HURRICANES, ACCIDENT STATISTICS, AND CONSERVATISM

The severe hurricanes in GOM (Andrew-1992, Lili-2002, Ivan-2004, Dennis-2005, Katrina and Rita-2005, Ike-2008), and the accident statistics in North Sea are resulting in even more overburden on the offshore industry. The regulatory requirements, and operational restrictions are causing more mobilization and installation times then usual, and the financial burden on vessel owners is significant. For instance, in order to meet the new Hurricane season requirements in GOM, some vessel owners have choosen to upgrade the existing mooring systems on some Mobile Drilling Units (MODU). The mooring system upgrades per rig were reported to cost between 6 and 12 million USD.

In general, the disasters and accidents cause a panic reaction; resulting in sometimes over-conservatism in engineering designs and structures. There is no doubt that a reliable and safe mooring system design is a must. Yet, no component of the mooring system should unnecessarily be over designed or over tested without a through understanding and analysis of the system in question. In this article, the proof tension testing of anchors will be elaborated with respect to the existing rules / regulations and the trends in the regulatory requirements.

Aftermath of hurricanes

The severe hurricanes Katrina and Rita have destroyed 113 out of 4000 platforms existing in the Gulf of Mexico (i.e. more than 97% survived). Ike's destruction figure is currently 54 out of the 1450 offshore oil and gas production platforms on its path. Most of the facilities damaged or destroyed by the storms were built prior to 1988. The post 1988 designs are based on 100-year storm and should sustain hurricanes up to category 5. The newest API interim guidance (2INT-DG - 2007) for design of offshore structures for hurricane conditions is aiming to raise the stakes higher. This leads to bigger vessels or smaller payloads, very high decks, and larger/stronger mooring systems.

During Ivan, Katrina and Rita, among the moored units, 17 MODUs broke loose from their location. Among these 17 MODUs that have drifted for over one mile, only in four cases the anchors were reported to dragged for a significant percentage of that drift distance. The loose MODUs can potentially be damaging to other surface structures along its drifting path, and if the mooring lines with anchors crosses over wells and pipelines. As a result the principal regulatory agency, Minerals Management Service (MMS), together with the U.S.Coast Guard, the Department of Energy has worked out means to improve the safety record. Their focus was primarily on upgrading the designs and mooring standards for Mobile Drilling Units (MODU). This has lead either to increasing the strength of anchor lines and mooring components, or to adding extra anchor lines (e.g. from 8 to 12 or 8 to 16 lines).

During Ike-2008, four MODUs are reported to gone adrift or had partial mooring failures.

The interim guidance and recommendations for GOM MODU mooring for 2006 and 2007 hurricane seasons are drafted by American Petroleum Institute (API Recommended Practice 95F, 2007). The MMS uses these recommendations to evaluate the applications for Permit to Drill (APD) and for Permit to Modify (APM).

With respect to the mooring issues, the API RP 95F supplements the API RP 2SK in mooring design and operating practices during GOM hurricane season. The API RP 95F provides the means of detecting weak points and assessing risks related to mooring system failures.

Specifically, for the anchors the API RP 95F recommends that the anchor holding capacity (for all types of anchors) shall be considered in the design of the mooring system. Anchor selection should be based upon capacity, availability, and potential to minimize damage to subsea infrastructure should an anchor failure occur in conditions such as:

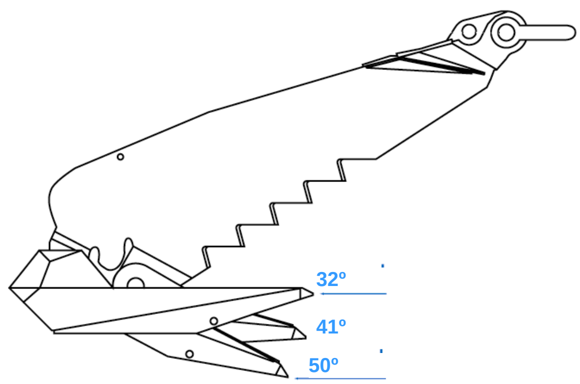
- A marine installation such as a pipeline lies in the dragging path between the anchor and the MODU or in a location in which mooring system failure could result in an anchor dragging across the installation
- A mooring line that can cross another mooring line
- Density or importance of seafloor or water column infrastructure merits a higher safety margin

In the absence of site-specific soil data, the appropriate upper and lower bound soil conditions for the general area of operation shall be considered. The guidance on anchor behavior and anchor selection is provided in Section 7 of API RP 95F.

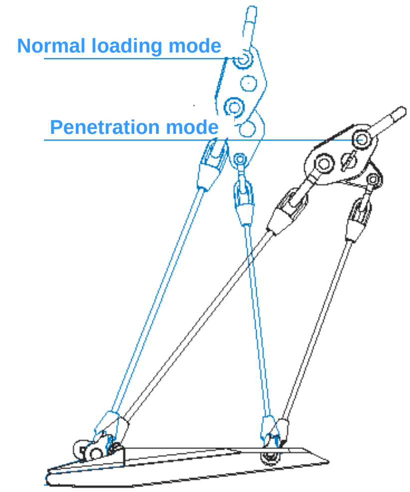
For drag embedment fluke and plate anchors used on MODUs during hurricane seasons, the API RP 95Fdoes not impose extra requirements for the proof tension (field test) loading of anchors. The proof tension (field test) loading of anchors should follow the recommendations given in API RP 2SK (2005). The API RP 95F accurately captures and addresses the relevant issues in the selection of anchor type for hurricane moorings.

The special considerations are given for drag embedded fluke anchors (e.g. our Stevpris and Stevshark anchor types) on windward line loading, uplift angle at the mudline, the behavior of anchor under out of plane loading, and the use of oversized anchors. The tests and industry experience show that the Vryhof Stevpris and Stevshark (Figure 1) anchors are outperforming under such uses and loading conditions.

For the drag embedded plate anchors (e.g. our Stevmanta VLA anchor type), the special consideration is given to penetration and mooring angles of the anchor, the anchor triggering (mode change from penetration to normal loading mode), and the out of plane or reverse loading. The behavior of Stevmanta VLA (Figure 1) has been proven with tests and actual project installations to meet the relevant hurricane mooring criteria. As the Stevmanta VLA is manufactured in two versions; the mobile and the permanent, depending on the consequence assessment, either the mobile or the permanent version of the Stevmanta VLA will best meet the hurricane mooring requirements. Moreover, due to its light weight, flexible shank, and releasable front legs (mobile version), the Stevmanta VLA has the least (if not zero) damaging risk to subsea installations if a mooring system failure occurs.



a) Stevshark anchor with various fluke/shank angle setting options



b) Stevmanta VLA: installation and normal loading modes

Figure 1: Drag embedment fluke (Stevpris / Stevshark) and plate anchors (Stevmanta VLA)

The special considerations for other anchor types used during hurricane season are outlined in API RP 95F, and are not subject to this article.

Audits and accident statistics in North Sea

The regulation of offshore safety in UK Continental Shelf (UKCS) is the role of Health and Safety Executive (HSE) and Department of Energy. In Norwegian Continental Shelf this role is shared by Norwegian Maritime Directorate (NMD), Petroleum Safety Authority (PSA) and Norwegian Petroleum Directorate (NPD).

For the UK continental shelf the audits and accident statistics between 1981 and 2003 are published by Health and Safety Executive (HSE). Within this period, among 3485 reported incidents on all moored units (permanent and mobile), 240 incidents relate to mooring system failures (a failure frequency of about 0.2). The mooring system failures include problems with mooring lines, mooring devices, winching equipment or fairleads, and anchors. Among the 240 mooring incidents only 34 incidents are categorized as accidents, the rest are incidents of near misses or insignificant situations. Only one of the 34 incidents categorized as accident relates to anchor drag due to one line being damaged and the tension control on the winches could not be implemented.

In Norwegian Continental Shelf, the incidents involving loss of more than one anchor line, and the general statistics of anchor system incidents between 1996 and 2005 are analyzed by the Petroleum Safety Authority (PSA). Among the total 48 incidents of varying degree of criticality, four incidents are related to the loss of anchor holding capacity and drag. All four events occurred in stormy weather and related to anchor overload. In the period 1996-2003, no storm dragging event was reported in the UK.

Like in many parts of the world, the mooring system failure incidents in UK and Norwegian continental shelf are related to a number of factors including failures in the work organization and responsibility, the lack of personal training, the equipment failure, etc.

Most of the incidents could possibly be avoided with good procedures in place with trained and well organized personnel.

Based on the results of audits the HSE in UK and the PSA in Norway have not identified a need for amendments to the existing regulations. However, PSA has expressed a need for a general raising of standards in the industry. According to PSA, although the mooring system is designed to withstand a line break, this is still an undesirable incident. Therefore, a limited anchor drag is interpreted as line failure and PSA is arguing that there is a need to increase the anchors' test load (test tension) on more mobile facilities. This demand should off course be interpreted very carefully and its justification should be checked against specific mooring, site soil, and anchor installation conditions. Due to equipment and capacity limitations, a rigid and technically unjustified higher test load requirement will be prohibitive for the vessel owners and operators to carry out their work. Moreover, in certain soil types the recovery of an unnecessarily over-tested anchor will be difficult and can result in equipment damages.

Practice of anchor proof test (field test) loading

The practice of raising tension on the mooring line and holding the tension at the anchor at a predefined value during a predefined period is termed as proof tension testing, field test loading or proof testing. A mooring system with drag anchors are usually subject to a proof tension testing to ensure the anchors are embedded correctly and the adequate installation holding capacity is achieved. The post installation capacity and the Ultimate Holding Capacity (UHC) of the same anchor is always much higher (at least a factor of 1.5 to 2) than its installation capacity.

Depending on the type of moored unit (permanent or mobile), the proof tension test level of a drag anchor is either specified by the selected classification society (certifying authority) or recommended in the governing regulations. In the case of permanent moorings (FPU, FPSO, FSO, SPM, etc.), the proof tension test level is specified by the classification society (certifying authority) and is usually between 80% and 100% of the maximum intact load level. The following table lists the anchor proof tension test level required by the major classification societies.

Class - Certifying authority	Analysis method	Return period	Required fluke anchor safety factor	Proof tension load level	Proof load / UHC ratio	Proof load duration
ABS	dynamic	100 year	Intact = 1.5 Damaged = 1	100% max intact 80% max intact in soft clay	0.53 - 0.67	30 min
DNV	dynamic	100 year	The minimum required proof tension load level is calculated from equilibrium equations for ULS and ALS cases. The factors of safety depending on the consequence class selected. Details can be found in DNV RP-E301		-	15 – 30 min
BV	dynamic	100 year	Intact = 1.5 Damaged = 1.05 Transient =1.05	80% max intact	0.53	-
LROS	dynamic	100 year	Intact = 1.5 Damaged = 1.15	80% max intact	0.53	20 min

In the case of temporary or mobile (MODU) mooring systems the proof tension test level of a fluke anchor is dependent on the local circumstances, available equipment capacity, and applied installation method. For instance, if the proof tension testing is carried out by anchor winches on the rig by tensioning diagonally opposite mooring lines against each other or for higher test tensions by tensioning one line against two or three of the other anchors the achievable proof test tension is limited to the stall capacity of the winch. The required stall capacity of anchor winces on MODUs is usually about 30-35% of the Minimum Breaking Load (MBL) of the line. In North Sea, the common practice has been to proof test tension the anchors to about 150-200 ton, which is about 30-35% of the break strength of a typical 3” rig chain.

In the case of preset mooring systems the anchor proof tension test level is limited by the available bollard pull capacity of the Anchor Handling Vessel (AHV) or the tensioning capacity of the dedicated surface or subsea tensioning equipment used.

The general guidance given for temporary (MODU) moorings in API RP 2SK, DNV-OS-E301 and ISO 19901-7.E.3 can be summarized as follows:

- The proof tension test load at the anchor should not be less than 3 times the anchor weight
- The proof tension test load at the winch should not be less than the mean line tension for an intact mooring under the maximum design condition. This requirement for close proximity moorings only
- The proof tension test should be equal to the maximum intact line tension expected at the location. If this tension cannot be achieved, a tension that has been proved sufficient from previous experience with the same type of anchors at the same location should be applied.
- Mooring line tensions may be controlled by active mooring line tension adjustments. However, this technique shall not be considered in the evaluation of mooring line tensions in the ultimate limit state (ULS) design event.
- The proof tension test load at a winch shall not be less than the maximum line tension for an intact mooring under the design event for the serviceability limit state (SLS).
- The proof tension test level is limited by the stall capacity of the anchor winches
- Duration of proof tension testing for mobile mooring is 15 to 20 minutes.

In the cases of high proof tension load requirement and the limited tension capacity of winches or vessels, the use Stevmanta VLA may present a better alternative. Because the anchor is designed to generate a capacity equal to 2.5 to 3.5 times the applied installation load after triggered to the normal loading mode.

Post installation behavior of tested anchor

The post installation capacities and behaviors of fluke and plate anchors are dependent on:

- Selected anchor type and size
- Anchor fluke/shank angle
- Anchor forerunner
- Applied installation load
- Soil type and stratigraphy

In general, the post installation capacity of the anchor is always higher than the applied proof tension test level unless the mobilized soil resistance has degraded due to active scour or soil specific properties.

The proof tension testing is essentially of a static loading nature. The anchor will resist the dynamic loads above this applied static load level without further movement as the soil will show higher strength under high rate of loading. The higher soil strength under higher rate of loading has been proven and an accepted property for many soils. The loading rate effect may result in an increase in anchor capacity as high as 1.7 (usually applied range 1.2 – 1.7) for cohesive soils and 1.1 - 1.2 for cohesionless soils.

The significant increase in anchor capacity is also observed due to soil setup and reconsolidation. The effect of soil reconsolidation is clearly seen in cohesive soils, and is dependent on the soil sensitivity or remolding. The increase in the anchor holding capacity due to soil reconsolidation can be as high as 1.6 (usual applied range 1.2 – 1.6). In some instances the soil reconsolidation is proven to cause anchor recovery problems on over tested anchors.

Adding these two factors, an anchor proof tension tested at a certain level can resist loads 1.2 to 2,7 times the applied proof load level.

Should the mooring loads exceed the post installation capacity of the anchor, a correctly selected and correctly set anchor will simply penetrate more to resists the load increases. For a given soil stratigraphy and soil conditions, the anchor penetration and drag behavior is controlled and predictable (Figure 2).

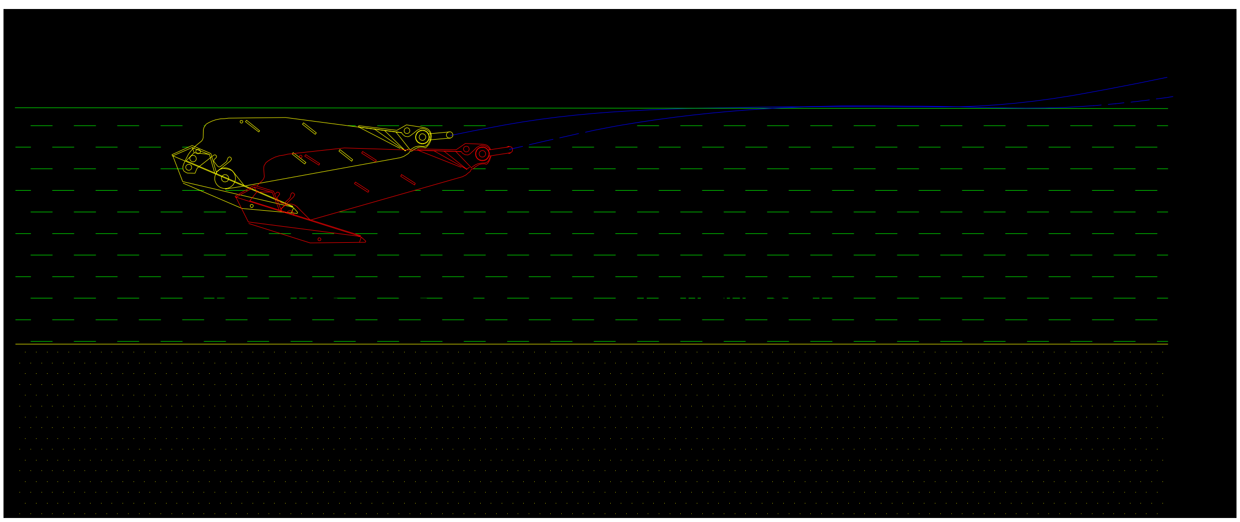


Figure 2: For the given anchor and soil conditions, the probability of further anchor penetration and drag is conditionally dependent on the probability of exceeding proof tension load level and the increased resistance from the post installation effects

In the case of Stevmanta VLA, the post installation capacity of anchor is 2.5 to 3.5 times the applied installation (shear pin break) load. For example if a Stevmanta VLA is installed at 200 tons, the anchor will not move for increased loads upto and below 500 or 700 tons.

If the several mooring lines fail, this will result in large directional changes of the remaining lines. Under these conditions the anchor will be subjected to side loads or out of plane loading. Under such side loading conditions, a properly set and sufficiently embedded drag anchor in cohesive soil will rotate to a new orientation, and will maintain its holding capacity.

One of the engineering services offered by Vryhof is the geotechnical characterization of the anchoring location, the anchor capacity, and anchor installation assessment for our clients; a service regularly used by our North Sea clients.

Conclusions

The experiences from hurricanes in GOM and audits in North Sea have resulted in adaptation of risk analysis approaches for mooring systems. To comply with the new requirements the vessel owners have increased their mooring capability by 40-50%, in other words the MODU mooring systems became 40 to 50% stronger than before. The organizational aspects, site specific assessments, and a better training of involved personnel are under the focus of regulatory bodies.

Although there are no changes in current regulations regarding the anchor proof tension load levels, the safety authorities are expecting higher proof tension load levels than usual. As a means of increasing the as installed reliability of the mooring system, the applied proof tension test load levels are increased in practice. The increase in the required proof tension load level on mobile moorings should not be unrealistic and impractical causing delays and risking equipment and capacity limits. The reliability on a fluke or plate anchor point should not be judged subjectively based on personal feelings only. From the reliability aspect of the anchor point, the drag anchors are in reality has the highest reliability. Because, the probability of an anchor point failure can in reality only be reduced by the capacity under which the anchor point is tested. In practice no other anchor type is subjected to proof tension test load levels as high as on the drag anchors.

The anchor design is an engineering discipline. The post installation capacity and behavior of a correctly selected and set anchor is predictable. What is important in this regard is the correct selection of anchor type and size, and the correct configuration/setting of the anchor by good understanding of site soil conditions. This is an engineering service offered by Vryhof.

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