SHIP STRUCTURE COURSE (Notes)

Week#1

The dimensions of structural elements of a ship may be determined either by the rules of classification societies or by the first principles of strength of materials course. In general, ship structure consists of plates or shells supported by stiffeners. Let us consider a deck beam, which is typical stiffener, for instance. The required section modulus of a transverse deck beam must be greater than the following (according to the rules of Germanicsher Lloyd):

Wd = *m·c·a·p·l2·k* [cm3]

where “*a*” is frame spacing (the distance between deck beams) in metres [m]; “*l*” is the length of unsupported span (in other words, the distance between supports) in metres [m]; “*p*” is the uniform pressure on deck [kN/m2]; “*k*” is a factor depending on the type of steel (without a unit); “*c*” is a factor for the type of supports (without a unit) and “*m*” is a factor depending on the panel ratio (without a unit). It must be noted that the formula above is only valid for steel structures.

We may draw two conclusions from the above formula:

i) It is an empirical formula that a unit analysis may not be applied, which can be easily seen that the unit on the left hand side of the equation [kN·m] is not equal the right hand side [cm3].

ii) The required section modulus (Wd) imposed by GL depends on the following four factors:

- External loads (pressures or forces)

- Length of unsupported span

- Type of end supports

- Type of materials

In fact, there is one more factor affecting the result which is hidden in the formula: The safety factor.

It is said that one may find the dimensions of a beam (stiffener) by the first principles of strength of materials. The maximum stress occurred in the structural member must be lower than a specified stress value for the material used. For instance, the maximum normal stress should not be greater than a “safe” value for normal stress of the material used:

σmax ≤ σSAFE

Or, the maximum shear stress should not be greater than a “safe” shear stress value for the material used:

τmax ≤ τSAFE

The maximum normal stress due to bending may be calculated by the following formula:

σmax = (Mmax/INA)·ymax

where “Mmax” is the maximum bending moment; “INA” is the second moment of area on the neutral axis (NA) and “ymax” is the maximum vertical distance from the neutral axis.

One may rearrange the above formula:

σmax = (Mmax)/(INA/ymax)

If the section modulus (SM) is defined as:

SM = (INA/ymax)

Then we may express the above formula in a different way:

σmax = (Mmax)/(SM) ≤ σSAFE

or

(SM) ≥ (Mmax)/ σSAFE

The maximum moment due to bending occurs in the middle of a beam (with a length of “*l*” [m], carrying uniform load “q” [N/m], and simply supported at both ends) is as follows:

Mmax = q·*l*2/8

Considering that the uniform load “*q*” [N/m] is the product of external pressure “*p*” [N/m2] and frame spacing “*a*” [m], that is, *q* = *p·a*, then the section modulus may be expressed as:

(SM) ≥ (*p·a·l*2)/(8·σSAFE)

which now looks more like the above formula (Wd) by GL.

Sample question 1: Calculate the required section modulus (Wd) for a transverse deck beam for the given values: *p* = 25 [kN/m2]; *a* = 750 [mm]; *l* = 2.5 [m]; *c* = 0.75; *k* = 1.0; *m* = 0.95.

Sample question 2: Calculate the required section modulus (SM) for a simply supported beam for the given values: *p* = 25 [kN/m2]; *a* = 750 [mm]; *l* = 2.5 [m]; σSAFE = 150 [MPa]. Compare the result with the above. Explain the reason for the difference between the two values, if there is any.

Week#2

A ship’s hull may be considered as a beam, too, which may be called “Hull Girder” or “Hull Beam”. One of the most dangerous situations in terms of longitudinal strength of a ship is that it stays on a wave whose length (λ) is close to the ship’s length (λ≈L). Indeed, when a ship is on a wave crest, the deck is in tension and the bottom is in compression, which is called “hogging” condition. When a ship is on a wave trough, the deck is in compression and the bottom is in tension, which is called “sagging” condition.

The mid-ship section modulus of a ship required by GL is given below:

Wmin = k·c0·L2·B· (CB+0.7) ·CRS·10-6 [m3]

The real mid-ship section modulus may also be calculated, which may then be compared with the value obtained by the above formula.

We need to know the position of the neutral axis (which is the centroid of the section for homogenous isotropic materials, also known as an axis where there is not any normal stress, that is, neither tension nor compression), because we need to calculate the second moment of area of the mid-ship section (INA) on the neutral axis. Then, we may calculate the real section modulus:

SM = INA / ymax

where ymax is the furthest distance from the neutral axis.

First, we decide which members to include in the calculation. All outer shell plating (bottom, side and deck) must be included. Almost all ships have double-bottom, which must be included, too. Also, if there are longitudinal bulkheads or double-skins at sides, they must be included. Structural members such as lower decks, bottom girders, side stringers, deck girders will be included. However, if there are openings at decks, those parts should be excluded.

In order to find the position of the neutral axis we may use the following approach:

yNA = ∫ydA / ∫dA ≈ ∑Ai·yi / ∑Ai

where “Ai” is the sectional are of each member, preferably in [m2] and “yi” is the vertical distance between the centroid of each member and the reference line, preferably in [m]. The choice of the position of the reference line is optional, but the base line (BL) of the ship may be a good choice. The choice of units (m, cm or mm) for the dimensions throughout the calculations is also optional, but for a mid-ship section modulus calculation (m×m: breadth in metres, height in metres) is suggested.

Once the position of the neutral axis has been determined, then the second moment of area (INA) on that axis may be calculated by using the Parallel Axis Theorem, which may be expressed by the following:

INA = ∑Ii + ∑Ai·di2

where “Ii” is the second moment of area of each member above the axis passing through the centroid of that member and “di” is the vertical distance between the centroid and the neutral axis, which may be expressed as:

di = yi - yNA

Sample question 3: Calculate the mid-ship section modulus of a tanker (Wmin) required by GL.

L =150 [m]; B =22 [m]; D =13 [m]; CB = 0.75; CRS=CRW=1.0; k =1.0;

c0 = {10.75 – [(300-L)/100]1.5}·CRW

Sample question 4: Approximately calculate the real mid-ship section modulus (SM) of the above tanker. Consider only the outer shell (bottom plating, side plating and deck plating) and the inner bottom plating, which is situated 1.5 metre above the base line. The thickness of all the plating is 13 [mm]. Then, compare it with the above result (Wmin) and make a comment.

Week#3

We may either use the rules by classification societies or the first principles in order to find the thickness of shell plating, too. For instance, for the bottom thickness, GL imposes that the greater of the following two values should be considered:

tB1 = 18.3·nf·a·(pB/σpl)1/2 + tK [mm]

tB2 = 1.21·a·(pB·k)1/2 + tK [mm]

where “pB” is the bottom pressure in [kN/m2]; “a” is the frame spacing in [m]; “tK” is the corrosion addition in [mm] (at least 1.5 [mm]). It must be noted that the formulae above only valid for steel structures.

The thickness of plating under lateral pressure supported by stiffeners may be found by the first principles. Again, we may consider a part of the plating (a strip with a unit breadth) as a beam. The unsupported length of the plating is the distance between stiffeners (frames). The section of the plating is a rectangle with a breadth of “unity” and the height of “t” (thickness of plating). We apply a similar approach used earlier:

σmax = (Mmax)/(SM) ≤ σSAFE

or

(SM) ≥ (Mmax)/ σSAFE

The maximum moment due to lateral bending occurs at the fixed ends:

Mmax = q·*l*2/12 = (p×“unit width”)·a2/12 = p·a2/12

SM = (INA/ymax) = [(breadth)×(height)3/12]/ymax = [(unity)·t3/12]/(t/2) = t2/6

SM = t2/6 ≥ (p·a2/12)/σSAFE → t ≥ a·[p/(2·σSAFE)]1/2

The plate thickness “t” determined by the simple bending due to lateral pressure must be checked for buckling, because deck plating (sagging condition) and bottom plating (hogging condition) due to longitudinal bending will be affected by compressive forces which may cause local plate buckling.

The critical buckling stress may be calculated by Euler’s formula:

σk = K·{π2·E/[12·(1-ν2)]}·(t/a)2

where E is the Young’s modulus; ν is the Poisson’s ratio and “K” is a factor depending on the type of framing (transverse or longitudinal) and on the type of edge supports (simply supported or fixed). It must be noted that the above formula is only valid for the elastic range.

Sample question 5: Calculate the bottom thickness (tB2) of a ship, both according to GL rules and by the formula from the first principles. Take whichever is greater as the bottom thickness. Then, check this value for the Euler buckling formula. Make a comment in the end.

a = 700 [mm]; p = pB = 75 [kN/m2]; k = 1.0; σSAFE = 150 [MPa]; σL-BOTTOM = 150 [MPa]; E = 210 [GPa]; ν = 0.3 and (with the assumption of fixed edges for longitudinal framing system) K ≈ 4.0