Problems met in stability calculations of offshore rigs and how to deal with them

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ABSTRACT

For the calculation of the hydrostatic stability of mobile offshore units, various authorities have nowadays adopted almost the same requirements. These requirements lean heavily on the application of wind overturning moment, equilibrium angles, downflooding and range of stability.
A discussion of the various ways to calculate the righting arms is given together with problems met in practice like backward sloping curves and heel angles for which the rig is unstable in trim or axis direction. The use of the gain in potential energy is investigated as a means to arrive at realistic righting arm curves. Though this suggests that free twist (or varying axis direction) is the preferred method, it is not without problems of its own. At this moment there does not seem to be a robust way to calculate stability other than using fixed trim (read: zero trim) and a fixed axis direction.
It is proposed to do (more) research into the actual reasons for a MODU to capsize due to environmental loading, preferably by model testing with wind and waves.

KEYWORDS

semi submersible; jack up; hydrostatic stability; free trim; free twist

INTRODUCTION

In the assessment of the safety of a floating offshore rig, hydrostatic stability plays a crucial role. In the past decades, the requirements focused on the stability parameters like initial stability (GM) and ratio between area under the righting- and wind overturning arm. Initially these requirements were derived from the requirements for ships. Additional insight obtained from actual experience and unfortunate accidents led to changes to the requirements such that they became more specific to the type of rig. Initially, each classification society had its own set of rules. In the past years, the criteria of the various regulations attained a certain degree of similarity though they still differ in details. Quite often additional clarification is needed regarding the proper interpretation of the requirements.
Experience in the past years has shown that the actual calculation of the righting arm curve is not as straightforward as it looks. It seems that the availability of powerful computer programs has reduced the attention of the user to getting reliable results. In the 1980's a lot of interesting research effort was put in hydrostatic stability. For example, in the period 1975 to 1991 12 papers of the OTC conference were devoted to this aspect, see figure 1 (Clauss, 1984, Collins et al, 1988, Dahle, 1985, De Souza et al, 1978, Huang et al, 1982, Huse et al, 1985, Kuo et al, 1977, Numata et al, 1975, Praught et al, 1985, Shark et al, 1989, Soylemez et al, 1988, Stiansen et al, 1988).
Most of them did consider semi submersibles, only one touched upon stability for jack-ups. In this period, low frequency motions was a new phenomenon which was hardly understood but which caught great attention. After 1991, interest in stability was lost (at least for the OTC). At that time also two papers were published which -at hindsight- hinted at the problems to come (Vassalos, 1985 and van Santen, 1986).

Note that nowadays, a modern semi submersible has much more reserve buoyancy above the waterline than those of 1980's.

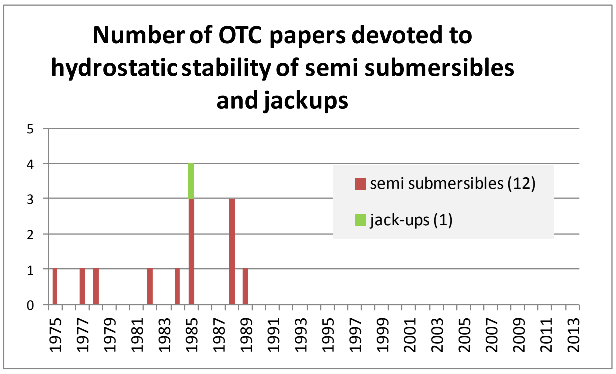

Fig. 1: OTC papers devoted to stability of MODU's

Examples of offshore structures

Examples of typical offshore structures are given in the figures below. Nowadays, a modern semisubmersible is less transparent than in the 1980's and the deck provides a lot of buoyancy (figure 2).

Fig. 2: Example of a large semi submersible.

Figure 3 gives an example of a large triangular jack-up, characterized by legs length of about 200 m, and natural roll and pitch periods of about 15 s.

At the lower end of the spectrum, small installation jack-ups have recently emerged, usually with four legs and a leg length about 80 m, see figure 4.

Fig. 3: Example of a large jack-up.

Fig. 4: Example of a small jack-up.

Summary review of requirements

Below, a schematic overview is given of the requirements as found in the IMO-2009 rules. It is certainly not meant to provide a detailed overview of the requirements. For details, reference is made to the specific requirements of class, IACS and IMO.

Operational condition

A distinction is made between transit, operational and survival condition. For survival, only intact has to be considered.

Intact, area requirement

The area under the righting arm curve should be larger than the area under the wind heeling curve by a given factor where a differentiation is made between jack-ups and semi submersibles. This assumes a sudden change of the wind speed from 0 to a fixed value and that induced heeling motion is undampened in still water. The reason for the difference in the ratio between semi submersibles and jack-ups is unknown.

Damage

A distinction is made in waterline damage and damage to a compartment somehow connected to the sea. For waterline damage, the penetration depth is limited to 1.5 m. For a semi submersible the angle of heel after damage (with wind) should not be greater than a specific angle (17 degrees). In addition there are some detailed requirements on the righting arm in relation to the wind arm. Specific requirements to the stability curve are given when a compartment connected to the sea is damaged.

For jack-ups, the rig should provide sufficient buoyancy to withstand waterline damage. When any compartment is damaged, a specific requirement is set on the range of positive stability, without the effect of wind and without considering downflooding.

Watertightness

The rig should be watertight up to at least the first intercept with the wind arm.

Weatertightness

The rig is to be weathertight up to the second intercept with wind or at the angle where the arm is zero again. Sometimes weathertightness should be guaranteed up to the angle at which the criteria are satisfied. This depends on downflooding being accepted or not.

GM value

In earlier class rules, a requirement on minimum GM was present, but not anymore. Nowadays, a modern semi submersible is allowed to operate with a GM of 0 m.

As is seen, the criteria focus on the following aspects:

- Sudden wind impact
- First and second intercept
- Downflooding
- Water- and weather-tightness

Nowhere in the regulations, the influence of waves is seen unless one views the escape of “alternative stability criteria” as offered in some rules as a means to include the effect of waves.

The approach shows that the evaluation of safety is done in a simplified and schematic way. This has the advantage that it lends itself for an analysis which should give equal result independent of the calculation method. But, there are two problems with this approach. First, it is a very schematic representation of how a rig capsizes. In nature, waves will be present and the wind will not suddenly rise to the maximum value. Second, doing the calculation in a correct manner is not as simple as it looks. Quite often, we have seen that heeling axis directions are investigated which have no link with reality. A particular problem is that -as customary with ships- free trim is to be used. In some cases, it can be shown that when using free trim and selecting an unfortunate axis direction, the rig is never allowed to leave the quay.

On the other hand, the present rules do not give much room for improvement. To improve the situation one has to go back to the basics and develop a better understanding of the capsize mechanism.

Experience with a variety of structures shows that even a seemingly simple stability calculation is not as straightforward as it looks. Note that the maximum loading condition of the rig and thus its commercial value depends on it. Therefore, it is stressed that unrealistic results of stability calculations must be avoided.

Stability calculations

There are various ways to perform a stability analysis. The most simple and failsafe approach is where the axis is fixed and rig is heeled around this axis with zero trim. Various axis directions are to be investigated to arrive at the most critical one.

Similar as with ships, free trim was introduced as a means to obtain the lowest righting arm curve. For a given axis direction and heel angle, free trim results in the lowest potential energy contained in the rig. The reason being that by setting the rig free to trim, potential energy is released which would otherwise be present due to forcing the rig to have a non-zero trim moment. But this is only true when the rig is stable in trim.

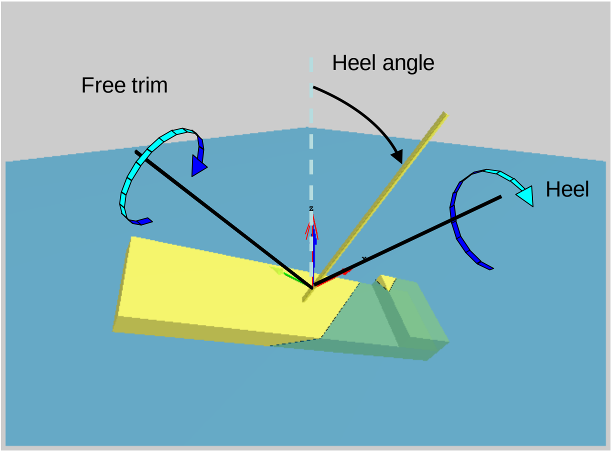

Fig. 5: Definition of heel and trim.

Within GustoMSC, the free twist method (also called variable axis direction) has been developed (Santen, 1986 and Santen, 2009). In this method, the direction of the heeling axis is varied such that the moment around the initial vertical axis is zero. By doing this, the trimming moment (being the horizontal component of the moment around the inclined twist axis) is zero whilst the trim angle is nil. In general, it results in the lowest energy build up in the system (van Santen STAB 2009).

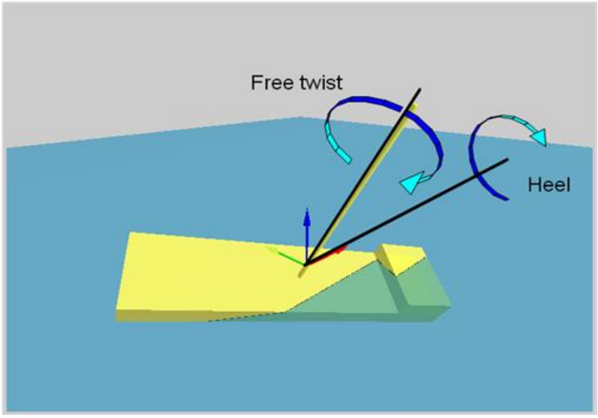

Fig. 6: Definition of twist and heel

Note that in the free trim method the waterline on an initially horizontal deck does not remain parallel with the heeling axis, see also figure 5. In contrast, for free twist, the waterline on an initially horizontal deck is always parallel with the heeling axis, see figure 6.

For ship-like structures, the free trim method is a sensible way to do the calculation. But, in this case the axis direction is always fixed to be the longitudinal axis. Would we perform the stability calculation for other axis directions, strange things occur. For instance, if we select a near transverse axis direction, the ship would experience large trim angles in order to get zero trim moment. As an example, consider a barge shown in figure 6. Figure 7 shows two righting arms for a longitudinal and almost transverse axis direction, whilst figure 8 shows the trim angles. For an axis direction of 80 degrees, large trim angles are observed.

By van Santen (STAB2009 and JU2009) more details are given for this case. Interestingly, for a ship, everyone will reject the righting arm obtained for a near transverse axis, but for offshore rigs it is not.

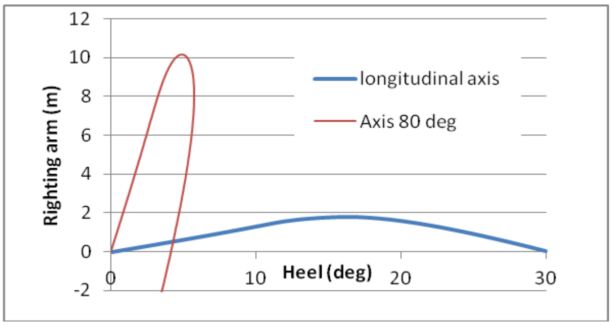

Fig. 7: Righting arms for free trim calculations for a longitudinal and almost transverse axis direction

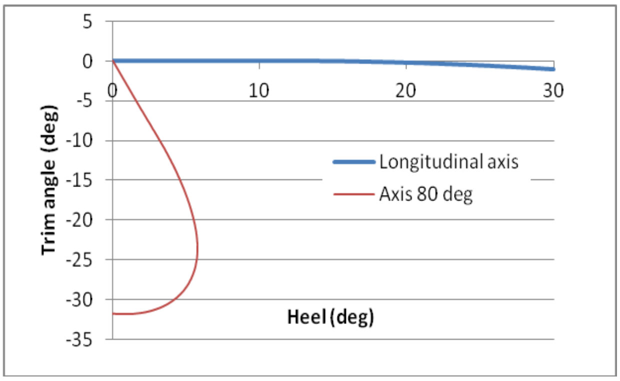

Fig. 8: Trim angles for free trim calculations for a longitudinal and almost transverse axis direction

Would we use free twist, the heeling axis direction remains almost longitudinal.
When using free twist, the energy in the system is minimized whilst heeling. The theoretical proof is given by Santen (STAB2009). For the barge, the free twist path is shown in figure 9.

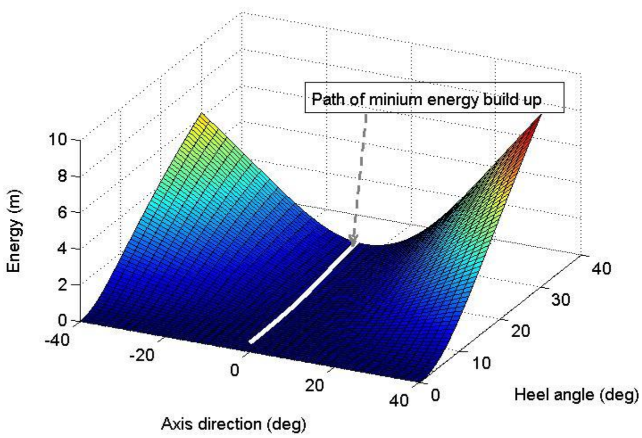

Fig. 9: Path of minimum energy build up for the barge

In this case, using free twist results in a realistic righting arm.

Large jack-up

For a triangular jack-up the preferred axis direction is not obvious and often an axis direction is selected for which large trim angles will be observed. An example is given for a large jack-up in intact condition which had to satisfy the NMD requirement of 30 degree range up to the second intercept with the wind arm. For an axis direction of 90 degrees the bow is pressed into the water. At around 25 degrees heel, a discontinuity in the curve is observed, see figure 10.
Would we force the heel to increase (which is the customary way to do the calculation) a jump in the trim angle will be observed, see figure 11. The proper continuation by the

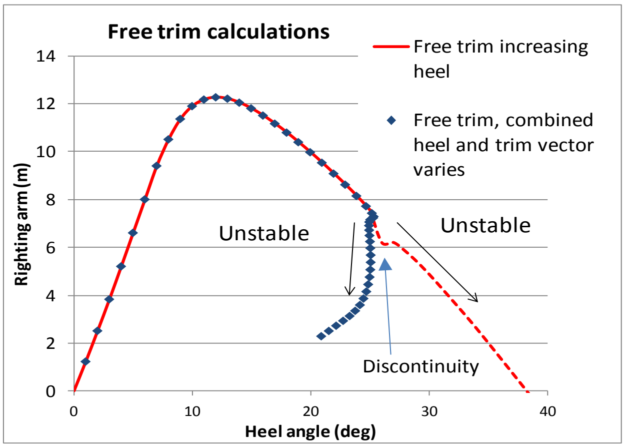

Fig. 10: Free trim calculations for a large jack-up, righting arm

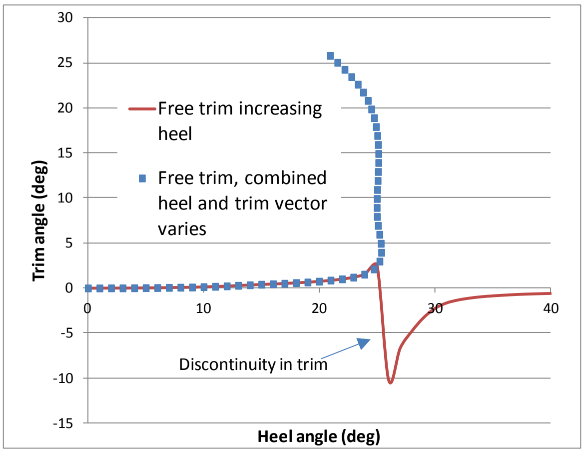

Fig. 11: Free trim calculations for a large jack-up, trim angle

backward sloping curve shows a gradual increase in the trim angle whilst the heel angle is to be reduced.

Most computer code can't calculate such a backward going curve. In a conventional calculation, the heel angle would be forced to increase beyond 25 degrees, which would result in a righting arm belonging to a completely different position which is not a proper continuation of the curve. This can be checked by looking and the rate of change in potential energy which should be equal to the energy input. Interestingly, even with zero VCG, the 30 degree NMD range can't be reached for an axis direction of 90 degrees. Would we use an axis direction of 270 degrees, the trim angle would be small and the 30 degree range would indeed be satisfied. This is shown in the energy plot, figure 12, for a draft 5.5 m where the VCB reaches a maximum (corresponding with the second zero crossing of the righting arm) for a heel angle of about 32 degrees.

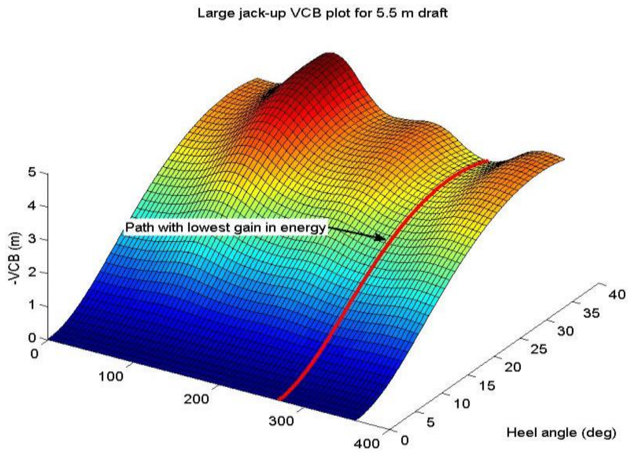

Fig. 12: Energy build up for a large jack-up

Small jack-up

Small wind turbine installation jack-ups are classed as jack-ups but their length over width ration is much larger than for the large drilling jack-ups. For operational reasons large centre compartments are present. When such a compartment is damaged the range of positive stability has to be larger than a specific value being 7+1.5*static angle. For the hull shown in

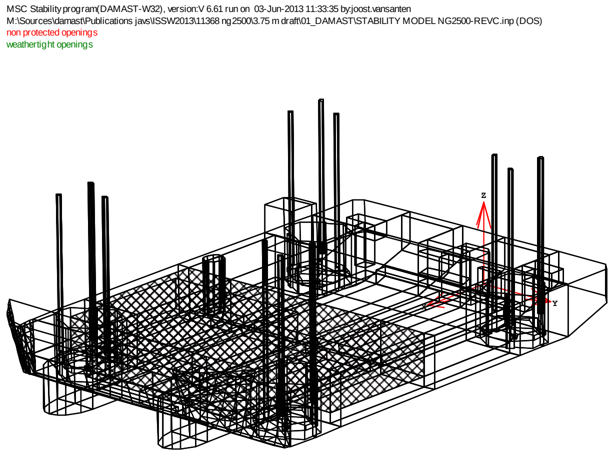

Figure 13, model of a damaged jack-up

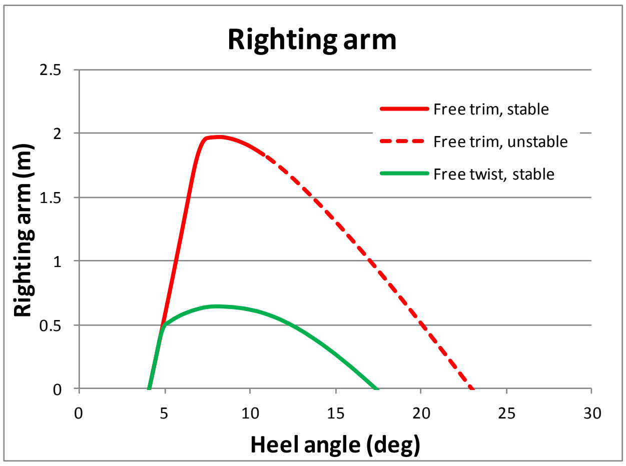

Fig. 14: Righting arms for small damaged jack-up

figure 13 with a damaged forward centre compartment, a free trim calculation results in a range of stability of about 19 degrees, see figure 14. A problem with the results is that for a heel angle exceeding 11 degrees, the vessel becomes unstable in trim. So, though the calculation indicates a range of positive stability of 19 degrees this would not be confirmed by actual testing as the vessel would capsize when heeled beyond about 11 degrees. The result of a free twist calculation shows a much smaller range of positive stability of about 13 degrees. For a proper interpretation it is necessary that in addition to the righting arm, the results must indicate if the vessel is stable in trim (or twist). Would we perform the stability calculation with a fixed trim (of 0 deg) the resulting righting arms do not cover either the free trim or free twist calculation, not even a reasonable manner, see figure 15.

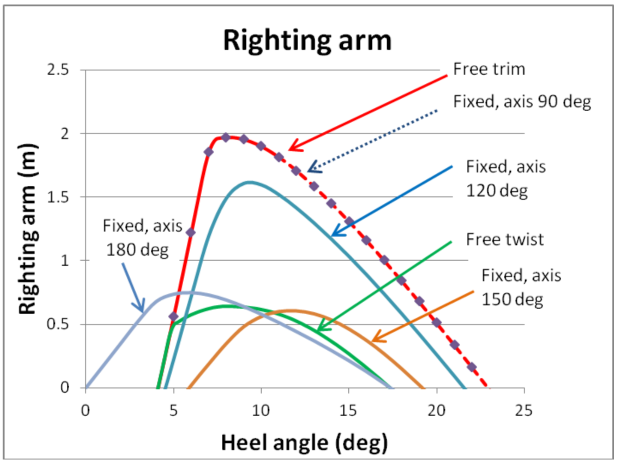

Fig. 15: Righting arms for various calculation methods

The reason for this is also seen in the energy plot for small heel angles. There is a sudden change when heeled from the equilibrium position (around 4.1 degrees heel) to larger heel angles.

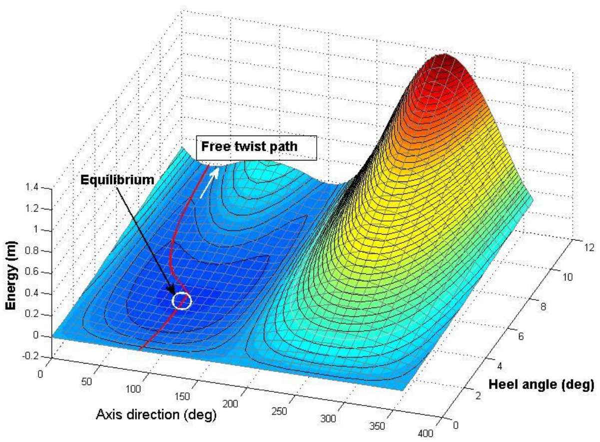

Fig. 16: Energy plot for the damaged jack-up at small heel angles

Semi submersible

Whilst the above suggest that free twist is the preferred method to calculate the righting arm, it is not free of problems of its own. For a semi submersible it is not uncommon that in a free twist approach, the righting arm curve has

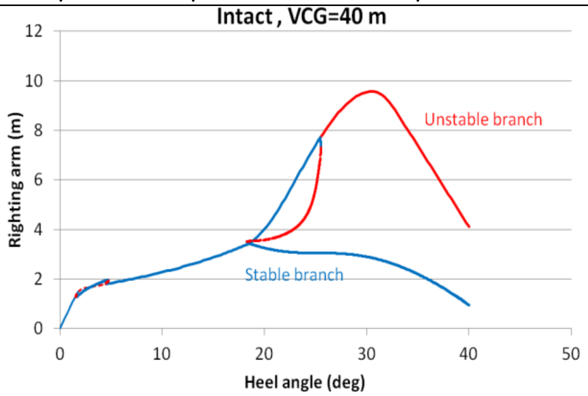

Fig. 17: Righting arm for a semi submersible, using free twist

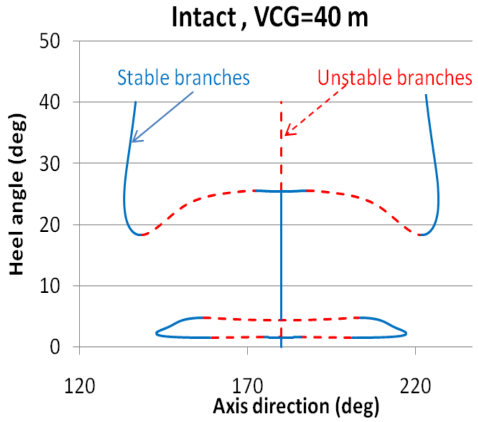

Fig. 18: Axis direction using free twist

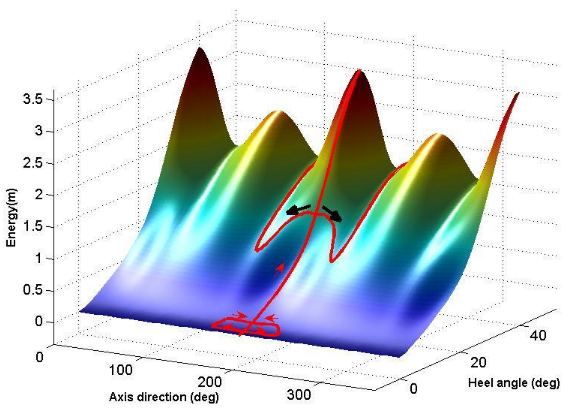

Fig. 19: VCB plot

unstable parts, see figure 17. When during progressive heel an unstable position is reached, the rig will suddenly change axis direction such that a new stable position is attained. This effect is visualized in figure 18 which shows the heeling axis direction for a free twist type of calculation and in figure 19

which shows the energy plot. In the energy plot, the path will follow the peaks and troughs, but only the troughs, being local minima, indicate stable positions. Note that when increasing the heel angle, the axis direction will suddenly change at a heel angle of about 26 degrees whilst for a decreasing heel angle it will suddenly change back at a heel angle about 19 degrees.
Modern semi submersible have a large amount of buoyancy above the waterline which makes it difficult to capsize them in intact conditions, even considering large waves. This is in contrast with jack-ups where the wave action is a factor to consider when looking at intact stability, (Standing et al 1999, van Santen 1999). Casualties with semi submersible are highly related to the rig not being intact anymore and thus susceptible to downflooding.

Conclusions

1. At this time, using stability parameters as a measure of safety ofoffshore rigs seems to be the only viable method. Though, especially for jack-ups, wave action can be important, there are no proven and generally accepted methods for dealing with wave action yet.
2. Allowing the rig to trim or twist freely is sensible as this generally leads to the slowest build up of potential energy for increasing heel angles. Thus the lowest righting arm curve is achieved.
3. Extending the free trim approach as used for ships to offshore units, in combination with a varying heeling axis direction, may lead to severe interpretation problems. Awareness of these problems is not widespread amongst the industry and requires more attention.
4. Observing large trim angles during the stability calculation indicates that the selected heeling axis is not proper.
5. Apart from choosing the proper axis direction, one must also take care that rig is stable in trim or twist up to the maximum heel angle needed for the evaluation of a particular criterion. Preferably the rig should be stable in trim or twist up to the point of capsize in heel.
6. The stability calculation procedure as now briefly given by class and authorities as “free trim” and “most critical” should be accompanied by a clarification note explaining how to do the calculation and how to handle the various problems met.

Recommendations

In the formal education of naval architecture more attention should be paid to the stability calculation of offshore rigs. It is essential that the students have a good understanding of the underlying principles. Also, it is important that results of computer programs should not be accepted without a good insight in the calculation method and in the validity of the results. In order to offer this insight, programs should output information like trim angle, axis direction (if variable), VCB value, stability of the position and identify possible discontinuities in the curve. It is the authors’ opinion that many programs fail in this respect.

Though in the 1980’s studies have been done into the possible capsize and downflooding of a semi submersible, there still is a need to improve actual knowledge of the capsize mechanism in a real world environment. This is especially true when considering stability of jack-ups.

Disclaimer

The opinions expressed are those of the author and not those of the company or organization that he is representing.

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