PRE-STRESSING AND POST-TENSIONING CONCRETE

LEARNING OUTCOME

Describe the minimum requirements relating to safe methods of work whilst performing pre-stressing and post-tensioning concrete.

ASSESSMENT CRITERIA

- Describe the statutory or minimum requirements in relation to pre-stressing and post-tensioning.
- List the safety precautions required when pre-stressing concrete elements by either pre-tensioning or post-tensioning techniques
- Describe the control strategies to be adopted during work activities where pre-stressing activities are being conducted.

REFERENCES

- Work Health and Safety Regulations 2011 – for associated activities, e.g. falls, plant etc.
- Hazardous Manual Tasks Code of Practice 2011
- Managing Risks of Plant in the Workplace Code of Practice 2013
- AS 3600 Concrete Structures
- AS 3610.1 Formwork for Concrete
- AS1349 Bourdon Tube Pressure and Vacuum Gauges
- AS4672.1 Steel Pre-stressing Materials – General Requirements
- AS4672.2 Steel Pre-Stressing Materials – Testing Requirements

PRE-STRESSING AND POST-TENSIONING

PRE-STRESSED CONCRETE – GENERAL

In conventional reinforced concrete, the high tensile strength of steel is combined with concrete's great compressive strength to form a structural material that is strong in both compression and tension. The principle behind pre-stressed concrete is that compressive stresses induced by high-strength steel tendons in a concrete member before loads are applied will balance the tensile stresses imposed in the member during service.

Pre-stressing removes a number of design limitations conventional concrete places on span and load and permits the building of roofs, floors, bridges, and walls with longer unsupported spans. This allows architects and engineers to design and build lighter and shallower concrete structures without sacrificing strength.

The principle behind pre-stressing is applied when a row of books is moved from place to place. Instead of stacking the books vertically and carrying them, the books may be moved in a horizontal position by applying pressure to the books at the end of the row. When sufficient pressure is applied, compressive stresses are induced throughout the entire row, and the whole row can be lifted and carried horizontally at once.

Compressive Strength Added

Compressive stresses are induced in pre-stressed concrete either by pre-tensioning or post-tensioning the steel reinforcement.

In pre-tensioning, the steel is stretched before the concrete is placed. High-strength steel tendons are placed between two abutments and stretched to 70 to 80 percent of their ultimate strength. Concrete is poured into molds around the tendons and allowed to cure. Once the concrete reaches the required strength, the stretching forces are released. As the steel reacts to regain its original length, the tensile stresses are translated into a compressive stress in the concrete. Typical products for pre-tensioned concrete are roof slabs, piles, poles, bridge girders, wall panels, and railroad ties.
In post-tensioning, the steel is stretched after the concrete hardens. Concrete is cast around, but not in contact with un-stretched steel. In many cases, ducts are formed in the concrete unit using thin walled steel forms. Once the concrete has hardened to the required strength, the steel tendons are inserted and stretched against the ends of the unit and anchored off externally, placing the concrete into compression. Post-tensioned concrete is used for cast-in-place concrete and for bridges, large girders, floor slabs, shells, roofs, and pavements.

Pre-stressed concrete has experienced greatest growth in the field of commercial buildings. For buildings such as shopping centers, pre-stressed concrete is an ideal choice because it provides the span length necessary for flexibility and alteration of the internal structure. Pre-stressed concrete is also used in school auditoriums, gymnasiums, and cafeterias because of its acoustical properties and its ability to provide long, open spaces. One of the most widespread uses of pre-stressed concrete is parking garages.

STATUTORY REQUIREMENTS

Under section 19 of the Work Health and Safety Act 2011 (WHS Act), a person conducting a business or undertaking must ensure, so far as is reasonably practicable, the health and safety of workers and others at the workplace. This includes providing a safe work environment, safe plant and structures and safe systems of work.
Section 17 of the WHS Act requires health and safety risks arising from the work to be effectively managed by eliminating or minimising them so far as is reasonably practicable. Part 3.1 of the Work Health and Safety Regulation 2011 (WHS Regulation) sets out the requirements for duty holders to manage risks, and establishes the hierarchy of control measures that must be followed (section 36).

POST-TENSIONING / PRE-STRESSED CONCRETE ELEMENTS

Purpose

The following information provides advice on managing risks to health and safety associated with the post-tensioning of pre-stressed concrete elements.

It is particularly relevant to:

- Principal contractors with management and control of construction projects where post-tensioning is intended to take place,
- Pre-casters of concrete elements intended to be post-tensioned,
- Post-tensioning contractors, their employees and their employees' elected health and safety representatives.

It sets out recommended precautions to be taken during the manufacture and post-tensioning of concrete elements, whether precast or cast in-situ, and then erected into position.

Background

Pre-stressed concrete is a composite material which utilises the natural compressive strength of concrete, while overcoming its weakness in tension by pre-compressing the concrete before it is subjected to its full design loadings.

Pre-compressing uses the technique of anchoring tensioned tendons of strands against two faces of the concrete element. The pre-stressed concrete element can be either pre-tensioned or post-tensioned.

In post-tensioned elements, the tendons are stressed after the concrete has been cast and allowed to reach a specified strength. These tendons are contained in metal sheathing or plastic ducts embedded in the concrete between the element's ends.

The post-tensioning technique can be used for stressing pre-cast concrete elements and for concrete elements cast in-situ.

The stressed tendons may be either bonded or un-bonded. Post-tensioning with bonded tendons is a method whereby the tensioned tendons located in the ducts are grouted with a cement slurry to achieve a bond with the concrete and to control corrosion in the tendons. In Australia, bonded tendons are used almost exclusively.

Producing pre-stressed concrete elements is a specialised form of construction work requiring highly trained personnel who understand and consistently apply the techniques and necessary precautions set out in the appropriate technical manuals and handbooks.

Nonetheless, minor variations to standardised work methods and procedures may be necessary to suit particular and specific site conditions.

This information will assist in identifying likely hazards and their associated risks so that adequate and appropriate control measures can be implemented.

Preplanning and coordination

Preplanning and coordination during the various stages associated with the post-tensioning procedures are essential to ensure that the concrete element is safe and without risks to health at all stages of its construction and during its design life.

Generally, the different stages can be categorised as manufacture, transport, erection, tensioning and grouting.

Preplanning should conclude with the preparation of a Safe Work Method Statement. This should be prepared by the principal contractor, in consultation with all relevant subcontractors and health and safety representatives.

Responsibilities

While it is the responsibility of the project design engineer to ensure that the building is designed and detailed so that it can be constructed as intended, the principal contractor, in association with the design engineer, the post-tensioning contractor, the formwork installation contractor, the pre-caster and erector (if applicable), should coordinate the planning of the complete construction sequence, inclusive of stressing.

Any variations to the design specifications must be authorised by the project design engineer and included in the final drawings, issued for construction.

Principal contractors must ensure that their workers and the workers of their subcontractors involved in all of the post-tensioning stages are provided with the necessary information, instruction, training and supervision to enable them to perform their work in a manner that is safe to themselves and other persons. The various subcontractors also share this obligation in relation to their own employees.

A Job Safety Analysis (JSA) should be prepared by the post-tensioning contractor, in consultation with the workers and their elected health and safety representative, to cover all stages of their work. The JSA will assist the principal contractor and the subcontractors to:

- Identify and manage risks associated with the procurement, materials handling, installation of post-tensioning components, use of equipment and stressing operations.
- Keep abreast of the current state of knowledge within this specialised field.
- Identify general and specialist training needs for employees.
- Ensure the final approved drawings are followed and all health and safety concerns are dealt with.

The direct supervision and coordination of the stressing operations is the responsibility of the post-tensioning contractor's nominated supervisor.

SPECIFIC ISSUES

Working platforms

The design and construction of working platforms should comply with the relevant Australian Standards. For example, where scaffolds are provided, they should be constructed in accordance with AS/NZS 4576 -- 1995: Guidelines for scaffolding.

To provide a safe working environment, working platforms need adequate working space, appropriate edge protection, and safe access and egress.

They must also be designed and constructed to safely support all expected loads, including impact loads. Factors that will determine the selection of an appropriate working platform include:

- the type and number of items of stressing equipment that may be in use
- the number of people required, or likely to be, on the work platform at any one time
- the likely material storage on the platform.

The platform should be large enough to enable the operators to remain clear of anchorages during stressing, and it should be at a height which eliminates or minimises risk of injury from over-reaching or awkward postures.

Formwork

In the case of cast in-situ concrete constructions, working platforms may be built integrally with the formwork.

Design and documentation for formwork should comply with the requirements of AS/NZS 3610 -- 1995: Formwork for concrete.

There are "fast shuttering" formwork systems designed to allow removal of forms within two to three days, leaving slabs to continue their curing supported on props at up to 3 meter spacing.

Such systems may not be suitable for some post-tensioned slabs, which are usually lightly reinforced and might not have developed adequate strength to be self-supporting when forms have been removed, particularly where these slabs are likely to receive early additional loads from materials and equipment.

Formwork and propping systems should be designed by a structural engineer experienced in formwork design.

Assembled formwork and propping systems should be checked by a competent person for compliance with the formwork design drawings and documented proof of such on-site checks should be readily available.

Provisions for stressing

Anchorages for stressing should be set out and tendon spacing marked on the ends. Since the wedging forces at anchorages are high, anti-burst provisions, such as special reinforcement, need to be installed and secured into position. [Note: "Anti-burst reinforcement" is a small steel reinforcing cage located at an anchorage.]

Pre-stressing ducts should be laid in accordance with the specified profile and adequately secured. Inadequate cover to duct tubes can result in concrete blow-outs during grouting operations.

Pre-stressing safety considerations

Stressing operations and associated preparations for stressing involve a variety of tasks which, if appropriate precautions are not taken, could endanger the health and safety of workers carrying them out and/or those in the vicinity.

- The area where preparations and stressing are intended to take place must be fully barricaded with solid panels and signage prominently posted to keep un-authorised personnel clear of this area.
- All personnel involved in the tasks should wear the personal protective equipment

identified in the JSA. This will generally include safety goggles, gloves, sturdy protective footwear and safety helmets.

- All personnel involved in the tasks should have adequate training in identifying the hazards of stressing and their associated risks.

Uncoiling, Cutting and Placing Strands

- Coils are very heavy, typically weighing 3 to 4 tonnes, and therefore the structural adequacy of the area where coils are to be placed must be verified. Manual handling issues associated with handling the coils should be controlled in accordance with hazardous manual tasks risk management procedures.
- Ensure that the coils are restrained with uncut restraining straps when placing them onto the strand frame. Uncontrolled release of the coil can result in whip-back with sufficiently high force to cause serious injury.
- Strands should not be cut by heat-type cutting equipment such as oxy-acetylene or LP gas torches, as this may compromise their load-bearing capacity under tension.
- When assembling tendons, thoroughly inspect each individual wire or strand for obvious flaws.

Pushing Strands into Ducts

- All strands for each of the tendons should be pushed into place in accordance with the drawings, making sure all personnel are kept clear of the direct line of ducting to prevent injury from strands exiting from the other end of the duct.
- Once the specified number of strands is in place, ensure that a "dead end" is created for each strand by securing them at the end of the element.

(Note: "Dead end" is the end of the tendon which is anchored in the concrete beam or slab whilst stressing takes place from the opposite (live) end. Dead ends may be of a "swaged", "onion" or "H" type.)

In strand set-ups where ends will protrude above the face of the concrete element and may create a hazard, they should be boxed or barricaded to prevent injury.

Concrete Pour

Concreting may be placed with either pumps or kibbles.

When concreting is being pumped, "chairs" or other means to support concrete pump lines above the reinforcement and tendons should be in place and well secured.

Where kibbles are used to place concrete, avoid dropping concrete in one place as tendons could be displaced. Concrete should always be allowed to flow in a controlled manner.

During concrete pouring:

- Ensure that the ducts and strands are not damaged during the pour. All damage should be promptly notified to the contractor's supervisor for repair. However, concrete around the anchorages needs adequate vibration to ensure a safe and sound seating for the anchorage.
- Concrete test cylinders should be taken at agreed intervals for storing and curing on site under conditions similar to those applying to the element being poured.

Barricades

Before final stressing commences, adequate barricades should be erected at all live ends of tendons being stressed. In the case of double live end tendons, barricades are needed at both ends, even if stressing is only occurring from one end.

An adequate barricade is one that has been designed to restrain and reduce impact from strands or jacks if strands snap or release under tension or if the system fails in some other way. They are generally constructed from timber and two separated layers of 17 mm form ply sheets and are placed behind jacks during final stressing and de-tensioning.

The ply sheets if struck by a strand or anchorage failure would be pierced, preventing any rebound hazards for operators.

Stressing operations

Before stressing operations
Prior to commencing stressing operations, the post-tensioning supervisor should verify that:

- Concrete around the anchorages has been examined. The principal contractor should be notified if the concrete is of poor quality.
- All concrete test cylinders have achieved the specified strength.
- The grips in the jacks on the stressing equipment are clean and free from dirt or grit and in good condition.
- The stressing equipment, i.e. jacks and their gauges, has appropriate service records and up-to-date calibration certificates. All jacks should have a durable tag securely attached which clearly shows the following information:
    - Final stressing pressure
    - Diameter and grade of the strand for which the jack is being used
    - Jack number
    - Corresponding gauge number
    - Date calibration expires
- The operator of the stressing equipment has documented evidence of appropriate training.
- A "NO GO" area of at least 2 metres radius is in place around the anchorages at the dead and live ends, with barricades behind the line of jacks and "Stressing in Progress. Keep Clear" signage prominently displayed at all appropriate locations

During stressing operations

- Tendons should be stressed in order from the furthest to the closest reachable to ensure that no person is standing in direct line of the jack or previously stressed strands.
- Ensure stress is applied gradually and evenly to tendons.
- Ensure that the specified initial and final stressing levels are not exceeded.

After stressing operations

When stressing operations are completed:

- Gain the design engineer's approval prior to cutting off excess tendons.
- Seal anchorage recesses following approval and prior to grouting the ducts.
- Do not perform tasks requiring impact, such as hammering, drilling or coring in the vicinity until the grouting of the ducts has been completed.

Grouting

Build-up of excessive pressure during grouting can result in "blow-outs" of the concrete, which could injure personnel in the vicinity.

To prevent blow-outs:

- Ducts should be blown through to ensure there are no blockages.
- Avoid non-continuous grouting to ensure no blockages or voids are in the tubes.
- Monitor the gauge of the equipment throughout grouting to ensure that excessive pressure does not develop.
- Retain barricades used during stressing operations and also barricade at a lower level if formwork has already been removed.

PRE-TENSIONED CONCRETE

Safety

Procedures / Safety Plan to ensure the safety of all persons during production, including details of no-go zones and protective barriers to prevent injury in the event of equipment failure.

Personnel

- Details of experience of personnel supervising tensioning activities.

Tensioning Of Tendons

Details and procedures for the following:

- Details of proposed tensioning equipment to be used and proof of its ability to carry out the work.
- Calibration of equipment.
- Recording of data.
- Stressing sequence.
- Method of determination of the initial force.
- Checking for slippage and friction loss.
- Handling and storage of tendons both in the coiled and made up states.
- Safety precautions during tensioning.

Pre-tensioning - Associated Works

Details and procedures for the following:

- Fabrication and placing of tendons:
    - ensuring traceability of tendons
    - method of placing
    - layout of tendons at anchorages
    - method of deflecting tendons, if appropriate
    - protection against corrosion.

- Method of tensioning tendons:
    - sequence of tensioning (for deflected strands)
    - calculation of forces at anchorages and at member mid points
    - estimated friction losses.
- Method of transfer of pre-stress.
    - release of tendons at end of stressing bed, including sequence of release
    - release of tendons between members.

MATERIALS

Supply of Tendons

The manufacturer / processor of the tendons shall hold a valid certificate of approval issued by the Australian Certification Authority for Reinforcing Steel (ACRS). Refer to http://www.acrs.net.au.

The Contractor shall provide:

- details of the composition of the tendons;
- test results in accordance in accordance with AS 4672.2 demonstrating compliance with AS 4672.1; and
- load extension graphs covering each coil to be used, taken from 3 representative samples, each 1.4 m long, from each coil.

Provision of the ACRS certification, details of tendon composition, evidence of compliance with AS 4672.2 and load extension graphs shall constitute a **HOLD POINT**.

Welding is not be permitted on or near tendons nor shall any heat be applied to tendons. Tendons which have been affected by welding, weld splatter and/or heat will be considered as non-conforming. Flame cutting of wire or tendon within 75 mm of where the tendon will be gripped by the anchorage or jacks is not be permitted.

Traceability

Wire, strand, bars and anchorages shall be labelled in accordance with the requirements of AS 4672 or AS 1314. Individual lengths of wire, strand or bar shall be traceable from the point of manufacture of coils or lots to their final location by a unique identification number. Each coil shall be clearly identified by use of a durable metal label to enable matching with the appropriate test certificates and load-extension graphs. Wire or strand not clearly identified shall not be used.

Anchorages shall be traceable from the place of manufacture to their final location by a unique identification number.

Handling, Storage and Fabrication of Materials

Materials shall be stored and handled in such a manner so that they are not damaged, contaminated or their physical properties altered. This includes:

- storage under a waterproof shelter,
- being supported above ground level; and
- kept free of all foreign matter on the surface.

Tendons shall free of surface pitting, kinks and other damage. Ducts shall not be damaged or kinked. Anchorage steel components including threads shall be protected from corrosion by greased wrappings or plugs until required for use.

TENSIONING EQUIPMENT

Dynamometers and each set of equipment comprising, pump, jack and pressure gauges shall be calibrated by an approved laboratory immediately prior to first use and then at intervals not exceeding 6 months and the true force at the jack determined from the calibration curve.

Pressure gauges shall:

- be concentric scale type gauges complying with AS 1349;
- not be less than a nominal size of 150 mm;
- read between 50% and 80% of its full capacity when the tendon is stressed to 75% of its breaking load; and
- be fitted with safety devices to protect pressure gauges against sudden release of pressure.

The measuring equipment used shall permit tendon force and elongation to be determined to an accuracy of ± 2%.

SAFETY

The Principal Contractor's Safety Plan and / or procedures must identify and manage the hazards to site personnel, other persons who might be affected by the stressing operation and nearby property and shall take the highest standard of care to ensure the safety of all affected persons and property in accordance with the provisions of the The Work Health and Safety Act 2011 (WHS Act) and The Work Health and Safety Regulation 2011 (WHS Regulation).

The Principal Contractor shall establish no-go zones with warning signs and substantial barricades in order to provide a protective barrier for site personnel, other persons and property and to prevent the entry of un-authorised persons into the hazard zone around and behind the jacking equipment.

Jacking and other site personnel shall not be permitted to stand behind the jack or close to the line of the tendons while stressing is in progress. During stressing operations, warning signs that conform to AS 1319 shall be displayed at both ends of the member being tensioned. The stressing jack shall be adequately supported and restrained in order to ensure that it cannot cause injury to personnel operating the jacking equipment should the jack lose its grip on the tendons or should the tendon fail.

TENSIONING OF TENDONS

General

Tensioning shall be performed only by personnel experienced in this type of work. Concrete shall not be drilled or any portion cut or chipped away or otherwise disturbed after pre-stressing, unless prior approval has been obtained.

Stressing Bed and Anchorages

The bed shall be constructed such that it will withstand the concentrated loads resulting from the application of the pre-stress without settlement, deflection or distortion. The anchorages shall prevent slip occurring before transfer of pre-stress to the members.

Placing of Tendons

Suitable devices shall be provided to ensure that the correct positioning of the tendons is maintained during casting. During placement, care shall be taken to prevent tendon surface contamination with foreign substances.

Tensioning Force Required

The required force shown on the drawings shall be achieved at the middle of the member immediately after all tendons have been anchored to the ends of the stressing bed.

The jacking force applied shall allow for any anticipated slip at the anchorage devices, wedge draw-in, friction losses and temperature changes.

Unless specified otherwise, the Contractor shall carry out trial stressing operations to establish the frictional resistance and also to confirm that the stated wedge draw-in is consistent with the type of jack and operator technique proposed.

Tensioning Procedure

In order to remove slack and to lift tendons off the bed floor, an initial force shall be applied to the tendons. The force which is applied initially to take up the slack of the tendon shall be sufficient to seat the jack firmly but shall not exceed the amount normally associated with the particular method of pre-stressing.

After application of the initial force, the tendon shall be accurately reference marked at both the jacking end and the dead end of the stressing bed, and at couplers if used, and elongations, slip and draw-in measured from these reference marks.

The tensioning force applied to any tendon shall be measured by direct reading of the pressure gauges and checked by comparison of the measured elongation with the elongation calculated from the load-extension graphs

Tendon Failure

Should any tendon fail before the concrete has been placed the tendon shall be replaced. Should any tendon in any member fail after the concrete has been placed the member shall be considered as non-conforming and a **HOLD POINT** shall apply.

Transfer of Pre-stress

Prior to the transfer of pre-stress, a **HOLD POINT** shall apply.

The pre-stressing force shall not be applied to the member(s) until all the concrete in the member(s) has attained the required compressive strengths shown on the Drawings. If the member(s) has been steam cured, the pre-stressing force shall not be applied until the temperature of the concrete has cooled to ambient air temperature.

Prior to transfer of the force to the member(s), all tendons shall be checked for slip at the reference marks and any tendons showing any increase in slip shall be deemed to be non-conforming. The tendons shall be marked at each end of every member prior to transfer to allow measurement of the pull-in to the concrete. Tendons shall be released gradually in such a manner as to minimise the shock of transfer of stress to the member(s). Under no circumstances shall tendons be severed while under tension.

Unless otherwise shown on the Drawings, on completion of the transfer of pre-stress the projecting lengths of tendons shall be cut off with a high speed abrasive disc or wheel so as to be flush with the end surface of the member. Flame cutting shall not be used.

Permissible Pull-in of Tendons

The maximum pull-in at transfer of any tendon shall not exceed 3 mm at any end. Pull-in exceeding this amount shall constitute a **HOLD POINT**. The cause of excessive pull-in shall be reported and investigated. Excessive pull-in may be considered as non-conforming.

Method of Tensioning

If the stressing sequence is not shown on the Drawings, the release of pre-tensioned tendons shall be done in such a sequence that produces a minimum of eccentric force in the member.

Only under exceptional circumstances and only with prior approval shall the maximum jacking force exceed 80% of the rated capacity of the jacking equipment used, or 85% of the specified minimum ultimate strength of the tendon or 75% of the minimum ultimate strength of the bar.

If, during tensioning, the check measurement of any individual strand elongation differs from its required value by +10% or -5%, a **HOLD POINT** shall apply. If the average measured extension of a group of tendons anchored at the same anchorage differs by more than ± 7%, a **HOLD POINT** shall apply.

Cutting of Tendons

Flame cutting of strands at unit ends is not permitted. Unless shown otherwise on the drawings, strands shall be friction cut, flush with the concrete surface. The exposed ends of the tendons and the concrete surface within 50 mm of the tendons shall be abraded to provide a clean sound surface. Strand cutting and coating shall be undertaken no earlier than 3 days after de-molding of beams. A liberal coating of high build non-sagging epoxy paste shall then be applied over the ends of the tendons and abraded concrete, unless shown otherwise on the Drawings.

Data to be Recorded

The following data, where applicable, shall be recorded and submitted as soon as practicable:

- Identification number of each dynamometer, gauge, pump and jack.
- Identification particulars of tendons.
- Initial forces/pressures and elongations.
- Final forces/pressures and elongations.
- Elongations obtained at all stages during tensioning, together with corresponding forces/pressures.
- Elongations and forces/pressures when resetting of jacks is required.
- Draw-in at both ends of tendons (where applicable).
- Draw-in of auxiliary wedges at the rear of the jack (where applicable).
- Hog of individual members, measured to the nearest 1.0 mm at the mid-length point of the member, immediately after transfer of pre-stress.

Version	Date	Author
1	30/06/2018	WHSQ