How a Bolted Joint Carries Load

A bolted joint can carry loads in tension (Fig. 13), in shear (Fig. 14) or by a combination of these.

The static load capacity of the joint will be determined largely by the size, strength grade and number of bolts installed. The capacity of a bolted joint to maintain integrity indefinitely under dynamic loading is dependent on installing the bolts with sufficient tension to prevent relative movement of the joined members.

Tension

The external load is resisted directly by bolt tension. If the joined members are rigid and the bolts are pretensioned, the mating faces will not separate until the externally applied load exceeds the total preload. This is because stress and strain are fundamentally related (the relationship constant is called Young's modulus in the range of elastic behaviour), so that the joint can't separate until the bolt length increases and the bolt length can't increase until the tension in it exceeds the preload (assuming service temperature below the creep range). This concept is valid when the joint members are stiffer (suffer less strain under a given force) than the bolt shank. It is true enough to be important even when the joint members and bolt are of the same material (e.g. steel), i.e., have the same modulus, because the area in compression between the bolt head and nut is much greater than

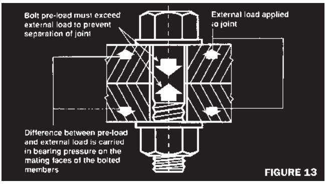


FIGURE 13

the area of the bolt shank in tension and so compresses much less than the bolt extends at any given bolt tension. Thus cyclic external load is experienced more as a change in pressure at the joint face than a change of tension in the bolt and in a well designed joint, the stress range in the bolts will be below their fatigue endurance limit.

Shear

The pre-load in the bolt(s) clamping the members together produces friction between them which resists the external load. The external force which this friction is capable of resisting without movement is proportional to the preload in the bolts and the coefficient of friction on the mating surfaces. When the frictional load transfer capacity is exceeded the ultimate capacity of the joint will be determined by shear on the fasteners and bearing on the joined members.

Methods of Control of Bolt Tightening

Several methods are available for controlling the establishment of a desired level of preload in bolts with the cost rising with increasing accuracy more or less as indicated

Table 16

Preload Measuring Method	% Accuracy	Relative Cost
Feel (Operators Judgement)	± 35	1
Torque Wrench	± 25	1 1/2
Turn-Of-The-Nut	± 15	3
Load Indicating Washers	± 10	3 1/2
Fastener Elongation	± 3 – 5	15
Strain Gauges	± 1	20

in Table 16. Each method has its applications and the choice should be made after an assessment of the particular requirements.

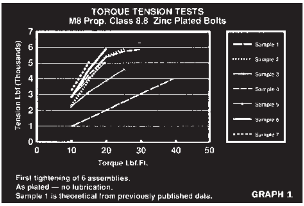
(1) Torque

Although torque bears no fixed relationship to fastener tension, the use of torque wrenches is the most common method of pre-load control because of simplicity and relative economy. Many factors, including surface texture (cut or rolled threads), surface coatings-lubrications, thread interference, speed of tightening, etc., affect the torque-tension relationship and up to ±25% variation in pre-load, has been measured on similar fasteners receiving identical torque. Closer control of torque/tension calibration for a particular lot can reduce variation to ±15%. With manual torque wrenches, the torque may be reset from or read off a built-in scale. Power tools are more productive when large numbers of bolts are to be tightened and may be pneumatic, electric or hydraulic, but generally require tightening of sample bolts in a bolt load measuring device to set a pressure regulator or stall-torque for the desired bolt tension rather than measuring torque directly. This requirement will give more accurate control of tension if setting is performed under job conditions with the bolts to be tightened.

Torquing of Bolts and Nuts

The purpose of controlling the torque applied to a fastener assembly is to induce a desired level of tensile force in the bolt (equals clamping force on the joint). Unless limited by some characteristic of the joint (e.g., a soft gasket), the amount of tension aimed for in general engineering practice is 65-75% of the minimum elastic capacity (proof load) of the bolt. By selecting bolts such that this level of tension is not exceeded by service load on the joint, loosening of the nut should not be a problem in most applications. Nyloc or Conelock nuts are recommended for joints where such pre-tensioning is not applicable and as an added insurance against loss of the nut, should the initial pre-tension be lost. The 65-75% of Proof Load level of pre-tension is sufficiently conservative to give reasonably reliable torque controlled tightening with indefinite reuseability of the assembly. For critical applications closer control or calibration checking is recommended. Because friction is the major unknown variable affecting the relationship between torque applied and tension induced, the presence of light oil lubrication is the minimum standard recommended for consistency in controlled tightening of fasteners. Most plain finish fasteners are supplied with a sufficient oil residue from their processing but plated finishes will generally require oiling or adjustment to the torque recommended in Blacks Fasteners Ltd Technical Data. For bolts with special surface finishes or assembled with anti-seize compounds or heavily greased, the torque-induced preload relationship is likely to be altered and the recommendations to require modification.

Table 17 lists factors based on averages for the torque-induced preload relationship by which the tabulated figures should be multiplied to correct for the most common surface condition variations. For other surface treatments or for specialised bolt assemblies involving higher preload requirement or special lock nut, etc., it may be desirable to experimentally determine the torque-induced preload relationship. Attention is drawn to the fact that because static friction is greater than dynamic friction, the best accuracy and consistency of torque control tightening is obtained when rotation of the fastener is steadily maintained until the torque increases to the set level.



First tightening of 6 assemblies.
As plated — no lubrication.
Sample 1 is theoretical from previously published data.
GRAPH 1

Allowing for this effect becomes more important as the set torque is approached; another purchase should be taken early enough to avoid stall before rotation continues. Difficulty maintaining steady movement up to the set torque is a drawback of some hydraulic tools used for large diameter fasteners. The steady impacting of pneumatic tools gives better results.

(2) Strain Control

a) Part Turn Tightening: This method involves imparting a controlled strain or extension to the bolt by measuring relative rotation from the point where the joint members are solidly compacted. It is most widely used in tensioning bolts in structural steel work.

b) Direct Tension Indicators: These proprietary devices are also based on controlled strain, but make use of design features in a bolt head, nut or washer to make the strain visible and measurable as a permanent witness of proper bolt tensioning.

c) Measurement of Bolt Extension: This is a time consuming but very accurate method. Bolt Length may be measured before and after tightening, with a micrometer

Table 17

Surface Condition		Factor
Galvanised	– Degreased	2.1
	– Lightly oiled	1.1
Zinc Plated	– Degreased	0.7*
	– Lightly oiled	0.9
Cadmium Plated	– Degreased	1.0
	– Lightly oiled	0.7
Phosphated and oiled		0.7
Standard finish plus heavy grease		0.7

** In previously published guidance for tightening by control of applied torque this factor shown as 1.9.*

Investigation of a 1991 complaint that assemblies torqued at this level were stripping found that the factor 0.7 is now appropriate. The writer conjectures that this variation is attributable to the change in plating practice from alkali-cyanide to acid chloride zinc plating electrolyte since this data was generated and perhaps more specifically to different lubricity of the brighteners used in these proprietary solutions.

The change emphasises that such published general information can only ever be regarded as a guide and verification of applicability for a specific application is advisable both initially and over time, particularly if any parameters are known to have changed.

It should be remembered also that such guidance is based on first tightening of single assemblies in isolation and that interactions in multifastener joints may result in changes to initial tension such that a detailed tightening sequence may need to be developed and followed for satisfactory service of the joint.

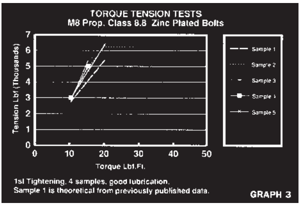
As well as scatter in the torque-tension relationship for different assemblies from the same lot, retightening of the same bolt may give a different torque tension relationship. Both the scatter and shift on retightening are minimised by good lubrication of threads and bearing face.

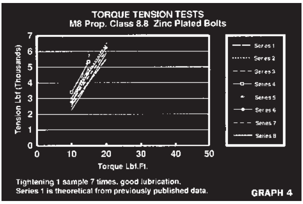
In recent tests of bright zinc plated parts the tension at a given torque was found to progressively reduce by 50% over five tightenings of an unlubricated assembly while a well lubricated assembly showed no reduction over five retightenings and only a 9% over twelve retightenings. The results of these tests are shown in Graphs 1-4.

in some joint configurations or by an electronic "sonar" type device from one end. Greatest accuracy is achieved when the strain value is obtained from the load extension curve of the fastener being used, but calculation based on Hooke's Law gives good correlation when allowance is made for the respective lengths and cross-sectional areas of the plain and threaded portions of the bolt shank effectively in the grip.

d) Pre-assembly Straining: The most common development of this method is the snug tightening of a normal nut on a bolt which has been heated to produce a calculated degree of thermal expansion. A hollow bolt with a hydraulically actuated internal loading ram is available which makes removal as easy as installation.

e) Strain Gauges: These are usually applied to the bolt





shank and calibrated in a load measuring machine.

(3) Combination Methods

Electronic sensors and microprocessors have been developed which simultaneously measure torque and/or angular rotation and/or instantaneous rate of change in these characteristics. Hand-held models are available with capacity for he size range common in automotive application but the methods are essentially confined to high volume application such as the simultaneous tightening of automotive engine head "bolts" (really cap screws). Their accuracy allows designs for bolts tensioned to their actual yield point and the implementation of this method has resulted in re-design with higher strength of standard metric nuts so that they are unlikely to strip on bolts so tightened.

(4) Direct Tensioning

In the most economic development of this method, tension applied by a calibrated hydraulic jack attached to an extension of the bolt or stud thread is transferred to a normal nut after it is snugged up to the joint. The relaxation of tension due to bedding in and deflection of the mating threads is consistent for given assembly types and can be allowed for to maintain accuracy of the desired residual tension. This may be the most practicable method for bolts over M36/1$^1/_2$" diameter and is particularly suitable for sealing of high pressure gasketed joints because manifolding of jacks enables simultaneous, uniform tensioning of many bolts.

Table 18 Recommended Assembly Torques

Bolt Type	Diameter mm	Bolt Tension Corresponding to 65% of Proof of Load kN	lbf	Recommended Assembly Torque Nm	ft.lbs
AS 1111	5	2.08	468	2.1	1.5
Blacks Property	6	2.94	661	3.5	2.5
Class 4.6	8	5.34	1200	8.5	6.3
Commercial Low	10	8.45	1900	17	12
Tensile Bolts	12	12.4	2788	30	22
	16	22.9	5148	7.3	54
	20	35.8	8048	14.3	106
	24	51.6	11600	248	183
	30	81.9	18412	491	362
	36	120	26977	864	637
	42	164	36869	1378	1016
	48	215	48334	2064	1522
	56	298	66993	3338	2462
	64	393	88350	5030	3710

The torques listed are for plain finish (uncoated) fasteners as supplied. Refer to page 24 and table 17 for effects of various finishes.

Table 19 Recommended Assembly Torques

Bolt Type	Diameter and Thread	Induced Bolt Preload or Tension Corresponding to 65% of Yield Load lbf	Recommended Assembly Torque to Give Induced Preload Equal to 65% of Yield Load lbf
AS 2451	1/4 BSW	750	3
Blacks BSW Low	5/16 BSW	1230	6
Tensile Bolts	3/8 BSW	1820	12
(Formerly AS B100)	7/16 BSW	2480	19
	1/2 BSW	3250	28
	5/8 BSW	5300	55
	3/4 BSW	7830	98
	7/8 BSW	10200	150
	1 BSW	13300	230
	1 1/8 BSW	16700	320
	1 1/4 BSW	21500	450
	1 1/2 BSW	30800	780

The torques listed are for plain finish (uncoated) fasteners as supplied. Refer to page 24 and Table 17 for effects of various finishes.

Table 20 Recommended Assembly Torques

Bolt Type	Diameter and Thread	Induced Bolt Preload or Tension Corresponding to 65% of Yield Load lbf	Recommended Assembly Torque to Give Induced Preload Equal to 65% of Yield Load lbf
AS 2465	1/4 UNF	2020	8
Blacks Grade 5	5/16 UNF	3190	17
Unified High	3/8 UNF	4840	30
Tensile Bolts	7/16 UNF	6570	48
(Same as SAE	1/2 UNF	8840	74
J429 Grade 5)	5/8 UNF	14170	150
	3/4 UNF	20610	260
	7/8 UNF	28150	410
	1 UNF	36660	610
	1/4 UNC	1760	7
	5/16 UNC	2890	15
	3/8 UNC	4290	27
	7/16 UNC	5880	43
	1/2 UNC	7870	66
	5/8 UNC	12480	130
	3/4 UNC	18400	230
	7/8 UNC	25550	370
	1 UNC	33480	560

Table 21 Recommended Assembly Torques

Bolt Type	**Diameter and Thread**	**Induced Bolt Preload or Tension Corresponding to 65% of Yield Load lbf**	**Recommended Assembly Torque to Give Induced Preload Equal to 65% of Yield Load lbf**
AS 2465	1/4 UNF	2830	12
Blacks Grade 8	5/16 UNF	4520	23
Unified High	3/8 UNF	6830	43
Tensile Bolts	7/16 UNF	9230	67
(Same as SAE	1/2 UNF	12500	104
J429 Grade 8)	5/8 UNF	19960	207
	3/4 UNF	29120	363
	7/8 UNF	39720	577
	1 UNF	51740	859
	1/4 UNC	2470	10
	5/16 UNC	4100	21
	3/8 UNC	6050	38
	7/16 UNC	8320	60
	1/2 UNC	11050	92
	5/8 UNC	17620	183
	3/4 UNC	26070	325
	7/8 UNC	36010	523
	1 UNC	47200	785

Table 22 Recommended Assembly Torques

Bolt Type	Diameter mm	Bolt Tension Corresponding to 65% of Proof Load kN	lbf	Recommended Assembly Torque Nm	ft.lbs
AS 1110	5	5.4	1214	5	4
Blacks Property	6	7.6	1709	9	7
Class 8.8	8	13.8	3102	22	16
Precision High	10	21.9	4923	44	32
Tensile Bolts	12	31.8	7149	77	57
	16	59.2	13309	190	140
	20	95.6	21492	372	274
	24	138	31024	640	472
	30	219	49233	1314	969
	36	319	71714	2297	1694
	(42)	437	98242	3671	2707
	(48)	573	128816	5500	4057
	(56)	792	178049	8870	6542
	(64)	1045	234925	13376	9866

AS 1110 covers sizes to M36 only. Data for sizes above this is given for information only. The Blacks Fasteners stocked range extends to M24 but sizes 30, 36 Property Class 8.8 Bolts and Nuts are available from structural stocks.

The torques listed are for plain finish (uncoated) fasteners as supplied. Refer to page 24 and Table 17 for effects of various finishes.

Table 23 Recommended Assembly Torques

Bolt Type	Diameter mm	Bolt Tension Corresponding to 65% of Proof Load kN	lbf	Recommended Assembly Torque Nm	ft.lbs
AS 1110	5	7.67	1724	8	6
Blacks Property	6	10.86	2441	13	10
Class 10.9	8	19.76	4442	32	23
Precision High	10	31.27	7030	63	46
Tensile Bolts	12	45.50	10229	109	81
	16	84.50	18996	270	200
	20	131.95	29664	528	390
	24	190.45	42815	914	675
	30	302.90	68095	1817	1341
	36	440.70	99073	3173	2342

The torques listed are for plain finish (uncoated) fasteners as supplied. Refer to page 24 and Table 17 for effects of various finishes.