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FASTENERS · PRELOAD · TORQUE · PROPERTY CLASSES · THREAD ENGAGEMENT · REFERENCE DOCUMENT · PUBLIC

Bolted joint reference

Designing a bolted joint around preload — property classes, torque-to-tension, thread engagement, locking methods, and the failure modes that come from getting clamp force wrong.

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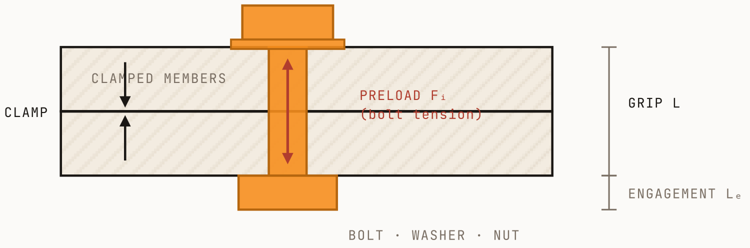
ABSTRACT

A bolted joint carries load through preload (clamp force), not by the bolt acting as a shear pin. You tighten the bolt to stretch it; the stored tension clamps the members. Because the clamped joint is far stiffer than the bolt, most of any external tensile load goes into relaxing the clamp rather than adding to bolt stress — which is why a properly preloaded joint barely feels fatigue and won't self-loosen.

Section 1 explains how the joint works. Section 2 covers property classes and materials. Section 3 is preload and tightening (torque-to-tension, the nut factor, method accuracy). Section 4 is thread engagement and stripping. Section 5 is joint design rules. Section 6 covers loosening and locking methods. Section 7 is failure modes and a tightening checklist.

BOLTED JOINT — PRELOAD & CLAMP FORCE



A BOLTED JOINT IS A STIFF SPRING IN TENSION CLAMPING MUCH STIFFER SPRINGS IN COMPRESSION. IT'S THE PRELOAD — NOT THE BOLT'S STATIC STRENGTH — THAT CARRIES CYCLIC LOAD AND STOPS THE JOINT SHAKING LOOSE.

CONTENTS

1. How a bolted joint works

Tightening a bolt stretches it like a spring; the stored tension is the **preload** (F_i), and the equal-and-opposite compression in the members is the **clamp force**. At rest they balance.

When an external tensile load F_e is applied, it is *shared* between the bolt and the joint in proportion to their stiffness. Because the clamped members are much stiffer than the slender bolt, the bolt picks up only a small fraction — the **load factor** $\Phi = k\_bolt / (k\_bolt + k\_members)$, typically 0.1–0.3. The rest of F_e simply relaxes the clamp. So a highly preloaded bolt sees only a small stress *swing* under cyclic load — the key to fatigue life — and the joint stays clamped as long as F_e never exceeds the preload.

1.1 Key terms

`Preload (Fᵢ)`	Bolt tension after tightening — the clamp force at zero external load
`Proof load`	The maximum tension a bolt takes with no permanent set (the design ceiling)
`Tensile stress area (Aₛ)`	Effective area of the threaded section used for stress (not the nominal Ø)
`Load factor (Φ)`	Fraction of external load that adds to bolt tension (k_bolt / (k_bolt + k_members))
`Grip length`	Clamped thickness from under the head to the nut bearing face
`Property class`	Strength grade marked on the head (e.g. 8.8, 10.9)

Design rule of thumb: **preload high (≈75% of proof), keep external load below preload, and give the bolt enough grip to stretch.** Those three decisions carry most joints.

2. Property classes and materials

Steel metric bolts are graded by **property class**, marked on the head. The first number ×100 ≈ tensile strength (MPa); the second ×10 ≈ yield as a % of tensile.

CLASS	PROOF S_p (MPA)	YIELD 0.2% (MPA)	TENSILE S_u (MPA)	NOTES
4.8	310	340	420	Low-carbon, general purpose
8.8	580 (≤M16) / 600	640	800	Med-carbon, quenched & tempered — the workhorse
10.9	830	940	1040	Alloy steel Q&T, compact high-load
12.9	970	1100	1220	Highest standard class; embrittlement-sensitive
A2-70 (304 SS)	—	450	700	Austenitic stainless, cold-worked
A4-80 (316 SS)	—	600	800	Marine / corrosion service

Use **8.8 by default**; step to 10.9/12.9 only when space forces a smaller, higher-strength bolt — and watch hydrogen embrittlement on plated high-strength parts. Stainless (A2/A4) trades strength for corrosion resistance and galls easily when run dry.

3. Preload and tightening

Target preload is normally **≈ 75% of proof load** for reusable joints: $F_i = 0.75 \cdot S_p \cdot A_s$. Permanent, yield-controlled joints go higher.

Torque is the usual but indirect way to reach that tension:

$T = K \cdot F_i \cdot d$ — where d is the nominal diameter and **K** is the nut factor (torque coefficient), which is dominated by friction under the head and in the threads.

THREAD / UNDERHEAD CONDITION	NUT FACTOR K
Clean & dry steel	0.20–0.30 (galls on stainless)
As-received, light oil	0.20 (default assumption)
Zinc plated	0.20–0.22
Black oxide	0.15
Oil / grease lubricated	0.12–0.15
MoS_2 / anti-seize / wax	0.10–0.12
PTFE coated	0.10–0.12

Because K varies so much, **torque is a scattered way to set preload** — the lubrication state matters as much as the wrench:

TIGHTENING METHOD	PRELOAD SCATTER
Torque by hand feel	±35%
Calibrated torque wrench	±25%
Torque + angle (turn-of-nut)	±15%
Torque-to-yield	±8%
Bolt stretch / ultrasonic / tensioner	±3–10%

Guideline torque, class 8.8, K = 0.20, ~75% proof (use the *Screw torque & preload* tool for the exact value with your K):

SIZE	TORQUE (N·M)	SIZE	TORQUE (N·M)
M3	1.3	M8	25
M4	3.0	M10	51
M5	6.0	M12	89
M6	10.5	M16	215

For class 10.9 multiply by ≈1.4; for 12.9 by ≈1.7. Always lubricate consistently or the same torque gives wildly different preload.

4. Thread engagement and stripping

Size the engagement so the **bolt breaks before the threads strip** — a bolt fracture is ductile and visible; a stripped thread fails silently. Minimum engagement length depends on the *nut/tapped material*, not the bolt:

NUT / TAPPED MATERIAL (STEEL BOLT)	MIN ENGAGEMENT L_e
Steel, ≥ bolt class	0.8–1.0 × d
Cast iron	~1.25 × d
Aluminium	1.5–2.0 × d
Magnesium / plastics	2.0–2.5 × d

Add 1–2 thread pitches in blind tapped holes for incomplete lead threads. The *Thread engagement* tool sizes L_e exactly for a given bolt class and parent material.

5. Joint design rules

- **Give the bolt grip. A long, slender bolt stores more stretch, so it holds preload through embedment and thermal cycling and sees a smaller fatigue swing. Short, stubby bolts lose preload from tiny settlements.**
- **Avoid soft joints in fatigue. Gaskets and stacked coatings creep and relax the clamp. Through-bolt to metal where possible, or specify a re-torque after seating.**
- **Washers spread the bearing load and protect the surface under the turned element**
  always use them on slotted holes, soft materials, and oversized clearance.
- **Spacing & edge distance: edge distance ≥ 1.5–2 × d, bolt spacing ≥ 2.5–3 × d.**
- **Shear joints: decide slip-critical (preload carries shear by friction) vs bearing (shank bears on the hole). Slip-critical needs full, verified preload.**
- **Don't over-clearance the hole**
  large clearance plus soft members invites slip and embedment.

6. Loosening and locking

Self-loosening is driven by **transverse (sideways) vibration** that momentarily overcomes thread friction and lets the nut back off (the Junker mechanism). The first defense is always **high, maintained preload with adequate grip** — most "loose bolts" are really under-preloaded bolts.

LOCKING METHOD	MECHANISM	VIBRATION RETENTION	REUSABLE
Correct preload + grip	clamp friction	high	yes
Nylon-insert nut (nyloc)	insert friction	medium	limited (≤ ~120 °C)
All-metal prevailing-torque nut	deformed thread	med–high	few reuses
Wedge-lock washer pair (e.g. Nord-Lock)	wedge cam under head	very high	yes
Threadlocker adhesive	cured resin fills threads	high (by grade)	single-use; degrease first
Split / spring lock washer	—	~none vs transverse vibration	—
Jam (double) nut	thread-tension reversal	med–high	yes
Castle nut + cotter / lockwire	positive form lock	very high	single-use pin

Note: the common split lock washer does **not** reliably prevent transverse self-loosening in modern testing — don't rely on it for vibration.

7. Failure modes and checklist

MODE	CAUSE	FIX
Fatigue fracture (head fillet / first thread)	low preload, short grip, stress raiser	preload ~75% proof, longer grip, rolled threads, head fillet
Thread stripping	too little engagement, soft nut, over-torque	increase L_e, harder nut/insert, control torque
Embedment / relaxation	rough or soft faces, coatings, gaskets settle	re-torque after seating, fewer interfaces, harder faces
Over-torque yield	wrong K, inconsistent lube	control method, use correct K
Hydrogen embrittlement	plated high-strength (≥10.9)	bake after plating, mechanical zinc, avoid in H_2 service
Galling (stainless)	dry threads seize on run-down	anti-seize, slower speed, dissimilar alloy pairing
Galvanic corrosion	dissimilar metals + electrolyte	matched/coated fasteners, isolation

7.1 Tightening checklist

- **Class**
  8.8 by default; 10.9/12.9 only when space forces a smaller bolt; A2/A4 for corrosion.
- **Size & preload**
  size by tensile stress area A_s; set target preload ≈ 75% proof.
- **Tightening spec**
  torque via $T = K \cdot F_i \cdot d$ with the actual K, or angle / yield / stretch for accuracy.
- **Engagement**
  verify L_e for the parent material (Section 4 / tool).
- **Grip & washers**
  adequate grip length; washers under the turned element; avoid soft/gasketed joints in fatigue.
- **Locking**
  match the method to vibration, temperature and reuse needs.
- **Specify on the drawing**
  class, finish/coating, torque (and method), locking feature, washer.