A quick method for the stability of jack-up platform towage

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Abstract: The stability of floating structures has long been one of the focuses of design. And more and more classification societies have issued the regulations documents for stability calculation. But these classic algorithms above are not concise. Especially when the angle of inclination is greater than 10 or 15 degrees, the calculation was tedious and not so accurate. This article introduces a quick and effective way by using the method of successive approximation. Its advantage is that we could reduce the calculation process. Guided by this thought, we can calculate the area of the transverse at large-angle first. And then we can get the value of stability subsequently. As comparison, a self-elevating platform is modeled by MAXSURF and then imported into the stability modules for further calculation. The result shows that the theoretical calculation result is coincided with the MAXSURF’s and the method introduced by this article is feasible.

Keywords: stability; jack-up platform; theoretic calculation.

1. Introduction

The problem of stabilities was born with the marine structures design. And the study on this has been going on for years. For now, the solution to the initial stability is relatively mature. Various stability calculations have discussed it in detail [1]-[3]. As for large angle stability, Gillmer T C et al[4] established an equation by the assumption of gravity. And this theory was well applied at that time. However, as people become stricter with the design, traditional calculations based on assumption of gravity don't behave so well on the condition of large-angle heeling. Marine structures like ships and platforms always suffer strong winds or waves all the year round.

Barrass B, Derrett C D R et al[5] did some research on the free surface area influence to stability. The inertia moment of the free surface did have influence to the stability. For the jack-up platforms in the course of towage are always set some ballast tank in order to satisfy the requirement. The influence should not be discounted. This article discussed it in detail.

LI Z, YANG Y, DU J et al[6] studied the stability of ships in the still water in detail. While calculating the wetting depth of the left and right side face of the transverse section with the step by step approaching methods, the influence of the trim which acts on the wetting depth of the every transverse section caused by the asymmetry of the fore and stern of ship is considered in their article.

ZHANG S, LI Z et al[7] took waves in to account based on the former conclusion. Then they stated that in accordance with the condition of the balance of the gravity and buoyancy and the condition that the sum of the trim moment is zero, the value of stability in rolling can be calculated.

But the calculation process above is so lengthy that it is not convenient to use in practical application. For these reasons, this article introduces the classical theory first and then raise an effective method to solve this problem. In order to simply the calculation, we will make the following assumption. First, the body is in the still water. Second, the waterplane is horizontal and remains unchanged. Upon these fundamental assumptions, we can deduce the algorithm further.

2. Theory outline

2.1. Classical theory

The stability of platform in the course of towage is similar with the ship's. Traditional statics divide stability calculation into two parts. They are initial stability and large angle stability. For the former one, its statical stability lever is represented by the following equation:

$$GZ = GM \sin \phi$$

The above formula is based on two assumptions:
(1) the structure’s rotational axis passes through the center of buoyancy.
(2) the flotation movement curve is a part of arc whose center is initial metacenter M and radius is initial metacentric radius \( BM \).

But when the heeling angle is larger than 10 or 15 degrees, the former theory will not be established. In other words, it is the large angle which may cause the immersed wedge volume asymmetry that makes the theory false. The asymmetry immersed wedge volume directly causes initial metacenter \( M \) no longer the intersection of the line of action of the buoyancy force and center line. And \( M \) could not be seen as a fixed point. So formula (1) is not applicable now. To solve this problem, we can use the righting arm to represent the stability. This is the length of the perpendicular drawn from the centre of gravity to the line of action of the buoyancy force. As shown in the Figure 1, the statical stability lever may be expressed as the following form:

\[
GZ = B_0R - B_0E
\]

In this formula, \( B_0R \) represents transverse horizontal distance which the center of buoyancy moves; \( B_0E = B_0G \sin \phi \), its value depends on gravity center position, called lever of gravity stability. We can see that the arm is decomposed into two terms, one depending on the ship form, the other on the vertical distribution of ship masses.

![Figure 1](image)

For a given displacement and centre of gravity, the display of the righting arm versus the heel angle is the curve of statical stability. In order to draw this curve, we have two methods. One is called variable displacement method and the other called equal displacement method. But both methods need special instrument and will cost lots of labor and resource. And the results are not satisfactory in the end. So looking for a quick and effective method is particular in the quick rhythm time of modernization.

### 2.2 Improved theory

For jack-up platforms, what we concerned with is the stability in course of towage. Though the platform’s shape is more regular than ship’s, we couldn’t use the Initial stability formula to replace its stability on the condition of large angle. Inspired by the traditional theory, we can get the accurate answers with the help of computers now.

As we know, the righting moments could be represented by the following equation:

\[
D_g \cdot l_0 = \rho g \int A(x)dx - D_g \cdot OG \sin \phi
\]

In this equation, \( D_g \) represents the mass; \( OG \) is the vertical dimension between barycenter and original point; \( \phi \) stands for the rolling angle; \( A(x) \) is the area of transverse section; \( y_{B1(x)} \) is the coordinate of the transverse center in the inertial coordinate system. The latter two parameters are the keys in the solving process. We will discuss them in detail next.

According to Figure 2, \( A(x) \) can be represented by an equation:

\[
A(x) = \int_0^Z 2b(z)dz + \int_0^Z b(z)dz + \int_0^Z b(z)dz + \frac{1}{2} \left[ b^2(z_1) - b^2(z_2) \right] \tan \phi
\]

From the equation, we can see that we introduced two variables- \( Z_1 \) and \( Z_2 \). They represent both side intersections of the tilted waterline and the object line called “immersion”. So the problem turns into how to
solve these two variables. With a standard transverse section, for example, the improved draft $T'$ equals the difference between original draft $T$ and $Z_s$.

During the solution to $Z_s$, we could divide the distance between $d_m$ and $T'$ into $n$ parts. So we can get the expression for $Z_s$.

$$Z_s = T' + \frac{x}{n} \cdot \frac{d_m - T'}{n}$$

(5)

And we can also get the expression of abscissa value of $x$ in the original coordinate system.

$$y(Z_s) = \frac{T' \cdot \tan \phi}{T}$$

(6)

Then, we could compare $y(Z_s)$ with the interpolation value $b(Z_s)$ by using the step-by-step method. When the difference between them approaches zero, $Z_s$ will reach its accurate value. Though we may face other situations beyond this normal case, the calculation principle is still applied.

For calculating $l_z$, the counting process is similar with the above we have discussed. What is noteworthy is that we should establish an equation to judge how to calculate the immersions for different shapes.

Now we have got these pairs of parameters and we can plug them into formula (3) to calculate $A(x)$. Because the structure's longitudinal moments must be zero. We can get the following equation:

$$\int_{x_{1}}^{x_{2}} xA(x)dx = 0$$

(7)

Plugging $A(x)$ into the equation above, we can get the true value of $Z_s$. The obtained value $Z_s$ can be looked as a point of rotation which depends on the draft to the distance between it and the deck ratio. The greater this ratio is, the farther distance between them will be. The significance of this point is that when the structure heels at big angle, both side volume what we call “immersed wedge volume” and “emerged wedge volume” is nearly the same.

After getting the value of $A(x)$, we are able to solve $y'_{B(x)}$ in the next. As the above process, we could research a certain section and divide this section into $n$ parts. And then we can easily get the coordinate values of the center of area by using the area center formula. Because our calculation is in the inertial coordinate system, we should switch the values to this coordinate system. We could use the following coordinate formula for transforming here:

$$y'_{B(x)} = y_{B(x)} \cos \phi - z_{B(x)} \sin \phi$$

(8)

For some regular platforms’ shapes, we could get the coordinate values of center point by using CAD's order “massprop” after we build a solid model. Then we can complete the calculation by using the parameters we get above in formula (3). Finally, we can get a series of values of $l_z$. Using these values as X-axis and the degrees as the Y-axis, we can draw a curve. And this is what we call “statical stability curve”. If we want it fairer, we can calculate more sections to reach this target.

3. Calculational Example
In order to verify the correctness of the calculation we discussed above, we will compare our results with the Maxsurf's. Because our theory is aimed at preliminary platform design and there is no available heeling experiment data. Considering this mainstream software's accurate calculation results, we are certain that it can reflect the fact well. We choose a jack-up platform (Figure 3) in Bohai Sea as an example. Its principal dimensions are listed as follows:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Hull</td>
<td>43 m</td>
</tr>
<tr>
<td>Breadth Moulded</td>
<td>36 m</td>
</tr>
<tr>
<td>Depth Moulded</td>
<td>4.5 m</td>
</tr>
<tr>
<td>Length of Legs</td>
<td>60 m</td>
</tr>
<tr>
<td>Light Ship Weight</td>
<td>3522 t</td>
</tr>
</tbody>
</table>

Aiming at reducing the calculation amount, we select one of the towage conditions for calculating. The platform is assumed in still water. Its draft is 3.0m. The centre of gravity is the point that coordinates, 18.765, 0.0006, 11.321. And other parameters are not listed in detail.

According to the data above, we can get the curve of statical stability below (Figure 4) on this condition by using the improved theory. In the figure, GZ represents the lever of statical stability and deg represents the heeling degrees.

For comparison, we build a simplified model like Figure 5 which doesn't contain the small influence caused by the superstructure and the free surface area. After setting some basic parameters like base line, zero point and DWL, we can import this model to the stability module for calculation. Before we start the analysis, we should finish the “load case” and “input” table at least. If we take the damage stability into account, we may set the damage table for more accurate result. But we don’t concern about this in this example. After all of these done, we can arrive at another curve like Figure 6.
4. Conclusion

By comparing the curves drawn in Figure 4 and Figure 6 calculated in part three, we can draw the following conclusions:

(1) Both results meet the criteria “GUIDELINES FOR TOWAGE AT SEA” well. This paper of guidelines requires initial stability height GM greater than 0.3m and the angle of vanishing stability beyond 35 degrees. From the figure, we can see that the result of the improved theory is more conservative than the MAXSURF’s and meets the need of safety production.

(2) Though all of the theory is based on the still water, the core thought-Turn the macro question into certain section's question- is also applied to other situations where structures suffer winds and waves. The difference between them is that the expression of $A(x)$.

(3) The difference between these two results may be caused by the platform's trim. Because the platform which is in the course of towage has a trim angle in fact. But when we make the calculation, especially calculating every section of the body, we don't concern about this factor. And this is what we need to study in the next step.

(4) Besides the difference and imperfection above, the improved theory mentioned in this article does help the calculation of stability in some ways and have a certain reference.

Future work will focus on the influence caused by the asymmetry of the fore and stern of ship and the free surface area to the stability when the platform heels. And then use this theory as the basis for researching the stability of structures which suffer waves and winds.
Acknowledgements

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References