6. Bolting

6.1 Introduction

The selection of a bolt for use in a structural steelwork connection will need to have regard to a variety of factors including:

- Load capacity of available bolt types.
- Cost of the installed fastener.
- Amount of joint slippage.
- Nature of the forces to be resisted.
- Degree of flexibility/rigidity desired in the joint.

in order to obtain, at least cost, a safe bolted connection.

Design Guide I: Bolting in Structural Steel Connections (Ref. 6.1) contains a detailed discussion of all of the above factors and provides a state-of-the-art summary of matters related to the use of bolts in steel structures.

This section concentrates on aspects which affect the economic use of bolts. Ref. 6.1 should be consulted for more details of all aspects of the use of bolts in steel structures.

The cost of a bolted connection includes:

- Cost of obtaining, cutting and holing components.
- Cost of the bolts.
- Cost of installing the bolts.
- Cost of inspection.

Every bolt specified should be a bolt that is needed – bolt numbers should be kept to the minimum needed from strength considerations.

The cost of installing bolts can vary considerably, depending on the bolting category.

6.2 Bolt Types

The two basic metric bolt types in use in structural engineering in Australia are:

- The commercial (Property Class 4.6) bolt.
- The high-strength structural (Property Class 8.8) bolt.

The identification of high-strength structural bolt and nut assemblies can be readily made from the bolt head and nut markings (see Ref. 6.1). In addition, a distinguishing feature is the larger bolt head and nut of the high-strength structural bolt compared to the commercial bolt.

Only a limited range of sizes of these bolts is of interest to structural engineers.

6.2.1 COMMERCIAL BOLTS

The commercial bolt is commonly used in the following diameters (the prefix M is used to designate ISO metric bolts):

M12 – purlin and girt applications.

M16 – cleats, brackets (relatively lightly loaded).

M20, M24 – general structural connections, holding down bolts.

M30, M36 – holding down bolts.

6.2.2 HIGH-STRENGTH STRUCTURAL BOLTS

The high-strength structural bolt is most commonly used in diameters:

M16 – designed connections in small members.

M20, M24, M30, M36

– flexible connections, rigid connections. Larger sizes (M30, M36) of the high-strength structural bolt should be avoided when full tensioning is required, since onsite tensioning can be difficult and requires special equipment to achieve the minimum bolt tensions.

6.3 Bolting Categories

In Australia, a standard bolting category system has been adopted for use by designers and detailers. This system is summarised in Table 6.1.

Category 4.6/S refers to commercial bolts of Property Class 4.6 conforming to AS 1111.1 tightened using a standard wrench to a 'snug-tight' condition.

Category 8.8/S refers to any bolt of Property Class 8.8, tightened using a standard wrench to a 'snug-tight' condition in the same way as for category 4.6/S. Essentially, these bolts are used as higher grade commercial bolts in order to increase the capacity of certain connection types. In practice they will normally be high-strength structural bolts of Property Class 8.8 to AS/NZS 1252, but any other bolt of Property Class 8.8 would be satisfactory.

Category 8.8/TF and 8.8/TB (or 8.8/T when referring generally to both types) refer specifically to high-strength structural bolts of Property Class 8.8 conforming to AS/NZS 1252, fully tensioned in a controlled manner to the requirements of AS 4100.

The system of category designation identifies the bolt being used by using its property class designation (4.6 or 8.8) and identifies the installation procedure by a supplementary letter (S – snug; T – full tensioning).

For 8.8/T categories, the type of joint is identified by an additional letter (F – friction-type joint; B – bearing-type joint).

As a consequence, the high-strength structural bolt may be specified in three ways:

- Snug-tightened- category 8.8/S
- Fully tensioned, friction-type – category 8.8/TF
- Fully tensioned, bearing-type – category 8.8/TB;

the level of tensioning being, of course, the same for both 8.8/TF and 8.8/TB categories.

6. Bolting

TABLE 6.1: Bolt types and bolting categories

Bolting Category	Method of Tightening	Nominal Bolt Tensile Strength (MPa)	Nominal Bolt Yield Strength (MPa)	Bolt Name	Standard Specification
4.6/S	Snug	400	240	Commercial	AS1111.1
8.8/S	Snug	830	660	High strength structural	AS/NZS 1252
8.8/TF (Friction type joint)	Full tensioning	830	660	High strength structural	AS/NZS 1252
8.8/TB (Bearing type joint)	Full tensioning	830	660	High strength structural	AS/NZS 1252

Two symbols have been added to the bolting category designations 4.6/S, 8.8/S, 8.8/TB.

N: bolt in shear with threads included in the shear plane (e.g. 8.8 N/S).

X: bolt in shear with threads excluded from the shear plane (e.g. 8.8 X/S).

In practice 8.8/S category would mainly be used in flexible joints where the extra capacity of the stronger bolt (compared to 4.6/S category) makes it economical. It is recommended that 8.8/TF category be used only in rigid joints where a no-slip joint is essential. Note also that 8.8/TF is the only category requiring attention to the contact surfaces.

A summary of the usage of Property Class 4.6 and Property Class 8.8 bolts is contained in Figures 6.1 and 6.2.

6.4 Factors Affecting Bolting Economy

6.4.1 BOLT GRADE

For a given diameter and assuming snug-tight category, Property Class 8.8 bolts offer far better structural economy than Property Class 4.6. This is because a Property Class 8.8 bolt costs only around 30% more than Property Class 4.6, but has over twice the shear capacity; moreover the installation labour cost is the same for both.

TABLE 6.2: Indicative Cost Ratios of Different Bolt Diameters

Bolt Diameter	High-strength structural bolt (Property Class 8.8) × 100 mm long, with nut & hardened washer. Threads included in shear plane.	
	Cost Index (supply only)	Cost Index per kN of shear capacity
M16	90	1.4
M20	100	1.0
M24	180	1.2
M30	400	1.7
M36	700	2.1

Notes:

1. The indicative cost ratios quoted are valid only within this table.
2. Shear capacity calculations are based on strength limit state design.

6.4.2 BOLT DIAMETER

Bolts of M20 and M24 diameter represent an optimum in many respects such as: purchase price (see Table 6.2), hole drilling and site installation. They should be preferred in all applications wherever possible.

Where special circumstances demand the choice of larger diameters (M30 or M36) they should be specified with the knowledge that a cost premium will be involved.

M30 and M36 bolts are not recommended for applications requiring full tensioning (8.8/TF or 8.8/TB) because it is difficult to obtain suitable portable equipment capable of inducing the high shank tensions required by AS 4100.

For this reason Property Class 8.8 bolts are rapidly taking over as the standard grade for structural engineering. Of course where fully tensioned categories are used, Property Class 8.8 bolts to AS 1252 are mandatory – see Clause 6.4.3. One application for Property Class 4.6 is in foundation bolts, especially where welded cages are used.

Guidance on the certification of bolts is given in Ref. 6.3 and 6.4.

6.4.3 BOLTING CATEGORY

Table 6.3 shows that snug-tightened bolts of Property Class 8.8 (i.e. 8.8/S category) offer the best value in terms of cost per kN of shear capacity. This is therefore the preferred bolting method.

Category 8.8/TB provides no greater structural capacity and would therefore be used only where some other consideration warrants it. An instance is where connection behaviour depends on the rigidity afforded by tensioned bolts as in rigid portal frame construction. 8.8/TB category has also been used on bolted bridges where the tensioning is merely a safeguard against nuts working loose in service.

Category 8.8/TF (friction-type joint) offers the poorest economy of all the options on a cost per kilonewton basis (see Table 6.3). It should be used only in applications where joint slippage cannot be tolerated. An example is a structure supporting vibrating machinery such as a coal washery.

6.4.4 THREADS IN OR OUT OF SHEAR PLANE

As the plain shank area of a bolt is greater than the core area at the threads. Thus an apparent gain of 35 to 40% in shear capacity is available if the threaded part of the bolt can be kept out of the joint shear plane.

However this benefit can often be illusory, especially on average connections with up to only 10 or so bolts. Any savings in bolts must be measured against the cost of longer bolts required, possible installation problems and the higher cost of supervision needed to ensure 'threads out'.

On the other hand on major structures with joints of around 50 bolts or more, a good case can be made for basing the design on threads excluded. Savings accrue from fewer bolts, smaller gusset plates and reduced installation time, while there is usually already a high level of supervision on these large projects to ensure correct installation.

One final point to be borne in mind is that there is never a case for considering 4.6/S category with threads excluded. It will always be more economic to use Category 8.8/S with threads included.

The topic of threads in versus threads out is discussed in more detail in Ref. 6.1.

6.4.5 BOLT FINISH

It is usual to only use either black uncoated bolts or galvanised bolts in structural steel connections. Galvanised bolts do not cost very much more than plain bolts and are now supplied as standard finish for Property Class 8.8 bolts.

In general the bolt finish should be matched to that of the structure itself. Uncoated bolts are satisfactory in low corrosion environments; galvanised bolts are needed where corrosion may be a consideration. They perform better and are much less costly than site-painted bolts.

Care is needed when galvanised bolts are to be fully tensioned, although proper procedures and good housekeeping on site will obviate problems – see Ref. 6.1.

TABLE 6.3: Indicative cost ratios of different bolting categories

Bolting Category	(One M20 galvanised bolt installed in a group, "threads included")		
	Shear Capacity (kN)	Cost Index (installed)	Cost Index per kN of Shear Capacity
4.6/S	44.6	80	1.66
8.8/S	92.6	100	1.00
8.8/TB	92.6	240	2.40

Notes:

1. The indicative cost ratios quoted are valid only within this table.
2. The above comparison is based on strength limit state. Since serviceability generally governs for 8.8/TF bolts, they have been excluded from this table.

6.4.6 INSPECTION

Part of the cost of bolt installation is the necessary inspection. With 4.6/S and 8.8/S categories such inspection is minimal and requires only a visual check that the correct type and number of bolts have been installed. Since the level of tightening is only 'snug', and this is achieved in the normal course of erection, no further checking is required.

In contrast, fully tensioned bolts (8.8/TF and 8.8/TB categories) require detailed inspection in accordance with AS 4100 to confirm that the tensioning procedure has been carried out. The inspection cost is a big component of the total in-place cost of a bolt. Inspection procedures are outlined in AS 4100 and are discussed in Ref. 6.1.

6.5 Summary for Economic Bolting

6.5.1 CHECKLIST

The essential points to be considered in the economical design of bolted connections are:

(a) Standardise as much as possible for a project.

(b) Adopt simple detailing.

(c) Only one bolt diameter and one bolting category should be used in smaller structures, more variety may be justified on a larger structure, but different diameters or categories should be used in accordance with a predetermined philosophy.

(d) Only one nominal size of bolt should be used in any single connection to facilitate the operation of punching or drilling holes, regardless of the size of the structure.

(e) Arrange for a minimum number of field connections by making large sub-assemblies in the shop.

(f) Bolts in double shear are markedly more efficient and thought should always be given to arranging the connection details accordingly if practicable. In some instances (e.g. flange splices) such an arrangement can be negated by increased erection difficulty.

(g) If possible, avoid bolted connections with more than five bolts in line parallel to the force, otherwise reduction in bolt efficiency will result (see Ref. 6.1).

(h) Try not to mix 8.8/S and 8.8/T bolting categories on the one job.

(i) For economy, it may appear desirable to exclude threads from the shear plane. However, practical reasons dictate that usually threads are considered included in the shear plane, unless detailing of the bolts indicates exclusion is possible (see Ref. 6.1).

(j) Corrosion protection of the bolts should be matched to the end use of the structure.

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