■Bolt strength

1) When bolt is subjected to tensile load

$Pt = \sigma t \times As$ …… (1)

$= \pi d^2 \sigma t/4$ … (2)

Pt : Tensile load in axial direction [kgf]
σb : Bolt yield stress [kgf/mm²]
σt : Bolt maximum allowable stress [kgf/mm²]
($\sigma t = \sigma b$/(safety factor α))
As : Bolt effective cross-section area [mm²]
$As = \pi d^2/4$
d : Bolt effective diameter (root diameter) [mm]

■Unwin safety factor α based on tensile strength

M	Static load	Repeated load		Impact load
		Pulsating	Alternating	
Steel	3	5	8	12
Cast iron	4	6	10	15
Copper, soft metals	5	5	9	15

Shear stress = Standard strength / Safety factor α   Standard strength: For ductile materials = Yield stress; For brittle materials = Fracture stress

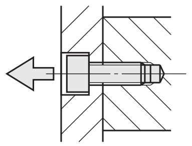
Example: Find a suitable size for a single hexagon socket head cap screw that will be subjected to repeated (pulsating) tensile loads of P=200 kgf. (Hexagon socket head cap screw material: 4137, 38~43 HRC, strength class 12.9)

From formula (1):

$As = Pt/\sigma t$
$= 200/22.4$
$= 8.9$ [mm²]

∴Finding the effective cross-section area larger than this value from the table at right shows that a 14.2 [mm²] M5 cap screw should be selected.

With additional consideration for the fatigue strength, and based on the strength class of 12.9 in the table, we select an M6 screw with maximum allowable load of 213 kgf.



Yield stress for strength class 12.9 σb=112 [kgf/mm²]
Maximum allowable stress σt=σb/(safety factor)
(From table above, safety factor=5)
=112/5
=22.4 [kgf/mm²]

2) For stripper bolts and others which are subjected to tensile impact loads, the selection is made based on the fatigue strength. (The bolt is subjected to 200 kgf loads in the same way. Stripper bolt material: 4137 33~38 HRC, strength class 10.9.)

From the table at right, for a strength class of 10.9 and a maximum allowable load of 200 kgf, the suitable bolt is a 318 [kgf] M8. Therefore we select a 10 mm MSB10 with a M8 thread section. When the bolt is subjected to shear load, also use a dowel pin.

■Bolt fatigue strength (For threads: fatigue strength = count of 2 million)

Nominal thread size	Effective cross-section area As mm²	Strength class 12.9 Fatigue strength* kgf/mm²	12.9 Maximum allowable load kgf	10.9 Fatigue strength* kgf/mm²	10.9 Maximum allowable load kgf
M 4	8.78	13.1	114	9.1	79
M 5	14.2	11.3	160	7.8	111
M 6	20.1	10.6	213	7.4	149
M 8	36.6	8.9	326	8.7	318
M10	58	7.4	429	7.3	423
M12	84.3	6.7	565	6.5	548
M14	115	6.1	702	6	690
M16	157	5.8	911	5.7	895
M20	245	5.2	1274	5.1	1250
M24	353	4.7	1659	4.7	1659

Fatigue strengths* have been excerpted from "Estimated values of fatigue limits for metal threads of small screws, bolts, and nuts" (Yamamoto) and modified.

■Screw plug strength

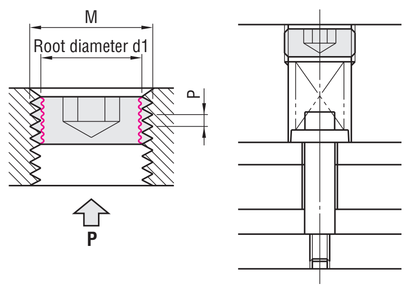
Find the maximum allowable load P when a MSW30 screw plug is subjected to impact load. (MSW30 material: 1045, tensile strength σb at 34~43 HRC 65 kgf/mm²)

Assuming fracture due to shear occurs at the MSW root diameter location, the maximum allowable load $P = \tau t \times A$.

$= 3.9 \times 107.4$
$= 4190$ [kgf]

When the tap is a soft materials, find the maximum allowable shear from the inside thread root diameter.

Shear cross-section area A=Root diameter d1×π×L
(Root diameter d1≒M−P)
A=(M−P)πL=(30−1.5)π×12
=1074 [mm²]
Yield stress≒0.9×Tensile strength σb=0.9×65=58.2
Shear stress≒0.8×Yield stress
=46.6
Maximum allowable shear stress τt=Shear stress / (Safety factor 12)
=46.6/12=3.9 [kgf/mm²]



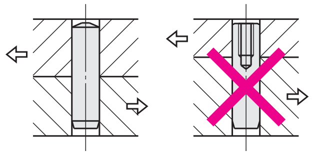
■Dowel pin strength

Find a suitable size for a single dowel pin which is subjected to repeated (pulsating) shear loads of 800 kgf. (Dowel pin material: 52100 hardness 58 HRC or higher)

$P = A \times \tau$
$= \pi D^2 \tau/4$
$D = \sqrt{(4P)/(\pi\tau)}$
$= \sqrt{(4 \times 800)/(3.14 \times 19.2)}$
$\fallingdotseq 7.3$

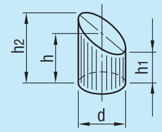
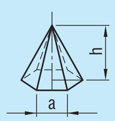
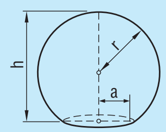
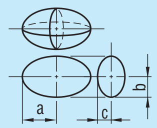
52100 yield stress capability σb=120 [kgf/mm²]
Maximum allowable shear strength τ=σb×0.8/(Safety factor α)
=120×0.8/5
=19.2 [kgf/mm²]

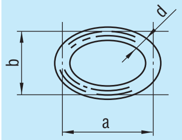
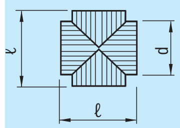
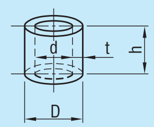
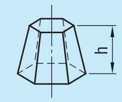
∴For an MS dowel pin, select a size of D8 or larger.
In addition, selecting a single size for all dowel pins makes it possible to reduce items such as tools and inventory.

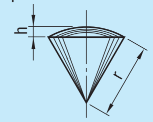
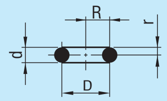
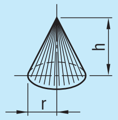
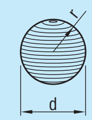


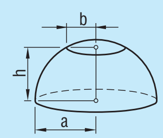
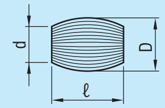
Do not use in such a way that load is applied to the threads.

The information provided here is only an example of calculating the strength. For actual selections, it is necessary to consider the hole pitch accuracy, hole perpendicularity, surface roughness, true roundness, plate material, parallelism, use of hardening, accuracy of the press machine, product production volume, tool wear, and various other conditions. Therefore the strength calculation value should be used only as a guide. (It is not a guaranteed value.)

3D shape	Volume V
Truncated cylinder 	$V = \frac{\pi}{4} d^2 h$ $= \frac{\pi}{4} d^2 \left(\frac{h_1 + h_2}{2}\right)$
Pyramid 	$V = \frac{h}{3} A = \frac{h}{6} arn$ A=Bottom surface area, r=Radius of inscribed circle, a=Length of 1 side of regular polygon, n=Number of regular polygon sides
Spherical crown 	$V = \frac{\pi h^2}{3}(3r - h)$ $= \frac{\pi h}{6}(3a^2 + h^2)$ a is the radius.
Ellipsoidal body 	$V = \frac{4}{3}\pi abc$ In the case of a rotating ellipsoidal body (b=c): $V = \frac{4}{3}\pi ab^2$

3D shape	Volume V
Ellipsoidal ring 	$V = \frac{\pi^2}{4} d^2 \frac{\sqrt{a^2 + b^2}}{2}$
Crossing cylinders 	$V = \frac{\pi}{4} d^2 (\ell + \ell' - \frac{d}{3})$
Hollow cylinder (tube) 	$V = \frac{\pi}{4} h (D^2 - d^2)$ $= \pi th (D - t)$ $= \pi th (d + t)$
Truncated pyramid 	$V = \frac{h}{3}(A + a + \sqrt{Aa})$ A,a=Surface area of each end

3D shape	Volume V
Conical section of sphere 	$V = \frac{2}{3}\pi r^2 h$ $= 2.0944 r^2 h$
Circular ring 	$V = 2\pi^2 R r^2$ $= 19.739 R r^2$ $= \frac{\pi^2}{4} D d^2$ $= 2.4674 D d^2$
Cone 	$V = \frac{\pi}{3} r^2 h$ $= 1.0472 r^2 h$
Sphere 	$V = \frac{4}{3}\pi r^3 = 4.1888 r^3$ $= \frac{\pi}{6} d^3 = 0.5236 d^3$

3D shape	Volume V
Zone of sphere 	$V = \frac{\pi h}{6}(3a^2 + 3b^2 + h^2)$
Barrel shape 	When curve has circumference that is an arc: $V = \frac{\pi \ell}{12}(2D^2 + d^2)$ When curve has circumference that is a parabola $V = 0.209\ell(2D^2 Dd + 1/4d^2)$

■Physical properties of metal materials

M	Density [g/cm³]	Young´s modulus E [kgf/mm²]	Coefficient of thermal expansion [M10⁻⁶ /°C]
Soft steel	7.85	21000	11.7
D2	7.85	21000	11.7
Powdered high-speed steel (HAP40)	8.07	23300	10.1
Carbide V30	14.1	56000	6.0
Cast iron	7.3	7500 ~ 10500	9.2 ~ 11.8
304	8.0	19700	17.3
Oxygen-free copper C1020	8.9	11700	17.6
6/4 brass C2801	8.4	10300	20.8
Aluminum A1100	2.7	6900	23.6
Duralumin A7075	2.8	7200	23.6
Titanium	4.5	10600	8.4

$1 kgf/mm^2 = 9.80665 \times 10^6$ Pa

■Finding the weight

Weight W [g] = Volume [cm³] × Density

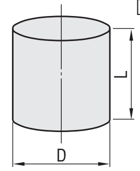
[Example] Material: Soft steel

Weight when D=ϕ16 and L=50 mm is found as follows.

$W = \frac{\pi}{4} D^2 \times L \times$ Density

$= \frac{\pi}{4} \times 1.6^2 \times 5 \times 7.85$

$\fallingdotseq 79$ [g]

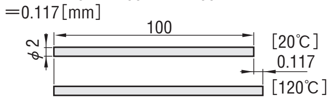


■Finding dimensional changes resulting from thermal expansion

Example: Material: D2

Example: The amount of dimensional change δ which occurs when a pin of D=ϕ2, L=100 mm is heated to 100℃ is the following.

δ = Coefficient of thermal expansion × Total length × Temperature change
$= 11.7 \times 10^{-6} \times 100$ mm $\times 100$℃
$= 0.117$ [mm]



■Finding dimensional changes resulting from Young´s modulus E

Example: Find strain λ when load P=1000 kgf is applied to a ϕ10×L60 pin. (Material: D2)

$E = \frac{PL}{A\lambda}$

$\lambda = \frac{PL}{AE} = \frac{1000 \times 60}{78.5 \times 21000}$

$\fallingdotseq 0.036$ mm

Cross-section area $A = \frac{\pi}{4} D^2 = 78.5$