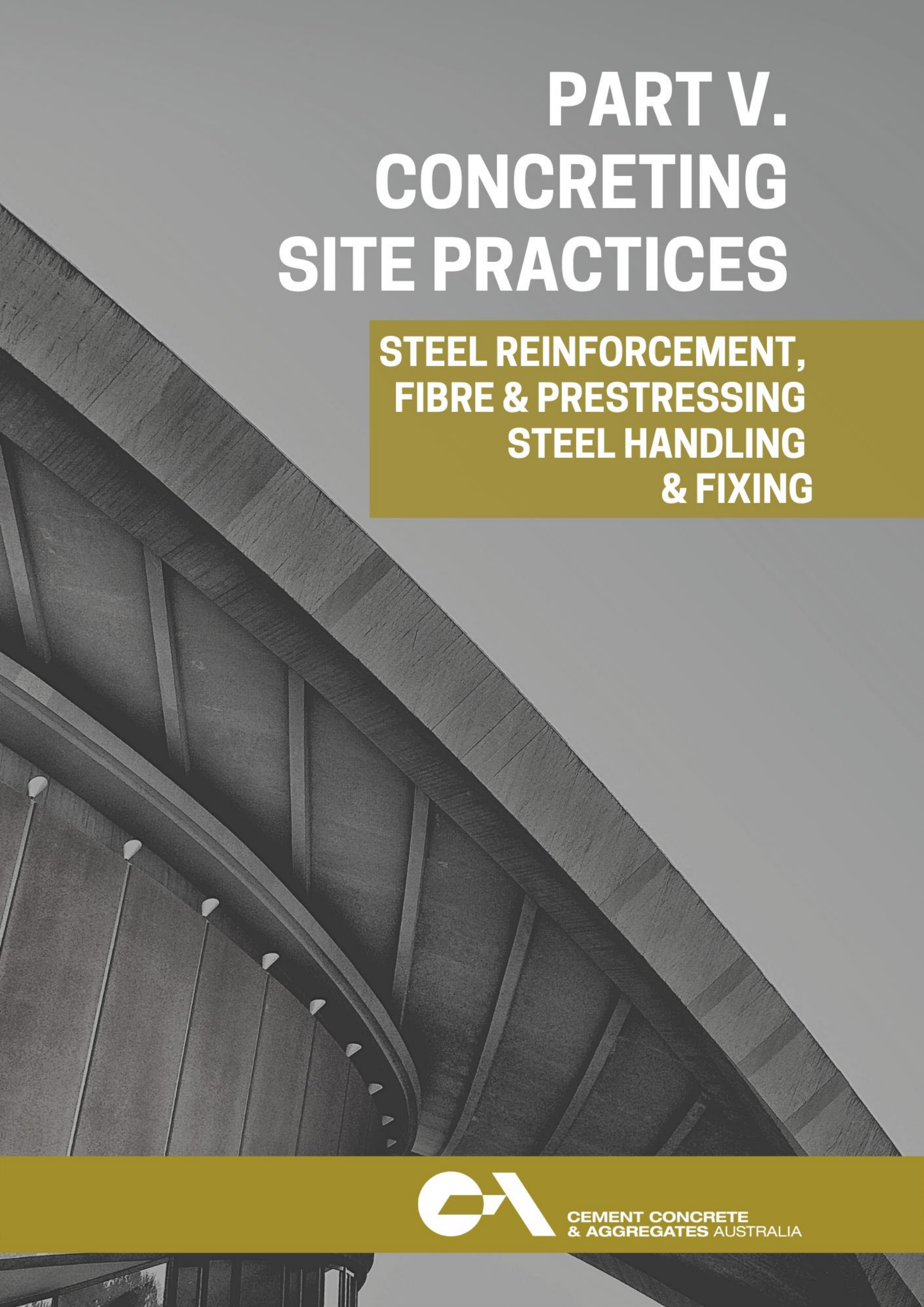

PART V. CONCRETING SITE PRACTICES

STEEL REINFORCEMENT, FIBRE & PRESTRESSING STEEL HANDLING & FIXING

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

CONTENTS

1. OUTLINE

This section provides information on the types of steel reinforcement used in Australia (including steel fibres), and guidance on its detailing, handling and fixing.

Also provided is guidance on the fabrication and fixing methods for prestressing steel as well as the techniques used to tension the steel tendons and to bond them into the concrete.

2. DETAILING AND FABRICATION OF STEEL REINFORCEMENT

2.1 GENERAL

The detailing and fabrication of reinforcement, within the tolerances specified for the project, are two of the most important facets of concrete construction.

Reinforcement is placed in concrete members to resist the stresses in the member that result from the loads imposed on it. The designer calculates the magnitude of the stresses and then determines both the amount and the position of the reinforcement required. If the structure is to perform as intended then the appropriate shape, strength grade, ductility class and size of reinforcement must be chosen, fabricated, fixed and surrounded by concrete as shown in the drawings.

Detailing

Detailing is considered to be the preparation of working drawings showing the size and location of the reinforcement used in all of the concrete structural elements that form the whole structure.

Good detailing ensures that reinforcement and concrete interact efficiently to provide satisfactory behaviour of the reinforced concrete structure under all loading conditions.

Good detailing also ensures that the constructability of the structural elements (e.g. spacing between bars to allow full compaction of concrete) is taken into account as well as it being an economical design.

The end product for the detailer is a set of drawings that provides the required details for the building contractor, steel fixer and the scheduler.

Scheduling
The first step in the fabrication of reinforcement is the preparation of a schedule which lists each individual bar profile or sheet of mesh required for the job. This will show:

- The profile, strength grade, ductility class and size of reinforcement for each item;
- The profile and dimensions of each item;
- The number of identical items;
- Identifying numbers or positions; and
- The total mass of steel reinforcement.

It is prepared by a scheduler from the structural drawings and other instructions. From this schedule, the reinforcement supplier will cut and bend reinforcement for delivery to the site.

Cutting
Straight bars are cut normally by shearing, which may slightly distort the end of the bar. If undistorted, square ends are required for items such as dowels for use in movement joints, friction cutting or sawing is preferred.

Where mesh is required in sheets less than the standard 6 m length, the mesh is cut and trimmed on site with bolt cutters, oxy-acetylene equipment or angle grinders.

Bending
Reinforcement may need to be bent during fabrication to accommodate it within the shape of the concrete member to provide anchorage. Bending may be carried out while the reinforcement is at normal temperatures, or whilst it is hot, at temperatures up to 600°C.

Heating of the steel is permissible provided the temperature is not allowed to exceed 600°C as an absolute maximum. If the temperature exceeds 450°C, the bars are downgraded, and the maximum strength is taken as Grade 250.

When reinforcement is bent at normal temperatures it loses a certain amount of its ductility, or it becomes more brittle. When steel is overstressed during bending operations, or is rebent, further reducing its ductility, it may become subject to 'brittle failure', where a sudden fracture of the steel under load occurs.

To prevent such brittle failures and to avoid overstressing of the concrete inside the bends, AS 3600 specifies minimum diameters for bends in bars of different strength grades to be used in different situations.

These recommendations are shown in **Table 11.1** and actually take the form of recommended minimum diameters for the pins around which the steel is bent during fabrication and take into account:

- The strength grade of steel;
- The diameter of the bar;
- The purpose of the reinforcement;
- The possibility of rebending; and
- Whether or not the bar is coated.

Typical pin diameters range from three times the diameter of wire or bars to be used in fitments to eight times the diameter of coated bars 20 mm in diameter or greater.

The recommendations set out in AS 3600 on the bending of reinforcement are formulated for bars complying with AS/NZS 4671. Steels not complying with this specification, e.g. some steels manufactured overseas, may be damaged by bending to the diameters recommended. In this context, it should also be noted that bending deformed bars over a diameter pin that is too small can also damage the bar. The deformations themselves may be crushed, causing minute cracks which act as stress initiators during subsequent bending operations.

Rebending
Although in principle the rebending of reinforcement is undesirable because of the reduction in its ductility, occasions do arise on site where some rebending is unavoidable. In all such cases, the proper equipment should be used. Bending with the aid of a pipe and/or sledgehammer is not acceptable.

For larger diameter bars, heating may be the only solution. In such cases, the temperature of the bar should be checked with the heat-indicating crayons normally used for welding, to ensure that the maximum permissible temperatures are not exceeded. If exceeded, AS 3600 requires the allowable stress in the steel to be drastically reduced. Heating of reinforcing steel on site should therefore never be undertaken without the approval of the design engineer.

Table 11.1 – Minimum Pin Diameters for Cold-bending Reinforcement (from Clause 17.2.3.3 of AS 3600)

Reinforcement	Minimum pin diameter – d_b = bar diameter (mm)
Fitments:	
– Grade 500L bars (mesh) and R250N bars	$3d_b$
– Grade D500N bars	$4d_b$
Reinforcement other than galvanised or epoxy coated, and which is not intended to be rebent	$5d_b$
Galvanised or epoxy-coated reinforcement	
– 16 mm diameter or less	$5d_b$
– 20 mm diameter or greater	$8d_b$
Reinforcement that is intended to be straightened or rebent	
– 16 mm diameter or less	$4d_b$
– 20 mm or 24 mm diameter	$5d_b$
– 28 mm diameter or greater	$6d_b$

2.2 TOLERANCES FOR FABRICATION

Tolerances on the fabrication of reinforcement stipulated in Clause 17.2.2 of AS 3600 are shown in **Table 11.2**. Maintenance of these is necessary, firstly to ensure that when fabricated, the reinforcement will fit within the mould or formwork for which it is intended; but secondly, and most importantly, that the concrete cover necessary to protect the reinforcement from the environment is maintained. Thus, it will be noted that reinforcement and fitments must not be longer than specified.

Table 11.2 – Tolerances for Fabricating Reinforcement (from Clause 17.2.2 of AS 3600)

Item	Tolerance
Fitments – on any overall dimension of bars or mesh	
– For deformed bars and mesh	–15, +0 mm
– For plain round bars and wire	–10, +0 mm
Reinforcement – on any overall dimension of bars or mesh	
– For lengths up to 600 mm	–25, +0 mm
– For lengths over 600 mm	–40, +0 mm
Cranked column bars	
– Overall offset	–0, +10 mm
End-bearing splices	
– Angular deviation from square for a sawn or machined end relative to the end 300 mm	2°

3. FIXING STEEL REINFORCEMENT

3.1 GENERAL

The position of the reinforcement may well be more important than the amount. For example, reinforcement specified to be placed in the top of a multi-span beam or slab, to resist the tension over intermediate supports, will be totally ineffective if placed in the bottom of the beam or slab.

Reinforcement also requires a minimum amount of cover to protect it from the effects of fire and/or from an environment that may cause it to rust and corrode. The tolerances specified for the fixing of reinforcement are designed to ensure that these minimum requirements are met.

3.2 HANDLING

Reinforcement should be checked for loose scale, mud and oil.

Loose scale is normally removed as the bars are handled in the fabricating factory, or during loading and unloading, and it is not usually necessary to carry out any special 'cleaning' procedure to remove it. Mill scale and light rust are generally thought to have little effect on bond. Indeed, moderate rusting is thought to improve bond.

Mud and dirt should be washed off before the bars are placed in the forms as they could be detrimental to bond and to the quality of the concrete.

Oil and grease should also be removed (with solvents) and care taken that bars do not become coated with form oil during fixing operations.

3.3 POSITIONING

General

It is essential that reinforcement be fixed in the position specified by the designer in the structural drawings. If it is not, then the structural performance, durability or fire resistance (perhaps all three) could be seriously impaired. Reference should be made to the placement tolerance set out in Clause 17.5.3 of AS 3600.

A number of methods are used to locate reinforcement correctly. These are discussed in the following sub-sections.

Bar Chairs

Bar chairs are generally used to support bar or mesh reinforcement above horizontal surfaces. They are available in a variety of shapes and may be made from wire, plastic or concrete. All bar chairs must comply with AS/NZS 2425.

They are also manufactured in a range of sizes, each of which provides a specific thickness of concrete cover. Indeed, some are manufactured so that different thicknesses of cover may be achieved with a single unit. Typical are concrete blocks which can be used with different faces uppermost and plastic chairs which can be positioned in a number of different ways. A range of bar chairs is illustrated in **Figure 11.1**.

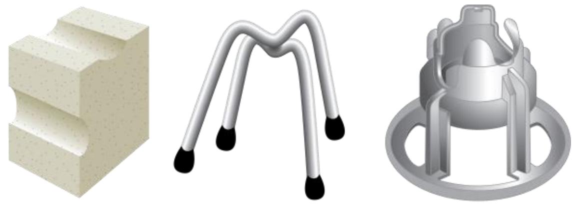

Figure 11.1 – Typical Bar Chairs

Factors which should be considered in the choice of a bar chair appropriate to the work in hand include:

Cover: A bar chair should be selected to provide the correct cover – not one 'close-to' that required. In using a multi-cover chair, care must be taken that it is positioned correctly.

Strength: Bar chairs have a load rating of 60 kg, 120 kg, 200 kg, 300 kg or more. It is important that the strength of the bar chairs be specified.

Type of bar chair: It is important that the type of bar chair (steel, concrete or plastic) is selected for exposure conditions of the concrete structure. For example, using an un-protected steel bar chair in a suspended slab with an exposed soffit could mean that the bar chair itself will corrode, producing staining and spalling of the concrete even though the reinforcement is correctly located.

Appearance: Where the soffit is exposed, the tips of the bar chairs may be seen. It is necessary, therefore, to consider the appearance of the completed element in choosing a suitable support for reinforcement.

Membrane damage: Bar chairs which could puncture damp-proof membranes during placing operations should be avoided or supported on purpose-made 'saucers'.

Stability: Some types of bar chairs are easily displaced or knocked over during concrete-placing operations. Selection should ensure that the risk of this is minimised.

Spacing of bar chairs: Combined with the strength, the spacing ensures that the weight of reinforcement, construction equipment and personnel can be supported. It also ensures that the deflection of reinforcement is limited and helps ensure that the required concrete cover is maintained. The required spacing will depend on the concrete placing method and the grade/size of reinforcement. Thus, the minimum spacing will range from 0.5 m to 1.0 m.

Spacers

Spacers that snap onto reinforcing bars are available to maintain the required distance from the bar to the face of the concrete. They are generally made of plastic. As for chairs, spacers must conform with AS/NZS 2425 and the selection and positioning of spacers must always be such as to ensure that the reinforcement is correctly positioned and that the surface appearance of the concrete is acceptable.

Tying

Reinforcing bars may be tied together, or to fitments, to form a 'cage' which helps maintain the bars in position during the subsequent concreting operations. Obviously, the cage must be strong enough to achieve this – sufficient fitments must be used for this purpose (**Figure 11.2**).

Figure 11.2 – Reinforcement being tied in Position

The most common tie material is a black annealed wire, 1.6 mm in diameter, although other forms of wire and plastic clips are available.

It is not necessary to tie bars at every intersection as ties add nothing to the ultimate strength of the structure. They serve only to keep the reinforcement in place during concreting. Nevertheless, it is better to provide too many than too few, particularly at the edge of slabs, around openings, at corners, and in similar locations where positioning of the reinforcement is particularly critical.

Welding

Reinforcing steel should not be welded except with the approval of the engineer. Such welding must then comply with AS/NZS 1554.3.

The locational welding of main bars into the corner of fitments may be approved but other welding should not be carried out within 75 mm of any bend of a radius less than eight times the bar size.

Splicing Reinforcement

Lengths of reinforcing bar or mesh may be joined or 'spliced' together in a variety of ways.

The most common method is simply to lap the bars or mesh. The lapped portion of the bars or mesh must always be in contact unless otherwise indicated on the drawings.

When mesh is lapped, the two outermost wires of one sheet must overlap the two outermost wires of the other. Meshes are available with the edge wires spaced closer together, thus reducing the area of the lapped zone and increasing the coverage of the sheet.

A variety of proprietary mechanical splices are also available for joining bars. These have different applications, advantages and disadvantages. It is vital, therefore, that the correct type of splice is used in any given situation and that the manufacturer's instructions on installation are followed.

Tolerances

A tolerance provides an acceptable allowance for small variations to the specified length or position of reinforcement. For reasons that include structural performance, durability and fire resistance, reinforcement must be in the position intended for it within an appropriate tolerance.

Tolerances for the positioning of reinforcement and tendons stipulated in Clause 17.5.3 of AS 3600 are shown in **Table 11.3**. Knowledge of these tolerances is essential for all those concerned with the fixing or checking of reinforcing.

4. STEEL FIBRE REINFORCEMENT

4.1 GENERAL

Section 7 of this guide has discussed the properties of steel fibres used in concrete. In this section the methods for dosing steel fibres into a concrete mix are also discussed. The aim of mixing fibres in concrete is that the end product has a uniform distribution of fibres in accordance with the mix design dose rate. There are some steps necessary to achieve this uniform distribution and further to that there are test methods used on the mixed concrete that can be used to verify that distribution.

Mixing Steel Fibres in Concrete

ACI 544.3R provides guidance on mixing of steel fibres into concrete. Loose steel fibres with higher aspect ratio (length to diameter ratio) are prone to what is referred to as 'balling' or binding together due to frictional effects between fibres. Once formed this 'ball of fibres' will be difficult to break up in the plastic concrete mix. If a number of these balls of fibres form during batching, then the concrete mix will not have the uniform distribution of fibres expected in the concrete mix.

Two methods are recommended to overcome this tendency to form fibre balls:

- One method is offered by some steel fibre manufacturers where the fibres are bonded together in groups of 20 or more fibres using water soluble glue. This prevents the fibres from balling and makes loading into the concrete mix a simpler process. The glue dissolves in the presence of mix water and the fibres distribute during mixing;
- The other method used is to load fibres through a screen sized to break up any balls of fibres before being loaded into the mixer via a conveyor. This is more effective if the rate of addition of fibres is reduced to avoid heaping of fibres on the conveyor.

Table 11.3 – Tolerances on Position of Reinforcement and Tendons (from Clause 17.5.3 of AS 3600)

Item	Deviation from specified position
For positions controlled by cover:	
– In beams, slabs, columns and walls	–5, +10 mm
– In slabs-on-ground	–10, +20 mm
– In footings cast in the ground	–10, +40 mm
(where a positive value indicates the amount the cover may increase and a negative value indicates the amount the cover may decrease)	
For positions not controlled by cover:	
– The location of tendons on a profile	5 mm
– The position of the ends of reinforcement	50 mm
– The spacing of bars in walls and slabs and of fitments in beams and columns	10% of the specified spacing or 15 mm, whichever is greater

In general, it is recommended that total mixing times for concrete containing steel fibres are extended by at least 30% to allow for loading and mixing the fibres through the plastic concrete. Batching equipment for weighing and delivering fibres to the mixer is a recent development towards safe and controlled addition of fibres to the concrete mixer where larger volumes of fibre concrete are being produced.

Testing Steel Fibre Distribution in Concrete

As well as the standard tests used for normal class concrete there are tests for the uniformity of fibre addition to concrete. One such method is VicRoads Test Method RC 377.01 *'Determination of the Fibre Content of Fresh Concrete (Wash-out Method)'*. The aim of the test is to assess the average content and the variability in measured fibre content (in kg/m^3) between three samples of the same batch of concrete. Generally, a tolerance on individual test samples is specified as well as the average. For example, a target dose of 30 kg/m^3 of a steel fibre may allow a minimum test sample value to be 22.5 kg/m^3 and minimum average of three samples to be 26 kg/m^3.

5. PRESTRESSED CONCRETE

5.1 GENERAL

There are two common systems used for constructing prestressed concrete structures. These systems are:

- Pre-tensioning;
- Post-tensioning.

These systems are discussed in the following sections.

5.2 PRE-TENSIONING

In a pre-tensioned member, tendons are first carefully positioned within the formwork and the design load or tension applied to them. Then, while tensioned, the concrete is cast around them and allowed to harden until it achieves sufficient strength (usually above 30 MPa) to resist the forces to be applied to it. The ends of the steel tendons are then released from their restraints and the stress in them is transferred to the concrete by the bond between the two materials.

The tendons used in pre-tensioning are usually in the form of small-diameter wires or strands (a combination of smaller wires). The diameters of these materials are kept small to increase the surface area available for bonding with the concrete. Crimped or indented wire is also commonly used to further increase bond (**Figure 11.3**).

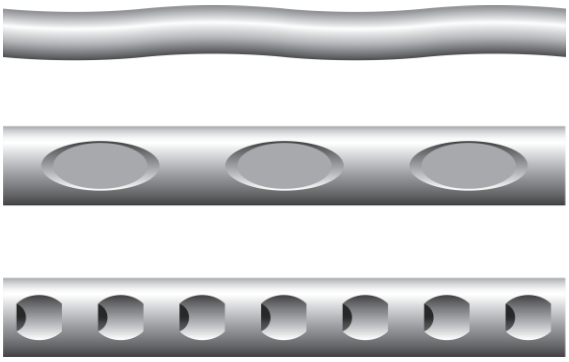

Figure 11.3 -Crimped or Indented Wire

5.3 POST-TENSIONING

When a member is to be post-tensioned, the concrete is first allowed to harden before the steel tendons are stretched or tensioned. They cannot therefore be allowed to bond with the concrete, at least not initially. Usually they are placed in ducts or holes that have been cast in the concrete, although sometimes they are greased and sheathed in plastic to prevent bond. In other cases, the tendons are fixed to the outside faces of the member.

After the concrete has gained sufficient strength, the tendons are tensioned and then fixed or anchored in special fittings cast into the ends of the concrete member. A wide variety of patented fittings and systems are available for this purpose. Typical slab and beam anchorages are shown in **Figures 11.4** and **11.5** respectively. The ducts are then filled with a cement grout which, when set, bonds the tendons to the concrete.

Figure 11.4- Typical Slab Anchorage

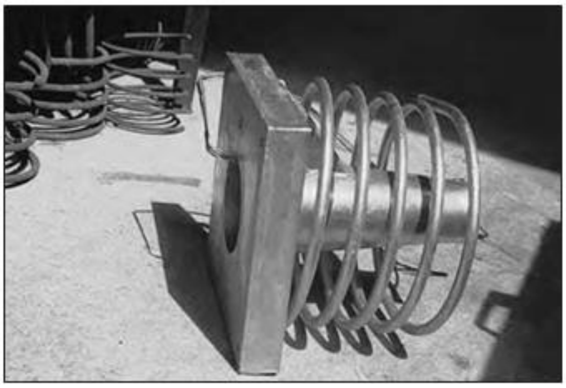

Figure 11.5 – Typical Beam Anchorage

5.4 APPLICATIONS

Although both pre-tensioning and post-tensioning systems are designed to apply prestress to concrete members, there are some practical differences in their fields of application. Thus, pre-tensioning is normally confined to the factory production of repetitive precast concrete units where the cost of the relatively large abutments or restraints, against which the prestressing jacks operate, can be justified. Alternatively, very strong and robust formwork may be constructed, and wires anchored against its ends.

Post-tensioning is more flexible in its application and may be carried out onsite. It permits the use of curved tendon profiles and is also suited to a wide variety of construction techniques, such as 'segmental construction' and 'stage stressing'. Since stressing is not carried out until the concrete has hardened, the concrete member itself provides the restraint against which the stressing jack operates (**Figure 11.6**).

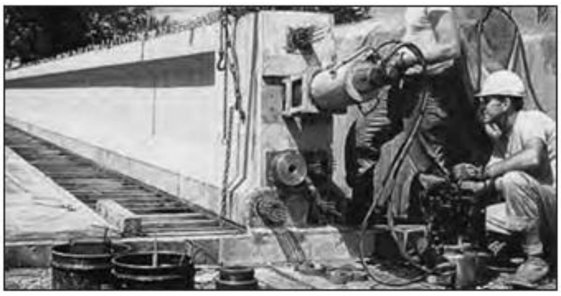

Figure 11.6 – Post-tensioning Jack operating on End of Concrete Girder

An example of a prestressed concrete bridge is shown in **Figure 11.7**.

Figure 11.7 – Multi-strand, Post-tensioned bridge, Mooney Mooney, NSW

Ducts

Ducts can be formed in concrete by casting in a flexible metal or plastic tube, by using an inflatable rubber tube or by using a removable steel former.

The use of a flexible metal tube is the most common method of forming a duct. The tubes are relatively thin yet can withstand onsite handling. Normally, tendons are cut to length and 'pulled through' or 'pushed into' the duct (i.e. positioned within it) prior to concrete being cast. This helps to locate and restrain the duct during concrete placing and avoids the major problem of trying to thread the tendons through the duct should it be damaged.

Where it is not possible to place the tendon in the duct prior to concreting, the duct may be held in position with a plastic tube, an inflatable rubber duct or a bundle of wires. Straight ducts can also be located with the aid of a slightly undersize steel tube.

Inflatable rubber formers should be supported and inflated to the manufacturer's instruct ions. They will normally require support at 300 mm centres and be inflated to about 200 kPa. When rubber formers are used in steam-cured concrete, care should be taken to ensure that the heat does not increase the pressure in the tube by an unacceptable amount. Rubber formers are usually deflated in steps and withdrawn immediately when the concrete has set and begun to harden, e.g. after about four hours from casting the concrete.

The use of removable steel formers is a somewhat risky procedure and is therefore normally limited to small lengths. Greasing of the tubes to prevent bonding with the concrete can interfere with subsequent bonding of the grout.

Anchorages

Anchorages comprise units or components which enable the tendon to be stressed, and then transfer the force in the stressed tendon to the concrete member or structure. They also commonly incorporate facilities to enable the ducts to be injected with a cement grout to protect the tendons from corrosion and bond them to the concrete.

6. CONSTRUCTION USING PRESTRESSING

6.1 PRESTRESSING SYSTEMS

Prestressing systems may be loosely described as the combination of methods and equipment that are used to tension the tendons and then to fix them so that they transfer their load to the concrete. They therefore include not only the anchorages, and in some cases, the tendons, but also the jacks which are used to stretch the tendons.

It is beyond the scope of this Guide to provide information on the many and varied systems which are used in Australia with most being patented. The manufacturers and/or suppliers should be contacted for details of these systems.

6.2 FIXING DUCTS AND ANCHORAGES

The correct placement of ducts within the formwork and securing them against movement during concreting are very important steps in prestressed concrete construction. In post-tensioned construction, tendons are very often draped or profiled within the member in order to obtain the maximum benefit from the prestress. This tendon profile, as it is known, is an important feature of prestressed design and any significant deviation from it may cause the member to deflect or behave in a way not anticipated in the design.

The importance of the tendon profile is recognised by AS 3600 which requires that the profile be maintained within 5 mm of that specified.

In positioning ducts, it is important to remember that the centreline of the duct will not coincide with the centreline of the tendon. With draped cables, the tendons, when tensioned, will bear against the top of the duct in the centre of a span, and with continuous cables, on the bottom of the duct over the supports.

In positioning and securing ducts within the formwork, care must be taken, therefore, that the profile is maintained (**Figure 11.8**). This is achieved by tying the duct to the reinforcing steel, chairs, or other supports. The fixings should be sufficiently rigid, and at sufficiently close centres, to prevent displacement of the duct during the concrete operation. Small ducts should be supported at about 1 m centres. Supports for large ducts, which naturally maintain an approximately correct profile due to the stiffness of the duct, should be 3 m or less, depending on the duct stiffness. In addition to displacements likely to be caused by the weight of concrete and the operation of the vibrator, displacement can occur due to flotation of the ducts. Fixing should prevent this from occurring.

Figure 11.8 – Positioning the Ducts in the Formwork

Particular care is necessary to ensure that the ducts are correctly located adjacent to the anchorages so that unintentional angular deviations do not occur. Un-tensioned reinforcement, particularly beam stirrups and end-zone reinforcement should have been detailed carefully by the designer to ensure the ease, accuracy and quality of duct placement.

Fabrication and placement details for anchorages are normally provided by the supplier and should include such details as anchorage block out dimensions, bolt hole dimensions, clearance requirements for stressing equipment etc.

Anchorages must be fixed to prevent movement during concreting. In cases where anchorages are attached to the end formwork, the latter must be sufficiently rigid to withstand the horizontal forces which can be imposed on the anchorages during the concreting operation, and the fixing detail should be such that the ingress of grout at this point is prevented.

6.3 PLACING AND COMPACTING CONCRETE

The concrete placing and compaction programme should be prepared in good time and must be carried out with the greatest possible care since defects in concreting are liable to cause problems during the stressing operation.

Just prior to placing concrete, the tendons and anchorages should be inspected carefully to ensure they are securely tied at all locations and that there is no possibility of mortar leaking into the duct or anchorage device during placing and compaction of the concrete.

Proper tendon alignment must be maintained ahead of the concrete placement and care taken to ensure that ductwork is not damaged. Ducts should not be stepped on nor damaged with vibrators.

If the duct is damaged, repairs should be made to prevent concrete from bonding to the tendons. Small holes can be repaired by using waterproof adhesive tapes. Larger holes should be covered by metal strips wrapped around the duct. The overlap should be at least 100 mm and the joints should be sealed by a waterproof adhesive tape.

Particular care should be taken at the end-zone and at grout pipes, air bleeds and reinforcement to ensure uniform compaction and to avoid unnecessary voids.

Immediately after concreting, where possible, cables should be pulled back and forth to ensure that they remain free.

6.4 STRESSING

The majority of stressing systems use hydraulic jacks to tension the steel tendons which may be tensioned singly or in groups. Jacks capable of exerting forces of up to 1,800 tonnes have been developed for stressing operations in large dams and similar applications but on most construction-sites jacks with capacities up to 300 tonnes would be employed (**Figure 11.9**).

Figure 11.9 – Typical Hydraulic Jack (with hydraulic hoses from compressor unit foreground)

In single-tendon stressing, each tendon is individually stressed. In multiple stressing, all the tendons in the duct are stressed at the same time. The smaller jacks used for single pulling allow easier jack handling, but the number of operations is increased. The large jacks used in multiple stressing reduce the number of stressing operations but may require mechanical handling. The type of jack employed must correspond to the prestressing system used and to the dimensions of the tendons. This must always be checked as must the stroke of the jack to ensure it is appropriate to the job. Stressing operations are carried out by crews specially trained in the use of the particular type of equipment used.

The time and sequence of stressing is determined by the designer to achieve the following objectives:

- Early partial stressing to minimise the development of shrinkage cracks. Typically stressing at 24 hours after casting;
- Early partial stressing to balance the self-weight of the slab and to enable formwork to be more economically used. For multi-storey construction, the early capacity to support subsequent floors is a primary consideration;
- The proper stressing sequence to avoid large differential stresses in adjacent cables or areas;
- In stage prestressing, to balance the loads being applied as the structure progresses.

The measurement of stressing load is usually based on load cells or dynamometers, confirmed by measurement of the elongation in the tension cable. Readings of extensions should be made with an accuracy of 1 mm. The first increment, which removes slack, will normally be 10-20% of the final jacking force. At this stage, the zero-reading for extensions are usually made.

The theoretical extension takes into account the tendon profile and friction.

After stressing has been completed, the tendons are anchored in accordance with the standard procedure of the prestressing system.

All data observed during the stressing operations should be recorded immediately in the stressing log. As these are the only available evidence of the required prestressing force having been reached, they should be signed by the person responsible for the stressing and kept in a safe place. The figures in the stressing log should take into account adjustments for zero readings and the elongation of tendons beyond the anchorages.

The load/elongation measurements provide vital information on the prestressing force obtained and on possibly significant deviations from the design assumptions. Meticulous stressing records are essential for a complete evaluation of the quality of the work. Before the stressing log is submitted to the designer the recorded extensions should be checked for any inconsistency. Two ducts with the same number of tendons, same drape and same stressing force should not have extensions varying by more than about 5%. Any inconsistencies should be investigated in consultation with the designer.

Tendons should not be cut or grouted and should be kept in such condition that they can be re-stressed until permission for work to proceed has been granted by the designer.

Because the measurements during stressing are influenced by random factors, acceptable limits for the difference between calculated and observed values should be stated by the designer. Where tolerance in extensions has not been specified, a realistic value may be taken as ±5% to ±10%.

6.5 GROUTING

In Australia, post-tensioned tendons are usually grouted in their ducts after the stressing operations for the following reasons:

- A reliable bond between the stressed tendon and the concrete member is established (in addition to the end anchorages);
- Should unforeseen circumstances cause the ultimate strength of a member to be exceeded; a properly designed member with bonded tendons will develop many distributed small cracks and fail in a ductile manner;
- The best protection the tendon can have is to be surrounded by cement-rich grout or concrete that is well compacted and

impermeable. Steel cannot corrode in an alkaline environment except when chlorides are present. This is why the chloride content of prestressed concrete may be specified at a level below that of normal class concrete in AS 1379.

Grouting should be carried out as soon as possible after stressing. However, the tendons must not be cut, nor must the duct be grouted until final approval of the stressing has been given. Grouting should generally not be delayed for more than seven days unless special precautions are taken. The period should be shorter in cases with aggressive environments.

Specification of the grouting procedure is essential to successful grouting and should address such items as grout composition and properties, duct soundness (i.e. there should be no obstacles or grout paths between ducts), grouting sequence, grouting pressure and rate, venting, volume checks, re-grouting or topping up, communication between operators at duct inlets and outlets, and safety.

Before grouting, the duct may be tested for blockages by means of compressed air (not preferred) or water. Connections for the grout hose to the duct should be free from concrete, dirt, etc. and vents should be inspected to make certain that they can be properly closed.

In cold climates, precautions should be taken to prevent the freezing of water in the un-grouted duct. After a period of frost, care must be taken that the duct and tendon are free from ice.

All grout used for the grouting of prestressing ducts should consist of Portland cement and water and specialised admixtures. Admixtures should be free from any product liable to damage the steel or the grout itself, such as chlorides, nitrates and sulfides.

The grout is generally tested for strength, fluidity and resistance to segregation. Suitable test methods are found in AS 1012.8.3, AS 1012.9, ASTM C939 and ASTM C1741 respectively.

Grouting records should be kept for each cable, and should contain itemised information on grout properties, pump pressures, volumes, rate of progress and environmental conditions.

The approval of the grouting for cables or groups of cables should be clearly marked by authorised signatures on record sheets.

From time-to-time difficulty may be experienced in grouting, due to such problems as the grout being improperly mixed or proportioned, improper flushing prior to injection or unintended obstructions in the post-tensioning ducts. The result is that one or more tendons may become partially grouted. In order to salvage members with problems such as these, holes must be drilled into the post-tensioning duct with great care in order to not damage the tendons. The extent of the grouting or the location of possible obstructions can thus be observed. After this has been done, the ducts should be flushed with lime water and the tendons grouted, using the drilled holes as ports. Alternatively, vacuum-assisted methods can be used. This is a specialised operation to be undertaken only by skilled crews in conjunction with the designer.

6.6 SAFETY

Prestressing involves the use of very large forces and high pressures in the hydraulic pipelines. Appropriate precautions must be taken to prevent accidents as these can have very serious consequences.

A number of organisations have prepared recommendations on safety precautions during stressing. These include:

- FIB report: *'Prestressed concrete: safety precautions in post-tensioning'*, Thomas Telford, London (1989);
- *'Safety Precautions for Prestressing Operations (Post-Tensioning)',* The Concrete Society, London (1980);
- *AS 1481 – Prestressed Concrete Code* (superseded), Standards Australia (1987);
- *'Code of Practice'*, Work-cover NSW (1993);
- *'Stress Safe, Stress Smart – Prestressing of Concrete Structures'* (video), available from the major post-tensioning companies.

7. ADDENDUM: SAFETY PRECAUTIONS FOR PRESTRESSING OPERATIONS

7.1 INTRODUCTION

This addendum is reproduced from Appendix B to the superseded AS 1481 *'Prestressed Concrete Code'* and provided for guidance.

The purpose of this addendum (notes) is to state some simple but sensible precautions to ensure that stressing is carried out with the maximum consideration of important safety factors. The operations involved in tensioning and de-tensioning prestressing tendons are not dangerous – as long as sufficient care is taken. The main problems are ignorance, lack of thought, and over-familiarity.

These notes have been based on successful experience over many years and are intended for use by the supervising engineer or supervisor in charge of stressing.

The following assumptions have been made:

- Stressing operations will be carried out by experienced personnel under a competent supervisor;
- The design and construction of the units concerned is of the required high standard;
- All equipment is in full working order and properly maintained.

7.2 PRECAUTIONS TAKEN BEFORE STRESSING

General

- Ensure that sightseers are kept away from stressing operations;
- Erect stout double-faced screens at the back of the jack to form a safety barrier;
- Display a large sign, 'ATTENTION – STRESSING IN PROGRESS – KEEP CLEAR', on the outside face of the safety screen to warn workmen and passers-by;
- Fence off the area between the safety screens and the unit being stressed, so that no one can pass between them during the stressing operations;
- Always refer to the supplier's detailed instructions for the equipment being used, and follow these instructions carefully;
- Check all equipment before use and report any signs of wear or defects;
- Instruct all operatives and supervisors to wear safety helmets during stressing operations;
- Display a notice adjacent to the stressing plant, giving the maximum design load of the bed and the upper limit of the position of the centre of gravity of the stressing wires;
- Ensure that adequate precautions have been taken to restrain any possible skewing or lifting of the stressing equipment during stressing or release;
- Do not permit any welding near high-tensile prestressing steel;
- Do not permit any prestressing steel to be used for earthing electrical equipment of any kind;
- Keep all equipment thoroughly clean and in a workmanlike condition (as badly maintained equipment always gives rise to trouble and consequently is dangerous).

Handling of Materials and Equipment

- Make sure that operatives wear gloves when handling prestressing tendons;
- Temporarily suspend any other construction operations which might require a workman to stand directly behind the jack during stressing;
- Be careful when handling coils of high-tensile wire or strand as these may whip back with force if not securely bound;
- When assembling tendons, check each individual wire or strand for obvious flaws;
- Do not allow grips to be exposed to the weather and become rusty;
- See that wedges and the inside surfaces of anchorages are clean so that the wedges are free to move inside;
- Ensure that the threads of bars, nuts and couplers are cleaned and oiled, and thread-protecting wrappings removed only at the last moment before use. (Threaded bars for pre-formed ducts must have suitable protection to the thread to avoid damage by abrasion.);

- Arrange for stressing to take place as soon as possible after the grips have been positioned.

7.3 PRECAUTIONS TAKEN DURING STRESSING

Using a Prestressing Jack

- NEVER STAND BEHIND A JACK DURING STRESSING OPERATIONS;
- Do not allow operatives to become casual because they have stressed hundreds of tendons successfully before. (The forces they are handling are enormous and carelessness may lead to loss of life.);
- Regularly examine hydraulic hoses as a matter of necessity, and likewise regularly drain and filter oil in the pump reservoir;
- Use only self-sealing couplings for hydraulic pressure pipes, and take particular care that no bending stresses are applied to end connections;
- Whenever possible, use only hydraulic equipment supplied with a bypass valve that is pre-set to a maximum safety load before stressing. (The maximum safety load should not be more than 90 percent of the minimum specified ultimate strength of the tendons.);
- Check hydraulic pressure pipes for flaws or bubbles after each stressing operation;
- Double-check the grips or fixing of tendons to the prestressing jack before stressing;
- Keep the wedges clean and free from dirt, remembering that wedge teeth do not last forever;
- In systems where more than one wire or strand is gripped at a time around the body of the jack, make sure the wedge pieces are not worn. (A slip of one wire or strand may well cause overloading on the others, which may lead to failure.);
- Tension tendons to a low initial stress (say 62 MPa), and then recheck wedges, fixings and position of jack, and set the extension gauge to zero at this stage;
- Do not strike the equipment with a hammer to adjust the alignment of the jack when the load is on;
- Check the fixings at the non-jacking end;
- Ensure that a competent person is always available at the non-jacking end to check on anchorages during stressing;
- Double-check tendon fixings before releasing tensions.

Pre-Tensioning

- NEVER STAND BEHIND A JACK DURING STRESSING OPERATIONS;
- Pin-up the top wires or strands before the others, and on completion check that they have been pulled straight and are not tangled or caught up in the forms. (Pinning-up refers to the initial pull in a tendon before marking for measurement of elongation.);

  NOTE*: A pinning-up force of 2.2 kN is recommended for wire of 5 mm diameter, and a force of 4.4 kN for a strand of 12.5 mm diameter. This should be enough loading to free any tangles and clear obstructions.*
- Before tensioning, ensure that all the wires or strands are secured against the possibility of flying loose, and regard the following as safeguards:
  i. Shutters and end-plates;
  ii. Hoops and stirrups enclosing tendons;
  iii. Heavy timers laid over tendons;
  iv. Rolls of hessian laid across tendons.
- Insist that during stressing operations all personnel must stand clear;
- Insist that the operator, when stressing strands singly, must not stand directly behind grips that have recently been tensioned;
- *Stressing, multi-wire or multi-strand:* When stressing multi-wire or multi-strand, apply a small extension initially and check the line to ensure that there are no loose or caught-up wires or end-plates, and only after this inspection should the full load be applied;
- In placing the packers, take care not to score the ram of the jack;
- *Stressing, single wires or single strands:* When stressing single wires or single strands, apply the full load and

extensions to each of the wires or strands and then lock-off. The loads and extensions should then be carefully noted by the supervisor;

- Place a protective guard over the grips before starting multi-strand stressing, and immediately after single-strand stressing is completed.

Post-tensioning

- After stressing, cut off wires or strands behind the anchorages, preferably with a disc cutting tool, a cropper or a snapping-off tool;
- Ensure that a clear eye shield is worn by operatives during grouting operations;
- Before grouting, check all ducts to make sure that none are blocked;
- If possible, use only threaded connectors between grout nozzles and grouting points. (A sudden spurt of grout under pressure can cause severe injury, especially to the eyes.);
- Do not peer into duct bleeders to see if grout is coming through. (Grout may jam temporarily and, as pressure is applied, may spurt suddenly from the bleeders, or the far end of the duct, causing serious injury.);
- When grouting over railways or public roads or other public places, take precautions to see that escaping grout does not cause a hazard to traffic below.

De-tensioning

- Before de-tensioning, remove all obstructions to the free movement of the units;
- Allow the crosshead to be jacked back by only the small amount that is just sufficient to free the packers;
- De-tension slowly and evenly, as any sudden movement may cause damage to the concrete units;
- If the tendons are de-tensioned one at a time, do this in the required sequence;
- Ensure that the supervisor keeps a record book and records the following information:
    i. Date into service of all new equipment;
    ii. Dates of exchanges of equipment, wedges, barrels etc.;
    iii. Number of uses to date of wedges, barrels etc.;
    iv. Confirmation that the inspection detailed below has been carried out.
- Ensure taking the following actions:
    i. Inspect and clean all wedges after each use, and record the fact in the book provided;
    ii. Clean the teeth of the wedges with a wire brush in order to remove any dirt or rust accumulated in the valleys of the teeth;
    iii. Replace worn segments as necessary;
    iv. Coat the backs of the wedges with graphite or wax, according to the grip manufacturer's instructions.
- Return all barrels to the stores for cleaning and checking along with the wedges. As a matter of necessity when returning barrels, see that the insides of the barrels are clean and that the wedges are free to move inside the taper;
- Inspect weekly for the following:
    i. Distorted anchor-plates;
    ii. Distortion of stressing equipment, crossheads, etc.;
    iii. Any cracked welding of the equipment.

8 REFERENCES

1) AS 3600 – *Concrete structures*
2) AS 5100.5 – *Australia Bridge design, Part 5: Concrete*
3) AS/NZS 4671 – *Steel for reinforcement of concrete*
4) AS 4672.1/NZS – *Steel prestressing materials, Part 1: General requirements*
5) ACI 544.3R – *Guide for specifying, proportioning and production of fiber – reinforced concrete* (2008)
6) VicRoads Test Method RC 377.01 – *Determination of the Fibre Content of Fresh Concrete (Wash-out Method)*
7) AS/NZS 1554.3 – *Structural steel welding, Part 3: Welding of reinforcing steel*
8) AS 1012.8.3 – *Methods of testing concrete – Methods of making and curing concrete – Mortar and grout specimens*
9) AS 1012.9 – *Methods of testing concrete – Compressive strength tests – Concrete, mortar and grout specimens*
10) ASTM C939 – *Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)*
11) ASTM C1741 – *Standard Test Method for Bleed Stability of Post-Tensioning Tendon Grout*
12) AS 1481 – *Prestressed Concrete Code* (superseded), Standards Australia (1987)
13) AS/NZS 2425 – *Bar chairs in reinforced concrete, Product requirements and test methods*

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