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SCANTLINGS OF LONGITUDINALLY
STIFFENED SHIP BOTTOM PLATING

TENTATIVE IDEAS ON
~~A~~ ON DESIGN METHOD

by

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I SCOPE

This is only a brief description of a design procedure and the ideas on which it is based. A detailed development and establishment of specific limits will be done later in conformity with ~~the~~ standard practices. The formulas are given only for b/t equal or smaller than sixty, and for A-7 steel.

II NOMENCLATURE

A Area of one subpanel = $A_{st} + bt$, in sq. in.

A_{st} Area of one tee stiffener (longitudinal), in sq. in.

$a = A_{st}/bt$ Ratio of stiffener area to plate area

B Width of ship hull, in inches

b Width of subpanel or spacing of tee stiffeners (longitudinals), in inches

c Fiber distance from the centroid of panel cross section, in inches

D Depth of ship hull, in feet

d Depth of tee stiffeners (longitudinals), in inches

E Modulus of elasticity (Young's modulus), in ksi

e Eccentricity of weld from the centroid of subpanel cross section, in inches

F_w Compressive force produced by shrinkage due to welding, in kips

I Moment of inertia of subpanel, in in.^4

I_H Moment of inertia of midship hull cross section, in $\text{in.}^2\text{ft.}^2$

L Spacing of transverse frames = span of one subpanel, in inches

- M Hogging moment due to standard wave, multiplied by *the* factor of safety, in ft-k
- M_1 Bending moment in subpanel due to lateral water pressure, in in.-k
- P Axial compressive load on subpanel resulting from hogging moment M, in kips
- q Lateral water pressure multiplied by factor of safety, in ksi
- r Radius of gyration of subpanel = $(I/A)^{\frac{1}{2}}$, in inches
- s Size of weld, in inches
- t Thickness of plate (skin), in inches
- y Fiber distance from the centroid of midship hull cross section, in feet
- σ Stress, in ksi

Subscripts

- b Bottom plating
- d Deck plating
- f Flange of stiffener (longitudinal)
- p Mid-thickness of plate
- u Ultimate (maximum obtainable)
- y Yield

Additional notation is defined where first used.

III STRENGTH OF LONGITUDINALLY STIFFENED PANELS

On the basis of literature studies and the results of the conducted experiments, ~~CFE~~ Report 248.4 and 248.5 (now in preparation), it is felt that the strength of a longitudinally stiffened panel subjected to axial and lateral loading can be

expressed by the following formula, which gives the maximum stress in the plate:

$$\sigma_u \cong \sigma_p = \frac{P}{A} + \frac{M_1}{I} c_p + \frac{P\delta}{I} c_p \quad (1)$$

where M_1 and δ are at the midspan of the panel and depend on the end conditions or continuity of the plate and stiffeners \bar{F} (longitudinals) at the transverse frames. The symbols are explained at the beginning under NOMENCLATURE.

The stress should also be checked in the stiffener flange at the transverse frames. The applicable formula is

$$\sigma_y \cong \sigma_f = \frac{P}{A} + \frac{M_1}{I} c_f \quad (2)$$

M_1 here is the moment in the subpanel unit at the transverse frame.

It should be noted that in the above formulas M_1 and δ are caused only by lateral loading q .

σ_u is the ultimate axial stress in the plate and it is, for all practical purposes, equal to the elastic buckling stress for riveted longitudinals and to the stress obtained from the graph in Fig. 5 for welded longitudinals.

P , the axial force per one subpanel unit, is equal to the axial force produced by the design hogging moment multiplied by the factor of safety.

q, the uniformly distributed lateral loading, is equal to the water pressure produced by the water head corresponding to the hull depth multiplied by the factor of safety.*

For practical ship scantlings it is safe to assume that

$$M_1 = \frac{qbL^2}{10}$$

both at midspan and transverse frames and that

$$\delta = \frac{qbL^4}{192EI}$$

Then Eqs. 1 and 2 become more specific:

$$\sigma_u \geq \sigma_{pl} = \frac{P}{A} + \frac{P}{I} \left(\frac{qbL^2}{10} + \frac{PqbL^4}{192EI} \right) \quad (3a)$$

$$\sigma_y \geq \sigma_{Fl} = \frac{P}{A} + \frac{qbL^2}{10I} c_f \quad (4a)$$

Based on the total hogging moment M Eqs. 3a and 4a are:

$$\sigma_u \geq \sigma_p = \frac{M}{I_H} y_b \left(1 + \frac{qbL^4 c_p A}{192EI^2} \right) + \frac{qbL^2 c_p}{10I} \quad (3b)$$

$$\sigma_y \geq \sigma_f = \frac{M}{I_H} y_b + \frac{qbL^2}{10I} c_f \quad (4b)$$

See Figs 1, 2, 3 and 4

* Water pressure should be computed according to ship design rules if they specify it differently than above.

A panel should also be checked as a column and any acceptable formula can be used.* It seems, however, that for the conventional range of ship loadings the stress formulas, Eqs. 1 and 2, are usually controlling the design of the bottom plating.

IV WELDING RESIDUAL STRESSES AND ULTIMATE STRENGTH OF PLATE

An approximate magnitude of the compressive residual stress in the plate due to welding can be found from the following equation:

$$\sigma_r = \frac{F_w}{A} \left(1 + \frac{e e'}{p^2} \right) \quad (5)$$

where e is the eccentricity of the weld from the c.g. of the subpanel, see Fig. 3, and F_w is the compressive force due to the shrinkage caused by welding. For the weld size s (in inches) equal to about 0.75 to 1.0 of the plate thickness t , F_w is given for A67 steel by:

$$F_w = 900 s^2 \text{ (kips)}^{**} \quad (6)$$

This formula applies to double fillet welds with the side dimension s , and to butt welds or double V welds with $s = t$.

* In the future a more rigorous beam-column analysis in the plastic region including residual stresses can be conducted to establish column curves for the more typical stiffener - plate combinations.

** The coefficient ⁹⁰⁰1000 was obtained from the available residual stress measurements. It appears that a more accurate formula for F_w should take into account the influence of s^2 , s/t and t .

Eq. 5 can be greatly simplified if the longitudinals are neglected and only the plate is considered. The error is rather small and on the safe side, i.e., the resultant residual stress is higher. Eq. 5 then becomes

$$\sigma_r = \frac{nF_w}{bt} = \frac{900ns^2}{bt} \quad (7)$$

where n is the number of the welds in one subpanel. In a typical subpanel there is only one double fillet weld connecting the longitudinal to the plate, i.e. n = 1.

With the known residual stress the ultimate strength of the plate is given by the difference of the elastic buckling stress and the residual stress*

$$\sigma_u = \sigma_{cr} - \sigma_r \quad (8)$$

The graph in Fig. 5 was obtained from Eq. 8 for an assumed plate buckling coefficient equal to 4.15. The ultimate plate strength then becomes a function of the b/t ratio and the weld size s and can be easily plotted.

* The validity of Eq. 8 is, however, restricted to low b/t ratios (less than 60). Further investigation is necessary for higher b/t ratios for which the postbuckling strength of the plate becomes important.

V PRELIMINARY DESIGN

For a preliminary design it can be assumed that the longitudinals have proportions as shown in Fig. 4 and that the effect of the deflection at the midspan between the transverse frames can be neglected.

Also, it can be assumed that the axial force per running inch of the plating width is equal to M/BD , where M is the total hogging moment multiplied by the factor of safety and B and D are the width and the depth of the ship hull, respectively. This approximation is on the safe side and gives values which are within about 6% of the exact values.

Then, for some specific ratio "a" of the stiffener area to the corresponding plate area

$$a = A_{st}/bt \quad (9)$$

Eqs. 3 and 4 for the stresses in the plate and in the flange become

$$\sigma_u \cong \sigma_p = \frac{M}{BD(1+a)t} + \frac{qL^2}{10 \sqrt{a} (3.75+0.56a)t^2 \sqrt{b/t}} \quad (10a)$$

and

$$\sigma_y \cong \sigma_f = \frac{M}{BD(1+a)t} + \frac{qL^2 (2.45+1.05a)}{10a \sqrt{a} (6.68+a)t^2 \sqrt{b/t}} \quad (11a)$$

With given M , q , B , D , L and assumed $a = A_{st}/bt$ and relative size of the weld s/t , Eqs. 10 and 11 can be easily solved for the required plate thickness for a few trial values of the ratio

b/t; σ_u is obtained for each b/t from the graph in Fig. 5.*

The equations for computing the plate thickness from Eqs. 10a and 11a are, respectively:

$$t = \frac{M}{2BD(1+a)\sigma_u} + \left[\left(\frac{M}{2BD(1+a)\sigma_u} \right)^2 + \frac{qL^2}{10\sqrt{a}(3.75+0.56a)\sigma_u\sqrt{b/t}} \right]^{\frac{1}{2}} \quad (10b)$$

and/or

$$t = \frac{M}{2BD(1+a)\sigma_y} + \left[\left(\frac{M}{2BD(1+a)\sigma_y} \right)^2 + \frac{qL^2(2.45+1.05a)}{10\sigma_y a\sqrt{a}(6.68+a)\sqrt{b/t}} \right]^{\frac{1}{2}} \quad (11b)$$

A suitable plate thickness and a b/t are then selected from the obtained results.

The depth of the longitudinals (stiffeners) is found from

$$d = 4t\sqrt{a(b/t)} \quad (12)$$

The other scantlings of the longitudinals are shown in Fig. 4.

For low b/t ratios (less than about 45) the above formulas for the plate thickness are not rigorously applicable because the panel strength ^{is} ~~is~~ not so much controlled by the plate instability as by ^{the panel strength} ~~the panel as a beam-column~~.** In this range it is suggested to use only the first formula, Eqs. 10, for determining the

* The operation can be greatly simplified by the use of appropriate nomographs.

** See the first footnote on page 5.

required plate thickness, because the second formula, Eqs. 11, ✓
is based on ^{the} yielding of the stiffener flange at the transverse
frame which can be tolerated.

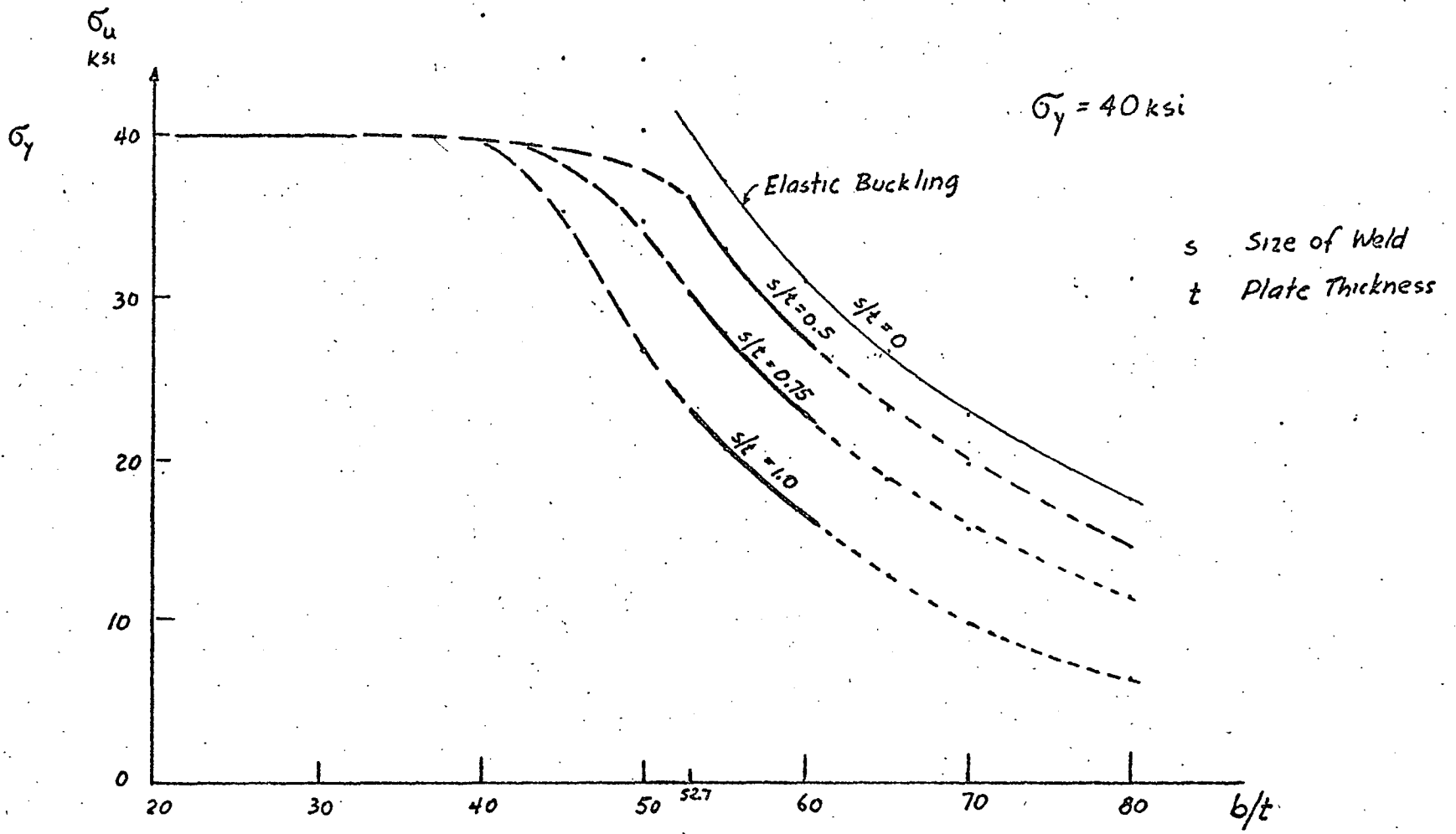


Fig. 5