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Shear stress and bending moment pdf

MDME: MANUFACTURING, DESIGN, MECHANICAL ENGINEERING Internal stresses and forces due to shear within a beam bending situation. Lecture Notes: shear in bending - worked exercises.pdf empty.one Lecture Video: FEA Shear in bending of I beam (4 mins) or jump to embedded video Transverse Shear Force in Bending In the bending moment chapter we looked at the Shear Force Diagram. This is actually the traverse shear force that is being determined - for a horizontal beam with vertical loads, this means it is the vertical shear force. Transverse Shear Force We can cut the beam to find the Bending Moment (by doing moment equation of ONE side).But what if we don't know where the maximum is? Are we going to pick lots of places to "cut" until we eventually find it? There is another way. We can use shear force to find bending moment, using a diagram method. But first - a definition of shear force in a beam. Imagine ONLY the sliding aspect of the beam, not the bending. This is a bit wierd since beams don't slide apart, they bend apart. But anyway, we still need to get this shear force thing happening. Imagine the beam as a stack of magnets. They can slide OK but not bend. Now if one hand pushes up and the other down, it slides. (shears) Of course, it doesn't matter which magnet slides, they all want to slide. This one just happened to have the least friction, but in fact every slice has the same shear force. Positive Shear Force In a diagram we would show it like this; When the left hand side (LHS) goes up then this is called positive shear force. A Shear Force Diagram (SFD) is a graph of the shear force all the way along a beam. We can construct a shear force diagram for a loaded beam, but the shear force at a particular point along the beam is actually the average for the cross-section. For more information about Shear Force Diagrams, see Bending Moment Average Shear Force along the length of a loaded beam. SFD = Shear Force Diagram Unfortunately, this is shear force cannot be used to determine the shear stress with the simple "stress equals force on area" equation. Why not? Because, as you might have guessed, shear stress it is not uniform throughout the cross-section. Drat. Longitudinal Shear in Bending In addition to the transverse shear force, a longitudinal shear force also exists in the beam. Evidence of this longitudinal shear force (i.e. a force parallel to the beam axis) is shown below. (a) Three planks not glued together. There is slippage between the planks. (b) Planks are glued together. No slippage occurs. Glue carries a shear load. The glue in the beam in Figure (b) carries a shear load parallel to the axis of the beam. This load produces a shear stress called the longitudinal (or horizontal) shear stress. Relationship Between Vertical And Horizontal Shear Stress The transverse and longitudinal shear forces produce stresses called the vertical and horizontal shear stresses. These stresses are shown acting on a small part of the beam in the figure above. At any particular point in the beam the horizontal shear stress is equal to the vertical shear stress. At any point in the beam; $\tau_v = \tau_h$ Where; τ_v = vertical shear stress τ_h = horizontal shear stress Proof To prove $\tau_v = \tau_h$ Force acting on a horizontal surface = $\tau_h x$ (ab) Force acting on a vertical surface = $\tau_v x$ (cb) Taking moments about anywhere on the front face of the element (e.g. the centre of it); $\tau_h (ab)c = \tau_v (cb)a$ So $\tau_v = \tau_h$ (Note: This works even if the element is a rectangular rather than a square prism) So we know they are the same, but that doesn't tell us how to calculate it. Calculating The Shear Stress Below shows a typical beam (a simply supported beam) Above: At the cross section y-y the shear load in the beam is 10 kN. However, the shear stress is not uniform throughout this cross section. The shear stress is largest at C, then a bit lower at B, and lowest at A for this particular beam. So when we investigate the section itself, the shear force varies with height. Now we focus on calculating the longitudinal shear stress at longitudinal plane B-B; (shown below in the cross sectional view) The shear stress at BB on the cross section can be calculated using; Where τ = shear stress (MPa), which is the same as τ_v or τ_h for a small element at section B-B Q = first moment of area (mm³) of the upper cross-section of the beam (above the B-B plane). Where $Q = A_1 y_1 + A_2 y_2$ A_1 = Area 1 (mm²) y_1 = distance from neutral axis to centroid of Area 1 (mm) A_2 = Area 2 (mm²) y_2 = distance from neutral axis to centroid of Area 2 (mm) Shear Stress using FEA: The stress labelling convention is; XX, YY, ZZ are the normal/planar stresses XY, XZ, YZ are Shear stresses in each of those 3 planes Note that the FEA analysis may give a positive of negative shear stress, depending on the orientation of the X,Y & Z axis with respect to the job. We can ignore the negative sign for now, it is only needed for heavy-duty 3D stress analysis which is beyond the scope of our study here. 1. Draw up beam in Inventor (give it 500mm long Z axis typical) 2. In Stress Analysis, use steel, but do not turn on gravity. 3. Constrain "fixed" at the wall, apply 25kN to the free end. 4. Simulate it, then probe at (X,Y,Z) = (0,30,100) using Stress YZ. The result is a shear stress in the YZ plane of 18.75MPa. (using an average mesh size of 1% of its length). FEA analysis of the beam in Ex3. Note that the probe point is 100mm away from the fixed constraint. This avoids the weirdness of a surface of immovable elements - which mucks up the shear stress for short distance. This becomes very important when analysing the shear stress between individual members in a composite cross-section, e.g. the shear stress in a welded joint between web and flange of an I beam. This is very interesting. It says that just above the junction F-B the long shear stress in the FLANGE is only 1.5 MPa, but immediately below that plane, in the WEB, the stress suddenly increases to 15 MPa. Obviously this is because the area is suddenly reduced from 100mm wide to 10mm wide - hence the stress increases 10 times. Makes sense. Here, FEA matching the results will be more difficult because the shear stress is being constrained by proximity to the flange. Using the same mesh refinement, the stress near the flange is sensitive to location. As we measure stress in the web as we approach the flange, the stress starts to deviate in the last few mm before it meets the flange; X (mm) Y (mm) Z (mm) Stress YZ (MPa) 0 60 100 15.43 0 63 100 18.43 0 64 100 16.28 0 64.5 100 15.15 0 64.9 100 14.25 0 65 100 13.14 0 65.1 100 0.13 0 65.5 100 0.15 0 66 100 0.18 Using FEA in Inventor to determine shear stress in a beam under bending BEAMS WITH A CIRCULAR CROSS SECTION. For a beam with a circular cross section the maximum shear stress occurs on the neutral axis. The maximum stress is calculated below. Shear Stress Variation In Beams From the previous examples you can see that the shear stress is not constant, but varies from the top to the bottom of the beam. If you were to calculate the shear stress at all points from top to bottom of a beam cross section and graph the magnitude of the stress you would get shear stress diagrams as shown below. Glues are often used today for making fabricated beams. The shear strength of the glue should be greater than the stress at the location of the glued joint. Alternatively select a glue with a shear stress greater than the maximum shear stress in the beam. Calculating The Longitudinal Shear Force The transverse shear force can be calculated using the procedure for shear force diagrams. The longitudinal (or horizontal) shear force cannot be calculated as directly. However, having calculated the shear stresses, the horizontal shear force can then be calculated. The horizontal shear force is used to find weld sizes and nail sizes in built-up beams. (Among other things) Above shows a typical beam. You will note that the bending moment varies along the beam. If you look at part of a beam closely (below), you can calculate the bending stress acting on the left hand side and the right hand side of the segment. The stresses acting on the right hand side of the segment are larger than those acting on the left hand side. This occurs because the bending moment is larger at the position of the right hand side. For equilibrium of the segment in Figure 13, \sum Horizontal forces = 0 $R_1 + S - R_2 = 0$ Hence the horizontal shear force balances out the difference in the bending forces. But... the horizontal shear force can be calculated from the shear stress equation! Tadaa! Now stress is force over area. From Figure at right (yet another view of that element of the beam), the shear force is S_1 , and it acts over an area $6x.b$. Hence the shear stress becomes, Example: FABRICATED BEAMS Beams are often made up, or in some cases strengthened, by adding top and bottom plates. In the nailed beam the nail carries the shear force on A.A. The weld carries the shear force between the top plate and the flange. Following those numbers (above) in more detail: $A = 150 * 50 = 7500$ mm² $y = 50$ mm $Q = Ay = 375E3$ mm³ $V = 1000N$ $I = 53E6$ mm⁴ $S/dx = QV/I = 7.08$ so if we invert this, $dx/S = 0.141$ But $S=450N$, so multiply by S ; $dx = 63.6$ mm Where does 965N/mm come from? It is the load per mm of a 10mm weld, where, from the welded joints formula (fillet welds); $F = 0.707 * \text{stress} * \text{length} * \text{size}$ $F = 0.707 * \text{stress} * 1 * 10$ $F = 7.07 * \text{stress}$ So re-arranging to give; $\text{Stress} = F / 7.07 = 965 / 7.07 = 136$ MPa (Which is the standard weld stress used in Ivanoff). With $S.F = 3$, gives electrode rating of $136 * 3 = 410$ MPa. In other words; $F = 0.707 * \text{stress} * \text{length} * \text{size}$ $F = 0.707 * (410/3) * 1 \text{mm} * 10 \text{mm} = 965$ N/mm The following notes are from; Dead load Dead load on a structure is the result of the weight of the permanent components such as beams, floor slabs, columns and walls. These components will produce the same constant 'dead' load during the lifespan of the building. Dead loads are exerted in the vertical plane. Dead load = volume of member x unit weight of materials By calculating the volume of each member and multiplying by the unit weight of the materials from which it is composed, an accurate dead load can be determined for each component. The different components can then be added together to determine the dead load for the entire structure. Plain concrete 23.5 Reinforced concrete 24 Glass 25.5 Mild steel 77 Hardwood 8 Table 1: Dead load comparisons of various materials Live loads page 003.htm Example: Area of floor = 6.0 m x 4.0 m = 24 m² Live load rating of a house = 1.5 kPa Therefore, live load of floor = 24 m² x 1.5 kPa = 36 kN All unfixed items in a building such as people and furniture result in a 'live' load on the structure. Live loads are exerted in the vertical plane. Live loads are variable as they depend on usage and capacity, therefore the AS 1170 table provides allowances which are based on conservative estimates. For example, the live load for a floor in a house is given as 1.5 kPa compared to a dance hall floor live load of 5.0 kPa. It is reasonable to expect that a dance hall would have more people in it than a house. Houses 1.5 Flats, apartments, motel bedrooms 2.0 Offices 3.0 Workshops 5.0 Parking, vehicle > 2.5 t 5.0 Hospitals, school assembly areas with fixed seating 3.0 Dance halls, bars, lounges 5.0 Table 2: Live load comparisons Simply-supported floor joists Analysis of your Design Variation To model this using Inventor, you will need to select a wood material. The closest to Radiata Pine is probably Birch, but these are constructed in plywood (web) and LVL (flange). LVL = Laminated Veneer Lumber. Plain wood in orthotropic, which means it is strong in one direction (like rope), but very much weaker in the other directions. However, these engineered wood materials (plywood and LVL) are approximately isotropic (same in every direction), at least in this application. Change Birch to isotropic. (Material Library > Select Birch > Physical > Mechanical > Behaviour > Isotropic) Actually, I tell a lie. The plywood is really closer to transversely isotopic, and the LVL is more like anisotropic. But in the arrangement of the beam they are loaded in their high strength directions, so we get away with calling them isotropic. Otherwise it will not calculate anyway, because anything except isotropic is MUCH more complicated. Tasks According to the design guide, these tables apply to a live floor load of 1.8kN. Use simply supported and minimum bearing support for floor loads only. (p4) Determine the maximum material shear stress in the web of the beam (by hand and by FEA). Determine the maximum material tensile stress in the flange of the beam. (by hand and by FEA) Drill the maximum sized hole in the worst position allowed and determine the highest Von Mises stress. Is this more of a shear issue or a tensile/compression issue? Repeat Task 4 for a maximum-sized rectangular hole in the worst position allowed. From Task 3, calculate the safety factor for tensile stress in the flange (research LVL properties) Determine the maximum shear flow of an un-cut beam. Determine the necessary shear force of the adhesive joint (per mm of length). Treat the joint as occurring exactly at the web/flange transition (i.e. disregard the groove in the flanges). Use manual calculations, because you don't have a choice this time! Increase this adhesion rating by the same the same safety factor as Task 6, to give a final value for glue joint strength in N/mm. 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