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PERFORMANCE OF STEEL JACKET PLATFORMS IN RECENT GULF OF MEXICO HURRICANES

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ABSTRACT

In the past few years there have been several large hurricanes in the Gulf of Mexico that have destroyed or damaged over 200 fixed offshore platforms. These include hurricanes Ivan (2004), Katrina (2005) and Rita (2005). Prior to these, the most recent hurricane to cause this level of damage was hurricane Andrew in 1992. Below water damage consisted of separated underwater braces, buckled braces, broken legs, and cracked connections. Above water damage consisted of wind and wave damage to decks and topsides equipment. Interestingly there has been little if any pile damage in any of these hurricanes. Although some newer platforms suffered damage and even destruction, most of the destroyed and damaged platforms were of older vintage and designed to American Petroleum Institute (API) Recommended Practice 2A-WSD (RP2A) practices that have since been improved. This paper summarizes the types of damage and destruction that has been found, including likely causes. It describes how some of this damage correlates to API design procedures. The work is based upon a series of projects funded by the Minerals Management Service (MMS) to study the effects of hurricanes on these types of offshore facilities.

INTRODUCTION

Hurricanes of large size have historically been infrequent in the Gulf of Mexico. However, between August 2004 and September 2005, the USA's largest asset of offshore oil and gas leases, was hit hard with Hurricanes Ivan, Katrina and Rita. The MMS estimated approximately 3,000 of the 4,000 platforms on the OCS of the GOM were in the direct path of these storms. The path of these three storms is shown in Figure 1. The extent of hurricane-force winds and waves impacted a vast amount of offshore infrastructure and the amount of damage was substantial. Nevertheless, there was no loss of life or significant pollution offshore attributed to the hurricanes.

These types of incidents provide the best guidance on the applicability of design codes. Hurricanes or storms that result in no damage, only validate design standards up to level of loading imposed by the event, with the loading perhaps not as high as the design standard loads. Events that cause structural damage and failures – like these hurricanes – are the real tests to determine if design codes are adequate. Was it that the event loads were larger than the design standard and hence the damage was expected, or was the load lower than the design standard and the damage was unexpected?

As a result of these storms, the industry and the MMS responded with several studies and committees to investigate the impact of the storms. The major industry effort was driven by the API HEAT (Hurricane Evaluation and Assessment Team) initiative. This effort involved several work groups associated with metocean studies, data gathering, structural evaluation, topsides evaluation and public communication of results. The MMS effort includes several special studies including the performance of fixed base steel jacket platforms. Some of the MMS work, which was also closely coordinated with the HEAT effort, is described here [Energo, 2007]. A companion OTC paper provides additional results [Puskar, 2007].

FIXED PLATFORM DATASET

Shortly following Hurricane Rita, the MMS issued a "NTL" or Notice to Leases [MMS, 2005] that required API RP2A Level I and II above water and underwater inspections respectively [API, 2000] of all platforms to the east of approximately the Texas – Louisiana border. The NTL line is shown in Figure 1. This area encompassed approximately 3,000 of the Gulf's 4,000 offshore platforms, including all platforms in offshore Louisiana (not including platforms in state waters). The API Level II inspection consists primarily of a visual swim-by of the platform by diver or ROV (Remotely Operated Vehicle) looking for underwater damage. If any underwater damage was located, or if there were indications of wave loading on the topsides, then additional API Level III "Close Visual Inspections" were required. Platforms owners then reported the progress or results of the inspections to the MMS on a regular basis.

In order to manage the results of this data, the MMS established an internal database that summarized the results of the post-hurricane inspection data. In order to further organize the data, and with the objective of further understanding of how and why the damage (or lack of damage) occurred, the *post-hurricane inspection data* was combined with the known *platform configuration data* available in the MMS files, such as water depth, year installed, number of legs, cellar deck elevation, etc. This data had previously been collected from most Gulf of Mexico platform owners via an NTL in 2003 [MMS, 2003] associated with assessment of platforms according to RP2A Section 17 (Section 17).

The combination of the *post-hurricane inspection data* and the *platform configuration data* provides a powerful set of information to understand how platforms performed in the hurricanes. Energo was contracted by the MMS to evaluate this data as well as to provide interface with the API HEAT effort. The data was further organized and several general trends were developed as discussed later. In addition to the general trends, an in-depth evaluation was made of the submitted inspection reports and in some cases associated detailed engineering reports. These included the typical types of damage found and possible causes.

The platforms were divided into categories for destroyed and major damage as a function of decade installed as shown in Figure 2. There are a total of 123 destroyed fixed platforms and approximately 200 damaged platforms. The destroyed platforms have been previously identified by the MMS [MMS, 2006].

Major damage was defined as significant damage either below or above water, or both. Damage below water included separated or torn members, cracked members, members with numerous holes, dents or a combination of these, cracked welds, missing members or buckled members. Similar damage to the jacket legs was also considered major. Damage above water included bent deck beams or any other form of significant damage to primary structural members. Similar to the destroyed platforms, there may also be an increase in the number of platforms with major damage as additional inspection information becomes available or is clarified. However, it is felt that at this time, well over one year since the hurricanes, that most of the significant damage has been located and that the number of platforms with major damage will not increase greatly. A significant number of platforms also sustained minor damage but the dataset did not provide an accurate count of these.

INFLUENCE OF PLATFORM VINTAGE

Figure 2 shows that the largest concentration of destroyed and damaged platforms were installed in the 1960's and 1970's. This matches well with previous findings of destroyed and damaged platforms from pervious Gulf of Mexico hurricanes [Puskar, et.al 1994; Puskar, et.al, 2004; Puskar, et.al. 2006]. The 1960's vintage platforms were designed and installed prior to any industry design standard. These platforms generally had low deck elevations, lacked strengthened connections (joint cans) and in some cases were designed to only a 25 year return period wave. As the industry gained design experience, the first edition of RP2A was developed and published in 1969. This provided an improvement in design as well as fabrication standards. However several key ingredients were still missing, including guidance on minimum deck elevation, a consistent design recipe to determine wave loads, the lack of specific 100 yr design wave heights and limited guidance on design of joints, member slenderness and other platform details. It is therefore no surprise that numerous 1970 vintage platforms were also destroyed and damaged.

Detailed review of some of the 1970's vintage platform damage indicates that it occurred in some of the key joints. Had these joints had even a slightly thicker wall thickness, as called for in the present RP2A, several of these platforms would have escaped these hurricanes with little or no damage. Figures 3 and 4 show examples of damage to an X joint and a T joint of 1970 vintage platforms that had insufficient joint wall thickness and the joints failed. These joints were repaired and the platforms returned to service.

Figure 2 shows that 35 platforms were destroyed and 72 platforms were damaged among those that were installed post 1980. This represents a vintage of platforms designed to the post-9th edition of RP2A, considered to be the time at which the RP2A platform design recipe had developed into a consistent and accurate approach. A key addition of the 9th edition was the inclusion of a specific wave load recipe including 100 year wave height criteria as a function of water depth. This allowed for a consistent design of all platforms to the same hurricane design loads. However, the reduction in the number of damaged and destroyed platforms post-1980 is not as large as seen in prior hurricanes. This is perhaps because of the magnitude and path of these recent hurricanes. Ivan and Katrina were exceptionally large storms with very large waves, and numerous platforms experienced loading larger than they were designed for, including wave-in-deck loading which is known to be detrimental to platforms. Rita, while not as large as Ivan and Katrina, went through some of the more western parts of the Gulf of Mexico that had not experienced a hurricane of significant size in decades. It may have been the first time that some of these platforms experienced significant metocean loading. These issues and others are still under study by API HEAT.

INFLUENCE OF PLATFORM CATEGORY

Figure 5 shows the 1980's and 1990's destroyed platforms as a function of their RP2A Section 17 assessment categories. There were only two A-1 high consequence platforms destroyed. The remainder are A-2 medium or A-3 low consequence platforms. Note that from 2000 onward, the platforms are classified per RP2A 21st edition Section 2 consequence criteria of L-1 high consequence, L-2 medium consequence or L-3 low consequence. The most important observation from this figure is that there were no RP2A 20th edition L-1 High Consequence platforms destroyed in the hurricanes. The 20th edition was issued in 1993 and included a new, major change to the RP2A wave load recipe, which resulted in a significant increase in the design metocean loading for new platforms (at that time all platforms were considered L-1). The industry began to implement the 20th edition wave load recipe in the mid 1990's. All L-1 platforms used the new wave load recipe from 2000 onward. The fact that none of these L-1 platforms were destroyed in the hurricanes is an indicator of the improved performance of these latest generation RP2A platforms.

There are however several post 2000 platforms that were destroyed, as shown by the nine L-2 and L-3 failures in Figure 5. The 21st edition of RP2A introduced the concept of "Consequence Based Design" that allowed platform owners to use a reduced metocean criteria for design that is less than 100 year conditions. The L-2 is a medium consequence structure and the L-3 is a low consequence structure (primarily caissons) with design return periods less than the 100 year conditions for L-1. These alternatives were provided as an option to the more robust L-1 design. As the name "consequence based design" implies, the L-2 and L-3 platforms are more susceptible to the consequences of damage and destruction in hurricanes, and this fact was demonstrated in these storms. Platform owners need to be aware of the fact that design to L-2 or L-3 conditions may result in the failure of even the newest platforms.

INFLUENCE OF DECK ELEVATION

There has been much discussion in the offshore industry about the amount of damage to platform decks due to wave impact from these hurricanes. Figure 6 shows an example of this type of damage that was observed on a platform at elevation (+) 73'-0" from MLLW. Note the horizontal tubular and the wide flange beams bowed towards the right side of the picture.

Figure 7 shows a plot of deck height vs. water depth for 84 of the destroyed platforms where the cellar deck elevation was available. Also shown for comparison are the deck elevation curves for the Section 17 A-1, A-2 and A-3 existing platforms as well as the RP2A Section 2 minimum deck elevation curves for new design platforms. The plot provides a feel for the range of deck elevations among the destroyed platforms. One observation to be drawn from this curve is that a majority of the platforms that were destroyed had deck elevations below the Section 2 minimum deck elevation curve for new design. The A-1 minimum deck elevation curve for high consequence platforms is also above most of the destroyed platform deck elevations. However, the A-2 deck elevation curve is below most of the deck elevations. The A-3 curve is below almost all of the deck elevations. Similar relationships were found for hurricane Ivan [Energo, 2006].

Many operators categorize their platforms as A-2 and use the associated Section 17 guidelines to establish the adequacy of the platform in hurricanes. According to Figure 7, a platform that has a minimum deck elevation above the A-2 criteria but below the A-1 criteria is at risk of damage or destruction in large hurricanes. A better indicator for adequacy is the A-1 and preferably the Section 2 deck elevation curves used for new platform design. Given all of the observed damage to platform decks in these storms, and given the increased risk of platform failure if the deck is hit by a wave, API is considering raising the required minimum deck elevation for new-build platforms. Actual performance of platforms in hurricanes, according to their deck elevations as shown in Figure 7 will be a useful reference to help establish these types of code improvements.

CONCLUSIONS

The recent Gulf of Mexico hurricanes destroyed or damaged over 300 fixed platforms, or about 10% of the 3,000 platforms exposed to hurricane winds. A majority of these platforms were installed prior to 1980 prior to the existence of RP2A, or during its early stages of development. Newer platforms performed much better. In fact there were no L-1 platforms destroyed and only 2 A-1 platforms destroyed that were installed post 1980. However, platform owners need to be aware that even new platforms designed to L-2 or L-3 standards might suffer major damage or even destruction in the event of a large hurricane. The improvements in RP2A platform design and fabrication guidance over the past 25 years is clearly evident.

ACKNOWLEDGMENTS

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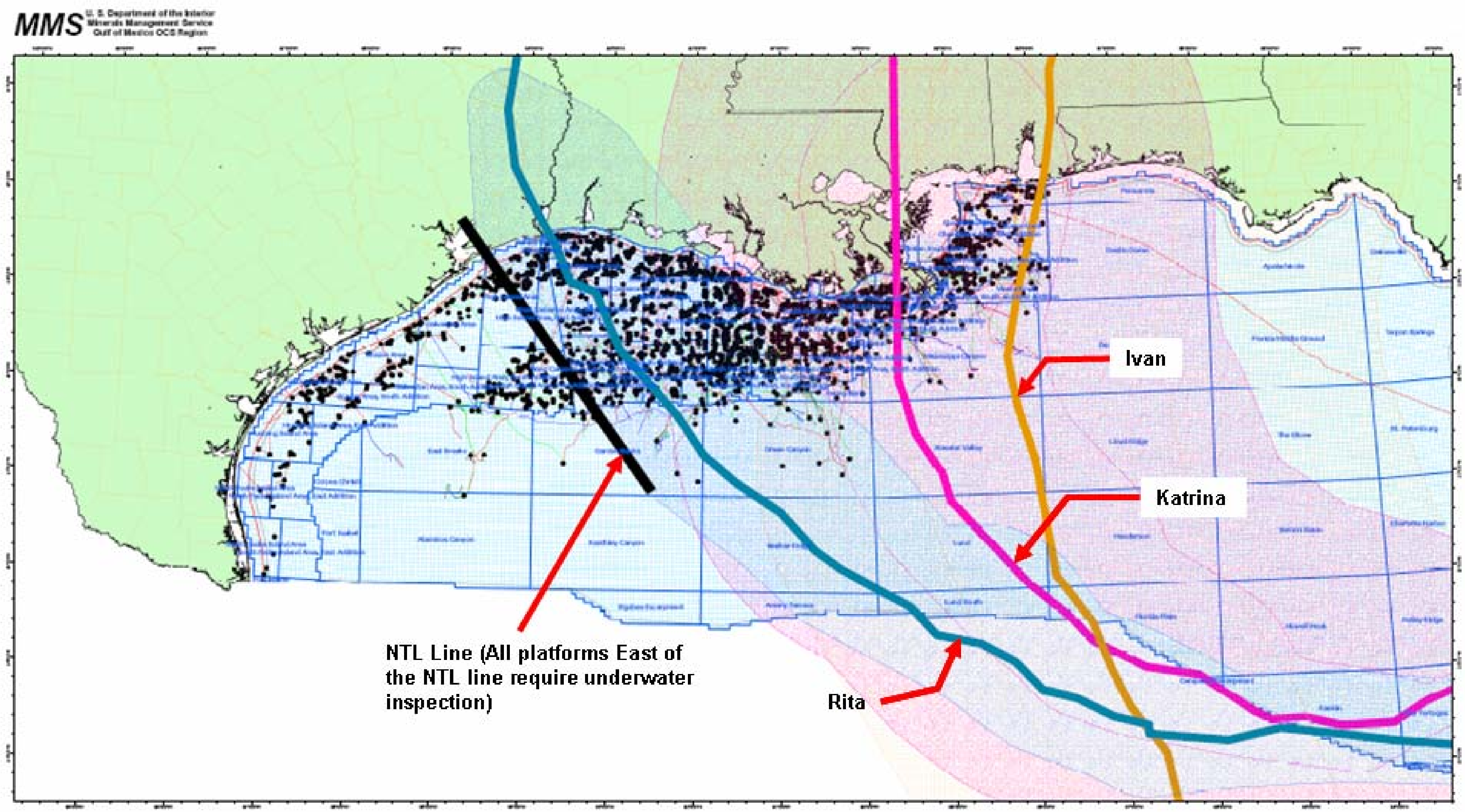

FIGURE 1. PATHS OF HURRICANES IVAN, KATRINA, RITA AND MMS NTL LINE (MMS)

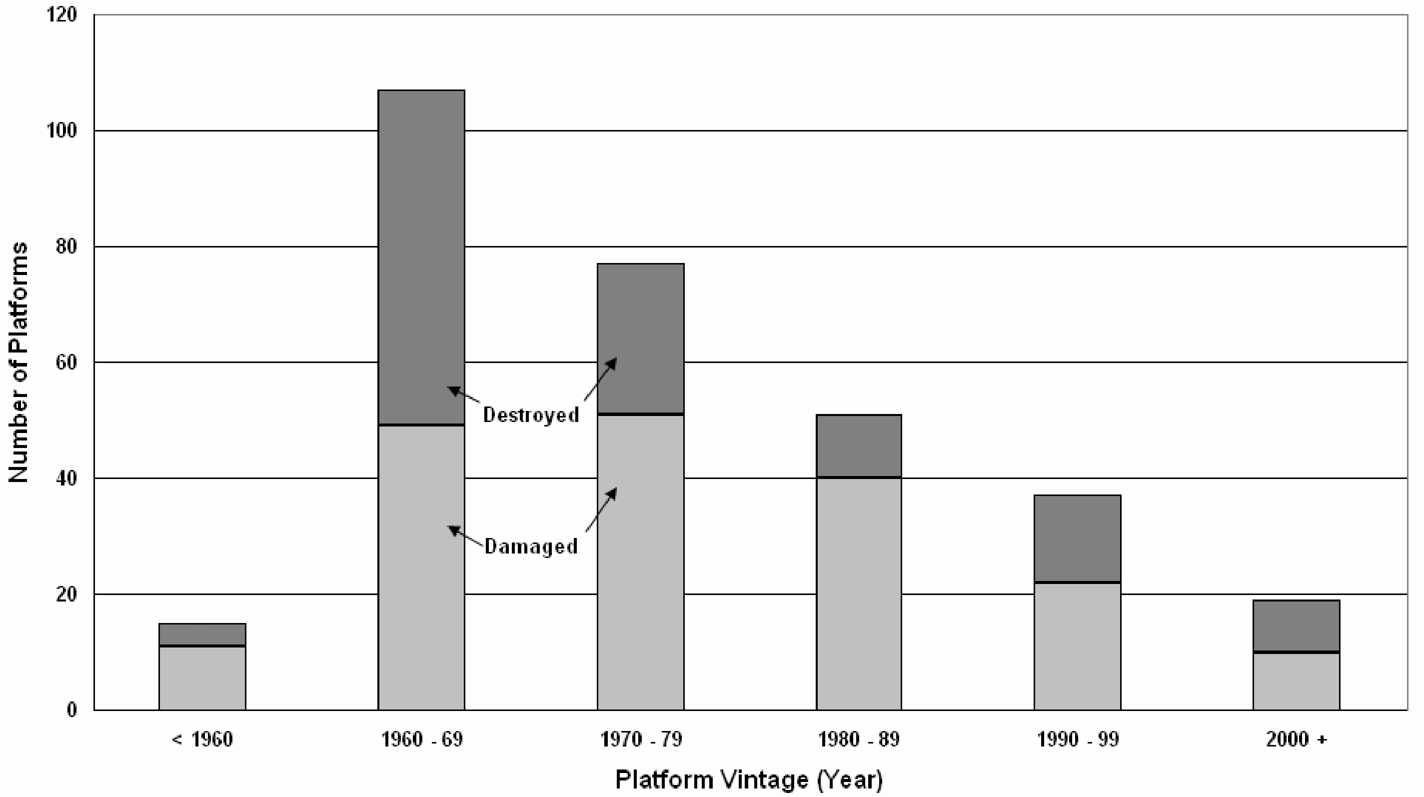

FIGURE 2. NUMBER OF DAMAGED AND DESTROYED PLATFORMS BY VINTAGE – HURRICANES IVAN, KATRINA & RITA

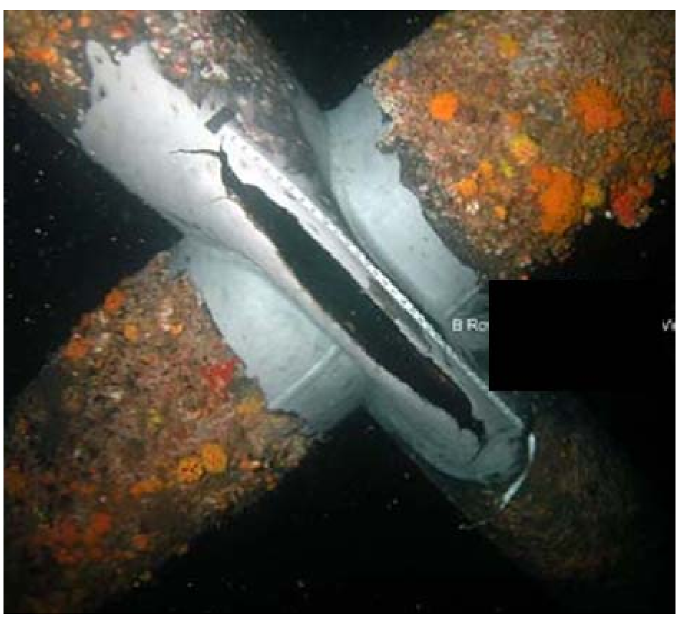

FIGURE 3 – DAMAGED X JOINT DUE TO INADEQUATE JOINT CAN THICKNESS

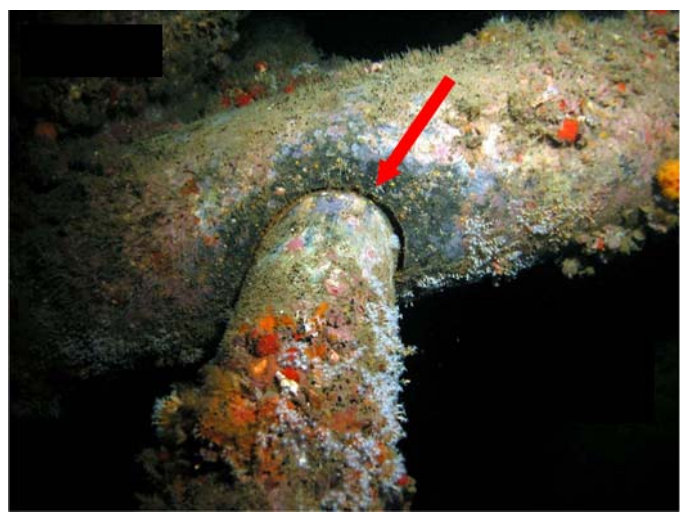

FIGURE 4 – DAMAGED T JOINT DUE TO INADEQUATE JOINT CAN THICKNESS

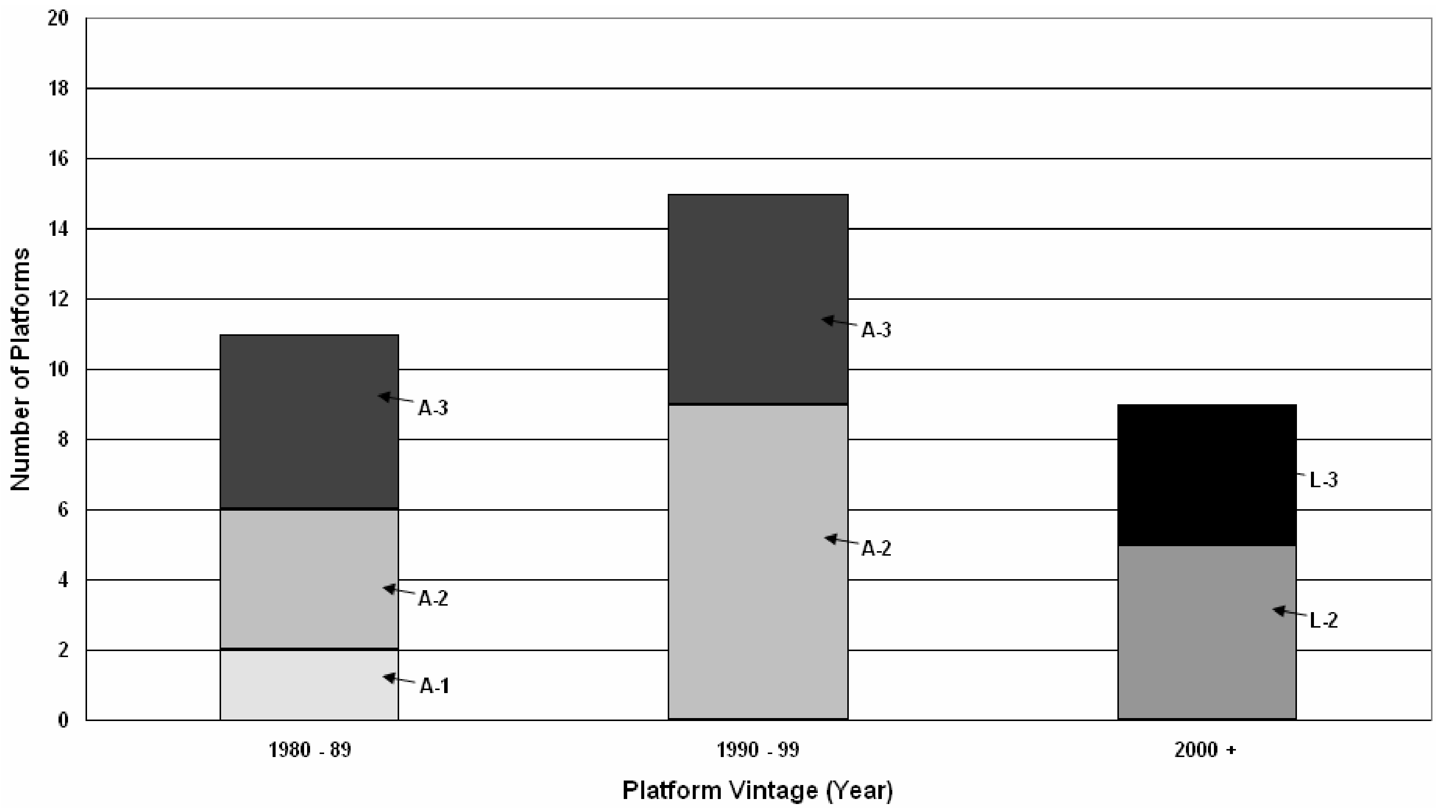

FIGURE 5. MODERN DESTROYED PLATFORMS BY VINTAGE – HURRICANES IVAN, KATRINA AND RITA

FIGURE 6. MAJOR DAMAGE TO DECK STRUCTURE DUE TO WAVE IMPACT

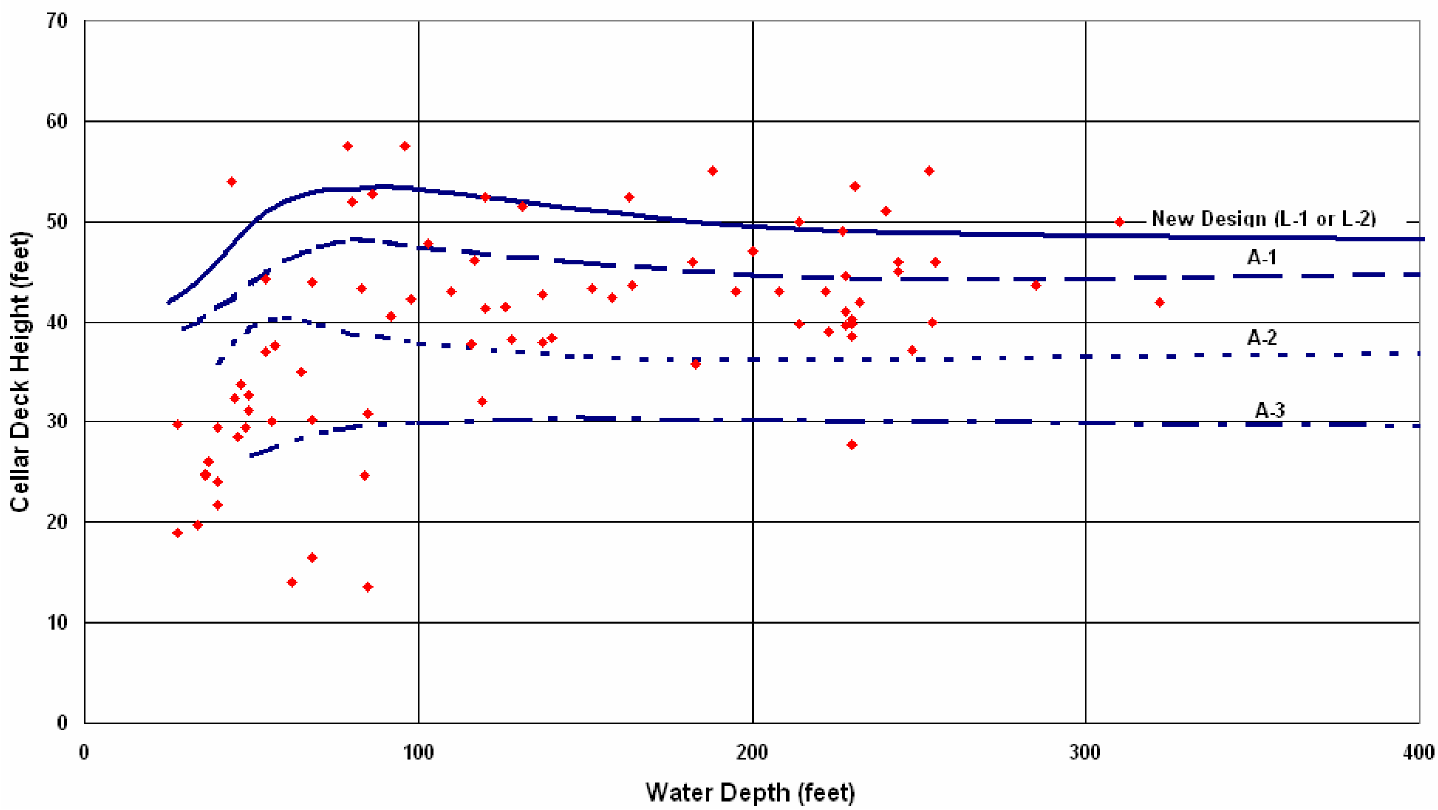

FIGURE 7. DESTROYED PLATFORMS BY DECK HEIGHT – HURRICANES IVAN, KATRINA AND RITA