Stability of Grounded Ship

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Abstract: The objective of this paper is to present an algorithm for computerized calculation of hydrostatic stability of a vessel in grounded/stranded condition. This is based on the physics of floating bodies and follows the quasi-static approach of usual conventional Naval Architectural calculations.

Key words: Buoyoancy , Statical Stability , Dynamical Stability, Pinnacle, Equilibrium, Heel, Trim ,Capsizing, Stranding

1. Introduction

Grounding is defined as the ship being aground or hitting/touching shore or sea bottom or underwater objects (wrecks etc.). Ship stability in grounded condition is no less important than the same in free-floating condition. Grounding/Stranding of ships is not exception; in fact numerous cases of ships' grounding have indeed been reported in the past and contributed to the significant number of marine accidents so it deserves greater attention in maritime safety. The grounding of tanker Braer (1994) is worth mentioning in this context.

As far as the knowledge of the author goes, there exists no international rules/regulations as of today which explicitly addresses the issue of stability of ship in grounded condition.

The author feels this aspect warrants investigation in course of design of the ship. Further, this is of prime necessity during salvage operation in case of real accidents involving grounding/stranding of the ship and also during dry docking of ship. Calculations are to be made to establish intact and damaged statical and dynamical stability for the vessel in grounded condition.

If a ship runs aground in such a manner that the bottom offers little restraint to heeling and/or trimming, as illustrated in fig-1, the reactions of the bottom may produce a heeling and/or trimming moment. As the ship grounds, part of the energy due to its forward motion may be absorbed in lifting the ship, in which case a reaction, R, between the bottom and the ship would develop. This reaction may be increased later as the tide ebbs. Under these conditions, the force of buoyancy would be supported by the combination of buoyancy and the reaction of the bottom. The ship would heel and/or trim until the moment of buoyancy about the point of contact with the bottom became equal to the moment of the ship's weight about the same point.

In case a ship stranded/settles on a fairly flat bottom, the transverse stability is of no relevance.

There is less possibility of a stranded ship capsizing as the result of ebbing tide. For this to occur it would be necessary for the ship to be grounded on a bottom such that there is no restraint to heeling in one or both directions until a very large angle is reached, as, for example, on a peak which was considerably higher than the surrounding bottom. When a ship is aground in the manner, as illustrated in Fig - 1, the heel would increase as the tide ebbs.

An algorithm for developing suitable software in order to accomplish such calculations for the investigation of vessel's stability in grounded condition have been illustrated in this paper. The algorithm is based on the principles of rudimentary physics and conventional procedure of Naval Architectural calculations.

It is assumed that the reader of this paper is generally conversant with the aspect of ships' stability and related Naval Architectural calculation.

Two types of grounding have been considered in this paper – Grounding on 'One Pinnacle' and on 'Two Pinnacles' as illustrated in Fig-2 & Fig-3 , the latter (i.e. the two pinnacle case) can be extended to the case of shelf stranding.

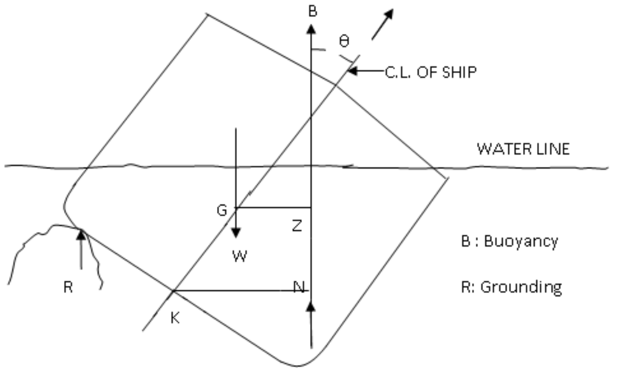

Fig: 1

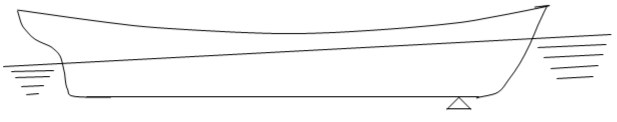

Fig – 2 : Grounded on Single Pinnacle

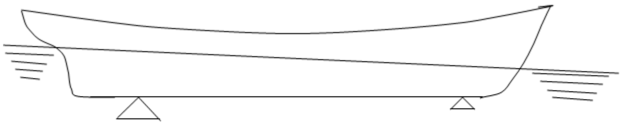

Fig – 3 : Grounded on Two Pinnacles

2. Method:

A step by step description of the algorithm has been presented here as follows. The description features some computer commands for explanatory purpose only, hence not to be looked for the syntactic correctness of the same. The illustration of the nomenclatures used in this paper has been given in Appendix - 3.

The flowchart as given in Appendix – 2 may also be referred for the logical sequence of the method.

Step 1:

A set of predefined values of the drafts (Tk=1,nd), angle of heels (θi=1,nh) and angle of trims (ϕj=1,nt) where nd = No. of drafts; nh = No. of heels; nt = No. of trims have been selected.

Step 2:

The array of hydrostatic parameters i.e. { WPA, LCF, TCF, IT, IL, VOL, LCB, VCB, TCB, KN } are determined for the vessel in the orientation at each of the combinations of predefined drafts, heel and trim conditions.

As it can be observed that a large amount of computation is involved in this step.

No. of calculation sets = No. of Drafts X No. of Heels X No. of Trims).

It is, therefore, obvious that manual calculation will be extremely tedious to accomplish, hence an appropriate computer routine is essentially needed for the task. The formulation for calculation is given in Appendix –1.

Step 3:

A data file is created compiling the values of the array of the hydrostatic parameters {WPA, LCF, TCF, IT, IL, VOL, LCB, VCB, TCB, KN} as obtained from Step-2.

This data file essentially contains ship-specific data as mentioned here below and is named in this paper as 'Vessel.inf'.

[Vessel.inf] 〈 { θ(i) , ϕ(j) , T(k), WPA(i, j, k); LCF(i, j, k); TCF(i, j, k); IT(i, j, k); IL(i, j, k); VOL(i, j, k); LCB(i, j, k); VCB(i, j, k); TCB(i, j, k) ;KN(i, j, k) } i=1, nh; j=1, nt; k=1, nd

Another data file is created to store information with regards to the situation when the vessel is grounded. This data file is named in this paper as 'Situation.inf' and contains the variables as shown below -

[Situation.inf] 〈 { ng; xg(i); yg(i); dg(i) } i=1, ng

Step 4:

In this step the mean draft at midship 'dref' for the vessel is determined.

```
Case-A: No. of Grounding Pinnacle = 1
        DO 10    j = 1, nt
        trim (j) = tan(ϕj)
10      dref (j) = dg (1)-xg(1) * trim(j)/LBP

Case-B: No. of Grounding Pinnacles = 2
        DO 11    j = 1, nt
        trim (j)=tan(ϕj)
11      dref (j)=dg(2)-xg(2)*
              (dg (2)-dg(1))/(xg(2)-xg(1))
```

Step 5:

Determine the hydrostatic parameters of the vessel for each of the combinations of, Heel and Trim conditions, and at the draft of 'dref (j)'.

```
    DO 20    i = 1, nh
      DO 20    j = 1, nt
      DO 30 k = 1, nd
      wpa1 (k) = WPA (i,j,k)
      lcf1 (k) = LCF (i, j,k)
      tcf1 (k) = TCF (i, j, k)
      it1 (k) = IT (i, j, k)
      il1 (k) =IL (i, j, k)
      vol1 (k) =VOL (i, j, k)
      lcb1 (k) =LCB (i, j, k)
      vcb1 (k) =VCB (i, j, k)
      tcb1 (k) = TCB (i, j, k)
30    kn1 (k) = KN (i, j, k)

      D = dref (j)
      wpad(i, j) = Intp { nd,T(k),
                 WPA1(k), D }
      lcfd(i, j) = Intp { nd,T(k),
                 LCF1 (k), D}
      tcfd(i, j) = Intp { nd,T(k),
                 TCF1 (k), D}
      itd(i, j) = Intp { nd,T(k),
                 IT1(k), D}
      ild(i, j) =   Intp { nd,T(k),
                 IL1(k),D}
      vold (i, j) = Intp { nd, T(k),
                 VOL1(k), D }
      lcbd(i, j) = Intp { nd,T(k),
                 LCB1(k), D}
      vcbd(i, j) = Intp { nd,T(k),
                 VCB1(k), D   }
      tcbd(i, j) = Intp{ nd,T(k), TCB1(k),D   }
20    knd(i, j) = Intp { nd,T(k), KN1(k), D   }
```

Step 6:

In case of grounding at one location (i.e. one pinnacle case) the lever ordinates to match the longitudinal moment about the grounding location for equilibrium trim at the defined angles of heel and at drafts = 'dref(j)' can be determined as follows.

```
      DO 40    i = 1, nh
      DO 40    j = 1, nt
40    TRMLEV(i, j, D) = vold(i, j) *ρ * (xg(1)
      –  lcbd(i, j)) - W*(xg(1)-LCG)
```

Step 7:

Now, the equilibrium trim and mean draft at midship corresponding to each of the predefined heel angle is determined

```
Case-A: No. of Pinnacles = 1
        DO 50    i = 1, nh
        DO 60    j = 1, nt
60      trmlev1 (j) = trmlev(i, j, D)
        etrm(i) = Intp { nt, trmlev1(j), trim(j),
        0.0 }
50      dref (i) = dg (1)-xg(1) * etrm(i)/LBP

Case-B: No. of Pinnacles = 2
        DO 70 i = 1 , nh
```

```
        etrm(i) = (dg(2)-dg(1))/(xg(2)-xg(1)) * LBP
70      dref(i)=dg(2)-xg(2)*(dg(2)-dg(1))/(xg(2)-xg(1))
```

Step 8:

Determine hydrostatic parameters for each of the pre-defined heel angle at their corresponding equilibrium trim angle.

```
        DO 80    i = 1, nh
        DO 100   j = 1, nt
        vol2 (j) = vold (i, j)
        lcb2 (j) = lcbd(i, j)
        vcb2 (j) =vcbd(i, j)
        tcb2 (j) =tcbd(i, j)
100     kn2(j) = knd(i, j)
        etvol (i) = Intp { nj, trim(j), vol2(j), etrm(i) }
        etlcb (i) = Intp { nj, trim(j), lcb2(j), etrm(i) }
        etvcb(i) = Intp { nj, trim(j), vcb2(j), etrm(i) }
        ettcb(i) = Intp { nj, trim(j), tcb2(j), etrm(i) }
80      etkn(i) = Intp{nj,trim(j),kn2(j),etrm(i) }
```

Step 9:

Determine grounding reactions (R1 & R2) and the values of Vertical Centre of Gravity and Transverse Centre of Gravity (VCGG & TCGG) for the vessel in the grounded condition in the orientation of equilibrium trim and at each of the predefined heel angle.

```
        DO 150 i = 1, nh
        IF No. of Pinnacle = 1
        R1 = W – etvol(i) * ρ
        ettcg(i) = (W*TCG-R1 * yg(1))/(etvol(i) * ρ)
        etvcg(i) = (W*VCG)/(etvol(i) * ρ )
        ELSEIF No. of Pinnacles = 2
        R1 = { etvol(i) * ρ *(xg(2) – etlcb(i)) – W * (xg(2) – LCG) } ÷ { xg(1) – xg(2) }
        R2 = { (W – (etvol(i)) * ρ } – R1
        ettcg(i) = (W * TCG – R1 * yg(1) – R2 * yg(2))/(etvol(i) * ρ)
150     etvcg(i) = (VCG*W)/(etvol(i)* ρ)
```

Step 10:

Determine transverse moment lever and also the statical stability levers at each of the pre-defined angle of heel (θ).

```
        DO 170     i = 1, nh
        LEVHEEL (i) = (etvol(i) * ρ *ettcb(i) - etvol(i) * ρ * ettcg(i))
170     GZGR(i) = etkn(i) – ettcg(i) * Sin(θi) - ettcg(i) * cos(θi)
```

Step 11:

Now, the final condition of equilibrium is determined as follows.

```
    θeq = Intp { nh, LEVHEEL(i), θ(i), 0.0 }
        AND the equilibrium trim
    ϕeq = Intp { nh, θ(i), etrm(i), θeq }
        And the equilibrium draft
    Teq = Intp { nh, etrm(i), dref(i), ϕeq }
```

The etrm(i) and dref(i) are obtained from Step - 7
Hence, the final equilibrium condition of the vessel is now established.

Step 12:

The hydrostatic parameters of the vessel at the final equilibrium condition are determined in this step

```
    EQVOL = Intp { nh, θ(i), ETVOL(i), θeq }
    EQLCB = Intp { nh, Q(i), ETLCB(i), θeq }
    EQVCB = Intp { nh, Q(i), ETVCB(i), θeq }
```

Step 13:

R1, R2, EQTCG, EQVCG, EQGM and EQDraft are determined as follows.

```
If
    No. of Pinnacle = 1
    R1 = W – EQVOL * ρ
    EQTCG = (W * TCG – R1 * yg(1))/ EQVOL * ρ
Else
```

```
    No. of Pinnacles = 2
    R1 = {EQVOL (i) * ρ *(xg(2) – EQLCB(i)) –
           W * (xg(2) – LCG) } ÷ { xg(1) – xg(2) }
    R2 = W – (EQVOL (i) * ρ ) – R1
    EQTCG = {EQVOL * ρ * TCG – R1 * yg (1) –
    R2 * yg(2)} ÷(EQVOL * ρ)

End if
EQVCG = (VCG * W)/( EQVOL * ρ)
EQGM=(EQIT/EQVOL–(EQVCG–QVCB)/Cos(θeq )
```

Step 14:

Check for occurrence of grounding.

Occurrence of grounding can be verified from the simple principle of balance of forces.

We can simply say if the ground reactions are less than 0.0 then it is a free floating case.

```
Case-A:
No. of Pinnacles = 2
If (R1.LE.0). AND. (R2.LE.0) THEN NO GROUNDING
ELSE
    GROUNDING HAS OCCURRED
ENDIF
Case-B:
No. of Pinnacle = 1
If (R1.LE.0.0) THEN NO GROUNDING
ELSE
    GROUNDING HAS OCCURRED
ENDIF
```

Step 15:

The likelihood of capsizing with the expected variation in tide can also be evaluated.

Owing to the tidal variation, the values of one or more variable(s) in the data file {Situation.inf} may get modified, hence steps-4 through step-14 need to be repeated considering the changed situation.

3. Conclusions

The algorithm described above has dealt with all the essential aspects of statical stability of a vessel in the grounded condition.

The algorithm mainly involves very common interpolation and integration operations, as such can easily be programmed using any standard computer language for execution on an widely available personal computer.

The author hopes the readers will find the algorithm informative and complete for the purpose of writing an appropriate program.

Of course, adequate care needs to be taken in developing the codes with due regard to providing guidance to the user enabling him to select appropriate values of the predefined input parameters as stated in Step-1 for dependable and reliable result. The time requirement for execution of program on a personal computer will be negligible, matter of few seconds only.

The results which can be obtained from the software may be summarized as follows –

1) Ground reactions
2) Draft, Trim, Heel and the Metacentric height at the equilibrium state in the grounded condition.
3) Statical stability levers (GZ) in the grounded condition.
4) Consequence to tidal variation.

The author is unaware if there exists presently any standard criteria for the stability of the vessel in grounded condition. It is viewed by the author that the floating ship stability criteria cannot be applied to the grounded ship, hence the maritime regulatory bodies may look in to the matter of establishing criteria for stability in grounded condition to enable the comparison of ships as regards to their soundness against vulnerability towards capsizing/sinking in aground condition.

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