This is a ***Free Preview*** of actual seminar **Handout** materials (Notes) and presentation **Slides** used in the training seminars offered by **Nutek, Inc**.

If you are planning to get an **appreciation and develop understanding** of the subject matter, read the Notes (*First of the available files*).

Should you wish to **self-study and learn how to apply the technique**, consider purchasing both Notes and Slides when available.

Recommended Self-study steps:

- *Review Notes first.*
- *Use Slides as more focused study. Review Notes to clarify concepts.*
- *Review examples and carry out exercises presented.*

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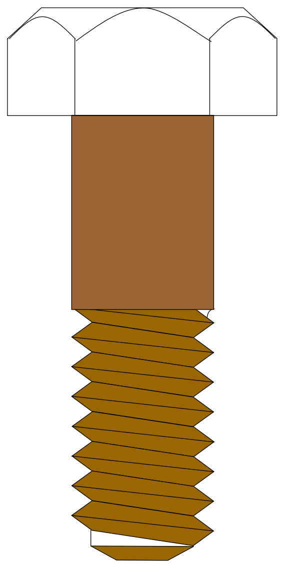
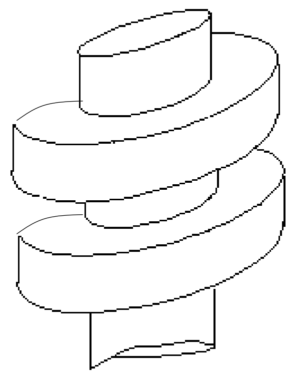
Seminar Handout - Preview Notes

Design and Behavior of Bolted Joints





Instructor:

Ranjit K. Roy, Ph.D., P.E., PMP

Trainer and Consultant

Phone: 248-540-4827 RKR@Nutek-US.com

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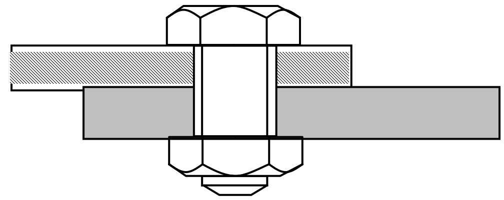
Design and Behavior of Bolted Joints



Course Description:

Modern buildings, vehicles, machinery, and physical products of all sizes and shapes are put together by joining smaller components with another. A vast majority among these is assembled with fasteners, as they need to come apart for potential repair, replacement, or maintenance. Simply put, a fastener is a screw, nut, bolt or stud with external or internal threads. Although, there are numerous types of fasteners used in commerce, understanding the design and behavior of a threaded joint serves to comprehend the basic principles applicable to all fasteners.

Why should you study fasteners? Approximately 200 billion fasteners are utilized by the industry each year. Many such fasteners play important roles in transportation, safety and comfort of our modern life. A typical automobile, for example, uses about 4000 nuts and bolts. Because a few of them once in a while would come loose, over half of the warranty dollars for the same automobile can be related to fasteners.

In spite of its immense importance, bolted joints are not well understood. Part of the theoretical and empirical relations work fairly well in the design phase. Unfortunately, in installations, that is, in the assembly process, the behavior of a bolted joint depends on a large number of variables that are difficult or impossible to predict and control. Obtaining the desired load and configuration is subjected to a high degree of uncertainty that calls for a greater need for understanding of the operating principles involved. Thus the specialists who design and assemble things which must not fail; airplanes, nuclear reactor, engine connecting rods, engine block heads, all kinds of safety related items in an automobile, etc., must learn all there is to known about the behavior of the joints concerned.

This short session is intended for practicing design and manufacturing professionals who are involved in assembly of electro-mechanical hardware components of any size and shapes with fasteners of all kinds. Attendees are expected to participate in hands-on group exercises and solve a number of problems on theoretical principles discussed in the class (*Attendees are required to bring a scientific calculator*).

Learning Objectives (bullet form):

Upon completion of this seminar, you will learn how to:

- Calculate forces in the fasteners
- Establish what torque to specify
- How to increase functional life of a joint
- Analyze joints and its failure mechanism
- Achieve better control of bolt tension and applied torque in the assembly operations
- Utilize torque application machines more effectively
- Reduce fastener related warranty and rework costs

Instructor's Background

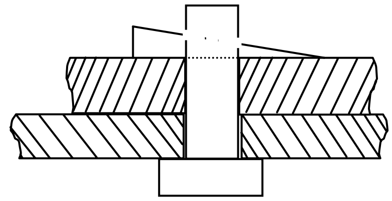
Ranjit K. Roy, Ph.D., P.E., PMP (Mechanical Engineering, president of NUTEK, INC.), is an internationally known consultant and trainer specializing in the Taguchi approach of quality improvement. Dr. Roy has achieved recognition for his down-to-earth style of teaching of the Taguchi experimental design technique to industrial practitioners. Dr. Roy began his career with The Burroughs Corporation following the completion of graduate studies in engineering at the University of Missouri-Rolla in 1972. He then worked for General Motors Corp. (1976-1987) assuming various engineering responsibilities, his last position being that of reliability manager. While at GM, he consulted on a large number of documented Taguchi case studies of significant cost savings. He is the author of the textbooks *A Primer On The Taguchi Method* - published by the Society of Manufacturing Engineers in Dearborn, Michigan, *Design of Experiments Using the Taguchi Approach: 16 Steps to Product and Process Improvement published (January 2001)* by John Wiley & Sons, New York, and of Qualitek-4 software for design and analysis of Taguchi experiments. Dr. Roy is a fellow of the American Society for Quality and an adjunct professor at Oakland University, Rochester, Michigan. Dr. Roy is listed in the **Marquis Who's Who** in the world.

ABOUT THE COURSE

Course Content

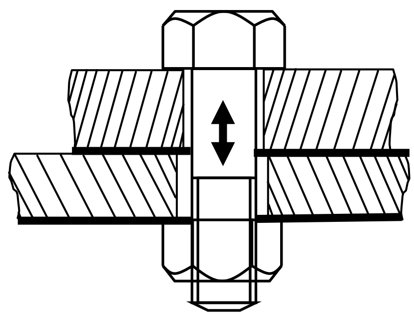
Section - A
Fundamental Principles and Supporting Theories

- Why Study Fasteners?
- Basic Principles of BOLT Operation
- English vs. Metric Units of Measurements
- Physics of Stationery Bodies
- Rigid Body in a State of Equilibrium
- Bolt Load and Free Body Diagram (FBD)
- Effect of Friction
- Friction Forces on Inclined Plane
- Principles of Conservation of Energy
- General Stiffness Principles
- Stress, Strain and Mechanical Properties
- Properties of Engineering Materials
- Equivalent Joint Stiffness
- Effect Of Joint Relaxation On Preload
- How To Minimize Relaxation
- Thermal Effect On Bolt Tension
- Joint Behavior And Geometry Under External Load



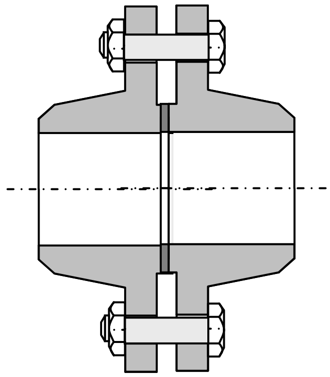
Section B
Fasteners Design Strategies and Assembly Considerations

- Torque and Tension Relationship
- The Short-Form of Torque vs. Tension Relation
- Uncertainty in Assembly Caused By Variability in Nut factor (K)
- Factors That Affect Tension Variability
- Assembly Torque and Tension Behavior
- Process Variation and Process Capabilities
- Primary Influencing Factors Affecting Preload
- Bolt Tightening Strategies
- Three Strategies Commonly Used to Control Preload
- Inspection of Installed Torque
- Bolt And Thread Geometry
- Bolt Identification
- Torque, Angle, and Tension Measuring Devices
- Torque Scatter Due To Tool
- Standardized Torque and Tension Values



- Bolted Joint Design Strategy
- Joint Assembly and Behavior
- Generalized Hooke's Law
- Mechanical Properties of Steel

Section – C



Gasketed Joints for Leak Prevention

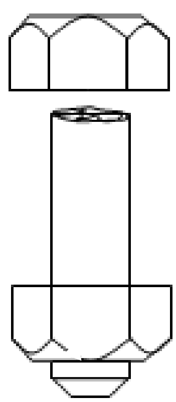
- Mechanical Behavior Of A Gasket
- Effect Of Creep And Relaxation On Gasket Behavior
- Example of Creep Relaxation
- Factors that Affect Creep
- Gasket Strenth - The P x T Factor
- Leakage Behavior Of Gasket – m and y Factors
- Gasket Selection
- Simplistic Design & Assmebly Guidelines
- Exercises

Gasketed Flanged Joint Design

- Objectives and Design Challenges
- Types of Flanged Joints
- Analysis of Flanged Joints – Simplified Model
- Design Steps
- Standards and Codes for Flanged Joints
- Example Flange Joint Design
- Exercise

Section – D

Causes and Prevention of Bolt Failure



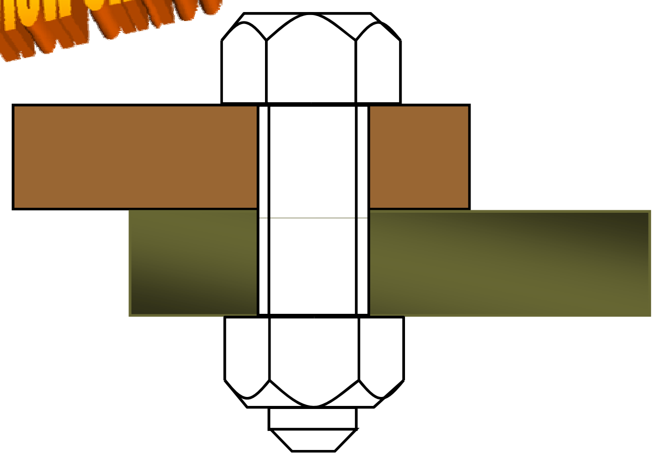
- Corrosion
- Essential conditions for Corrosion
- Chemistry of Corrosion
- Strategies for Corrosion Reduction
- Combating Corrosion
- Common Types of Coating
- Commercial Fastener Coatings
- Causes Of Joint Failure
- Mechanical Failure Modes of Bolted Joints
- Prevention of Vibration Loosening
- Mechanical Properties Of Typical Medium/Low
- Carbon And Case Hardened Steels

Appendix

Continued ……………..

Design and Behavior of Bolted Joints

Seminar Presentations - Preview Slides



by

Ranjit K. Roy, Ph.D., P.E., PMP

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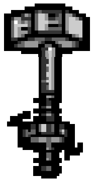
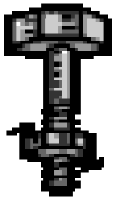
Design and Behavior of Bolted Joints



Welcome!



Participants from ????

Class Starts at: 8:00 AM **Instructor: Ranjit Roy**

Seminar Logistics

Ref. Page N/A

- Start Time
- End Time
- Breaks (15 min after 55 -70 minutes of class)
- Lunch Time (55 minutes)
- Second day of the seminar – Schedule
- Facilities
- Activities: Examples/solutions and group exercises that require calculations (need a scientific calculator)
- Slides to Handout (Reference and textbook)
- Distractions: Please turn off cell phones and pagers

Introduction

Ref. Page N/A

Instructor:

- Mechanical engineer
- Working in industry since 1973.
- Independent consultant since 1987
- Specializes in product and process design improvement technique
- Published books and developed technical software
- Adjunct professor (Oakland University, Rochester, MI since 1976)

Participant Introduction

Participants: (please tell the class)

- Who you are
- Your reasons for attending this session
- How you would make use of information from this seminar
- What do you WISH to do most when you have some free time

Training Reference Materials

Handout - Content of most slides shown in this part of the presentation may be found in the seminar handout.

Design and Behavior of Bolted Joints

(2)
-Select and determine size of bolt

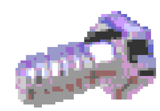
-Thread engagement

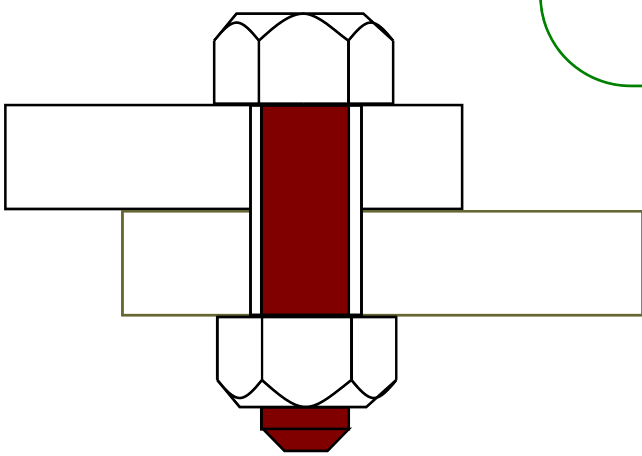
- Assembly torque

(3)

- Stress, strain
- -Elastic limits
- -Stiffness
- -Nut factor
- -Fatigue
- -Relaxation
- -Corrosion

(1)
Fasteners
– Threaded fastener
– Bolted joint





Expected Participant Benefits

Ref. Page N/A

- Understand the engineering principles that control the behavior of threaded fasteners (Bolted Joints)
- Calculate design specifications from book values (Theoretical data)
- Conduct appropriate studies to generate joint data
- Specify assembly instructions
  - Torque required
- Design Flanged Joints and specify required torque
- Understand different modes of joint failure

Why Study Fasteners

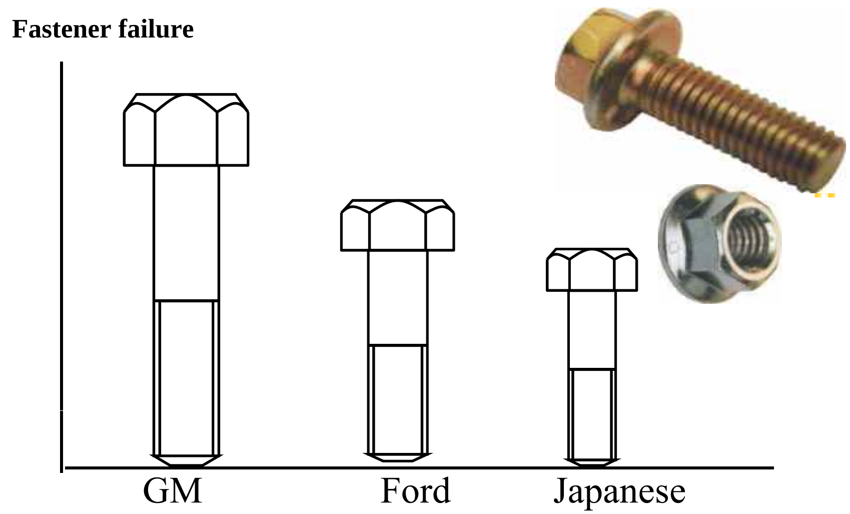
Ref. Page A-6

- Fasteners is the most common cause of warranty failures in automobiles.

- Bolted joints are the primary means of fastening in automobiles. Typical vehicles like Ford Taurus uses 4000 bolts. About 1,500 are used in body alone.

- Probability that some of these bolts are loose is very high.

- Approximately 200 billion fasteners are utilized by the industry each year. Many such fasteners play important roles in transportation, safety and comfort of our modern life.



Why Bolted Joints?

Ref. Page A-7

• Bolted joints are primary fasteners used in automobile and other mechanical parts and machinery.
• Principles and theories that support the behavior of bolt are also applicable to other fasteners (screws, rivets, welds, etc).

Bolts are preferred fasteners for the following reasons:

- Easy to remove and re-assemble
- Strong
- Long lasting
- Reusable
- More resistant to corrosion

Safety Issues

• There are over 4,000 fasteners used to put together in an automobile (Taurus, Escort).
• Many of these fasteners hold the safety components of the vehicle together.

Recalls/Litigations: 97 Explorer – Compressor hose, 1982 Corvette – brake pads, 79 Buick Century

Warranty: 60% of warranty repairs are related to fasteners (Leaks, Rattles, Loose bolt, Poor attachments, etc.)

Basic Principles of Bolt Operation

Ref. Page A-8

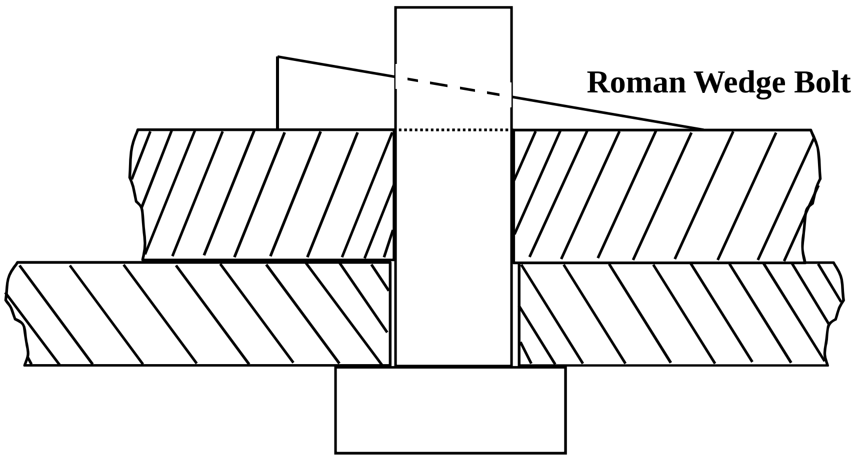
What keeps the two pieces together without sliding?

What keeps the two plates stay tight?

Force (load, tension, preload, compressive force. .)

What creates the compressive load?

What keeps the wedge in place?



Roman Wedge: The wedge was an aggressive formation used by the Roman army to 'crack open' enemy lines. Relatively small groups of legionaries could form such a triangle and then drive their way into the enemy ranks. As more Roman soldiers reinforced the wedge from behind, the enemy line could be forced apart. As breaking the enemy's formation was very often the key to winning a battle, the wedge formation was vitally important battlefield tactic of the Roman army.

Inclined Plane - Wedge

Ref. Page A-8

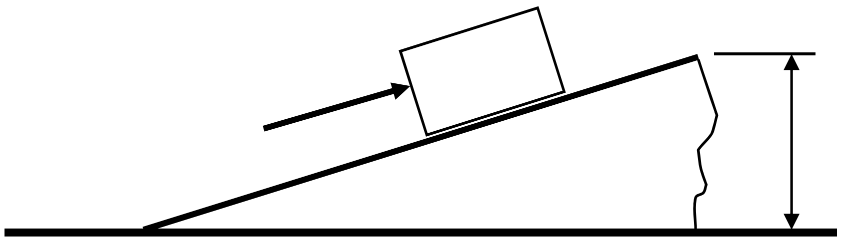
•What keeps the two pieces together without sliding?

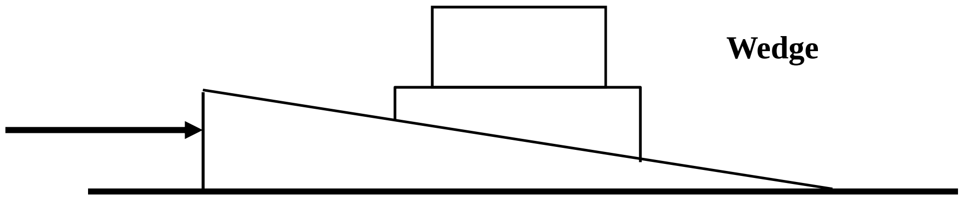
•What keeps the two plates stay tight?

•Force (load, tension, preload, compressive force. .)

•What creates the compressive load?

•What keeps the wedge in place?





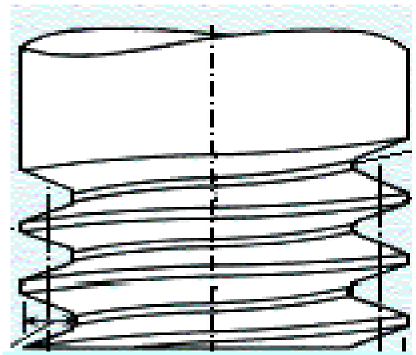
Inclined plane – Wedge

Friction – between Wedge and the contacting surfaces.

Screw – Spiraled Inclined Surface

Ref. Page A-9

Instead of the WEDGE, modern screw/thread uses SPIRAL/INCLINED surface to produce the load in the bolt.

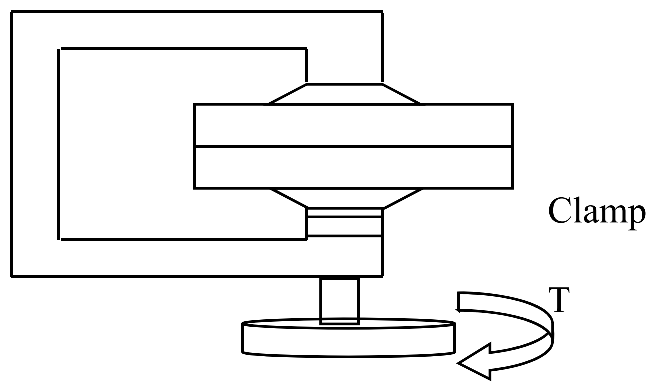


Spiraled Inclined Surface – SCREW

A turn of the screw moves the screw one pitch distance.

Example: Screw Jack for automobile lifts the vehicle one pitch distance when turned one full revolution.

Securing assembly is the objective of any fastener. The key to securing assembly that last for the life of the product is PROPER CLAMP LOAD.

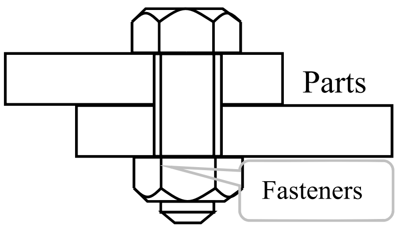


How is CLAMP LOAD Obtained?

Ref. Page A-10

Correctly designed parts	+	Proper assembly method	=	Desired Clamp Load

A joint consists of joining parts and fasteners.



The reliability of a joint depends on three items.

1. Quality of Parts
2. Design of Joint
3. Assembly Method

(See seminar handout)

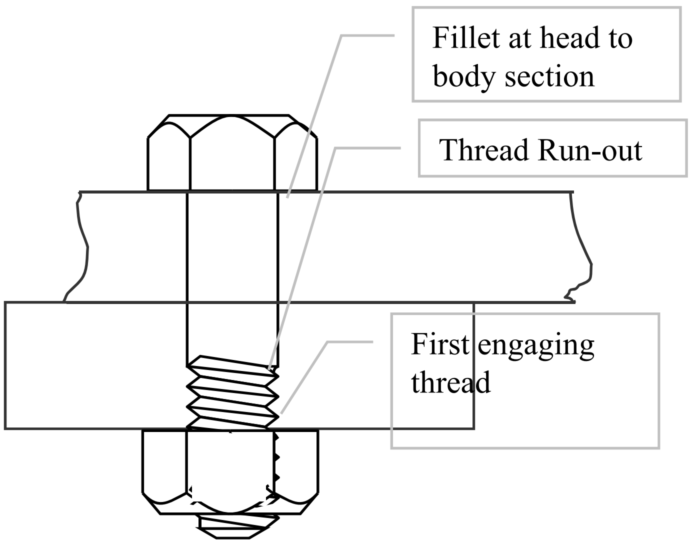
Where is a bolt most likely to fail?

Ref. Page A-11

•Head to body fillet

•Thread Run-out

•First thread at engagement (In common applications, the first three engaged threads carry most of the final clamp load)



English vs. Metric Units of Measurements

Ref. Page A-12

English:	lbs.	Inch	sec.	psi
Metric:	**kg**	**m**	**sec.**	**Pa.**

1 inch = 25.4 mm
= .0254 m
1 lb. = .4536 kg.

1 m = 39.37 inch.
1 Kgf = 2.20 lbf.

Force = mass x accl.

1 lb. force = 1 lb.-m x 32.2ft/sec^2

1 kg. force = 1 kg. x 9.81 m/sec^2
= 9.81 Newton

1 lb. force = .4536 x 9.81 = 4.45N

1 N = .225 lbf.

G = 9.81 m/sec^2 = 386.4 in/sec^2

Conversions:

1 lbs/in = [.4536 x 9.81 N/m2] / [.0254 m/in = 175.2 N/m
1 psi = [1 x .4536 x 9.81] / (.0254)2 N/m^2 = 6.894 x 10^3 pa

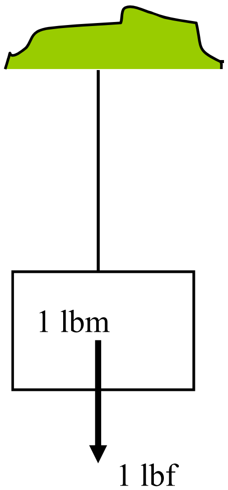
Types of Loads

Ref. Page A-13

Loads are always represented by a force vector in a Free Body Diagram.

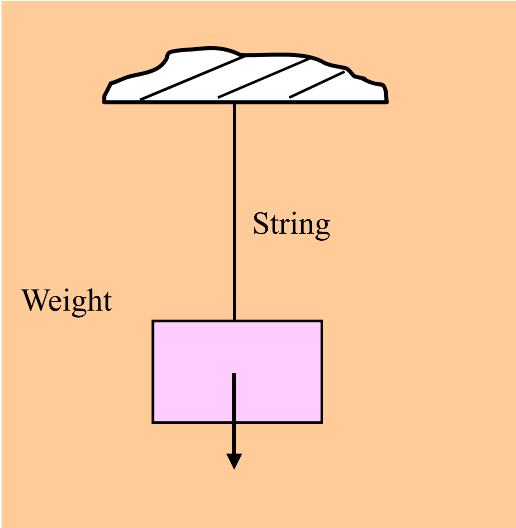
Causes of loads:

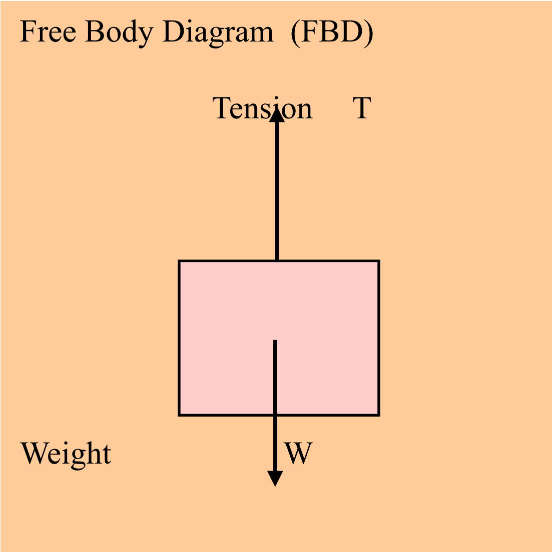
- gravitational (weight)
- mechanically applied
- inertial
- magnetic



Free Body Diagram (FBD)

Ref. Page A-14





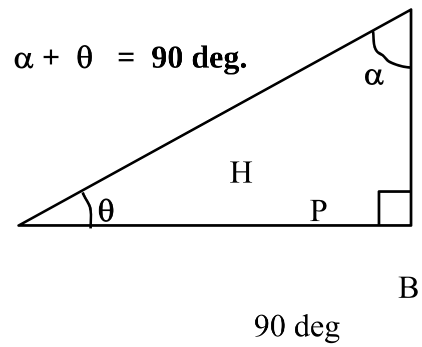
Review example FBD in handout.

Trigonometry

Ref. Page A-16

Why do we need it?

Break forces into components.



Angle, θ	Sinθ	Cosθ	Tanθ
0 degrees	0	1.0	0
30	0.50	0.866	0.577
45	0.707	0.707	1.0
60	0.866	0.50	1.732
90	1.0	0	α

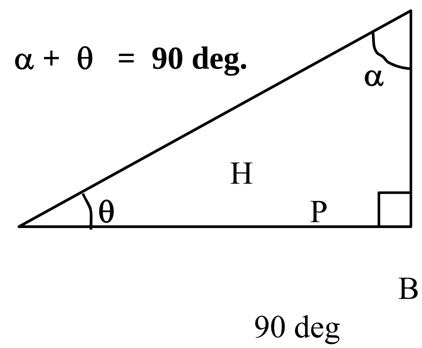
Easy method to memorize

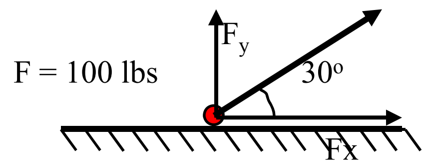
$(0)/2$	$= 0$
$(1)/2$	$= 0.50$
$(2^{½})/2$	$= 0.707$
$(3^{½})/2$	$= 0.866$
$(2)/2$	$= 1.0$

Trigonometry

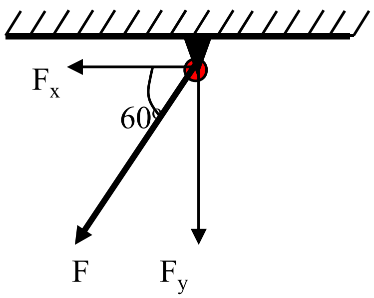
Ref. Page A-16

Break forces into components.



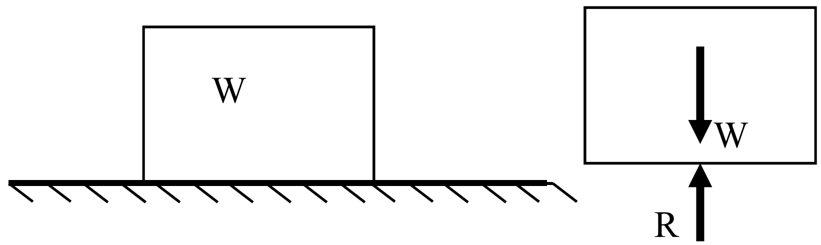


$F_x = F \cos 60°$
$F_y = F \sin 60°$



Rigid Body in a State of Equilibrium

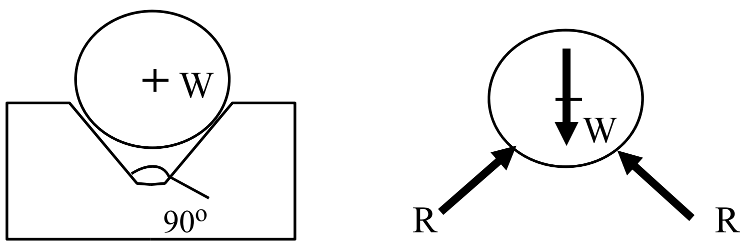
Ref. Page A-17



$\Sigma F_V = 0 \uparrow +$

$R - W = 0$

Or $\mathbf{R = W}$



$\Sigma F_V = 0 \uparrow +$

2R Cos 45 - W = 0

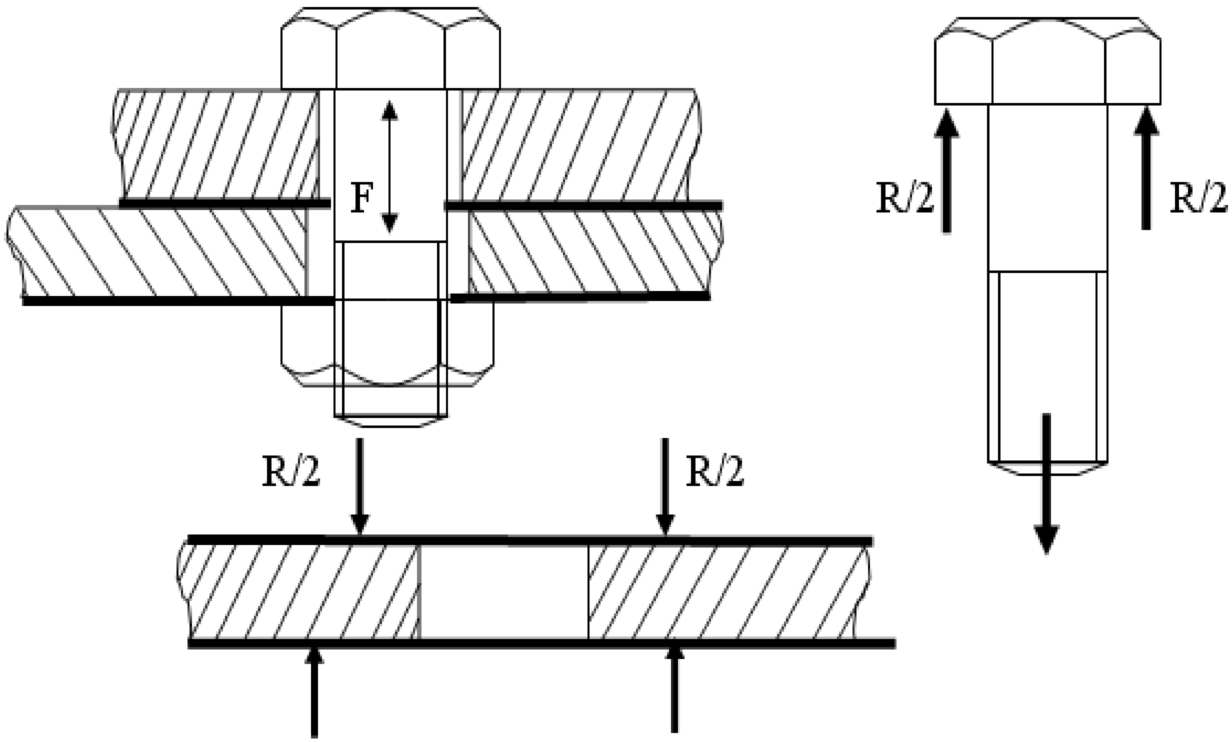
or

R = W / 2R Cos 45

Review examples in handout.

Bolt Load and the Free Body Diagram (FBD)

Ref. Page A-18



Review FBD of bodies on inclined plane and how it applies to bolt treads in handout.

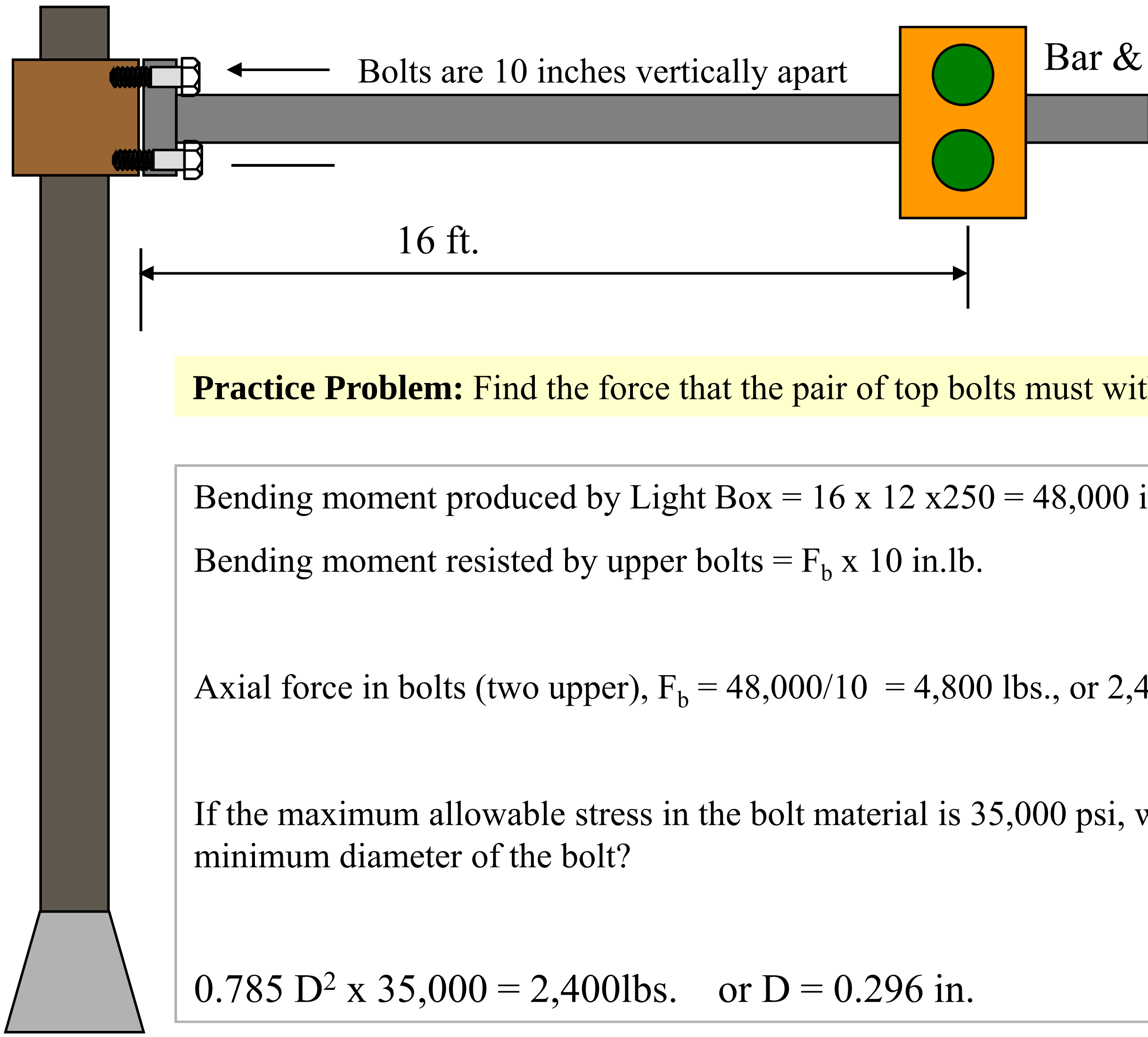
Time to Practice & Learn

Ref. Page N/A

Let's do some calculation and see how the concepts discussed apply to real life applications

Most of the practice exercises are not in your handout. Please take notes and/or do it yourself.

Example Application: Force on Bolt (Not in Handout)



Practice Problem: Find the force that the pair of top bolts must withstand.

Bending moment produced by Light Box = 16 x 12 x250 = 48,000 in.lb.

Bending moment resisted by upper bolts = F_b x 10 in.lb.

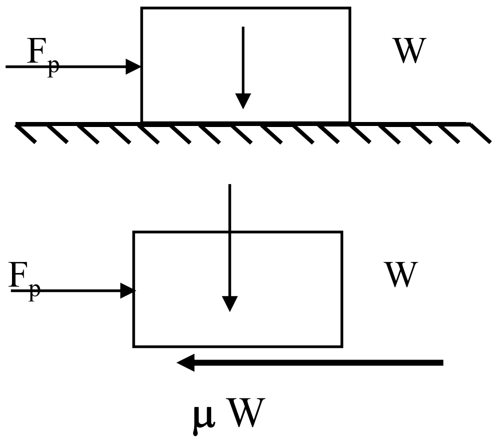
Axial force in bolts (two upper), F_b = 48,000/10 = 4,800 lbs., or 2,400 lbs. in each bolt

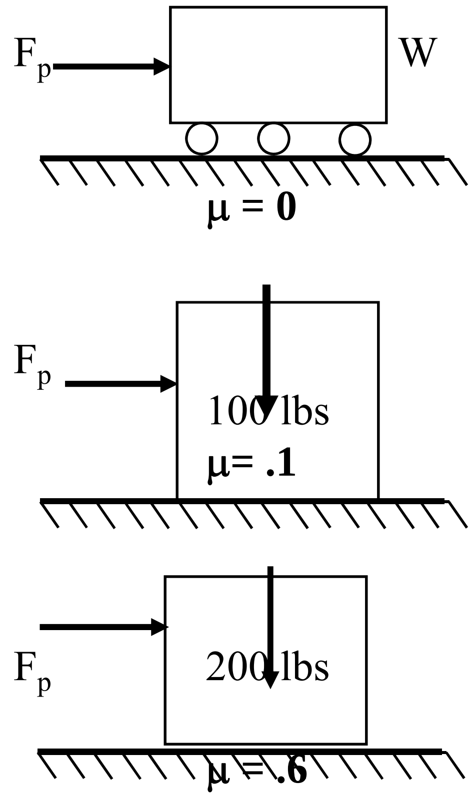
If the maximum allowable stress in the bolt material is 35,000 psi, what should be the minimum diameter of the bolt?

$0.785\ D^2 \times 35{,}000 = 2{,}400$lbs. or $D = 0.296$ in.

Effect of Friction

Ref. Page A-19



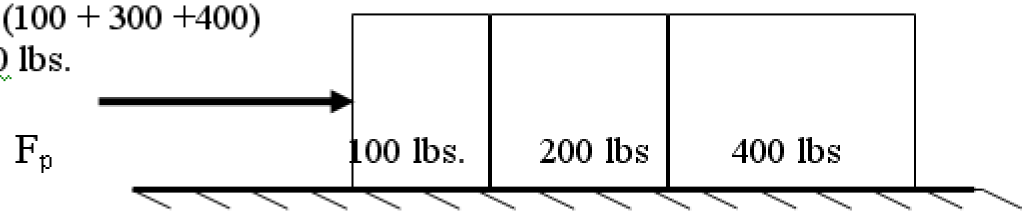


Review examples in handout.

Additive Friction Effects

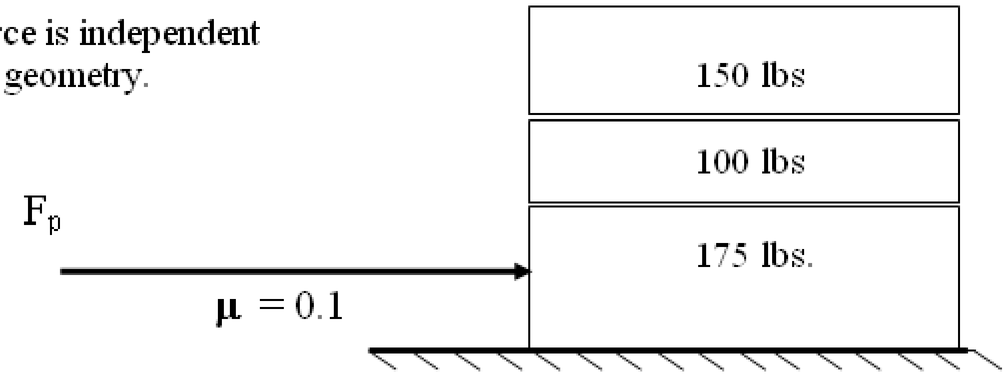
Ref. Page A-20

$F_p = .25\ (100 + 300 + 400)$
$= 200$ lbs.



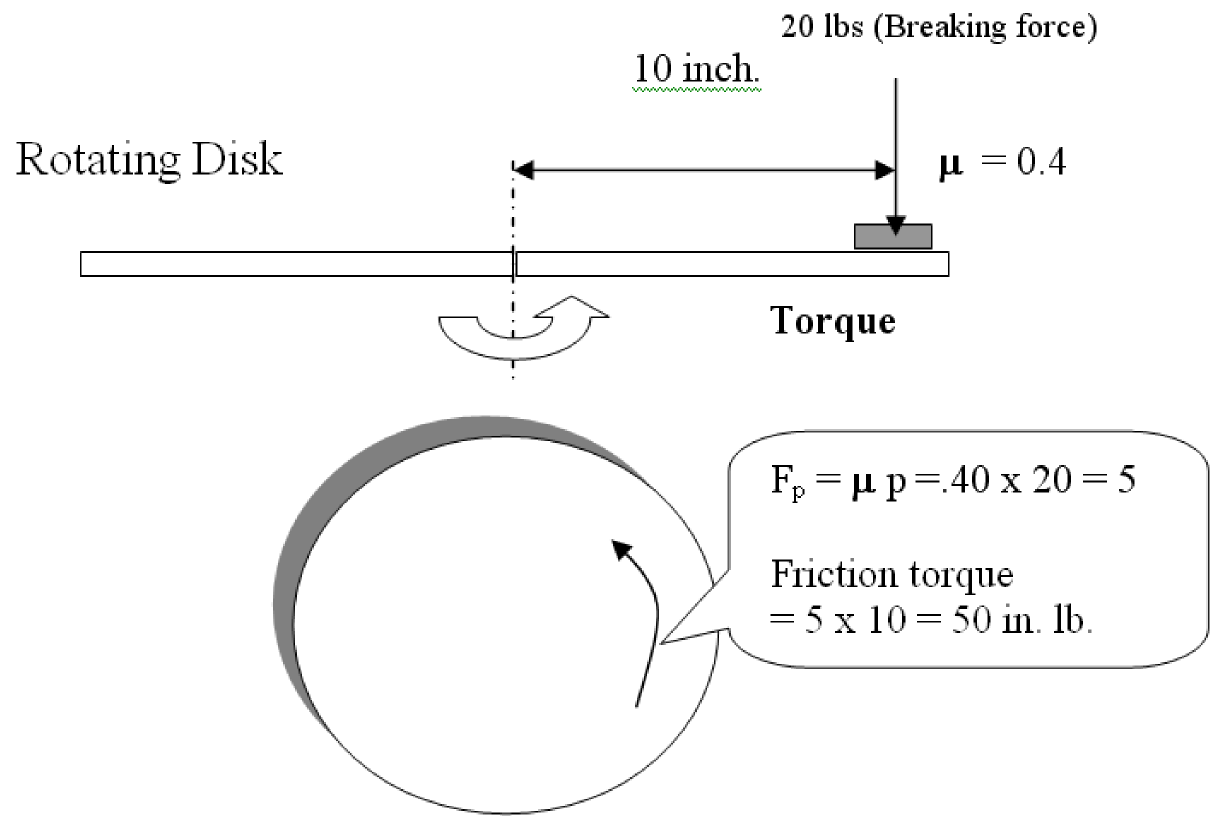
$\mu = 0.25$

Friction force is independent of size and geometry.



Rotating Disk Friction

Ref. Page A-20



Time to Practice & Learn

Ref. Page N/A

Let's do some calculation and see how the concepts discussed apply to real life applications

Most of the practice exercises are not in your handout. Please take notes and/or do it yourself.

Example Application: Useful Conversions (Not in Handout)

Other Useful Conversions

1000 ft = 304.8 m
= 0.1894 miles

1000 lbs. = 453.6 Kg
= 14580 Troy oz

1000 ft.lbs. = 323.8 cal
= 0.37 W-hr.
= 1356 Joules
= 1.285 BTU

Force exerted by 1 lb = 1 lbf.
Mass of 1 lb = 1/g = (1/32.17)

g = 9.81 m/sec^2 = 32.17 ft/sec^2 = 386.4 in/sec^2

Kinetic Energy Formula = ½ M V^2
M = 100 kg. = 220.46 lbs.
V = 20 m/sec. = 65.617 ft/sec.
K.E = 0.50x220.46x65.617^2/32.17 = 14,753 ft.lb.
= 0.50x100x20 = 20,000 Joules

VOLUME
1000 cm^3 = 1 Liter = 200 Tea Spoon = 67.62 Table Spoon
= 1.057 Quart = 2.11 Pint = 33.81 Fluid Ounce

ENERGY
1 Calorie = 1/100 of heat required to raise 1 gram of water from 1 – 100^{o}C at atmospheric pressure.
= 4.1868 Joules

Force on Bolts Fastening Brake Pads

Ref. Page B-N/A

A vehicle weighing 3,000 lbs is slowed down from 40 miles/hour in 5 seconds. What is the force experienced by 2 bolts used to attach the disk-brake pads.

Assume: 4 brakes, 8 inches radial distance, Tire size = 30 in (Dia).

40 m/h = 58.7 ft/sec.

KE = (1/2) M V ^{2}

Stopping Distance = Average Speed x Time

Work Done = Force x Distance (by Linear force)

Work Done = Torque x Rotation (in Radian)

KE of vehicle is dissipated in the form of heat to the environment.

Force on Bolts Fastening Brake Pads

Vehicle KE = 0.50 x 3,000 x $(58.7)^2$ / 32.17

= 160,663 ft.lbs. (52,022 Cal)

This is the amount of energy that has to be spent to stop the vehicle during 5 seconds. The maximum distance allowed to stop the vehicle is the distance covered in 5 sec while moving at 40 m/h (58.7 ft/sec.)

Stopping Distance = 58.7x 5 sec/2 = 147 ft.

For a 30 in dia. tire, the angular distance covered can be calculated as:

Tire/wheel Rotation = 147x12/(Πx30)

= 18.72 turns = 58.8 radians

What happens to the KE of the vehicle?

The amount of energy spent in breaking (dissipated to the environment) is worth the amount of heat required to raise temperature of 52 liter of water by 1 degree centigrade.

*Vehicle motion is opposed by the torque applied by the brake and can be calculated from the friction force (**F**) at the brake pad and the radial distance.*

(Four brakes applied at 8 in. radial distance)

Torque generated by brake = F x (8/12) x 4= 2.67F

Also, the braking torque generates WORK equivalent to the KE of the vehicle when applied over the rotation during 5 seconds.

Torque x rotation = work done or energy

Torque (braking) = 160,663/58.8 = 2,732 ft lbs.

This toque is generated by the force applied to the braking disk by the brake pads. Thus,

2.67 F = 2,732 ft.lbs

Or **F** = 2,732/2.67 = 1,023 lbs.

Force (Shear force) at each bolt holding the BRAKE PAD (fastened by four bolts)

= 1,023/2 = 255.75 lbs.

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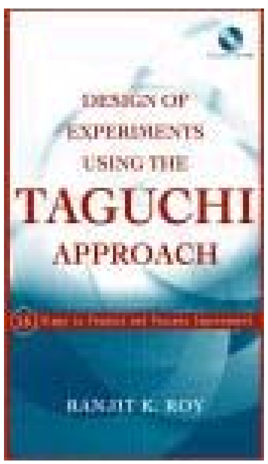

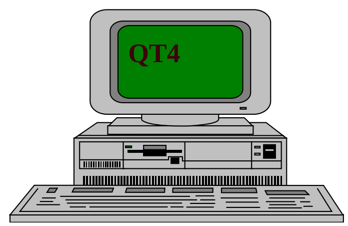

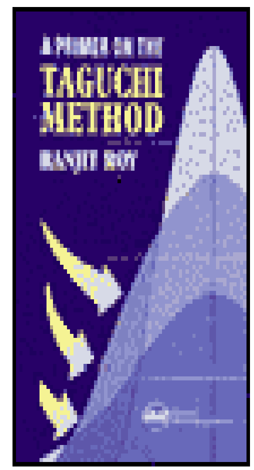

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