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# Introduction to the test cases

Stability analysis for offshore rigs differs from the usual stability analysis in the sense that the direction of the heeling axis is not fixed to be in the longitudinal direction. According to the regulations, one should analyze the stability for the most critical axis. As the regulations do not give a clear definition of both the calculation method and critical axis, differences may appear amongst the calculations done by various programs.

This document describes the standard test cases for stability analysis done with the method used by GustoMSC. This method and the test cases are well documented in various publications. The jackup example is based on the jackup case published by ABS, ref[1] and ref[3]. The semi submersible test case is a simplified model based on an actual design, ref[3].

A separate document gives the numerical results obtained for the two cases. That document is in landscape because of the width of the output.

The purpose of this document is to provide a set of test cases which can be used to verify software. The test cases const of models and results obtained.

References:

1 Breuer, J.A. and Sjölund, K.G., 2006, “Orthogonal Tipping in Conventional Offshore Stability Evaluations”, Proceedings of the 9th International conference on Stability of Ships and Ocean Vehicles (STAB 2006).

2 Santen, JA van, 1986, “Stability calculations for jack-ups and semi-submersibles”, Conference on computer Aided. Design, Manufacturer and Operation in the Marine and Offshore Industries CADMO 1986,Washington

3 Santen, JA van, The use of energy build up to identify the most critical heeling axis direction for stability calculations for floating offshore structures,STAB 2009 Conference St Petersburg

4 Santen, J.A., The use of energy build up to identify the most critical heeling axis direction for stability calculations for floating offshore structures, review of various methods, 12th Jack Up Conference 2009, City University, London

5 Santen, JA van, 2013, “Problems met in stability calculations of offshore rigs and how to deal with them”,International Ship Stability Workshop 2013, Brest

Note the following:

In the original STAB 2009 publication the width of the damaged compartment for the semisubmersible was indicated to be 7.0 m. This should be 6.0 m. So the flooded volume is 600 cubic meter.

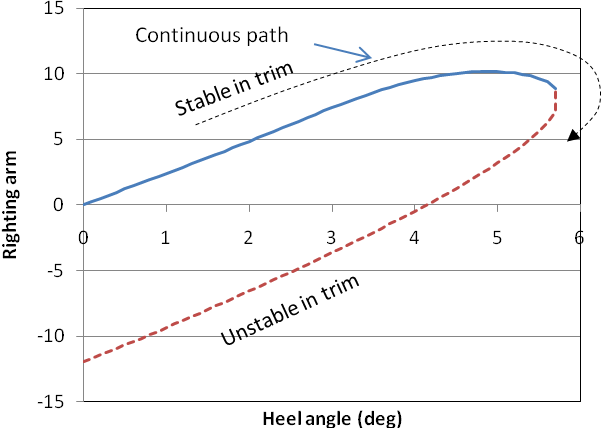
# Calculation method.

## Introduction

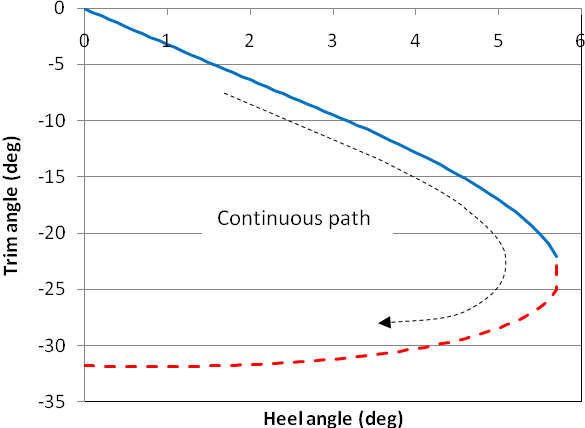
When analyzing the stability properties of offshore structures one has to find the most critical axis direction. In the Class requirements, one may also find that free trim is to be used. As discussed in refs[2-5] this can lead to serious problems in obtaining a realistic GZ curve. The reason to let the structure to trim for a given axis direction and heel angle is sensible as it reduces the amount of potential energy given by the distance between centre of gravity and centre of buoyancy. Instead of letting the structure to trim to achieve this low energy position, one can also vary the axis direction whilst the trim remains nil. As is shown in ref [3] allowing a free rotation around the initial vertical axis (“free twist” ) automatically results in the lowest energy build up for a given heel angle.

However, the combination of critical axis direction and free trim can lead to surprising results with prematurely stopping of the GZ curve which in fact curves backward one a modest heel angle is reached. Reference [3] contains an example of such a curve for a simple barge.

For instance when choosing an axis direction of 80 degrees, (which is almost a transverse) the GZ curve looks like:



The corresponding trim angle is given by:



For a ship type of structure is is obvious that an axis direction of 80 degrees is not proper, but for an arbitrary offshore structure it is not.

Would we use free twist, the following –realistic- results are found:

For the GZ curve:

For the axis direction:

When using a fixed axis direction in combination with free trim, the inclination of an initially vertical axis (rotating with the structure) is the combination of trim and heel angles. When using free twist, the inclination of an initially vertical axis (rotating with the structure) equals the heel angle.

In order to make valuable test cases, the presented data covers

* Fixed axis direction, zero trim, varying heel angles
* Fixed axis direction, free trim, varying heel angles
* Free twist (freely varying axis direction), zero trim, varying heel angles
* Equilibrium positions

The method used to obtain the numerical results is as follows:

1. the object is rotated, thus the waterline remains horizontal
2. the rotations are done for an axis system with the origin at the centre of gravity
3. for the selected direction of the heeling axis, the structure is rotated around a vertical axis. A positive direction of the heeling axis means that (seen from above) the structure is rotated clockwise by the selected angle.
4. The heel angle is applied by rotation the structure around the heeling axis.
5. When (free) trim is used, the structure is rotated around an inclined axis which was horizontal before applying heel. This axis is fixed to the structure and perpendicular to the heeling axis. The heeling axis is kept horizontal.

Steps 4 and 5 can be interchanged as the trim rotation is around a structure fixed axis system:

4. Apply trim around a horizontal axis perpendicular to the heeling axis. Keel the heeling axis horizontal

5. Apply heel by rotating the object around the horizontal heeling axis

This is shown schematically in the figure on the next page.

Note that the way the object is rotated does influence the results



In terms of Eulerian angles:



# Free trim and free twist

Free trim

For a freely floating body on which only an overturning moment acts, the moment around a vertical axis is zero. Hence, the restoring moment vector has a horizontal direction, parallel to the water plane. In the free trim method, the moment around an axis perpendicular to the heeling axis is made to be zero by giving the object a trim angle. This trim angle is usually found by an iterative search. For a ship shaped object, the trim angle required to have zero trim moment is usually quite small. For an object shaped like an offshore structure being it a jack-up or semi submersible, the trim angle needed to achieve zero trim moment can be quite large, see the references.

Free twist.

The free twist method was introduced by GustoMSC, see the CADMO 1986 paper, ref[2]. Others (like GHS and NAPA) use similar methods, named variable axis direction or alike. The basic idea is to change the direction of the heeling axis whilst keeping the trim angle to zero. This method avoids problems met when using free trim. The references discuss these problems and how free twist can be a solution.

# Details of the calculation of the hydrostatic properties

The calculation method to obtain the results presented here is given in the CADMO 1986 paper. It is based on a description of the object by a collection of compartments each described by flat planes. In this way, the hydrostatic properties can be calculated in an exact manner without the approximations associated with slicing up the object in frames. This method is very precise without small irregularities in the results. So, when using a different approach, small deviations from the results presented here can be present. Note that the models used in the calculations are not the Rhino models found in the package.

As is customary, the heel angle is changed by a constant step. For free twist, using a starting angle of zero degrees gives problems as any axis direction will result in zero trimming moment. Hence, for zero heel, any axis direction satisfied the zero trimming moment condition. Therefore, when using free twist, the process is reversed by starting at a large angle.

For some cases, steadily increasing or decreasing the heel angle may cause the calculation to stop prematurely. As discussed in the references, a continuous curve can be found by a steady change in the combined heel- and axis vector. In the program this is called free twist automatic. The end heel angle in the table below (with the cases) is artificial as it is only used to determine the total number of steps to be calculated.

During the inclination process it is possible that a jump in righting arm curve is observed. This occurs when the GZ obtained from two consecutive heel angle are not a proper continuation of the curve (see the references). In the output, this is checked by looking at the change in potential energy (being the change in VCB relative to Centre of Gravity) and the change in area under the GZ curve. When a mismatch is found a question mark is put in the appropriate line.

When a position is unstable (in trim or twist), the line is set to having a red font.

# Testcases

Tow test cases are available. One is a jackup, the other a semi submersible.

## Jackup

The shape is shown in the figure below. It is the same as found in ref[1].



The shape given above shows the outer boundary. No additional corrections for shell or appendages are applied. The shaded area indicates a possible damaged compartment. In the calculation the permeability of the compartment is set to 1.0.

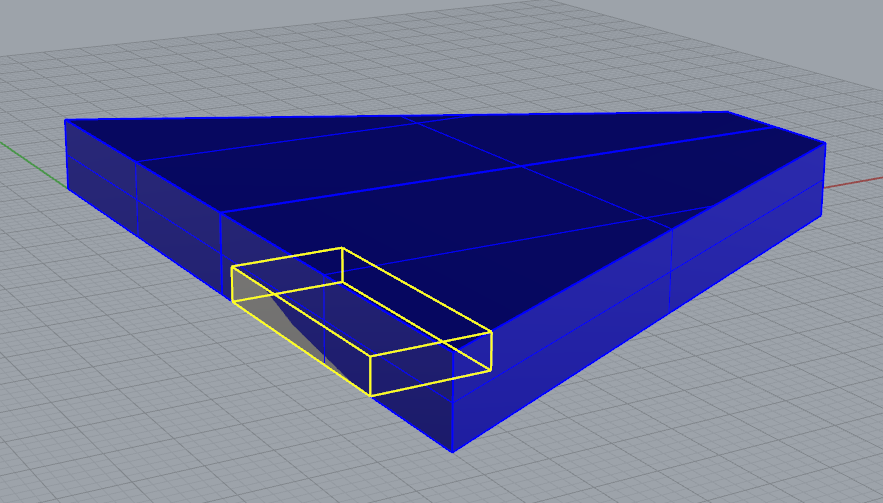
## Semi submersible

The semi submersible is a simple 4 column, 2 floater design shown below. Also for this rig, no additional coefficients for shell and appendages are used. The permeability for compartment damage is set to 1.0. For this rig, the transit draft of 9.10 m is used.

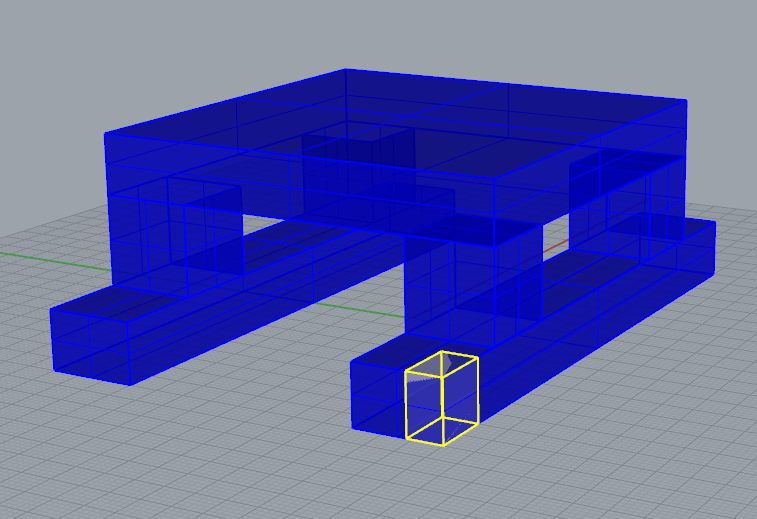


## Rhino files

The package also contains Rhino files. The shape of the jack-up in the rhino file is given below. It’s even keel intact hydrostatic properties have been verified with the original mode and found in excellent agreement.



The shape of the semi submersible in the rhino file is given below. Also for this model, it’s even keel intact hydrostatic properties have been verified with the original mode and also found in excellent agreement.



The following units are used:

Length: meter

Volume: cubic meter

Displacement t(on)

Angles: degrees

# Explanation of the results

Each block of data has a header with general information:

**Stability program(DAMAST-W32), version:V 6.65 used by GustoMSC Page 1**

**Run on 21-Nov-2013 09:15:29 by:joost.vansanten**

**Rig name:**

**Project :**

directory:M:\Sources\damast\Publications javs\Paper stab 2009\dss simple

files:

M:\Sources\damast\Publications javs\Paper stab 2009\dss simple\damastin-6m damage.txt (DOS)

**normal right handed axis system used**

**STABILITY, no trim, no twist**

no blocks defined

Number of compartments:9 (prismatic:4 bracing:5 cones:0 facet:0 group:0 and disabled:0)

No damaged compartments

specific density : 1.02500 tf/m\*\*3

shell and appendages: 1.00000

**Weight and CoG, defined relative to input axis system, for even keel**

Weight (t) X(m) Y(m) Z(m)

Fixed weight : 28000.000 0.000 0.000 40.000

Tanks : 0.000 0.000 0.000 0.000

============================================

TOTAL : 28000.000 0.000 0.000 40.000

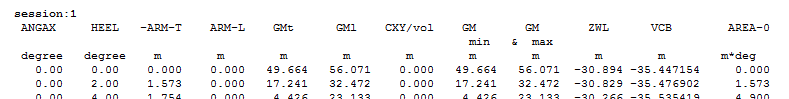
even keel draft relative to input origin: 9.106, intact

axis from: 0.00 to: 0.00 step: 30.00

heel from: 0.00 to: 30.00 step: 2.00

trim : 0.0

Next, the results are given, as an example:



Meaning of the used abbreviations:

ANGAX direction of the heeling axis

Heel Heel angle

-ARM-t restoring arm, being the Y position of the centre of buoyancy relative to the Centre of gravity. As this value is negative for small angle, is has the minus sign in front of it.

ARM-L trimming arm, being the X position of the centre of buoyancy relative to the Centre of gravity.

GMt metacentric height for heel. For non zero heel, it is the instantaneous value.

GMl metacentric height for trim. For non zero heel it is the instantaneous value.

CXY/vol cross product of the waterline inertia around its centre divided by the submersed volume: ∫ x y dAwl /volume

GM min minimum metacentric height considering Mohr’s circle for the waterline area

GM max maximum metacentric height considering Mohr’s circle for the waterline area

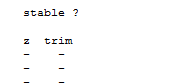
ZWL vertical position of the waterline above the centre of gravity

VCB vertical position of the centre of buoyancy above the centre of gravity. This is a measure for the potential energy in the system

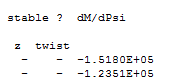
AREA-0 area under the righting arm curve starting at the first upward crossing

When performing a free trim or free twist calculation, additional information about the stability of the position is given.

Free trim:



Free twist:



The value of dM/dPsi is the derivative of the moment around the (heel, inclined ) twist axis for a variation in axis direction.

# Cases

Results for the following cases are presented. These cases are also discussed in ref[3 and 4].

## Jack up

Cases 5 and 6 are cases which start with a large heel angle, axis direction about 30 degrees. It is the left branch shown in the next figure. For case 5 the heel angle is steadily decreased. For case 6 the *vector sum* of the step in heel and axis direction is steadily decreased. This caused the path to follow the indicated arrow instead of going down to zero heel.



Such a path can only be obtained by varying the combined heel and axis direction change vector.

Cases 7 and 8 cover the damaged cases using free twist:



Case 10 represent the damaged case using free trim. It uses an axis direction near the axis directions found for free twist, case 9.



Semi submersible:



The path for cases 3, 4 and 5 are as shown below



The path for case 9 is shown below:

