The University of Tennessee at Martin

MARTIN School of Engineering

Mechanical Fasteners –
Tensile and Shear Stress Areas

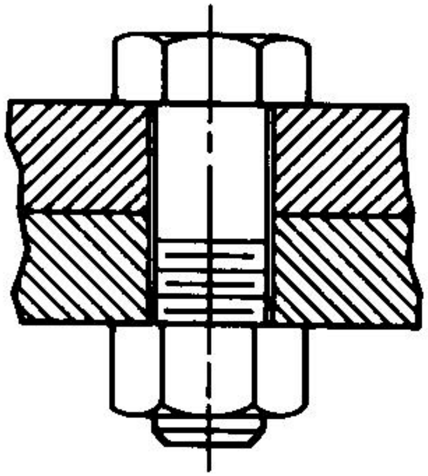
Lecture 28

Engineering 473
Machine Design

MARTIN

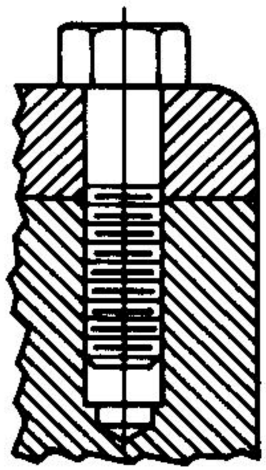
Threaded Fasteners

Bolt – Threaded fastener designed to pass through holes in mating members and to be secured by tightening a nut from the end opposite the head of the bolt.



(a) Hex bolt

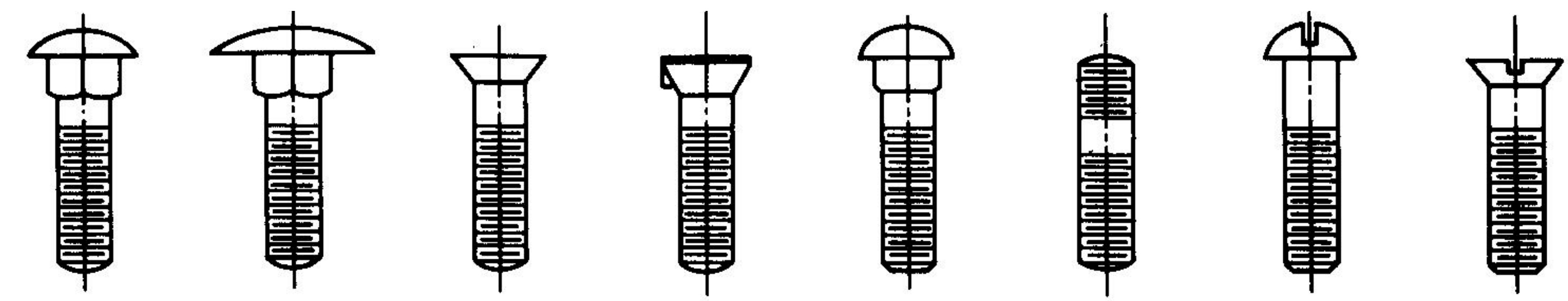
Screw – Threaded fastener designed to be inserted through a hole in one member and into a threaded hole in a mating member.



(b) Hex head cap screw

Mott, Fig. 18-1

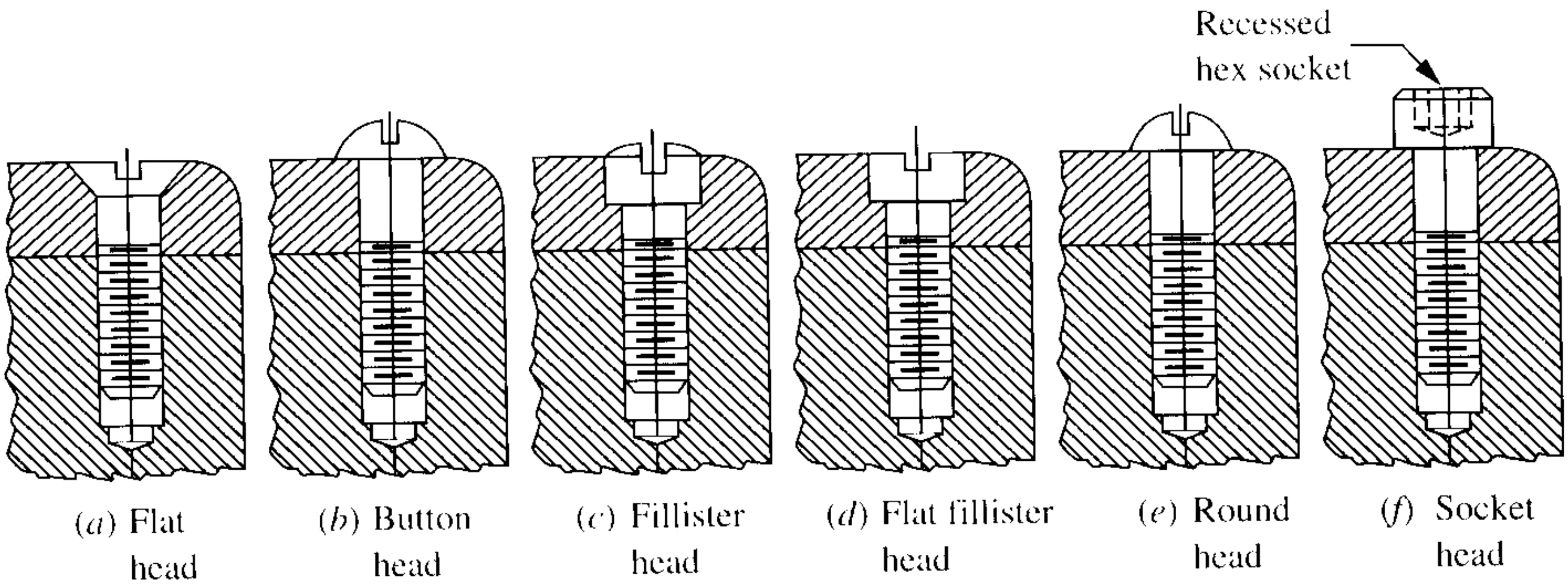
Bolts



(*a*) Carriage bolt (*b*) Elevator bolt (*c*) Countersunk bolt (*d*) Plow bolt (*e*) Track bolt (*f*) Stud bolt (*g*) Stove bolt (*h*) Stove bolt

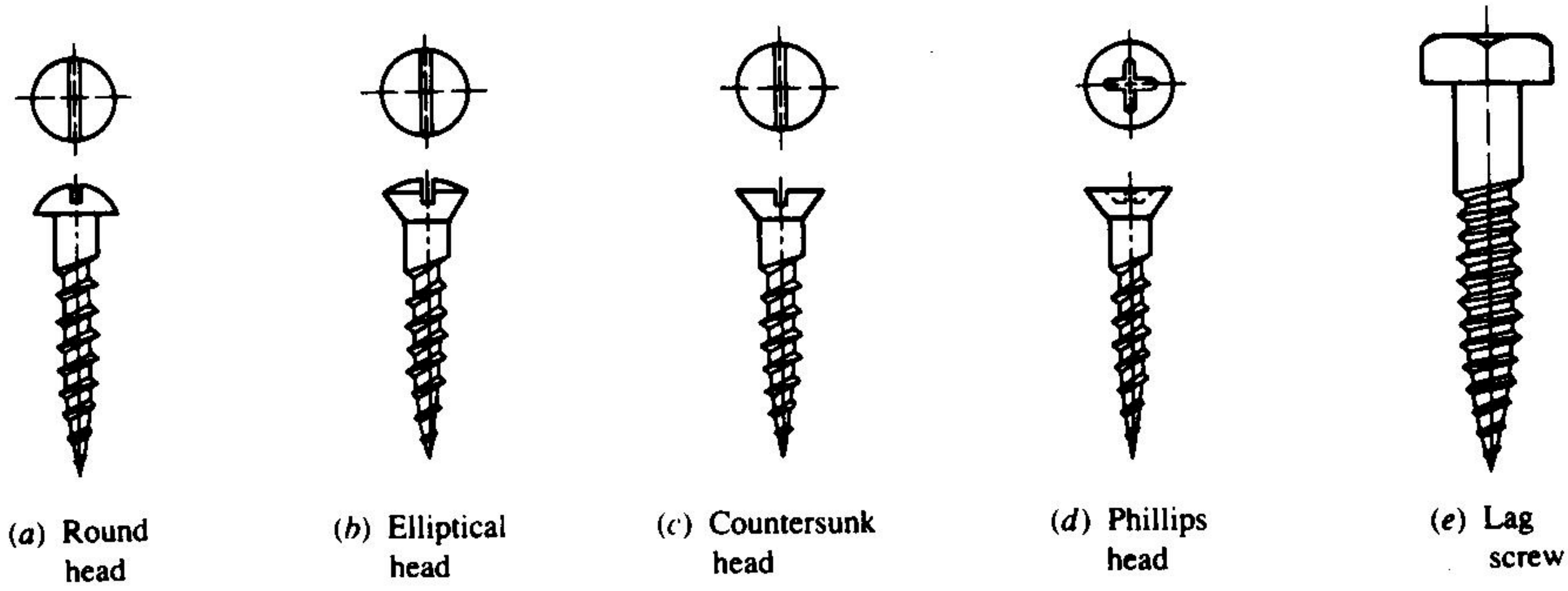
Mott, Fig. 18-2

Machine Screws



Mott, Fig. 18-3

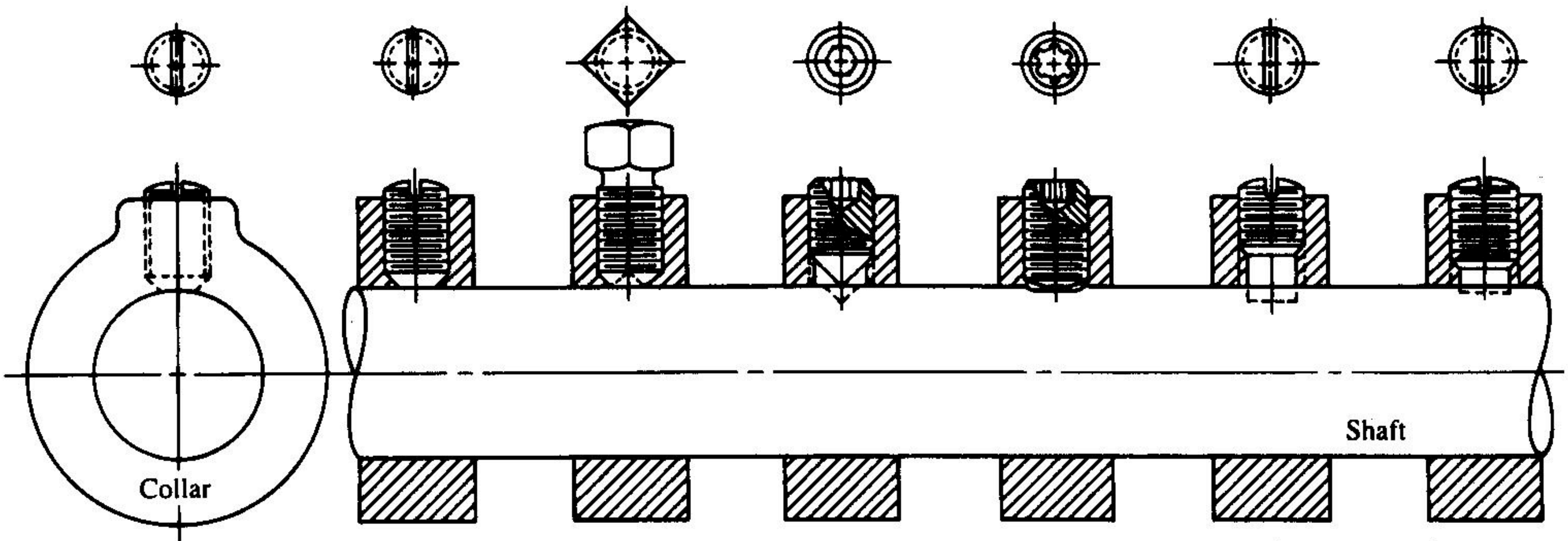
Sheet Metal and Lag Screws



Sheet metal screws are often self-tapping.

Mott, Fig. 18-4

Set Screws



Set screws are used to develop a normal force between two objects (e.g. collar and shaft).

Mott, Fig. 18-5

Thread Standards
(Inch Series)

American Standard B1.1-1949

First American standard to cover the Unified Thread Series agreed upon by the United Kingdom, Canada, and the United States. Represents the basic American standard for fastener threads. Threads made to this standard are called "unified threads".

ANSI B1.1-1989/ASME B1.1-1989

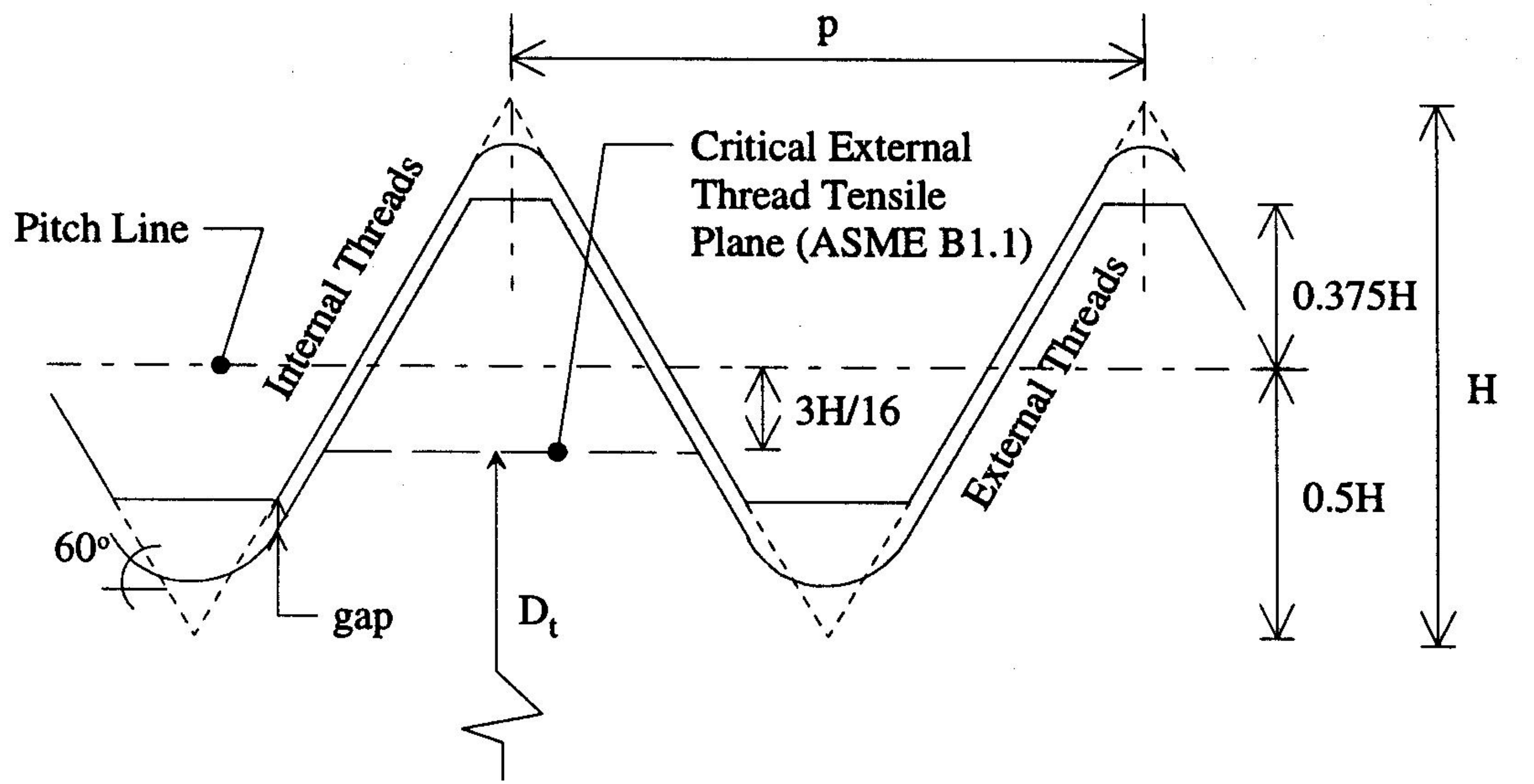
Revised standard that still incorporates much of the original standard.

Thread Standards
(Metric Series)

ANSI B1.13M-1983 (R1989)

Contains system of metric threads for general fastening purposes in mechanisms and structures. Fasteners made to this standard are often referred to as M-series.

Thread Profiles



The pitch line or diameter is located at ½ the height of the theoretical sharp v-thread profile.

Thread Series

Thread Series – groups of diameter-pitch combinations distinguished from each other by the number of threads per inch applied to a specific diameter.

Unified Coarse-Thread Series (UNC or UNRC)

Most commonly used in the bulk production of bolts, screws, nuts for general engineering applications.

Unified Fine-Thread Series (UNF or UNRF)

Use when more threads per inch are required (i.e. where are short length of engagement is available).

M-Series

Metric system of diameters, pitches, and tolerance/allowances.

Thread Classes

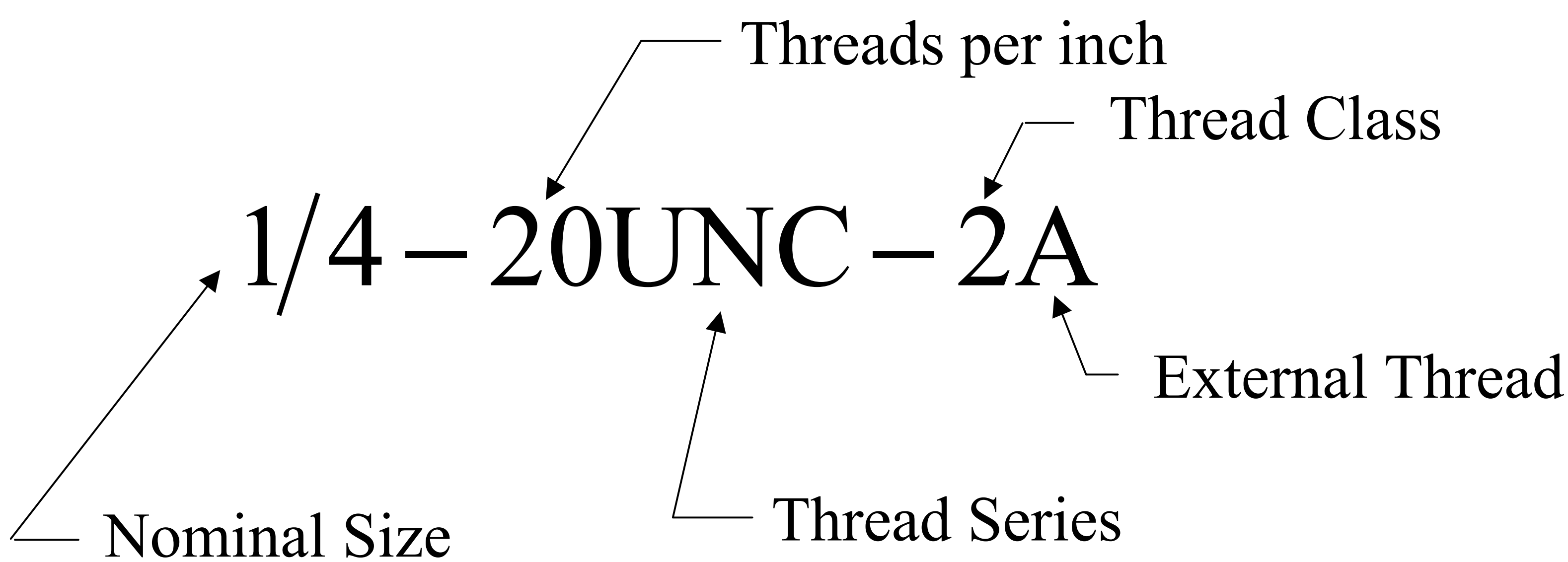
Thread Classes – Define the amount of tolerance and allowance associated with a particular thread.

Classes 1A, 2A, 3A – apply to external threads. Class 2A is the most commonly used.

Classes 1B, 2B, 3B – apply to internal threads. Class 2B is the most commonly used.

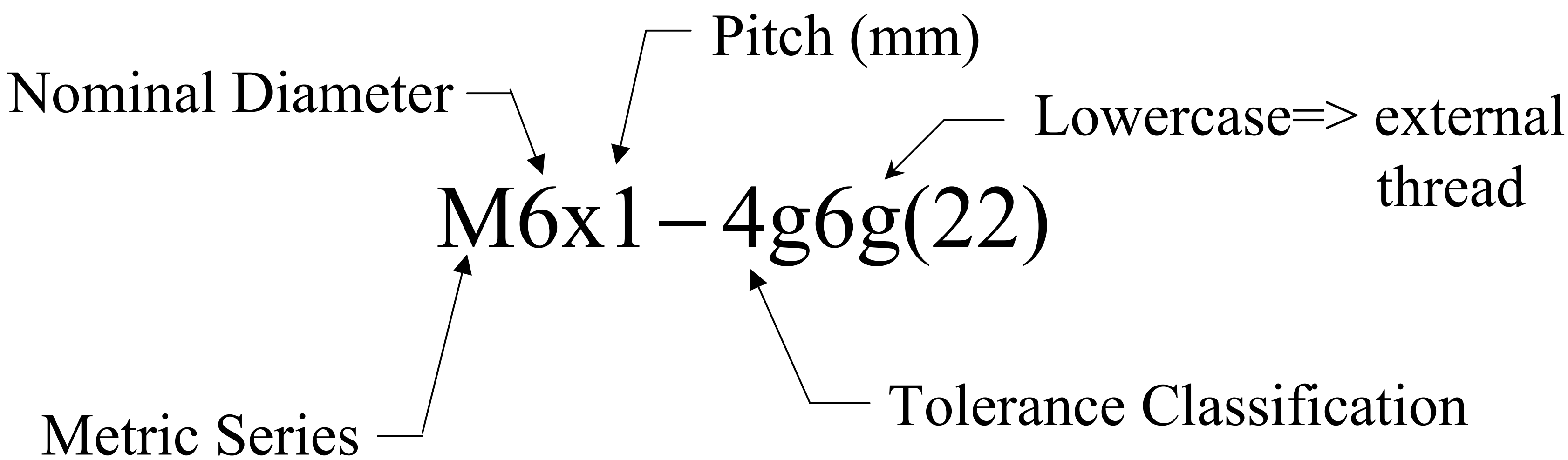
Thread Designations
(Inch Series)

The following is an example of the standard method used to designate bolt and screw thread requirements on a drawing or in a specification.



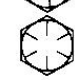
Thread Designations
(Metric Series)

The following is an example of the standard method used to designate bolt and screw thread requirements on a drawing or in a specification.



Material and Strength Designations

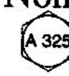
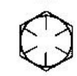
TABLE 18–1 SAE grades of steels for fasteners

Grade number	Bolt size (in)	Tensile strength (Ksi)	Yield strength (Ksi)	Proof strength (Ksi)	Head marking
1	1/4–1½	60	36	33	None
2	1/4–3/4	74	57	55	None
	>3/4–1½	60	36	33	
4	1/4–1½	115	100	65	None
5	1/4–1	120	92	85	
	>1–1½	105	81	74	
7	1/4–1½	133	115	105	
8	1/4–1½	150	130	120	

Mott, Table 18-1

Material and Strength Designations
(Continued)

TABLE 18–2 ASTM standards for bolt steels

ASTM grade	Bolt size (in)	Tensile strength (Ksi)	Yield strength (Ksi)	Proof strength (Ksi)	Head marking
A307	1/4–4	60	(Not reported)		None
A325	1/2–1	120	92	85	
	$>1–1\frac{1}{2}$	105	81	74	
A354-BC	$1/4–2\frac{1}{2}$	125	109	105	
A354-BD	$1/4–2\frac{1}{2}$	150	130	120	
A449	1/4–1	120	92	85	
	$>1–1\frac{1}{2}$	105	81	74	
	$>1\frac{1}{2}–3$	90	58	55	
A574	0.060–1/2	180		140	(Socket head cap screws)
	5/8–4	170		135	

Mott, Table 18-2

Material and Strength Designations

TABLE 18–3 Metric grades of steels for bolts

Grade	Bolt size	Tensile strength (MPa)	Yield strength (MPa)	Proof strength (MPa)
4.6	M5–M36	400	240	225
4.8	M1.6–M16	420	340[a]	310
5.8	M5–M24	520	415[a]	380
8.8	M17–M36	830	660	600
9.8	Ml.6–M16	900	720[a]	650
10.9	M6–M36	1 040	940	830
12.9	M1.6–M36	1 220	1 100	970

[a]Yield strengths are approximate and are not included in the standard.

Mott, Table 18-3

Tensile Stress Area

The average axial stress in a fastener is computed using a "tensile stress area".

$$\sigma_{ave} = \frac{F}{A_t}$$

$$A_t = \frac{\pi}{4}\left[\frac{D_r + D_p}{2}\right]^2$$

$F \equiv$ Axial Force

$D_r \equiv$ Root Diameter

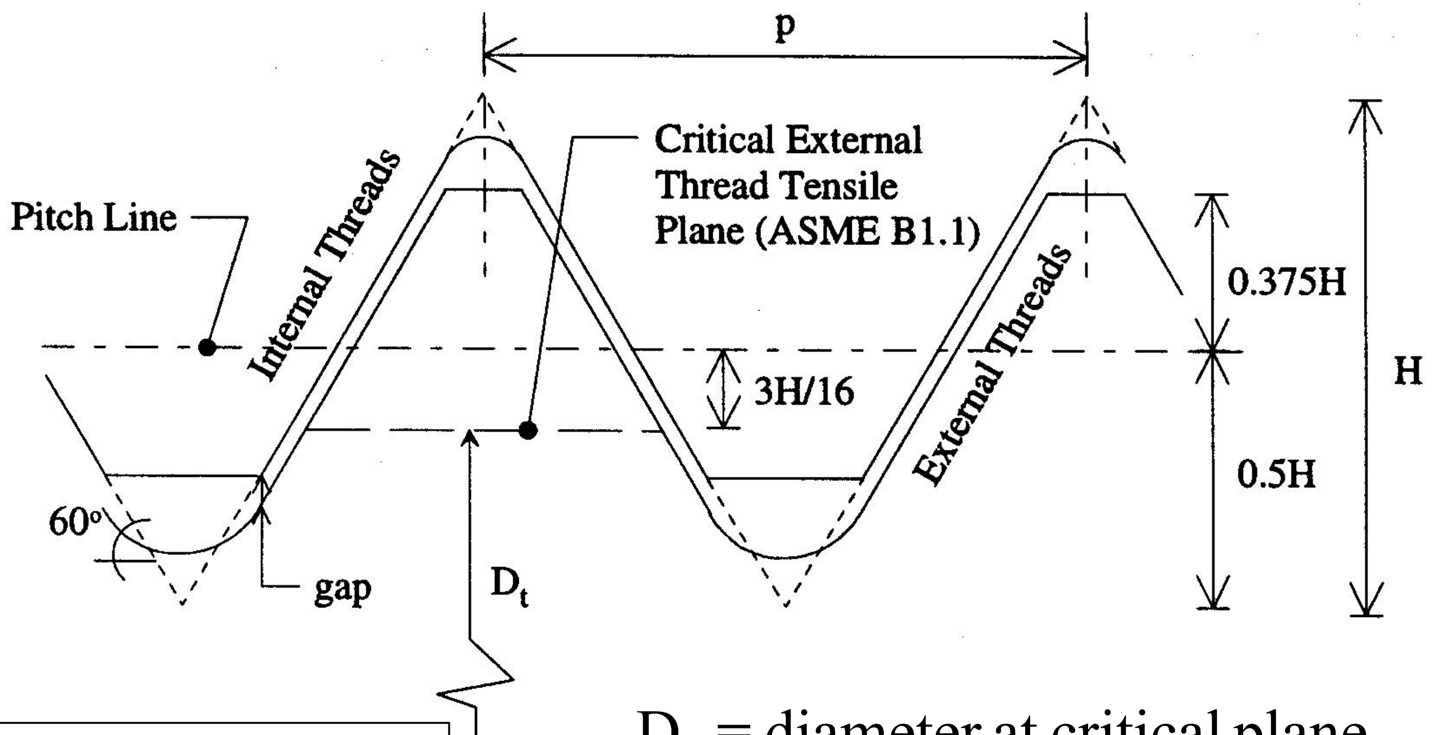
$D_p \equiv$ Pitch Diameter

$A_t \equiv$ Tensile Stress Area

$\sigma_{ave} \equiv$ Average axial stress

Tests of threaded rods have shown that an unthreaded rod having a diameter equal to the mean of the pitch diameter and the minor diameter will have the same tensile strength as the threaded rod.

Tensile Stress Area
(Continued)



$$D_t = d_b - 2\left(\frac{3}{8}H + \frac{3}{16}H\right)$$

$$H = \frac{1}{2n} \cdot \tan(60^\circ)$$

$D_t \equiv$ diameter at critical plane

$d_b \equiv$ diameter of bolt

$H \equiv$ theoretical height of thread

$n \equiv 1/p =$ threads/in

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Tensile Stress Area
(Continued)

$$D_t = d_b - 2\left(\frac{3}{8}H + \frac{3}{16}H\right)$$

$$H = \frac{1}{2n} \cdot \tan(60°)$$

$$D_t = d_b - \frac{\tan(60°)}{n}\left(\frac{3}{8} + \frac{3}{16}\right)$$

$$D_t = d_b - \frac{9\sqrt{3}}{16n}$$

$$A_t = \frac{\pi}{4} \cdot D_t^2$$

$$A_t = \frac{\pi}{4}\left(d_b - \frac{0.9743}{n}\right)^2$$

This is the formula used by manufacturers of inch series fasteners to publish the tensile area in their catalogs.

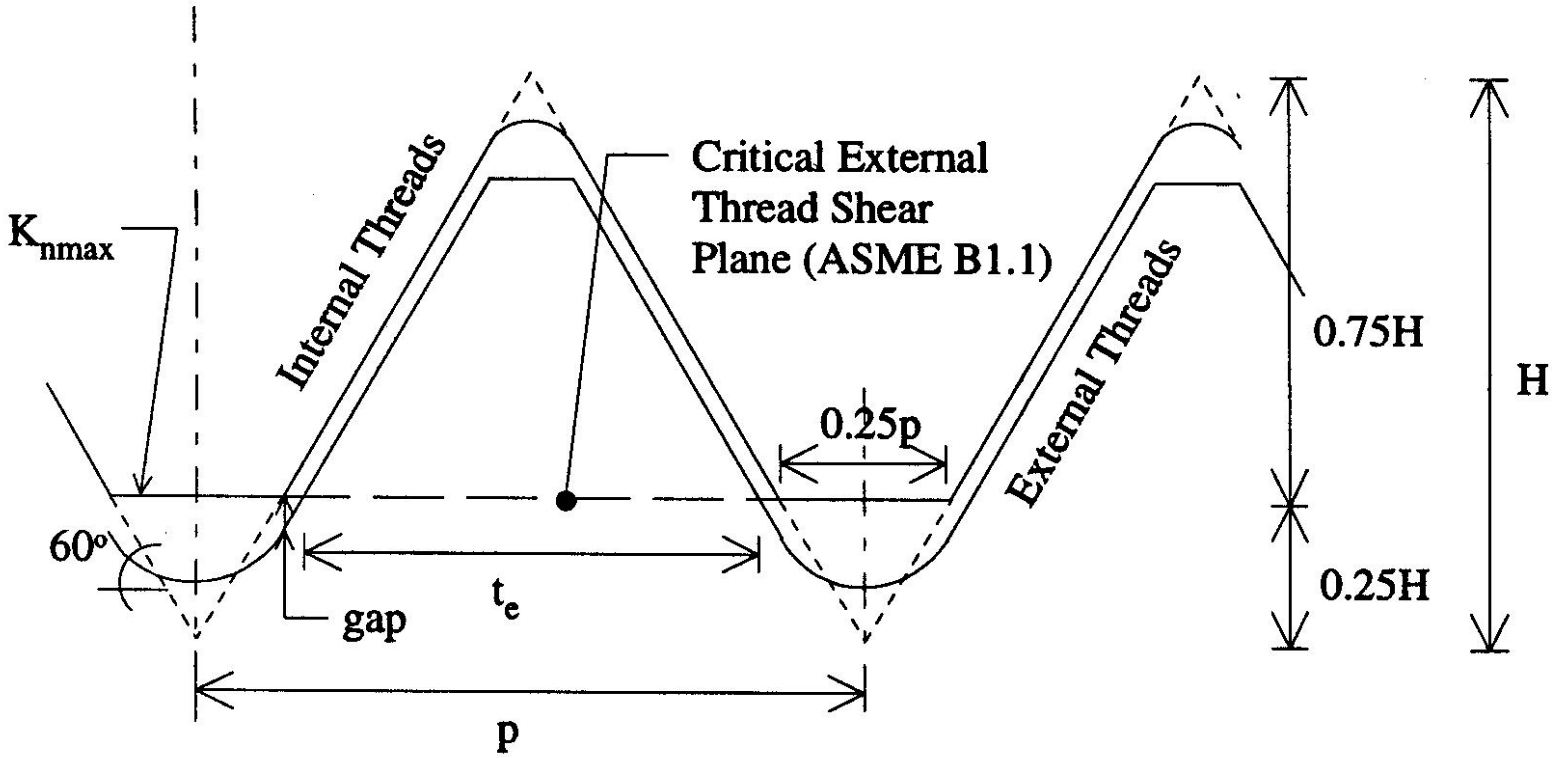
Tensile Stress Area
(Continued)

The following formula may be obtained in a similar manner for metric series threads.

$$A_t = \frac{\pi}{4}\left(d_b - \frac{0.9328}{n}\right)^2$$

Shear Area of External Thread

Consideration of the interaction between mating threads must be considered to establish the shear area of an external thread.



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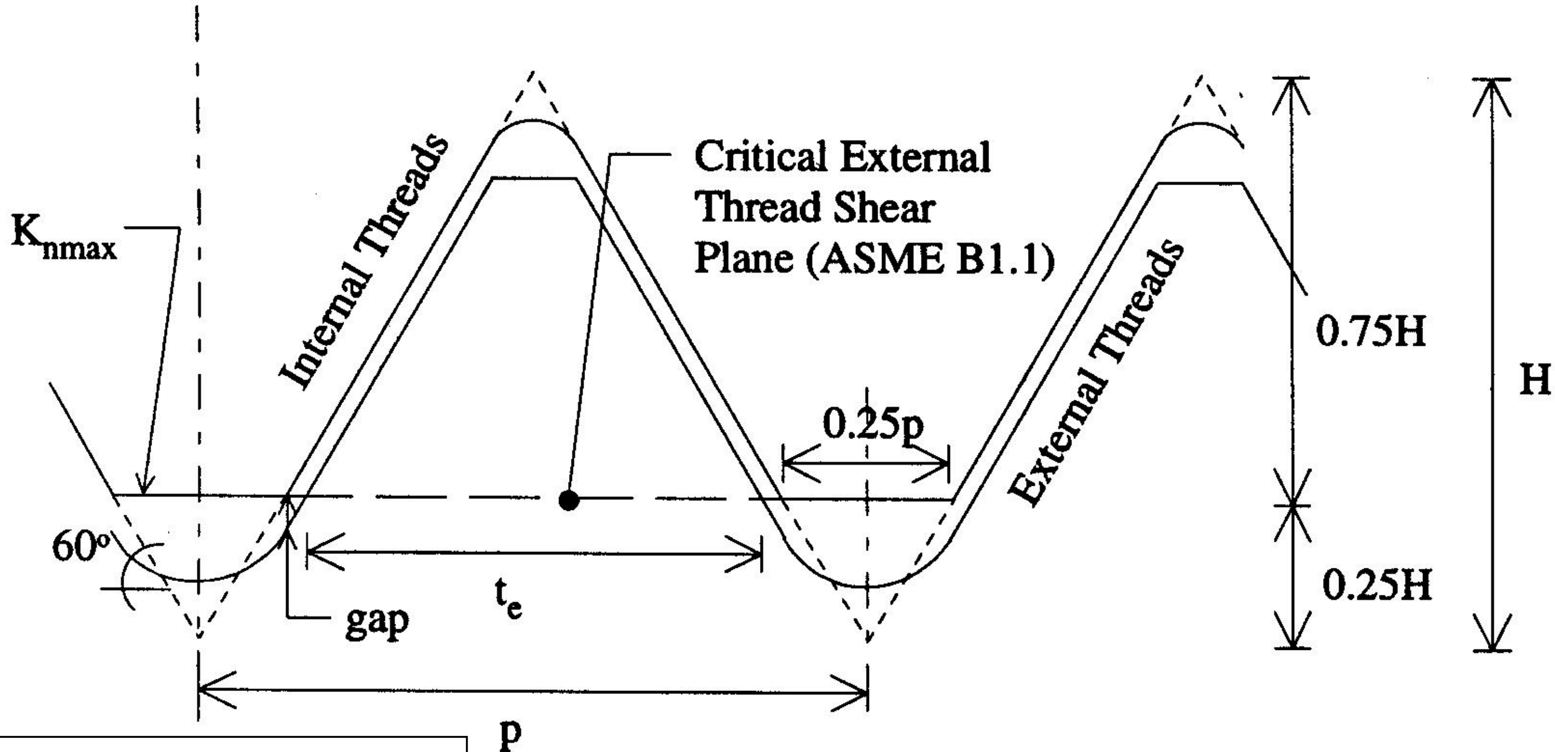
Shear Area of External Threads

(Continued)



$$A_{s,e} = \pi \cdot K_{n,max} \cdot t_e \cdot n$$

$$\tan(30°) = \frac{0.5t_e}{0.75H - gap}$$

$A_{s,e} \equiv$ shear area of external thread

$K_{n,max} \equiv$ maximum minor diameter of internal thread

$t_e \equiv$ thickness of external thread at critical shear plane

$n \equiv$ threads per inch

Shear Area of External Threads
(Continued)

$$A_{s,e} = \pi \cdot K_{n,max} \cdot t_e \cdot n$$

$$\tan(30°) = \frac{0.5t_e}{0.75H - gap}$$

$$H = \frac{1}{2n}\tan(60°) = \frac{\sqrt{3}}{2n}$$

$$t_e = 2 \cdot \tan(30°)\left(0.75\frac{\sqrt{3}}{2n} - gap\right)$$

$$gap = \frac{1}{2}\left(K_{n,max} + \frac{1}{2}\frac{\sqrt{3}}{2n} - E_{s,min}\right)$$

$E_{s,min}$=minimum pitch diameter of the external thread

$$t_e = 2 \cdot \frac{1}{\sqrt{3}}\left[\frac{3}{4}\frac{\sqrt{3}}{2n} - \frac{1}{2}\left(K_{n,max} + \frac{1}{2}\frac{\sqrt{3}}{2n} - E_{s,min}\right)\right]$$

$$t_e = \frac{1}{2n} + \frac{1}{\sqrt{3}}\left(E_{s,min} - K_{n,max}\right)$$

The gap equation is based on tolerance data.

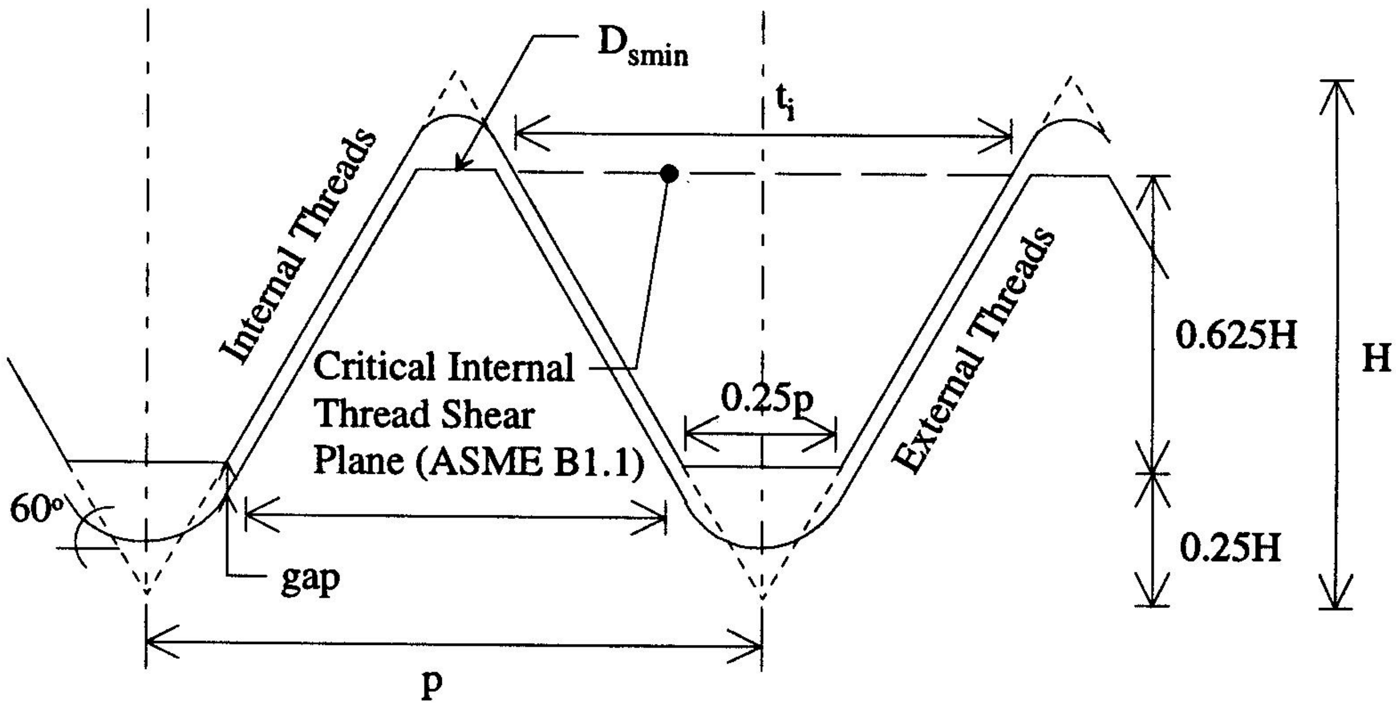
Shear Area of External Threads
(Continued)

$$A_{s,e} = \pi \cdot n \cdot K_{n,max} \cdot \left[\frac{1}{2n} + \frac{1}{\sqrt{3}} \left(E_{s,min} - K_{n,max} \right) \right]$$

This equation appears in the ANSI standards and gives the shear area per unit length of engagement. It must be multiplied by the length of engagement, L_e, to obtain the actual shear area. This area is often reported in manufacturers data sheets for bolts and screws.

$$A_{s,e} = \pi \cdot n \cdot K_{n,max} \cdot \left[\frac{1}{2n} + \frac{1}{\sqrt{3}} \left(E_{s,min} - K_{n,max} \right) \right] \cdot L_e$$

Shear Area of Internal Threads



$$A_{s,i} = \pi \cdot D_{s,min} \cdot t_i \cdot n$$

$D_{s,min} \equiv$ Minimum major diameter (external thread)

$t_i \equiv$ thickness of internal thread (critical plane)

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Shear Area of Internal Threads
(Continued)

Similar to the previous derivation, an equation that takes into account the tolerances of the thread system can be derived to compute the shear area of the internal thread.

$$A_{s,i} = \pi \cdot D_{s,min} \cdot n \cdot \left[\frac{1}{2n} + \frac{1}{\sqrt{3}} \left(D_{s,min} - E_{n,max} \right) \right]$$

$E_{n,max} \equiv$ maximum pitch diameter of the internal threads

Length of Engagement
(Equal Strength Materials)

If the internal thread and external thread material have the same strength, then

Tensile Strength (External Thread)

$$S_t = \frac{F_{max}}{A_t}$$

Shear Strength (Internal Thread)

$$0.5S_t = \frac{F_{max}}{A_{s,i} \cdot L_e}$$

$$F_{max} = S_t A_t = 0.5 S_t A_{s,i} L_e$$

$$L_e = \frac{2A_t}{A_{s,i}}$$

Length of Engagement
(Unequal Strength Materials)

If the internal thread and external thread do not have the same material, then

Tensile Strength (External Thread)

$$S_{t,e} = \frac{F_{max}}{A_t}$$

Shear Strength (Internal Thread)

$$0.5S_{t,i} = \frac{F_{max}}{A_{s,i} \cdot L_e}$$

$$F_{max} = S_{t,e}A_t = 0.5S_{t,i}A_{s,i}L_e$$

$$L_e = \frac{2A_t \cdot S_{t,e}}{A_{s,i} \cdot S_{t,i}}$$

Bolt/Nut Design Philosophy

ANSI standard bolts and nuts of equal grades are designed to have the bolt fail before the threads in the nut are stripped.

The engineer designing a machine element is responsible for determining how something should fail taking into account the safety of the operators and public. Length of engagement is an important consideration in designing machine elements with machine screws.

Assignment

A 5/16-18UNC-2A fastener is made from a material having a yield strength of 120 ksi. The fastener will be engaged with a nut made from the same material. Compute the tensile stress area, shear stress area per length of engagement, and minimum length of engagement. Dimensional information on the threads is given below.

The minimum pitch diameter of the external thread is 0.2712 in., and the maximum minor diameter of the internal thread is 0.265 inch, minimum major diameter of the external thread is 0.3026 in, and the maximum pitch diameter of the internal threads is 0.2817 (reference Table 4, page1544, Machinery's Handbook).