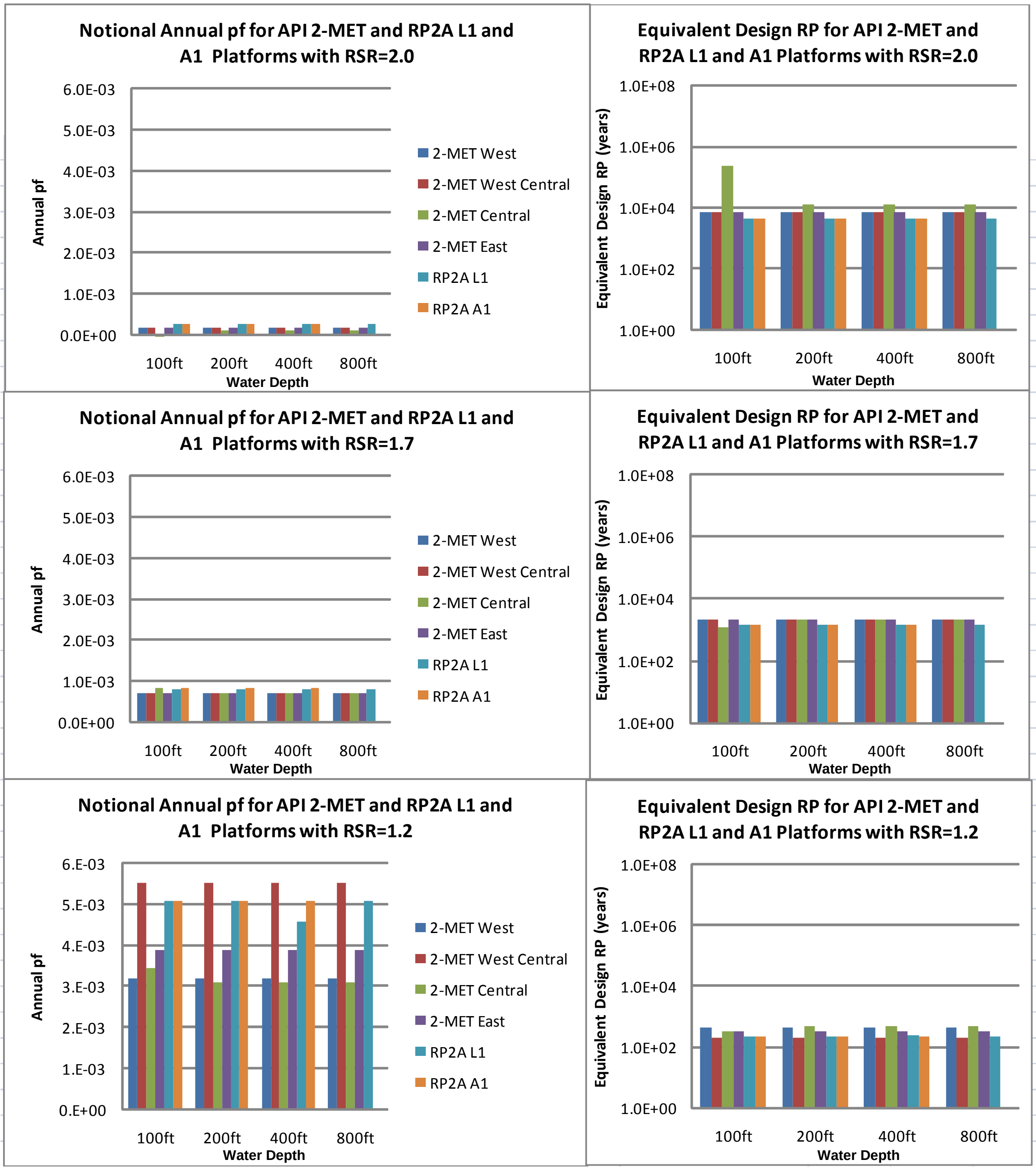


Figure 4.4 Comparative Results for L1 and A1 Platforms, Generic Method, RSR=2.0, 1.7 and 1.2

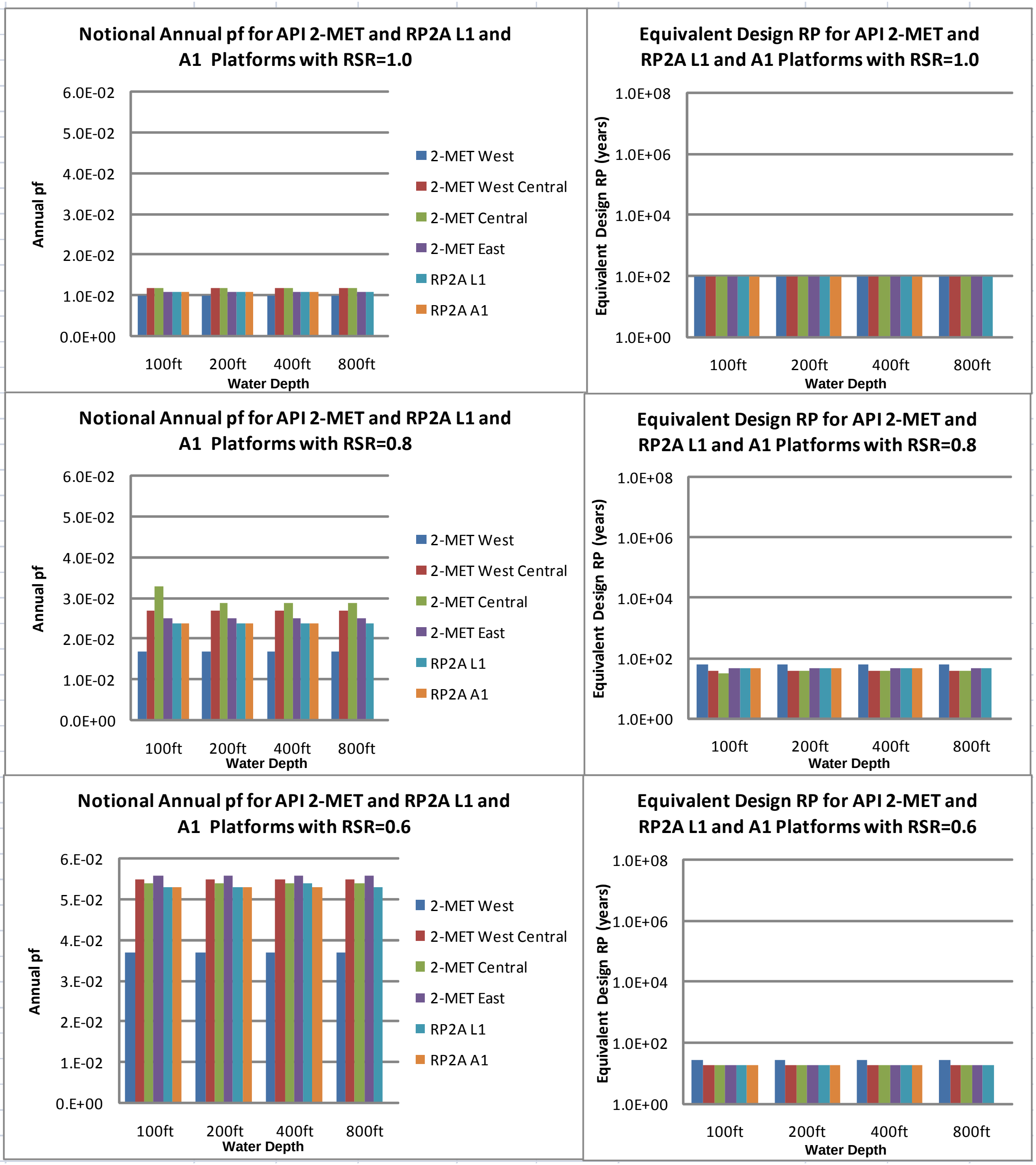


Figure 4.5 Comparative Results for L1 and A1 Platforms, Generic Method, RSR=1.0, 0.8 and 0.6

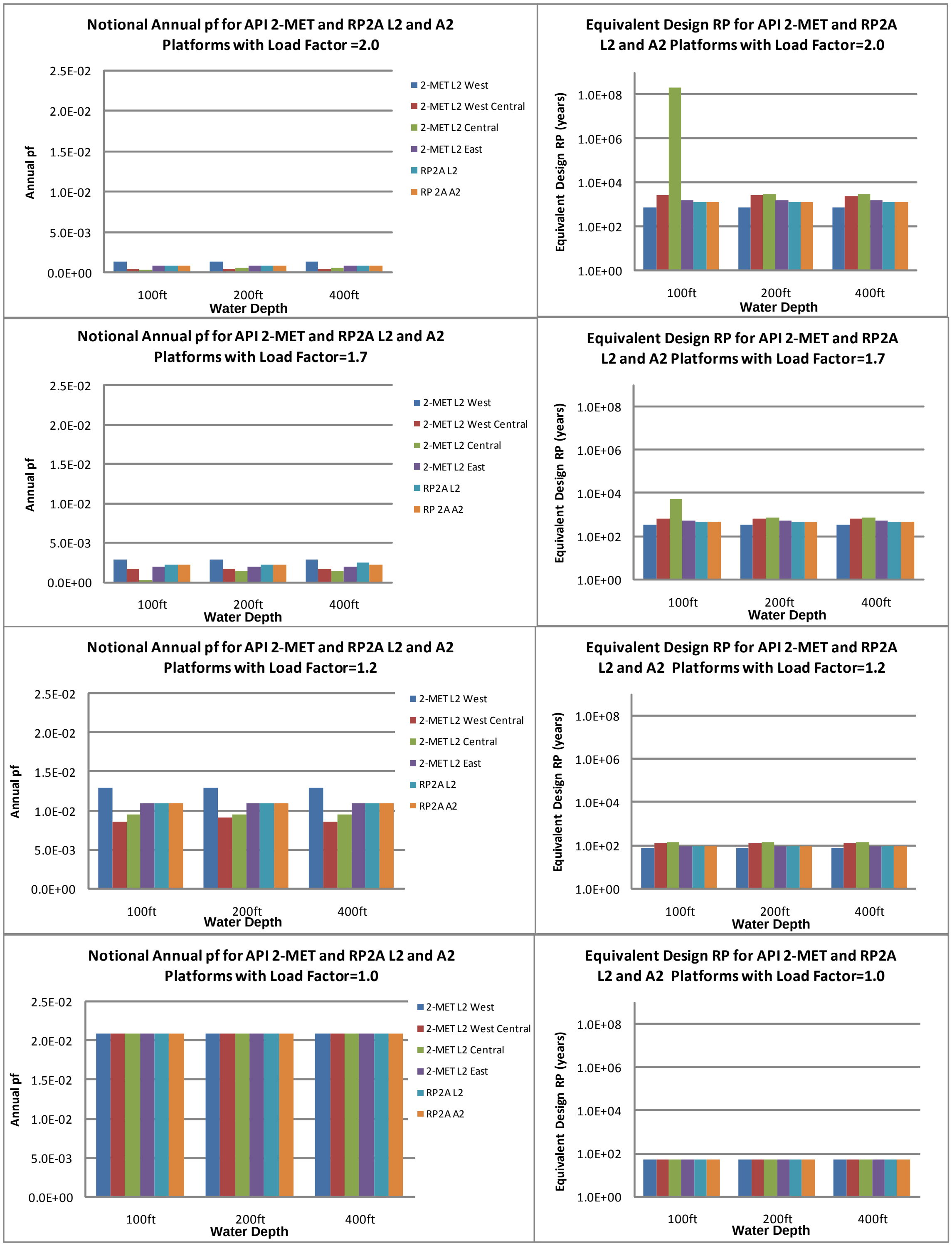


Figure 4.6 Comparative Results for L2 and A2 Platforms, Generic Method, Load Factor = 2.0, 1.7, 1.2 and 1.0

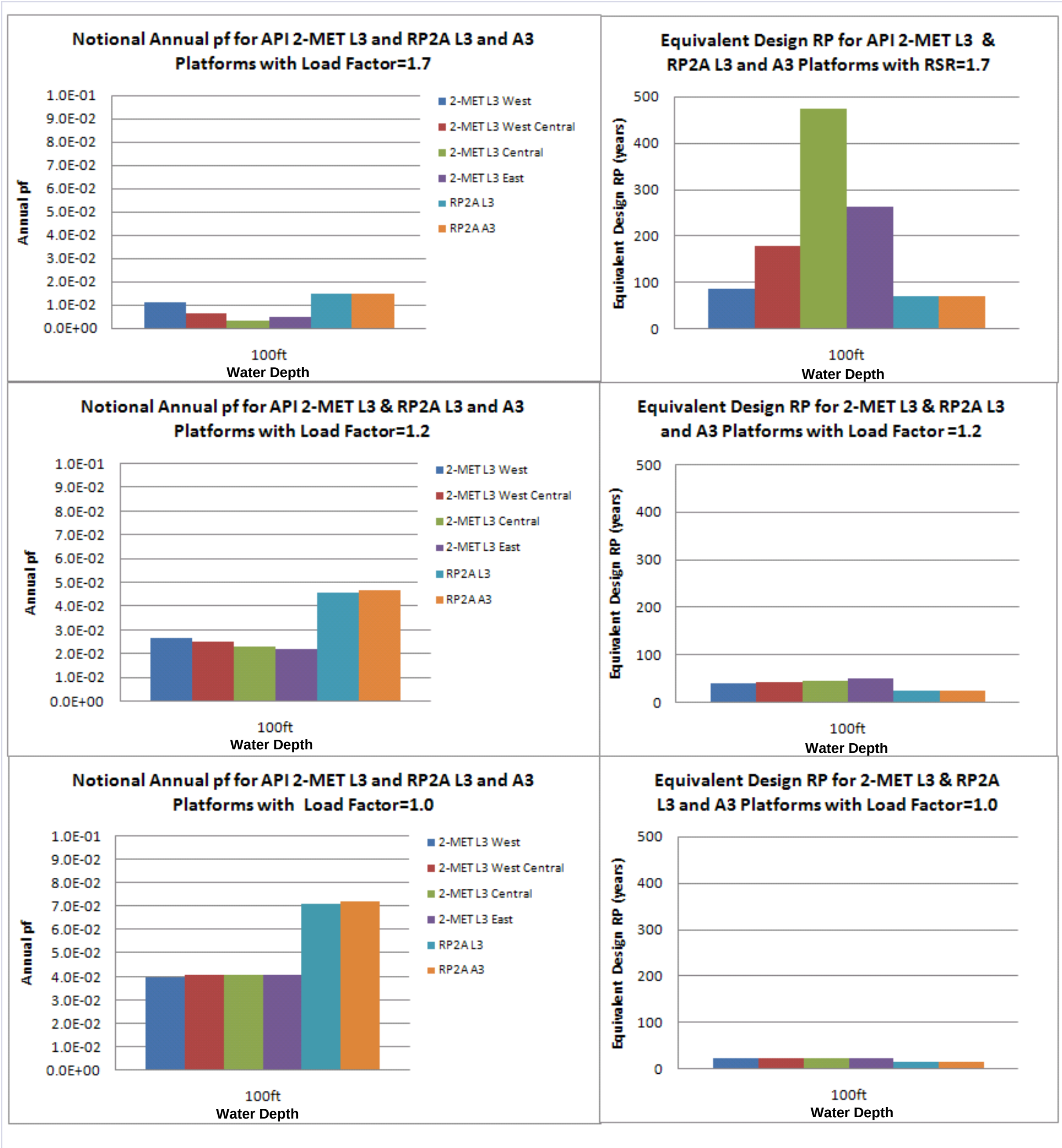


Figure 4.7 Results for L3 and A3 Platforms, Generic Method, Load Factor = 1.7, 1.2 and 1.0

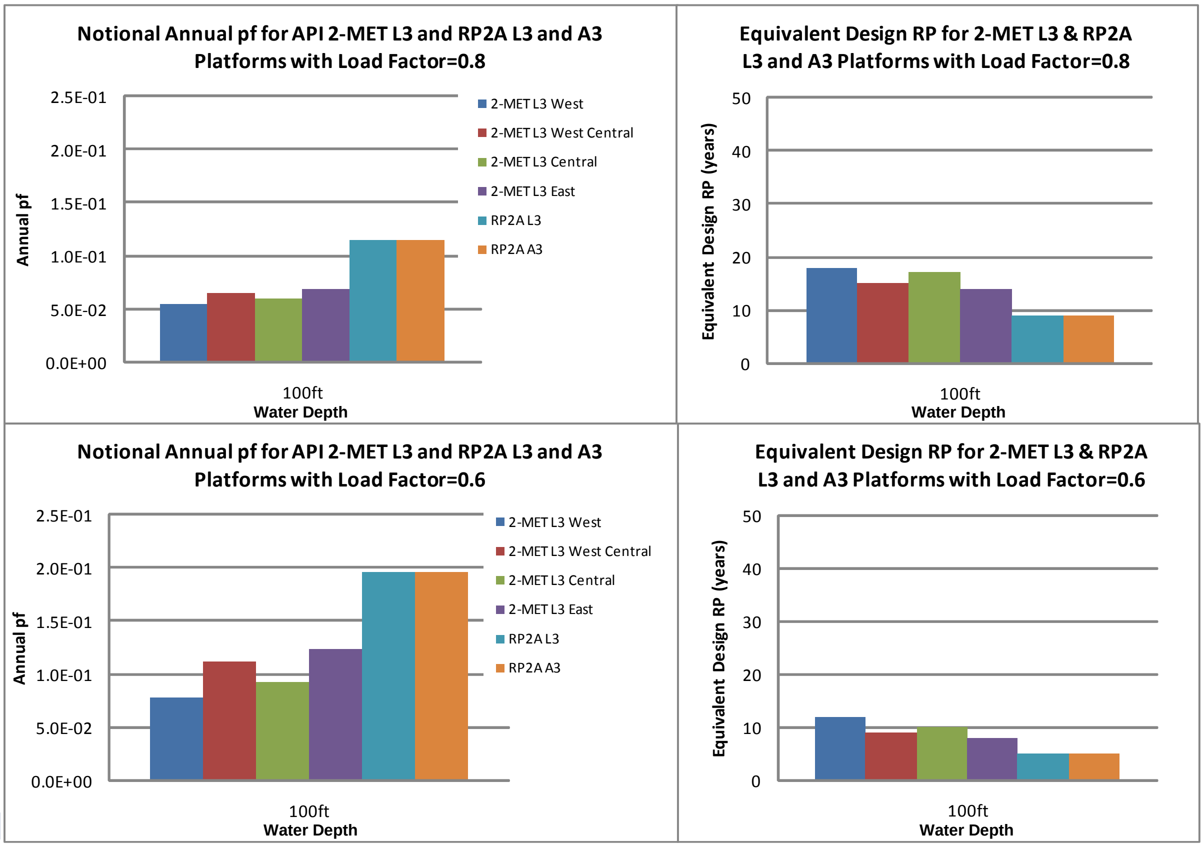


Figure 4.8 Results for L3 and A3 Platforms, Generic Method, Load Factor = 0.8 and 0.6

5.0 PLATFORM RELIABILITY - DETAILED METHOD

The Detailed Method allows for a more precise description of the platform, specifically wave and current loading that can be used to determine a more refined pf. In particular, it allows for WID loading which has been the cause of numerous GOM platform failures.

WID loading is a critical issue in the GOM due to the large increase in wave height with increase in return period throughout the GOM. The historical use of 100 yr criteria as a baseline to establish deck elevations appears to lead to extreme waves that impact the deck. Such WID loading is believed to explain a large number of the destroyed and heavily damaged platforms in recent hurricanes. Figure 5.1 shows two examples of platforms that have been damaged by WID in Hurricane Ike in September 2008. Although the platforms are still standing, they are essentially destroyed and may be decommissioned since such damage is difficult to repair.

This section looks more closely at platform reliability including WID and also how the reliability calculated using the Detailed Method compares to the Generic Method. General conclusions are discussed at the end of the section.

5.1 Platforms Considered in Sensitivity Studies

Four platforms are considered in the sensitivity studies with characteristics as shown in Table 5.1. The platforms were taken from prior studies of platform performance in hurricanes [Energo, 2006 & 2007]. These cases were chosen to evaluate the effects of different water depths. The platform water depth was rounded to the nearest 100ft for the purpose of this study. In addition, Cases 1 and 2 have the same water depth, and by comparing the results from these two cases the platform-specific differences (number of piles, framing, etc.) controlling pf can be shown. If it can be shown that the platform-specific differences from are not significant, then the trend observed from other cases can be considered general. Detailed data is available for all four of these platforms including platform capacity based upon 3D structural pushover analyses and detailed wave loading information containing the required C_1, C_2, C_3 and C_4 data, especially the C_4 terms related to the effect of WID loading.

Table 5.1 Key Characteristics of the Four Platforms Studied

CASE	PLATFORM LOCATION	WD (ft)	STR. TYP	LONG FRAME	TRAN FRAME	DECK ELEV (FT)	VINTAGE
PLATFORM 1	WD	200	6-P	XH, KH	XH, KH	48	1973
PLATFORM 2	EC	200	4-P	KH	KH	40	1972
PLATFORM 3	SS	100	4-P	/H	/H	35	1976
PLATFORM 4	MP	300	8-P	K	K	46	1969

Figure 5.1 Examples of Wave-in-Deck Damage to GOM Platforms from Hurricane Ike 2008

The C parameters as listed in Table 5.2 only relate to the base shear acting on these platforms given wave height and current speed. The specific capacities of these platforms are not used in this approach; instead, the capacities are normalized to a range of RSRs in order for sensitivity comparisons assuming that the capacity varies. This allows the process to determine the effect of varying capacity.

Table 5.2 C Values for the Four Platforms Studied

	C_1	C_2	C_3	C_4
Platform 1	0.59	5.98	2.06	0.013
Platform 2	0.44	5.67	2.04	0.0052
Platform 3	0.96	3.99	1.85	0.054
Platform 4	0.47	7.54	2.10	0.033

Notes:

- To apply to Equation (3), the load unit is in kips, wave height unit is in feet, and current unit is in knot.
- The C coefficients are as follows: C_1=shape, C_2=current, C_3=hydrodynamic load and C_4=WID.
- See Section 3.3 for more information

5.2 Detailed Method Results

The sensitivity results are performed for the following two major categories:

- Sensitivity with respect to a constant RSR in three of the GOM regions where offshore platforms are located (Central, West Central and West). The results show that by requiring a constant RSR in all regions, the pf does not stay constant, but rather is a function of deck elevation.
- Sensitivity with respect to a constant capacity in the same three GOM regions. This sensitivity case can be used to determine the reliability of a platform by changing deck height. The results show reduction in pf that can be gained by increasing the deck elevation for a platform.

Within the above two major categories, the following sensitivity cases were also performed:

a. Sensitivity with respect to the Central, West Central and West regions.
b. Sensitivity to platform differences within the same range of water depths.
c. Sensitivity with respect to platform water depths.
d. Comparison to the Generic Method.

e. Comparison to three options for minimum deck requirements as described in API guidance:

   Option 1: 100 yr crest elevation plus 15% plus 5ft air gap (2DG)
   Option 2: 100 yr crest elevation plus 5ft air gap (2DG)
   Option 3: RP2A 21^{st} Edition minimum deck elevation per Figure 2.3.4-8.

The detailed results for annual failure probabilities are shown in Figures 5.2 to 5.9. In all results, both the annual pf and RSR are plotted (pf on the left vertical axis, and RSR on the right vertical axis) for cross references. The results are summarized in the following discussions.

Sensitivity to Deck Elevation for Constant RSR

From a regulatory point of view, it is instructive to quantify the increase of failure probability (with lower deck height) with a given RSR. Although a constant RSR is specified, for platforms with lower deck elevations, their failure probability will increase due to WID loading at a lower Hmax, and hence a lower return period. This increase in failure probability is due to the substantial and sudden increase in global base shear from WID as incorporated into the C_4 term in Equation (3). In the present case a constant RSR (1.7 or 1.2 as shown in the figures) is given; this implies at a lower deck height, the capacity of the platform has to be increased in order to achieve the same RSR. Even with this increase in capacity, for platforms with a low deck elevation the pf will still increase (as compared to platforms with high deck) due to the increased uncertainty (i.e., spread) of global platform load from the addition of the WID load component.

It is noted that the increase in pf is not monotonic. For example, the chart on the upper right corner of Figure 5.2 shows that the annual failure probability increases as the deck elevation was decreased from 70ft to 50ft, but from 50ft to 40ft there is a slight decrease in annual pf. As explained above, the increase in annual pf is due to the increasing spread on global load due to the WID component. However, at the same time the platform capacity is also increased in order to be normalized to a constant RSR. For capacity, a constant cov of 10% is assumed in the reliability calculations (see Table 3.1). This implies for cases where a very large capacity is needed in order to normalize to a constant RSR, the uncertainty spread in capacity can outpace the global load uncertainty. In this case, the failure probability will decrease. This only occurs in the Central and for the RSR=1.7 case. In this case, very large capacity is required in order to maintain a constant RSR at a low deck height.

This increase in annual pf is quantified in Table 5.3 for platforms with an RSR of 1.7, representing a new platform designed to RP2A, and an RSR of 1.2 representing an existing A1 platform. A 40ft reference deck elevation was selected to illustrate the change in pf with deck elevation. The ratio of increase is found to be from 2.1 to 4.6 for RSR=1.7, and 1.2 to 1.6 for RSR=1.2. For example, for RSR=1.7, Figure 5.2 middle right hand plot shows a constant pf of

$1x10^{-3}$ is achieved at a deck elevation of 60ft. For a deck elevation of 40ft the pf decreases to $2.8x10^{-3}$ or a ratio of about 2.8. Hence the probability of the platform failing is increased by a factor of 2.8 if the deck elevation is at 40ft instead of 60ft. For a higher RSR, the sensitivity to deck height is more significant than lower RSR platforms. This is because the lower RSR platforms essentially fail by other means such as global load on the jacket, regardless of deck elevation. In contrast, the newer higher RSR platforms are strong enough to resist extreme loads on the jacket, but once WID in deck occurs they are more quickly vulnerable to failure.

Table 5.3 Annual pf Increase by Lowering Deck Height to 40ft above MWL

Platform Water Depth	Constant RSR=1.7	Constant RSR=1.2
Central Region		
100ft	2.5	1.4
200ft	2.3	1.3
300ft	2.6	1.4
West Central Region		
100ft	4.2	1.3
200ft	2.7	1.2
300ft	4.6	1.3
West Region		
100ft	3.8	1.6
200ft	2.1	1.3
300ft	3.0	1.5

Sensitivity of Platform Specific C factors

Comparison of Platforms 1 and 2 (Figures 5.2 to 5.5), which both have a WD of 200ft indicate that the trend is similar in terms of sensitivity to deck height, even though the platforms have different structural configurations and hence different C factors. Thus it is concluded that generally the results for Platforms 3 and 4 (100ft and 300ft water depths, respectively) can be considered applicable to most platforms in those water depths (100ft and 300ft). Similar comparisons for other platforms in deeper WDs were not conducted since there were no candidate platforms available for this study with the data necessary for the Detailed Approach.

Approximate Required Deck Height to Reach Constant Annual pf

From Figures 5.2 to 5.9, the deck elevation at which the pf reaches a constant value can be identified. The resulting constant pf deck elevations are summarized in Table 5.4.

The distinctions for "constant capacity" and "constant RSR" cases were made, as the "constant capacity" case is more relevant to design of a single platform if such a design were to be moved from region to region it the GOM, and the "constant RSR" case is more relevant from a regulatory point of view. However, from Table 5.4 it was found these two cases result in required deck elevations that are not significantly different.

The required deck elevations to achieve a constant RSR are higher in the Central, as expected since this region has the highest Hmax waves. The required heights in the West Central and West are approximately the same. For higher RSR platforms, the required deck elevations are higher, also as expected.

For platforms with RSR=1.7, a deck elevation of 70ft is required in the Central, and 60ft is required in the West Central and West, to maintain a constant pf. Below these deck elevations, an increase in pf from 2.1 to 4.6 times can be expected, depending on the deck elevation.

For platforms with RSR=1.2, a deck elevation of 60ft is required in the Central, and 50ft is required in the West Central and West. Below these deck elevations, an increase in pf from 1.2 to 1.6 times can be expected.

For platforms in water depth of 100ft and shallower, the above-mentioned deck heights can be lowered somewhat, typically 5ft to 10ft, from the numbers as indicated above, since the wave crest elevations are limited by the breaking wave effect due to the more shallow water.

Comparison to Generic Method

The benefit of the Generic Method is that the process involved is more straightforward and more efficient. It can be used for quick assessment of many sensitivity studies with a limited amount of platform information (RSR). However, in the Generic Method the effects from current and WID load are not inherently included. Figures 5.2 and 5.3 illustrate the differences of results between the Detailed Method and the Generic Method. A red square is shown and labeled in the right hand plots of these figures that represents the pf for the platform as determined by the

Generic Method. Since no WID load is considered in the Generic Method, the comparisons can only be made at a point where the pf has stabilized at higher deck elevations (80ft for these examples, although it is applicable at lower deck elevations where the pf is constant). The comparison indicates that the Detailed Method gives slightly higher results than the Generic Method due to the inclusion of current in the base shear equation, Equation (3). The overall conclusion is that for platforms with higher deck elevations the Generic Method is adequate. As shown in Table 5.4, this is approximately 60ft to 70ft for higher strength platforms with RSR of 1.7 and 50ft to 60ft for lower strength platforms with RSR of 1.2.

Table 5.4 Deck Height when Constant pf is Achieved

Platform Water Depth	Constant Capacity		Constant RSR	
	RSR=1.7 (at high deck)	RSR =1.2 (at high deck)	RSR=1.7	RSR=1.2
Central Region				
100ft	60ft	50ft	60ft	60ft
200ft	70ft	60ft	70ft	60ft
300ft	70ft	60ft	70ft	60 ft
West Central Region				
100ft	50ft	50ft	50ft	50ft
200ft	55ft	50ft	60ft	50ft
300ft	60ft	50ft	60ft	50ft
West Region				
100ft	60ft	50ft	60ft	50ft
200ft	60ft	50ft	60ft	50ft
300ft	60ft	50ft	60ft	50ft

<u>Comparisons of API Deck Elevation Options.</u>

In Figures 5.2 to 5.9, the required deck heights (described in Section 5.2) for the three API options are indicated. The Options are defined at the beginning of this Section, with Option 1 providing the highest deck elevation. The overall results show that for RSR=1.7, Option 1 results in a constant pf. For RSR=1.2, both Options 1 and 2 result in a constant pf. Option 3 is the same as Option 2, except in the Central region in which the Option 3 is found to increase the pf significantly. Further discussion of these results is provided below.

Option 1 (100 yr crest plus 15% plus 5ft) provides a constant pf for an RSR of 1.2 or 1.7 for all regions and all WDs considered (100ft to 300ft). The change in pf with deck elevation is most sensitive as a function of deck elevation for the Central. Option 2 and Option 3 do not provide a constant pf for all regions and WDs.

Option 2 (100 yr crest plus 5ft) provides a constant pf for an RSR of 1.2 for all regions and all WDs considered (100ft to 300ft.) For shallower water depth of 100ft, represented by Figure 5.6, it was found that Option 2 is also adequate for an RSR of 1.7 to ensure a constant pf level, due the effect of breaking waves which limits the water depth.

Option 3 (RP2A) was found to only be adequate for RSR=1.2 cases in the West Central and West. For other cases such as RSR=1.7 or Central, Option 3 was found to result in significantly higher pf when compared to the other two Options.

Considering the above observations and the variation of pf according to deck elevation between the regions, it is apparent that the establishment of deck elevation based upon 2DG which uses the 100 yr wave crest plus a static value such as a 5ft air gap will result in different pfs for the regions. This is due to the varying slope of the wave height hazard curve in each region. For example, Table 5.4 shows that the required deck elevations to obtain a constant pf range from 50ft to 70ft depending upon the 2MET regions and water depth. These values are not consistent with the 2DG recommended deck elevations for these regions (Option 1 or Option 2). Hence the API deck elevations will results in inconsistent pfs across the GOM. An alternative approach is to establish the deck elevation based upon a consistent return period in all regions. For example, the 1000 yr return period wave crest elevation. Additional study, beyond the scope of this effort, is required to determine the specific return period that best meets regulatory and industry needs.

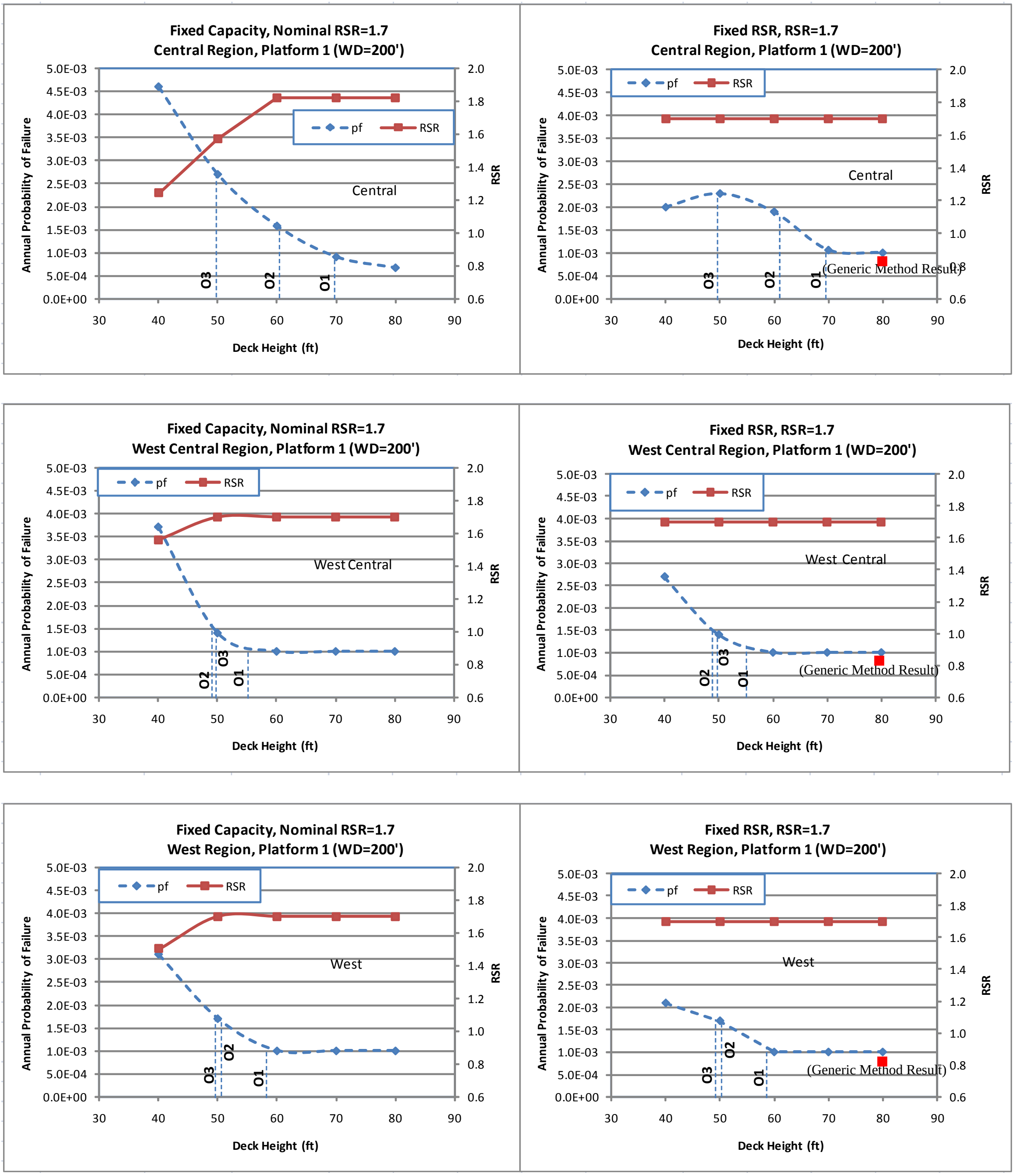
5.3 Detailed Method Conclusions

The above results show some interesting trends and observations. The key conclusions from the Detailed Method are as follows.

- The historical API method of establishing the deck elevation based upon the 100 yr wave crest elevation plus a factor (e.g., 5ft air gap) results in a different pf for the various 2MET regions. This is due to the different wave height hazard slope in the regions. An alternative approach is to establish the minimum deck elevation based upon a given return period such as a 1000 yr wave. This will result in a constant pf across all of the GOM regions. The specific return period needs to be developed based upon further study beyond the scope of this effort.

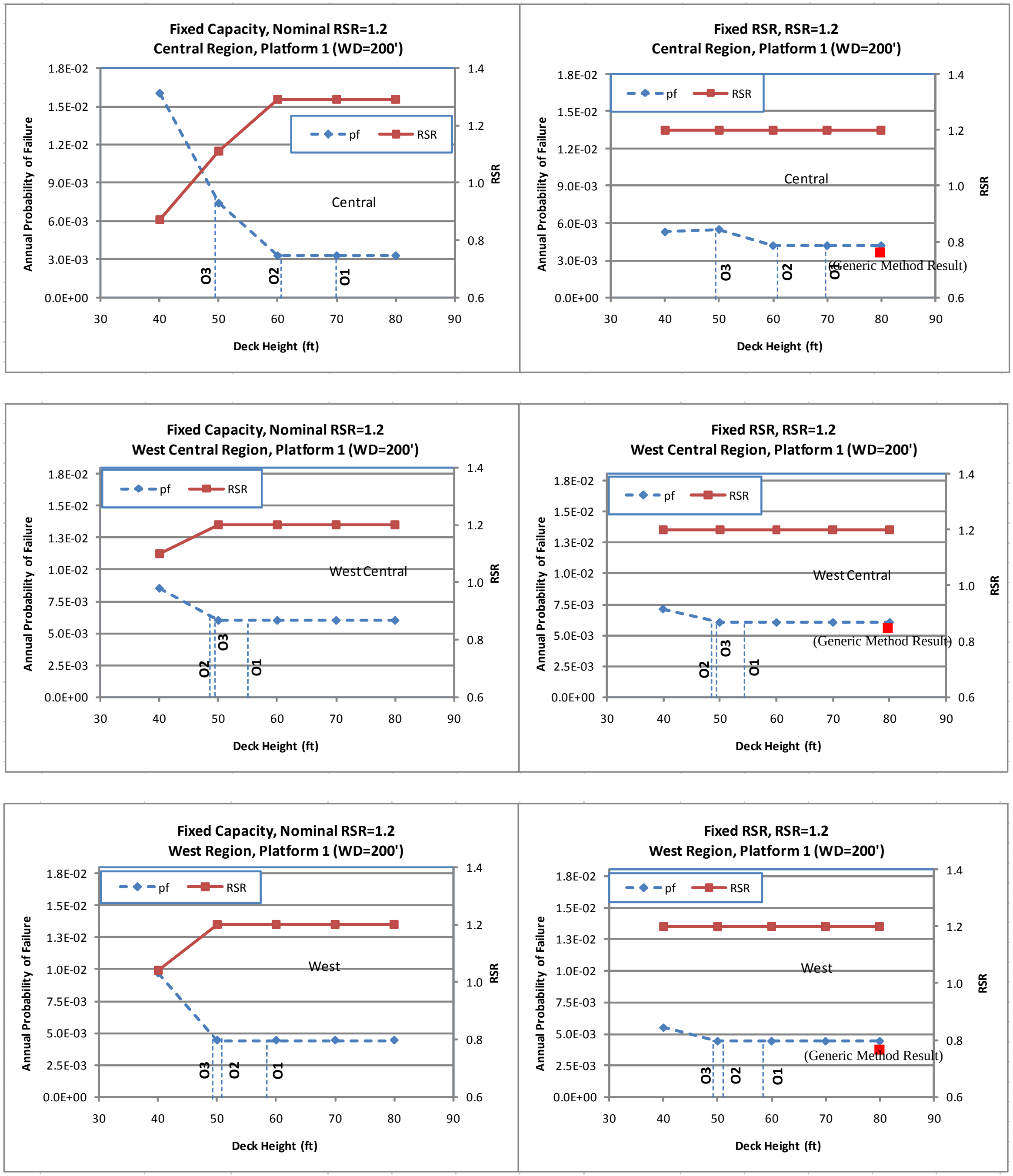
- The 2DG deck elevation Option 1 (5ft plus 15% crest) results in a constant pf for platforms with an RSR of 1.7 for most water depths and regions. An RSR of 1.7 is representative of a new design structure.

- The 2DG Option 2 (5ft only) results in a constant pf for platforms with an RSR of 1.2 for most water depths and regions. An RSR of 1.2 is representative of an A1 structure.
- The RP2A deck elevation (Option 3 in the figures) results in the highest pf for all cases. This helps explain the large amount of deck damage observed in recent hurricanes since most of these platforms had deck elevations based upon RP2A (or less in some cases).
- A comparison of pf results from the Generic Method and the Detailed Method show that the pf values from either method match well once the constant pf value has been obtained – i.e. provided the deck elevation is high enough to be at the constant pf value. See the red squares in the right hand plots of Figures 5.2 and 5.3.



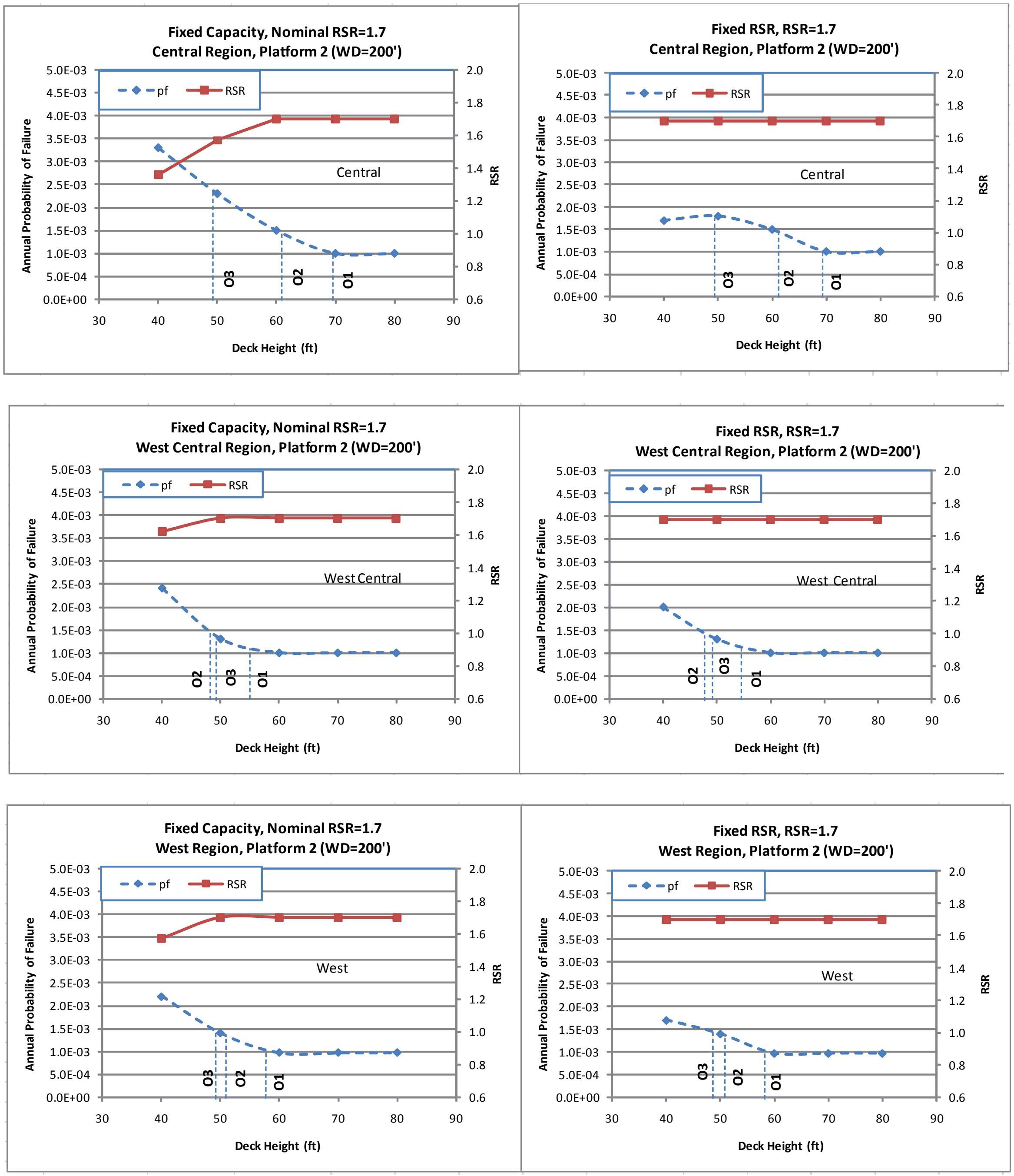
Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.2 Sensitivity of Deck Elevation, Platform 1 with RSR = 1.7



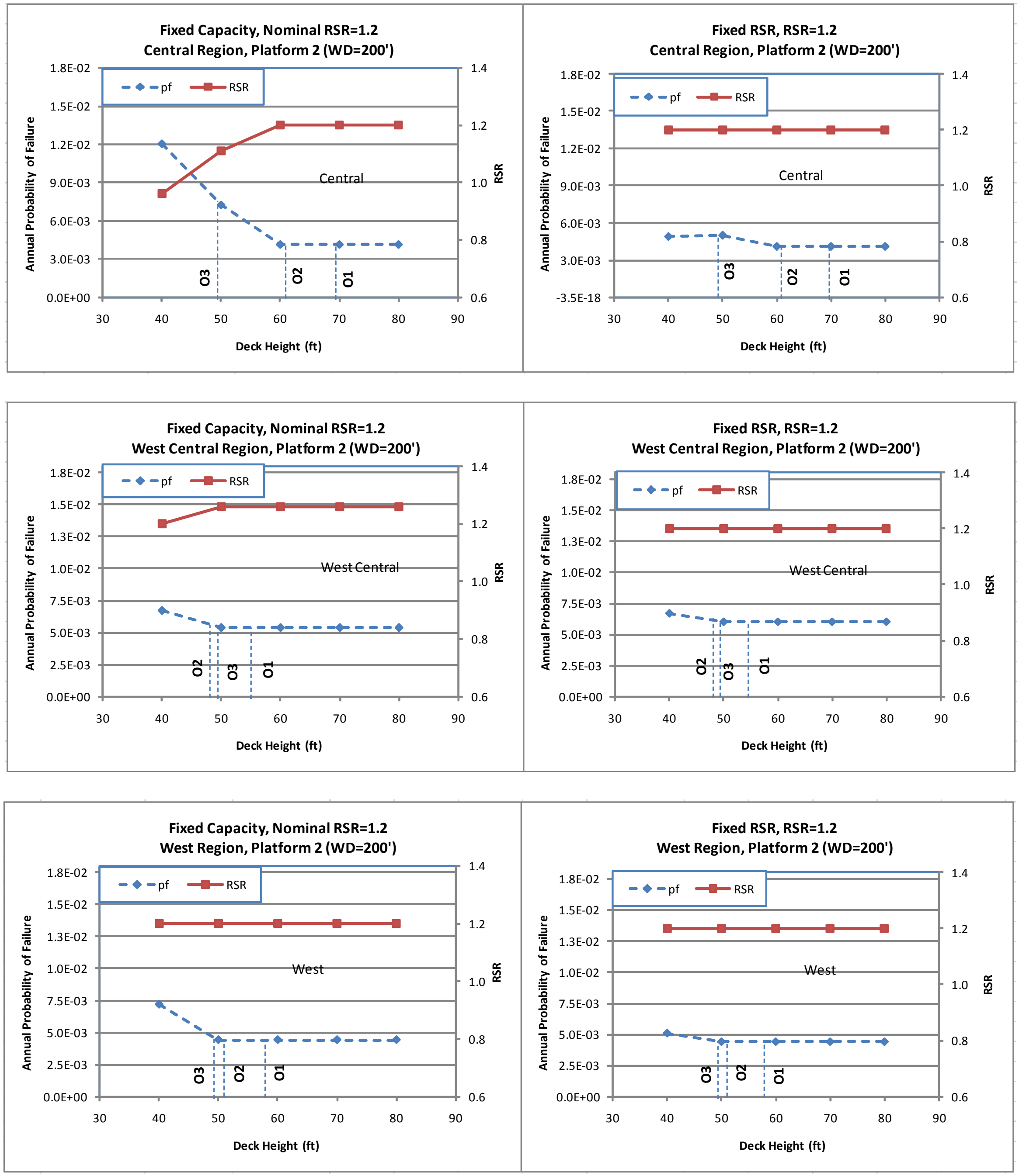
Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.3 Sensitivity of Deck Elevation, Platform 1 with RSR = 1.2



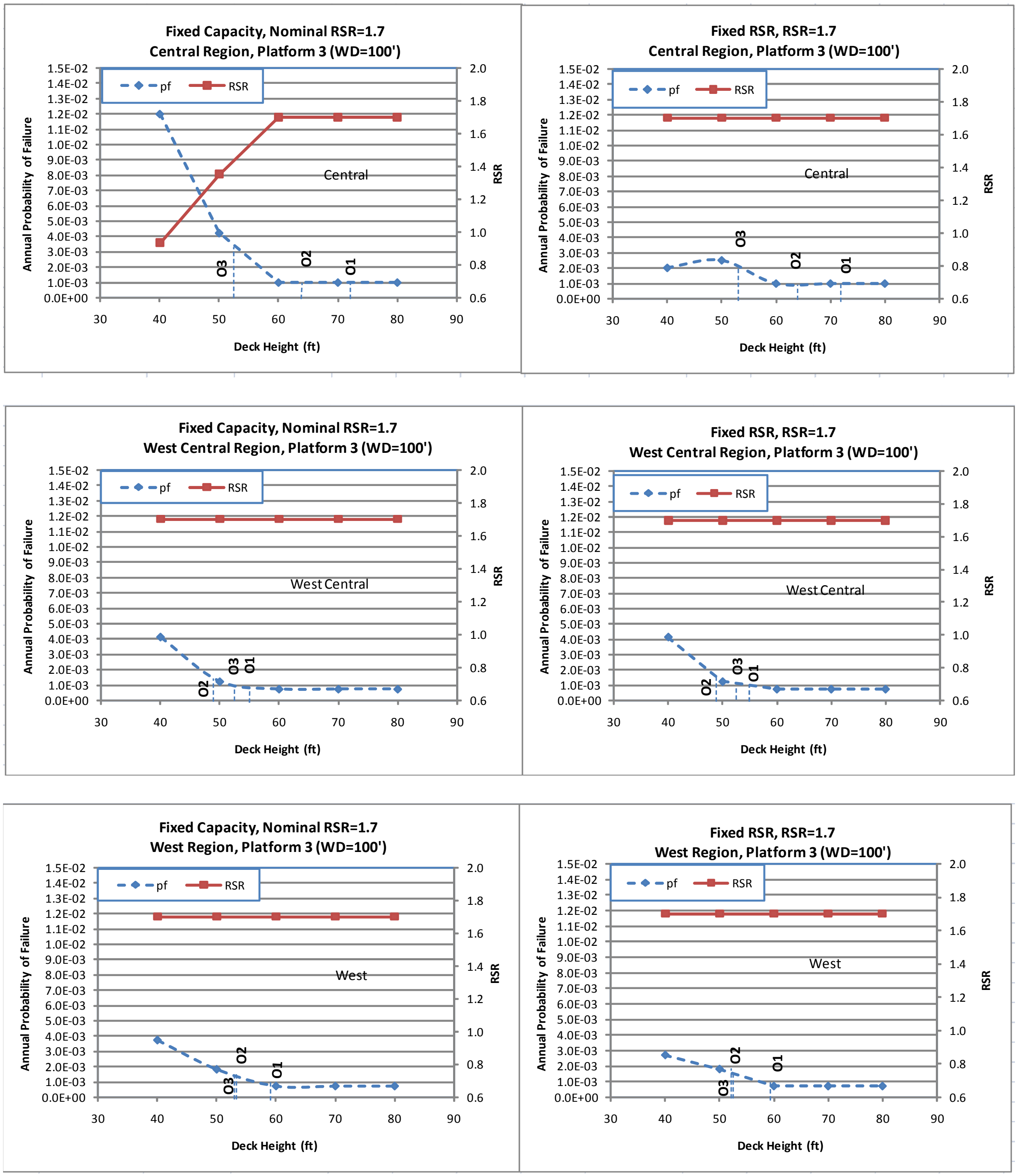
Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.4 Sensitivity of Deck Elevation, Platform 2 with RSR = 1.7



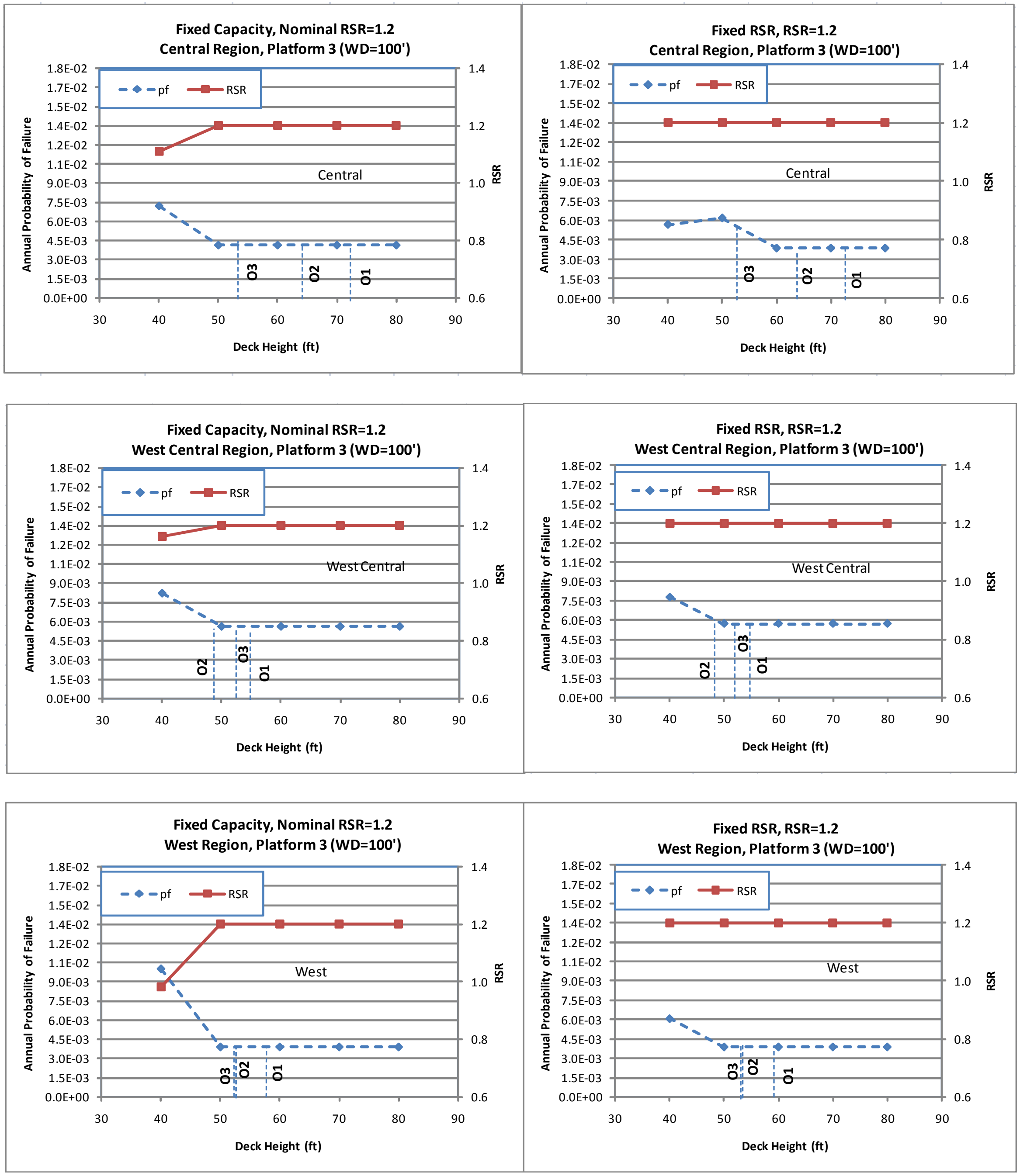
Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.5 Sensitivity of Deck Elevation, Platform 2 with RSR = 1.2



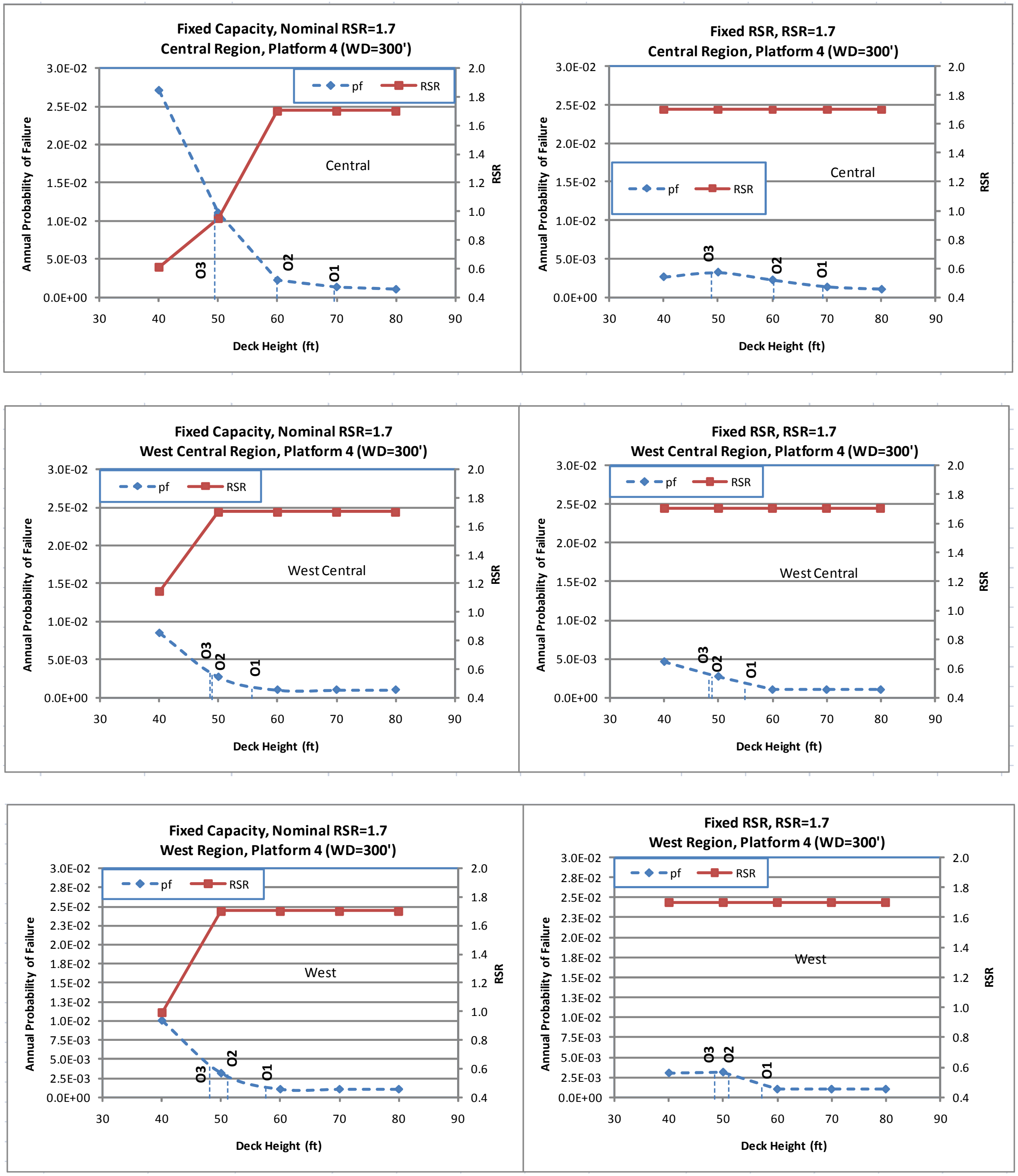
Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.6 Sensitivity of Deck Elevation, Platform 3 with RSR = 1.7



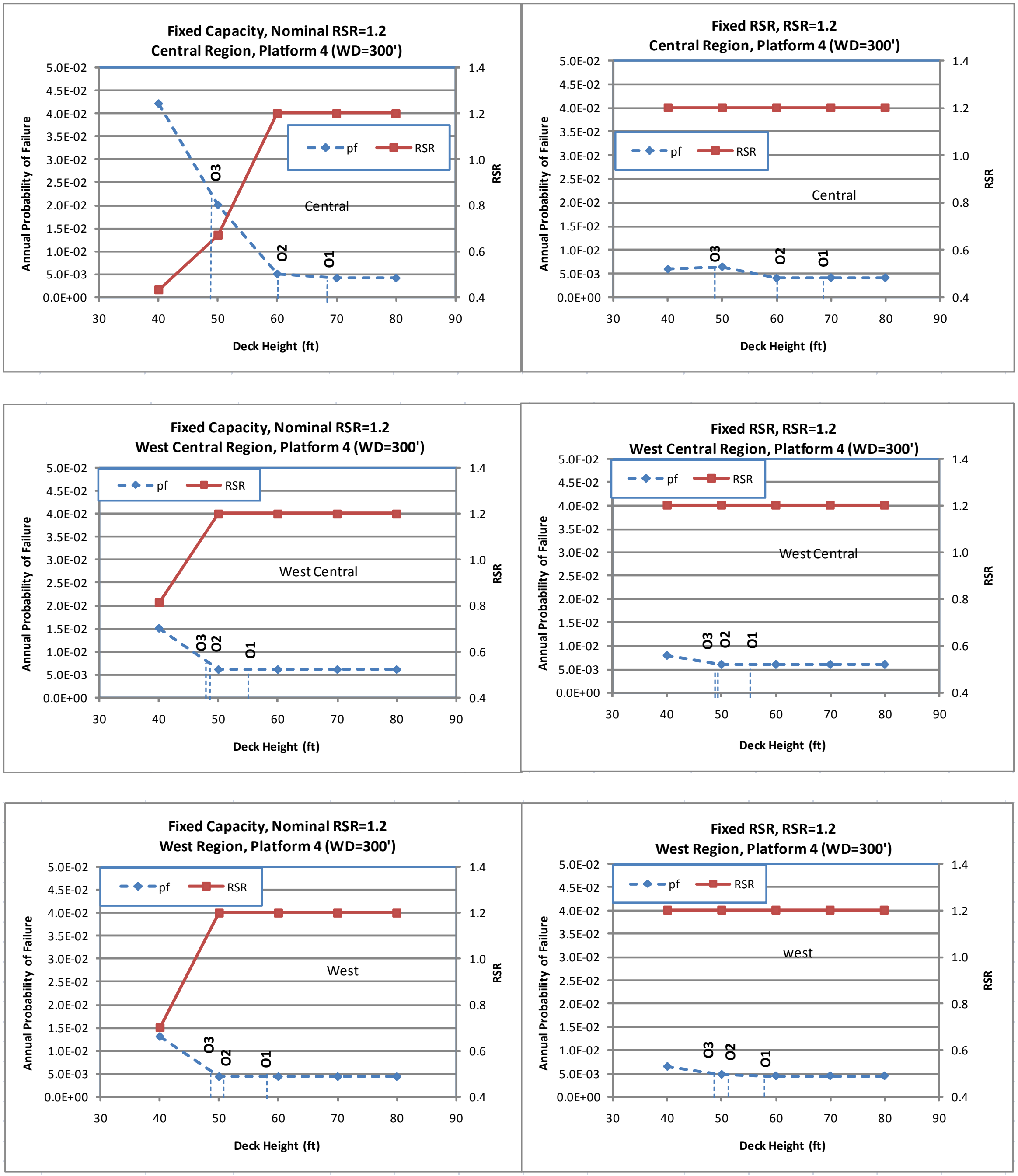
Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.7 Sensitivity of Deck Elevation, Platform 3 with RSR = 1.2



Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.8 Sensitivity of Deck Elevation, Platform 4 with RSR = 1.7



Note:
Vertical dashed lines in plots refer to the following:
O1 = 2DG Deck Height Option 1
O2 = 2DG Deck Height Option 2
O3 = RP2A Deck Height

Figure 5.9 Sensitivity of Deck Elevation, Platform 4 with RSR = 1.2

6.0 SPECIFIC GOM PLATFORMS STUDY

6.1 Background

The prior sections of this study discuss numerous cases of GOM platforms studied, some with basic characteristics such as RSR for the Generic Method and some with structural analyses taken from industry files for the Detailed Method. Ideally, additional platforms would be available for the Detailed Method so that even more configurations can be investigated. However, the Detailed Method requires considerable data for each platform. This includes platform capacity by direction as well as the platform base shear versus wave height and current, including WID effects, so that the "C" coefficients can be obtained. The C coefficients are typically not available for most platforms undergoing a Section 17 type assessment, which is the most common source of platform capacity studies.

As part of this project, nineteen platforms were obtained from MMS and industry files. Some of these platforms were used for the Detailed Method described in the previous section. The others had insufficient data to perform the necessary detailed reliability calculations. Therefore, for these platforms, only the Generic Method was used to compute pf and compare results. The work is discussed in this section.

6.2 Candidate Platforms

Table 6.1 lists the key characteristics of the nineteen candidate platforms. Figure 6.1 shows their general location in the GOM.

The platforms have been labeled R1, R2, R3, etc. (R for Reliability Study) in order to maintain confidentially about the exact location of the platform. The water depth has also been slightly modified so that the platform cannot be specifically identified. Only the general area is shown, such as WD, ST, etc. and the corresponding 2MET region. The specific platform name and block number is not provided, again to maintain confidentiality. Such information is not necessary to perform the reliability calculations. The platforms represent a range of water depths, locations, vintages, platform types and RSR.

Table 6.1 Characteristics of the Candidate Platforms

Reliability Sanitized Name	RSR	Area	2MET Region	WD (ft)	STR TYP	LONG FRAME	TRAN FRAME	DECK HT (ft)	VINTAGE	SLOTS	pf
R1	1.42	MC	West Central-Central Transition	425	8-P	/	/K	49	1970's	24	1.70E-03
R2	3.40	MP	Central	125	4-P	X	X	48	1980's	12	1.80E-18
R3	1.79	MP	Central	275	4-P-SK	XH	XH	50	1990's	24	5.00E-04
R4	1.55	MP	Central	275	OTHER	KH	/KH	50	1990's	0	1.20E-03
R5	1.31	SP	Central	525	TRI	/XH	/XH	51.9	1990's	6	2.50E-03
R6	1.05	SP	Central	275	8-P	K	K	49	1970's	40	3.40E-03
R7	1.25	SP	Central	475	4-P SK	XH	XH	Unknown	1990's	21	3.10E-03
R8	UR<1	SP	Central	450	8P-SK	/H,XH,KH	XH	Unknown	1970's	29	NA
R9	UR<1	SP	Central	450	8P-SK	/H,XH,KH	XH	Unknown	1980's	24	NA
R10	2.35	ST	West Central-Central Transition	475	4-P	XH	KH	Unknown	2000+	8	5.00E-04
R11	1.26	VK	Central	125	4-P	XH	XH	52	1990's	6	2.60E-03
R12	1.26	VK	Central	125	B-CAS	N	N	52	2000+	3	2.60E-03
R13	1.66	VK	Central	725	4-P	X	X	49	1990's	10	9.00E-04
R14	UR<1	WD	West-West Central Transition	125	4P	/H	/H	Unknown	2000+	0	NA
R15	1.53	WD	West Central-Central Transition	375	4-P-SK	XH	XH	49	1990's	0	1.20E-03
R16	1.94	WD	West Central-Central Transition	375	4-P	XH	XH	49	1990's	0	2.00E-04
R17	UR<1	WD	West Central-Central Transition	150	6-P	XH, KH	XH, KH	48	1970's	12	NA
R18	1.51	EC	West Central	200	4-P	KH	KH	40	1970's	12	1.50E-03
R19	1.42	SS	West Central	100	4-P	/H	/H	35.2	1970's	0	2.20E-03

Figure 6.1 General Location of Candidate Platforms in the GOM (Note: R8 at same location as R9)

6.3 Platform pfs

Since all that was known about the platforms was their general location and their RSR, the Generic Method was used to determine the platform pf. The same technical approach and set of variables as defined in Section 3.2 were used for the analysis.

Table 6.1 lists the resulting pf in the last column. Platforms that list a UR<1 in the RSR column were evaluated by the owner using a design level approach based upon Unity Ratios (also called Unity Checks) all being less than 1, indicating that the platform passed the assessment. In these cases a specific RSR was not available. The pf for these platforms is shown as NA=Not Applicable.

Figure 6.2 shows the resulting pfs for the candidate platforms plotted as a function of water depth. The platform ID is shown inside the circle with a green circle indicating the platform is located in the Central and a red circle indicting the platform is located in the West Central. The platforms with a yellow-shaded circle are L1 platforms; no shading indicates an A1 platform. L1 platforms are defined here as any platform installed in the 2000s since RP2A 21st edition was published in 2000. Note that some of these platforms are located in the Central to West Central Transition region. The horizontal green line shows the pf for an RSR of 1.2 in the Central and the red line shows the pf for an RSR of 1.2 in the West Central. An RSR of 1.2 is the minimum acceptable RSR per 2EX.

Also shown on Figure 6.2 is the historical $3x10^{-3}$ pf for GOM platforms as described later in Section 7. The results indicate that all but two of the platforms, R6 and R7, have a pf lower than the historical GOM pf. Table 6.1 shows that platforms R6 and R7 have the lowest RSRs of the group, resulting in low pfs. Hence the 1.2 target RSR used for 2EX is a reasonable minimum standard.

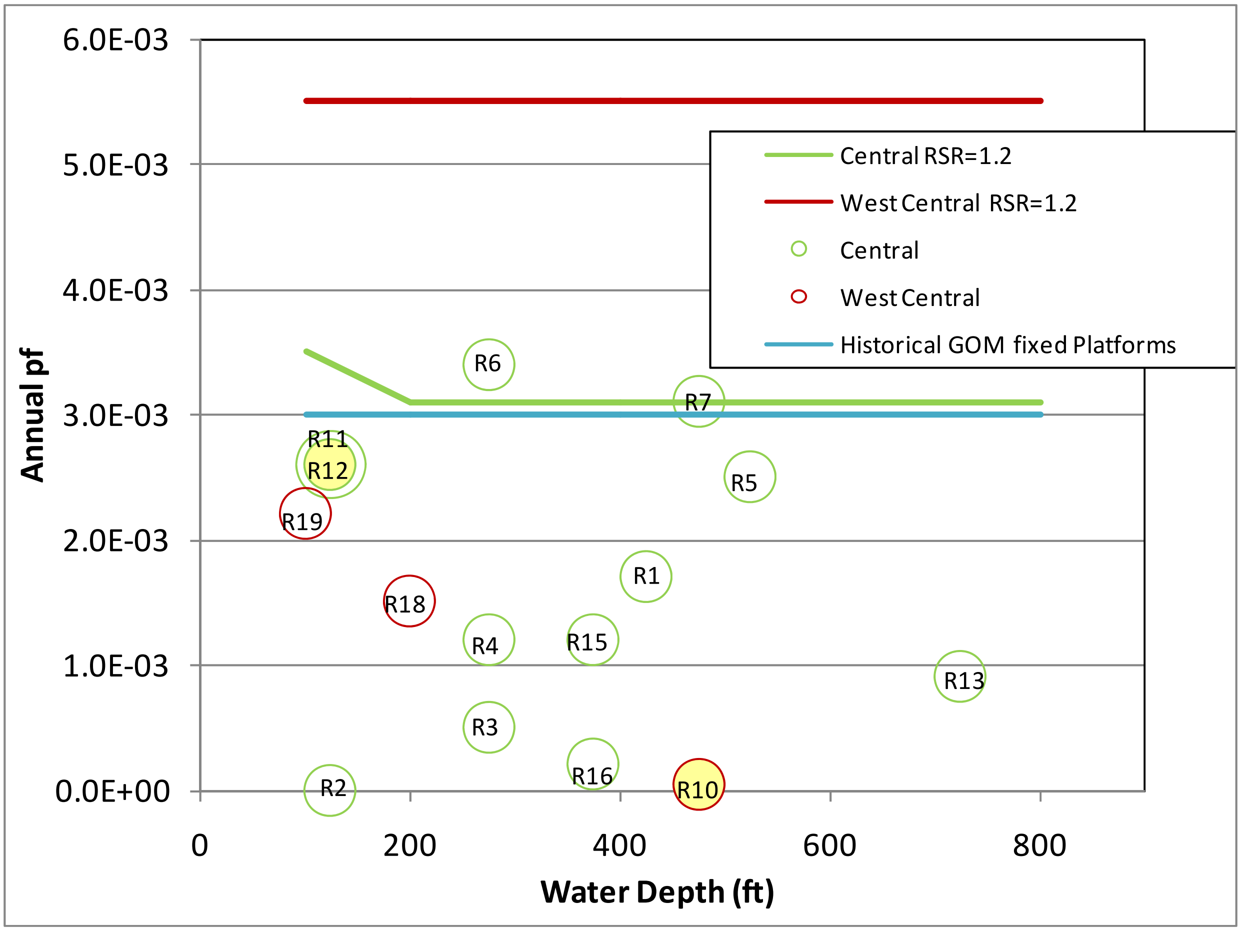


Figure 6.2 pf of Candidate Platforms as a Function of Water Depth
(Note: A yellow filled circle indicates L1 platform)

7.0 HISTORICAL RELIABILITY

7.1 Background

Hurricanes of large size that damage or destroy platforms have historically been infrequent in the Gulf of Mexico as shown in Table 7.1. The table indicates that there have been 270 reported failures of fixed platforms since the 1940's when the first platforms were installed in the Gulf [Energo, 2007]. This table represents destruction of the platform in the sense that the platform was either completely destroyed in the hurricane, such as toppled to the seafloor, or was so severely damaged that the platform could not economically be repaired and had to be decommissioned.

The first reported platform failures occurred shortly after the first platforms were installed in the Gulf of Mexico in the 1940s. Numerous platform failures occurred during some of the larger hurricanes in the 1960's such as Carla, Hilda and Camille and these hurricanes provided the lessons learned and incentives to develop API standards for platform design, namely RP2A for design of steel jacket fixed platforms that had its first edition in 1969. Many of the platforms designed prior to the first edition of RP2A suffered from lower return period design waves (e.g., 25 yr compared to modern design for 100 yr), inadequate deck elevation and lack of strengthened joints (i.e., joint cans). Table 7.1 identifies numerous platforms that were reported destroyed in some of these early hurricanes; however, it is believed that there were additional platforms destroyed but were not reported by the operator since there were minimal reporting requirements at that time.

In the past fifteen years there have been several large hurricanes that have damaged or destroyed multiple offshore platforms. Hurricane Andrew was the first in 1992 and destroyed approximately 40 fixed platforms and caissons [Puskar, et.al, 1994]. Hurricane Lili in 2002 destroyed or damaged seven platforms [ABS Consulting, 2004]. Hurricane Ivan in 2004 destroyed seven platforms [Energo, 2006]. Ivan was followed closely by Katrina and Rita in 2005, which damaged or destroyed approximately 116 fixed platforms [Energo 2007]. In 2008 Hurricane Gustav destroyed 2 platforms and Hurricane Ike destroyed 60 platforms [MMS, December 2008]. There were fortunately no life safety or significant environmental consequences due to any of these failures since the platforms were all evacuated prior to the hurricanes and the platforms contained equipment with anti-pollution devices, such as down-hole safety valves.

Table 7.1 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	40	API RP2A Section 17 for assessment of existing platforms
10	Lili	2002	7	MMS sponsored studies
11	Ivan	2004	7	API, MMS and Industry sponsored studies
12	Katrina	2005	47	API Interim Hurricane Guidelines, May 2007
13	Rita	2005	69	API Interim Hurricane Guidelines, May 2007
14	Gustav	2008	2	API 2009 RP2A Updates
15	Ike	2008	60	API 2009 RP2A Updates
Total			**270**	

* Based upon published reports at the time. Additional failures are likely to have occurred but not reported.
** Fixed platforms and caissons only. Additional platforms may have been decommissioned later as a result of the hurricanes.

Figure 7.2 shows the paths of Ivan, Katrina and Rita as they moved through over 3,400 Gulf of Mexico platforms, indicated by the small dots. Also shown in Figure 7.2 are the 2MET GOM metocean regions defined as East, Central, West Central and West. The Central has significantly higher metocean conditions than the other three regions. The figure gives an indication of the number of platforms contained within each region, with the West Central containing the largest number, followed by the Central and West. Ivan and Katrina passed through the Central which has the highest metocean criteria per 2MET. Rita primarily impacted platforms in the West Central. Rita was a lesser storm than Ivan or Katrina, but in fact destroyed more platforms. This is thought to be attributed to the fact that Rita exposed more platforms to hurricane winds and waves and the platforms exposed were generally of older vintage and more prone to destruction. However, as shown by this study, and as demonstrated in 2008 by Ike, the steeper metocean hazard curve in the West Central may also be driving the Rita and Ike destruction in this region.

The platforms destroyed by Hurricanes Katrina and Rita are shown in Figure 7.3 along with the tracks of both storms. Figure 7.4 shows the platforms that were destroyed in Gustav and Ike. Many of these platforms are in the same region as those destroyed by Rita. In fact, several of the platforms that were destroyed in Ike had been damaged and then repaired prior to Ike arriving.

Figure 7.5 shows a sonar image of a destroyed platform that was toppled by hurricane waves and was found lying on the seabed. Figure 7.6 shows a platform that was sheared off at the waterline, likely due to WID. There is little chance of repairing such a damaged platform and most platforms with this level of damage were considered destroyed.

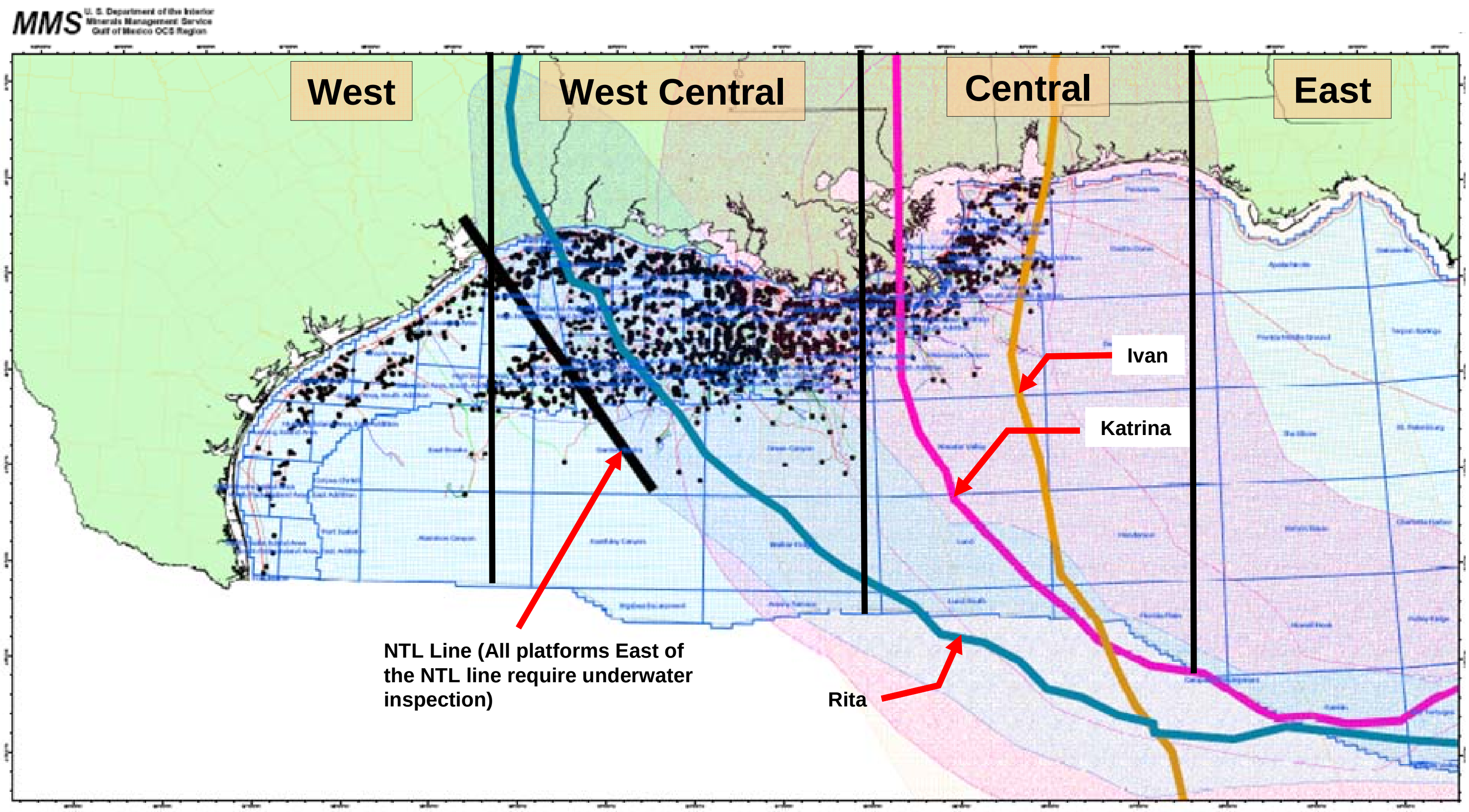


Figure 7.2 Path of Hurricanes Ivan, Katrina and Rita and the Gulf of Mexico Offshore Infrastructure [Energo 2007]
The dots indicate specific platforms. The West, West Central, Central and East Regions are per API Bulletin 2INT-MET, May, 2007. All platforms located east of the NTL had to be inspected following the hurricanes per MMS NTL 2005-G20, 2005.

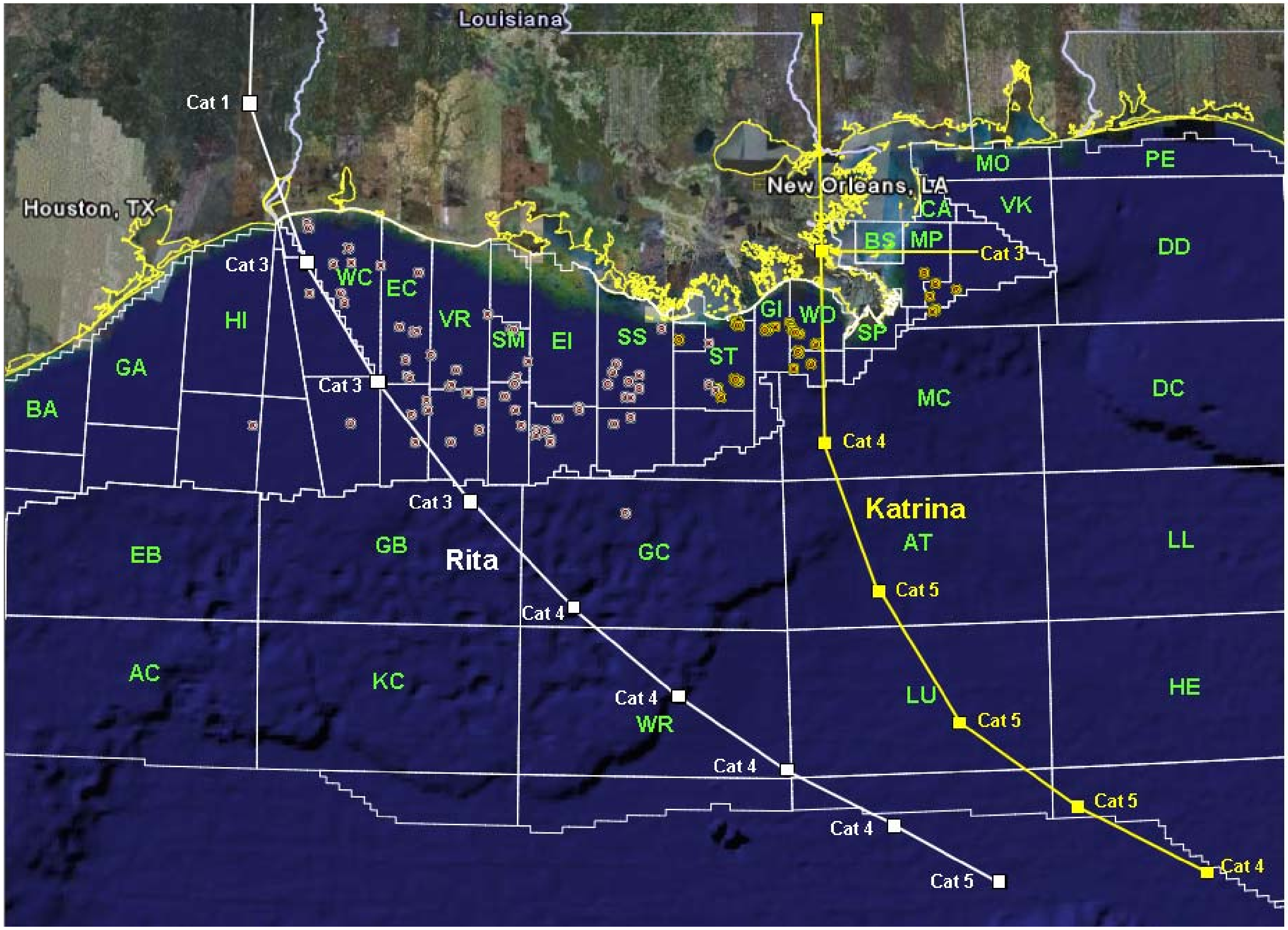


Figure 7.3 Fixed Platforms Destroyed in Hurricanes Katrina and Rita 2005
The dots indicate destroyed platforms. Yellow dots are platforms destroyed by Katrina.
The SSI Category of the hurricanes at selected locations is also shown.

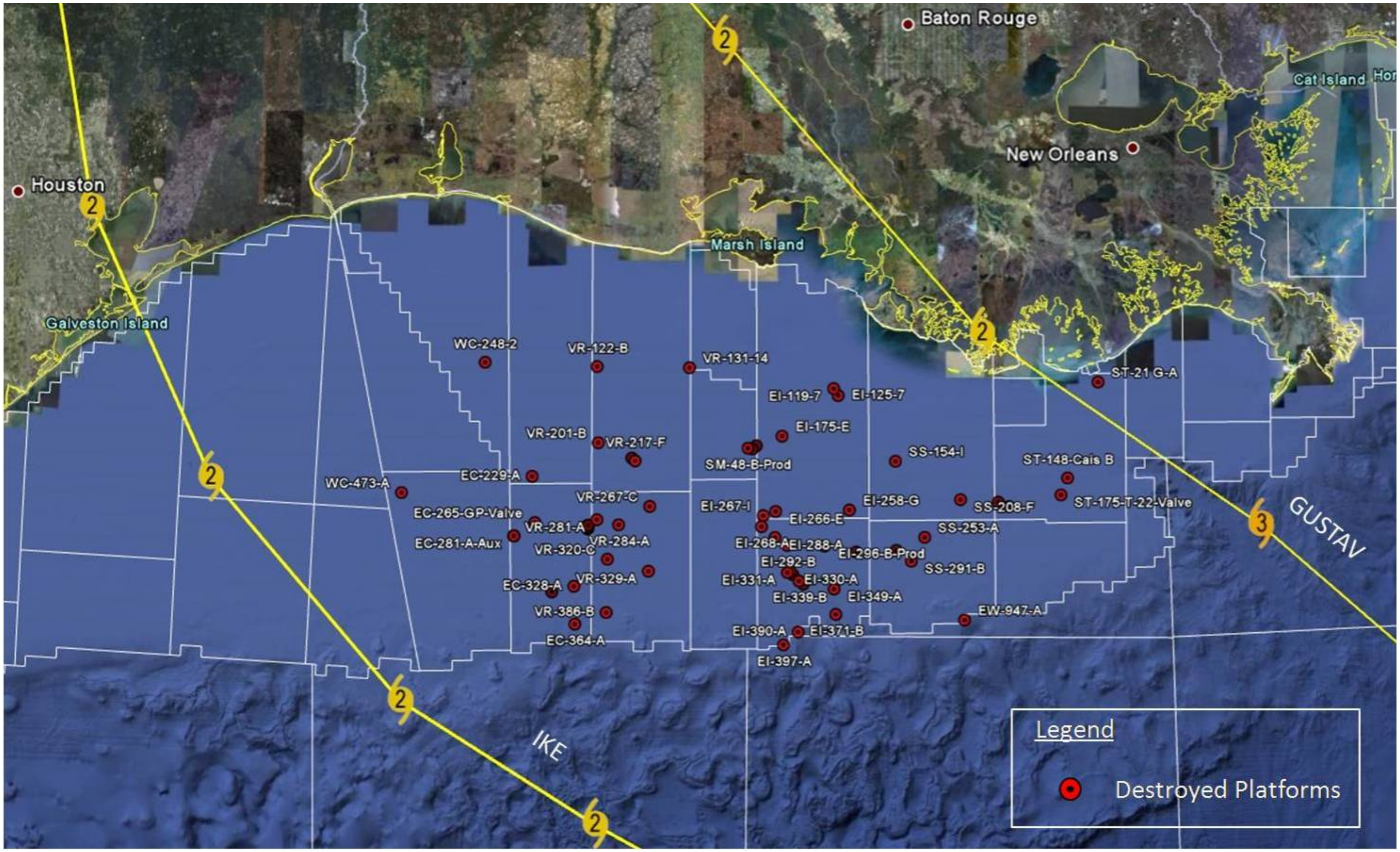


Figure 7.4 Fixed Platforms Destroyed in Hurricanes Gustav and Ike 2008

The dots indicate destroyed platforms.

The SSI Category of the hurricanes at selected locations is also shown.

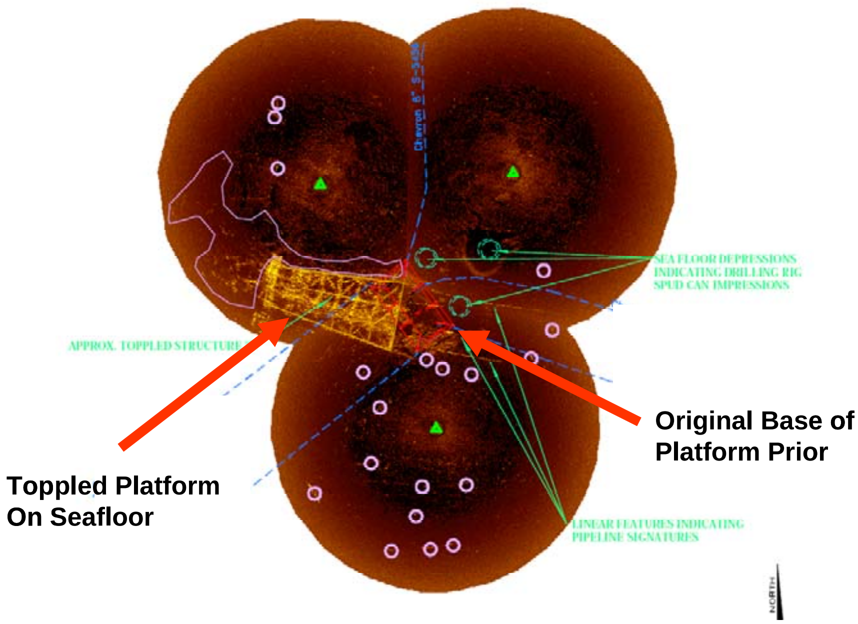


Figure 7.5 Sonar Image of Toppled Platform On-bottom [Energo 2007]

Figure 7.6 Destroyed Platform Sheared at Waterline [Energo 2007]

7.2 Historical Reliability in the GOM

The historical probability of fixed platform failures due to hurricanes, as function of annual return period, can be estimated as a function of the number of platforms destroyed to the number of platform years of exposure. Because of the lack of reliable data prior to about 1980 only the last 3 decades have been considered. Table 7.1 shows that a total of 238 fixed platforms have been destroyed since Hurricane Frederic in 1979.

The Gulf of Mexico currently has about 4,000 platforms in place. In the 1980's, there was an average of about 2,500 platforms in place [Bea, et.al, 1988]. For the purposes of this study, it is estimated that the population of platforms in the 1990s was an average of the current and 1980s populations, or approximately 3,250 platforms. The total number of platform years over about the past three decades can therefore be estimated as:

1980's: 2,500 platforms x 10 yrs = 25,000 platform years

1990's: 3,250 platforms x 10 yrs = 32,500 platform years

2000's: 4,000 platforms x 8 yrs = 32,000 platform years

Total = 89,500 platform years

Using 238 platform failures in this timeframe from hurricane Frederic on, then the historical probability of failure is computed as 238 failures / 89,500 platform years equals approximately 0.003 failures per year (3x10-3).

The estimated pf for new design platforms, which typically have an RSR of 1.7, is about 8x10-4 as shown in Figure 4.2. This is a lower pf than the historical 2x10-3. The estimated pf for existing A1 platforms (RSR=1.2) is about 3 to 5x10-3, which is close to the historical pf. A2 and A3 platforms have higher pfs. This explains why most of the observed failures in hurricanes have been platforms with lower RSRs, likely less than 1.2. Note that the 1.2 RSR is the 2EX target for existing platforms and results in a pf about the same as historical performance.

Generally, it is difficult to directly compare historical pfs, which are based upon *actual* statistics, to computed or *notional* pfs, based upon technical studies like this since there is additional uncertainty in the notional pfs due to the computational process. However, comparisons such as the above can be made to provide an approximate relationship as well as establish trends.

7.3 Reliability in Other Worldwide Regions

There have been numerous studies over the years to investigate the historical (actual) and notional (computed) pfs of offshore platforms. Table 7.2 summarizes the pfs published by several authors. The pfs range from $1x10^{-3}$ to $1x10^{-5}$ depending upon location and consequence of failure. The lower pf values of 10^{-5} as used especially in the North Sea are for platforms that are not evacuated in advance of the extreme storm event.

Some of these regions now have dual design criteria where the platform is designed to respond elastically with normal factors of safety to the 100 yr condition. The platform must also be shown to survive a large wave, for example 10,000 yr (equating roughly to a pf of 10^{-5}), although the platform may be damaged. This is a method of ensuring that the pf target is achieved.

Table 7.2 - Example Worldwide pfs for Offshore Platforms Referenced by Others

Source	Location	pf	Comment
Stiff, 2009	Gulf of Mexico	$2x10^{-4}$ to $1x10^{-3}$	MODU JIP, referenced pf range for fixed platforms
Stahl, et.al., 2000	Gulf of Mexico	$5x10^{-4}$ high consequence $2x10^{-3}$ low consequence	High and low consequence were the original Section 17 GOM platform types. There was no medium.
THIC, 1992	Offshore California	$1x10^{-3}$ seismic load	Existing platforms
Stahl, 1986	North Sea	$5x10^{-4}$	Manned during design event
ISO 19901-2, 2004	Worldwide Offshore Structures Seismic Design	$4x10^{-4}$	API will adopt this for seismic RP2EQ in 2009
ISO 19902, 2008	Worldwide Steel Offshore Structures	$1x10^{-5}$	Metocean loading. Applied mostly in North Sea at this time.

As described above, other worldwide regions have target pfs ranging from 10^{-3} to 10^{-5}. Per prior Sections 4 and 5, new design platforms in GOM with RSR=1.7 have a pf of about 10^{-4}. Most worldwide offshore areas do not evacuate the platform during the design metocean event and therefore a lower pf of 10^{-5} is targeted. Since GOM platforms are evacuated in advance of significant hurricanes and are therefore essentially unmanned platforms during the design event in order to ensure life safety, it is reasonable to have a higher targeted pf.

Other factors besides life safety should also be considered when establishing a target pf, including environmental, economic and political. For example, the recent hurricanes in the GOM since Ivan have shown that the worldwide price of oil can fluctuate based upon the perceived threat to the US oil supply due to GOM hurricanes. However, such studies that consider all these factors are beyond the scope of this project.

8.0 KEY RESULTS AND CONCLUSIONS

The key results and conclusion are summarized as follows. Additional secondary results and conclusions are discussed in the report.

1. Compared to RP2A, the 2MET criteria for all types of platforms (L1, L2, A1, A2, etc.) show an equal or lower pf across all of the 2MET regions. In other words, 2MET results in offshore platforms that have the same or slightly better reliability than RP2A.

2. For platforms with RSRs on the order of 1.7, representative of new design API L1 high consequence platforms, the pf is about the same in all four of the 2MET regions with the pfs on the order of 7×10^{-4}. A higher RSR will result in a lower pf. The 1.7 RSR is the estimated minimum RSR for a new platform designed to RP2A 21st Edition using working stress design methods. See Figure 1.1.

3. For platforms with RSRs on the order of 1.2, representative of existing high consequence A1 platforms, the pf is highest in the West Central compared to the other regions. The West Central pf is about 5 to 6×10^{-4}, and is also about the same as RP2A. The other regions have a pf of about 3 to 4×10^{-4} or a reduction of about 1.5 to 2 compared to the West Central. The 1.2 RSR is the estimated minimum RSR for A1 platforms in the GOM [Krieger, et.al., 1994]. The higher pf in the West Central is driven by the steeper slope of the Hmax curve as a function of return period compared to the other regions. The large number of destroyed platforms in the West Central in recent hurricanes is perhaps explained in-part by the higher pf in this region, although other factors such as the number of exposed platforms and the vintage of the platforms in the West Central also influence the number of destroyed platforms [Energo, 2007]. See Figure 1.2.

4. The pf decreases by an order of magnitude with an increase in RSR from 1.2 to 1.7. An RSR of 1.2 is the approximate RSR for existing high consequence A1 platforms and an RSR of 1.7 is the expected minimum RSR of new platforms designed to RP2A. Hence, new design L1 platforms are generally an order of magnitude (i.e., 10 times) more reliable than the minimum API standard for existing A1 platforms. This helps explain why there have been only a few L1 failures in recent hurricanes compared to numerous A1 platforms.

5. The "old" RP2A L1 minimum deck elevation results in a higher pf compared to the "new" 2DG recommendations (i.e., wave crest + 5ft air gap + 15% of crest height). This helps explain the large amount of WID damage observed in recent hurricanes since most of these platforms had deck elevations based upon RP2A recommendations (or less in some cases). The historical API method of establishing the deck elevation based upon the 100 yr wave crest elevation plus a 5ft air gap results in a different pf for the various

2MET regions. This is due to the different slope of the Hmax curve in each region. An alternative recommended approach is to establish the minimum deck elevation based upon a given return period, such as a 1000 yr wave. This will result in a constant probability of not having WID across all of the GOM regions. This will also ensure that if the wave heights and associated hazard slopes of the regions are revised by API in the future, then the probability of not having WID will still be the same. The specific return period needs to be developed based upon further study beyond the scope of this effort.

6. The historical pf of GOM platforms for hurricane conditions is approximately $3x10^{-3}$. Generally, it is difficult to directly compare historical pfs, which are based upon *actual* statistics, to computed or *notional* pfs, based upon technical studies like this since there is additional uncertainty in the notional pfs due to the computational process. However, comparisons can be made to provide an approximate relationship as well as establish trends. Hence a comparison of historical pf to the pfs computed in this study for 2MET is as follows:

    - The estimated pf for new design L1 high consequence platforms, which typically have a minimum RSR of 1.7, is about $7x10^{-4}$. This is an order of magnitude lower pf than historical, as should be the case for new design platforms. A new design platform with a RSR higher than 1.7, achievable with structural design features such as X-bracing and thicker member and joints, will have an even lower pf.

    - The estimated pf for existing A1 high consequence platforms, which typically have a minimum RSR of 1.2, is about 3 to $6x10^{-3}$. These pfs are about the same as or slightly higher than the historical pf. Note that the 1.2 RSR is the 2EX target for high consequence existing platforms and results in a pf about the same as historical performance.

    - The estimated pfs for existing L2, A2, L3 and A3 low and medium consequence existing platforms is in the range of 10^{-2}. This explains why many of the observed failures in recent hurricanes have been platforms with lower RSRs typical of these types of platforms. Compared to RP2A, the 2MET criteria for all types of platforms (L1, L2, A1, A2, etc) shows an equal or lower pf across all of the 2MET regions. In other words, 2MET results in offshore platforms that have the same or slightly better reliability than RP2A

7. Other worldwide regions have target pfs ranging from 10^{-3} to 10^{-5}. New design platforms in the GOM with RSR=1.7 have a pf of about 10^{-4}. Most worldwide offshore areas do not evacuate the platform during the design metocean event and therefore a lower pf of 10^{-5} is targeted. Since GOM platforms are evacuated in advance of significant hurricanes, and are therefore essentially unmanned platforms during the design event, it is reasonable to have a higher targeted pf. However, other factors such as environmental,

economic and political need to be considered to determine a target pf for the GOM. Such studies that consider all these factors are beyond the scope of this project.

9.0 REFERENCES

ABS Consulting (ABSC), *Hurricane Lili's Impact on Fixed Platforms, Final Report to MMS*, June 2004.

API-DG, 2007, *Interim Guidance for Design of Offshore Structures for Hurricane Conditions , API Bulletin 2INT-DG*, American Petroleum Institute, May 2007.

API-EX, 2007, *Interim Guidance on Assessment of Existing Offshore Structures for Hurricane Conditions, API Bulletin 2INT-EX* American Petroleum Institute, May 2007.

API-MET, 2007, *Interim Guidance on Hurricane Conditions in the Gulf of Mexico, API Bulletin 2INT-MET*, American Petroleum Institute, May 2007.

API RP 2A-WSD, *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design*, 21st edition, Supplement 2, 2005.

Bea, R.G., Puskar, F.J., Smith, C., Spencer, J., *Development of AIM (Assessment, Inspection, Maintenance) Programs for Fixed and Mobile Platforms*, Proceedings, 20th Offshore Technology Conference, OTC No. 5703, May 1988.

Cornell, C. A., *Structural Reliability – Some Contributions to Offshore Technology*, OTC 7753, May 1995.

De, R., *Risk Analysis Methodology for Developing Design and Assessment Criteria for Fixed Offshore Structures*, OTC 7755, May 1995.

Energo Engineering, *Assessment of Fixed Offshore Platform Performance in Hurricanes Andrew, Lili and Ivan*, report submitted to MMS, January 2006.

Energo Engineering, *Assessment of Fixed Offshore Platform Performance in Hurricanes Katrina and Rita*, report submitted to MMS, May 2007.

ISO 19901-2, *Seismic Design Procedures and Criteria*, International Organization for Standardization, 2004.

ISO 19902, *Fixed Steel Offshore Structures*, International Organization for Standardization, 2008.

Krieger, W., et.al., *Process for Assessment of Existing Platforms to Determine their Fitness for Purpose*, Offshore Technology Conference, OTC No. 7482, May 1994.

Ku, A., Stiff, J.J., Huang, B. and Puskar, F.J. *MODU Mooring Reliability Analysis for Hurricane Conditions in the Gulf of Mexico*, Offshore Technology Conference, OTC No. 20147, May 2009.

MMS, 2008, *MMS Completes Assessment of Destroyed and Damaged Facilities from Hurricanes Gustav and Ike*, Posted on MMS Website, December.

Petrauskas, C., et.al., *Metocean Criteria/Loads for Use in Assessment of Existing Offshore Platforms*, OTC 7484, 1994.

Puskar, F. J., Aggarwal, R. K., Cornell, C. A., Moses, F. and Petrauskas, C., *A Comparison of Analytical Predicted Platform Damage During Hurricane Andrew*, Offshore Technology Conference, OTC No. 7473, May 1994.

Stahl, B., S. Aune,, J. Gebara and C. A. Cornell, *Acceptance Criteria for Offshore Platforms*, Journal of Offshore Mechanics and Arctic Engineering, Vol. 122, August 2000, pp. 153-156.Stiff, J.J., *MODU Risk- MODU Mooring Comparative Risk Assessment*, Offshore Technology Conference, OTC No. 20143, May 2009.

THIC - Iwan, W.D., Thiel, C.C, Housner, G.W., Cornell, C. A., *Seismic Safety Requalification of Offshore Platforms*, Prepared for API, May 1992.

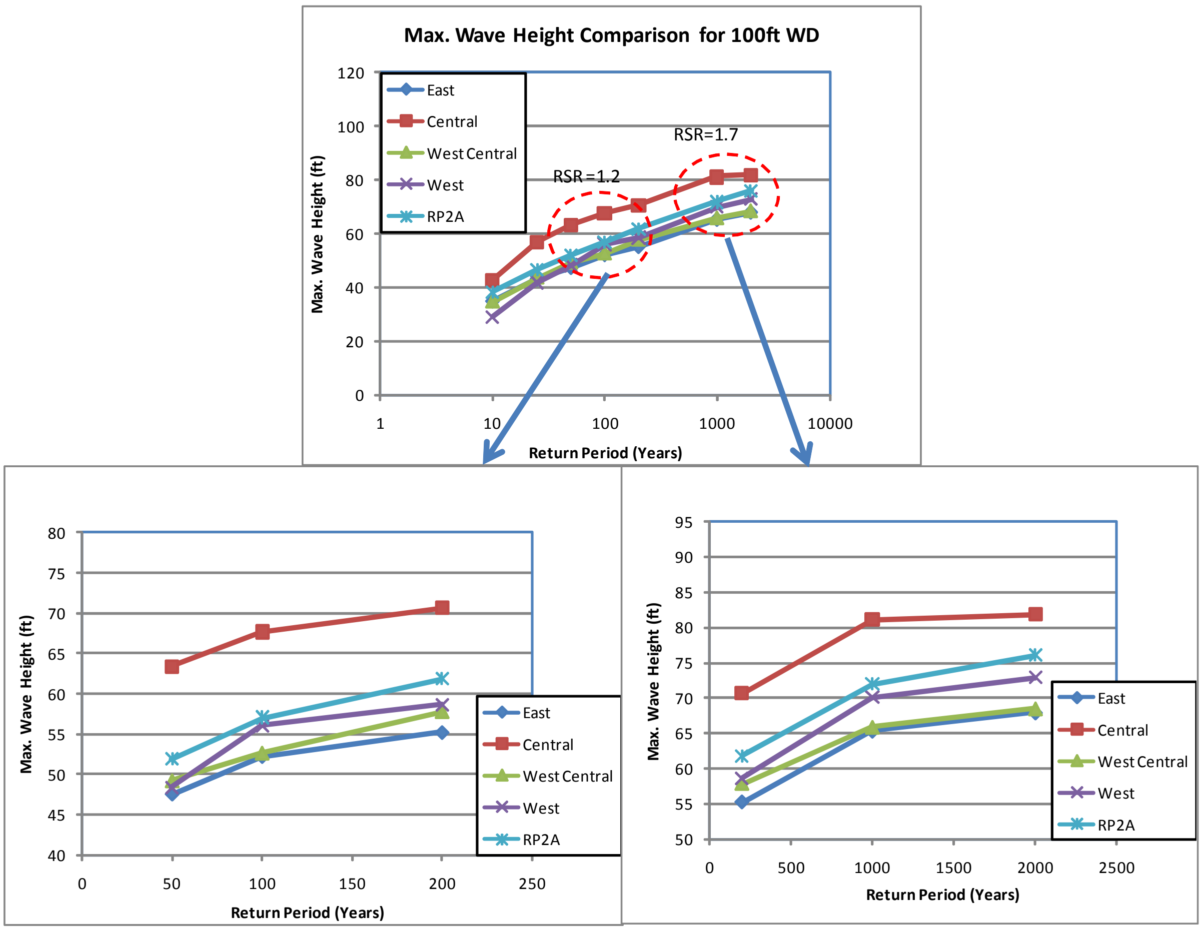
Appendix A – Additional Metocean Data

This Appendix contains the detailed 2MET and RP2A plots that show more clearly the slope of the GOM wave height hazard curves for RSRs of 1.2 and 1.7 as described in Section 3. Waves control the design of fixed platforms and are of the most interest for this study.

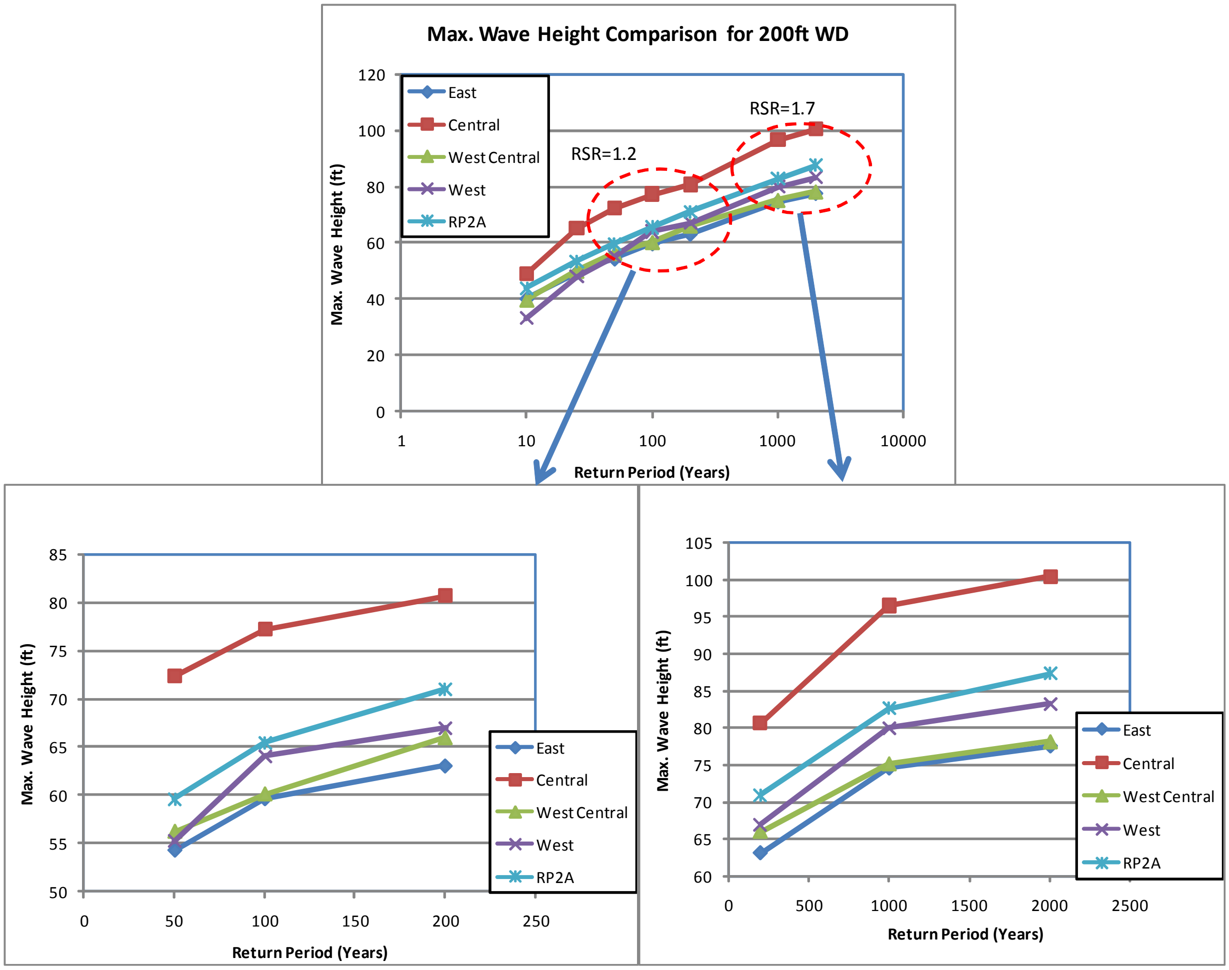
The plots are as follows:

- 100ft water depth
- 200ft water depth
- 400ft water depth
- 800ft water depth

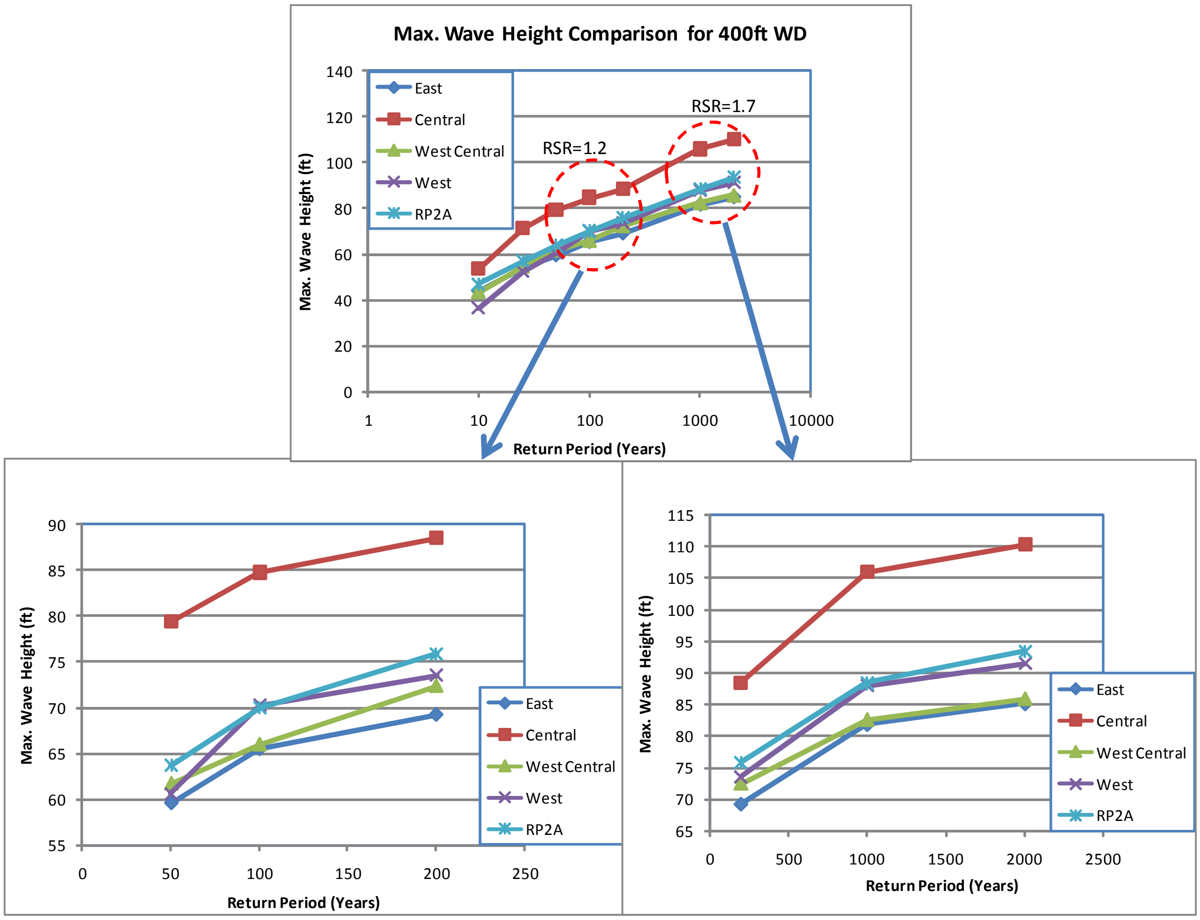
GOM 100ft Water Depth



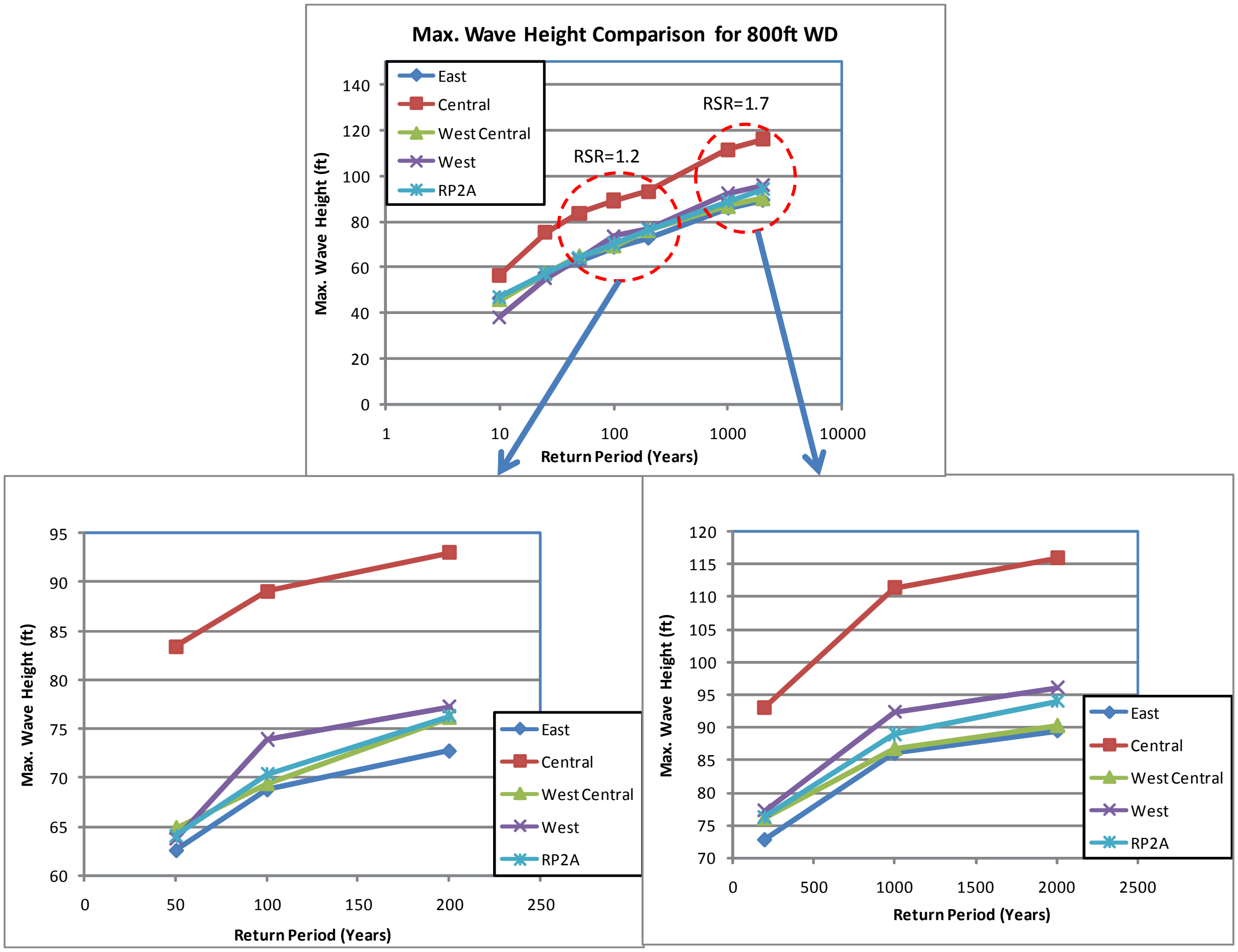
GOM 200ft Water Depth



GOM 400ft Water Depth



GOM 800ft Water Depth



APPENDIX B – TABULAR RELIABILITY RESULTS

Tables are provided with the numerical values of the reliability calculations in Section 4. The results are cross referenced to the corresponding figure in the report.

B1. L1 and A1 Platforms (RSR Applied)

Table for Figure 4.2a

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.7

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	7.3E-04	7.3E-04	7.3E-04	7.3E-04
2-MET West Central	7.3E-04	7.3E-04	7.3E-04	7.3E-04
2-MET Central	8.5E-04	7.3E-04	7.3E-04	7.3E-04
2-MET East	7.3E-04	7.3E-04	7.3E-04	7.3E-04
RP2A L1	8.2E-04	8.2E-04	8.3E-04	8.2E-04
RP2A A1	8.4E-04	8.4E-04	8.4E-04	

Table for Figure 4.2b

Equivalent Design Return Period (Years) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.7

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	2,110	2,110	2,110	2,110
2-MET L1 West Central	2,110	2,110	2,110	2,110
2-MET L1 Central	1,180	2,110	2,110	2,110
2-MET L1 East	2,110	2,110	2,110	2,110
RP2A L1	1,496	1,496	1,489	1,496
RP2A A1	1,496	1,496	1,496	

Table for Figure 4.3a

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.2

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	3.2E-03	3.2E-03	3.2E-03	3.2E-03
2-MET West Central	5.5E-03	5.5E-03	5.5E-03	5.5E-03
2-MET Central	3.5E-03	3.1E-03	3.1E-03	3.1E-03
2-MET East	3.9E-03	3.9E-03	3.9E-03	3.9E-03
RP2A L1	5.1E-03	5.1E-03	4.6E-03	5.1E-03
RP2A A1	5.1E-03	5.1E-03	5.1E-03	

Table for Figure 4.3b

Equivalent Design Return Period (Years) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.2

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	435	435	435	435
2-MET L1 West Central	197	197	197	197
2-MET L1 Central	340	459	459	459
2-MET L1 East	320	320	320	320
RP2A L1	220	220	253	220
RP2A A1	220	220	220	

Table for Figure 4.4 RSR = 2.0

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 2.0

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	1.9E-04	1.9E-04	1.9E-04	1.9E-04
2-MET West Central	1.9E-04	1.9E-04	1.9E-04	1.9E-04
2-MET Central	4.5E-06	1.4E-04	1.4E-04	1.4E-04
2-MET East	1.9E-04	1.9E-04	1.9E-04	1.9E-04
RP2A L1	2.8E-04	2.8E-04	2.8E-04	2.8E-04
RP2A A1	2.8E-04	2.8E-04	2.8E-04	

Table for Figure 4.4 RSR =2.0

Equivalent Design Return Period (Years) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 2.0

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	6,814	6,814	6,814	6,814
2-MET L1 West Central	6,814	6,814	6,814	6,814
2-MET L1 Central	220,000	12,620	12,620	12,620
2-MET L1 East	6,814	6,814	6,814	6,814
RP2A L1	4,599	4,599	4,606	4,600
RP2A A1	4,599	4,599	4,599	

Table for Figure 4.4 RSR = 1.7

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.7

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	7.3E-04	7.3E-04	7.3E-04	7.3E-04
2-MET West Central	7.3E-04	7.3E-04	7.3E-04	7.3E-04
2-MET Central	8.5E-04	7.3E-04	7.3E-04	7.3E-04
2-MET East	7.3E-04	7.3E-04	7.3E-04	7.3E-04
RP2A L1	8.2E-04	8.2E-04	8.3E-04	8.2E-04
RP2A A1	8.4E-04	8.4E-04	8.4E-04	

Table for Figure 4.4 RSR=1.7

Equivalent Design Return Period (Years) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.7

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	2,110	2,110	2,110	2,110
2-MET L1 West Central	2,110	2,110	2,110	2,110
2-MET L1 Central	1,180	2,110	2,110	2,110
2-MET L1 East	2,110	2,110	2,110	2,110
RP2A L1	1,496	1,496	1,489	1,496
RP2A A1	1,496	1,496	1,496	

Table for Figure 4.4 RSR = 1.2

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.2

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	3.2E-03	3.2E-03	3.2E-03	3.2E-03
2-MET West Central	5.5E-03	5.5E-03	5.5E-03	5.5E-03
2-MET Central	3.5E-03	3.1E-03	3.1E-03	3.1E-03
2-MET East	3.9E-03	3.9E-03	3.9E-03	3.9E-03
RP2A L1	5.1E-03	5.1E-03	4.6E-03	5.1E-03
RP2A A1	5.1E-03	5.1E-03	5.1E-03	

Table for Figure 4.4 RSR=1.2

Equivalent Design Return Period (Years) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.2

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	435	435	435	435
2-MET L1 West Central	197	197	197	197
2-MET L1 Central	340	459	459	459
2-MET L1 East	320	320	320	320
RP2A L1	220	220	253	220
RP2A A1	220	220	220	

Table for Figure 4.5 RSR =1.0

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.0

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	1.0E-02	1.0E-02	1.0E-02	1.0E-02
2-MET West Central	1.2E-02	1.2E-02	1.2E-02	1.2E-02
2-MET Central	1.2E-02	1.2E-02	1.2E-02	1.2E-02
2-MET East	1.1E-02	1.1E-02	1.1E-02	1.1E-02
RP2A L1	1.1E-02	1.1E-02	1.1E-02	1.1E-02
RP2A A1	1.1E-02	1.1E-02	1.1E-02	

Table for Figure 4.5 RSR=1.0

Equivalent Design Return Period (Years) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 1.0

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	100	100	100	100
2-MET L1 West Central	100	100	100	100
2-MET L1 Central	100	100	100	100
2-MET L1 East	100	100	100	100
RP2A L1	100	100	100	100
RP2A A1	100	100	100	

Table for Figure 4.5 RSR=0.8

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 0.8

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	1.7E-02	1.7E-02	1.7E-02	1.7E-02
2-MET West Central	2.7E-02	2.7E-02	2.7E-02	2.7E-02
2-MET Central	3.3E-02	2.9E-02	2.9E-02	2.9E-02
2-MET East	2.5E-02	2.5E-02	2.5E-02	2.5E-02
RP2A L1	2.4E-02	2.4E-02	2.4E-02	2.4E-02
RP2A A1	2.4E-02	2.4E-02	2.4E-02	

Table for Figure 4.5 RSR =0.8

Equivalent Design Return Period (yrs) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 0.8

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	60	60	60	60
2-MET L1 West Central	38	38	38	38
2-MET L1 Central	31	37	37	37
2-MET L1 East	44	44	44	44
RP2A L1	45	45	45	45
RP2A A1	45	45	45	

Table for Figure 4.5 RSR=0.6

Notional Annual pf for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 0.6

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET West	3.7E-02	3.7E-02	3.7E-02	3.7E-02
2-MET West Central	5.5E-02	5.5E-02	5.5E-02	5.5E-02
2-MET Central	5.4E-02	5.4E-02	5.4E-02	5.4E-02
2-MET East	5.6E-02	5.6E-02	5.6E-02	5.6E-02
RP2A L1	5.3E-02	5.3E-02	5.4E-02	5.3E-02
RP2A A1	5.3E-02	5.3E-02	5.3E-02	5.3E-02

Table for Figure 4.5 RSR =0.6

Equivalent Design Return Period (years) for API 2-MET L1 and RP2A L1 and A1 Platforms with RSR = 0.6

	100ft WD	200ft WD	400ft WD	800ft WD
2-MET L1 West	27	27	27	27
2-MET L1 West Central	18	18	18	18
2-MET L1 Central	18	18	18	18
2-MET L1 East	18	18	18	18
RP2A L1	19	19	19	19
RP2A A1	19	19	19	19

B2. L2 and A2 Platforms (Load Factor)

Table for Figure 4.6 Load Factor (LF) = 2.0

Notional Annual pf for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 2.0

	100ft	200ft	400ft
2-MET L2 West	1.4E-03	1.4E-03	1.4E-03
2-MET L2 West Central	5.6E-04	5.6E-04	5.6E-04
2-MET L2 Central	3.4E-04	6.0E-04	6.0E-04
2-MET L2 East	9.2E-04	9.2E-04	9.2E-04
RP2A L2	9.1E-04	9.1E-04	9.1E-04
RP 2A A2	9.1E-04	9.1E-04	9.1E-04

Table for Figure 4.6 Load Factor = 2.0

Equivalent Design Return Period for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 2.0

	100ft	200ft	400ft
2-MET L2 West	7.9E+02	7.9E+02	7.9E+02
2-MET L2 West Central	2.7E+03	2.7E+03	2.4E+03
2-MET L2 Central	2.1E+08	3.0E+03	3.0E+03
2-MET L2 East	1.7E+03	1.7E+03	1.7E+03
RP2A L2	1.3E+03	1.3E+03	1.3E+03
RP 2A A2	1.3E+03	1.3E+03	1.3E+03

Table for Figure 4.6 Load Factor = 1.7

Notional Annual pf for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 1.7

	100ft	200ft	400ft
2-MET L2 West	2.9E-03	2.9E-03	2.9E-03
2-MET L2 West Central	1.7E-03	1.7E-03	1.7E-03
2-MET L2 Central	2.0E-04	1.4E-03	1.4E-03
2-MET L2 East	1.9E-03	1.9E-03	1.9E-03
RP2A L2	2.2E-03	2.2E-03	2.5E-03
RP 2A A2	2.2E-03	2.2E-03	2.2E-03

Table for Figure 4.6 Load Factor = 1.7

Equivalent Design Return Period for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 1.7

	100ft	200ft	400ft
2-MET L2 West	374	374	374
2-MET L2 West Central	719	719	719
2-MET L2 Central	5,430	801	801
2-MET L2 East	588	588	588
RP2A L2	507	507	507
RP 2A A2	507	507	507

Table for Figure 4.6 Load Factor = 1.2

Notional Annual pf for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 1.2

	100ft	200ft	400ft
2-MET L2 West	1.3E-02	1.3E-02	1.3E-02
2-MET L2 West Central	8.6E-03	9.2E-03	8.6E-03
2-MET L2 Central	9.5E-03	9.5E-03	9.5E-03
2-MET L2 East	1.1E-02	1.1E-02	1.1E-02
RP2A L2	1.1E-02	1.1E-02	1.1E-02
RP2A A2	1.1E-02	1.1E-02	1.1E-02

Table for Figure 4.6 Load Factor = 1.2

Equivalent Design Return Period for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 1.2

	100ft	200ft	400ft
2-MET L2 West	76	76	76
2-MET L2 West Central	130	130	130
2-MET L2 Central	149	149	149
2-MET L2 East	97	97	97
RP2A L2	98	98	98
RP2A A2	98	98	98

Table for Figure 4.6 Load Factor = 1.0

Notional Annual pf for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 1.0

	100ft	200ft	400ft
2-MET L2 West	2.1E-02	2.1E-02	2.1E-02
2-MET L2 West Central	2.1E-02	2.1E-02	2.1E-02
2-MET L2 Central	2.1E-02	2.1E-02	2.1E-02
2-MET L2 East	2.1E-02	2.1E-02	2.1E-02
RP2A L2	2.1E-02	2.1E-02	2.1E-02
RP2A A2	2.1E-02	2.1E-02	2.1E-02

Table for Figure 4.6 Load Factor=1.0

Table: Equivalent Design Return for API 2-MET L2 and RP2A L2 and A2 Platforms with LF = 1.0

	100ft	200ft	400ft
2-MET L2 West	50	50	50
2-MET L2 West Central	50	50	50
2-MET L2 Central	50	50	50
2-MET L2 East	50	50	50
RP2A L2	50	50	50
RP2A A2	50	50	50

B3. L3 and A3 Platforms WD=100ft (Load Factor Applied)

Table for Figures 4.7 and 4.8 Notional Annual pf

Notional Annual pf for API 2-MET L3 and RP2A L3 and A3 Platforms

LF	API 2-MET L3				API RP2A	
	West	West Central	Central	East	L3	A3
1.7	1.1E-02	6.0E-03	3.0E-03	5.0E-03	1.5E-02	1.5E-02
1.2	2.7E-02	2.5E-02	2.3E-02	2.2E-02	4.6E-02	4.7E-02
1.0	4.0E-02	4.1E-02	4.1E-02	4.1E-02	7.1E-02	7.2E-02
0.8	5.5E-02	6.6E-02	6.0E-02	6.9E-02	1.2E-01	1.2E-01
0.6	7.8E-02	1.1E-01	9.3E-02	1.2E-01	2.0E-01	2.0E-01

Table for Figures 4.7 and 4.8 Equivalent Design Return Period

Equivalent Design Return Period for API 2-MET L3 and RP2A L23and A3 Platforms

LF	API 2-MET L3				API RP2A	
	West	West Central	Central	East	L3	A3
1.7	88	178	475	262	70	70
1.2	38	42	44	48	23	22
1.0	25	25	25	25	15	15
0.8	18	15	17	14	9	9
0.6	12	9	10	8	5	5