Lecture 1.
Course Syllabus
MAE 311
Machines and Mechanisms I
Spring 2003

Instructor:

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Course Web Page: TBA

Course Prerequisites:

EAS 209 and MAE 381. You should not take this course unless you have passed EAS 209 or its equivalent. A working knowledge of solid mechanics and stress analysis will be especially useful. If you haven't taken MAE 381, please see Prof. Soom.

Textbook:

Mechanical Engineering Design. Shigley and Mischke, McGraw-Hill, **5th Edition**. This is a McGraw Hill Classic Edition. (The 6th edition is NOT SUITABLE)

Grading

Homework Assignments	15%
Two tests	20-25% each
Final exam	35%
One/two mini-projects?	0–5% each

Approximate cut offs for final grades are A/B 85, B/C 70, C/D 55, and D/F 45. Plus/minus grades will be used.

What is Mechanical Design?

Formulation for plans for the physical realization of machines, devices, systems, instruments, products…to fulfil a need.

Design Process

Statement of need
Specification
Conceptual/preliminary design
Detailed design, analysis, optimization
Testing and evaluation
Manufacturing
Sales and service
Eventual disposal

Modern concurrent or integrated design considers all aspects "simultaneously."

Some Features of Design

- No unique solutions
- Constraints
  (time, cost, weight, size, etc.)
- Many variables
- Many factors, aspects are included

Some key factors

- Strength (avoid fracture, failure: static or fatigue, wear)

This will be the main emphasis in this course

- Shape, rigidity, deflection, compliance
- Cost
- Reliability, quality
- Ease of manufacturing
- Weight, size
- Energy consumption
- Environmental impact
- Life cycle considerations
- Maintenance and service
- Noise and vibration

Design hierarchy

1. System, machine, vehicle, assembly product…
2. Subsystem, subassembly, module
3. Sub subsystem…
4. ….
5. Component, part, element

Elements, parts, components:

Shafts, axles…
Brackets, frames, housings…
Fasteners, bolts, machine screws, rivets…
Welds, brazes, solder joints, bonds…
Springs
Bearings, journal, rolling element
Gears, couplings
Brakes, clutches, pulleys

Covered in Chapters 8-17 in text

We will consider

…how the elements work

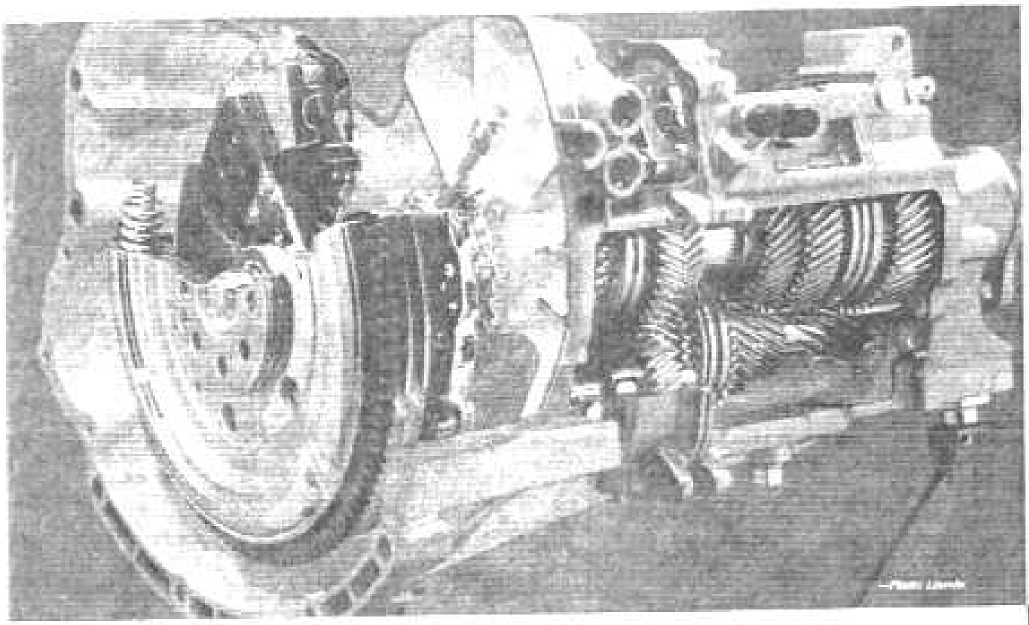
…basis for design or selection

…detailed design or seleciton

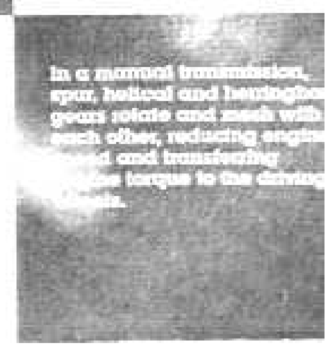
Generally we will assume that overall loading is known from static or dynamic considerations

Examples

	P
#1 - Standard transmission	7
#2. MINI and Suspension	8
#3 - Escalade engine and transmission.	9

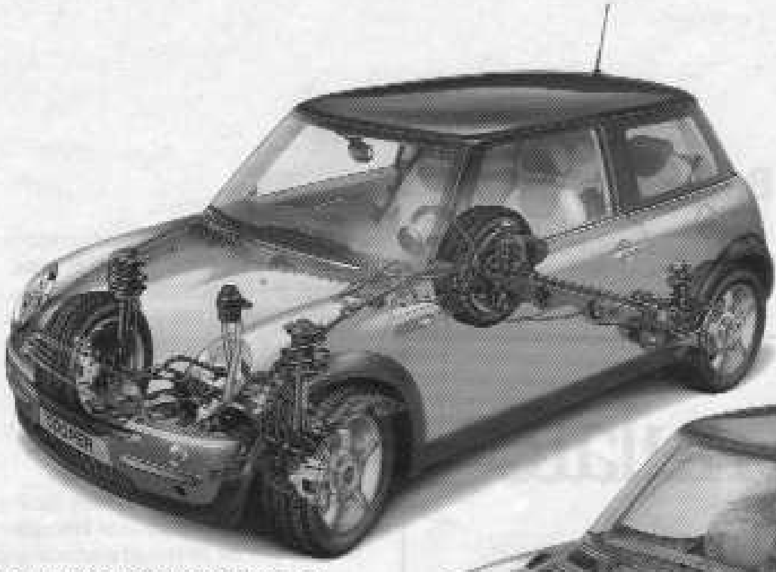


gallons annually. That's no
much — only about 3 per
cent of all the automotive
lubes sold — because of th
heavy preference in the
United States for automat
transmissions. Elsewhere,
the market is much larger
as in Europe, where 70 to
80 percent of autos are
shifted manually. Emergin
auto markets such as Asia
and Latin America also
strongly favor manual
transmissions.



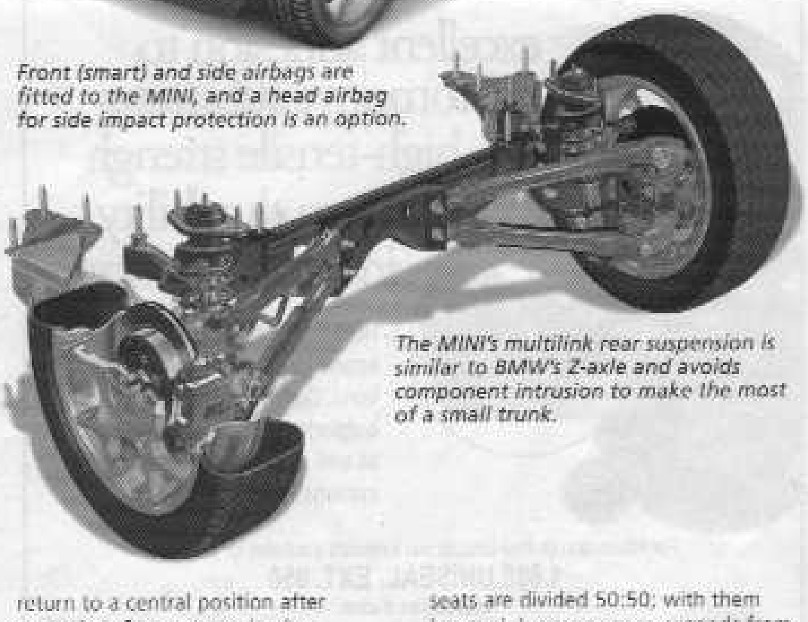
In a manual transmission, spur, helical and herringbo gears rotate and mesh with each other, reducing engine ...d and transferring ... torque to the driving ...els.

Blueprint for Gear Oils



The MINI has MacPherson struts at the front and a multilink system at the rear.

Front (smart) and side airbags are fitted to the MINI, and a head airbag for side impact protection is an option.



The MINI's multilink rear suspension is similar to BMW's Z-axle and avoids component intrusion to make the most of a small trunk.

polished alloys. Both versions of the MINI have a hood that incorporates the front fenders and headlamps. The doors have frameless electric windows. The car's A-pillars are concealed behind a black, high-gloss plastic panel, and the B- and C-pillars are "hidden" behind glass, giving the impression of a continuous window extending around the car.

The original Mini had its speedometer placed centrally, and so has the new MINI. A rev counter is positioned above the steering column. The speedometer contains fuel-level, coolant-temperature, and tire-pressure warning indicators. An optional trip computer can be incorporated within the speedometer. If a satellite navigation system is specified, the speedometer is positioned next to the rev counter. In fact, the interior of the new MINI is very different from that of the minimalist—even stark—1959 Mini. Dashboard trim includes a wood option, and the steering wheel can incorporate a multifunction facility with stereo and cruise control functions. The Steptronic CVT can also be controlled from the steering wheel. The original Mini had toggle switches—so has the new MINI, but they are caged for safety. Unlike the original, the switches are sprung to return to a central position after operation. Sports seats, lumbar control, and two-level seat heating are other options that would have been unthinkable 42 years ago. Rear seats are bucket-shaped, and the car's high, level roofline aids headroom. The rear seats are divided 50:50; with them lowered, luggage space expands from a very modest 150 to 670 L (5.3 to 23.7 ft³).

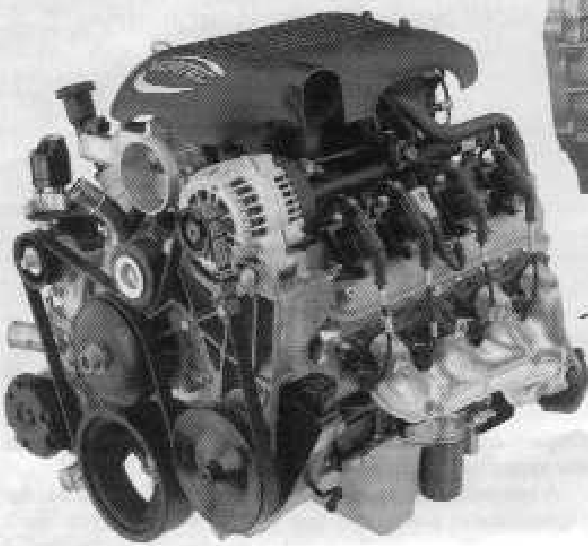
Stuart Birch

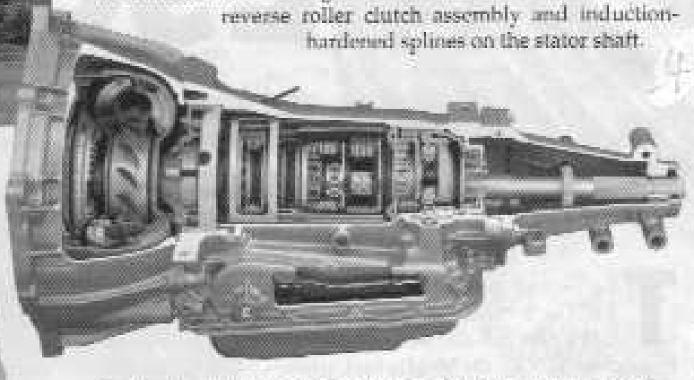
Interesting? Circle 35
Not interesting? Circle 36

#3

Escalade weight-saving features include an aluminum tailgate.

The Vortec 6000 engine is linked to a new Hydra-Matic 4L60-E HD (heavy-duty) four-speed automatic transmission. The heavy-duty version of the 4L60-E in the Vortec 5300-equipped Escalade was upgraded to handle the larger engine's greater power and torque. Compared to the 4L60-E, it has five pinions in the input and reaction gear sets for 20% more torque capacity. New aluminum-construction bushings in the stator shaft and an extra clutch plate (7 vs. 6) in the third and fourth gear clutch provide higher torque capacity. For improved durability, a new induction heat treating process is used for the turbine shaft and strength is improved at the lubrication points. In addition, there are larger diameter clutch rollers in the low/reverse roller clutch assembly and induction-hardened splines on the stator shaft.





The Escalade's Vortec 6000 engine is linked to a new Hydra-Matic 4L60-E HD (heavy-duty) four-speed automatic transmission upgraded to handle the engine's greater power and torque.

The Escalade's full-time, all-wheel-drive system's torque split is 38/62% front/rear for balanced handling characteristics in normal operation. However, a viscous coupling transfer case can continuously adjust the torque to the wheels when slip is detected. The system automatically transfers torque to the wheels with better grip and restores the 38/62% ratio when full traction is regained. The transfer case is constructed of magnesium and has a "pancake-style" differential.

The Escalade's axles were upgraded, with synthetic fluid reduc-

Lecture 2

But first we will cover:

Ch 1. Introduction…you should read. Includes general discussion, codes and standards, strength and stress, factors of safety, economics, units

Ch 2-3 Stresses and deflections (mostly stresses some topics will be introduced as needed later in the course) Simple tension-compression, bending, shear, torsion, thick-walled cylinders, stress concentrations, contact stresses, combined stresses, principal stresses

Ch 5 Material properties
Ultimate strength, Yield strength, Shear strength, brittle vs. ductile materials, notch sensitivity

Ch 6 Static failure
Ch 7 Fatigue failure

STRESS and STRENGTH

Strength: Material Property or obtained from material property

$S_u \rightarrow$ Ultimate Strength

$S_y \rightarrow$ Yield Strength

Stress: Force (Applied) per unit area, σ or τ

FACTOR of SAFETY

$$n = \frac{S}{\sigma}$$

S ← appropriate Strength

σ ← appropriate (maximum) stress

n → >1 to account for variability + unknown effects

ALLOWABLE STRESSES

Sometimes we will combine Factor of Safety and Strength ... many codes do this .... to get an "allowable stress," σ_{all}, which is NOT to be exceeded

$$\sigma_{all} = \frac{S}{n} \geq \sigma_{max}$$

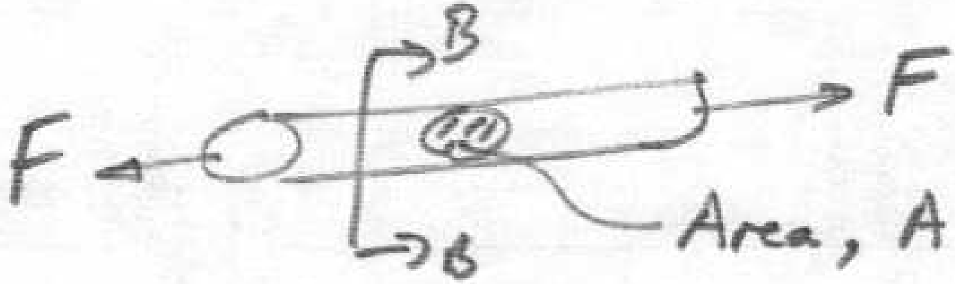
This is specified

all stresses must be less than σ_{all}

This is implied

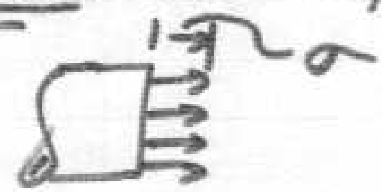
BASIC STRESS CALCS

I Tension & Compression

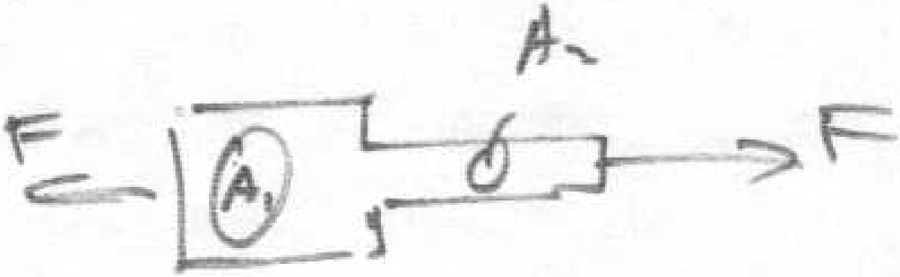


$$\sigma = \frac{F}{A}$$

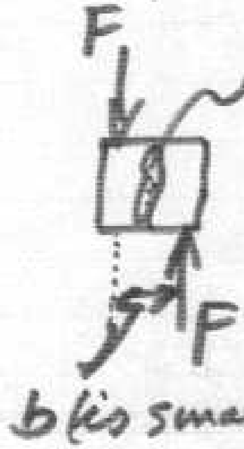
<u>Stress</u> is Uniform



Section B-B



II Simple Shear

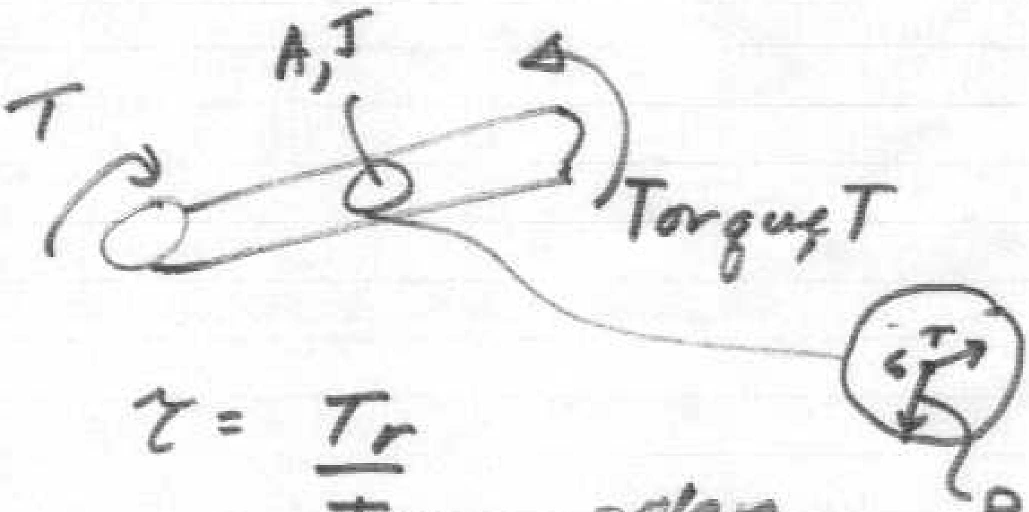


$$\tau = \frac{F}{A}$$

(ignore moment due to Fb)

Stress is <u>uniform</u> ... harder to achieve than uniform tension

III Torsion

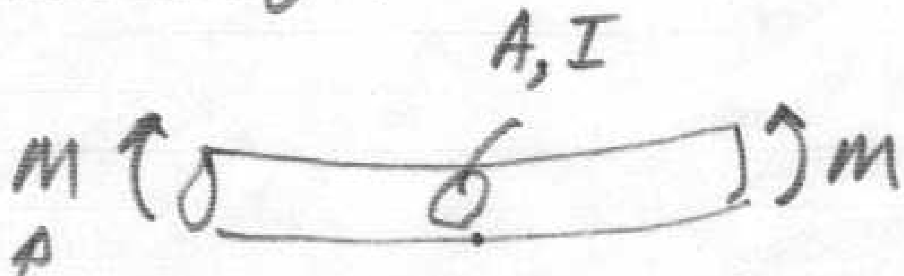


$$\tau = \frac{Tr}{J}$$ ← polar of inertia (polar 2nd moment)

$$\tau_{max} = \frac{T\rho}{J}$$

TABLE A18

Bending (Pure)



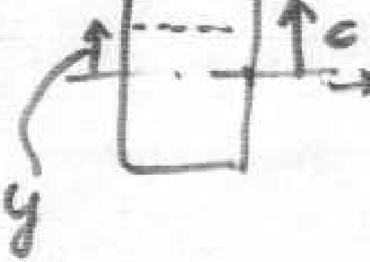
Bending moment

$$\sigma = \frac{My}{I}$$

y — distance from neutral axis

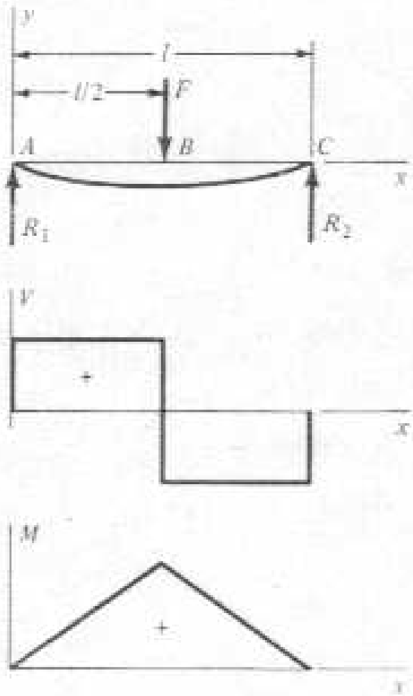
I — Area moment of inertia Table A-18

e.g. **Rectangular Beam**



$$\sigma_y = \frac{My}{I} \qquad \sigma_{max} = \frac{Mc}{I}$$ tension or comp.

Bending and Shear



$$R_1 = R_2 = \frac{F}{2} \qquad V_{AB} = R_1$$

$$V_{AB} = R_1 \qquad V_{BC} = -R_2$$

$$M_{AB} = \frac{Fx}{2} \qquad M_{BC} = \frac{F}{2}(l - x)$$

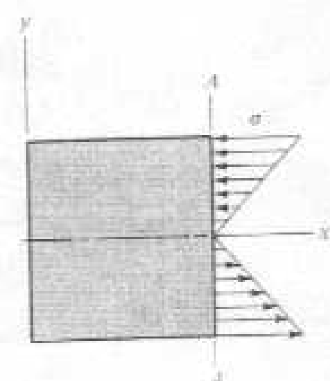
$$y_{AB} = \frac{Fx}{48EI}(4x^2 - 3l^2)$$

$$y_{max} = -\frac{Fl^3}{48EI}$$

Example from Table A-9

M develops tension and compression as in pure bending

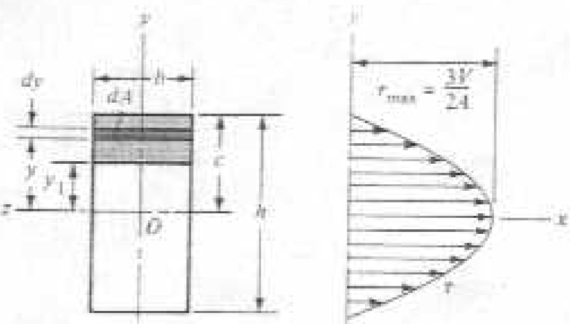
$$\sigma = \frac{My}{I}$$



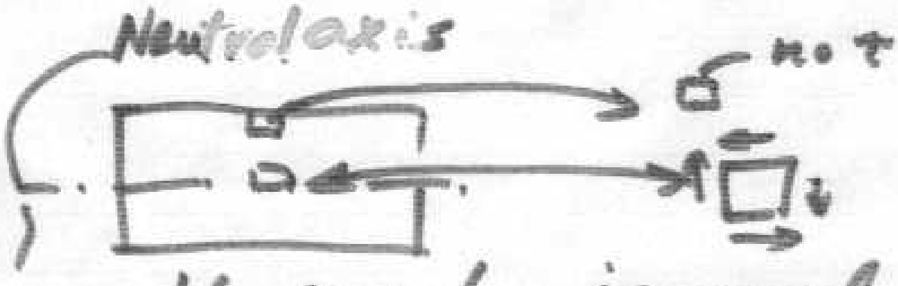
V develops shear stresses

- must be zero at top and bottom fibers
- maximum at neutral axis

e.g.

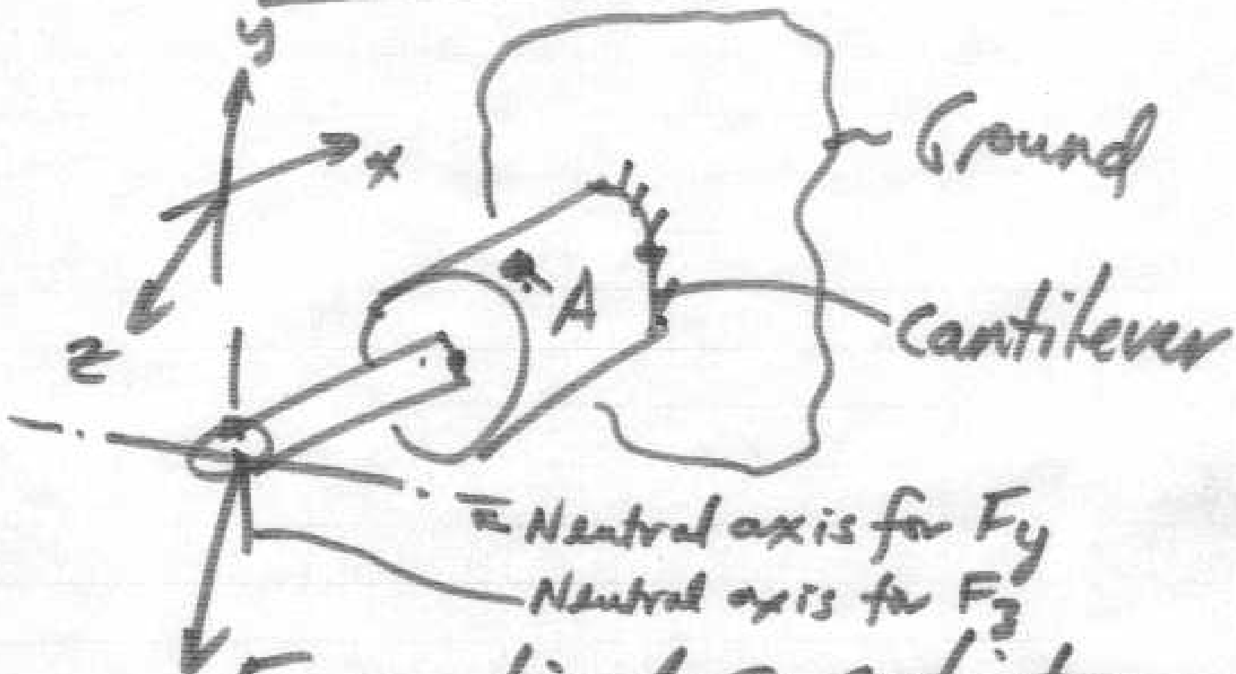


See table 2-4 for other shapes and τ_{max}



V can be ignored except for very short beams. Stresses due to M dominate

Example



F applied @ arbitrary angle

Components F_x, F_y, F_z

Element A – ON TOP SURFACE

due to F_y

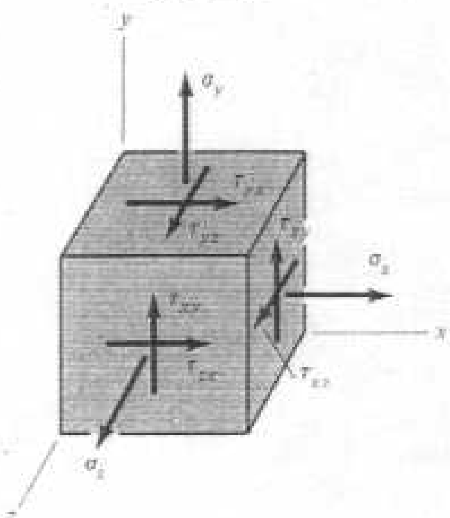
$\sigma_{F_y} + \sigma_{F_x} = \sigma$

τ_{F_z}

Principal Stresses

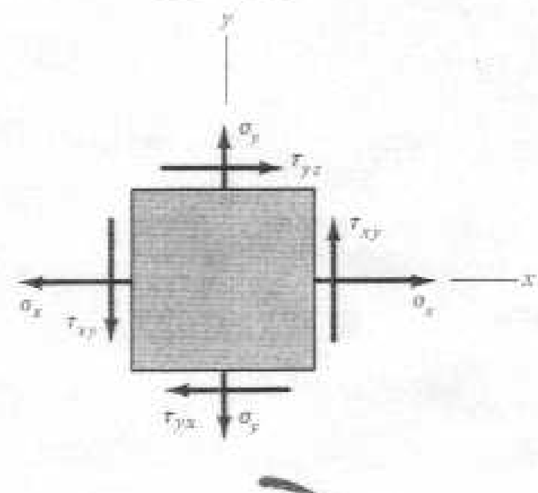
General state of Stress on an element

3-D



(a)

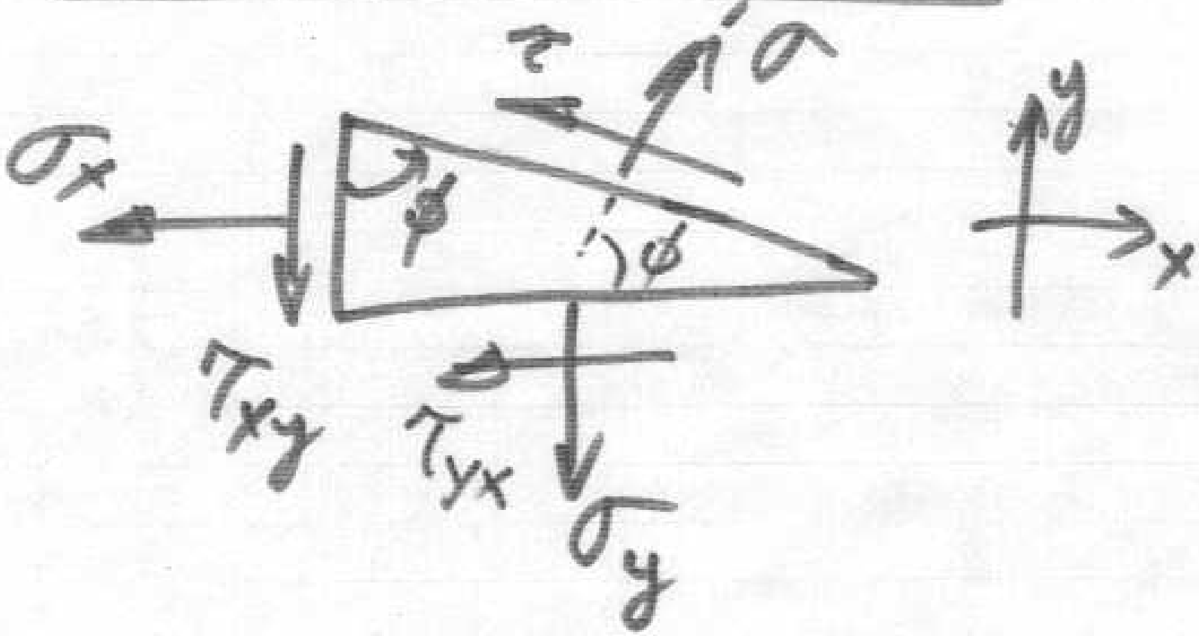
2-D



(b)

Clockwise shear is +ve

First Consider 2-D



Equilibrium requires

$$\sigma = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\phi + \tau_{xy} \sin 2\phi$$

$$\tau = -\frac{\sigma_x - \sigma_y}{2} \sin 2\phi + \tau_{xy} \cos 2\phi$$

for any ∡ ϕ

i.e. $\Sigma F_x = 0$ $\Sigma M = 0$

$\Sigma F_y = 0$

PRINCIPAL STRESSES

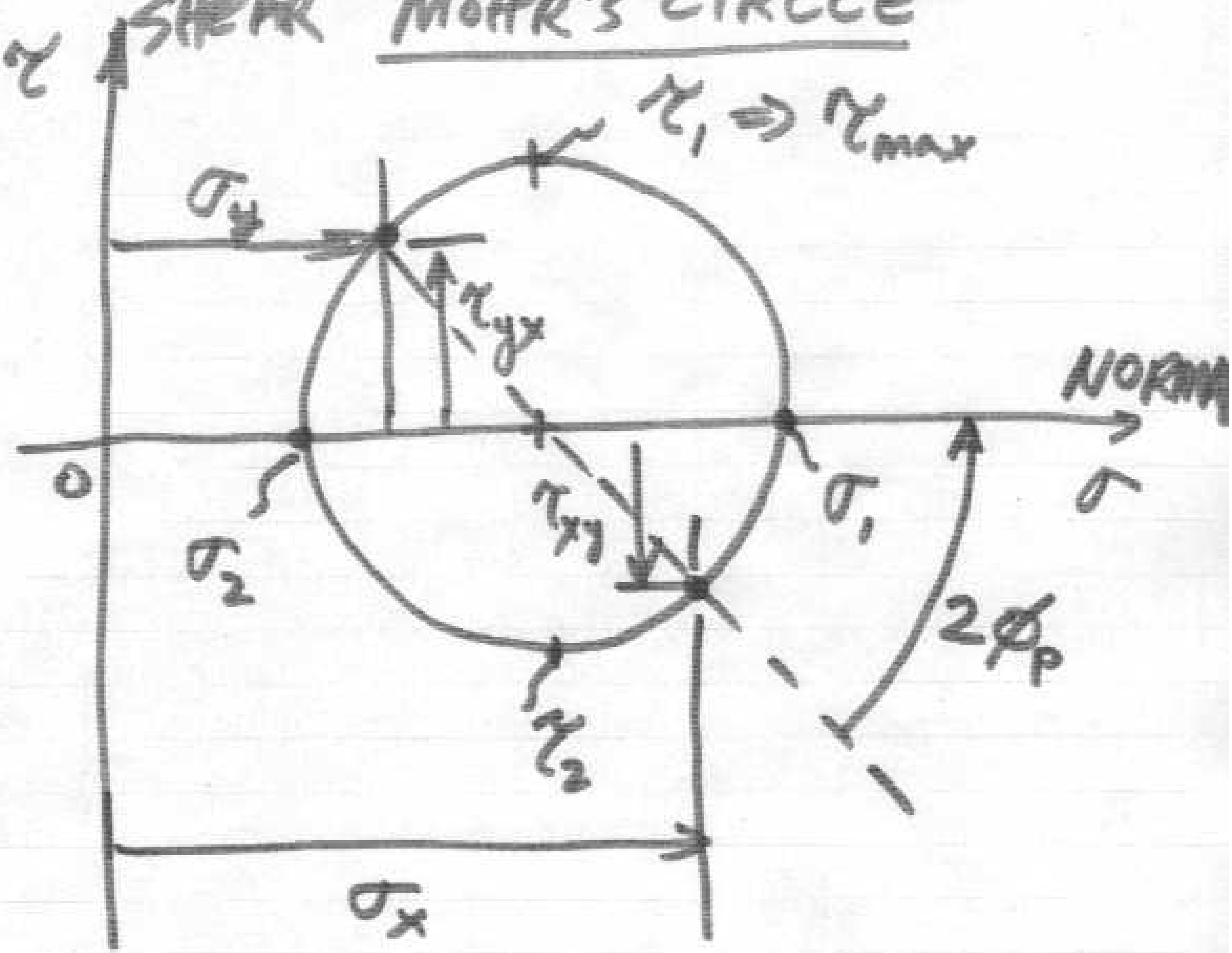
I σ_1, σ_2 ARE STRESSES ON ANGULAR FACE (ANGLE ϕ) WHERE SHEAR STRESS IS ZERO

II σ_1 AND σ_2 ARE THE MAX AND MIN NORMAL (TENSION, COMPRESSION) STRESSES ON THE ELEMENT

III MAXIMUM SHEAR STRESS OCCURS ON ELEMENT AT 45° TO PLANES OF σ_1, σ_2

$$\tau_{max} = |\sigma_1 - \sigma_2|$$

MOHR'S CIRCLE



TYPICALLY,

① OBTAIN $\sigma_x, \sigma_y, \tau_{yx}, \tau_{xy}$ FROM STRESS CALCS

② DETERMINE σ_1, σ_2, PRINCIPAL STRESSES & MAX SHEARSTRESS τ_{max}

USING EQ'S

$$\sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \quad \cdots (2\text{-}8)$$

ALSO

$$\tau_{max} = |\sigma_1 - \sigma_2|/2$$

ANGLE ϕ_p determined from:

$$\tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\phi_p + \tau_{xy} \cos 2\phi_p$$

$$= 0$$

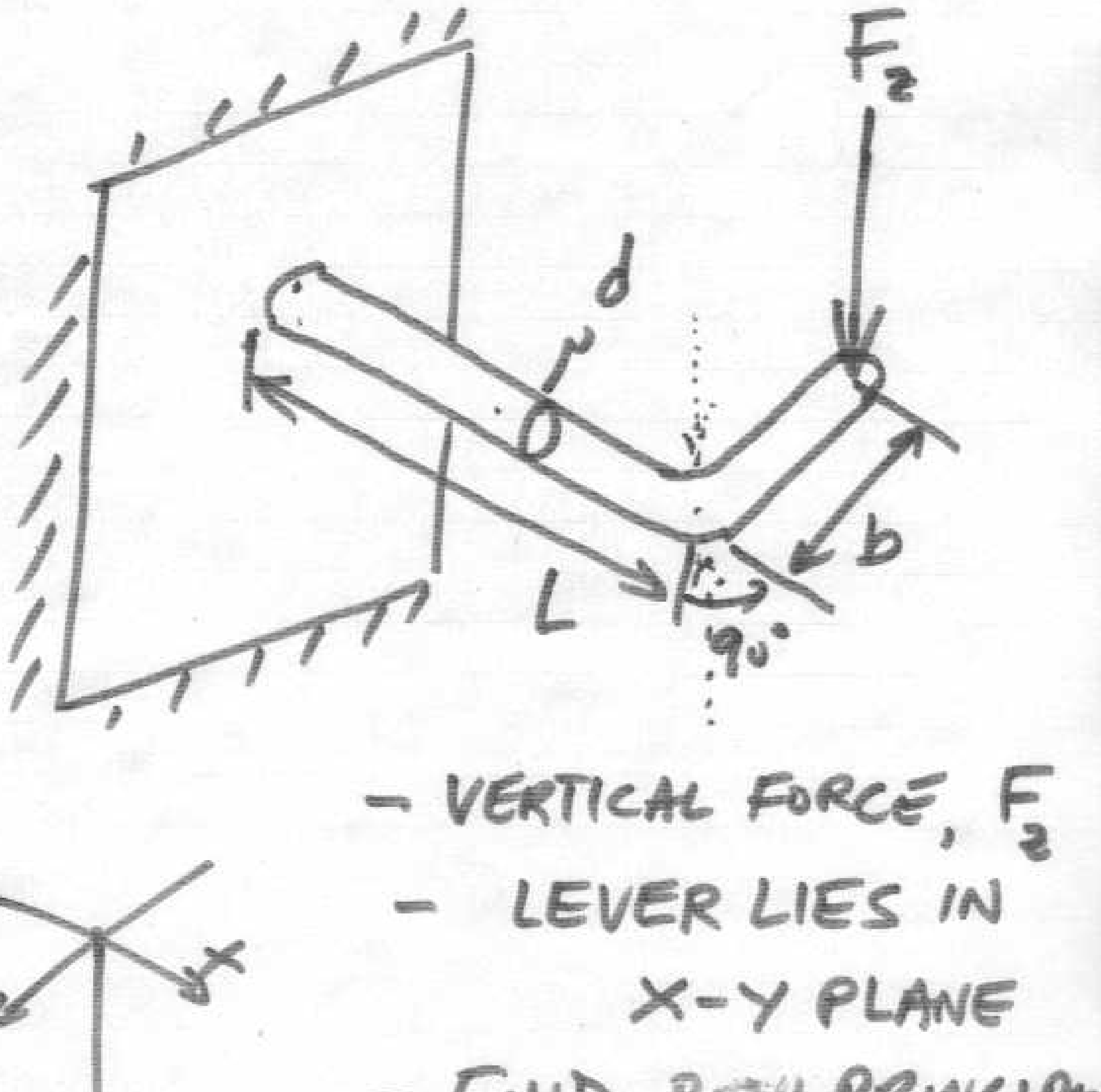
$$\therefore \tan 2\phi_p = \frac{2\tau_{xy}}{\sigma_x - \sigma_y} \quad \cdots (2\text{-}4)$$

Compression -ve

Tension +ve

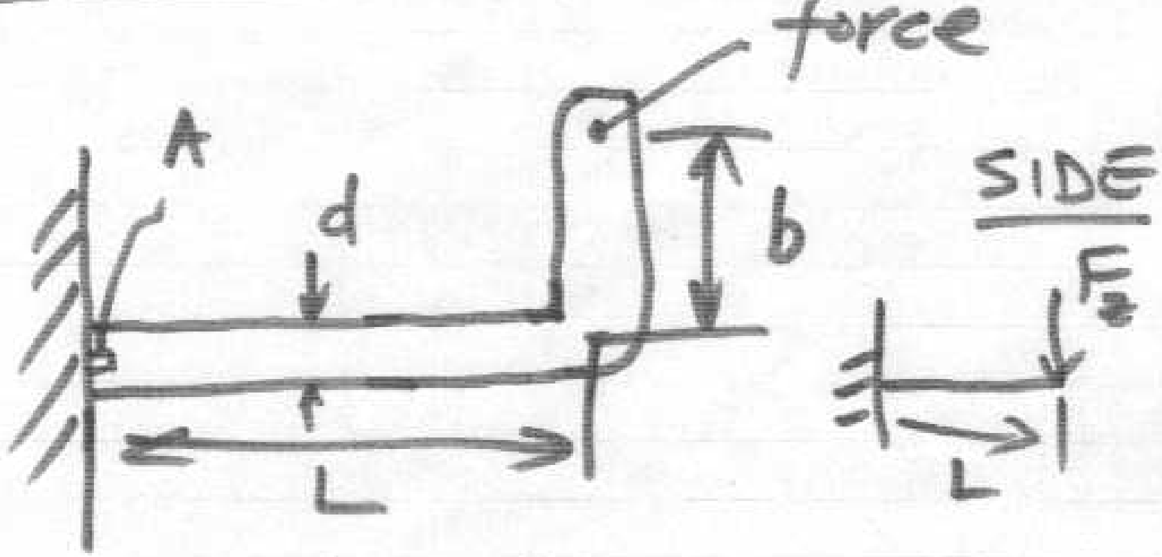
READ OVER EXAMPLE 2-1

ANOTHER EXAMPLE

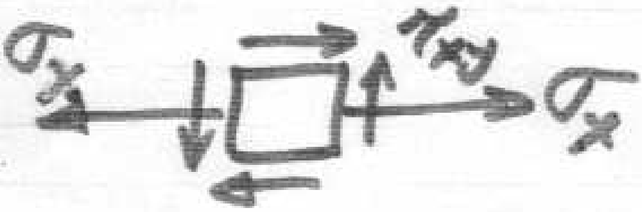


- VERTICAL FORCE, F_z
- LEVER LIES IN X-Y PLANE
- FIND BOTH PRINCIPAL STRESSES + MAX SHEAR

VIEW FROM ABOVE



ELEMENT "A" (LIKELY LOCATION OF MAX STRESS)



F_z causes bending moment @ A

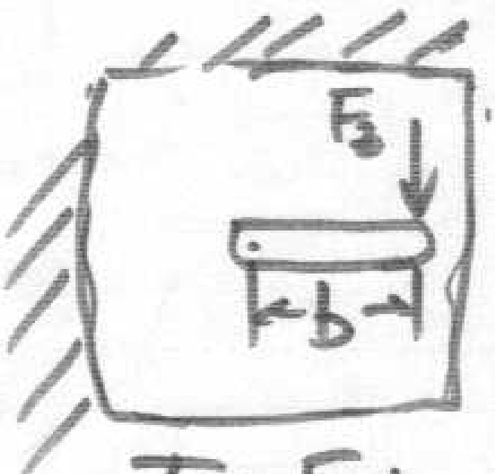
$$M = F_z L$$

max tensile stress due to bending

$$\sigma_x = \frac{Mc}{I} = \frac{M(d/2)}{\frac{\pi d^4}{64}} = \frac{32M}{\pi d^3}$$

ASSUME $\sigma_x = 60\ MPa$

VIEW FROM "END"



F_2 places torque on rod resulting in shear stress, τ_{xy}

$$T = F_2 b$$

$$\tau_{xy} = \frac{T(d/2)}{J} = \frac{T(d/2)}{\pi d^4/32}$$

$$\tau_{xy} = \frac{16T}{\pi d^3}$$ $\Rightarrow$ TORSION

assume:

$$\boxed{\tau_{xy} = 40\ \text{MPa}}$$