Proven High Efficiency Anchor for Harsh Cyclonic Environments

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Abstract- **Harsh offshore environments in the Gulf of Mexico and offshore Australia have lead to a compelling need for high efficiency anchors that present minimal risk to natural and industry assets when utilized for mooring. Efficiency is measured in both capacity versus mass and in the relative cost of installation for a given application. Risk to assets is measured by performance when mooring systems are overloaded by cyclonic storms in excess of the design condition.**

This paper covers the key development steps of the OMNI-Max anchor; high efficiency gravity installed marine foundation for mooring. Included are the key design challenges, the fundamental behavioral properties of the anchor, experience from offshore testing, full scale installation histories, and documented tropical cyclone performance.

I. Introduction

In the wake of Petrobras's wide spread use of its Torpedo anchor technology, the offshore mooring industry opened its eyes once again to a marine anchor that could be released underwater and reach its design position within the marine soil under its own weight. This basic principal dates back to some of the most primitive anchor technology, a stone with a rope tied around it.

The torpedo pile technology is widely used by Petrobras today but that experience concentrated in offshore Brazil in a non-cyclonic environment. The anchor itself offers the known benefit of not requiring any bollard pull to set and also can be advantageous as far as relative size to comparable suction pile based technology. These two key advantages sparked the development of a new gravity installed anchor which could help address growing needs for a high efficiency anchor to be used in areas of harsh cyclonic activity with subsea assets.

The Gulf of Mexico has experienced significant and more frequent mooring failures due to massive tropical cyclones in the mid 2000's that had strength well beyond the mooring systems they damaged. Many times the Mobile Offshore Drilling Unit (MODU) that were designed to hold station in moderate strength tropical cyclones, broke free and drifted more than 100-miles off location. When these MODUs break free, they pose a risk to an ever increasing network of pipelines and production facilities that feed local markets by way of potentially dragging their conventional anchors.

Most conventional anchor types are designed to perform reliably in an in-plane configuration, meaning that the orientation of the load being applied is in the direction the anchor has been installed to. When conventional anchor types are loaded in an out-of-plane configuration, this typically causes either increased drag distances while the anchor re-orientates itself or loss of capacity and the anchor pulls out of the soil.

Another aspect of tropical cyclones are that they can impose high loads on any side of a mooring system. Unlike highly directional environments, not knowing which directions the design environments may come from leaves the designer no option to orientate the mooring system for a biased robustness. Essentially, the designer in an area with tropical cyclones is facing a design storm that may come from nearly any direction but also impose extreme loads in multiple directions over the course of the storm approaching and leaving. This is illustrated by the hindcast data from Hurricane Gustav [1] in Figure 1. As shown as the storm approached it intensified as the direction of the loads swept around, and then ultimately passing right over the example location.

II. The Need for a Better Anchor

A. Current Anchor Technology

The conventional anchor, or high holding capacity drag embedment anchor (HHC DEA) are the most widely utilized anchor type in the world for MODU mooring. In the US Gulf of Mexico approximately 70% of all anchors used in MODU mooring are HHC DEAs. These anchors do not currently exhibit high levels of reliability in out-of-plane loading and there is no guidance in place to help manage the risk in these extreme loading conditions. The most popular mitigation measure is implemented by increased proof loading of the anchors to embed them as deep as reasonably possible. This will help the anchors achieve the maximum possible capacity and hopefully increase their ability to resist pull-out in an extreme storm case that causes multiple mooring line failure.

Drag-installed vertically loaded anchors (VLAs) have gained popularity in recent years due to their relatively low cost and ability to resist high anchor uplift angles. The biggest issue with VLAs in extreme loading conditions are that they are extremely sensitive to how they were installed. High reliability is usually only achieved when the installation engineering is completed in significant detail and assurance that the anchor fluke is sufficiently penetrated before shearing a pin and orientating the anchor in its highest capacity fluke angle. With VLAs, the user cannot simply execute a standard installation process and expect that the anchor will orientate

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itself and perform in extreme condition with a high level of reliability [2]. Additionally, if the out-of-plane loading is of a high enough angle, the ability of a deep set VLA to re-orientate is limited. This is sometimes considered a benefit since this scenario would reduce the chances of the whole anchor pulling out and more likely would only allow the shank or shank assembly to drag along with the MODU. To recover most VLAs, the anchor line is pulled back over the anchor allowing the shank to slide back or be released from the front end of the fluke. Figure 2 shows a commonly used VLA and how the shank is attached in a long slot along the fluke. This allows these anchors to be easily recovered, but also makes them vulnerable to being pulled out of the soil in an extreme condition; when all but one or two mooring lines are left intact and the loads are acting in the opposite direction from how they were installed.

Suction pile anchors have long been used as a low risk anchor foundation for MODUs. Suction piles are still designed to be very robust in capacity and there have been no suction piles pulled out during extreme storm conditions. The biggest disadvantage to suction piles is their relatively high cost of installation. Their size leads to the requirement for multiple vessel trips to pre-install. This relative size is clearly visible in Figure 3 which has two 12-foot by 60-foot long suction pile anchors. When piles have experience significant out-of-plane loading, the structural capacity of the pad-eye attachment has failed in some instances. These pad-eyes, however, have not lead to any damage to pipelines.

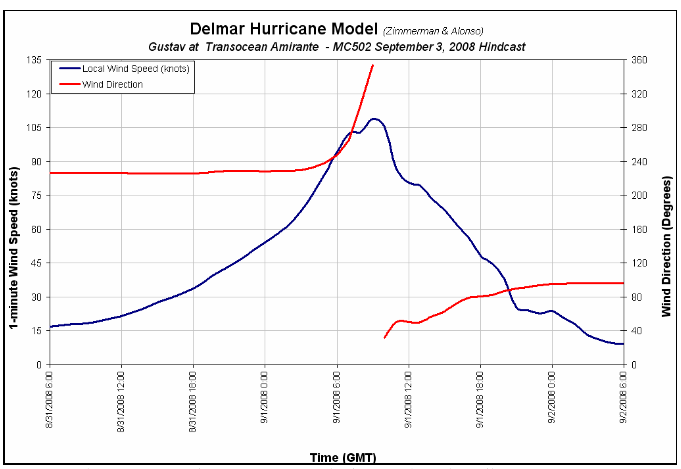

Figure 1. Hurricane Gustav Hindcast Directionality at MC502


Figure 2. Drag-installed Vertically Loaded Anchor

Figure 3. Suction Pile Anchors

B. Development of an Anchor Solution

In 2004, Delmar began development of a new anchor that would address the current issues facing MODU mooring in harsh cyclonic environments. The result of an extensive lab testing program was the OMNI-Max anchor [3].

This anchor technology allowed for efficient installation since the relative size of the anchors was less than half of an equivalent suction pile, giving the ability to install a complete set of anchors in one vessel mobilization. A full set of anchors is shown in Figure 4 on a single vessel mobilization.

The design is such that once its installed, reliable performance can be verified by checking the penetration. This penetration is easy for a Remotely Operated Vehicle (ROV) to visually verify as shown in Figure 5. Since the anchor is installed in the vertical position and the geometry is such that the lower fluke fins are much smaller than the upper fluke fins, the anchor will key itself with a high level of reliability. The relative size difference between the lower and upper fluke fins is shown in Figure 6. The fluke fins are also adjustable, so the area ratio from lower to upper fluke fins can be adjusted to suit a given soil strength gradient. The attachment point has been designed with an offset fix angle from the center axis of the anchor which, once keyed, will act like an anchor shank and induce a forward moment that will keep the tip of the anchor pointed downward into stronger soil. In fact, the design is such that under extreme loading, the anchor will key itself and then dive into deeper, stronger soil until it reaches equilibrium or the mooring line above breaks.

Another important aspect designed into the anchor is its ability to achieve high holding capacity in the out-of-plane loading conditions. The attachment point of the anchor has been designed so it can swivel 360-degrees around the axis of the anchor. This gives the anchor the ability to achieve maximum capacity in nearly any direction. In instances of multiple MODU mooring line failures in extreme cyclones, this anchor is designed to give each mooring line attached to the rig the ability to help hold the MODU on location; even if the MODU has already lost more than half of its mooring system to over-load.

These aspects of the anchor design make nearly impossible to drag one of these anchors with a failed MODU and thus mitigate nearly all anchor drag related risk to subsea assets.

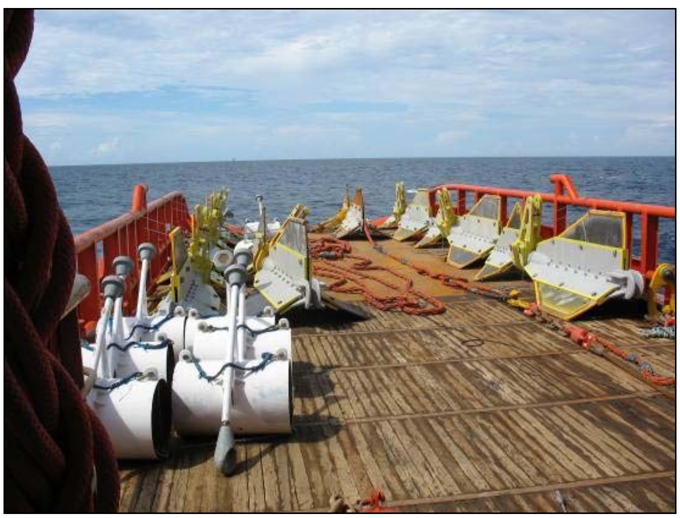
Figure 4. VLA Single Vessel Mobilization

Figure 5. OMNI-Max Penetration Check


Figure 6. OMNI-Max Upper and Lower Fluke Fins Size Difference

C. *Application and Use of this Anchor Technology*

Both Shell and Anadarko conducted full-scale offshore tests of this anchor technology. Anadarko was the first operator to install and hook an OMNI-Max anchor to a MODU in 2007 [3].

The OMNI-Max anchor was utilized on the last remaining eight-leg mooring MODU operating in the US Gulf of Mexico in 2008. ENI Petroleum saw the ability to use this technology to mitigate potential risk to subsea assets by using the OMNI-Max on all eight of the mooring lines on the *Transocean Amirante*. While on location in the central Gulf of Mexico the *Amirante* experienced more than 100-knot sustained winds from Hurricane Gustav which was beyond the strength storm its mooring system was designed to. After the hurricane passed and the first reconnaissance flights were able to assess damage in the Gulf, it was discovered that the *Amriante* was still on location however appeared to have experienced multiple line failure. This was not unexpected.

Recovery efforts uncovered that seven of the eight mooring lines had broken and the MODU was held on location by one last mooring line applying a load approximately 170-degrees from it original orientation. The recovered orientations of the mooring system and the MODU is shown in Figure 7. The OMNI-Max anchor effectively provided holding capacity in almost the exact opposite direction from its planned azimuth. Anchor handling operations were also able to verify that all of the eight anchors had penetrated deeper than their original installed depths. In one case, an anchor with an original installed depth of 58-feet, dove to a depth of 120-feet before the mooring line reached its break point [1].

At the time of this paper, more than 120 installations have been successfully completed. For the first time, the OMNI-Max anchor was used on more locations to mitigate subsea risk in the Gulf of Mexico than suction piles even though fewer OMNI-Max anchors were available to the market at the time.

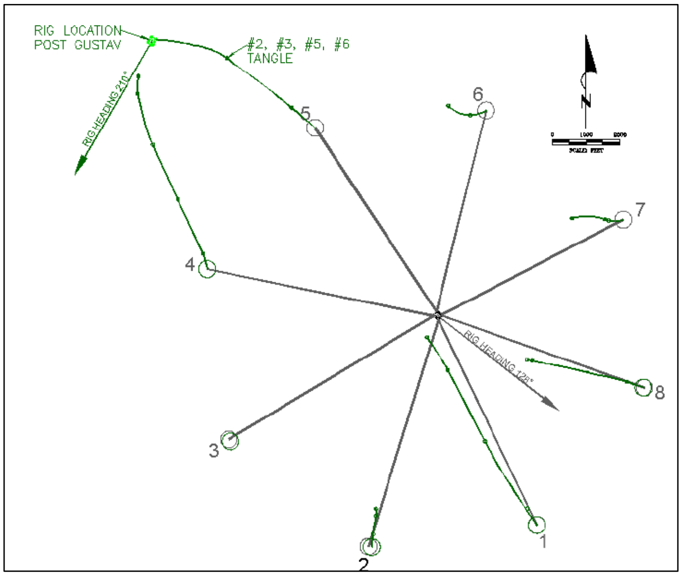

Figure 7. Transocean Amirante after Hurricane Gustav

III. Conclusion

The OMNI-Max anchor technology is now a proven foundation that offers mooring designers in areas of harsh cyclonic environments a highly effective and efficient mitigation measure against subsea risk.

Less than half the size of an equivalent suction pile, this anchor technology is able to achieve high holding capacity in nearly any direction. Hurricane Gustav demonstrated that the OMNI-Max anchor can withstand extreme loading conditions and help lead to possible increased survivability of MODU mooring systems.

Acknowledgment

This anchor technology would have been so quickly or widely accepted without the support and hard work of Sherman Scott, Matt Smith, and John Shelton.

References

[1] E.H. Zimmerman, M.W. Smith and J.T. Shelton, “Efficient Gravity Installed Anchor for Deepwater Mooring,” Houston, May 2009.

[2] Evan H Zimmerman, Malcom Sharples and Daniel J. Alonso, “Delmar MODU Mooring Risk Assessment JIP Report,” Houston, December 2007.

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