A Research on :

Prestresed Concrete

(pretensioning and post tensioning)

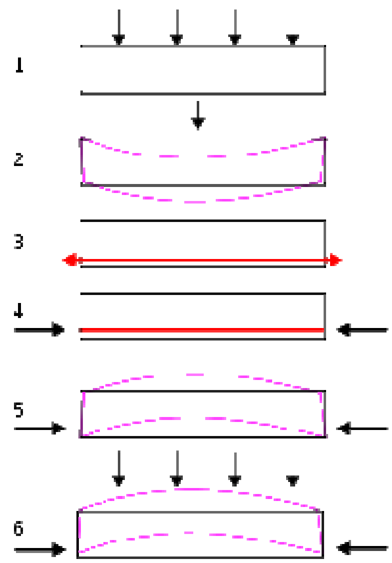
Prepared by :

ENG. JAMAL JALAL SAEED

MEMBERSHIP NO.٣٧٨٦ ... MAY ٢٠١٢

Prestressed concrete

Prestressed concrete: is a method for overcoming concrete's natural weakness in tension. It can be used to produce beams, floors or bridges with a longer span than is practical with ordinary reinforced concrete. Prestressing tendons (generally of high tensile steel cable or rods) are used to provide a clamping load which produces a compressive stress that balances the tensile stress that the concrete compression member would otherwise experience due to a bending load. Traditional reinforced concrete is based on the use of steel reinforcement bars, rebars, inside poured concrete.



Prestressed concrete diagram

Concrete compressed with heavily loaded wires or bars to reduce or eliminate cracking and tensile forces.

Concrete reinforced by either pretensioning or posttensioning, allowing it to carry a greater load or span a greater distance than ordinary reinforced concrete. In pretensioning, lengths of steel wire or cables are laid in the empty mold and stretched. The concrete is placed and allowed to set, and the cables are released, placing the concrete into compression as the steel shrinks back to its original length. In post tensioning, the steel in the concrete is stretched after the curing process. Prestressing places a concrete member in compression; these compressive stresses counteract the tensile bending stresses of an applied load.

❖ Advantages of Prestressing

The prestressing of concrete has several advantages as compared to traditional reinforced concrete (RC) without prestressing. A fully prestressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete.

The following text broadly mentions the advantages of a prestressed concrete member with an equivalent RC member. For each effect, the benefits are listed.

١) Section remains uncracked under service loads

¾ Reduction of steel corrosion

• Increase in durability.

¾ Full section is utilised

• Higher moment of inertia (higher stiffness)

• Less deformations (improved serviceability).

¾ Increase in shear capacity.

¾ Suitable for use in pressure vessels, liquid retaining structures.

¾ Improved performance (resilience) under dynamic and fatigue loading.

٢) High span-to-depth ratios

Larger spans possible with prestressing (bridges, buildings with large column-free

spaces)

Typical values of span-to-depth ratios in slabs are given below.

Non-prestressed slab ٢٨:١

Prestressed slab ٤٥:١

For the same span, less depth compared to RC member.

• Reduction in self weight

• More aesthetic appeal due to slender sections

• More economical sections.

٣) Suitable for precast construction

The advantages of precast construction are as follows.

• Rapid construction

• Better quality control

• Reduced maintenance

• Suitable for repetitive construction

• Multiple use of formwork (Reduction of formwork) .

❖ Limitations of Prestressing

Although prestressing has advantages, some aspects need to be carefully addressed.

• Prestressing needs skilled technology. Hence, it is not as common as reinforced concrete.

• The use of high strength materials is costly.

• There is additional cost in auxiliary equipments.

• There is need for quality control and inspection.

❖ Prestressing can be accomplished in two ways: **pre-tensioned concrete**, and Post**-tensioned concrete**.

١- Pre-tensioned concrete

Although prestressed concrete was patented by a San Francisco engineer in ١٨٨٦, it did not emerge as an accepted building material until a half-century later. The shortage of steel in Europe after World War II coupled with technological advancements in high-strength concrete and steel made prestressed concrete the building material of choice during European post-war reconstruction. North America's first prestressed concrete structure, the Walnut Lane Memorial Bridge in Philadelphia, Pennsylvania, however, was not completed until ١٩٥١.

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 prestressed 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.

Prestressing 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.

Pre-tensioned concrete is cast around already tensioned tendons. This method produces a good bond between the tendon and concrete, which both protects the tendon from corrosion and allows for direct transfer of tension. The cured concrete adheres and bonds to the bars and when the tension is released it is transferred to the concrete as compression by static friction. However, it requires stout anchoring points between which the tendon is to be stretched and the tendons are usually in a straight line. Thus,

most pretensioned concrete elements are prefabricated in a factory and must be transported to the construction site, which limits their size. Pre-tensioned elements may be balcony elements, lintels, floor slabs, beams or foundation piles. An innovative bridge construction method using pre-stressing is the stressed ribbon bridge design.

Stressed ribbon pedestrian bridge, Grants, Oregon, USA

- POST-TENSIONING CONCRETE

What is post-tensioning:
Post-tensioning is a method of reinforcing (strengthening) concrete or other materials with high-strength steel strands or bars, typically referred to as tendons. Post-tensioning applications include office and apartment buildings, structures, slabs-on-ground, bridges, sports stadiums, rock and soil anchors, and water-tanks. In parking many cases, posttensioning

allows construction that would otherwise be impossible due to either site constraints or architectural requirements.

Although post-tensioning systems require specialized knowledge and expertise to fabricate, assemble and install, the concept is easy to explain. Imagine a series of wooden blocks with holes drilled through them, into which a rubber band is threaded. If one holds the ends of the rubber band, the blocks will sag. Post-tensioning can be demonstrated by placing wing nuts on either end of the rubber band and winding the rubber band so that the blocks are pushed tightly together. If one holds the wing nuts after winding, the blocks will remain straight. The tightened rubber band is comparable to a post-tensioning tendon that has been stretched by hydraulic jacks and is held in place by wedge-type anchoring devices.

Forms of Prestressing Steel:

Wires

Prestressing wire is a single unit made of steel.

Strands

Two, three or seven wires are wound to form a prestressing strand.

Tendon

A group of strands or wires are wound to form a prestressing tendon.

Cable

A group of tendons form a prestressing cable.

Bars

A tendon can be made up of a single steel bar. The diameter of a bar is much larger than that of a wire.

What is tendon ?

A post-tensioning "tendon" is defined as a complete assembly consisting of the anchorages, the prestressing strand or bar, the sheathing or duct and any grout or corrosion-inhibiting coating (grease) surrounding the prestressing steel.

Stages of Loading:

The analysis of prestressed members can be different for the different stages of loading.

The stages of loading are as follows.

١) Initial : It can be subdivided into two stages.

a) During tensioning of steel

b) At transfer of prestress to concrete.

٢) Intermediate: This includes the loads during transportation of the prestressed members.

٣) Final: It can be subdivided into two stages.

a) At service, during operation.

b) At ultimate, during extreme events.

BENEFITS

To fully appreciate the benefits of post-tensioning, it is helpful to know a little bit about concrete. Concrete is very strong in compression but weak in tension, i.e. it will crack when forces act to pull it apart. In conventional concrete construction, if a load such as the cars in a parking garage is applied to a slab or beam, the beam will tend to deflect or sag. This deflection will cause the bottom of the beam to elongate slightly. Even a slight elongation is usually enough to cause cracking. Steel reinforcing bars (“rebar”) are typically embedded in the concrete as tensile reinforcement to limit the crack widths. Rebar is what is called “passive” reinforcement however; it does not carry any force until the concrete has already deflected enough to crack.

Post-tensioning tendons, on the other hand, are considered “active” reinforcing. Because it is prestressed, the steel is effective as reinforcement even though the concrete may not be cracked. Post-tensioned structures can be designed to have minimal deflection and cracking, even under full load.

Advantages of Post-Tensioning

Post-tensioning, which is a form of prestressing, has several advantages over standard reinforcing steel (rebars):

- It reduces or eliminates shrinkage cracking—therefore no joints, or fewer joints, are needed
- Cracks that do form are held tightly together
- It allows slabs and other structural members to be thinner
- It allows us to build slabs on expansive or soft soils
- It lets us design longer spans in elevated members, like floors or beams

Nature of Concrete-Steel Interface :

- Bonded tendon

When there is adequate bond between the prestressing tendon and concrete, it is called

a bonded tendon. Pre-tensioned and grouted post-tensioned tendons are bonded tendons.

- Unbonded tendon

When there is no bond between the prestressing tendon and concrete, it is called

unbonded tendon. When grout is not applied after post-tensioning, the tendon is an

unbonded tendon.

Bonded post-tensioned concrete

Prestress post-tension anchor

In bonded systems, two or more strands are inserted into a metal or plastic duct that is embedded in the concrete. The strands are stressed with a large, multi-strand jack and anchored in a common anchorage device. The duct is then filled with a cementitious grout that provides corrosion protection to the strand and bonds the tendon to the concrete surrounding the duct. Bonded systems are more commonly used in bridges, both in the superstructure (the roadway) and in cable-stayed bridges, the cable-stays. In buildings, they are typically only used in heavily loaded beams such as transfer girders and landscaped plaza decks where the large number of strands required makes them more economical.

Rock and soil anchors are also bonded systems but the construction sequence is somewhat different. Typically, a cased hole is drilled into the side of the excavation, the hillside or the tunnel wall. A tendon is inserted into the casing and then the casing is grouted. Once the grout has reached sufficient strength, the tendon is stressed. In slope and tunnel wall stabilization, the anchors hold loose soil and rock together; in excavations they hold the wood lagging and steel piles in place.

Bonded post-tensioned concrete is the descriptive term for a method of applying compression after pouring concrete and the curing process. The concrete is cast around a plastic, steel or aluminium curved duct, to follow the area where otherwise tension would occur in the concrete element. A set of tendons are fished through the duct and the concrete is poured. Once the concrete has hardened, the tendons are tensioned by hydraulicjacks that react (push) against the concrete member itself. When the tendons have stretched sufficiently, according to the design specifications, they are wedged in position and maintain tension after the jacks are removed, transferring pressure to the concrete. The duct is then grouted to protect the tendons from corrosion. This method is commonly used to create monolithic slabs for house construction in locations where expansive soils create problems for the typical perimeter foundation. All stresses from seasonal expansion and contraction of the underlying soil are taken into the entire tensioned slab, which supports the building without significant flexure. Post-tensioning is also used in the construction of various bridges, both after concrete is cured after support by falsework and by the assembly of prefabricated sections, as in the segmental bridge.

The advantages of this system over unbonded post-tensioning are:

١. Large reduction in traditional reinforcement requirements as tendons cannot destress in accidents .
٢. Tendons can be easily "woven" allowing a more efficient design approach .
٣. Higher ultimate strength due to bond generated between the strand and concrete .
٤. No long term issues with maintaining the integrity of the anchor/dead end.

Unbonded post-tensioned concrete


Tendon (cable) tails after tensioning

An unbonded tendon is one in which the prestressing steel is not actually bonded to the concrete that surrounds it except at the anchorages. The most common unbounded systems are monostrand (single strand) tendons, which are used in slabs and beams for buildings, parking structures and slabs-on-ground. A monostrand tendon consists of a seven-wire strand that is coated with a corrosion-inhibiting grease and encased in an extruded plastic protective sheathing. The anchorage consists of an iron casting and a conical, two-piece wedge which grips the strand.

Unbonded post-tensioned concrete differs from bonded post-tensioning by providing each individual cable permanent freedom of movement relative to the concrete. To achieve this, each individual tendon is coated with a grease (generally lithium based) and covered by a plastic sheathing formed in an extrusion process. The transfer of tension to the concrete is achieved by the steel cable acting against steel anchors embedded in the perimeter of the slab. The main disadvantage over bonded post-tensioning is the fact that a cable can destress itself and burst out of the slab if damaged (such as during repair on the slab). The advantages of this system over bonded post-tensioning are:

١. The ability to individually adjust cables based on poor field conditions (For example: shifting a group of ٤ cables around an opening by placing ٢ to either side).

٢. The procedure of post-stress grouting is eliminated.
٣. The ability to de-stress the tendons before attempting repair work.

Picture number one (below) shows rolls of post-tensioning (PT) cables with the holding end anchors displayed. The holding end anchors are fastened to rebar placed above and below the cable and buried in the concrete locking that end. Pictures numbered two, three and four shows a series of black pulling end anchors from the rear along the floor edge form. Rebar is placed above and below the cable both in front and behind the face of the pulling end anchor. The above and below placement of the rebar can be seen in picture number three and the placement of the rebar in front and behind can be seen in picture number four. The blue cable seen in picture number four is electrical conduit. Picture number five shows the plastic sheathing stripped from the ends of the post-tensioning cables before placement through the pulling end anchors. Picture number six shows the post-tensioning cables in place for concrete pouring. The plastic sheathing has been removed from the end of the cable and the cable has been pushed through the black pulling end anchor attached to the inside of the concrete floor side form. The greased cable can be seen protruding from the concrete floor side form.Pictures seven and eight show the post-tensioning cables protruding from the poured concrete floor. After the concrete floor has been poured and has set for about a week, the cable ends will be pulled with a hydraulic jack.

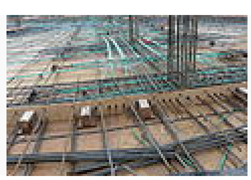
١. Rolls of post-tensioning cables

٢. Pulling anchors for post-tensioning cables

٣. Pulling anchors for post-tensioning cables

٤. Pulling anchors for post-tensioning cables

٥. Post-tensioning cables stripped for placement in pulling anchors



٦. Positioned post-tensioning cables

٧. Post-tensioning cable ends extending from freshly poured concrete

٨. Post-tensioning cable ends extending from concrete slab

٩. Hydraulic jack for tensioning cables

١٠. Cable conduits in formwork

CONSTRUCTION

In building and slab-on-ground construction, unbounded tendons are typically prefabricated at a plant and delivered to the construction site, ready to install. The tendons are laid out in the forms in accordance with installation drawings that indicate how they are to be spaced, what their profile (height above the form) should be, and where they are to be stressed. After the concrete is placed and has reached its required strength, usually between ٣٠٠٠ and ٣٥٠٠ psi ("pounds per square inch"), the tendons are stressed and anchored. The tendons, like rubber bands, want to return to their original length but are prevented from doing so by the anchorages. The fact the tendons are kept in a permanently stressed (elongated) state causes a compressive force to act on the concrete.
The compression that results from the posttensioning counteracts the tensile forces created by subsequent applied loading (cars, people, the weight of the beam itself when the shoring is removed). This significantly increases the load-carrying capacity of the concrete.

Since post-tensioned concrete is cast in place at the job site, there is almost no limit to the shapes that can be formed. Curved facades, arches and complicated slab edge layouts are often a trademark of post-tensioned concrete structures.
Post-tensioning has been used to advantage in a number of very aesthetically designed bridges.

PT Construction Basics

Construction of post-tensioned slabs on grade is very similar to using reinforcing steel, except for the tensioning step. Cables are arranged as indicated by the engineer and chaired to run through the center of the slab. For residential construction, tendons at ٤٨ inches on center are common. Commercial foundations will have much more steel. Tendons can be easily routed around obstructions.

Even congested tendons can be routed around obstructions.
Digital Concrete Scanning Services

A residential post-tensioned concrete slab will typically be ٨ inches thick and use ٣٠٠٠ psi concrete. Once the concrete has gained strength to ٢٠٠٠ psi, typically within the ٣ to ١٠ days recommended by PTI, the tendons are stressed.

Tendons today are seven high-strength steel wires wound together and placed inside a plastic duct. At each end a PT anchor is located and these are located in pockets embedded into the slab edge. When the strands are stressed, the wires will stretch—about ٤ inches for a ٥٠ foot strand—to apply ٣٣,٠٠٠ pounds of load. Stressing should only be done by qualified workers. After stressing, the tendon is cut off and the pocket in which the anchors are located is filled with grout to protect them from corrosion.

Larger structural concrete members may also be post-tensioned, especially in bridges and floors and beams in parking structures. The process is very similar to that used for slabs, except on a bigger scale. One interesting difference is that the tendons will often be "draped" so that they are low at the midpoint of a beam and high at the supports—this places the steel at the point of highest tension where it can keep the concrete held together tightly. Unbonded tendons, used in residential slabs, remain free to move within the duct and are protected from corrosion by grease.

PT tendon placement and stressing is usually done by companies with certified workers who specialize in this work.

CRITICAL ELEMENTS

There are several critical elements in a post-tensioning system. In unbonded construction, the plastic sheathing acts as a bond breaker between the concrete and the prestressing strands. It also provides protection against damage by mechanical handling and serves as a barrier that prevents moisture and chemicals from reaching the strand. The strand coating material reduces friction between the strand and the sheathing and provides additional corrosion protection.

Anchorages are another critical element, particularly in unbonded systems. After the concrete has cured and obtained the necessary strength, the wedges are inserted inside the anchor casting and the strand is stressed. When the jack releases the strand, the strand retracts slightly and pulls the wedges into the anchor. This creates a tight lock on the strand. The wedges thus maintain the applied force in the tendon and transfer it to the surrounding concrete. In corrosive environments, the anchorages and exposed strand tails are usually covered with a housing and cap for added protection.

ENSURING QUALITY CONSTRUCTION

The amount of post-tensioning strand sold has almost doubled in the last ten years and the post-tensioning industry is continuing to grow rapidly. To ensure quality construction, the Post-Tensioning Institute (PTI) has implemented both a Plant Certification Program and a Field Personnel Certification Training Course. By specifying that the plant and the installers be PTI certified, engineers can ensure the level of quality that the owner will expect. PTI also publishes technical documents and reference manuals covering various aspects of post-tensioned design and construction.

Applications - Advantages

The advantages of prestressed concrete include crack control and lower construction costs; thinner slabs - especially important in high rise buildings in which floor thickness savings can translate into additional floors for the same (or lower) cost and fewer joints, since the distance that can be spanned by post-tensioned slabs exceeds that of reinforced constructions with the same thickness.

Increasing span lengths increases the usable unencumbered floorspace in buildings; diminishing the number of joints leads to lower maintenance costs over the design life of a building, since joints are the major focus of weakness in concrete buildings.

There are post-tensioning applications in almost all facets of construction. In building construction, post-tensioning allows longer clear spans, thinner slabs, fewer beams and more slender, dramatic elements. Thinner slabs mean less concrete is required. In addition, it means a lower overall building height for the same floor-to-floor height. Post tensioning can thus allow a significant reduction in building weight versus a conventional concrete building with the same number of floors. This reduces the foundation load and can be a major advantage in seismic areas. A lower building height can also translate to considerable savings in mechanical systems and façade costs. Another advantage of post-tensioning is that beams and slabs can be continuous, i.e. a single beam can run continuously from one end of the building to the other. Structurally, this is much more efficient than having a beam that just goes from one column to the next.

Post-tensioning is the system of choice for parking structures since it allows a high degree of flexibility in the column layout, span lengths and ramp configurations. Post-tensioned parking garages can be either stand-alone structures or one or more floors in an office or residential building.

In areas where there are expansive clays or soils with low bearing capacity, post-tensioned slabs-on-ground and mat foundations reduce problems with cracking and differential settlement.

Post-tensioning allows bridges to be built to very demanding geometry requirements, including complex curves, variable super elevation and significant grade changes.

Post-tensioning also allows extremely long span bridges to be constructed without the use of temporary intermediate supports. This minimizes the impact on the environment and avoids disruption to water or road traffic below. In stadiums, post-tensioning allows long clear spans and very creative architecture. Post-tensioned rock and soil anchors are used in tunneling and slope stabilization and as tie-backs for excavations. Post-tensioning can also be used to produce virtually crack-free concrete for water-tanks.

The first prestressed concrete bridge in North America was the Walnut Lane Memorial Bridge in Philadelphia, Pennsylvania. It was completed and opened to traffic in ١٩٥١.

Prestressing can also be accomplished on circular concrete pipes used for water transmission. High tensile strength steel wire is helically-wrapped around the outside of the pipe under controlled tension and spacing which induces a circumferential compressive stress in the core concrete. This enables the pipe to handle high internal pressures and the effects of external earth and traffic loads

* Prestressed concrete is the main material for floors in high-rise buildings and the entire containment vessels of nuclear reactors.

* Unbonded post-tensioning tendons are commonly used in parking garages as barrier cable. Also, due to its ability to be stressed and then de-stressed, it can be used to temporarily repair a damaged building by holding up a damaged wall or floor until permanent repairs can be made.

Post-Tensioned Buildings

Buildings with monostrand unbonded tendons post-tensioned slabs are becoming a widely used application of prestressed concrete. This method achieves performance and construction improvements over other construction methods. However, in order to reap the benefits of this method, proficiency is required in both structural design and construction.

Post-tensioned slabs is a preferred method for industrial, commercial and residential floor slab construction. The increasingly extensive use of this method is due to its advantages and its nature of easy application to a wide variety of structure geometry and design solutions.

Prestressed floor systems using monostrand tendons may be designed as either one or two way slab systems, and may be flat plate, flat slab waffle slab, or other slab sections. The prestressing is achieved by individually tensioning tendons, placed within internally greased protected plastic sleeves, arranged in the slab prior to casting. Compressive stresses are applied to the concrete via tendon anchors. Prestressing is performed within three to seven days of casting.

Unlike the multi-strand system (which is primarily suited for beams and girders) the monostrand method allows prestressing of slabs as thin as ۱۵cm. while maintaining vertical optimal curvatures for the structure. The monostrand system is also simpler, requires less in site organization, and is more forgiving to construction variances.

Advantages afforded by unbonded slab prestressing as compared with alternative designs include:

- Increased speed of construction as prestressing allows for faster stripping and reuse of formwork.
- Thinner slabs resulting from post-tensioning by virtue of improved deflection behavior and improved section utilization.
- Improved economy due to reduced slab thickness and associated concrete costs, reducing building weight with the corresponding foundation reductions, reduced building height with the corresponding decrease in building skin area, and a reduced amount of mild reinforcing rebar.

- Large area slabs can be maintained with no control joints.
- Simpler coordination between consultants due to a flat slab underside, the design and installation of utilities systems is simpler (heating, air conditioning, sprinklers, etc.)
- Increased design flexibility allows simple solutions even for structures with irregular geometry, without the need for transverse or longitudinal beams.
- Longer spans can be achieved improving the architectural structure flexibility.
- Long-term deformations due to creep, which are usually significant in concrete slabs, are almost nonexistent in unbonded tendons prestressed slabs.
- Longer building life cycle due to the uncracked nature of the prestressed concrete. This advantage also creates slabs more resistant to water penetration, and the structure behaves monolithically.
- Post-tensioned slab on grade – by post-tensioning, large area of slab on grade for any propose, can be designed without any joint, improving performance of the slab, increasing life span and reducing maintenance cost.

IBM Building, Petach Tikva

The slabs were designed so they will enable lengthening the building in the future with monolithical connection.

- Post-tensioned slabs, no columns between the core and the exterior envelope.

Part of the slab before placing the concrete

Spans up to ١٦ meters carry heavy loads of landscaped area.

References (by internet) :

١- Prestressed Concrete.
٢- Cement and Concrete Basics.
٣- Pretensioning and post tensioning concrete.
٤- Pre-tensioning Systems and Devices.
٥- Advantage of prestressing.