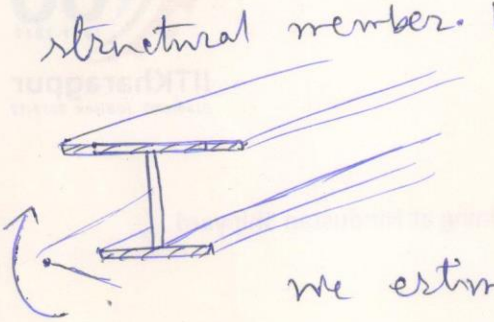
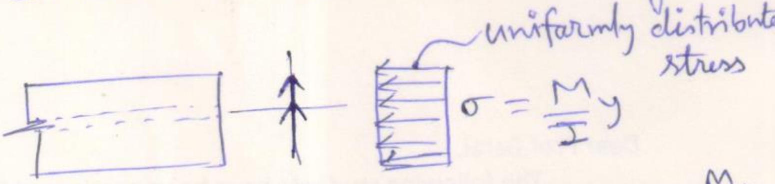
Shear Lag

This is also an important aspect of stiffened plate which arises from the material continuity of various components of a structural member. Let us consider an I-beam bending

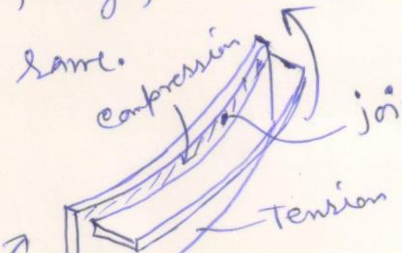




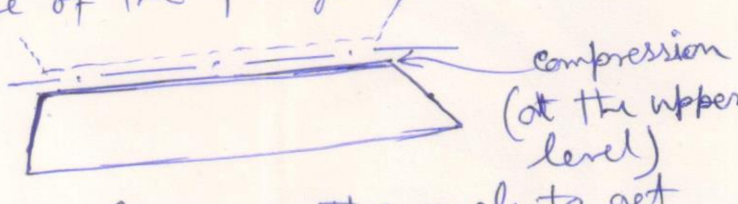
we estimate the stress in the flange as $\sigma = \frac{M}{I} y$, by assuming that the stress is uniformly distributed on the flang. However in reality, the stress distribution is not uniform. If we isolate the flanges and the web as shown,

the bending rigidity of the web is much higher than the flanges.

Hence, when we try to bend the beam, first the web tries to bend and then the stress is transferred to the flanges. This is because the material is continuous from the web to the flange, and the strain at the joint of the two must be same.

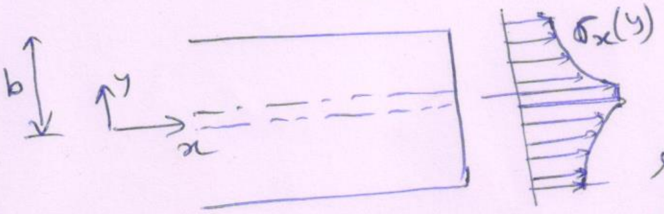


The shape of the flange tries to become as shown



and the web applies shear force on the web to get a shape like what is shown. This shear causes normal stress on the flange. (Earlier while studying shear, (longitudinal shear), we have seen that the variation of normal stress causes longitudinal shear.)

This shear reduces as we move further from the web along the flange; and so the normal stress. This is called shear lag, i.e., material in flange away from the web is lagging in shear force transfer

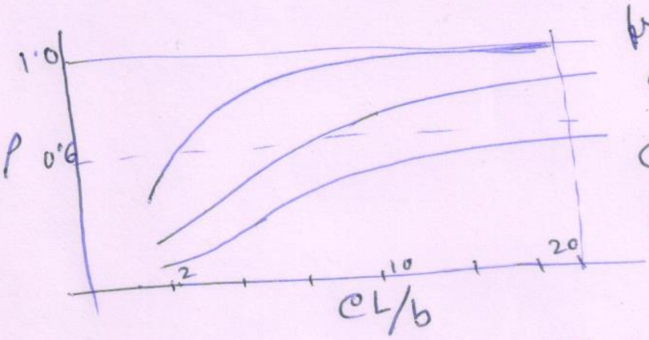


An effective breadth from the web is defined as ρb which would sustain same load if the stress was uniform at the level σ_B.

here, ρ = Plate (here, ~~web~~ flange plate) effectiveness factor.

Hence, $(\rho b).\sigma_B = \int_0^b \sigma_x(y)\, dy$

The figure below is drawn approximately from textbooks.



cL/b = aspect ratio, b = flange width

cL = total span of beam between location of zero bending moment.

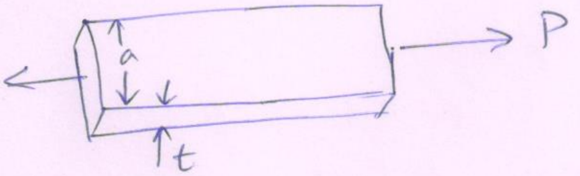
Hence, if cL/b is large, $\rho \to 1$, i.e., if span is large or width is small then $\rho \simeq 1$ or the full width of flange is effective.

However, if cL/b is smaller, i.e., span is small or width is large, then $\rho < 1$ or full flange width is not effective to resist bending. Hence, for stiffened plate, if we want to make the full width of the plate(flange) effective, we need to decide over the stiffener spacing accordingly.

(you may refer: "Strength of ships and Ocean Structures, SNAME)

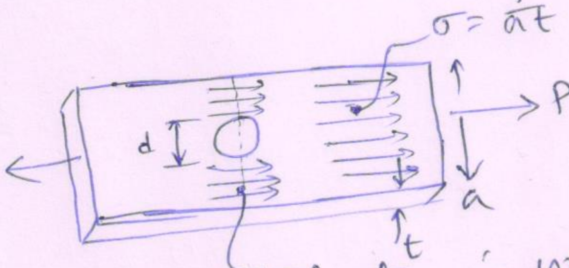
Stress Concentration

This is localized stress which appears due to abrupt change in material continuity or localized loading.



Here the stress inside the object $= \sigma = \dfrac{P}{at}$

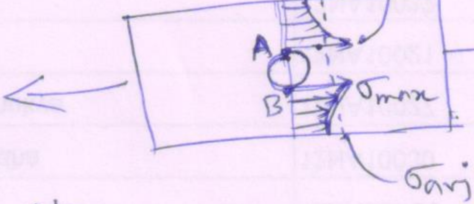
We can also call this as "average stress".



If stress is uniform in this region, then $\sigma_{avg} = \dfrac{P}{(a-d)t}$

However in reality the stress distribution at the hole is not uniform.

In reality, σ at this point A ~ B is $\sigma_{max} = 3 \times \sigma_{avg}$

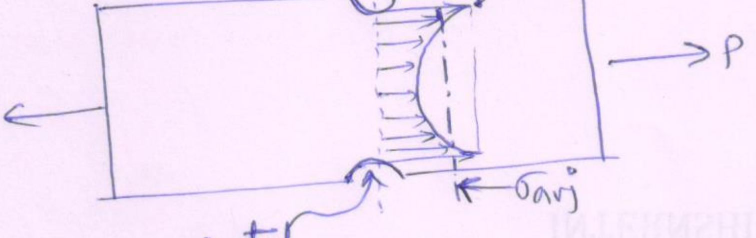


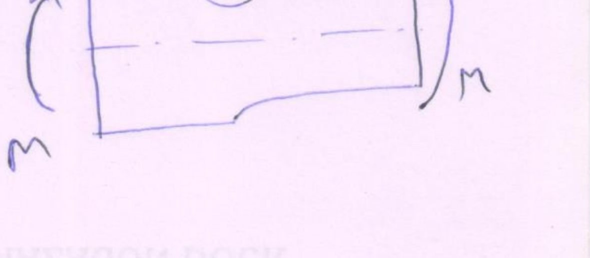
We can write, $\displaystyle\int_A \sigma_{true}\, dA = \int_A \sigma_{avg}\, dA = \sigma_{avg} \cdot A$

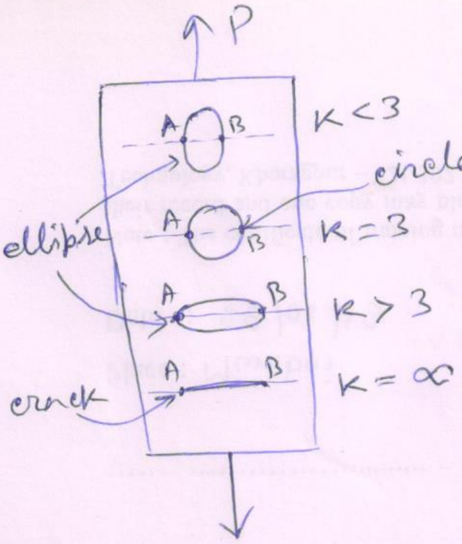
$$\therefore \sigma_{avg} = \frac{\int_A \sigma_{true}\, dA}{A}$$

Typically, σ_{max} is written as, $\sigma_{max} = K \cdot \sigma_{avg}$, where K = stress concentration factor.

At any location of material ~~discon~~ discontinuity, this concentration of stress appears.







The stress concentration factor due to the discontinuities shown here is given as $K = 1 + 2\sqrt{\frac{R}{r}}$

where, R = width of the opening = (AB) length

r = local radius at the edge (A or B)

The values of 'K' are given beside the figures. For the crack, theoretically $r = 0$ and so the factor $= \infty$.

So you can imagine that if the local stress due to the stress concentration effect exceeds the yield limit, the discontinuity may actually increase and eventually the section may fail.

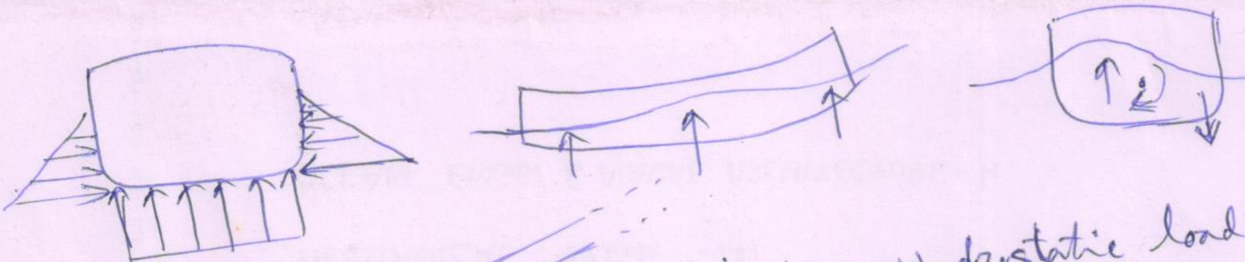
Stress concentration play a vital role in fatigue of material. An existing crack (or defect) in the section will grow in time due to dynamic load and after a number of load application, the section may fail. This is so called fatigue failure.

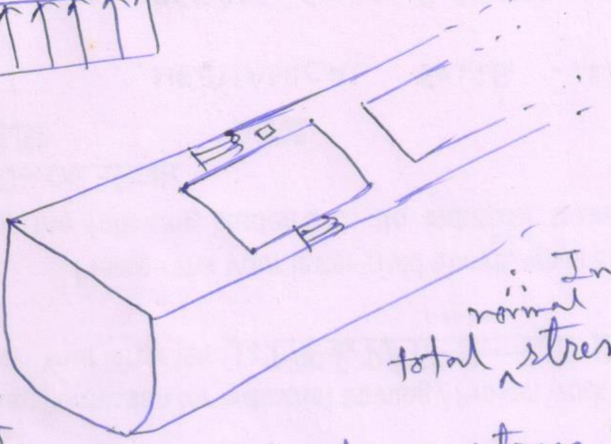
Often, Finite Element modelling is employed in order to find the stress concentration factor of a section with material discontinuity. The whole section is modelled carefully with suitable elements and the local stress is estimated from the elements at the point in question. However, care should be taken in order to ensure that proper mesh convergence study has been carried out to avoid obtaining unrealistic results from FEM modelling.

Apart from that, for modelling simple sections or finding the stress concentration factors, various recommended practices (DNV-GL, API, NORSOK, IRS, etc.) can be referred.

Combined stress

You have seen that a ship undergoes longitudinal bending like a beam. It withstands buoyancy by the transverse frames. Then, due to longitudinal bending, longitudinal shear force (and complementary shear in section) appears. Also due to ship torsion (and warping restraint), shear and normal stress will appear in the section. All these stresses appear simultaneously, and so we also should check for combined stress.





Hydrostatic load is mainly carried by transverse frame.

In longitudinal direction, the

total normal stress is $= \sigma_{sag/hog} + \sigma_{warping} + \sigma_{local}$

for deck plate

total shear stress is $= \tau_{\substack{vertical \\ shear}} + \tau_{\substack{torsional \\ shear}}$

Note that hatch opening corners will experience stress concentration.

Refer at least one recommended practice, DNV/IRS/ABS to see how the structural checking of the hull is made.

Once you get σ_x and τ at a point, you can combine them by following standard approaches to obtain combined stress (Principal stress, Von-mises stress etc.). You must have learnt these in Solid Mechanics. Standards/codes/RPs can also be referred for the same.