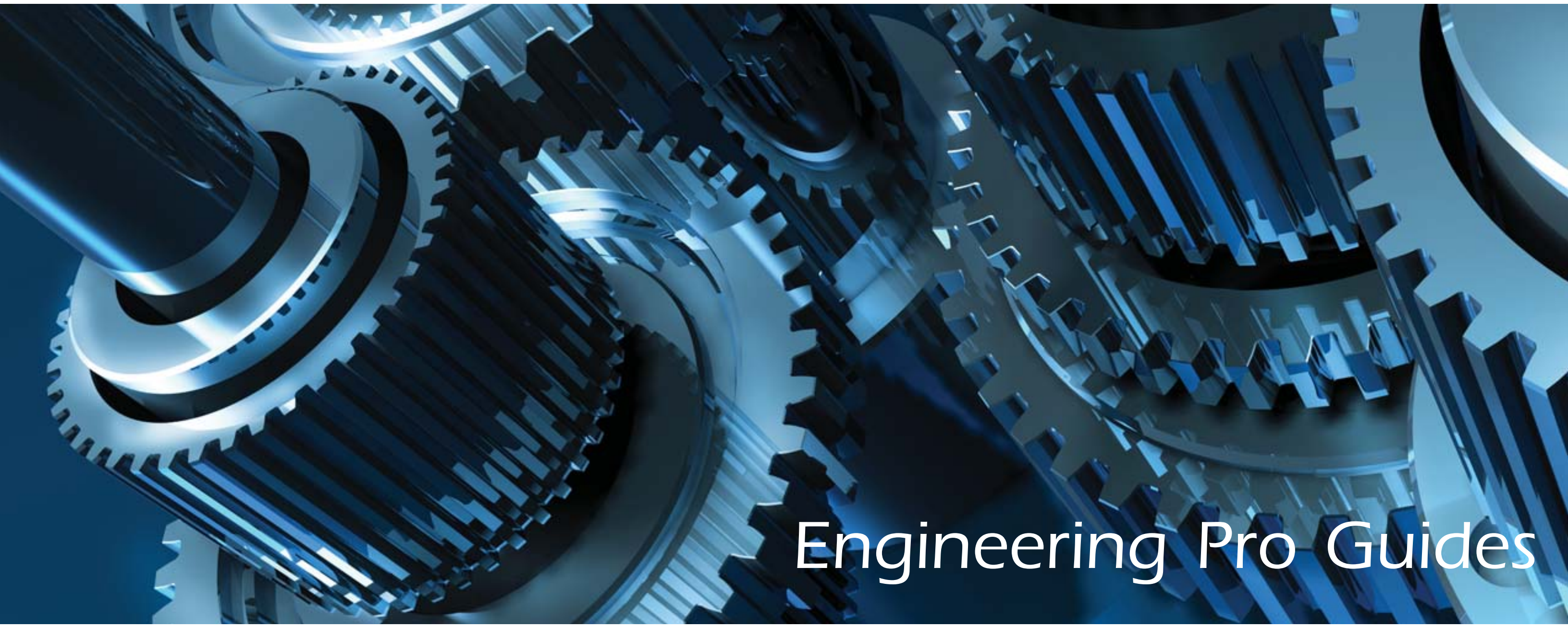
Mechanical Machine Design and Materials PE



Technical Study Guide How to pass the exam

- Creates an understanding of the key exam concepts and skills
- Simplifies and focuses your studying
- Follows the exam outline and teaches the main topics.
- Covers Basic Eng. Practice, Eng. Sci. & Mech., Materials Strength of Materials, Vibration, Components Joints, Fasteners and Support Knowledge.

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Table of Contents

SECTION 1
INTRODUCTION

Introduction

Table of Contents

1.0 Introduction

One of the most important steps in an engineer's career is obtaining the professional engineering (P.E.) license. It allows an individual to legally practice engineering in the state of licensure. This credential can also help to obtain higher compensation and develop a credible reputation. In order to obtain a P.E. license, the engineer must first meet the qualifications as required by the state of licensure, including minimum experience, references and the passing of the National Council of Examiners for Engineering and Surveying (NCEES) exam. Engineering Pro Guides focuses on helping engineers pass the NCEES exam through the use of free content on the website, http://www.engproguides.com and through the creation of books like sample exams and guides that outline and teach you how to pass the PE exam.

The key to passing the PE exam is to learn the key concepts and skills that are tested on the exam. There are several issues that make this key very difficult. First, the key concepts and skills are unknown to most engineers studying for the exam. Second, the key concepts and skills are not contained in a single document. This technical guide teaches you the key concepts and skills required to pass the Machine Design & Materials Mechanical P.E. Exam.

1.1 Key Concepts and Skills

How are the key concepts and skills determined?

The key concepts and skills presented in this book were first developed through an analysis of the topics and information presented by NCEES. NCEES indicates on their website that the P.E. Exam will cover an AM exam (4 hours) followed by a PM exam (4 hours) and that the exam will be 80 questions long, 40 questions in the morning and 40 questions in the afternoon. The Machine Design & Materials Mechanical PE exam will focus on the following topics as indicated by NCEES. (http://ncees.org/engineering/pe/):

I. Principles (40 questions)

A) Basic Engineering Practice *(9 questions)*
   1 Engineering terms and symbols
   2 Interpretation of technical drawings
   3 Quality assurance/quality control (QA/QC)
   4 Project management and economic analysis
   5 Units and conversions
   6 Design methodology (e.g., identifying requirements, risk assessment, verification/validation)

B) Engineering Science and Mechanics *(10 questions)*
   1 Statics
   2 Kinematics
   3 Dynamics

C) Material Properties *(8 questions)*
   1 Physical (e.g., density, melting point, optical)
   2 Chemical (e.g., corrosion, alloys, oxidation)

SECTION 2
BASIC ENGINEERING PRACTICE

Section 2.0 - Basic Engineering Practice

Table of Contents

Control Chart Factors

n	A2	A3	~~c4~~	B3	B4	~~d2~~	~~1/d2~~	~~d3~~	D3	D4
2	1.880	2.659	~~0.7979~~	0.000	3.267	~~1.128~~	~~0.8862~~	~~0.853~~	0.000	3.267
3	1.023	1.954	~~0.8862~~	0.000	2.568	~~1.693~~	~~0.5908~~	~~0.888~~	0.000	2.575
4	0.729	1.628	~~0.9213~~	0.000	2.266	~~2.059~~	~~0.4857~~	~~0.880~~	0.000	2.282
5	0.577	1.427	~~0.9400~~	0.000	2.089	~~2.326~~	~~0.4299~~	~~0.864~~	0.000	2.114
6	0.483	1.287	~~0.9515~~	0.030	1.970	~~2.534~~	~~0.3946~~	~~0.848~~	0.000	2.004
7	0.419	1.182	~~0.9594~~	0.118	1.882	~~2.704~~	~~0.3698~~	~~0.833~~	0.076	1.924
8	0.373	1.099	~~0.9650~~	0.185	1.815	~~2.847~~	~~0.3512~~	~~0.820~~	0.136	1.864
9	0.337	1.032	~~0.9693~~	0.239	1.761	~~2.970~~	~~0.3367~~	~~0.808~~	0.184	1.816
10	0.308	0.975	~~0.9727~~	0.284	1.716	~~3.078~~	~~0.3249~~	~~0.797~~	0.223	1.777
11	0.285	0.927	~~0.9754~~	0.321	1.679	~~3.173~~	~~0.3152~~	~~0.787~~	0.256	1.744
12	0.266	0.886	~~0.9776~~	0.354	1.646	~~3.258~~	~~0.3069~~	~~0.778~~	0.283	1.717
13	0.249	0.850	~~0.9794~~	0.382	1.618	~~3.336~~	~~0.2998~~	~~0.770~~	0.307	1.693
14	0.235	0.817	~~0.9810~~	0.406	1.594	~~3.407~~	~~0.2935~~	~~0.763~~	0.328	1.672
15	0.223	0.789	~~0.9823~~	0.428	1.572	~~3.472~~	~~0.2880~~	~~0.756~~	0.347	1.653
16	0.212	0.763	~~0.9835~~	0.448	1.552	~~3.532~~	~~0.2831~~	~~0.750~~	0.363	1.637
17	0.203	0.739	~~0.9845~~	0.466	1.534	~~3.588~~	~~0.2787~~	~~0.744~~	0.378	1.622
18	0.194	0.718	~~0.9854~~	0.482	1.518	~~3.640~~	~~0.2747~~	~~0.739~~	0.391	1.609
19	0.187	0.698	~~0.9862~~	0.497	1.503	~~3.689~~	~~0.2711~~	~~0.733~~	0.404	1.596
20	0.180	0.680	~~0.9869~~	0.510	1.490	~~3.735~~	~~0.2677~~	~~0.729~~	0.415	1.585
21	0.173	0.663	~~0.9876~~	0.523	1.477	~~3.778~~	~~0.2647~~	~~0.724~~	0.425	1.575
22	0.167	0.647	~~0.9882~~	0.534	1.466	~~3.819~~	~~0.2618~~	~~0.720~~	0.435	1.565
23	0.162	0.633	~~0.9887~~	0.545	1.455	~~3.858~~	~~0.2592~~	~~0.716~~	0.443	1.557
24	0.157	0.619	~~0.9892~~	0.555	1.445	~~3.895~~	~~0.2567~~	~~0.712~~	0.452	1.548
25	0.153	0.606	~~0.9896~~	0.565	1.435	~~3.931~~	~~0.2544~~	~~0.708~~	0.459	1.541

d_2 and $1/d_2$: These two terms are crossed out because these values are only used to determine A_2.

$$A_2 = \frac{3}{d_2\sqrt{n}};\ where\ n = sample\ size$$

d_3: This term is crossed out because it is only used to determine D_3 and D_4.

$$D_3 = 1 - \frac{3d_3}{d_2};\ D_4 = 1 + \frac{3d_3}{d_2};$$

B_3, B_4: These terms are used in s-charts to find UCL and LCL.

$$UCL_s = B_4\bar{s};\ LCL_s = B_3\bar{s}, where\ \bar{s}\ is\ the\ average\ standard\ deviation\ (centerline)$$

9.6 Solution 6 – Unit Conversions

Background: A boiler is sized at 10 boiler horsepower. The input to the boiler is 10 boiler horsepower. It is found that the boiler outputs 300,000 BTUH of heat to produce steam.

Problem: The efficiency of the boiler is most nearly?

First convert boiler horsepower to BTUH by using your Engineering Unit Conversions book.

$$1\ boiler\ horsepower = \ 33{,}479\ Btuh$$

$$10\ boiler\ horsepower * 33{,}479 = \ 334{,}790\ Btuh$$

There are other boiler efficiency equations, but in this example problem the simplest efficiency is found, which is just output energy divided by input energy.

$$Efficiency = \frac{output}{input}$$

$$Efficiency = \frac{300{,}000\ Btuh}{334{,}790\ Btuh} = 89.6\%$$

Correct Answer: D) 89%

SECTION 3
ENGINEERING SCIENCE & MECANICS

Section 3.0 – Engineering Science & Mechanics

Table of Contents

Simple beam with a concentrated load

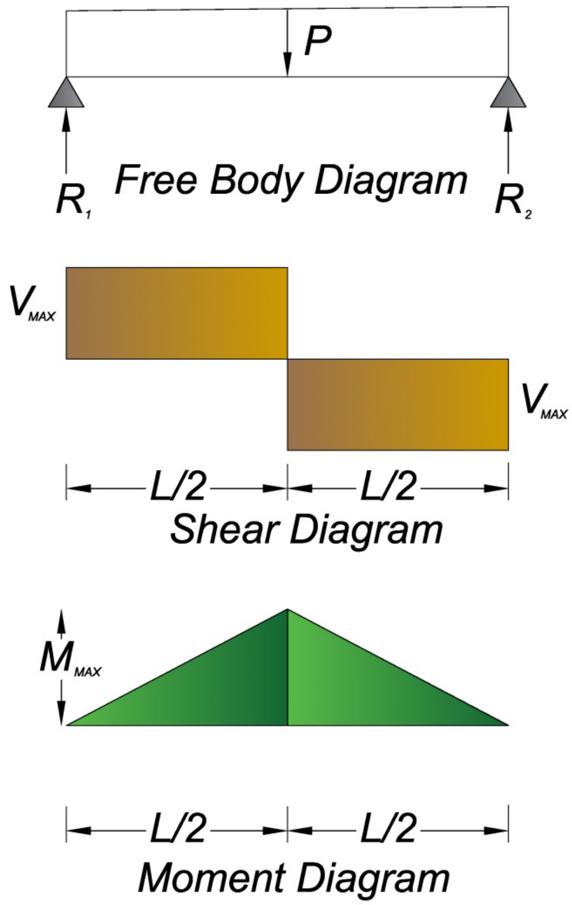


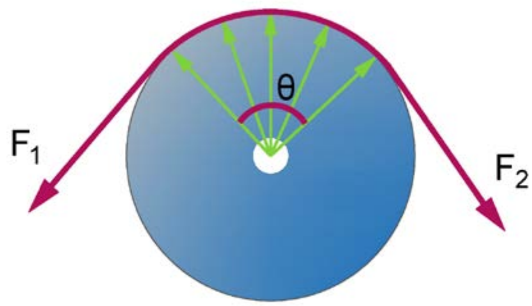
Figure 15: Simple beam with concentrated load diagrams.

This diagram is typically used when a beam is supported at both ends and it is used to support a concentrated load. The downward force is equal to load. There will be upward reaction forces at the support that will counteract the concentrated load. The force at each support will be equal to one-half the entire weight.

$$R_1 = R_2 = \frac{P}{2}\ (lbf)$$

The next figure shows the shear force diagram. The shear force acting at any point "x" on the beam is either +P/2 or –P/2. The shear force is at its maximum at the supports. The slope of the line in this diagram is straight, because unlike the distributed load, the only forces acting upon the beam are the reaction forces and the concentrated load. The previous diagram had external forces acting on the beam throughout the entire length, which changed the shear force at each point along the beam.

The bending moment acting at any point "x" on the beam is governed by the following equation. The moment is at its maximum at the center. The moment will be equal to zero when "x" is equal to "L" or "0".



$$Pulley, Flat\ Belt\ Friction \rightarrow F_2 = F_1 e^{\mu\theta}$$

$$\theta = Contact\ surface;\ \mu = static\ or\ kinetic\ friction$$

You should always make sure that your angle values are in radians, when using this equation.

If you encounter a V-belt situation which will be discussed more in the Mechanical Components Section, then you should use the following equation. The alpha term is the angular gap in radians between contact surfaces, since the belt is grooved. See Mechanical Components for more discussion into this topic.

$$V - Belt\ Friction \rightarrow F_2 = F_1 e^{\mu\theta / \sin(\frac{\alpha}{2})}$$

3.2 Kinetics

Kinetics is the study of the relationship between the motion in kinematics and forces acting upon masses. The previous force diagrams assumed that the forces balanced, thus there was zero net force acting upon the objects. However, if there is a net force that is not balanced, then the object will experience acceleration directly proportional to the magnitude of this force and inversely proportional to the mass of the object. The equation below summarizes this statement.

$$Newton's\ 2nd\ Law \rightarrow \sum F_x = ma_x\ ; \sum F_y = ma_y\ ; \sum F_z = ma_z$$

Similar to the section on Friction, this law applies to all directions, x, y and z. This law also applies to angular type problems as well.

$$\sum \tau = I\alpha$$

$$where\ I = moment\ of\ inertia;\ \alpha = angular\ moment$$

3.2.1 Conservation of Energy and Momentum

Another way to solve kinetic type problems on the PE exam is to use the conservation of energy and conservation of momentum equations. The basic concept is that energy and momentum is conserved and you can use these conservation equations to solve for unknowns.

SECTION 4
MATERIAL PROPERTIES

Section 4.0 – Material Properties

Table of Contents

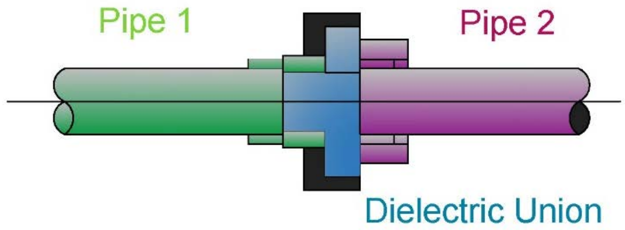


Figure 5: A dielectric union separates two connected pipes of dissimilar metals with a non-conductive washer shown in blue. Normally an electrochemically reaction will occur from the more noble metal to the less noble metal with the water serving as the path connecting the two metals. The dielectric union stops this reaction by physically separating the metals.

3.1.3.2 Cathodic Protection

Cathodic protection uses a sacrificial anode that has a more negative electrode potential than the metal it is protecting. The two metals are connected, typically by a wire, and ultimately the corrosion occurs at the sacrificial anode and not the protected metal. Typical sacrificial anode materials are zinc, aluminum, or magnesium.

Another method of cathodic protection is by *galvanization*. In this process, a metal is coated with zinc, typically by *hot dip galvanizing*, which submerges the metal into liquefied zinc. The protective coating then acts as the sacrificial anode to the metal beneath it. Even if part of the metal is exposed, the zinc will still act as the anode and protect the adjacent metal. It is important to note that galvanization does not protect against acidic corrosion.

For additional information on corrosion, the NACE Corrosion Engineer's Reference Book provides a compilation of data, tables, and charts of various corrosion types, causes, and protection methods. It is more technical than required for the test, but provides a comprehensive reference of supportive data for corrosion engineers.

3.2 Oxidation

The corrosion of metals does not always require a liquid to promote the electrochemical reaction. Oxidation is the act of corrosion in gas and for the purposes of the exam the gas will be air. It will be difficult to test this topic numerically, but you should be familiar with the overall concept of oxidation and chemically how oxidation occurs.

A metal with two electrons (divalent) will be combined with ½ oxygen molecule to form a metal-oxide.

$$M + \frac{1}{2} O_2 \rightarrow MO$$

If the metal has more electrons, then the same ratio will be used to complete the above reaction. For example, the following shows the reaction for aluminum.

$$2Al + \frac{3}{2}O_2 \rightarrow Al_2O_3$$

Aluminum has 3 electrons, thus the least common multiple is 6 electrons, which requires 2 aluminum molecules and 3 oxygen molecules. More examples of the oxidation reaction are shown in the table below.

Metal		*Oxygen*	*Reaction*
Aluminum	$2Al \rightarrow 2Al^{3+} + 6e^-$	$\frac{3}{2}O_2 + 6e^- \rightarrow 3O^{2-}$	$2Al + \frac{3}{2}O_2 \rightarrow Al_2O_3$
Chromium	$2Cr \rightarrow 2Cr^{3+} + 6e^-$	$\frac{3}{2}O_2 + 6e^- \rightarrow 3O^{2-}$	$2Cr + \frac{3}{2}O_2 \rightarrow Cr_2O_3$
Nickel	$Ni \rightarrow Ni^{2+} + 2e^-$	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	$Ni + \frac{1}{2}O_2 \rightarrow NiO$
Iron	$Fe \rightarrow Fe^{2+} + 2e^-$	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	$Fe + \frac{1}{2}O_2 \rightarrow FeO$
Beryllium	$Be \rightarrow Be^{2+} + 2e^-$	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	$Be + \frac{1}{2}O_2 \rightarrow BeO$
Cobalt	$Co \rightarrow Co^{2+} + 2e^-$	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	$Co + \frac{1}{2}O_2 \rightarrow CeO$
Manganese	$Mn \rightarrow Mn^{2+} + 2e^-$	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	$Mn + \frac{1}{2}O_2 \rightarrow MnO$
Silver	$Ag \rightarrow Ag^{2+} + 2e^-$	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	$Ag + \frac{1}{2}O_2 \rightarrow AgO$
Silicon	$Si \rightarrow Si^{4+} + 4e^-$	$\frac{2}{2}O_2 + 4e^- \rightarrow 2O^{2-}$	$Si + \frac{2}{2}O_2 \rightarrow SiO_2$
Titanium	$Ti \rightarrow Ti^{4+} + 4e^-$	$\frac{2}{2}O_2 + 4e^- \rightarrow 2O^{2-}$	$Ti + \frac{2}{2}O_2 \rightarrow TiO_2$
Molybdenum	$Mo \rightarrow Mo^{4+} + 4e^-$	$\frac{2}{2}O_2 + 4e^- \rightarrow 2O^{2-}$	$Mo + \frac{2}{2}O_2 \rightarrow MoO_2$

The following figure shows how a metal oxide film forms on the surface of a metal with 2 electrons.

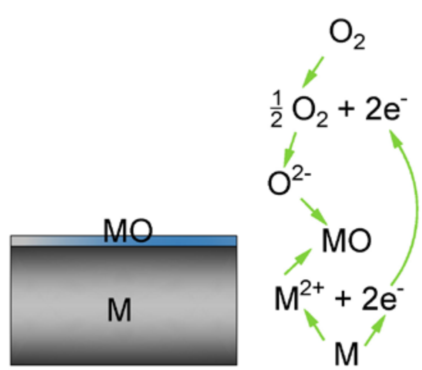
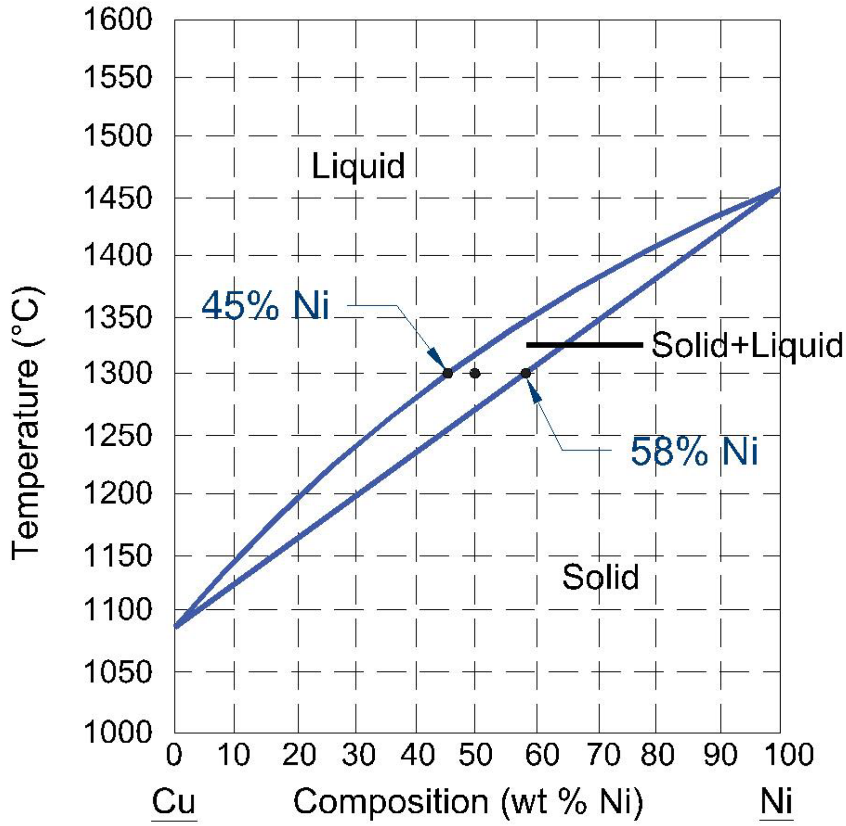


Figure 6: Oxidation occurs when electrons flow from the metal to the air. This causes a film to form on the top layer of the metal. This film is a metal-oxide.

5.7 PROBLEM 7: ALLOYS

A copper-nickel alloy has 50% nickel and exists as a solid-liquid mixture at 1300°C? What is the percentage by weight of solid at this temperature?



a) 38%

b) 50%

c) 62%

d) 63%

6.6 SOLUTION 6: STRESS-STRAIN

A cylindrical rod has a diameter of 0.5 inches. This rod is stressed in tension with a force of 3,500 lbf. This causes the diameter of the rod to be reduced to 0.4998 inches. The rod is made of a material with a modulus of elasticity of 15 x 10^6 psi. What is Poisson's ratio of this material?

Poisson's ratio is defined by the following equation.

$$v = -\frac{\varepsilon_y}{\varepsilon_x}$$

$$\varepsilon_x = stain\ in\ direction\ of\ tension;\ \varepsilon_y = strain\ perpendicular\ to\ directon\ of\ tension$$

$$\varepsilon_y = \frac{\Delta diameter}{diameter} = \frac{0.4998 - 0.5000}{0.5000} = -.0004$$

In order to solve for the strain in the direction of tension you need to use the modulus of elasticity equation.

$$E = \frac{\sigma}{\varepsilon_x}$$

$$15\ x\ 10^6\ psi = \frac{\frac{F}{A}}{\varepsilon_x} = \frac{\frac{3{,}500\ lbf}{\pi * 0.25^2}\ psi}{\varepsilon_x}$$

$$\varepsilon_x = .001188$$

Now plug in the strains into the first equation.

$$v = -\frac{-.0004}{.001188} = 0.3366$$

The correct answer is most nearly, **d) 0.34**.

SECTION 5
STRENGTH OF MATERIALS

SECTION 5.0 – STRENGTH OF MATERIALS

TABLE OF CONTENTS

$$S = section\ modulus\ (in^3); I = moment\ of\ inertia\ (in^4);$$

$$c = perpendicular\ distance\ from\ neutral\ axis\ to\ surface\ ooif\ beam\ (in)$$

The section modulus is a measure of the strength of the beam's geometry. A larger moment of inertia or a smaller distance between the center of gravity and the surface will result in a stronger beam than a beam of equal material properties but a smaller moment of inertia or a larger distance "c". This is reiterated with the next figures.

The cross section of a beam will determine its moment of inertia. Thus a larger cross section will result in a larger section modulus, which will result in lower stresses in the beam.

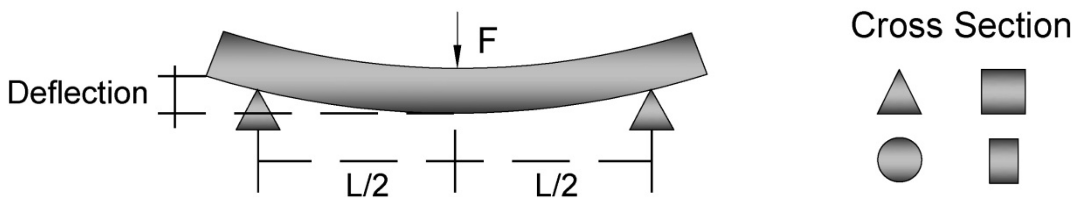


Figure 5: The strength of a material during bending is dependent on the length of the object, the material properties and the cross section of the object.

The following figure shows that the stresses due to tension and compression in a beam during bending vary based on the location relative to the center of the cross section of the beam. The top and bottom of the beam will experience the highest levels of stress.

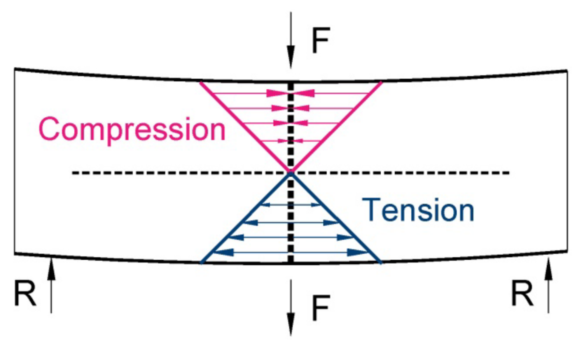


Figure 6: Cross section of a beam in bending. The maximum stress will occur at the surface of the beam. The distance from the center of the beam to the surface uses the variable, "c".

The final maximum beam stress equation will be the maximum moment multiplied by the maximum distance, "c" divided by the second moment of area (moment of inertia).

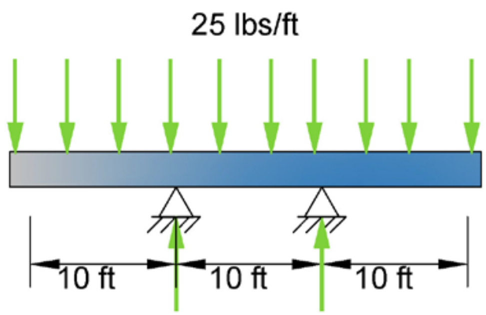
$$\sigma_{\text{beam max}} = \frac{M_{max} * c}{I};$$

4.2 DEFLECTION

10.0 SOLUTIONS

10.1 SOLUTION 1 - BENDING

A wood beam is situated as shown in the figure below. The material has strength of 900 psi. The beam shall be designed to have a safety factor of 2.0. What should be the dimension of the height of the beam? Assume the height of the beam is 2 times the width of the beam.



First, use your beam diagrams from either your Machinery's Handbook or the link that was previously discussed and solve for the reactionary forces.

$$R_1 = \frac{25 * 30 * (30 - 2(10))}{2 * 10} = 375\ lbs$$

$$R_2 = \frac{25 * 30 * (30 - 2(10))}{2 * 10} = 375\ lbs$$

Next use these reaction forces to solve for the max moment of inertia.

$$M_{max} = -\frac{25 * 10^2}{2} = 1{,}250\ lb - ft$$

Finally, use the section modulus equation to solve for the dimensions of the beam.

$$S = \frac{I}{c} = \frac{\mathrm{M}}{\sigma_{\mathrm{allow}}}; \text{where } \mathrm{I} = \frac{\mathrm{bh}^3}{12} \text{ and } \mathrm{c} = \frac{\mathrm{h}}{2} \text{ and } \mathrm{b} = \frac{1}{2}\mathrm{h}$$

$$\sigma_{\mathrm{allow}} = 2 * 900\mathrm{psi} = 1{,}800\ \mathrm{psi}$$

$$\frac{\frac{1}{2}h(h^3)}{h/2} = \frac{1{,}250\ lb - ft}{1{,}800\ \mathrm{psi}};$$

$$h^3 = \frac{1{,}250\ lb - ft * (12\frac{in}{ft})}{1{,}800\ \mathrm{psi}};$$

$$h^3 = \frac{1{,}250\ lb - ft * (12\frac{in}{ft})}{1{,}800\ \mathrm{psi}};$$

$$h^3 = 8.33\ in \rightarrow h = 2.03\ in$$

SECTION 6
VIBRATION

SECTION 6.0 – VIBRATION

Table of Contents

$$Overdamped \rightarrow \zeta > 1$$

$$Characterizing\ Function \rightarrow y(t) = C_1 e^{r_1 t} + C_2 e^{r_2 t}$$

$$r_1 = -\left(\zeta - \sqrt{\zeta^2 - 1}\right)\omega_n; r_2 = -(\zeta + \sqrt{\zeta^2 - 1})\omega_n;$$

$$C_1 and\ C_2\ are\ constants$$

The equations for the constants are not shown because this would make the equations take longer than 6 minutes to solve on the PE exam. The constants are a function of initial displacement and velocity. In most problems, you will be given the constants in order to focus on the more critical concepts in these equations like damping ratio, natural frequency and damped frequency.

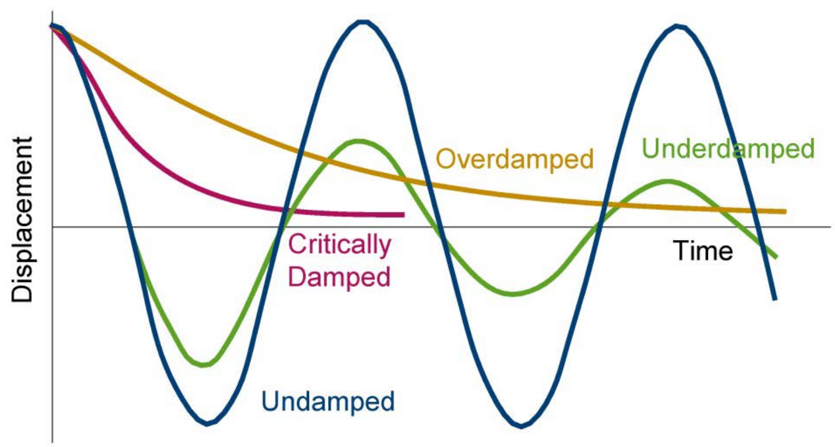


Figure 4: There are four classifications of damped systems that depend on the damping ratio. This graph shows the different effects of the different damping classifications.

3.2 TRANSMISSIBILITY

Transmissibility is a term used to describe the effectiveness of the damping. Transmissibility is the ratio of the vibrational force that is measured after damping to the ratio of the vibrational force entering the machine design system. A low transmissibility means that the damping system is effective as opposed to a high transmissibility means that the damping system is ineffective. The equation to determine transmissibility is shown below. In this equation a new term called Frequency Ratio is introduced. This is the ratio of the damped frequency to the natural frequency. The other term shown is the damping ratio.

$$Transmissibility = \frac{\sqrt{1 + 4\zeta^2 r^2}}{\sqrt{(1 - r^2)^2 + 4\zeta^2 r^2}}$$

$$Frequency\ Ratio \rightarrow r = \frac{\omega_d}{\omega_n};$$

The equation above can also be shown in graphical terms. There may be a chance that you will be given this graph on the exam and a question may involve finding the transmissibility given the damping ratio and frequency ratio.

Also you should be familiar with typical damping factors. Rubbers and neoprene pads have larger damping factors of around 0.05 to 0.15. Steel and other metal springs have order of magnitudes lower damping factors around 0.005. This means that to achieve a lower transmissibility for these metal springs, you need a smaller frequency ratio as compared to rubbers and neoprene pads that will need a larger frequency ratio.

For really small damping ratios, the transmissibility is reduced to the following equation.

$$TR\ (Negligible\ damping) = \left|\frac{1}{1-r^2}\right|$$

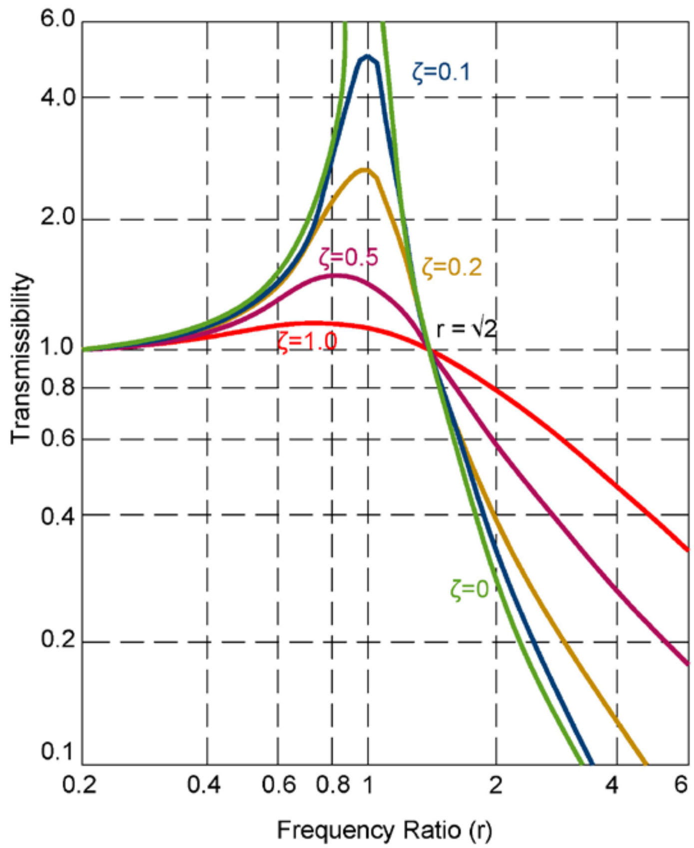


Figure 5: This graph shows the transmissibility as a function of various frequency ratios for different damping ratios.

SECTION 7
MECHANICAL COMPONENTS

Section 7.0 – Mechanical Components

Table of Contents

$$N = pulley\ rotational\ speed\ (RPM);$$

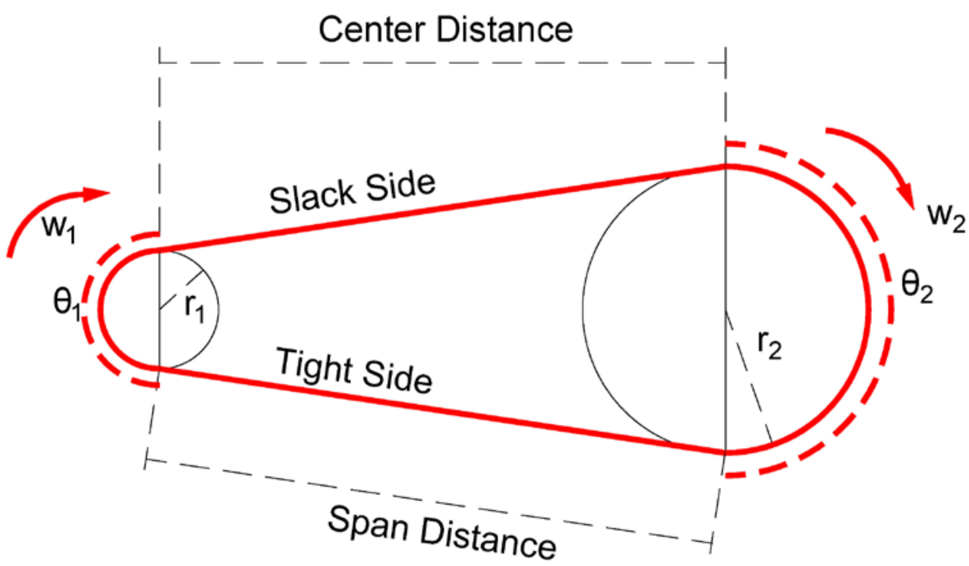


Figure 20: This figure shows the variables for belt drives that will help you to solve the following equations.

The angle of wrap is given as theta 1 and theta 2. These angles are important because they determine the amount of the belt that is in contact with the pulley.

$$\theta_1 = 180° - 2 * (sin^{-1}\left[\frac{r_2 - r_1\ (in)}{span\ distance\ (in)}\right]);$$

$$\theta_2 = 180° + 2 * (sin^{-1}\left[\frac{r_2 - r_1\ (in)}{span\ distance\ (in)}\right]);$$

The amount of torque on each of the pulleys can be found with the below equations. Torque is a function of the difference in tensions between the tight and slack side and the radius of the pulley. The larger pulley will have a larger torque and a larger difference between the tight and slack side will have a larger torque.

$$Pulley\ Torque\ 1 \rightarrow T_1 = r_1 * (F_{tight} - F_{slack})$$

$$Pulley\ Torque\ 2 \rightarrow T_2 = r_2 * (F_{tight} - F_{slack})$$

The ratio of the tight and slack forces is equal to the natural logarithm of the angle of wrap and the coefficient of friction.

$$\frac{F_{tight}}{F_{slack}} = e^{\mu\theta}$$

$$\mu = coefficient\ of\ friction;\ \theta = angle\ of\ wrap\ in\ radians$$

Belt drive questions can also revolve around the speed of the two pulleys. The ratio of the speeds of the two pulleys or sheaves is inversely proportional to their diameters.

$$\frac{D_1\omega_1}{2} = \frac{D_2\omega_2}{2}$$

When you multiply the radius (one-half diameter) by the rotational speed, the result is the linear speed of the pitch line. You can visualize this if you were to imagine a single point moving along the belt. The linear speed of this single point, also known as linear pitch speed, is shown below.

$$v = \frac{D_1\omega_1}{2} = \frac{D_2\omega_2}{2}$$

The above equation only works if the rotational speed is in radians per time. If the rotational speed is given in RPM, then RPM must first be converted to radians per minute.

$$v\left(\frac{ft}{min}\right) = \frac{D_1(ft) * \omega_1\left(\frac{rev}{min}\right) * \frac{2\pi}{rev}}{2}$$

7.1.1 V-Belt Drive

A v-belt drive is similar to the flat belt drive, except the belt is constructed with a v-shape (trapezoidal) groove. This male groove fits into the female pulley notches. This allows the belt to move at high speeds without falling off.

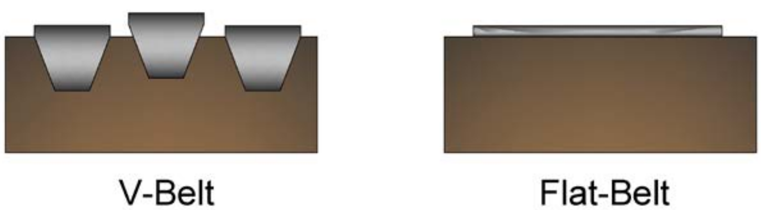


Figure 21: A v-belt has grooves that reduce slippage. A flat belt on a pulley is also shown for comparison.

This new geometry will affect the equations that were shown for the flat belt drive. The angle of the groove will determine the ratio of the tight and slack forces.

The stroke is not the entire length of the cylinder, because there is some clearance involved. Thus the total volume of the compressed air is the area of the cylinder multiplied by the stroke.

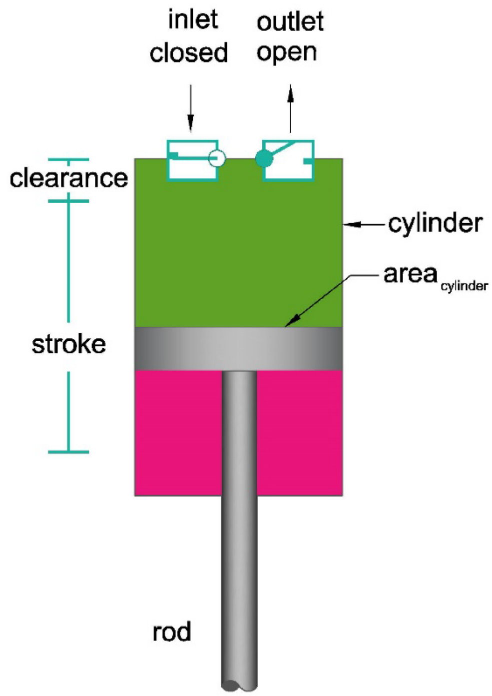
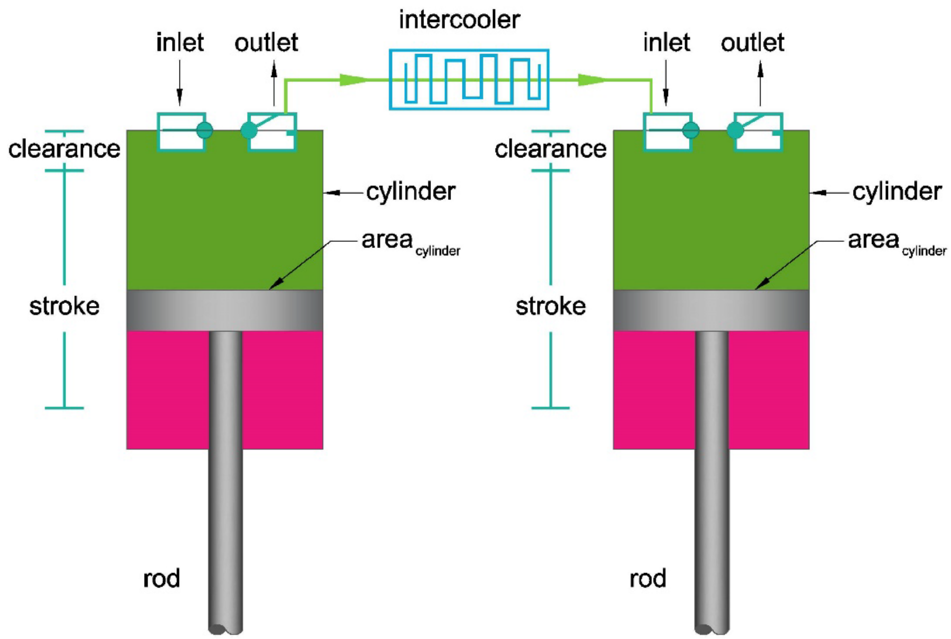


Figure 51: A single stage piston, which shows the area of the cylinder and the stroke.

A two stage piston compressor is comprised of two cylinders that are situated in series. These multi stage compression systems are used because as the cylinder compresses the air, the air rises in temperature. When the temperature rises, the efficiency goes down. A compressor system will have multiple stages of compression but with cooling in between each stage to increase the efficiency of compression.



16.0 SOLUTIONS

16.1 SOLUTION 1 – PRESSURE VESSELS

A pipe is carrying compressed air at a pressure of 500 psi. The pipe has an internal diameter of 19.5” and the pipe has a thickness of 0.5”. The ends of the 10’ long pipe is capped at both ends and sealed airtight. What is the hoop stress developed in the pipe?

The pipe can be treated as a thin walled vessel because the ratio of the radius to the thickness is greater than 10.

$$\frac{9.75''}{0.5''} > 10 \rightarrow thin\ walled\ pressure\ vessel\ assumption$$

So you can use the thin walled pressure vessel equation to find the hoop stress.

$$\sigma = \frac{PR}{t}$$

$$\sigma = \frac{500\ psi * (9.75'')}{0.5''}$$

$$\sigma = 9{,}750\ psi$$

The correct answer is most nearly, **(d) 9,750 psi**.

16.2 SOLUTION 2 – PRESSURE VESSEL

A cylindrical pressure vessel has an internal pressure of 1,000 psi. The pressure vessel has an internal diameter of 15.5” and a thickness of 0.25”. One end of the pressure vessel will be capped with a bolt-nut system. What force should the cap be capable of withstanding?

In this question you must find the pressure acting upon the capped end. This is equal to the internal pressure multiplied by the area of the capped end.

$$Force = \sigma(psi) * area(in^2)$$

$$Force = 1{,}000\ psi * \pi * 19.5^2 * 0.25$$

$$Force = 2.99\ x\ 10^5\ lbf$$

The correct answer is most nearly, **(c)** $\mathbf{3.0\ x\ 10^5\ lbf}$

SECTION 8
JOINTS AND FASTENERS

Section 8.0 – Joints and Fasteners

Table of Contents

3.5 Shear Flow in Fasteners

Shear flow is defined as the shear stress over a distance. In Machine Design, shear flow is used heavily when several components are joined together to make a single component. The typical example is several beams joined together to make a single, stronger beam. Since the components are separate pieces, there will be transverse or longitudinal forces that will cause the fastener to fail. Shear flow can also be applied to adhesives, which will be discussed in the adhesive section.

Shear flow is a function of the shear stress that acts upon the built-up beams, the first moment of area and the second moment of area. The difficult skill to learn when doing these types of problems is making sure you get the correct moment of areas for the correct axes.

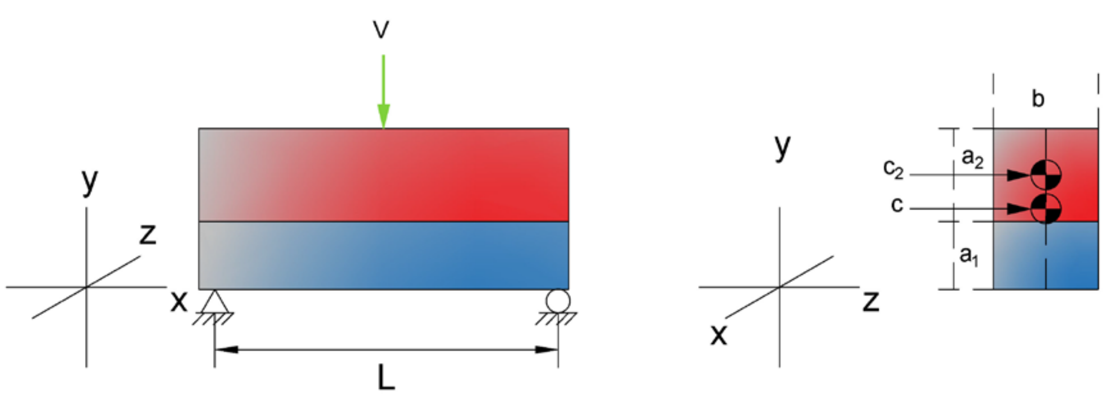
$$q[\frac{lbs}{in}] = \frac{V_y[lbs] * Q_x[in^3]}{I_x[in^4]}$$

$$q = shear\ flow; V_y = shear\ force\ perpendicular\ component;$$

$$Q_z = first\ moment\ of\ area\ about\ z - axis; I_z = second\ moment\ of\ area\ about\ z - axis$$

This equation can be best seen through a series of examples. In this example, two beams are joined together with fasteners. The fasteners are not shown in this example. There is a shear force that acts upon the two beams in the vertical, y-direction. In this example, you must find the first moment of area about the z-axis and the second moment of area.

The first moment of area about the x-axis is equal to the sum of the areas multiplied by the distance from the x-axis. On the PE exam, simple geometries should be given, so this will simplify to the area of the beam or component in question multiplied by the distance between the centroid of the total joined component and the component in question, which is most often the component furthest from the centroid.



Side View

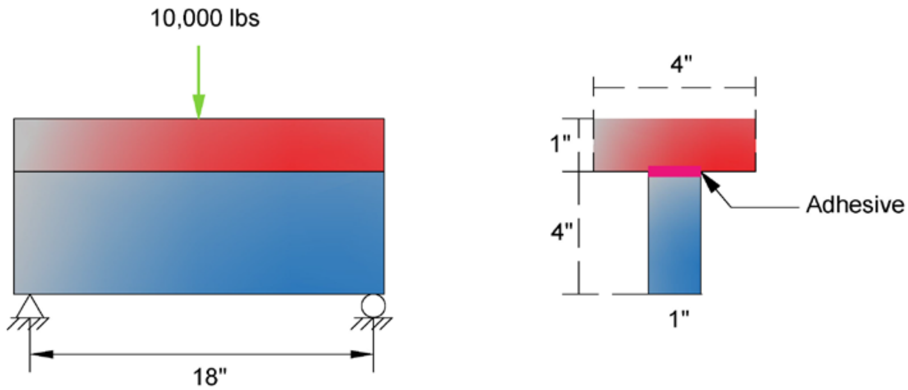
Cross Section View

$$Q_z = \int y_i * dA$$

$$Q_z = (Distance\ between\ centroids) * Area_{beam}$$

5.9 PROBLEM 9 – ADHESIVES

A beam is made by gluing two boards together as shown in the cross section below. What is the shear stress in the glue?



(a) 2,750 psi

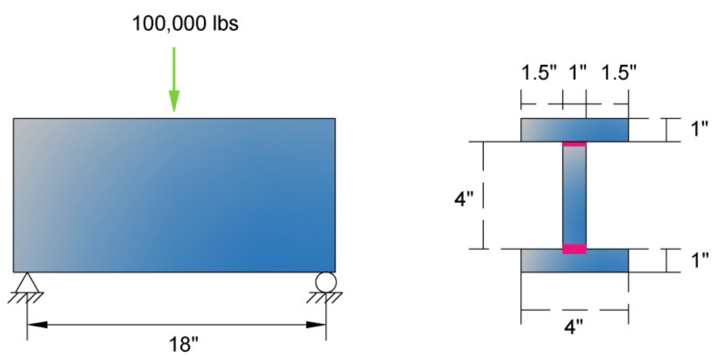
(b) 3,500 psi

(c) 4,120 psi

(d) 5,780 psi

5.10 PROBLEM 10 – ADHESIVES

What is the second moment of area of the combined beams in the diagram below?

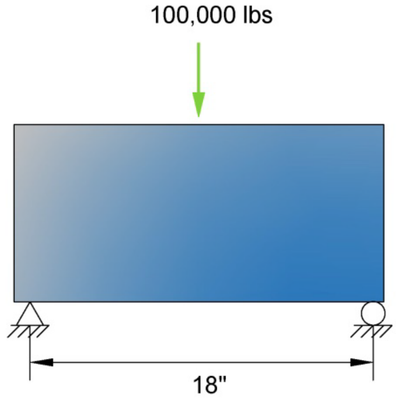


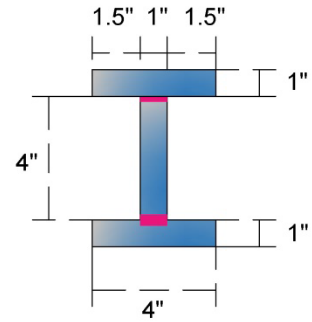
(a) 16 in^4

(b) 56 in^4

(c) 72 in^4

(d) 92 in^4





In order to solve this problem, use the shear flow equation. The shear force is given as 100,000 lbs and the second moment of area is given. You only need to solve for the first moment of area for the upper beam. The centroid in the y-axis for this symmetrical geometry is at the center of the combined beam and the center of the upper beam.

$$q[\frac{lbs}{in}] = \frac{V_y[lbs] * Q_x[in^3]}{I_x[in^4]}$$

$$q[\frac{lbs}{in}] = \frac{100{,}000\ [lbs] * d_{centroid\ to\ centroid} * Area[in^3]}{56[in^4]}$$

$$q[\frac{lbs}{in}] = \frac{100{,}000\ [lbs] * (2.5\ in) * (4\ in * 1\ in)}{56[in^4]}$$

$$q = 17{,}857\ lbs/in$$

Since the adhesive thickness is 1 in. The shear stress is shown below.

$$\tau = \frac{17{,}857 \frac{lbs}{in}}{1\ in} = 17{,}857\ psi$$

The correct answer is most nearly, (a) 17,900 psi.

SECTION 9
SUPPORTIVE KNOWLEDGE

Section 9.0 – Supportive Knowledge

Table of Contents

- UL Listing means that UL has tested representative samples of the product and determined that it meets UL's requirements. These requirements are based primarily on UL's published and nationally recognized Standards for Safety.
  Source: http://www.ul.com/aboutul/

4.5 ASME

The American Society of Mechanical Engineers or ASME publishes standards that set the minimum standards for design and construction of various mechanical products.

Here is the index to the entire ASME Standards:

https://www.asme.org/shop/standards

The following are some of the most commonly used ASME standards. Please do not purchase these standards for the PE exam. These standards are only listed below to give you an idea of what type of material is covered by ASME.

• Safety Code for Elevators and Escalators (A17.1/CSA B44 - 2007): This standard covers the design, construction, operation, inspection, testing, maintenance, alteration, and repair of elevators and escalators.

• Process Piping (B31.3 - 2006): The B31.3 Code contains requirements for piping typically found in petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and related processing plants and terminals. This code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping.

• Gas Transmission and Distribution Piping Systems (B31.8 - 2007): The B31.8 Code covers the design, fabrication, installation, inspection, testing, and other safety aspects of operation and maintenance of gas transmission and distribution systems, including gas pipelines, gas compressor stations, gas metering and regulation stations, gas mains, and service lines up to the outlet of the customer's meter set assembly.

• Valves Flanged, Threaded and Welding End (B16.34 - 2009): This Standard applies to new construction. It covers pressure-temperature ratings, dimensions, tolerances, materials, nondestructive examination requirements, testing, and marking for cast, forged, and fabricated flanged, threaded, and welding end and wafer or flangeless valves of steel, nickel-base alloys, and other alloys.

• The ASME Boiler & Pressure Vessel Code (BPVC) is an American Society of Mechanical Engineers (ASME) standard that regulates the design and construction of boilers and pressure vessels.

Section 2.0 also introduced standards that provide information on Engineering Terms and Symbols, along with drawing standards.

8.5 SOLUTION 5 – TESTING AND INSTRUMENTATION

A hardness tester uses a diamond indenter. Which of the following hardness values cannot be found with this type of indenter?

The Rockwell tests can use both a diamond indenter and a steel sphere, depending on the hardness scale used.

The Vickers test uses a diamond indenter.

The Knopp test uses a diamond indenter.

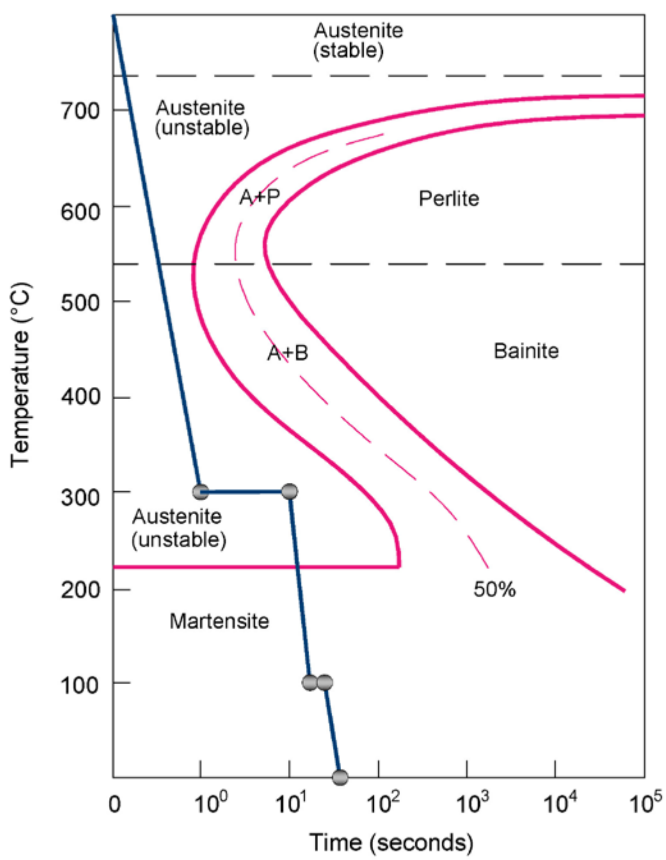
Only the Brinell test uses solely a steel sphere.

The correct answer is most nearly, (a) Brinell.

8.6 SOLUTION 6 – MANUFACTURING PROCESSES

Which of the following final states best describes the result of the following heat treatment process? Use the following graph.

Heat to 800 C. Cool to 300 C within 1 second. Once at 300 C, keep at 300 C for 9 seconds. Then rapidly cool within 1 second to 100 C. Keep at 100 C for 20 seconds and then rapidly cool within 1 second to room temperature.



SECTION 10
CONCLUSION

10.0 CONCLUSION

If you have any questions on this book or any other Engineering Pro Guides product, then please contact:

Justin Kauwale at contact@engproguides.com

Hi. My name is Justin Kauwale, the creator of Engineering Pro Guides. I will be happy to answer any questions you may have about the PE exam. Good luck on your studying! I hope you pass the exam and I wish you the best in your career. Thank you for your purchase!

SECTION 11
CHEAT SHEETS

Section 1.0 – Introduction

(No cheat sheets are provided for this section)

Section 2.0 – Basic Engineering Practice

Units and Conversions (Dimensional Analysis)		
Term	US to SI	SI to US
Acceleration (g)	$32.2 \frac{ft}{s^2}$	$9.81 \frac{m}{s^2}$
Force (F)	$1\ lbf = 4.48\ N$	$1\ N = 0.2248\ lbf$
Mass (m)	$1\ slug = 14.59\ kg$	$1\ kg = 0.0685\ slug;$
	$1\ lb = 0.4536\ kg$	$1\ kg = 2.205\ lb;$
Stress (σ)	$1\ psi = 6.90x10^{-3}\ MPA$	$1\ MPA = 145\ psi$
	$1\ psi = 1 \frac{lbf}{in^2}$	$1\ PA = 1 \frac{N}{m^2}$
Density (ρ)	$1 \frac{lbm}{ft^3} = 16.02 \frac{kg}{m^3}$	$1 \frac{kg}{m^3} = 0.0624 \frac{lbm}{ft^3}$
	$1 \frac{lbm}{ft^3} = 1.602x10^{-2} \frac{g}{cm^3}$	$1 \frac{g}{cm^3} = 62.4 \frac{lbm}{ft^3}$
	$1 \frac{lbm}{in^3} = 27.7 \frac{g}{cm^3}$	$1 \frac{g}{cm^3} = 0.0361 \frac{lbm}{in^3}$
Length (l)	$1\ in = 25.4\ mm$	$1\ mm = 0.0394\ in$
	$1\ in = 2.54\ cm$	$1\ cm = 0.394\ in$
	$1\ ft = 0.3048\ m$	$1\ m = 3.28\ ft$
Area (A)	$1 ft^2 = 0.093\ m^2$	$1\ m^2 = 10.76\ ft^2$
	$1\ in^2 = 6.452\ cm^2$	$1\ cm^2 = 0.1550\ in^2$
Volume (V)	$1 ft^3 = 0.0283\ m^3$	$1\ m^3 = 35.32 ft^3$
	$1\ in^3 = 16.39\ cm^3$	$1\ cm^3 = 0.0610\ in^3$
Energy (Q)	$1\ BTU = 1054\ J$	$1\ J = 9.48\ x\ 10^{-4}\ BTU$
	$1\ lbf - ft = 1.356\ J$	$1\ J = 0.738\ lbf - ft$
	$1\ BTU = 778\ lbf - ft$	$1\ J = 1 \frac{kg - m^2}{s^2} = 1\ N - m$
Power (P, q)	$1\ BTUH = 0.293\ W$	$1\ W = 3.414\ BTUH$

	$1\ BTUH = 1\ \frac{BTU}{HR}$	$1\ W = 1\frac{J}{S}$
	$1\ HP = 745.7\ Watts$	$1\ W = 0.00134\ HP$
Temperature (T)	$T(°\mathrm{F}) = \frac{9}{5}(T(°K) - 273) + 32$	$T(°C) = \frac{5}{9}(T(°F) - 32)$
	$T(°\mathrm{F}) = \frac{9}{5}\left(T(°C)\right) + 32$	$T(°K) = T(°C) + 273$

Control Chart Factors

n	A2	A3	c4	B3	B4	d2	1/d2	d3	D3	D4
2	1.880	2.659	0.7979	0.000	3.267	1.128	0.8862	0.853	0.000	3.267
3	1.023	1.954	0.8862	0.000	2.568	1.693	0.5908	0.888	0.000	2.575
4	0.729	1.628	0.9213	0.000	2.266	2.059	0.4857	0.880	0.000	2.282
5	0.577	1.427	0.9400	0.000	2.089	2.326	0.4299	0.864	0.000	2.114
6	0.483	1.287	0.9515	0.030	1.970	2.534	0.3946	0.848	0.000	2.004
7	0.419	1.182	0.9594	0.118	1.882	2.704	0.3698	0.833	0.076	1.924
8	0.373	1.099	0.9650	0.185	1.815	2.847	0.3512	0.820	0.136	1.864
9	0.337	1.032	0.9693	0.239	1.761	2.970	0.3367	0.808	0.184	1.816
10	0.308	0.975	0.9727	0.284	1.716	3.078	0.3249	0.797	0.223	1.777
11	0.285	0.927	0.9754	0.321	1.679	3.173	0.3152	0.787	0.256	1.744
12	0.266	0.886	0.9776	0.354	1.646	3.258	0.3069	0.778	0.283	1.717
13	0.249	0.850	0.9794	0.382	1.618	3.336	0.2998	0.770	0.307	1.693
14	0.235	0.817	0.9810	0.406	1.594	3.407	0.2935	0.763	0.328	1.672
15	0.223	0.789	0.9823	0.428	1.572	3.472	0.2880	0.756	0.347	1.653
16	0.212	0.763	0.9835	0.448	1.552	3.532	0.2831	0.750	0.363	1.637
17	0.203	0.739	0.9845	0.466	1.534	3.588	0.2787	0.744	0.378	1.622
18	0.194	0.718	0.9854	0.482	1.518	3.640	0.2747	0.739	0.391	1.609
19	0.187	0.698	0.9862	0.497	1.503	3.689	0.2711	0.733	0.404	1.596
20	0.180	0.680	0.9869	0.510	1.490	3.735	0.2677	0.729	0.415	1.585
21	0.173	0.663	0.9876	0.523	1.477	3.778	0.2647	0.724	0.425	1.575
22	0.167	0.647	0.9882	0.534	1.466	3.819	0.2618	0.720	0.435	1.565
23	0.162	0.633	0.9887	0.545	1.455	3.858	0.2592	0.716	0.443	1.557
24	0.157	0.619	0.9892	0.555	1.445	3.895	0.2567	0.712	0.452	1.548
25	0.153	0.606	0.9896	0.565	1.435	3.931	0.2544	0.708	0.459	1.541

Section 6.0 – Vibration

Vibration Basics		
Term	**Equation**	**Description**
Frequency/ Period	$f = \frac{1}{T}$ or $f * T = 1$	$f = frequency\ (Hz); T = period\ (sec)$
Angular Frequency	$\omega\ (radians/sec) = 2\pi f$	
Root Mean Square	$RMS = \frac{\sqrt{y_1^2 + y_2^2 + y_3^2 \ldots + y_n^2}}{n}$	
Root Mean Square of Sine Wave	$RMS_{sine\ wave} = \frac{V_{max}}{\sqrt{2}}$	
Springs	$F = k * x$	$F[N];\ k = stiffness\ \left[\frac{N}{m}\right];$ $x = deflection[m]$ $F[lbf];\ k = stiffness\ \left[\frac{lbf}{in}\right];$ $x = deflection[in]$
Natural Frequency	$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}\ (Hz)$	SI
	$f_n = \frac{1}{2\pi}\sqrt{\frac{kg}{m}}\ (Hz)$	US
k-values for various situations	Helical Coil Spring	$k = \frac{GD^4}{64Nr^4}$
	Longitudinal Bar	$k = \frac{AE}{L}$
	Simply Supportd Beam at Mid-span	$k_{beam} = \frac{48EI}{L^3}$
	Stiffness o a Cantilever Beam at its End	$k_{beam} = \frac{3EI}{L^3}$
	Torsional Stiffness of Shaft	$k_{t,shaft} = \frac{JG}{L}$
	Equivalent Stiffness of n Springs in Parallel	$k_{springs\ \vert\vert} = k_{s1} + k_{s2} + k_{sn};$
	Equivalent Stiffness of n Springs in eries	$k_{springs,series} = \frac{1}{k_{s1} + k_{s2} + k_{sn}}$
Natural Frequency	$\omega_n = \sqrt{\frac{k}{m}}$ or $\sqrt{\frac{kg_c}{m}}\ \left(\frac{radians}{second}\right);$	

<table>
<tr><th colspan="3">Power Screws</th></tr>
<tr><th>Term</th><th>Equation</th><th>Description</th></tr>
<tr><td>Square Threads Torque</td><td>$$T_{lift} = \frac{Fd_m}{2} * \left(\frac{\pi\mu d_m + l}{\pi d_m - \mu l}\right)$$
$$T_{lower} = \frac{Fd_m}{2} * \left(\frac{\pi\mu d_m - l}{\pi d_m + \mu l}\right)$$</td><td>$Torque = (lb - ft);$
$F = screw\ load\ (lbf);$
$d_m = mean\ or\ pitch\ diameter (ft)$
$\mu = coefficient\ of\ friction$
$(unitless);$
$l = lead\ (ft);$</td></tr>
<tr><td>Lead calculations</td><td colspan="2"><table>
<tr><td>Start</td><td>Pitch</td><td>Lead Distance</td></tr>
<tr><td>Single</td><td>P</td><td>L = P</td></tr>
<tr><td>Double</td><td>P</td><td>L = 2*P</td></tr>
<tr><td>Quad</td><td>P</td><td>L + 4*P</td></tr>
</table></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Square Threads Torque</td><td>$$\tan(\lambda) = \left(\frac{L}{\pi * d_m}\right)$$
$$T_{lift} = \frac{Fd_m}{2} * \left(\frac{f + \tan(\lambda)}{1 - \tan(\lambda)}\right)$$
$$T_{lower} = \frac{Fd_m}{2} * \left(\frac{f - \tan(\lambda)}{1 + \tan(\lambda)}\right)$$</td><td>$\lambda = lead\ angle$</td></tr>
<tr><td>Acme Threads Torque</td><td>$$T_{lift} = \frac{Fd_m}{2} * \left(\frac{f + \cos(\phi) * \tan(\lambda)}{\cos(\phi) - \tan(\lambda) * f}\right)$$
$$T_{lower} = \frac{Fd_m}{2} * \left(\frac{f - \cos(\phi) * \tan(\lambda)}{\cos(\phi) + \tan(\lambda) * f}\right)$$</td><td>$Torque = (lb - ft);$
$F = screw\ load;$
$d_m = mean\ diameter\ or$
$pitch\ diameter$
$\mu = coefficient\ of\ friction$
$(unitless);$
$l = lead;$
$\phi = angle\ of\ friction$
$= 14.5° \ for\ acme\ threads;$
$\lambda = lead\ angle;$</td></tr>
<tr><td>Torque due to Collar</td><td>$$T_{collar} = \frac{F * f * d_c}{2} *$$</td><td>$f = collar\ coefficient\ of\ friction;$
$d_c = mean\ diameter\ of\ collar;$</td></tr>
<tr><td>Locking Condition</td><td>$f > \tan(\lambda)$</td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
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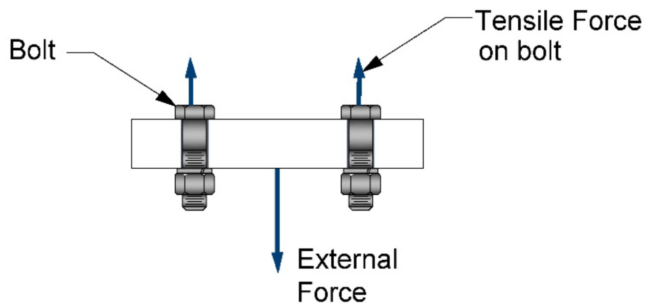
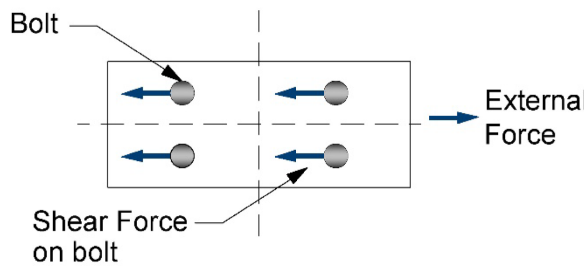
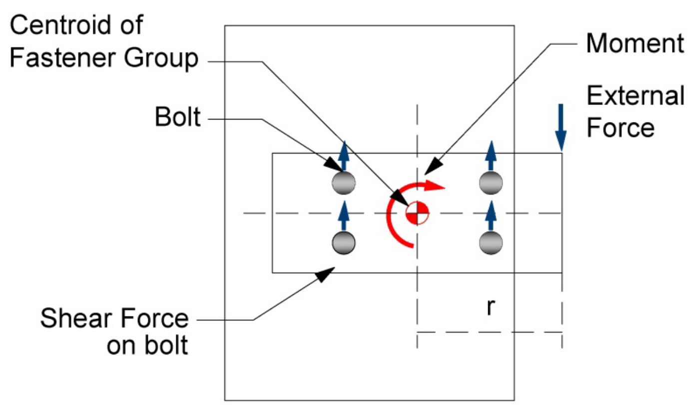
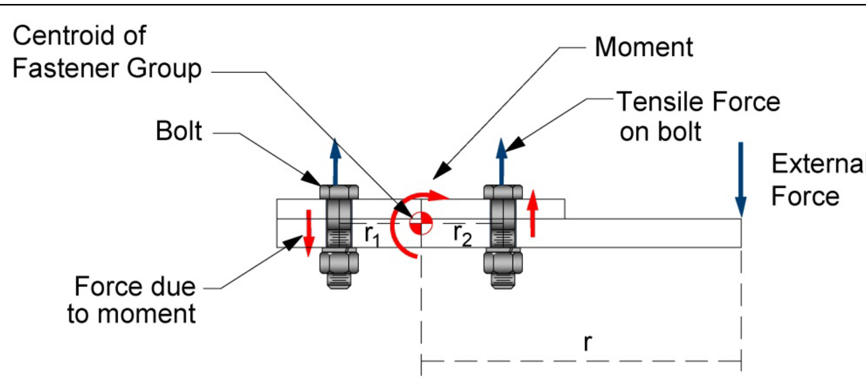
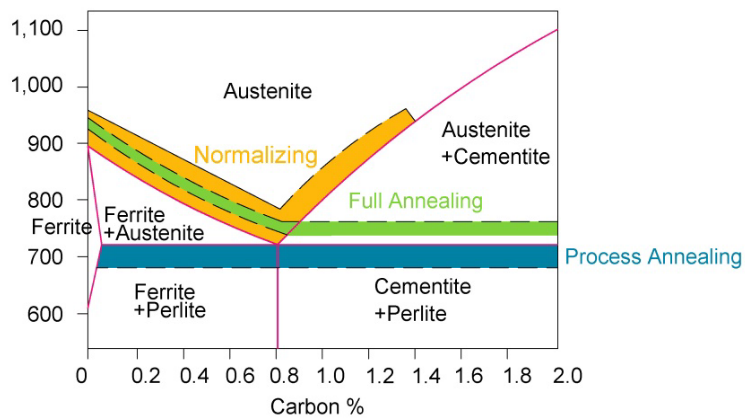
</table>

Fatigue – Actual Endurance Strength	$S_{sa} = \dfrac{rS_{se}S_{ut}}{rS_{ut} + S_{se}}$	$S_{se} = fatigue\ endurance\ strength$ $S_{ut} = ultimate\ tensile\ strength$
Fatigue – slope of load-line	$r = \dfrac{\sigma_a}{\sigma_m}$	
Concentric Tensile Force		
Concentric Shear Force		
Eccentric In-Plane Force		
Eccentric Out-of-Plane Force		

Section 9.0 – Supportive Knowledge

Manufacturing Processes		
Term	**Equation**	**Description**
Turning	$D_{new} = D_{old} - 2 * (depth\ of\ cut)$	
Machining		Any machine process that removes material from a component
Turning		Turning is used to reduce the diameter of a cylinder
Boring		Boring is used to enlarge existing holes
Drilling		Drilling is used to create a round hole
Milling		Milling is the process where a machine component is fed past a rotating cutting tool. The tool removes material along the direction of the feed
Molding		Metal is heated to liquid form and then poured into a mold

Annealing



Fits & Tolerances		
Clearance Fit		Occurs when there is positive clearance between the hole and the shaft
Interference Fit		Occurs when there is a fit with negative clearance between the hole and shaft
Transition Fit		Occurs when there is both positive or negative clearance
Hole Basis		Size of the hole is kept constant and the shaft size is varied to get a different fit
Shaft Basis		Size of the shaft is constant and the hole-size is varied to achieve the desired fit

Codes & Standards		
ASTM		American Society of Testing and Materials
AWS		American Welding Society's
ANSI		American National Standards Institute: Provides fastener minimum strength and other properties, but this information is also included in Machinery's Handbook
UL		UL is an independent safety science company. It tests equipment, materials and products to confirm if they meet the UL safety standards
ASME		The American Society of Mechanical Engineers or ASME publishes standards