

PART II. CONSTITUENTS OF CONCRETE

**REINFORCING &
PRESTRESSING
STEEL PROPERTIES**



**CEMENT CONCRETE
& AGGREGATES AUSTRALIA**

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1 OUTLINE

Reinforced concrete and prestressed concrete are composite materials made up of concrete and some form of reinforcement – most commonly steel rods, bars, mesh, wire or strand.

The reinforcement in reinforced concrete is usually provided by steel bars that may also be in the form of a welded mesh. Bars are normally associated with beams and columns and mesh with floors and walls. However, mesh may also be used in beams and columns with bars often used in floors.

In prestressed concrete the prestressing may be in addition to standard reinforcement. The prestress forces are provided by wire, strand or hot rolled bars.

This section provides basic information on the identification of and key specified properties of reinforcing and prestressing wires, strand, bars and mesh for use in concrete. It also provides

information on the types of reinforcement and prestressing wires, strand and bars used in Australia.

2 REINFORCEMENT TYPES

2.1 GENERAL

Steel reinforcement is defined in AS 3600 as '*steel bar, wire or mesh but not tendons*'. This definition precludes the use of non-tensioned prestressing materials (strand, bars and wires) as reinforcement if the structure is to comply with the Standard. It also requires that reinforcement be deformed bars or mesh except that plain bars may be used for fitments.

The Concrete Structures Standard (AS 3600) refers to AS/NZS 4671 for reinforcement types and quality.

2.2 STANDARD BARS

In Australia, reinforcing bars are manufactured to comply with the requirements of AS/NZS 4671. There are a number of processes by which they can be manufactured and these, along with the chemical composition of the steel, can significantly affect the properties of the bar.

'Microalloy' reinforcement is produced by adding small amounts of an alloy, e.g. niobium and/or vanadium to the steel during its manufacture. During the hot-rolling process, these precipitate as very fine nitrides or carbides which help increase the minimum yield strength. Microalloy bars are produced in sizes up to 20 mm in Australia and also larger than 36 mm with limited quantities.

'Quenched and self-tempered' (QST) reinforcement is produced by the controlled water quenching of the outer layers of hot-rolled bar, thereby hardening it and increasing the minimum yield strength. At the same time, the process preserves the excellent durability and weldability of the parent material.

Both processes can achieve satisfactory bendability, re-bendability and weldability in high-strength bar. Nevertheless, all reinforcing

bars do not behave in the same manner in respect of these properties. Care should therefore always be taken to ensure that reinforcing bars comply with the requirements of AS/NZS 4671.

The Australasian Certification Authority for Reinforcing and Structural Steels (ACRS) is an independent body formed in 2000 to undertake third-party product certification on steel reinforcing bar, wire and prestressing tendons. Modelled on CARES in the UK, ACRS certification ensures end-user confidence that supplied reinforcement materials meet the relevant Australian Standards. More information on ACRS is available on their website 'steelcertification.com'.

Classification and Designation of Reinforcement

In accordance with AS/NZS 4671 requirements, reinforcing steel is classified by: profile; strength grade; relative ductility and size.

Profile

Reinforcing bars can be either plain, deformed ribbed or deformed indented. The profiles are designated by the letters R (Round), D (Deformed ribbed) and I (deformed Indented) respectively. Generally, only D (Deformed ribbed) bars will meet the intention of the requirement in the concrete design Standards that reinforcement be deformed. However, Section 7.4 of AS/NZS 4671 contains a test method to measure the bond performance of indented bars or ribbed bars with ribs not meeting the specification set out in AS/NZS 4671.

Strength Grade

The tensile strength of reinforcement measures how strong it is when it is pulled or stretched. When steel is stretched and then released, it will return to its original length provided it is not overloaded (i.e. it will behave elastically). As the tensile load increases, a point will be reached where it will not recover (the steel is permanently stretched or has yielded). The steel is then classified as having a certain yield strength – the stress at which it first began to yield. The unit used for 'yield stress' is MPa.

Strength grade is designated by the numerical value of the lower characteristic yield stress – typically 250, 500, 600 and 750 MPa.

Reinforcing steel with a strength grade above 250 MPa is also required to comply with the specification of an upper characteristic yield stress. The upper characteristic yield stress will not exceed the lower yield stress by more than the values given in AS/NZS 4671.

There are also limits on the minimum strain in the steel at yield stress for all reinforcement types according to the Ductility Classes of steel.

All steel has limits on carbon, sulfur and phosphorous content.

Ductility Class

The relative ductility of steel reinforcement is identified by a Ductility Class of 'L', 'N' or 'E' representing, in order, Low Ductility, Normal Ductility or Earthquake (high) Ductility. Each is specified by a minimum ductility ratio (steel tensile failure stress at maximum force divided by the yield stress).

Identification of Standard Grades of Reinforcement

The standard grades of reinforcing steels can be identified by either an alphanumeric marking system on the surface of the bar or by a series of surface features on the product at intervals of not more than 1.5 m (see **Figure 6.1**). In addition, deformed reinforcement has to carry marks enabling the steel producer to be identified.

Further, AS/NZS 4671 sets out requirements for the labelling of each bundle of reinforcing steel or mesh (see Clause 10.3).

Table 6.1 provides design data related to common reinforcing bar sizes used in Australia.

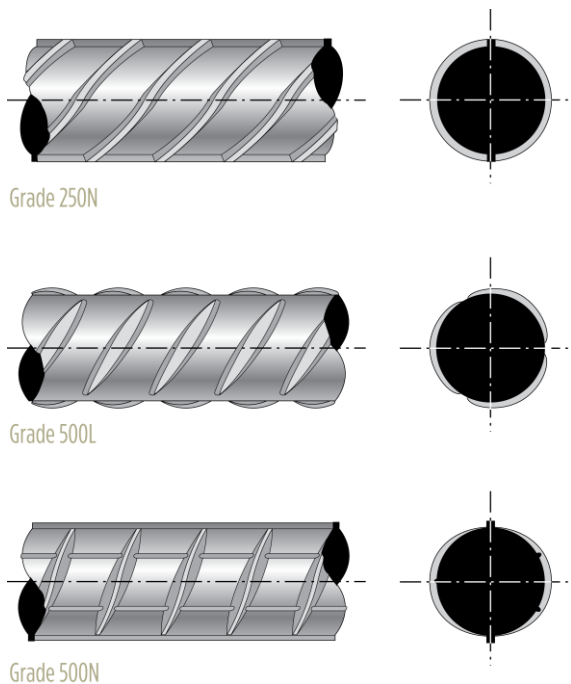


Figure 6.1 – Examples of Grade Identifiers (Refer to AS/NZS 4671 for Other Grade Examples)

Table 6.1 – Design Data for Reinforcing Bars in Australia (from Table 7.5(A) of AS/NZS 4671)

Nominal diameter (mm)	Cross-sectional area (mm ²)	Mass per metre length (kg/m)	Strength and ductility class
10.0	78.5	0.617	500N
12.0	113	0.888	500N
16.0	201	1.58	500N
20.0	314	2.47	500N
24.0	452	3.55	500N
28.0	616	4.83	500N
32.0	804	6.31	500N
36.0	1,020	7.99	500N
40.0	1,260	9.86	500N
50.0	1,960	15.4	500N

Weldability

Reinforcement conforming to AS/NZS 4671 is weldable. Depending on the manufacturing process used and the chemical composition of the steel, requirements for welding may vary.

Designers should consult the manufacturer's literature for specific advice. Welding should be carried out in accordance with AS 1554.3. More detailed information and guidance can be gained from Weld Australia technical notes. Note that 500 MPa reinforcement manufactured overseas may not conform to AS/NZS 4671. It may have a higher carbon equivalent content, making the requirements for welding more stringent.

Generally, welding reinforcement complying with AS/NZS 4671 will require:

- The use of hydrogen-controlled electrodes;
- The use of special precautions in adverse conditions, e.g. wet weather, temperatures $\leq 0^{\circ}\text{C}$;
- The use of preheating when bars over 25 mm diameter are being welded.

Note the limitation on the location of welds in a bar that has been bent and re-straightened (Clause 13.2.1(f) of AS 3600), i.e. it shall not be welded closer than $3d_b$ to the area that has been bent and re-straightened.

Bending and Rebending Reinforcement

AS/NZS 4671 specifies for bars of diameter ≤ 16 mm a 90° bend and rebend test and for bars > 16 mm a 180° bend test. These requirements will ensure that bars likely to be re-straightened in the field, i.e. with $d \leq 16$ mm, will still satisfy the required ductility.

2.3 MESH REINFORCEMENT

Manufacturing Process

Mesh reinforcement consists of a grid of cold-rolled steel bars welded together in a regular pattern (either square or rectangular). The bars used in the manufacture of mesh may be plain, deformed or indented, and are required to comply with the requirements of AS/NZS 4671. Deformed bar is the more widely used, but wire or indented bars may be appropriate for certain applications.

Mesh is manufactured on automatic machines that weld 'transverse' bars to the 'longitudinal' bars to produce a mesh that is then cut to

standard lengths. The longitudinal bars may vary in diameter between 4 and 11.9 mm. When the mesh pattern is square, the transverse wires are the same diameter as the longitudinal wires. Rectangular mesh has transverse bars from 7.6 mm to 11.9 mm diameter at a pitch of 100 mm or 200 mm regardless of the diameter of the longitudinal bars.

Designation of Welded Mesh

Welded mesh is designated in a similar fashion to reinforcing steel. The designation reflects:

- *Profile* – the shape of the bars by the letters; R (Round), D (Deformed) or I (Indented);
- *Strength grade* – by the numerical value of the lower characteristic yield stress;
- *Configuration of orthogonal bars* – by the letters S (Square) or R (Rectangular) configuration;
- *Ductility Class* – by the letters L (Low), N (Normal) or E (Earthquake);
- *Size* – by the numerical value of the nominal diameter of the longitudinal bar expressed in millimetres;
- *Transverse spacing of the longitudinal steel* – by the numerical value of the transverse spacing expressed in millimetres divided by 100; and
- *Transverse reinforcement in rectangular meshes* – by the numerical value of the nominal diameter expressed in millimetres.

Mesh is designated by listing the above designators in the order of profile, strength, configuration, ductility, size and spacing. For example, a square mesh consisting of nominal 9 mm diameter deformed ribbed bars at 200 mm centres, of Grade 500 low ductility steel is designated 'D500SL92'. If all the welded mesh ordered or required for the project was to be deformed ribbed bars, of the same strength, then the designation for that project could be abbreviated to 'SL92'.

Table 6.3 sets out meshes commonly available in Australia.

Mesh is most commonly used in slabs and walls. Rectangular mesh is used in road

pavements and slabs that span one way or are rectangular, whereas in slab-on-ground construction square mesh is most popular.

Special meshes include: 'girder wrap' for use in fire protection work; 'trench mesh' for use in footings in domestic and other low-rise structures; and mesh made with Ductility Class N bar. Mesh can also be bent to form reinforcing cages or fitments for beams and columns.

2.4 STAINLESS STEEL BARS

Stainless steel reinforcement is becoming more readily available and is sometimes used in extremely aggressive situations where its higher cost can usually be justified. It is not required to be isolated from normal reinforcement and can be used in locations which are subjected to aggressive exposure while normal reinforcement is used in more protected locations. Stainless steel can be welded using appropriate electrodes and techniques. Care is required when fabricating and bending it to prevent contamination from normal reinforcement.

Stainless steel reinforcement properties are required to be in accordance with AS 3600 which refers to British Standard BS 6744. It is estimated that the stainless-steel reinforcement complying with BS 6744 has a ductility class equivalent to AS/NZS 4671 Class N. Two characteristic yield strengths are used in Australia – 200 MPa and 500 MPa (see **Table 6.2**).

There can also be a significant loss of bond with plain stainless-steel bars but, for deformed bars, the bond strength is similar to that for normal reinforcement.

Table 6.2 – Yield Strength and Ductility Class of Reinforcement (from Table 3.2.1 of AS 3600)

Reinforcement		Characteristic yield strength (MPa)	Characteristic uniform Strain at maximum stress (strain)	Ductility Class
Type	Designation Grade			
Plain Bar to AS/NZS 4671	R250N	250	0.05	N
Bar deformed to AS/NZS 4671	D500L (fitments only)	500	0.015	L
	D500N	500	0.05	N
Welded mesh, plain, deformed or indented to AS/NZS 4671	D500L	500	0.015	L
	D500N	500	0.05	N
Stainless steel plain bar to BS 6744	200	200	0.05	N or E
Stainless steel ribbed bar to BS 6744	500 ^(*) <i>(*) Maximum Grade allowed by AS 3600 and AS 5100.5</i>	500	0.05	N or E

3 PRESTRESSING WIRE, STRAND AND BARS

3.1 TENDONS

General

The steel wires, strand and bars used in prestressed concrete are often referred to as 'tendons'. Tendons used in prestressed concrete are generally manufactured from high tensile steel. The tendons may be 'normal stress-relieved' or 'low-relaxation stress-relieved', although the latter is by far the more common.

When steel is tensioned to a high stress, and then held at a constant length under that stress, there will be a loss of stress in the steel as it 'relaxes' under the load. Low-relaxation steel is commonly specified because it can maintain a higher tensile stress over time than normal steel. Normal-relaxation and low-relaxation steel are not therefore directly interchangeable.

All prestressing tendons should carry a mill certificate from the manufacturer (or a nominated testing authority) which clearly identifies them. Particular attention should be paid to the physical and chemical properties of the steel, protective coatings, physical damage, corrosion, and to its handling and storage.

Rejected material should be clearly marked and removed from the site.

Prestressing steel is sensitive to rusting, notches, kinks and heat. The steel is protected against rusting in transit to the site and, on site, should be suitably stored under cover in dry surroundings.

Research has shown that a light, hard oxide on the tendons is desirable in pre-tensioned members, since it improves the bond characteristics of the tendons. It should also be desirable in bonded, post-tensioned work. However, prestressing steel is more sensitive to corrosion than ordinary reinforcing steel because the individual prestressing wires or strands are small in diameter in comparison to reinforcing bars. Corrosion and, in particular, pitting reduce the cross-sectional area of the tendon by a relatively large amount. Tendons must therefore be checked for indications of pitting corrosion. When this is found, the tendons should be rejected.

For much the same reason, tendons should be checked for notches or kinks. By providing focal points for stress concentrations, they invite stress corrosion, or in severe cases, over-stressing.

Tendons are also susceptible to excessive heat which can destroy or alter the high-tensile

characteristics of the steel. Welding operations should never be carried out on, or adjacent to, prestressing tendons.

Tendons may consist of individual wires, strands, or bars as shown in **Table 6.4**.

Table 6.3 – Meshes Commonly Available in Australia (from Table 7.6(A) of AS/NZS 4671)

Mesh type and reference number	Longitudinal bars		Crossbars		Mass of 6 m x 2.4 m sheet (kg)	Cross-sectional area/m width	
	No. x dia. (mm)	Pitch (mm)	No. x dia. (mm)	Pitch (mm)		Longitudinal bars (mm ² /m)	Cross bars (mm ² /m)
Rectangular							
RL1218	25 x 11.9	100	30 x 7.6	200	157	1,112	227
RL1018	25 x 9.5	100	30 x 7.6	200	109	709	227
RL818	25 x 7.6	100	30 x 7.6	200	79	454	227
Square, with edge side-lapping bars							
SL102	10 x 9.5 + 4 x 6.75	200 100	30 x 9.5	200	80	354	354
SL92	10 x 8.6 + 4 x 6.0	200 100	30 x 8.6	200	66	290	290
SL82	10 x 7.6 + 4 x 5.37	200 100	30 x 7.6	200	52	227	227
SL72	10 x 6.75 + 4 x 4.75	200 100	30 x 6.75	200	41	179	179
SL62	10 x 6.0 + 4 x 4.24	200 100	30 x 6.0	200	33	141	141
Square, without edge side-lapping bars							
SL81	25 x 7.6	100	60 x 7.6	100	105	454	454
Trench meshes							
L12TM	N x 11.9	100	N/A	N/A	N/A	1,112	N/A
L11TM	N x 10.7	100	N/A	N/A	N/A	899	N/A
L8TM	N x 7.6	100	N/A	N/A	N/A	454	N/A

NOTE: The edge bar on SL meshes may be replaced by smaller diameter edge bars of equal or greater total cross-sectional area provided the smaller bars meet the minimum ductility requirements of the bar to be replaced.

Prestressing Wire

High tensile steel wire, up to 8 mm in diameter, is most commonly used for the tendons in pre-tensioned concrete. It should comply with the requirements of AS 4672.1 and may be 'as drawn (mill coil)' wire, 'stress relieved' wire or 'quenched and tempered' wire.

Wire diameters are kept small to increase the surface area available for bond, or bond may be improved by rolling small indentations into the wire or by crimping **Figure 6.2**.

Wire is usually supplied on specially wrapped coils. Before unwrapping, the coils should be placed on a purpose-made spindle that has

outside restrainers and a brake to prevent unravelling and crossing of the wire.

Table 6.4 – Tensile Strength of Commonly Used Wire, Strand and Bar

Material type and relevant Standard	Nominal diameter (mm)	Area (mm ²)	Minimum breaking load (kN)	Minimum tensile strength (MPa)
Wire – AS 4672.1	5	19.6	34.7	1,770
	7	38.5	64.3	1,670
	9.5	55.0	102	1,850
7-wire super strand – AS 4672.1	12.7	98.6	184	1,870
	15.2	143	250	1,750
	15.2 EHT	143	261	1,830
Bars – super grade only – AS 4672.1	26	562	579	1,030
	29	693	714	1,030
	32	840	865	1,030
	40	1,232	1,269	1,030

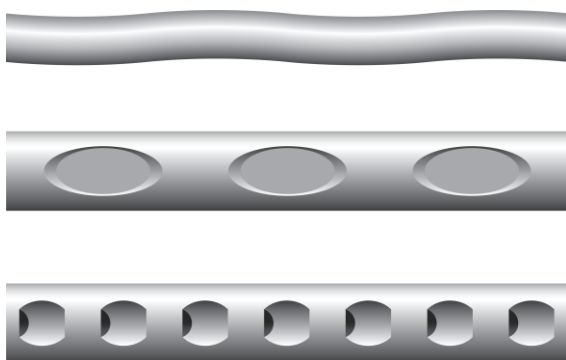


Figure 6.2 – Crimped or Indented Wire

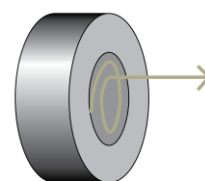
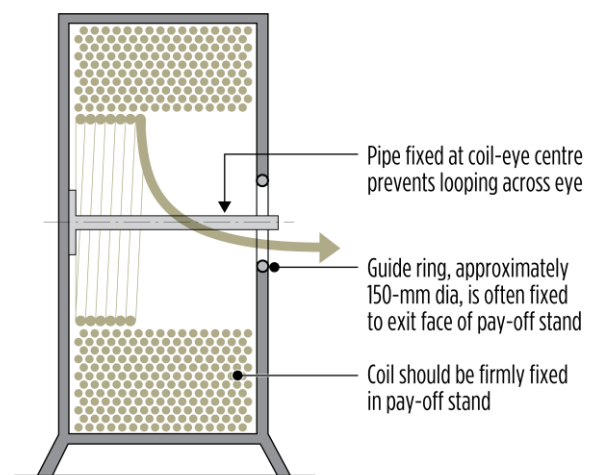
Prestressing Strand

Strand is composed of a central wire tightly enclosed by other wires laid helically around it.

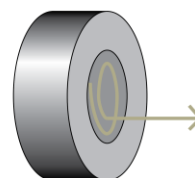
Strands commonly consist of seven wires (7-wire strand) and are normally between 8 mm and 18 mm in diameter. They should comply with the requirements of AS 4672.1. In Australia, the most common strand is the 12.7 mm-diameter 7-wire super-grade stress-relieved low-relaxation strand. Its minimum breaking load is 184 kN at a nominal steel tensile strength of 1,870 MPa.

Strand is supplied on large drums or in large coils with a centre pull to unwind. The same care should be taken when releasing the first section as with wires.

Centre pulling of coils is a more convenient method, provided certain precautions are taken. The first precaution is to prevent the coil expanding, collapsing or tangling. The second precaution is to ensure the lay of the strand is tightened as it is pulled off the coil. Strand acquires a twist as each loop is removed, and this twist should be directed in such a way as to tighten the lay. Manufacturers should be consulted for the direction of the lay (Figure 6.3).



LEFT HAND LAY
Loop travels counter-clockwise round the eye of the coil



RIGHT HAND LAY
Loop travels clockwise round the eye of the coil

Figure 6.3 – Centre Pulling of Wire and Strand

Prestressing Bars

Prestressing bars should comply with AS 4672.1. They are used to provide large forces in restricted areas, being relatively easy

to handle and simple to couple with threaded connections. Bars are suited to short length stressing or where restressing or coupling is required.

3.2 IDENTIFICATION OF PRESTRESSING WIRE, STRAND AND BARS

The designation of prestressing steel is identified by an alphanumeric sequence providing information on the applicable standard (AS/NZS 4672.1), nominal diameter, tensile strength and other properties such as:

- Type of strand or bar (e.g. '7 wire ordinary' or 'bar');
- Wire surface (a letter indicating surface features such as 'P' for plain or 'R' for ribbed);
- Treatment (such as 'S' for stress relieved);
- Relaxation class ('Relax 1' or 'Relax 2');
- Ductility class (for quenched and tempered wires);
- Direction of Lay (Left or Right) – see **Figure 6.3**.

For example, a common 7 wire strand with 12.7 mm diameter is designated as follows:

AS/NZS 7672.1-7 wire ordinary-12.7-1860-Relax 1-Right

4 OTHER PROPERTIES OF REINFORCEMENT, PRESTRESSING WIRE, STRAND AND BARS

4.1 ELASTIC MODULUS

The elastic modulus for all steel reinforcement is assumed to be 200×10^3 MPa for design of reinforced concrete using the Australian design Standards and does not significantly vary with strength grade of the steel.

For prestressing tendons and hot rolled high tensile steel alloy bars the elastic modulus is estimated to range between 195×10^3 MPa and 215×10^3 MPa. Prestressing strand is

estimated to have an elastic modulus between 195×10^3 MPa and 205×10^3 MPa.

4.2 COEFFICIENT OF THERMAL EXPANSION

The coefficient of thermal expansion of steel reinforcement is similar to that of concrete. In the Australian design Standards, a value of $12 \times 10^{-6} / ^\circ\text{C}$ is used for normal steel reinforcement. For stainless steel reinforcement this may vary from $13 \times 10^{-6} / ^\circ\text{C}$ to $16 \times 10^{-6} / ^\circ\text{C}$ depending on the quality of steel as designated in BS 6744 and its reference EN 10088-1.

5 REFERENCES

- 1) AS 3600 – *Concrete structures*
- 2) AS 5100.5 – *Bridge design, Part 5: Concrete*
- 3) AS/NZS 4671 – *Steel for the reinforcement of concrete*
- 4) AS/NZS 4672.1 – *Steel prestressing materials, Part 1: General requirements*
- 5) AS 1310 – *Steel wire for tendons in prestressed concrete*
- 6) AS 1311 – *Steel tendons for prestressed concrete, 7-wire stress-relieved steel strand for tendons in prestressed concrete*
- 7) AS/NZS 1554 – *Structural steel welding (series of Standards)*
- 8) AS 1554.3 – *Structural steel welding, Part 3: Welding of reinforcing steel*
- 9) BS 6744 – *Stainless steel bars, Reinforcement of concrete, Requirements and test methods*
- 10) EN 10088-1 – *Stainless steels, List of stainless steels*

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