Saimaa University of Applied Sciences
The Faculty of Technology, Lappeenranta
Double Degree Programme in Construction and Civil Engineering

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USAGE OF POST-TENSIONED STRUCTURES IN SAINT-PETERSBURG

Bachelor's Thesis 2011

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APPENDICES

ABSTRACT

Victoria Sulina
Usage of Post-tensioned Structures in Saint-Petersburg, 93 p., 4 apps
Saimaa University of Applied Sciences, Lappeenranta
Technology, Double Degree Programme in Civil and Construction Engineering
Bachelor's Thesis 2011
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The study was commissioned by Finnmap Consulting Oy. The purpose of this thesis was to introduce the concept of post-tensioning, applications of post-tensioning, to study calculation stages and calculation programs for post-tensioning, to show the way of normal approval process and approval process for post-tensioned structures in Saint-Petersburg.

The thesis should be of interest to design engineers working with designing of post-tensioned structures, which are going to be built in Saint-Petersburg.

The first part of the thesis contains the post-tensioning definition, advantages of post-tensioning, post-tensioning systems, stages of post-tensioning and applications of post-tensioning.

The second part includes the general information about calculation process according to Eurocode 2, stages of calculation process, calculation stages and rules in ADAPT-PT program and an example of calculation with this program.

The thesis continues by the stages of normal approval process for design documentation in Saint-Petersburg. This part includes the required documentation, verification of documentation, results of state expert examination and the order of charging for state expert examination.

The last part consists of the approval process for post-tensioned structures in Saint-Petersburg. This part consists of the procedure of development of special technical conditions, the procedure of approval process when special technical conditions are not required, the required documentation for approval process and the results of approval process.

As a result of this project, the post-tensioning concept was found out. Also the calculation process for post-tensioned structures was described. Finally, the normal approval process and approval process for post-tensioned structures were described by stages.

Keywords: Post-tensioning, Calculation, Approval process

1 INTRODUCTION

The client of this thesis is Finnmap Consulting Oy, which is part of FMC Group. Finnmap Consulting Oy is an international structural engineering company. The assignments of the company cover all areas of structural engineering. Although the company has quite a large experience of working in Russia, there is a need of the summarizing the information about post-tensioning concept, calculations for post-tensioning and the approval process of design documentation. The approval process is the main part of thesis work, which is of greatest interest to the company.

The main aims of this work are:

1. To introduce the post-tensioning concept
2. To introduce the calculations for post-tensioning and to find out the stages of calculations
3. To introduce and show stages of the normal approval process for design documentation in Saint-Petersburg
4. To introduce and show stages of the approval process of design documentation for post-tensioned structures in Saint-Petersburg.

The main problem is in state expert examination of the calculations and drawings in Saint-Petersburg state expertise centre. Because nowadays there are no new design norms for designing of post-tensioned structures. With new norms it is possible to calculate only pre-tensioned structures. So there is a necessity for Finnmap Consulting designers to know the steps of approval process in Saint-Petersburg.

The normal approval process is divided into stages, which are required for every normal object. But post-tensioned structures, according to Russian norms, are objects the reliability and safety requirements of which, set by Russian technical standards, are not sufficient. So it is needed to develop the special technical conditions for post-tensioned structures. This work shows the main steps, the required documentation, time and other conditions for understanding the approval process in Saint-Petersburg.

2 POST-TENSIONING CONCEPT

2.1 Prestressed concrete

Prestressed concrete is a combination of high strength concrete and steel strands. This combination makes very strong and good-work structures that are used in the building of roof slabs, bridge girders and railroad ties. Prestressed concrete was invented and patented in 1886 by Henry Jackson, an engineer from San Francisco. This type of concrete became the material of choice in Europe after World War II, due to the shortage of steel. The Walnut Lane Memorial Bridge, built in 1951 in Philadelphia, Pennsylvania, became the first structure in America made of this type of material.

Prestressed concrete can be created using two different methods: pre-tensioning and post-tensioning. The pretension method involves stretching high tensile steel strands between abutments located at both ends of the concrete casting bed. After the strands are taught, concrete is poured into the beds, where it surrounds and adheres to the strands. Once the concrete is dry it will have bonded to the steel. With pre-tensioning the reinforcement is prestressed in formwork, before pouring the concrete. Fixed anchorages for tendons are needed outside the formwork; therefore the method is primarily suitable for factory production of precast elements, where several units can be prestressed with the same tendons in a long line.

There are several reasons to use this type of concrete in various structures. Beams are made of prestressed concrete so they can resist stress without cracking. A pile is prestressed so it does not crumble with the forces of heavy transportation and driving.

Creating prestressed concrete using the post-tension method involves applying compression after the concrete has been poured and hardened. The concrete is poured around a curved duct that has had steel strands ran through it. Upon curing, tension is applied to the strands using hydraulic jacks. The strands are then wedged into place so the tension remains after the hydraulic jacks have been removed. With post-tensioning the reinforcement is stressed after hardening of the concrete. The anchorages are fixed into the concrete, and without need for external anchorages the method is suitable for in-situ construction.

Pre-tensioning is accomplished in a precasting plant before arriving at the job site. Post-tensioning is usually performed at the building site, especially when the structural units are too large to transport from factory to site. In most countries until recently, the most common use of prestressed concrete in buildings has been in the form of precast pre-tensioned elements, such as hollow core slabs, double T-slabs and beams of various shapes. Post-tensioning has been used mainly in bridges.

One reason for the limited application of post-tensioning in building is that the traditional systems for post-tensioning have been adapted to bridges, where the need for space, grouting and heavy stressing equipment is not a major problem. Another reason is that engineers involved in building design have been unfamiliar with post-tensioning and its potentials (Stathis N. Bousias et al., 2005).

2.2 Definition of post-tensioning

Post-tensioning is a technique of pre-loading the concrete in a manner which eliminates, or reduces, the tensile stresses that are included by the dead and live loads. Post tensioning is a method of strengthening concrete or other materials with high-strength steel strands, wires or bars. High strength steel ropes, called strands, are arranged to pass through the concrete. When the concrete has hardened, each set of strands is gripped in the jaws of a hydraulic jack and stretched to a pre-determined force. Then the strand is locked in a purpose-made device, called an anchorage, which has been cast in the concrete. The strand is thereafter held permanently by the anchorage.

The non-jacking end of the strand may be bonded in concrete, or it may be fitted with a pre-locked anchorage which has also been cast in the concrete.

The anchorage at the jacking end is called a live anchorage whereas the one at the non-jacking end is termed a dead anchorage. To allow the strand to stretch in the hardened concrete under the load applied by the jack, bond between the strand and concrete is prevented by a tube through which the strand passes. The tube, termed a duct or sheathing, may be metal or plastic pipe, or it may consist of a plastic extrusion moulded directly on the rope. If extruded, the strand is injected with rust-inhibiting grease. After stressing, the sheathing, if not of the extruded kind, is grouted with cement mortar using a mechanical pump. The terms tendon and cable, are the general names for the high strength steel lengths used in post-tensioning – equivalent to reinforcement in reinforced concrete.

Post-tensioning application includes office and apartment buildings, parking structures, slabs-on-ground, bridges, sports stadiums, rock and soil anchors, and water-tanks. In many cases, post-tensioning allows construction that would otherwise be impossible due to either site constraints or architectural requirements. There are post-tensioning applications in almost all sectors of construction. In building construction, post-tensioning allows longer clear spans, thinner slabs, fewer beams and more slender elements. Thinner slabs mean less concrete is required. On the other hand 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.

Rebar is what is called “passive” reinforcement. It does not carry any force until the concrete has already deflected enough to crack. On the other hand, post-tensioning tendons are considered “active” reinforcing. When 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.

In most countries until recently, the most common use of prestressed concrete in buildings has been in the form of precast pre-tensioned elements, such as hollow core slabs, double T-slabs and beams of various shapes. Post-tensioning has been used mainly in bridges. One reason for the limited application of post-tensioning in building is that the traditional systems for post-tensioning have been adapted to bridges, where the need for space, grouting and heavy stressing equipment is not a major problem. Another reason is that engineers involved in building design have been unfamiliar with post-tensioning and its potentials (Post-tensioning Institute, 2000).

2.3 Advantages of post-tensioning

There are post-tensioning applications and its advantages in almost all facets of construction. In building construction, post-tensioning allows longer clear spans, thinner slabs, fewer beams and more slender elements. Thinner slabs mean less concrete is required. On the other hand it means a lower overall building height for the same floor-to-floor height. (Dr. Bijan O. Aalami, 2006) 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 the major advantage in seismic areas. A lower building height can also translate to considerable savings in mechanical systems and facade costs.

Another advantage of post-tensioning is that beams and slabs can be continuous. 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 structures have improved seismic performance, because of lesser weight and shorter overturning moment arm.

From economical point of view building structures offer three key areas of advantages. The first one is the direct cost reduction. Post-tensioning offers direct cost reduction over conventionally reinforced slabs primarily by reducing concrete and rebar material quantities as well as rebar installation labor. There are several factors contributing to direct cost reduction:

- Less concrete material
- Less rebar

- Less labor cost for installation of material
- Simplified formwork leads to less labor cost
- Rapid re-use of formwork leads to less formwork on jobsite
- Reduced material handling
- Reduction in slab thickness reduces total building height and cost.

The second area of advantages is improved construction efficiency. Since post-tensioned slabs are designed to carry their own weight at time of stressing, they can significantly improve construction efficiency and deliver an additional to indirect savings. The factors contributing to improved construction efficiency are:

- Shorter construction cycles
- Less material handling
- Simpler slab soffit
- Quicker removal of shoring gives more access to lower slabs.

The third one is superior structural performance. The prestressing in post-tensioned slabs takes optimal advantage of tendon, rebar and concrete properties to deliver an economical structural system. There are several factors contributing to superior structural performance:

- Efficient use of high strength materials to achieve long spans
- Crack and deflection control – life cycle is longer
- Crack free slabs are more waterproof
- Reduced floor-to-floor height
- Economy in column and footing design.

(Partha Pratim Roy, 2011)

2.4 Post-tensioning systems

Post-tensioning construction is classified as bonded and unbonded, depending on whether the tendon ducts are filled with a mortar grout after stressing (bonded), or whether the tendons are greased and paper wrapped, greased and plastic covered or moisture tight (unbonded). Use of unbonded construction eliminates the time and cost involved in grouting which becomes an important economic factor in applications such as floor slabs of apartment buildings which usually contain a large number of small tendons. In unbonded post-tensioning system tendons remain detached from concrete along their length for the entire life of structure. In grouted (bonded) system tendons are attached to the encasing concrete along their entire length and follow the deformation of concrete.

Bonded post-tensioned systems are more commonly used in bridges, both in superstructure (the roadway) and in cable- stayed bridges, the cable- stays. In buildings bonded systems typically only used in heavily loaded beams such as transfer girders and landscaped plaza decks where the large number of strands required, which makes them more economical.

Post-tensioning systems may also be divided into three categories, depending on whether the stressing tendon is monostrand, multistrand or bar. 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 unbonded systems are monostrand (single strand) tendons, which are used in slabs and beams for buildings, parking structures and ground-slabs. A monostrand tendon consists of a seven-wire strand that is coated with corrosion-inhibiting grease and encased in an extruded plastic protective sheathing. The anchorage of unbonded tendon consists of an iron casting and a conical, two-piece wedge which grips the strand. The components for unbonded post-tensioning systems are: tendon (greased and plastic coated), anchorage casting, wedges, pocket former (grommet) to create a stressing recess and stressing equipment.

In most post-tensioned construction, the prestressing tendons are embedded in the concrete before the concrete is cast. These internally post-tensioned systems can be either bonded or unbounded. In some bridge and retrofit applications, the post-tensioning tendons are mounted outside the structural member. These are referred to as external post-tensioned systems.

Most of the internally grouted post-tensioned systems are considered to be bonded. Unbonded systems allow relative movement between the strand and surrounding concrete throughout its service life. Most single-strand systems and all external post-tensioning systems fall under this category. (Pawan R. Gupta et al., 2006, pp. 59)

2.4.1 Bonded post-tensioning systems

Bonded post-tensioning systems consist of tendons with multiple strands or bars. The strands or bars are placed in corrugated galvanized steel, high density polyethylene (HDPE) or polypropylene (PP) ducts. Depending on the site conditions and system used, the strands may be installed before the concrete is placed or the ducts can be installed without the strands. The strands are then pulled or pushed through the ducts. Once the concrete has hardened the tendons are stressed and the ducts filled with grout. Inlets and outlets are provided at high/ low points to ensure that the grout fills the ducts completely. Figure 2.1 shows the components of a typical multistrand grouted system.

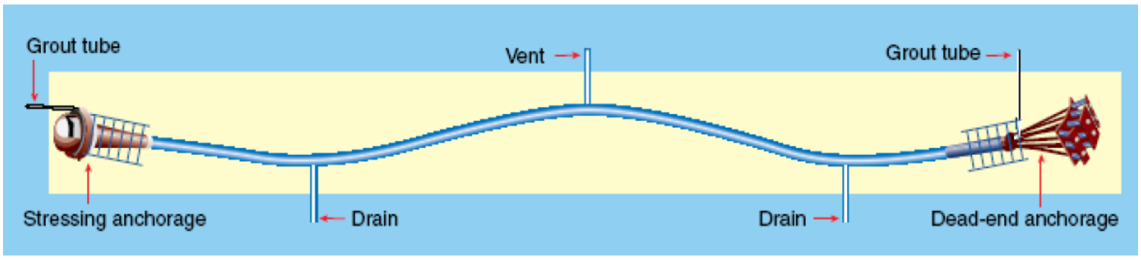


Figure 2.1 Components of a multistrand bonded system (VSL International Ltd., 2011)

The grout provides an alkaline environment and protects the prestressing strands from corrosion. It also bonds the strands to the surrounding concrete.

2.4.2 Unbonded post-tensioning systems

The tendons in an unbounded system typically consist of single-strands that are coated with a corrosion-inhibiting coating and protected by extruded plastic sheathing.

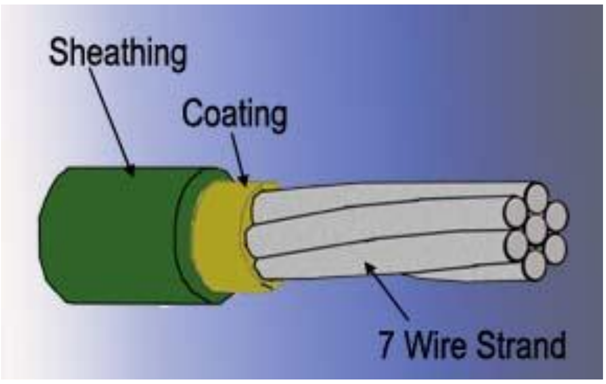


Figure 2.2 Typical components for an unbounded system (Speciality Steel, 2011)

This allows the strand to move inside the plastic sheathing and prevents ingress of water. The strands are anchored to the concrete using ductile iron anchors and hardened steel wedges. The tendon is supported by chairs and bolsters along its length to maintain the desired profile. Figure 2.2 shows the typical components and construction sequence for an unbounded system.

Depending on the exposure of the single-strand unbounded system it can be classified as a standard and encapsulated system. Encapsulated systems are required for aggressive environments where there is a possibility of tendon exposure to chlorides or other deleterious substances. Encapsulated tendons are designed to prevent any ingress of water during and after construction.
Figure 2.3 shows anchorage with encapsulated tendon.

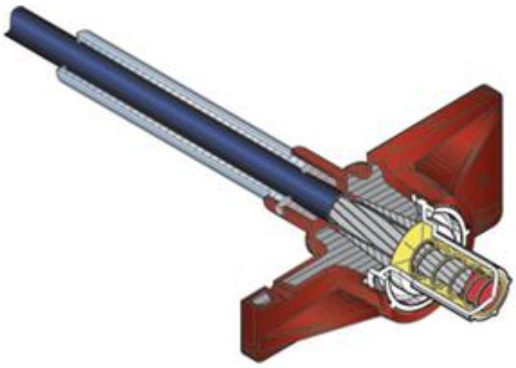


Figure 2.3 Anchorage with encapsulated tendon (General Technologies Inc., 2011)

2.4.3 Differences between bonded and unbonded systems

Unbonded systems can be with internal and external post-tensioning. Internal post-tensioning is usually applied for elements, when it is needed to increase the height of cross-section. Usually this system is applied for thin slabs and for transversal reinforcement of bridges. External post-tensioning is usually applied for bridge construction (for hollow-core prefabricated elements).

Advantages of unbonded post-tensioning:

1. Good protection against corrosion
   Prefabricated elements with double and triple corrosion protection. There are a lot of problems with corrosion in bonded elements due to injection of low quality.
2. It is possible to control the value of tensioning.
3. Limited losses due to friction
   - Friction coefficient in unbonded structures 0.05
   - Friction coefficient in bonded structures 0.20
4. Increased moment arm.

Disadvantages of unbonded post-tensioning:

1. Reduced moment arm for external post-tensioning
2. Higher amount of normal reinforcement
   Tendons have a small influence on crack formation. So it is necessary to put more normal reinforcement.

2.4.4 Load Bearing capacity

According to experience, behavior of structures (bonded and unbonded) is the same at ultimate limit state and serviceability limit state. The basic premise – for unbonded structures is needed more normal reinforcement. If this premise is not satisfied, the beams with bonded post-tensioning show better distribution of cracks, than unbonded (with insufficient amount of normal reinforcement). Beams with unbonded post-tensioning have several cracks with large width, so the life cycle of beams will be shorter. So in unbonded structures it is necessary to provide a sufficient amount of normal reinforcement. The type of post-tensioning affects on shear forces. Bonded systems work as a truss model. Unbonded systems with insufficient amount of normal reinforcement work as arch with a tie.

2.4.5 External post-tensioning

Tendons in an external post-tensioned system are installed outside the structural concrete member except at anchorages and deviation points. External tendons can be either straight between anchorages or can run through deviator blocks to create a harped profile. External tendons are used in bridges, retrofit and repair applications.

Prestressing steel used in external post-tensioned systems is either greased or plastic-sheathed (as in a typical unbounded single-strand tendon), or enclosed in a duct which is subsequently filled with grout. Greased and plastic-sheathed tendons and associated hardware are covered with a coating such as metal lath and plaster, when required to provide fire protection. Regardless of tendon coating, externally post-tensioned systems allow relative movement between the tendon and the member to which is attached and are therefore considered to be unbounded in practice.

2.4.6 Multi-strand post-tensioning

The multi-strand post-tensioning system is predominantly used in civil structures, including bridges, silos, tanks and off-shore structures. It is a robust and reliable bonded prestressing system.

The individual strands are anchored in a common anchor head with a wedge grip system and the strands are simultaneously stressed. Individual strand stressing is possible in some circumstances. After stressing, the ducting is pressure filled with a cement grout. The choice between the anchorage types depends on structural requirements, availability and dimensional constraints.

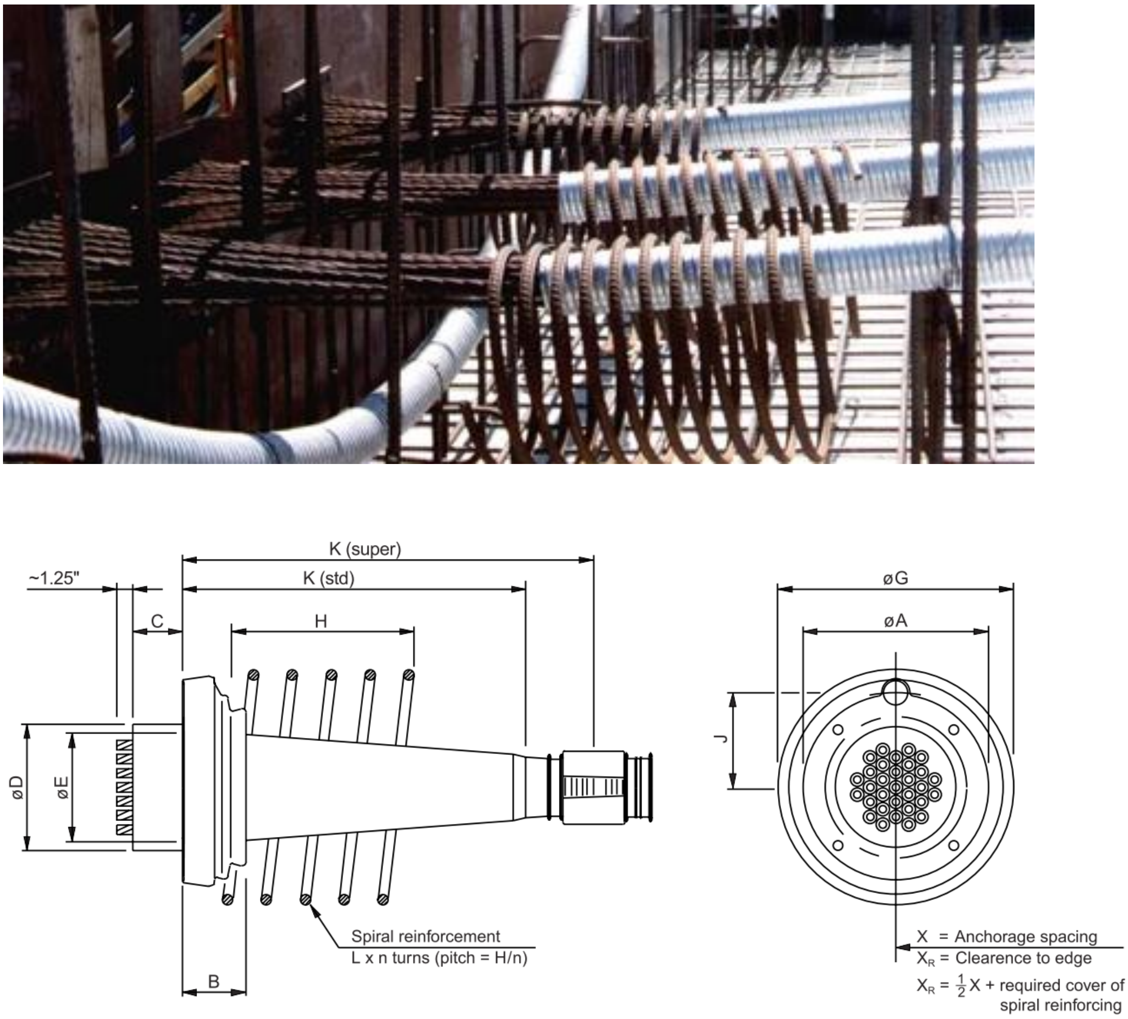


Figure 2.4 Multi-strand post-tensioning. Anchorage system (VSL International Ltd., US Technical Data and Dimensions, 2011)

The individual strands are anchored in a common anchor head with a wedge grip system and the strands are simultaneously stressed. Individual strand stressing is possible in some circumstances. After stressing, the ducting is pressure filled with a cement grout. The choice between the anchorage types

depends on structural requirements, availability and dimensional constraints. Multistrand post-tensioning is shown in Figure 2.4.

2.4.7 Monostrand post-tensioning

The monostrand post-tensioning system with unbonded greased and sheathed strand was developed to suit efficient construction methods. These light and flexible monostrands can be easily and rapidly installed and as there is no grouting can lead to economical solutions. Each end of the strand is anchored in an individual anchorage device. The following types of anchorage are available: stressing anchorage, dead end anchorage and coupler.

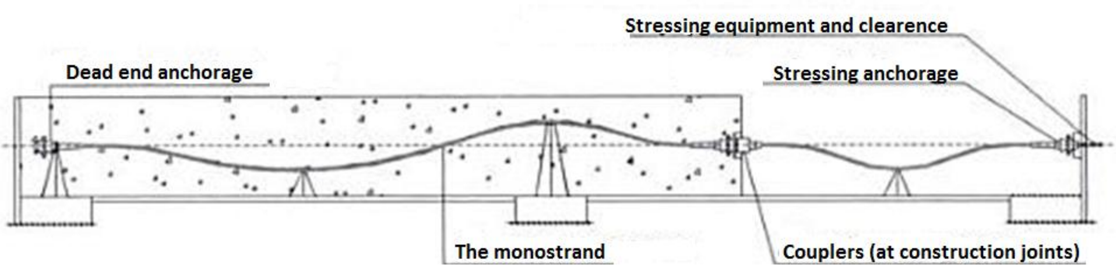


Figure 2.5 Monostrand system (Stathis N. Bousias et al., 2005)

In monostrand post-tensioning system the tendon consists of a single 7-wire steel strand, PT coating, dead end anchorage, stressing end, and intermediate anchorage for long tendons, which are shown in Figure 2.5. The plastic sheathing forms the primary corrosion protection and the corrosion preventive grease the secondary protection. Monostrand is shown in Figure 2.6.

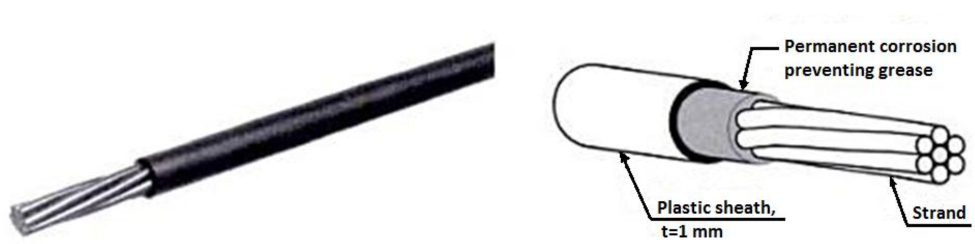


Figure 2.6 Monostrand (Stathis N. Bousias et al., 2005)

In case of bonded monostrand tendons, a corrugated metal or plastic conduit is used, which is grouted after completion of the stressing operation. A special transition piece (grout connector or grout pipe) allows for grouting.

2.5 Stages of post-tensioning

In post-tensioning systems, the ducts for tendons (or strands) are placed along with the reinforcement before the casting of concrete. The tendons are placed in the ducts after the casting of concrete. The duct prevents contact between concrete and the tendons during the tensioning operation.

Unlike pre-tensioning, the tendons are pulled with the reaction acting against the hardened concrete. If the ducts are filled with grout, then it is known as bonded post-tensioning. The grout is a neat cement paste or a sand-cement mortar containing suitable admixture.

In unbonded post-tensioning, the ducts are never grouted and the tendon is held in tension solely by the end anchorages. The following sketch shows a schematic representation of a grouted post-tensioned member. The profile of the duct depends on the support conditions. For a simply supported member, the duct has a sagging profile between the ends. For a continuous member, the duct sags in the span and hogs over the support. Figure 2.7 shows post-tensioning bonded scheme.

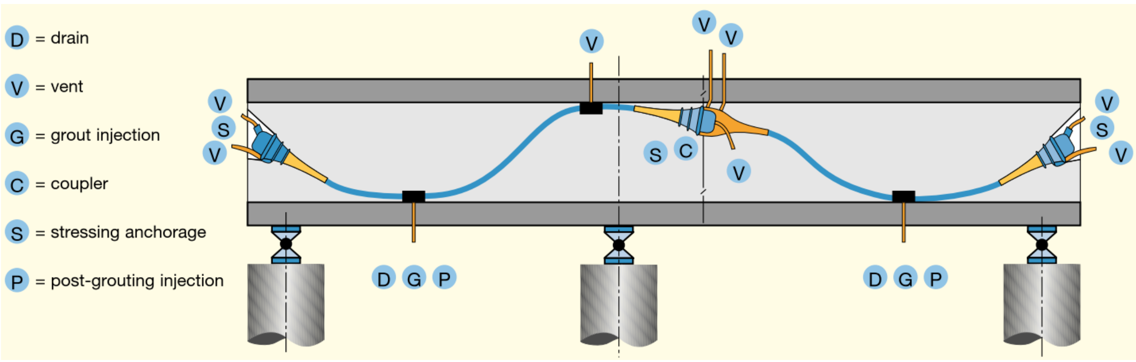


Figure 2.7 Post-tensioning bonded scheme (DYWIDAG-Systems International, 2006)

The main stages of post-tensioning in general:

1. Casting of the concrete
2. Placing of the tendons
3. Placing of the anchorage block and jack
4. Applying tension to the tendons
5. Seating of the wedges.

The stages are shown schematically in the Figure 2.8.

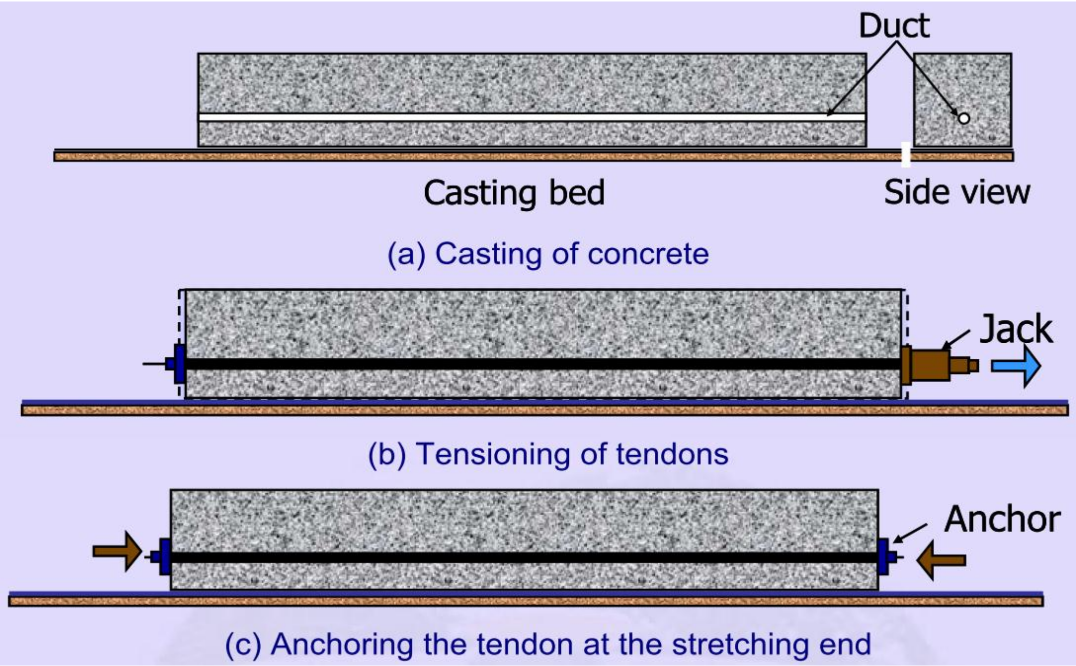


Figure 2.8 Stages of post-tensioning (Dr. Amlan K Sengupta and Prof. Devdas Menon, 2011)

After anchoring a tendon at one end, the tension is applied at other end by a jack. The tensioning of tendons and pre-compression of concrete occur simultaneously. A system of self-equilibrating forces develops after the stretching of the tendons. (Dr. Amlan K Sengupta and Prof. Devdas Menon, 2011)

2.6 Applications of post-tensioning

Apart from floor systems there are many other possible applications of post-tensioning in building structures that can result in significant savings. The list includes moment-resisting frames, shear walls, service cores, transfer beams and plates, foundations, masonry walls, hangers and ties.

2.6.1 Parking structures

Numerous post-tensioned parking structures built today are constructed as free standing structures. Others are constructed as part of hotels, condominiums, apartment and office buildings, and other facilities. The use of post-tensioning in parking structures offers several advantages, including initial and lifecycle cost savings, low maintenance costs, crack control and watertight structures, smooth riding surfaces, lighting and security, fire resistance, reduced structural depth, longer spans and other.

The Redbrook Financial Center (Figure 2.9) development in Owings Mills, Maryland included a 37700 m^2 parking structure with 4 elevated levels. The columns of the concrete structure were placed such that 18, 3 m beam spans and 8, 2 m slab bays were required. Further, the slab dimensions were 0, 2 m thick on all levels.

These dimensional constraints the use of cast-in-place post-tensioned construction. To increase the durability of the structure and mitigate deflections of the beams and slab, bonded post-tensioned systems were utilized. In general, the use of a bonded post-tensioning system resulted in the reduction of slab mild steel for the project.

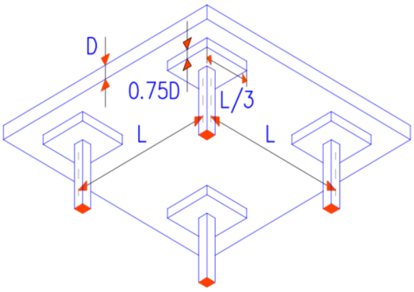
The slab tendons were partially stressed the day after each concrete pour to prevent shrinkage cracking in the slab, while stressing was completed when concrete reached a compressive strength of about 20 MPa. Grout was mixed and placed using a high performance, low-bleed grout and colloidal mixer. Trumpets with bypass pipes connected anchorages with ducts across construction joints to create continuity in the tendon through concrete pours. This allowed the contractor to grout each slab tendon from only one location. Grout vents were placed at end anchorages and at beam high points to allow air to escape and ensure the total grout encapsulation. The garage now provides over 1,500 convenient parking spaces for the tenants of the Redbrook Financial Center.

Figure 2.9 The Redbrook Financial Center parking structure, Maryland, USA (VStructural, LLC., 2010)

2.6.2 Floor systems

Floor systems can be classified in different ways, for instance insitu versus precast floors, single span versus multi span floors, and slab on beams versus two-way systems. There are two main categories, one-way systems and two-way systems. Each of these is further sub-divided into different groups, depending on whether beams are used, and if so, whether the beams are of wide shallow type often referred to as “band beams”, or conventional narrow beams. (Ed Cross, 2011)

Each of these groups can then be further sub-divided by slab type (flat solid slab, flat voided slab, with or without drop panels, ribbed slab, waffle slab, banded slab, flat plate), beam type (solid or voided beams, with or without drop panels), and construction method (different combinations of insitu and partly precast construction, including the use of steel trough decking as composite slab formwork).The three most common floor systems used for building structures such as offices, shopping centers and parking structures are the flat plate (Figure 2.11), flat slab (Figure 2.10) and banded slab (Figure 2.12). For high rise construction a fourth system is widely used which consists of band beams at relatively close spacing spanning from the building perimeter to the service core.



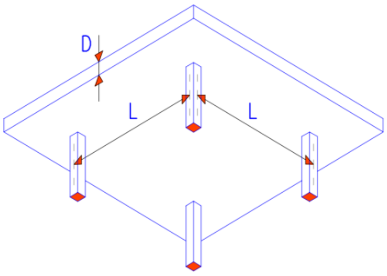


Figure 2.10 Flat slab (Ed Cross, 2011)   Figure 2.11 Flat plate (Ed Cross, 2011)

There are the specific advantages of post-tensioning floor systems:

- Reduction of structural depth results in a reduced building height and corresponding savings in cladding and vertical services, or allows to fit additional storeys into the given maximum building height
- Increase of length span allows larger column-free areas and thus more flexibility in the floor use
- Reduction of floor weight and of material consumption – the size of columns, walls and foundations is reduced and less material is used for the floor framing itself
- Flexibility in layout of services – with post-tensioning it is often possible to choose a floor system with a flat soffit while a corresponding reinforced concrete floor would need beams or ribs.

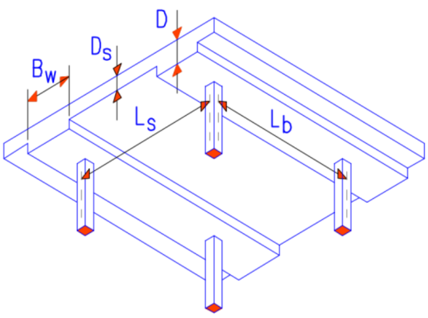


Figure 2.12 Banded slab (Ed Cross, 2011)

2.6.3 Moment-resisting frames

Moment-resisting frames consist of columns and beams rigidly connected to resist moments and shears from lateral and gravity loads. While for low-rise buildings the floor framing itself and its supporting columns may have sufficient stiffness and strength to resist wind loads, for medium and high-rise buildings it is usually necessary to provide shear walls, peripheral or internal frames, or both in order to brace the building against side sway, particularly so in seismic areas. Post-tensioning of frames has the added advantage that the stiffness is increased or, conversely, the member sizes can be reduced. Both the beams and the columns can be post-tensioned.

The beam tendons can be continuous from end to end of the frame, either with parabolic drapes to balance gravity loads, or straight in the top and bottom of the beams, or as combination of straight and draped tendons, depending on whether the design is dominated by gravity or lateral loads. The columns can either be post-tensioned by strand tendons continuous with couplers, or by stress bars coupled at every floor.

In order to reduce the construction time of moment-resisting frames, many contractors prefer to partly or completely precast the columns and beams which then only need to be erected and connected on site. In these cases post-tensioning offers the additional advantage that the prestress across the joints between precast elements provides sufficient clamping force to transfer shear in friction, avoiding reinforcing bar splices or couplers with the corresponding insitu concrete, or welded structural steel connectors. Because post-tensioned precast frames usually require only simple mortar joints they can be constructed quite expediently. There is an arrangement of post-tensioned precast frames in Figure 2.13.

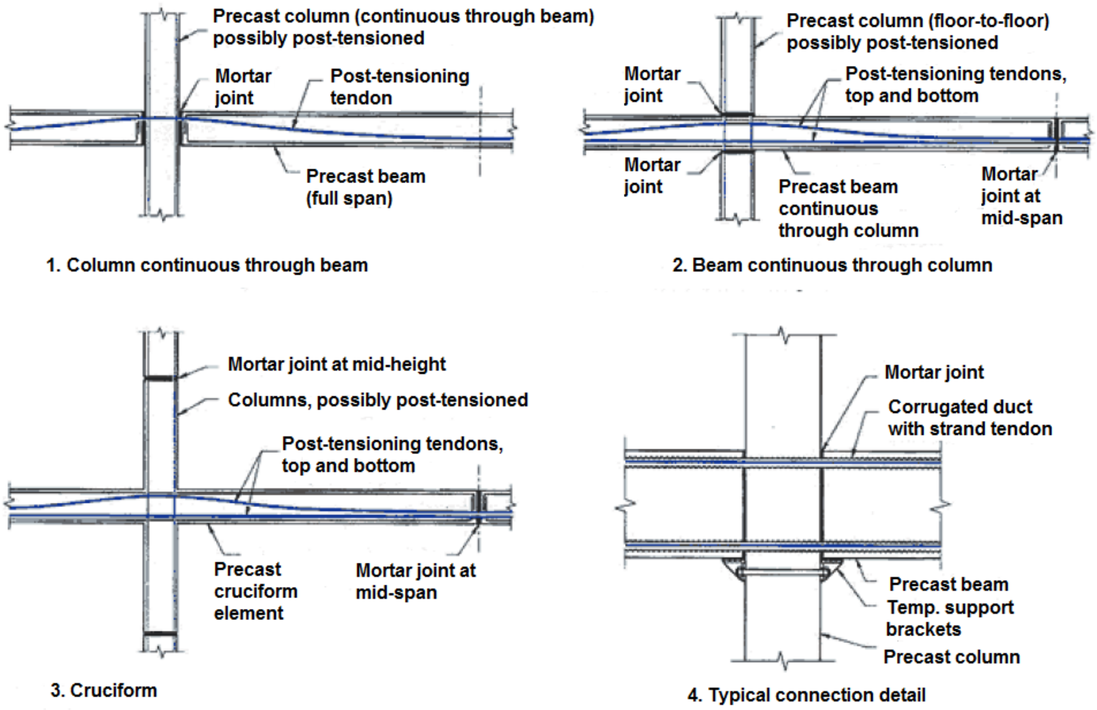


Figure 2.13 Arrangements of post-tensioned precast frames (Franz A. Zahn et al., 1992).

2.6.4 High-rise buildings example

360 Condominiums is a high-profile residential development applying an unbonded post-tensioning system in the heart of Austin, Texas. As part of the City of Austin's Green Building Program, the 44-story cast-in-place concrete structure includes environmentally friendly features such as high-efficiency air filters, an Energy Star roof, low-flow toilets, high-performance glass, low-VOC (volatile organic compounds) paints and finishes and water-efficient landscaping. In Figure 2.14 you can see this building under construction.

Using post-tensioned concrete played a major role in keeping the construction process and the structure itself green. Because of its durability, ease of production and cooling properties, concrete is already widely accepted as a viable green building material. The use of post-tensioning further elevates its environmentally-friendly status by ensuring a more efficient use of materials. It is estimated that post-tensioned concrete can save up the space per level versus traditionally reinforced concrete. The amount of concrete and reinforcement by using post-tensioned concrete for 10 floors can be enough to create an additional floor.

Figure 2.14. 360 Condominiums, Texas, USA (VStructural, LLC, 2010)

On this project, post-tensioning materials were utilized on 44 levels. In total, over 300000 meters of monostrand were installed along with 29,453 anchors. Level nine of the structure is the transfer level between the parking garage and the residential portion of the complex. The design included nine transfer girders. Stressing of the girders took place in three stages as the levels on top of the garage were constructed. At 180 meters tall, 360 Condominiums holds the distinction of being one of the tallest buildings not only in Austin, but also in the state of Texas.

In summary, the advantages of post-tensioning moment-resisting frames are:

- Increase of frame stiffness and reduction of member sizes
- Reduction of reinforcement percentages, thus simpler details and consequently faster construction cycle.

There are added advantages for frames constructed of precast elements:

- Connection possess is high strength and large stiffness
- Simple mortar joints
- No welded steel connectors with the corresponding high-level quality assurance procedures.

2.6.5 Transfer beams and transfer plates

In many high-rise hotel and office buildings large column-free lobbies are required at ground level, often extending over several floors, while the hotel or office floors above have columns and walls at much closer spacing. The transition from the small support grid to the large column spacing in the lobby is either by means of transfer beams or a transfer plate. In order to transfer the high concentrated forces from the columns and walls of the upper levels to the lower supports these beams and plates usually require considerable depths and large reinforcement quantities. Post-tensioning is a very effective way to reduce both the depth and the reinforcement content. Figure 2.15 shows the principle of a post-tensioned transfer beam. The prestressing force enables an arch system to form within the beam, transferring the column forces from the upper floors to the supports. Part of the loads, including the self-weight of the beam, is balanced by the upward acting deviation forces from the parabolic tendons.

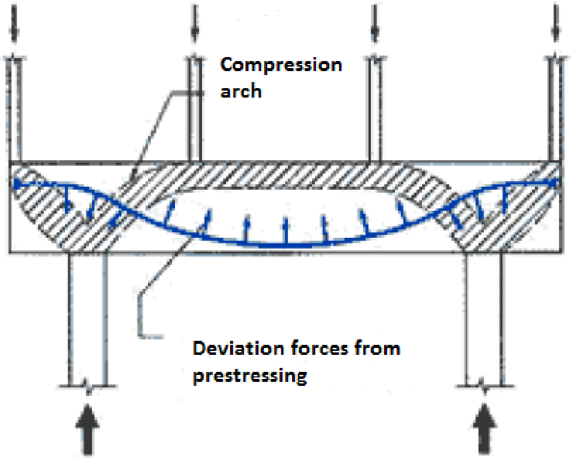


Figure 2.15 Principle of post-tensioned transfer beam (Franz A. Zahn et al., 1992).

The same principle applies to transfer plates. An example of a large transfer plate is the one used in the Pacific Place building in Hong-Kong. This 222-meter tall building consists of a large area that extends up to the 57-meter level, with residential and hotel space above. A 4.5 meter thick solid concrete slab transfers the loads from the closely spaced supports of the apartment/ hotel complex to the widely spaced supports of the commercial/ parking complex. In Figure 2.16 you can see the section with location of transfer plate. The original design as a reinforced concrete slab required almost 500 kg/m^3 of reinforcing steel. Owing to the very shear forces, a reduction of the plate thickness was not practical, but a post-tensioned alternative permitted reducing the reinforcement content to 180 kg/m^3. (Crigler, 2008)

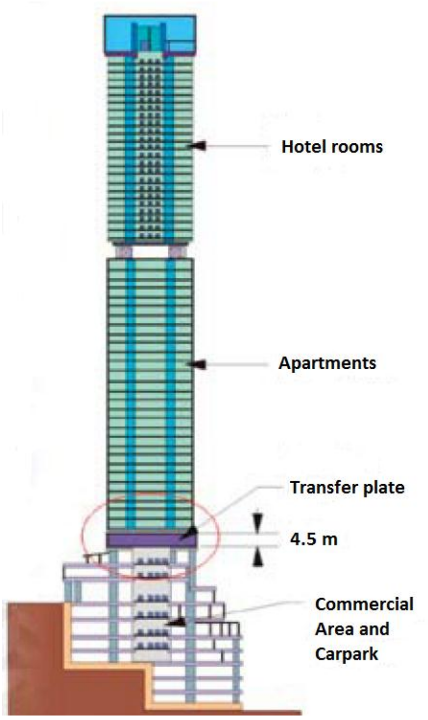


Figure 2.16 Section with location of transfer plate (Crigler, 2008)

2.6.6 Wall panels

Reinforced concrete structural walls are used to brace framed building structures against side sway. The replacement of most of the vertical reinforcement by high strength post-tensioning tendons therefore simplifies the steel fixing and thus results in overall construction time savings. Also, post-tensioning improves the cracking behaviour of concrete walls.

For walls constructed of precast panels, post-tensioning offers the added advantage that the prestress provides an active clamping force to transfer shear across the interface between two panels in friction. Only simple mortar joints are required if the panels are connected by post-tensioning. The horizontal strand tendons are continuous from end to end of the wall and are pushed or pulled into cast-in corrugated ducts. The vertical prestress is provided by stress bars coupled at mid-height of each floor. The panels must be temporarily braced for stabilization until all the tendons and bars have been stressed. (Franz A. Zahn et al., 1992).

In summary, the advantages of post-tensioned structural walls are:

- Reduction of reinforcement, simpler details and faster construction cycle
- Vertical tendons provide continuous chord reinforcement

There are advantages for walls constructed of precast panels:

- Connection possesses high strength and large stiffness
- Simple mortar joints.

2.6.7 Post-tensioned foundations and ground anchors

Post-tensioning of foundation mats or beams offers the following advantages:

- Reduction of the thickness and reinforcement quantity
- The corresponding reduction of the construction time
- The improvement of the cracking and deflection behaviour, which in turn results in an increase of the stiffness.

A special form of post-tensioned foundations are ground anchors and tension piles, which play an important role in resisting large overturning moments due to wind or earthquake loads (Figure 2.17).

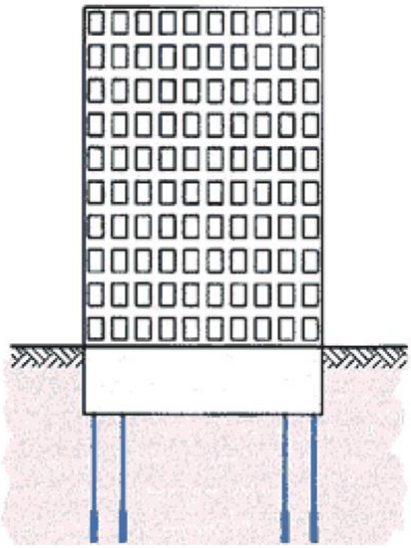


Figure 2.17 Ground anchors and tension piles (Franz A. Zahn et al., 1992).

2.6.8 Post-tensioned masonry walls

Masonry walls usually carry only small, if any, super-imposed gravity loads. Vertical post-tensioning tendons placed in the cores significantly increase the strength and ductility of masonry walls. Post-tensioning system for masonry uses unbonded greased and plastic-sheathed strands (monostrands) that are inserted into steel pipes placed in sections while the blocks or bricks are laid. Self-activating anchorages are placed at the base of the wall which grip the strands when inserted. The tendons are stressed from the top of the wall (Franz A. Zahn et al., 1992).

2.6.9 External post-tensioning

External Post-Tensioning was first used in the late 1920's but has since undergone resurgence in use in bridges, both in new construction and in strengthening of existing structures. Post tensioning as a means of strengthening existing bridges has been in use since the 1950s and there are many examples of its use throughout the world.

External post-tensioning is well adapted to bridges due to the resulting reduction of congestion inside the concrete and the high degree of corrosion resistance provided by the system. External tendons are easy to inspect and, if necessary, replace. They are ideal for strengthening existing structures and, apart from their uses in bridges, can be used for a wide range of other applications, including buildings, silos and reservoirs (VSL International Ltd., 2011).

In many situations where the technique has been applied, the prestress is applied through prestressing cables, either single or group strand. In some applications, the stress has been applied through high tensile bars, jacked either using hydraulic jacks. In a few cases the stress is applied using more unconventional techniques. For example, stress in a tendon can be developed by anchoring a straight the tendon in place and imposing a deflection at mid-span (A.F. Daly and W. Witarnawan, 1997)

2.7 Application of post-tensioning in Saint-Petersburg

Post-tensioning in Saint-Petersburg is in the development stage. The number of completed buildings with post-tensioning method is less than ten. The post-tensioning system, which is used in Saint-Petersburg nowadays, is unbonded post-tensioning system of Spanish company MEKANO 4, S.A. The company OOO KOTA has technical permition for using this system in Saint-Petersburg.
The strands used for post tensioning tendons are comprised of 7-wires low relaxation steel.

The most common diameters are 0.6” (15.2/15.7 mm) and 0.5” (12.7/12.9mm) corresponding to tensile strengths of 1770/1860 N/mm2 and 1860 N/mm2 respectively. Post-tensioned tendons are encapsulated within the deck in a duct which is usually manufactured in corrugated steel (sometimes galvanised) with a wall thickness between 0.3 mm and 0.5 mm. The ducts are normally supplied in 4-6 m lengths and are coupled on site. Ducts are injected with cementatious grout, wax or other corrosion resistant compounds after stressing.

Figure 2.18 shows a general scheme of a tendon consisting of two part tendons joined by a coupler.

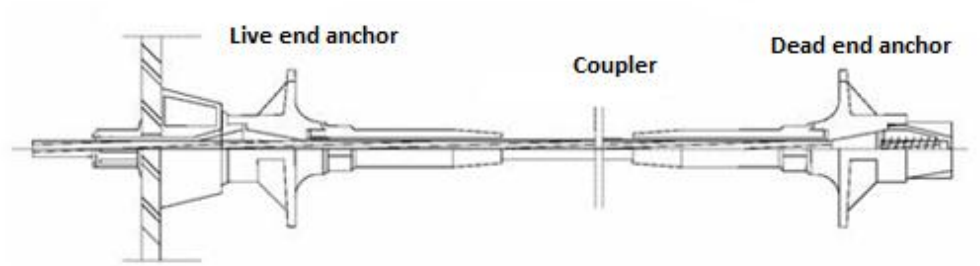


Figure 2.18 General scheme of tendon (MEKANO 4, S.A.)

Live End anchorages facilitate the introduction of a post tensioning force in the tendon with the tensioning operations carried out by hydraulic jacks. Each basic anchorage consists of a cast trumpet anchor plate and wedges. Live end anchorage for bonded systems is shown in Figure 2.19. Live end anchorage for unbonded systems is shown in Figure 2.20.

In situations where the anchorages have to be cast into the concrete or are inaccessible, a range of Dead End (Passive) anchorages is provided. These Dead End anchorages MPT comprise trumpet, anchor plate, extrusion grips and retention plate.

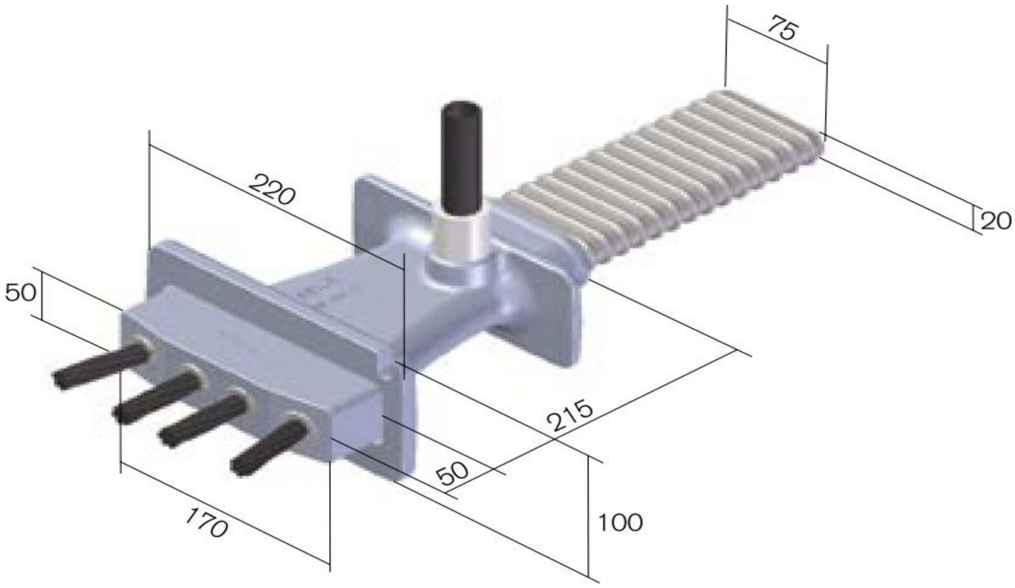


Figure 2.19 Live end anchorage for bonded systems (MEKANO 4, S.A.)

During design process of post-tensioned structures with MEKANO 4, S.A. system, it is necessary to consider the requirements of the following norms:

- SNiP 2.01.07-85 Loads and actions
- SNiP 2.03.11-85 Corrosion Protection Of Building Components
- SNiP 3.01.03-84 Survey operations in construction
- SNiP 12-01-2004 Construction management.
- SNiP 12-03-2001 Labor safety in construction industry. Part 1.
- SNiP 12-04-2002 Labor safety in construction industry. Part 2.

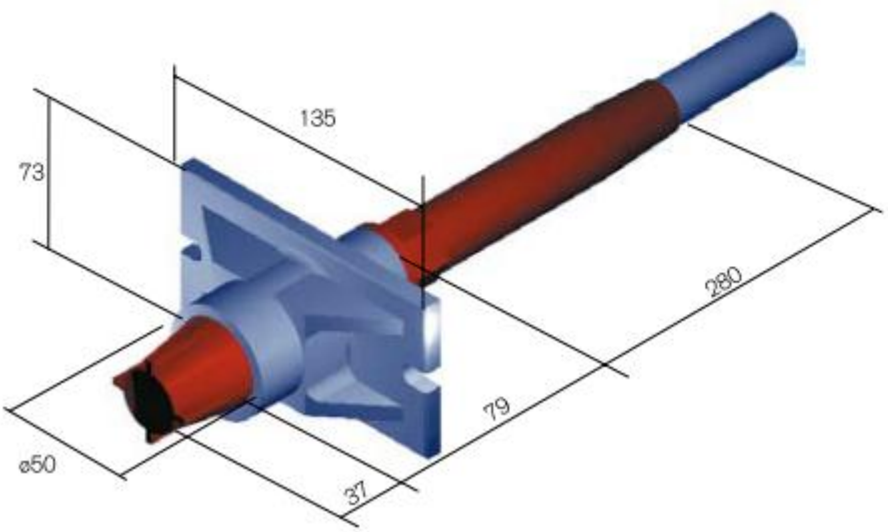


Figure 2.20 Live end anchorage for unbonded systems (MEKANO 4, S.A.)

One of the buildings in Saint-Petersburg with post-tensioning is Nokian Tyres. Design documentation was made by Finnmap Consulting Oy. Nokian Tyres mixing building is located on the Nokia tyre plant site, at the area of brickworks in Vsevolozhsk.

Building has different number of floors – two, three and five storied parts. Maximal height is 28.5 m. There is no basement in the building. Basic work material was reinforced concrete, for stiffness diaphragms – steel. Multispan cast-in-situ reinforced concrete beams JPK750*1000 (span 11400mm) with unbonded post-tensioning were used in this project. Tensioning force was 250 кN/cable (tensioning after 75% of maturing). Figure 2.21 shows Nokian Tyres completed building in Vsevolozhsk.

Figure 2.21 Nokian Tyres, Vsevolozhsk.

Tendon Tensile strength	Units N/mm2	0.6'' 1550/1770	0.6'' 1640/1860
Production		The central strand and 6 external strands	The central strand and 6 external strands
Diameter	mm	15.7	15.7
Area	mm^2	150	150
Weight without protective covering	kg/m	1.18	1.18
Fracture load F_u	kN	265.5	279
Instantaneous tension force	kN	212.5	223
Tensioning force after tension process	kN	186	195.5
Relaxation (1000 h,	%	2.5	2.5

20˚C, 70% F_u)			
Young's modulus of elasticity	N/mm^2	195 000	195 000

Table 2.1 Mekano 4 tendons (OOO KOTA,2011)

3 CALCULATIONS FOR POST-TENSIONED STRUCTURES

3.1 General information

According to Eurocode 2 the prestress is that applied to the concrete by stressed tendons. The effects of prestressing may be considered as an action or a resistance caused by prestrain and precurvature. The bearing capacity should be calculated accordingly.

In general prestress is introduced in the action combinations defined in EN 1990 as part of the loading cases and its effects should be included in the applied internal moment and axial force. The contribution of the prestressing tendons to the resistance of the section should be limited to their additional strength beyond prestressing. This may be calculated assuming that the origin of the stress/ strain relationship of the tendons is displaced by the effects of prestressing. (BS EN 1992-1-1:2004)

3.2 Prestressing force

Maximum stressing force

The maximum force applied to a tendon, P_0 (i.e. the force at the active end during tensioning) shall not exceed the following value.

$$P_0 = A_p \cdot \sigma_{0\max} \qquad (3.1)$$

where:

A p – is the cross-sectional area of the tendon

σ_{0max} – is the maximum stress applied to the tendon

$$\sigma_{0max} = 0,8 * f_{pk} \qquad (3.2) \quad \text{or}$$

$$\sigma_{0max} = 0,9 * f_{p0,1k} \qquad (3.3)$$

Whichever is the lesser is taken into the calculation.

Overstressing is permitted if the force in the jack can be measured to an accuracy of ± 5 % of the final value of the prestressing force. In such cases the maximum prestressing force P_0 may be increased to 0, 95* $f_{p0,1k}$.

3.2.1 Limitation of concrete stress

Local concrete crushing or splitting stresses behind post-tensioning anchors shall be limited in accordance with the relevant European Technical Approval. The strength of concrete at application of or transfer of prestress shall not be less than the minimum value defined in the relevant European Technical Approval.

If prestress in an individual tendon is applied in steps, the required concrete strength may be reduced linearly according to the applied prestress. The minimum strength $f_{cm}(t)$ at the time t should be 30% of the required concrete strength for full prestressing given in the European Technical Approval.
The concrete compressive stress in the structure resulting from the prestressing force and other loads acting at the time of tensioning or release of prestress, should be limited to:

$$\sigma_c \leq 0{,}6\, f_{ck}(t) \qquad (3.4)$$

where
$f_{ck}(t)$ - is the characteristic compressive strength of the concrete at time *t* when it is subjected to the prestressing force. If the compressive stress permanently exceeds *0, 45* $f_{ck}(t)$ the non-linearity of creep should be taken into account. (BS EN 1992-1-1:2004)

3.2.2. Prestressing force

In post-tensioning the prestressing force and the related elongation of the tendon shall be checked by measurements and the actual losses due to friction shall be controlled. The prestressing force at the time t = t_0 applied to the concrete immediately after tensioning and anchoring during post-tensioning shall not exceed the following value:

$$P_{m0} = A_p \cdot \sigma_{pm0} \qquad (3.5)$$

where:
σ_{pm0} – is the stress in the tendon immediately after tensioning or transfer.

$$\sigma_{pm0} = 0{,}75 \cdot f_{pk} \qquad (3.6) \qquad \text{or}$$

$$\sigma_{pm0} = 0,85 * f_{p0,1k} \qquad (3.7)$$

where:

f_{pk} - is the ultimate strength of the tendon

$f_{p0,1k}$ - is the 0, 1% proof stress of the tendon

Whichever is the lesser σ_{pm0} is taken into the calculation.

At a given time *t* and distance *x* (or arc length) from the active end of the tendon, the prestressing force *P(x, t)* is equal to the maximum force P_{m0} imposed at the active end, less the losses. When determining the prestressing force P_{m0} the following influences shall be considered:

- elastic deformations ΔP_c
- short term relaxation ΔP_r
- losses due to friction $\Delta P_{\mu(x)}$
- anchorage slip ΔP_{s1}.

The mean value of the prestressing force $P_{m,t}$ at the time $t > t_0$ shall be determined with respect to the prestressing method. The losses of prestress as a result of creep and shrinkage of the concrete and the long term relaxation of the prestressing steel shall be considered. (BS EN 1992-1-1:2004)

3.3 Losses of prestress

The designer's attention is drawn to the need to allow for losses of prestress when calculating the design forces in tendons at the various stages considered in the design. The causes of the losses are listed in EC2. Because of the uncertainty in estimating such losses, it is suggested that experimental evidence should be used where it is available. In the absence of such data, EC2 suggests values for the various parameters that can be used for design.

3.3.1 Immediate losses due to the instantaneous deformation of concrete

Account should be taken of the loss in tendon force corresponding to the deformation of concrete, taking account the order in which the tendons are stressed. This loss, ΔP_c, may be assumed as a mean loss in each tendon as follows:

$$\Delta P_c = A_p \cdot E_p \cdot \sum \left[\frac{j \cdot \Delta\sigma_c(t)}{E_{cm}(t)}\right] \qquad (3.8)$$

where:

$\Delta\sigma_c(t)$ – is the variation of stress at the centre of gravity of the tendons, applied at time j – is a coefficient equal to $(n-1)/2n$, where n is the number of identical tendons successively prestressed. As an approximation this may be taken as 1/2.

1 – for the variations of permanent actions applied after prestressing

3.3.2. Losses due to friction

Eurocode 2 specifies the standard formula for calculating the force lost in overcoming duct friction when the tendon is stressed. The losses due to friction

$$\Delta P_{\mu}(x) = P_0(1 - e^{-\mu(\theta + kx)}) \qquad (3.9)$$

where:

θ – is the sum of the angular displacements over a distance x (irrespective of direction or sign)

μ – is the coefficient of friction between the tendon and its duct

k – is an unintentional angular displacement (per unit length)

x – is the distance along the tendon from the point where the prestressing force is equal to P_0.

The values μ and *k* are given in the relevant European Technical Approval. The value μ depends on the surface characteristics of the tendons and the duct, on the presence of rust, on the elongation of the tendon and on the tendon profile. The value *k* for unintentional angular displacement depends on the quality of workmanship, on the distance between tendon supports, on the type of duct or sheath employed, and on the degree of vibration used in placing the concrete. There are the coefficients of friction μ of post-tensioned tendons and external unbonded tendons in the Table 3.1.

	Post-tensioned tendons[1)]	External unbonded tendons			
		Steel duct/ non lubricated	HDPE duct/ non lubricated	Steel duct/ lubricated	HDPE duct/ lubricated
Cold drawn wire	0,17	0,25	0,14	0,18	0,12
Strand	0,19	0,24	0,12	0,16	0,10
Deformed bar	0,65	-	-	-	-
Smooth round bar	0,33	-	-	-	-
[1)]for tendons which fill about half of the duct					

Table 3.1 Coefficients of friction of post-tensioned tendons and external unbonded tendons (BS EN 1992-1-1:2004)

In the absence of more exact data in a European Technical Approval, values for unintended regular displacements will generally be in the range 0,005< k< 0,01 radians per meter may be used. For external tendons, consisting of parallel wires or strands, the losses of prestress due to unintentional angles may be ignored.

3.3.3. Losses at anchorage

Account should be taken of the losses due to wedge draw-in of the anchorage devices, during the operation of anchoring after tensioning, and due to the deformation of the anchorage itself. Values of the wedge draw-in are given in the European Technical Approval.

Eurocode 2 mentions this cause of loss of prestressing force, but does not specify the values to be used. Appropriate values can be obtained from the anchorage manufactures and should be checked on site, particularly if the member is short, when the loss due to this cause can be critical.

3.3.4 Long term losses

The long term losses may be calculated by considering the following two reductions of stress:

- due to the reduction of strain, caused by the deformation of concrete due to creep and shrinkage, under the permanent loads
- the reduction of stress in the steel due to the relaxation under tension

The relaxation of steel depends on the reduction of strain due to creep and shrinkage of concrete. This interaction can generally and approximately be taken into account by a reduction factor 0, 8. Formula (3.11) shows a simplified method to evaluate long term losses at location x under the permanent loads.

$$\sigma_{p,c+s+r} = \frac{\varepsilon_S(t,t_0)E_p + 0{,}8\Delta\sigma_{pr} + \alpha\varphi(t,t_0)(\sigma_{c(g+q)} + \sigma_{cp0})}{1+\alpha\frac{A_p}{A_c}(1+\frac{A_c}{I_c}z_{cp}^2)[1+0{,}8\varphi(t,t_0)]} \qquad (3.10)$$

where

$\sigma_{p,c+s+r}$ – variation of stress in the tendons due to creep, shrinkage and relaxation at location x, at time t

$\varepsilon_s(t,t_0)$ – estimated shrinkage strain

$\alpha \quad E_p/E_{cm}$

E_p – modulus of elasticity for the prestressing steel

E_{cm} – modulus for elasticity for the concrete

$\Delta\sigma_{pr}$ – determined for a stress of $\Delta\sigma_p = \Delta\sigma_{p(g0+q)}$

where

$\Delta\sigma_{pg0}$ – is the initial stress in the tendons due to prestress and quasi-permanent actions

$\varphi(t,t_0)$ – creep coefficient at a time t and load application at time t_0

$\sigma_{c(g+q)}$ – stress in the concrete adjacent to the tendons, due to self-weight and any other quasi-permanent actions

σ_{cp0} - initial stress in the concrete adjacent to the tendons, due to prestress

A_p – area of all the prestressing tendons at the level being considered

A_c – area of the concrete section

I_c – second moment of area of the concrete section

z_{cp} – distance between the centre of gravity of the concrete section and the tendons

Compressive stress and the corresponding strains should be used with a negative sign. Formula (3.11) applies for bonded tendons when local values of stresses are used. The mean values should be calculated between straight sections limited by the idealized deviation points for external tendons or along the entire length in case of internal tendons. (BS EN 1992-1-1:2004)

3.4 Effects of prestressing at ultimate limit state

In general, the design value of the prestressing force may be determined by:

$$P_d = \gamma_p P_{m,t} \quad (3.11)$$

For prestressed members with permanently unbonded tendons, it is generally necessary to take the deformation of the whole member into account when calculating the increase of the stress in the prestressing steel. If no detailed calculation is made, it may be assumed that the increase of the stress from the effective prestress to the stress in the ultimate limit state is 5%.

If the stress increase is calculated using the deformation state of the entire system the mean values of the material properties should be used. The design value of the stress increase

$$\Delta\sigma_{pd} = \Delta\sigma_p \cdot \gamma_{\Delta p} \quad (3.12)$$

shall be determined by applying partial safety factors as follows:

$\gamma_{\Delta P,sup} = 1{,}2$

$\gamma_{\Delta P,inf} = 0{,}8$

If linear analysis with uncracked sections is applied, a lower limit of deformations may be assumed and

$\gamma_{\Delta P,inf} = 1{,}0$ or $\gamma_{\Delta P,sup} = 1{,}4$ may be used. (BS EN 1992-1-1:2004)

3.5 Effects of prestressing at serviceability limit state and limit state of fatigue

For serviceability calculations, allowance shall be made for possible variations in prestress. Two characteristic values of the prestressing force at the serviceability limit state are estimated from:

$$P_{k.sup} = r_{sup} \cdot P_{m,t} \quad (3.13)$$

$$P_{k.inf} = r_{inf} \cdot P_{m,t} \quad (3.14)$$

where:

$P_{k.sup}$ is the upper characteristic value

$P_{k.inf}$ is the lower characteristic value

In general the following assumed values for r_{sup} and r_{inf} are considered to be sufficient:

$r_{sup} = 1{,}05$ and $r_{inf} = 0{,}95$ for unbonded tendons

$r_{sup} = 1{,}10$ and $r_{inf} = 0{,}90$ for post-tensioning with bonded tendons

3.6 Arrangement of prestressing tendons and ducts

The ducts for post-tensioned tendons shall be located and constructed so that:

- The concrete can be safely placed without damaging the ducts
- The concrete can resist the forces from the ducts in the curved parts during and after stressing
- No grout will leak into other ducts during grouting process

Bundled ducts for post-tensioned members should not normally be bundled except in the case of a pair of ducts placed vertically one above the other. The minimum clear spacing between ducts should be in accordance with that shown in Figure 3.1.

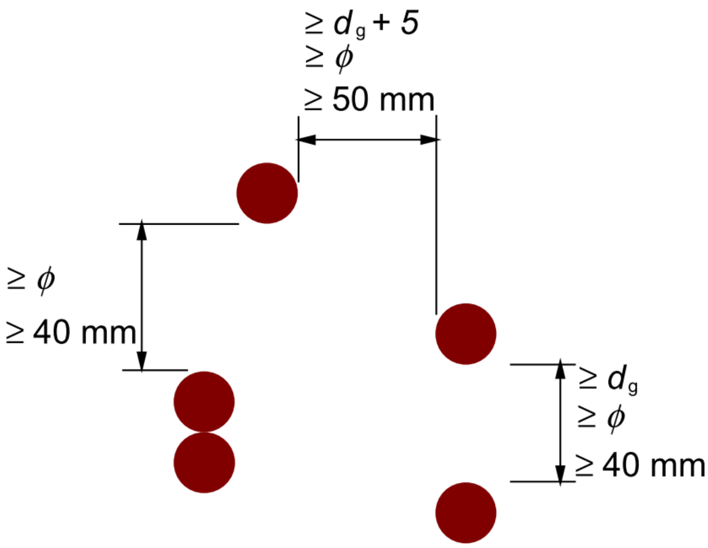


Figure 3.1 Minimum clear spacing between ducts. (BS EN 1992-1-1:2004)

3.6.1 Minimum cover, c_{min}

In order to transmit bond forces safely and to ensure adequate compaction, the minimum cover should not be less than the value for post-tensioned structures:

- Circular duct for bonded tendons: diameter of the duct
- Rectangular duct for bonded tendons: lesser dimension or 1/2 greater dimension but not less than 50 mm

There is no requirement for more than 80 mm for either type of duct.

3.7 Anchorage zones of post-tensioned members

The design of anchorage zones should be in accordance with Eurocode 2 rules. When considering the effects of the prestress as a concentrated force on the anchorage zone, the design value of the prestressing tendons should be in accordance with partial factors of prestress and the lower characteristic tensile strength of the concrete should be used.

3.7.1 Partial factors for prestress

Prestress in most situations is intended to be favourable and for the ultimate limit state verification the value of γ_p should be 1, 0 (see Table 3.1).

The design value of prestress may be based on the mean value of the prestressing force (see EN 1990 Section 4)

Design situations	γ_p for prestress
Persistent and Transient	1,00
Accidental	1,00

Table 3.2 Partials factors for prestress actions (BS EN 1992-1-1:2004)

In the verification of the limit state for stability with external prestress, where an increase of the value of prestress can be unfavourable, a value of 1,30 for γ_p should be used. This value may be reduced to 1, 2 in the verification of local effects. For the serviceability limit state the value of γ_p should be 1,0.

The bearing stress behind anchorage plates should be checked in accordance to 6.7 of Eurocode 2.Tensile forces due to concentrated forces should be assessed by a strut and tie model, or other appropriate representation (see 6.5 of Eurocode 2). Reinforcement should be detailed assuming that it acts at its design strength. If the stress in this reinforcement is limited to 300 MPa no check of crack widths is necessary.

As a simplification the prestressing force may be assumed to disperse at an angle of spread 2β (see Figure 3.2), starting at the end of the anchorage device, where β may be assumed to be arc tan 2/3.

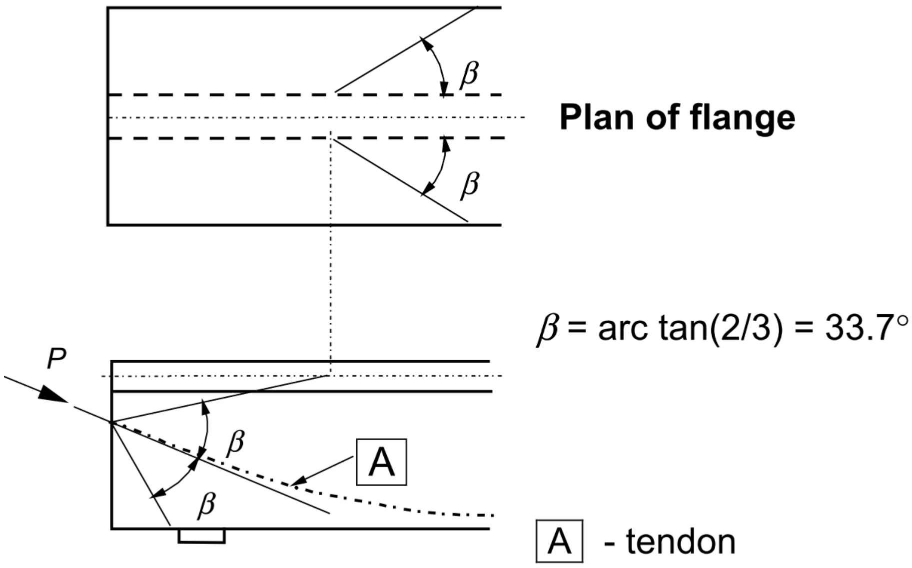


Figure 3.2 Dispersion of prestress (BS EN 1992-1-1:2004)

3.8 Stages of loading

In a post-tensioned concrete member, some or all of the reinforcing steel is put into tension shortly after the concrete is placed and hardened, by elongation it with hydraulic jacks and anchoring it against the concrete with mechanical anchorage devices. This induces compressive forces and bending moments into the concrete, precompressing areas of the cross section that will be subsequently subjected to tensile stresses from applied loads. This greatly increases the applied load producing first flexural cracking, and results in greater efficiency in resisting stresses resulting from applied loads.

Post-tensioned concrete members are investigated at three distinct loading stages:

1. At transfer of prestress force:
    - Behavior is elastic; plane sections remain plane; stresses are proportional to strains.
    - Prestress force is maximum before any short or long term losses.
    - Applied loading is minimum (no live or super imposed dead load).
    - Flexural stresses are limited to permissible values.
2. Under service loading
    - Behavior is elastic; plane sections remain plane; stresses are proportional to strains

- Applied loading is full unfactored dead and live loads. Live loads depend on occupancy
- Prestress forces are at effective levels, after all short and long-term losses.

3. At nominal strength:
    - Behavior is inelastic; plane sections are assumed to remain plane but are not proportional to strains
    - Applied loading is full factored dead and live loads
    - Prestress forces are at nominal strength levels.

3.8.1 Analysis and design

The structural analyses of a post-tensioned concrete member involve the systematic engineering examination of an existing or proposed member where all geometry, loading reinforcing, and other properties are known. The structural design of the member involves starting with architectural criteria for geometry (spans and permissible depths) and occupancy (loading), and determining, by iteration, the final dimensions, material properties, and reinforcing.

Although all structural design involves an iterative process of simply guessing an initial design, a starting point, then analyzing the design, modifying it based on the results of the analysis, and performing the analysis again on modified design. This cycle continues until the designer is satisfied with the final design. The number of iterations involved in the design process is a function of how closely the initial “guess” resembles the final design.

3.9 Post-tensioning design stages

Preliminary steps:

1. Member thickness
2. Cover to rebar and prestressing.

Computational steps:

1. Geometry and structural system

2. Material properties
3. Loading
4. Design parameters
5. Actions due to dead and live loading
6. Actions due to post-tensioning
7. Stress check for serviceability
8. Minimum passive reinforcement
9. Strength calculation for bending
10. Punching shear check
11. Deflection check
12. Stresses at transfer
13. Tendon and reinforcement layout
14. Comparison of hand (simple frame analysis) and computer (equivalent frame method) solutions.

    (Dr. Bijan O. Aalami, 2004)

3.10 Calculation program for post-tensioned structures

ADAPT-PT is the state-of-the-art industry standard computer program for the analysis and design of one-way or two-way post-tensioned floor systems and beams. ADAPT-PT is a Windows-based program. It is based on a single story frame analysis with upper and lower columns. There is a user interface in the Figure 3.3.

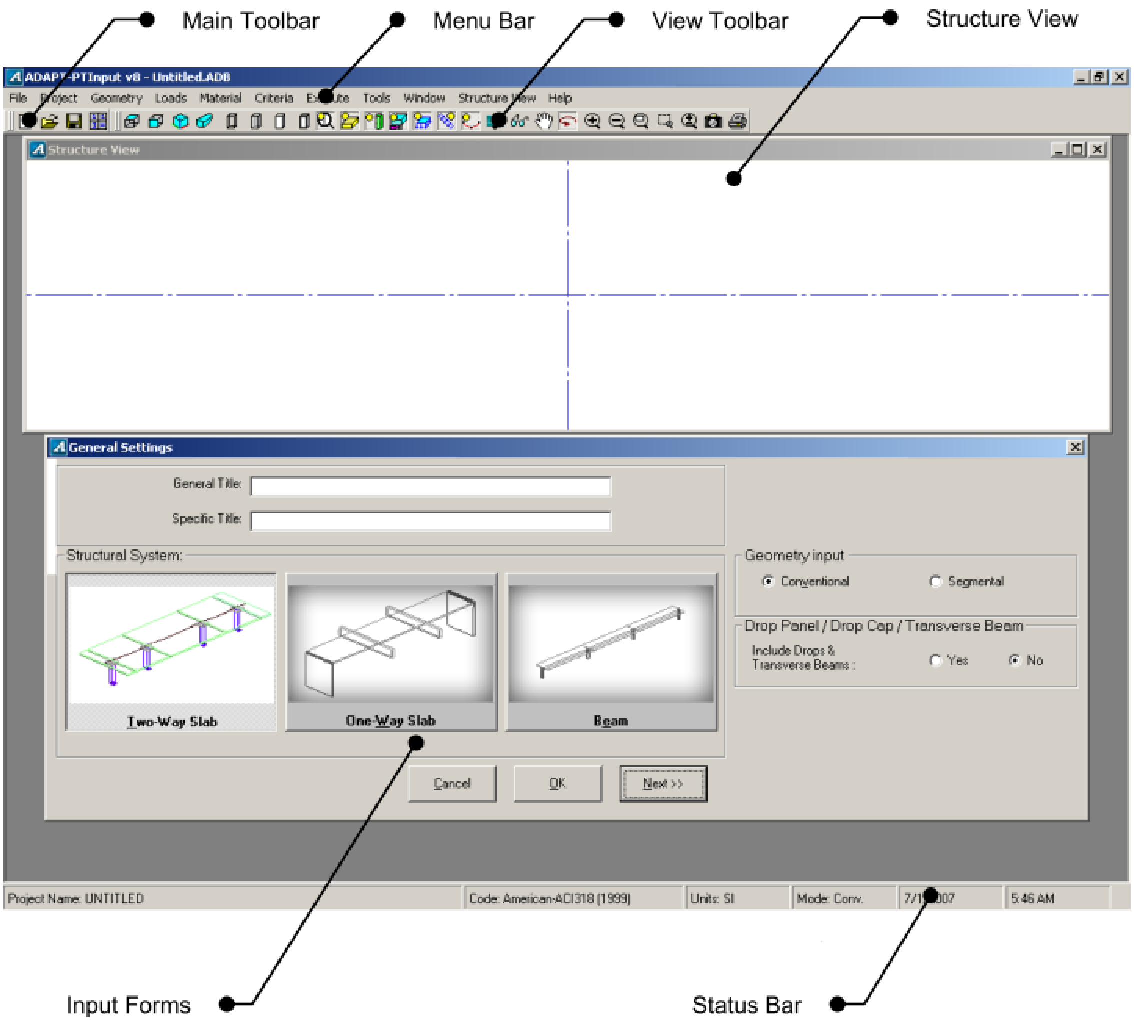


Figure 3.3 User interface of ADAPT-PT (ADAPT-PT, 2010)

ADAPT-PT allows drop panels of different sizes to be specified for different supports. Having a general frame analysis module for variable sections, ADAPT-PT can accurately model a wide range of drop cap or panel geometries. Also, special modeling features implemented in the program facilitate the modeling of local thickening in the slab along the line of columns, generally referred to as slab bands.

The slab/beam frame may be supported by walls, beams, or columns with different connection details such as clamped, rotational, free and more.
Box girder bridge sections can be readily modeled as equivalent I-sections. ADAPT-PT is well suited for a first design of box girder bridges, where an initial

estimate of the amount and location of prestressing is sought to achieve given stress levels and design criteria.

The program recognizes and accounts for the difference between the effective width in bending and pure compression. Using the geometry of the structural model input by the user, the program calculates the selfweight loading of the structure for combination with other loads. The calculated values of the selfweight are reported in the program's output. All the three systems of units—the American customary units (ft-lb), SI units (mm, Newton), and the MKS units (m, kg)—can be executed from the same copy of the software. Also, all the different codes are integrated into a single version.

A library of tendon profiles allows the user to select a suitable tendon layout for each particular case. Common profiles included are the simple parabola, reversed parabola, simple parabola with straight portions over the supports, harped, strait and extended reversed parabola tendons. Low relaxation and stress-relieved strands, as well as unbonded and grouted post-tensioning systems, are also supported by ADAPT-PT.

Uniform, line, partial, concentrated loads and moment, triangle, variable and trapezoidal loads may be specified in practically unlimited numbers and variations. ADAPT-PT accounts for the shift in the location of the neutral axis of a member at changes in cross-section along the member length. Thus, the program can correctly handle steps along a member.

ADAPT-PT executes either automatically or interactively. In its automatic mode, based on user's specifications, the software determines the required post-tensioning and the associated reinforcement. In its interactive mode, the program displays the calculated required post-tensioning on the screen to the user. There is the option to modify both the forces and the drapes during the program execution, and recycle the selection until a satisfactory design is obtained. Or, it is possible to input the conditions of an existing design. ADAPT-PT allows to select the actual number and position of strands along a member.

In the interactive mode, users can graphically view the distribution of stresses, tendon profile and the required post-tensioning. This provides a good guide for users to achieve an optimum design.

Stresses are computed and reported using the actual forces and drapes selected. This feature distinguishes ADAPT-PT from simple programs, where a single-pass analysis is performed, in which the option of the user-initiated changes in post-tensioning are not reflected in the subsequent calculations. ADAPT-PT has a multi-pass processor. It updates all the design values based on changes made in the tendon profile and force before it concludes its report of design values.

Serviceability design of the slab or beam is achieved through a detailed stress control followed by a deflection calculation. Where stresses exceed the cracking limits of concrete, a cracked section deflection estimate is carried out using an equivalent moment of inertia.

A strength analysis and design is conducted to determine any non-prestressed reinforcement that may be necessary to meet the ultimate strength limit conditions. Other code requirements for non-prestressed reinforcement, such as the minimum requirements of the building codes, are also checked and a listing of the reinforcement based on different criteria is reported. Bar sizes and lengths are selected and reported both in a graphical and tabulator format, ready to be entered on the structural drawings.

The punching shear option checks the adequacy of the column caps as well as the immediate slab or drop panel region beyond the cap and provides punching shear reinforcements if required. For one-way slabs and beams, a one-way shear analysis is carried out. Shear reinforcement is calculated and the stirrup requirements are given.

In variable force method ADAPT-PT calculates the change of tendon force along its length and can use the force at each location along the length of a member to perform a code check for that location. In addition to the immediate losses due to friction, and seating loss, and at user's option, the software accounts for the long-term stress losses along the length of the structure. Since long-term losses for grouted tendons are functions of local strain, an iterative non-linear capability is built into the program. The non-linearity in the solution is with increments of load. In the effective force mode, the force along each tendon is assumed constant. In this case, the design is based on a non-iterative linear solution in terms of the effective force.

Another execution option is the computation only of immediate losses resulting from the friction and seating of strands. The long-term losses in prestressing are then effected through a user defined lump sum stress loss.

The geometry of the structural model can be viewed on the screen in a three-dimensional space. The capability to rotate, pan, zoom and view the model allows the user to examine the structure in detail prior to the execution of the program. Errors in data entry or modeling are readily detected when user's input is displayed on the computer screen. Hard copies of the graphical display of the structural model can be readily obtained.

ADAPT-PT uses the detailed scheme throughout its operation. This scheme is based on 1/20th point values along each span. However, to retain the simplicity of presentation of the report, in addition to the optional 1/20th point reports, a summary of the solution is compiled for the left, center and right of each span.
In addition to graphical reports, the outcome of the analysis and design is composed into a clear text file that can be viewed, edited and printed by user. The content and extent of the report can be controlled by user through a user-friendly menu.

It is also possible to generate a one-page graphical summary report that extracts and incorporates all important design information in an easy-to-interpret format. The report may also be exported as a DXF file for incorporation into construction documents.

The graphical display option of ADAPT-PT provides a vivid exposition of the distribution of calculated values along the entire structure or for its selected members. The displays include moments, shears, stresses, post-tensioning required, post-tensioning provided, tendon profile, deflections, and reinforcement required and provided. Each graph may be printed or exported as a .bmp or a metafile.

ADAPT-PT input data is stored in a single file with the .ADB extension. However, the program is also backward compatible with input generated by earlier Windows versions of the program. ADAPT-PT is integrated into the ADAPT-Builder software suite. Structural models generated using the Modeler module of the Builder suite can automatically be transferred to ADAPT-PT for analysis and design. This capability provides a seamless link between the Finite Element Method of ADAPT-Builder and ADAPT-PT. (ADAPT-PT, 2010)

3.10.1 Stages of calculation in ADAPT-PT

1. Project information

   It includes specification of general information and analysis and design options.

   - General project information
   - Selection of the geometry input option

     If the model spans with uniform geometry where the tributary width, section type and/or section depth do not change within a

     span, it is necessary to select "conventional" input. This will also give an option to include drop caps, drop panels, and/or transverse beams.

     If the model spans with non-uniform geometry within a span, it is necessary to select "segmental" input.
   - Selection of the type of a structural system

2. Specifying the analysis and design options

   Analysis options:

   - Automatic

- Interactive

  The interactive mode gives the user an opportunity to optimize the design by adjusting the tendon forces and tendon drapes in each span.
- Moment reduced to face-of-support

  The calculated moment at the support centerline will be adjusted to face-of-support and used in design.
- Redistribute moments (post-elastic)

  The program will perform redistribution of moments and readjust elastic moments based on the provisions of the selected design code.
- Using equivalent frame method

  This option is available only for two-way systems.
- Increase moment of inertia over supports.

  This option affects the relative stiffness of the beam and column members. It also, in turn, affects the relative distribution of the moments and may affect the amount of post-tensioning required. The option is available for one-way systems and two-way systems where the Equivalent Frame Method is not used.

Design options:

- Using all provisions of the code.

  The program will consider all provisions of the selected design code including calculation of minimum rebar for serviceability, check for cracking capacity and add reinforcement if needed, considering the contribution of post-tensioning in strength check.

3. Geometry

   There are three basic screens: Span Geometry, Support-Geometry, and Support-Boundary conditions. Additional screens are used to enter effective flange widths, segmental data, drop caps, drop panels and transverse beams.

   Span geometry screen is shown n the Figure 3.4.

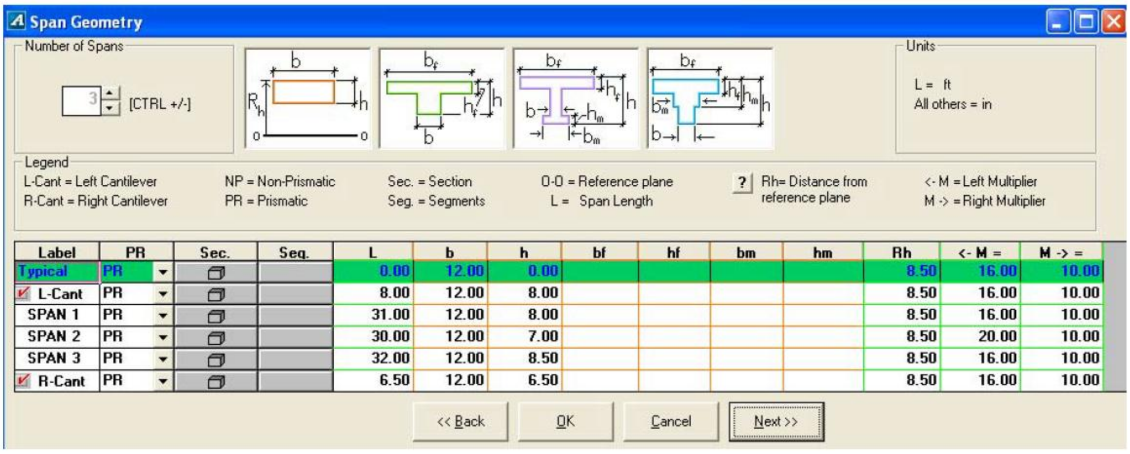


Figure 3.4 Span geometry.

- The span geometry can be modeled as prismatic (uniform) or non-prismatic (non-uniform). The geometry without changes in cross-section along the span excluding geometry of drop cap, drop panels or transverse beams is called prismatic (uniform) geometry.
- Geometry of a cross-section that changes along the span is called non-prismatic (non-uniform) geometry. It is necessary to model span geometry as non-uniform if at least one span is not uniform.
- Specifying effective flange width
- Specifying geometry of drop cap or transverse beam

  Specifying support geometry and stiffness

  This screen is used to input support heights, widths and depths of supports. Support selection options will change depending on the structural system which is selected
- Specifying support geometry and stiffness.

  If the model is two-way system or a beam, the available support options will be: lower column, both columns, no columns

  If the model is one-way system the support options will be: lower wall, both walls, point support or transverse beam.
- Specifying support boundary conditions. This screen is used to enter support widths and column boundary conditions

4. Loads

ADAPT-PT allows to specify a variety of load types including dead, live, earthquake or wind loads (lateral loads).

- Specifying dead, live and other loads.
  It is necessary to specify loaded spans, class of the load, the type of loads there.
- Specifying lateral loads.
  ADAP- PT allows to specify lateral loads (wind or earthquake loads) as unbalanced concentrated moments acting at the face of supports.

5. Material
   - Specifying concrete material.
   - Specifying reinforcement material
   - Specifying post-tensioning material
     The information entered here is used to calculate the ultimate moment capacity of the member when the "effective force" option of the program is used. When the "tendon selection" option is used, the program calculates the effective stress. The stress in the tendon at nominal strength is calculated from the effective stress and the reinforcement ratio.

6. Criteria
   - Specifying the design code
     The current version of ADAPT PT features ACI318 (1999) and ACI318 (2005), IBC 2006, ACI318 (2008), IBC 2009, Australian-AS3600 (2001), British-BS8110(1997), Canadian-A23.3 (1994), Canadian-CSA04 (2004), European-EC2(2004), Indian-IS1343 (2004), Hong Kong-CoP(2007) and Chinese GB 50010(2002).
     ADAPT-PT allows to specify any criteria, so it is possible to use another codes.
   - Specifying Base Non-Prestressed Reinforcement
     The program allows you to specify a base reinforcement that is taken into consideration when designing the structure.
   - Post-Tensioning system parameters

- Edition of base reinforcement
- Specifying allowable stresses
- Specifying recommended post-tensioning values

  This screen allows the user to specify minimum and maximum values for average pre-compression (P/A; total prestressing divided by gross cross-sectional area) and percentage of dead load to balance (Wbal)
- Specifying calculation options.

  The two options are “force selection” and “force/tendon” selection. “Force selection” is the default option. In order to use “tendon selection”, the “force/tendon selection” option must be specified.

  If “force/tendon selection” is specified, the screen will prompt for the information required to calculate the prestress losses. The values given as defaults are fairly typical in the industry and should be used unless more accurate information is available. Long-term losses may either be entered as a lump sum value, or the information required to calculate them may be entered.
- Specifying tendon profile

  The parameters used to define the tendon are shown in the schematics at the top of the screen, which is shown on Figure 3.5. The profile and values shown, a reversed parabola with the low point at mid-span and inflection points at span length/10, are the defaults. These are typical industry defaults; they will be appropriate for most designs with essentially uniform loading. Note that if a non-standard profile, i.e. a low point at somewhere other than midspan is used, this must be clearly called out on the structural drawings. Transfer girders and slabs with heavy concentrated loads may require a harped profile. The low point is usually specified to coincide with the column being transferred or the concentrated load.Tendons in the model can have up to three different profiles: tendon A, tendon B, and tendon C. (ADAPT-PT, 2010)

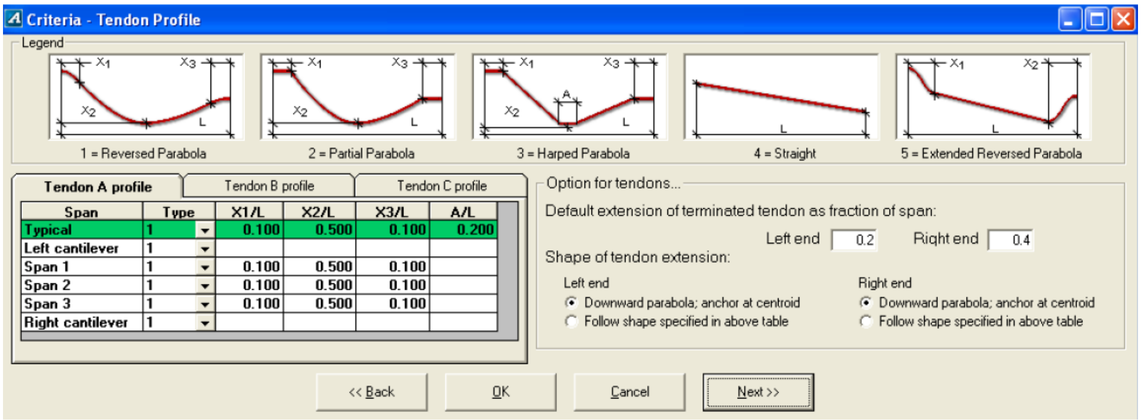


Figure 3.5 Specifying tendon profile.

- Specifying minimum covers.

  This screen is used to specify minimum covers for both the post-tensioning tendons and mild-steel reinforcement

- Specifying minimum bar length.
- Specifying load combinations.

  This screen is used to define the load combination factors for service, strength (ultimate), and initial load conditions. It also gives an access to the input screens for lateral loads and lateral loads combinations.

  It is also used to enter any applicable material factors or strength-reduction factors. The default values depend on selected design code. (ADAPT-PT, 2010)

  Load combination screen is shown in Figure 3.6

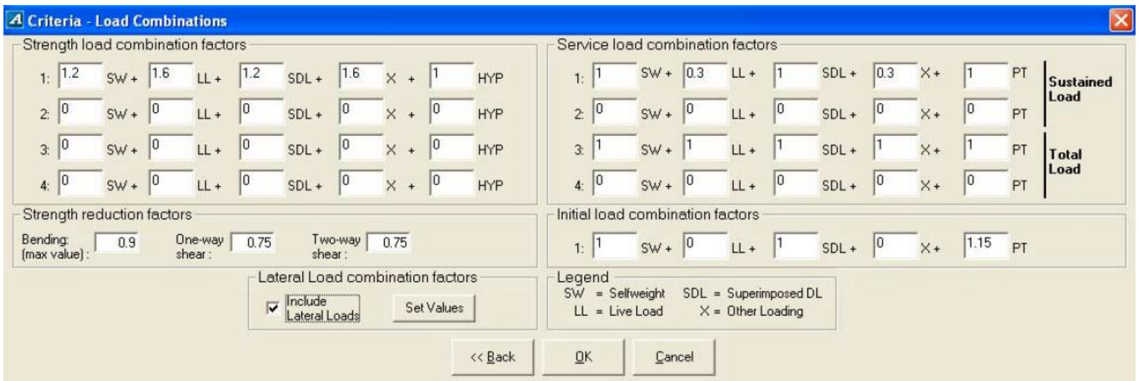


Figure 3.6 Specifying load combinations.

3.10.2 Analysis and Design Steps

Based on current codes, each structure is to be analyzed and designed to meet or exceed the stipulated code requirements for two conditions, namely serviceability and strength.

3.10.3 Serviceability

Serviceability means that the structure should satisfactorily perform its required function during the in- service condition. When applied to a reinforced concrete structure this is translated to mean:

- Deflections should be acceptable.
- Limiting crack size by providing a minimum amount of mild reinforcement over the supports and at midspans; ensuring durability by limiting cracks and the penetration of moisture and water.

ADAPT checks for deflection and minimum reinforcement. (ADAPT-PT, 2010)

3.10.4 Strength

Strength check establishes that the structure designed has a minimum code specified margin of safety against collapse. To this end, factored shears and moments (also referred to as design shears and moments) are calculated from the serviceability actions and checked against the strength formulas. If a section is found to be inadequate, mild reinforcement is added to meet the required strength. In some cases the analysis has to be repeated using larger cross-sections.

Using the previously described input parameters, ADAPT-PT calculates all moment rebar and shear reinforcing requirements for the slab system. The required rebar is calculated at 1/20 th points in each span, as well as each face of support, if desired. Rebar amounts are based upon code specified criteria for all strength and service requirements applicable to the slab system in question.
The program will also calculate the total number and length of bars to be placed at each location in the slab, based upon user-specified bar sizes, inflection

points and code criteria. Also included in results is an estimate of the total weight of rebar in the slab and of the average weight per unit area.

Shear capacity is checked at critical locations in each span. For two-way slabs the punching shear is checked at each support. For beams and one-way slabs the required shear spacing is calculated at 1/20 th points in each span. (ADAPT-PT, 2010)

3.11 Calculation of moment capacity of post-tensioned member

ADAPT-PT checks the reinforcement requirements at 1/20th points along each span, in addition to the face-of-supports. At each location, the design capacity of the design section is first calculated. If the capacity does not equal or exceed the design moment, the program calculates the reinforcement necessary to cover the shortfall.

The moment capacity is calculated with the following formulas:

$$M_n = A_{pw} \cdot f_{ps} \cdot \left(d_p - \frac{a}{2}\right) + A_s \cdot f_{yd} \cdot \left(d_s - \frac{a}{2}\right) + A_{pf} \cdot f_{ps} \cdot \left(d_p - \frac{h_f}{2}\right) \quad (3.1)$$

where:

A_{pw} – cross-sectional area of

f_{ps} – tensile strength of prestressing steel

d_p – depth of prestressed tendon

a – depth of compression zone

A_s – area of reinforcement within the tension zone

f_{yd} - design yield strength of reinforcement

d_s – depth of reinforcement

A_{pf} – area of flange

h_f – height of flange

$$M_n = A_{ps} \cdot f_{ps} \cdot \left(d_p - \frac{a}{2}\right) + A_s \cdot f_{yd} \cdot \left(d_s - \frac{a}{2}\right) \quad (3.2)$$

where:

A_{ps} – total cross section of all tendons

$$f_{yd} = \frac{f_{yk}}{\gamma_s} \quad (3.3)$$

where:

f_{yk} – characteristic yield strength of reinforcement

γ_s – partial safety factor for the properties of reinforcement or prestressing steel

$$f_{cd=}0.85 \cdot \frac{f_{ck}}{\gamma_c} \quad (3.4)$$

where:

f_{ck} – characteristic compressive cylinder strength of concrete at 28 days

γ_c – partial safety factor for material properties

$$A_{pf} = \frac{[0.85 \cdot f_{cd} \cdot (b - b_w) \cdot h_f]}{f_{ps}} \quad (3.5)$$

where:

f_{cd} – design value of concrete cylinder compressive strength

b – overall width of cross section

b_w – width of web

$$A_{pw} = A_{ps} - A_{pf} \quad (3.6)$$

$$d_p = h - CGS \quad (3.7)$$

where:

h – overall depth of a cross section

CGS – central of the tendon gravity

$$d_s = h - c \quad (3.8)$$

where:

c – covering layer

Depth of compression zone:

$$a = \frac{A_{ps} \cdot f_{ps} + A_s \cdot f_{yd}}{0.85 \cdot f_{cd} \cdot b_w} \quad (3.9)$$

$$A_{ps} = A_p \cdot n_p \quad (3.10)$$

where:

A_p – area of post-tensioned tendon.

n_p - amount of post-tensioned tendons.

M_n should be less than M_u, where M_u – ultimate moment in structure

3.12 Example of the calculation

The example of calculation is shown for post-tensioned cast-insitu concrete beam in building for multifunctional business center “Baltic Pearl”, which site is located in Saint-Petersburg.

Dead weights of the beam (B x H = 800 mm x 1200 mm) and slab from respective area are:

$g_0 = 0{,}8\ m \cdot 1{,}2\ m \cdot 25 kN/m^3 + 0{,}23\ m \cdot 8{,}1\ m \cdot 25 kN/m^3 = 70{,}6\ kN/m$

Dead load of surface structures is:

$g_2 = 1{,}5\ kN/m^2 \cdot 8{,}1 m = 12{,}2\ kN/m$

Live load is:

$q = 8{,}0 kN/m^2 \cdot 8{,}1\ m = 64{,}8\ kN/m$

Live is skipped automatically by the program in order to define the most severe load combination. Program uses multiple Codes. This calculation has been made with Eurocode 2 Concrete Structures applied with general rules for post-tensioned structures. Program calculates using load balancing and equivalent frame method (EFM) for calculation.

Load combinations

1. Strength load combinations:
   - SW + 1.2 LL + 1.3 SDL + 1.2 X + 1 HYP
2. Service load combinations:
   - Quasi Permanent Load

     1 SW + 0.95 LL + 1 SDL + 1 PT
   - Frequent Load

     1 SW + 0.9 LL + 1 SDL + 1 PT
3. Initial load combinations

   1 SW + 1.15 PT ,

where:

SW – Self weight Load

LL – Live Load

SDL – Superimposed Dead Load

X – Other Loading

HYP – Hyper Static Load

PT – Prestressing Load

Geometry

1. Plan

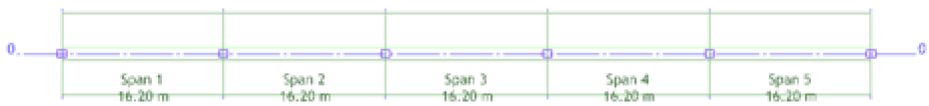


Figure 3.7 Plan for calculation (Finnmap Consulting Oy, 2011)

2. Elevation

Figure 3.8 Elevation for calculation (Finnmap Consulting Oy, 2011)

Applied loads

1. Superimposed Dead Load

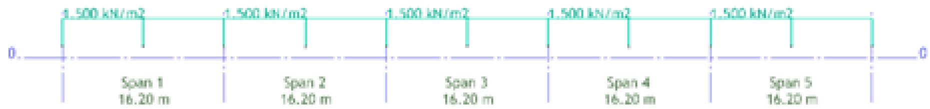


Figure 3.9 Superimposed dead load (Finnmap Consulting Oy, 2011)

2. Live Load

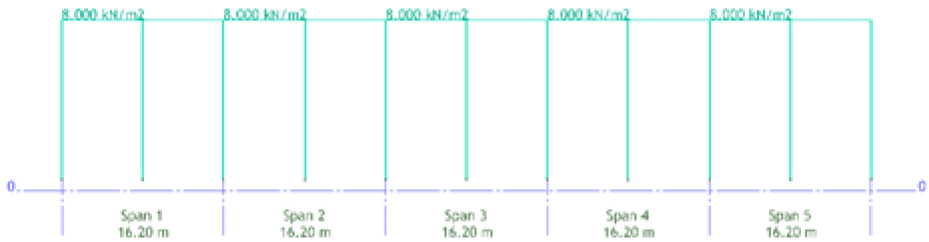


Figure 3.10 Live load (Finnmap Consulting Oy, 2011)

3.13 Results

The results of the calculation are shown in report. There are tables and diagrams with results in report. Tables and diagrams are made for different load cases and load combinations. Also the report includes post-tensioning diagrams.

For each load case report includes the following diagrams:

- Moment diagrams
- Shear diagrams
- Stress diagrams
- Deflection diagrams.

For each service load combinations report includes the following diagrams:

- Stress diagrams
- Moment diagrams
- Rebar diagrams.

For each strength load combinations report includes the following diagrams:

- Moment diagrams
- Rebar diagrams.

Post-tensioning diagrams are the following:

- Diagrams of post-tensioning required and provided
- Tendon height diagrams
- Deflection diagrams.

The tendon height diagram shows the elevation of the tendon profile selected. The stress diagram plots maximum compressive and tensile stresses at the top and bottom face of the member. Post-tensioning diagram shows the required and provided post-tensioning force at $1/20^{th}$ points along each span. Diagrams for Superimposed Dead Load, service and strength load combinations, and post-tensioning diagrams are shown in Appendix 1

.

3.14 SOFiSTiK software for calculation of post-tensioned structures

The SOFiSTiK program system enables to analyze and design pre-stressed concrete bridges and buildings in one continuous process, starting with the planning stage up to the final check analysis. For the analysis model one can choose between a frame system as well as a finite element system. The SOFiSTiK module GEOS is a tool for the definition of tendon geometry, stress sequences and load case assignment.

GEOS supports any necessary input for any geometry (straights, splines, 3D curves) and any stressing sequence (pre-tensioned, post-tensioned, internal, external). All the relevant losses such as wedge slip, friction, wobble are part of the standard results provided as output. As a result load cases are prepared wherein one or several tendons act as a load on the structure. When analyzing this load case the pre-stressing action itself is divided into two parts - the primary and the secondary effects. The results of both effects can either be handled as a couple or individually as it suits the selected design code.

When defining the geometry specific boundary then the definitions are set by the user. These boundary conditions can be at the begining and end of the tendon (independent from any element subdivision) the top and bottom position together with radius, straight parts with a specific length, tangents to the geometry.

GEOS provides specific design results. The stressing sequence is described in detail with any relevant information concerning the actual jacking. The tendon as well as the duct geometry are both displayed as an offset to the element bottom giving information about the stirrups and the detailed duct position. (SOFiSTiK AG, 2011)

Pre-Stressing in SOFiSTiK siftware includes:

- Cubic 3D spline
- Editing in plan- elevation view and in cross-section

- With/ without composite
- External tendon guide
- Tendon guide for girder- and shell elements
- Tension bed procedure
- Library for tension procedure
- Tension diagram
- Tension control
- Graphical input.

SlabDesigner PRO - 2D non-linear FEA & Design. The SlabDesigner PRO is a powerful 2D FEA (Finite element analysis) package handling the analysis of slabs, walls, frames or grillages. It comes with an AutoCAD-based pre-processor, CAD-based section generator, automatic superpositioning, interactive result viewers and automatic report generation.

SlabDesigner PRO comes with many advanced features like non-linear cracking analysis for slabs and beams, non-linear bedding and supports, integrated t-beam design and many international codes like BS, EC, DIN, SIA, ÖNORM, ACI, BBK/BRO (Sweden), SNIP (Russia). The SlabDesigner PT Pro package offers additionally the option of analysing and designing Pre- and Post-tensioned slab with SOFiPLUS and SSD data input. (SOFiSTiK AG, 2011)

3.15 Stages of calculation with SOFiSTiK software

There are stages of calculation in SOFiSTiK software in general:

1. General system information

   When starting a new project, the system Information dialogue offers a new system type: 2D Prestressed Slab.

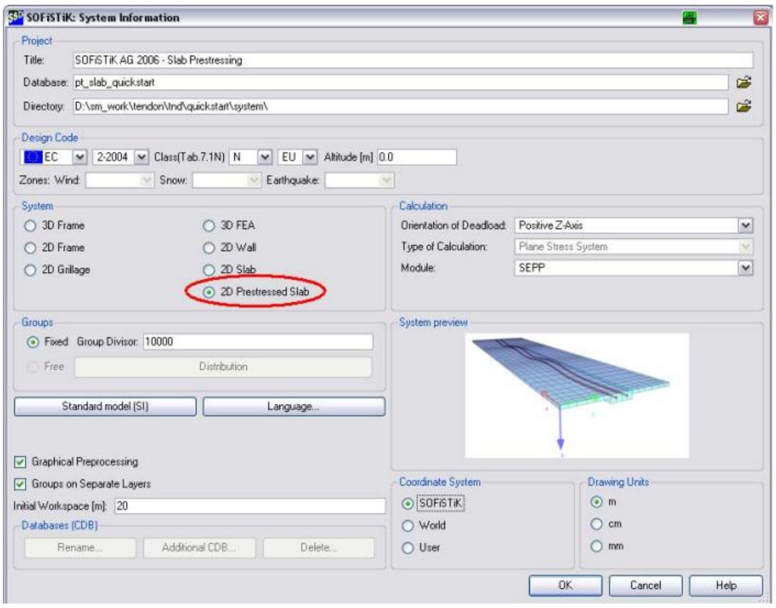


Figure 3.11 System Information dialogue (SOFiSTiK AG, 2011)

2. Input prestressing system

   After confirming the project settings, the SSD task tree offers two special tasks. The task Prestressing system provides the possibility to select various systems which are provided by the software. Task Analysis of Slab Prestress compures the resulting forces for existing slab tendons.

3. Graphical input of tendons with graphical pre-processor SOFiPLUS.

   Three icons for the input of three elements: input of tendons, input of support lines, input of stop lines.

4. SOFiPLUS Tendon Dialogue (prestress direction, kind of prestressing, tendon geometry, straight part in top position,transition, distance of axis to concrete edges).

5. Analysis and Post Processing with SSD . After the definition of the tendons with SOFiPLUS, the SSD is used to control the further analysis and the post-processing.

6. Creating the report of tendon calculation.

   (SOFiSTiK AG, 2011)

4 NORMAL APPROVAL PROCESS IN SAINT-PETERSBURG

4.1 General information

The subject of state expert examination is the assessment of conformity of project documentation requirements of technical regulations, including sanitary and epidemiological, environmental requirements, the requirements of state protection of cultural heritage sites, with fire, industrial, nuclear, radiation and other safety, as well as the results of engineering research, and evaluation of conformity engineering survey results with the technical regulations.

Project documentation of the capital construction and engineering survey results, which are carried out to prepare project documentation, should be a subject of state expert examination, except the following cases:

- Detached family houses for one family with the number of floors not more than three
- Houses with the number of floors not more than three, consisting of several blocks, which number does not exceed ten. Each block is designed for one family, has a common wall without openings to the adjacent blocks. Every block is located on a separate land part and has the access to common areas.
- Apartment houses with number of floors not more than three, consisting of one or more block-sections, which total amount does not exceed four. Each block-section consists of several apartments and common areas. Each block-section has a separate entrance with access to common areas.
- Construction objects with a number of floors not more than two, which total area is not more than 1500 square meters. The building is not intended for living or manufacturing. Except of extremely hazardous, technically complicated or unique objects.
- Construction objects with a number of floors not more than two, which total area is not more than 1500 square meters, which are designed for manufacturing. These objects do not require the establishment of sanitary protection zones or have installed sanitary protection zones

within the boundaries of land, or the establishment of such zones is required. Except of extremely hazardous, technically complicated or unique objects.
(Town Planning Code, 2004)

State expert examination of design documentation is not needed, if a building permit is not required for construction, reconstruction and repair of objects in such cases as:

- Construction of a garage or other private buildings on the private person’s land for individual purposes not related to business activities.
- Construction of objects, such as kiosks and sheds
- Construction on the land of buildings and structures of accessory use
- Changes in structures or their parts, if such changes do not affect on the structural and other characteristics of reliability and safety of the structure.

Also it is not needed in the case of an examination of the design documentation, which is re-used and have received the endorsement of the expert examination (typical design documentation), or modifications to this design documentation are not affecting on the structural and other characteristics of reliability and safety of the structure. (Town Planning Code, 2004)

The state expert examination of design documentation and examination of engineering survey results conducted by the federal executive authorities, executive authorities of the Russian Federation or by the subordinated to these authorities state agencies.

It is prohibited to conduct other examinations of design documentation except of state expert examination and state ecological examination of design documentation. State ecological examination is necessary for objects, which are designed in the special economic zone of Russian Federation, on the continental shelf of Russian Federation, in internal sea waters, in a territorial sea of Russian Federation, on the lands of specially protected nature areas.

The Ministry of Regional Development of Russian Federation is organizing and conducting public examination of the following types of projects:

- The objects, which construction, reconstruction or repairing are expected to perform in two or more subjects of the Russian Federation
- The objects, which construction, reconstruction or repairing are expected to make in the exclusive economic zones of Russian Federation, on the continental shelf of the Russian Federation, in internal sea waters and territorial sea of the Russian Federation.
- The objects of defense and security, and other objects, details of which constitutes a state secret
- The objects of cultural heritage (historical and cultural monuments) of federal importance (in order to save them)
- Extremely dangerous and technically complex objects
- The unique objects (Regulation № 145, 2007)

The extremely dangerous and technically complex objects include:

- Nuclear objects, including nuclear aggregates, warehouses for nuclear and radioactive materials
- Hydrotechnical structures of first and second classes in accordance with the laws of Russian Federation.
- Line-cable communication structures and communication structures in accordance with the laws of Russian Federation
- Power lines and other objects of power supply network with the voltage of 300 kilovolts and more
- The objects of space environment infrastructure
- Airports and other objects of the aviation infrastructure
- The infrastructure of public railway transport
- The underground
- Ports with the exception of the specialized maritime ports, which are intended for sports and pleasure crafts
- Public federal roads and related transportation engineering structures.
- Hazardous industrial facilities

The unique objects include:

- A height of over 100 meters
- Spans more than 100 meters
- The presence of console longer than 20 meters
- The penetration of the underground part (fully or partially) below the mark of the planning of land more than 10 meters
- The presence of structures and structural systems, which are subject to non-standard methods of calculation, with physical or geometrical nonlinear properties, or which require the development of special calculation methods (Regulation № 145, 2007)

4.2 Documentation for state expert examination

The following documentation is needed for the state expert examination of the project documentation:

1. The application for state expert examination (Annex 2), which includes:
   - Identifying information about the organization who has made the preparation of the design documentation (the full name and postal address of the design company)
   - Identification information about the object of construction, project documentation (name of construction, reconstruction or repair object), postal address of object, basic technical and economic characteristics of the (area, volume, length, number of floors, production capacity and other)
   - Identification information about the applicant (surname, name and details of identity documents, postal address, place of residence of the developer and owner or the full name of legal entity, the location and postal address of the developer and owner
2. Design documentation for the object in accordance with requirements of Russian Federation for design documentation
3. Information about the cost of design and survey works (ПИР) (may be specified in the application)
4. Registration card in two copies, endorsed by the chief of the estimation department (Appendix № 2)

5. Acceptance card of the design documentation, agreed in the Environmental Protection (OOC) department
6. Urban development plan of the site
7. Conclusion of KGIOP (The Committee of State Control, Use and Protection of History and Culture) about the land use
8. The copy from the Rules of land use and development of St. Petersburg (ПЗЗ) and Act about the protection of the boundaries of cultural heritage with the location of the site
9. A copy of the design task
10. The endorsement of the state ecological examination if it was needed.
11. Documents confirming the applicant to act on behalf of the developer, or owner (if the applicant is not the developer or owner)
12. It is required the presence of the contact person from the general designer organization during the delivery of the design documentation to the state expert examination

Organization of the state examination can request additionally the calculations of structural and technological solutions used in the design documentation. These calculations and materials must be submitted by the applicant within 5 days after receipt of the request.

Design documentation should be submitted on paper in three copies. Design documentation for the object can be made in relation to different stages of construction and reconstruction of the construction object. (Regulation № 145, 2007)

4.3 Calculations and drawings necessary for the state expert examination

1. For buildings with height more than 75 meters it is necessary to show the results of physical modeling in an aerodynamic tunnel (according to TSN 31-332-2006)
2. Surveys of existing buildings at risk zone (30 meters) and indicating the technical condition category to the buildings

3. A survey of apartments and a survey of foundations (pits with absolute levels)
4. Geotechnical Study (according to Section 3 of TSN 50-302-2004) for buildings, embedded into a district of existing buildings
5. A detailed technical study of reconstructed buildings in a case of strengthening of the foundations or the superstructure (according to SP 50-102-2003)
6. The required calculations:
   - Overall design scheme, the material structure and its strength and weight characteristics
   - The cross section of the bearing elements, yielding units of prefabricated elements, the elastic characteristics for the base of foundations
   - Temporary and permanent loads - the weight of floors, walls, suspended walls
   - The resulting data - reinforcement of foundations, reinforcement of the most loaded walls, columns and beams, slabs, efforts in the lower columns, the efforts in piles, sludge, accelerate structural vibration, roll, bending of the top of the building
   - For buildings with girderless scheme it is necessary to show the calculation of the punching of central part of slab from the columns and the calculation of the deformations taking into account the crack opening
7. Load scheme for the foundations
8. Drawings of foundations for all structures
9. For residential buildings it is necessary to show design drawings for all units and outbuildings. The composition of the drawings should include layout of columns, walls and slab of the basement floor, layout of columns and beams of the lower floors (if they differ from a typical floor), drawings layouts of walls and floors with typical sizes, drawings of joints between beams and columns, the reinforcement drawings of the main load-bearing elements
10. In public, commercial and residential buildings, parking garages it is necessary to show the layout of elements with sections of bearing

elements and the main joints, the principle reinforcement drawings of columns, slabs and beams

11. For metal structures it is necessary to show the computational schemes of frames, the basic units, the statement of the elements with cross sections and calculated effort
12. For the outer walls it is necessary to show the cross section, the link layers in the walls, fixing the walls to the joists and the node bearing on joists or foundation
13. For reconstruction it is necessary to show the drawings of joints for strengthening of bearing structures
14. The project of strengthening of existing buildings should be examined only with the new building design documentation. (Regulation № 145, 2007)

4.4 Verification of the documentation

Organization for the state expert examination should check the documentation from three to ten days after receipt of design documentation. After this period the agreement with calculation of fees or a c is directed to the applicant .

The reasons for refusal to make the state expert examination are:

- Lack of documentation sections according to 12 and 13 paragraphs of 48 article 48 of the Town Planning Code of Russian Federation
- The discrepancy of the results of engineering research content and form in accordance with part 6 of 47 article of the Town Planning Code of Russian Federation
- A representation not of all documents for state expert examination, including a lack of positive conclusion of state expert engineering survey results (if the design documentation is directed at the state examination after the examination of results of engineering survey)

In a case of refusal all the documentation should be returned to the applicant. (Regulation № 145, 2007)

4.5 State expert examination

State expert examination starts after the applicant shows the confirmation of payment for state expert examination in accordance with the contract. The duration of the state expert examination should not exceed 3 months. During the state expert examination the rapid changes can be added to the design documentation according to the contract. (Regulation № 145, 2007)

The order of state expert examination for a non-residential building (90 days):

1. 1 – 3 days are for:
   - The adoption of the documentation
   - Giving the number to the documentation
   - State expert examination starts with confirmation of payment according to contract.

3 4 – 29 days are for:
   - Examination
   - Preparation of expert comments.
     If the additional information is needed for state expert examination, the request is sent to the developer
   - Transfer of comments to the complex sector.

4 30 - 40 days are for:
   - Preparation of the comments
   - The comments are sent to the developer with 2-3 copies of design documentation
   - Developer makes the necessary corrections and shows the copy of the design documentation to experts.

5 41 - 79 days are for:
   - Working with comments.

6. 80 – 90 days are for:

- Preparation of the final conclusion. Developer should receive all design documentation in the department of complex preparation of conclusions
- closure of the case.

The order of state expert examination for a period of 45 days (residential building):

1. 1 – 3 days are for:
   - The adoption of the documentation
   - Giving the number to the documentation
   - State expert examination starts with confirmation of payment according to contract.
2. 4 – 29 days are for:
   - Examination
   - Preparation of the comments.
3. 30 – 45 days are for:
   - Preparation of the final conclusion. Developer should receive all design documentation in the department of complex preparation of conclusions
   - Closure of the case.

(Regulation for state expert examination of design documentation and engineering survey in St. Petersburg, 2009)

4.6 Results of state expert examination

The result of a state expert examination is the positive or negative conclusion.
The negative conclusion of state expert examination can be challenged by developer or customer in a legal process.
The positive conclusion should be issued to the applicant in 4 copies.

In a case of loss of the state expert examination conclusion, the applicant is entitled to receive the copy of conclusion. The applicant should send to the state expert examination a written request and may get the duplicate within 10 days from the date of request. Duplicate is free of charge. (Regulation № 145, 2007)

4.7 State expert re-examination

Design documentation and can be sent on re-examination (two or more times) to the state expert examination after the negative conclusion or when changes in the design documentation affect on the structural reliability or safety of the structure.
(Regulation for state expert examination of design documentation and engineering survey in St. Petersburg, 2009)

The order of re-examination.

1. 1- 3 days are for:
   - The adoption of the documentation
   - Giving the number to the documentation.
2. 40 - 80 days are for:
   - Removing the comments of a negative conclusion
3. 80 – 90 days for non-residential buildings and 35 to 45 - for residential buildings
   - Preparation of the final conclusion. Developer should receive all design documentation in the department of complex preparation of conclusions
   - Closure of the case.

In a case of removal of all comments before the date specified in agreement, positive conclusion can be issued within 15 days. Re-examination which requires re-examination of design documentation is carried out in the manner prescribed for a primary consideration. Only new design documentation is examined. Other documentation is checked for compatibility with the modified design documentation. (Regulation № 145, 2007)

4.8 The order of charging for state expert examination

The fee for state expert examination of design documentation is the responsibility of applicant.

The fee for state expert examination (P_d) is determined by the formula:

$$P_d = B_{pd} \times K_i \qquad (4.1)$$

where:

B_{pdd} - basic price for the state expert examination of design documentation (in rubles).

K_i - ratio, which shows the inflation compared to situation in 1. 2001.

Basic price for state expert examination (B_{pd}) is determined by the formula:

$$B_{pd} = (C_1 + C_2 \times A_1 + C_3 \times A_2) \times K_1 \times K_2 \qquad (4.2)$$

where:

C_1 – the first constant value, equal to 100 000 rubles.

C_2 – the second constant value, equal to 35 rubles.

A_1 – area of land, measured within the perimeter of a future building (in square meters).

C_3 – the third constant value, equal to 3.5 rubles.

A_2 –total area of the construction object (in square meters).

K_1 – coefficient, which shows the application of design documentation.

K_1 = 1, if design documentation is for construction or reconstruction purposes.

K1=0.5, if the purpose of design documentation is repairing.

K_2 – coefficient, which shows the complication of design documentation

K_2 =1,15, if the site is located above the mine workings, in seismic zones when seismic magnitude of 7 on the Richter scale, in karst and landslide zones, in zones of permafrost, collapsible or swelling soils.

K_2 =1, 2 – if the site is located in seismic zones when seismic magnitude of 8 on the Richter scale.

K_2 = 1, 3 – if the site is located in seismic zones when seismic magnitude of 9 on the Richter scale.

$K_2 = 1$ – in other cases. (Regulation № 145, 2007)

4.9 The order of charging for state expert re-examination

The amount of value-added tax is taken into account, when calculating the amount of fee for state expert examination. For the state expert re-examination the fee is calculated as a 30 percent of the fees of the primary examination.
If the documentation for state expert re-examination is submitted within 14 days after receiving the negative conclusion, the fee for re-examination of design documentation is not charged. (Regulation № 145, 2007)

5 APPROVAL PROCESS FOR POST-TENSIONED STRUCTURES IN SAINT-PETERSBURG

5.1 Legislation issues

Following documents regulate demands and rules for design and construction of buildings and structures:

- Town planning code of Russian Federation
- Technical regulations about safety of building and structures
- Development and approval procedure of Special Technical Conditions for developing of Project documentation for building object, issued by Ministry of Regional Development from 1.04.2008. (Appendix 2)
- Resolution №87 About the parts of design documentation and requirements to their contents from 16.02.2008.

According to Technical regulations about safety of buildings and structures, the buildings and structures should be identified according their responsibility level.
As result of identification the building or structure should be related to one of the following levels:

- High responsibility level
- Normal responsibility level
- Low responsibility level.

(Federal law № 384, 2009 .Technical Regulations on the Safety of buildings and structures)

High responsibility level will be related those buildings which in accordance with Town planning code of Russian Federation are defined as specially dangerous, technical difficult or unique objects.

The post-tensioned structures are classified as unique and not supported with actual standards and Special Technical Conditions (STU) should be developed for them.

The following norms regulate designing of reinforced concrete structures:

- SNiP 52-01-2003 Concrete and reinforced concrete structures. Principal rules.
- SP 52-101-2003 Concrete and reinforced concrete structures without prestressing.
- SP52-102-2004 Prestressed concrete structures.
- SP52-103-2007 Building structures of monolithic reinforced concrete.

The standard SP52-102-2004 is named as covering both types of structures (prestressed and post-tensioned), but in fact it describes only prestressed prefabricated structures.

The standard SP52-102-2004 is called as Prestressed concrete structures, because in Russian terminology structural types both prestressed and post-tensioned are named as prestressed structures.

In Russian terminology prestressing of concrete can be carried out by:

1. Tensioning of reinforcement on abutments before concrete hardening (factory works)
2. Tensioning of reinforcement on concrete after concrete hardening (site works)

According to European norms, the first is prestressed structure and the second is post-tensioned structure. As a result, the norm SP52-102-2004 can be applied only to design of structures with tensioning of reinforcement before concrete hardening (according to European norms - prestressing).

The post tensioned structures are mentioned in the norm SP52-103-2007. The norms recommend the usage of unbonded prestressed high stressed tendons K-7 by spans of more than seven meters.

5.2 Special Technical Conditions

In accordance with Regulation №87 About the parts of design documentation and requirements to their contents, if the development of design documentation for capital construction object insufficient requirements for reliability and security established by regulatory and technical documents, or such requirements are not installed, the documentation should be provided by the development of Special Technical Conditions. (Regulation № 87, 2008)

Special technical conditions (STU) are technical norms (for the purposes of the concrete object of capital construction), containing the additional technical requirements in the sphere of safety, reflecting specifics of engineering surveys, design process, construction activities, operation and demolition of the object.

Depending on the degree of provision of would-be built object with actual statutory regulations by the decision of Client there can be developed STU of 3 kinds:

- Specifications containing technical requirements for design, construction and operation of the objects, specified in p. 48 of Town Planning Code of Russian Federation (Collected Legislation of Russian Federation, 03.01.2005 N 1 (part 1), p. 16), objects of cultural heritage (historical and cultural monuments)) and other objects, for design of which reliability and safety requirements, set by technical standards, are not sufficient
- Specifications containing technical requirements on seismic safety during design process, construction and operation of objects on the plots with seismicity of more than 9 points for all kinds of objects

- specifications containing technical requirements for design and construction of objects as to fire safety.

5.3 Content of STU

STU should contain the following data:

- Detailed arguments for the necessity of STU development and missing regulatory requirements for this concrete object, stated in accordance with the structure of actual technical norms in this area
- List of forced deviations from requirements of actual technical regulatory documents, containing arguments for its necessity and activities compensating these deviations.

Besides, in STU there should be stated:

- Reason for the construction
- Data including name and location for the object and construction conditions
- Information about Investor (Client), general engineering company and STU developer
- Description of the whole object and its main elements with exposition of space-planning and construction solutions with annex of plot organization chart and drawings of architectural and planning concept.

5.4 Procedure of development of special technical conditions

STU is developed in accordance with Client's (Investor's) technical requirements by engineering, research or another company, possessing scientific and technical potential and practical experience in the relevant field.
In the technical requirements there should be specified:

- Short arguments for necessity of STU development
- Information about objects
- Importance level in accordance with actual construction standards
- Other requirements necessary for STU development, including requirements connected with fire and seismic safety.

STU development should be prefaced with definition of conceptual engineering solutions of the object (including space-planning solutions and construction solutions, applied materials and items). As well as the analysis of existing regulatory framework in relation to the specific object, that is the basis for development of missing statutory regulations or missing norms for certain directions. Conceptual engineering solutions can be defined in respect to the whole object, it's parts or certain kinds of constructions of engineering systems.
(Decree № 36. Procedure of development and approval of special technical conditions for the development of design documentation for the object of capital construction, 2008)

5.5 Procedure of special technical conditions approval

Approval of STU is conducted by Russian Federation Ministry of Regional Development (Minregion of Russia).
The stages of STU approval are shown in Table 5.1.

№	Stages	Time
1	Developing of design documentation and calculations for post-tensioned structures. The documentation is done by design company.	1-2 months
2	Ordering of STU from Concrete Institute (VNIIZB, Moscow). During this stage Concrete Institute can appear some requirements for drawings or calculations. The fulfillment of requirements can be done together with development of STU.	1-1.5 months
3	Technical council in Minregion. One month is an unreal period for this stage, because during this period it is necessary to study materials, ask questions, get answers, to convene a council and to issue approval.	1-3 months
4	The whole time for design and approval process for STU.	3-6.5 months

Table 5.1 Stages of Special Technical Conditions Approval.

The STU developing duration depends on design task. The realistic schedule for STU developing is according to experience 1-1.5 months for not complex object. Together with approval time it can take till 4.5 month.

The time reducing is possible if STU developing and post-tensioned design will be organized parallel in close contact between specialists. The approval procedure is most critical point. Even official 3 month term can be exceeded according STU developer VNIIZB (Concrete Institute, Moscow).Consideration of submitted Documentation in Minregion includes:

- Study of the content of submitted documents and materials
- Scientific and technical expertise of STU
- Preparation of finding of Minregion of Russia based on the results of Documentation consideration
- Making decision about approval or refusal to approve STU.

(Decree № 36. Procedure of development and approval of special technical conditions for the development of design documentation for the object of capital construction, 2008)

5.6 Documentation for approval process

For the consideration of the question concerning STU approval, building owner provides Minregion of Russia with the following documentation:

1. Application of building owner prepared in any form for STU consideration addressed to Minister of Regional Development, signed by the head or acting head and affixed with the seal of organization (if application is made by legal entity) – the original, one copy
2. Explanatory note containing information about the necessity of STU development, accepted project engineering solutions, compensating activities (in case if decision about deviation from actual technical norms is accepted), description of statutory regulations containing new technical requirements (in case of development of new requirements), information about safety measures at the object, and

if necessary – information about STU approval by concerned federal executive bodies. measures is provided in case of favorable conclusion of MES of Russia (the original, one copy)

3. STU draft in two copies signed by the executives of developer, numbered and signed by officials of the developer. In the application should be the schemes of site organization and drawings of architectural and planning decisions (the original, two copies)
4. STU containing technical requirements for design and construction of objects in the part of fire safety measures is provided in case of favorable conclusion of MES of Russia
5. Copy of technical requirements for STU development, certified by the head of building owner or acting head.

(Decree № 36. Procedure of development and approval of special technical conditions for the development of design documentation for the object of capital construction, 2008)

5.7 Results of approval process.

Decision about approval of rejection of STU is made by Minister or authorized by his order person within one month from the date when Minregion of Russian Federation receives the documentation. In specific cases by the decision of Minister, time for consideration of documentation and making relevant decisions can be extended to 3 months.In the event of refusal to approve STU in the decision there must be specified sufficient reasons for the refusal. Based on the results of Documentation consideration Department prepares Finding about approval (or refusal to approve) of STU.

Building owner is to be informed about the decision by Minregion of Russia within three working days from the date the decision is made by sending corresponding written notification. Notification can be signed by Minister, supervising Deputy Minister, Department Head or persons performing their duties on the basis of order. In case of STU approval notification is accompanied with STU copy. In case of refusal to approve STU notification is accompanied with:

- Finding copy;
- one copy of STU.

After elimination of reasons for refusal to approve STU, Documentation can be resubmitted for consideration according to the standard procedure. In case of necessity of introduction of changes in previously approved STU, building owner submits relevant Documentation to Minregion of Russia according to the standard procedure. In addition, in case of approval of newly changed STU, previously approved STU becomes invalid since the date of decision about approval of new STU, that is to be reflected in relevant Finding.

Approved STU comes under archive storage and accounting in the relevant register. The following information is to be necessarily included into the register:

- Building owner (name, organizational and legal form, location, bank details
- Information about the head (name, telephone)
- STU name
- Date and number of Finding about STU approval
- Changes in STU
- Other information necessary for STU accounting.

Building owner has the right to recall his application in any moment of Documentation consideration by sending written notification to Minregion of Russia. In that case examining the merits of Documentation ends up and about it there is made the conclusion legalized by Minister or authorized person.
(Decree № 36. Procedure of development and approval of special technical conditions for the development of design documentation for the object of capital construction, 2008)

5.8 Approval process when special conditions are not required

When developing of STU is not required according to Procedure of development and approval of special technical conditions for the development of design documentation for the object of capital construction (Appendix 2),the stages of post-tensioning approval are shown in Table 5.2.

№	Stages	Time
1	Developing of design documentation and calculations for post-tensioned structures. The documentation is done by design company.	1-2 months
2	Verification calculations in Concrete Institute (VNIIZB, Moscow).	1-1,5 months
3	State expert examination in Saint-Petersburg state expert examination center and positive conclusion.	1-3 months
4	The whole time for design and approval process.	3-6,5 months

Table 5.2 Stages of approval process when Special Technical Conditions are not required.

CONCLUSION

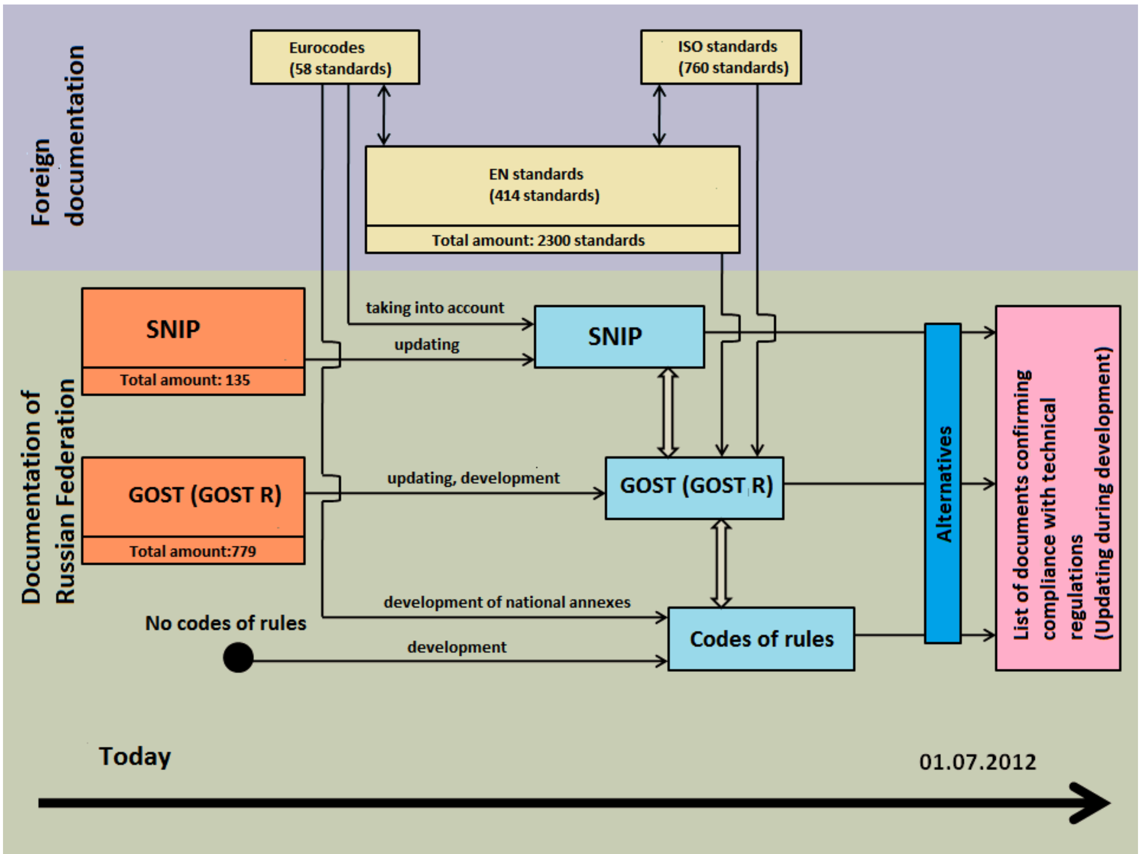
During my thesis work there were introduced the following parts:

- The post-tensioning concept
- The calculations for post-tensioning and stages of calculations
- The stages of the normal approval process for design documentation in Saint-Petersburg
- The stages of the approval process of design documentation for post-tensioned structures in Saint-Petersburg.

The necessary documentation, preliminary time, results and other conditions for approval process in Saint-Petersburg are shown in thesis work. In Appendices the application forms for normal approval process and approval process for post-tensioned structures are shown.

Recently has appeared a tendency in Russian Federation for searching ways towards convergence of Russian norms to Eurocodes. According to Report from Ministry of Regional Development of Russian Federation on ”Harmonization of Russian and European systems of normative documentation in construction” from 2 December 2010, the transition to Eurocodes legislative decree cannot be fast, because the whole construction industry in Russian Federation is focused on application of domestic regulations, taking into account national features of Russian Federation (climatic, social, seismic,geophysical, geologicalhazardous process es). Implementation of Eurocodes in Russian Federation should be pursued through an integrated programmatic approach, designed not for one year and it takes into account the specifics of the Russian Federation.

Moreover, at present, Russian Ministry of Regional Development is working to update and harmonize the existing building codes and regulations with European standards. In high availability is about 25 SNIP norms, which must be approved by the Ministry of Regional Development of Russian Federation in the new edition. According to Report from Ministry of Regional Development of Russian Federation on ”Harmonization of Russian and European systems of normativeв documentation in construction” from 2 December 2010, the block diagram for adoption of the Eurocodes as national standards and codes of rules is:



In summary, I would like to add that approval process with Special Technical Conditions is a temporary process in Russian Federation. The legislation documentation can be changed in future and the easier way for approval process for post-tensioned structures can appear.

FIGURES

TABLES

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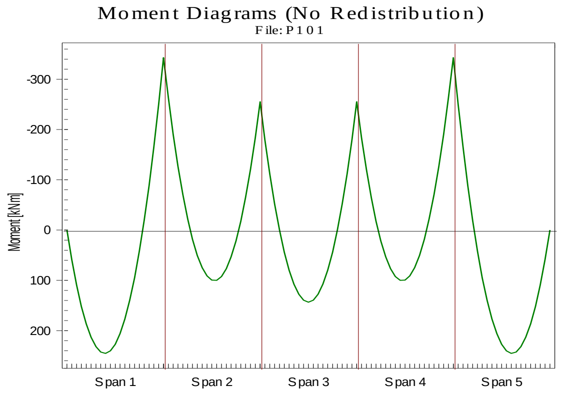
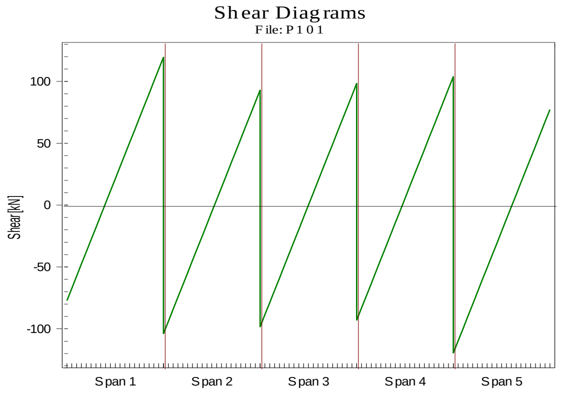
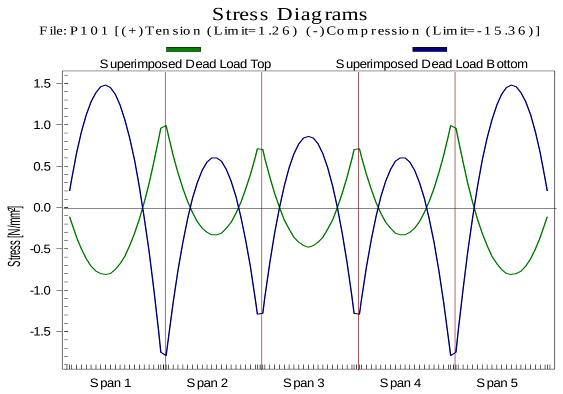
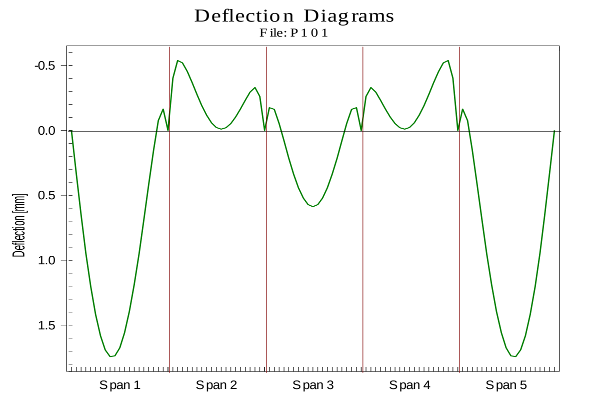
Example of calculation in ADAPT-PT program

LOAD CASE: Super Imposed Dead Load

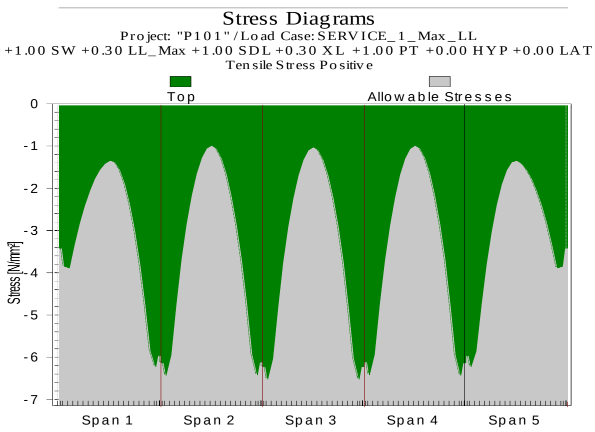


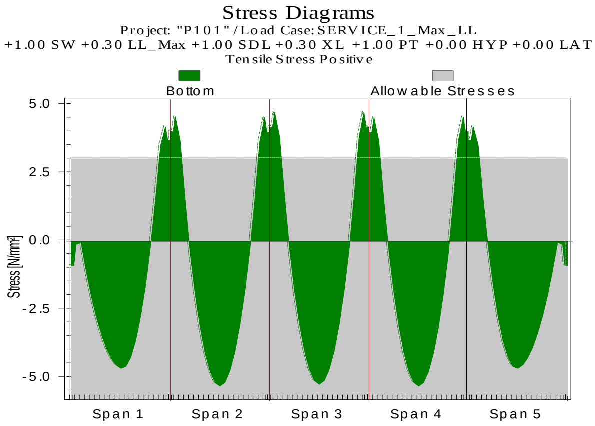




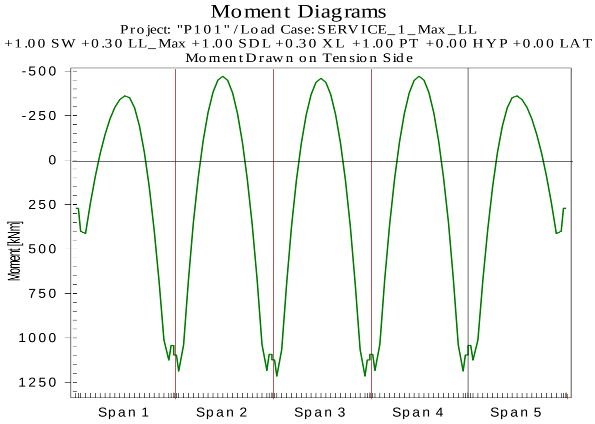


LOAD COMBINATION: SERVICE_1_Max_LL

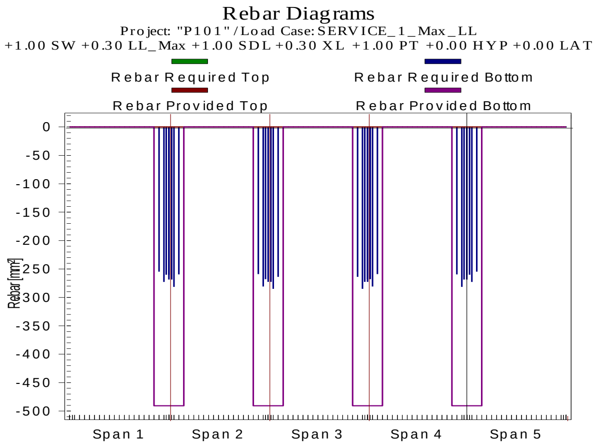




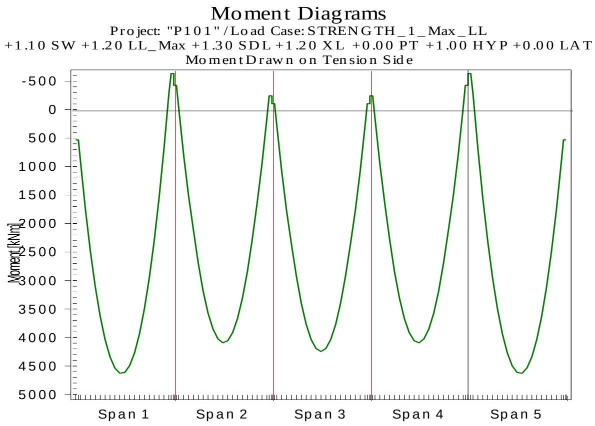
SERVICE COMBINATION STRESSES
(Tension stress positive)



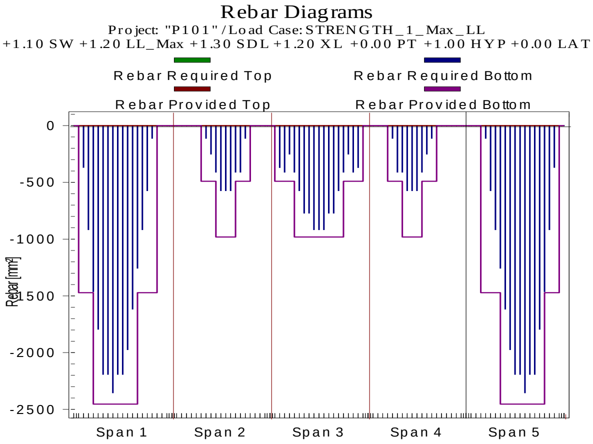
DESIGN MOMENT
(Moment is drawn on tension side)



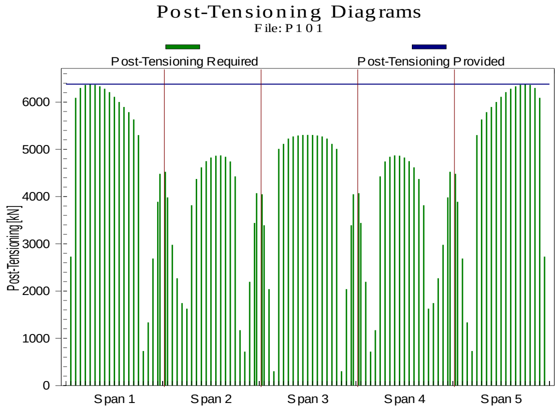
LOAD COMBINATION: STRENGTH_1_Max_LL



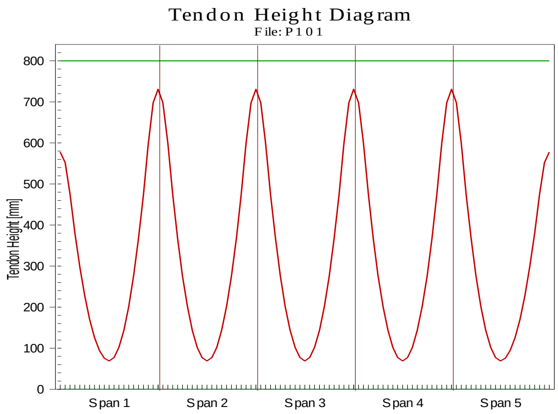
DESIGN MOMENT
(Moment is drawn on tension side)



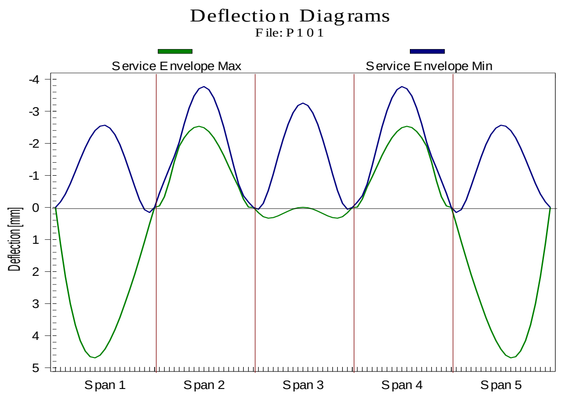
REINFORCEMENT



POST-TENSIONING
REQUIRED AND PROVIDED



POST-TENSIONING
PROFILE



DEFLECTION REQUIRED AND PROVIDED

Ministry of Regional development of Russian Federation. Order #36 from 1.04.2008

Procedure of development and approval of special technical conditions for the development of design documentation for the object of capital construction

I. General conditions

1. This procedure of development and approval of special technical conditions for the development of design documentation for the object of capital construction establishes general requirements for the development and approval of project specific standard (STU) in case if reliability and safety requirements, set by technical standards, are not sufficient for development of design documentation for the object of capital construction (hereinafter – object), or such requirements are not set.
2. STU are technical norms, containing (for the purposes of the concrete object of capital construction) additional to set or missing technical requirements in the sphere of safety, reflecting specifics of engineering surveys, design process, construction activities, operation and dismantling (demolition) of the object.
3. Depending on the degree of provision of would-be built object with actual statutory regulations by the decision of Client there can be developed STU of 3 kinds:
   - specifications containing technical requirements for design, construction and operation of the objects, specified in p. 48 of Town Planning Code of Russian Federation (Collected Legislation of Russian Federation, 03.01.2005 N 1 (part 1), p. 16), objects of cultural heritage (historical and cultural monuments)) and other objects, for design of which reliability and safety requirements, set by technical standards, are not sufficient;
   - specifications containing technical requirements on seismic safety during design process, construction and operation of objects on the plots with seismicity of more than 9 points for all kinds of objects;
   - specifications containing technical requirements for design and construction of objects as to fire safety.

II. Procedure of development of special technical conditions and requirements for its content

4. STU is developed in accordance with Client's (Investor's) technical requirements by engineering company, research or another company, possessing scientific and technical potential and practical experience in the relevant field.
5. In the technical requirements there should be specified short arguments for necessity of STU development, information about objects importance level in accordance with actual construction standards, and also other requirements necessary for STU development, including requirements connected with fire and seismic safety.
6. STU development should be prefaced with definition of conceptual engineering solutions of the object (including space-planning solutions and construction solutions, applied materials and items), as well as the analysis of existing regulatory framework in relation to the specific object, that is the basis for development of missing statutory regulations or missing norms for certain directions. Conceptual engineering solutions can be defined in respect to the whole object, it's parts or certain kinds of constructions of engineering systems.
7. STU should contain the following data:
    - detailed arguments for the necessity of STU development and missing regulatory requirements for this concrete object, stated in accordance with the structure of actual technical norms in this area;
    - list of forced deviations from requirements of actual technical regulatory documents, containing arguments for its necessity and activities compensating these deviations.

Besides, in STU there should be stated:

- reason for the construction;
- data including name and location for the object and construction conditions;

- information about Investor (Client), general engineering company and STU developer;
- description of the whole object and its main elements with exposition of space-planning and construction solutions with annex of plot organization chart and drawings of architectural and planning concept.

8. It is acceptable to include in STU regulations containing deviations from actual norms providing arguments for necessity of such deviations and development in the structure of STU regulations compensating these deviations. Similarly additional requirements should be justified in comparison with the requirements established in actual technical regulatory documents.
9. STU structure is defined in the stage of drafting technical requirements for its development and, as a rule, should match the structure of actual technical norms in this area. Additional requirements of each section (subsection) of STU should be referred to the certain regulatory document or its section. Concrete structure of sections and its content is to be defined by STU developer in accordance with the demands of technical requirements.
10. Certain provisions, contained in regulatory documents of foreign countries, can be included in STU structure upon condition that they match Russian Federation Law.
11. STU does not contain regulations, contained in actual technical regulatory documents, including arithmetic formulas of another formation. Notations and units, used in STU, should match notations and units accepted in construction norms and rules, Russian Federation state standards and national standards.
12. Technical requirements as part of STU should be concrete and should allow the possibility of control in due course.

III. Procedure of special technical conditions approval

13. Approval of STU is conducted by Russian Federation Ministry of Regional Development (hereinafter – Minregion of Russia). Activities on STU approval as well as preparation of documents mentioned in this Procedure are conducted by Department defined by the Order of Minister of Regional development (hereinafter – Department).
14. For the consideration of the question concerning STU approval, building owner provides Minregion of Russia with the following documents (hereinafter – Documentation):
    - prepared in any form application of building owner for STU consideration addressed to Minister of Regional Development, signed by the head or acting head and affixed with the seal of organization (if application is made by legal entity);
    - explanatory note containing information about the necessity of STU development, accepted project engineering solutions, compensating activities (in case if decision about deviation from actual technical norms is accepted), description of statutory regulations containing new technical requirements (in case of development of new requirements), information about safety measures at the object, and if necessary – information about STU approval by concerned federal executive bodies. STU containing technical requirements for design and construction of objects in the part of fire safety measures is provided in case of favorable conclusion of MES of Russia;
    - STU draft in two copies signed by the executives of developer;
    - copy of technical requirements for STU development, certified by the head of building owner or acting head.

Documentation provided by the Client is not a subject to return, except for the cases set by this Procedure.

15. Decision about approval of rejection of STU is made by Minister or authorized by his order person within one month from the date when Minregion of Russian Federation receives the documentation. In specific

cases by the decision of Minister, time for consideration of documentation and making relevant decisions can be extended to 3 months.

In the event of refusal to approve STU in the decision there must be specified sufficient reasons for the refusal.

16. In case if Documentation is submitted to Minregion of Russia with violation of the list set by p. 14 of this Procedure, it is to be returned to building owner without examining the merits of the case within ten calendar days from the date of Documentation submission to Minregion of Russia.
17. Consideration of submitted Documentation includes:
    - study of the content of submitted documents and materials;
    - scientific and technical expertise of STU;
    - preparation of finding of Minregion of Russia based on the results of Documentation consideration (hereinafter – Finding);
    - making decision about approval or refusal to approve STU.
18. For Documentation consideration and preparation of Finding Department can engage qualified experts.
19. Organization or specialists who took part in development of design documentation, their affiliated persons as well as organizations for state expertise and state experts employed in such organizations can not be engaged in scientific and technical expertise.
20. Based on the results of Documentation consideration Department prepares Finding about approval (or refusal to approve) of STU. Above mentioned Finding, agreed with the supervising Deputy Minister of Regional Development of Russian Federation, is to be submitted to Minister or person authorized by Minister Order for decisions, mentioned in point 15 of this Procedure.
21. Upon the results of submitted Finding consideration Minister or person authorized by Minister Order makes decision about approval of STU or refusal to approve STU. Above mentioned decision is to be documented by approval of submitted Finding, that in chronological order gets relevant serial number.
22. In case of favorable decision, approval of STU is documented by putting on the front page of STU approving resolution of Minister or authorized by order

person as well as putting on each page of STU (on two copies) approving resolution of Department Head. After the approval of STU they are to be approved by building owner.

23. Building owner is to be informed about the decision by Minregion of Russia within three working days from the date the decision is made by sending corresponding written notification. Notification can be signed by Minister, supervising Deputy Minister, Department Head or persons performing their duties on the basis of order. In case of STU approval notification is accompanied with STU copy, legalized in accordance with the requirements of point 22 of this Procedure. In case of refusal to approve STU notification is accompanied with:
    - Finding copy;
    - one copy of STU.
24. After elimination of reasons for refusal to approve STU, Documentation can be resubmitted for consideration according to the standard procedure.
25. In case of necessity of introduction of changes in previously approved STU, building owner submits relevant Documentation to Minregion of Russia according to the standard procedure. In addition, in case of approval of newly changed STU, previously approved STU becomes invalid since the date of decision about approval of new STU, that is to be reflected in relevant Finding.
26. Approved STU comes under archive storage and accounting in the relevant register. The following information is to be necessarily included into the register:
    - building owner (name, organizational and legal form, location, bank details,
    - information about the head (name, telephone);
    - STU name;
    - date and number of Finding about STU approval;
    - changes in STU;
    - other information necessary for STU accounting.

    Maintenance of register is realized by Department.

27. Building owner has the right to recall his application in any moment of Documentation consideration by sending written notification to Minregion of Russia. In that case examining the merits of Documentation ends up and about it there is made the conclusion legalized by Minister or authorized person.

To the Head of Saint-Petersburg State expert examination center (Директору Санкт-Петербургского государственного автономного Учреждения «Центр государственной экспертизы»)

APPLICATION from ”__” ____________ 20__
(З А Я В Л Е Н И Е от «___» ____________20 __г.)

____
applicant (заявитель)

request to conduct the state expert examination of (просит провести государственную экспертизу)

____
of design documentation and results of engineering survey (проектной документации и результатов инженерных изысканий), of design documentation (проектной документации), of results of engineering survey and design documentation for external engineering networks and construction solutions of foundations in a case of providing a standard or re-used design documentation (результатов инженерных изысканий и проектной документации по внешним инженерным сетям и конструктивным решениям фундаментов, в случае предоставления типовой или повторно применяемой проектной документации)

____
in a full version, at a specific stage of construction process - to indicate what kind of stage
(в полном объеме, на конкретный этап строительства – указать, на какой именно)

stage of design (стадия проектирования)**:**

____

for the following targets (для целей)**:**

____
construction, reconstruction, repairing of the object of capital construction

(строительства, реконструкции, капитального ремонта объекта капитального строительства)

the name of object (наименование объекта)**:**

____

the address of site (на земельном участке по адресу)**:**

____
city, district, street, number of site (город, район, улица, номер участка)

source of financing (источник финансирования)**:**

____

technical and economic performance of the object of capital construction (технико-экономические показатели объекта капитального строительства)**:**

Buildings and structures (Здания и сооружения)			**Linearly extended objects** (Линейно-протяженные объекты)		
The name (Наименование)	**Amount** (Кол-во)	**Units** (Ед. изм.)	**The name** (Наименование)	**Amount** (Кол-во)	**Units** (Ед. изм.)
Area of construction within land acquisition (Площадь участка в границах землеотвода)			**the type of object** (вид объекта)	**length** (протяженность)	

Area of construction (Площадь застройки)			**The width of road (diameter, cross section – for networks)**Ширина проезжей части (диаметр, сечение - для инженерных сетей)		
Total building area (Общая площадь здания)			**Presence of networks in the road** (Наличие инженерных сетей в составе дороги)		
Building volume (Строительный объем)			**Presence of networks in the road** (Наличие инженерных сетей в составе дороги)		
The amount of floors (Кол-во этажей)			**Presence of networks in the road** (Наличие инженерных сетей в составе дороги)		
Productive capacity (Производительность) (при наличии)			**Presence of networks in the road** (Наличие инженерных сетей в составе дороги)		
Estimation cost (Сметная стоимость)	**at current prices** (в текущих ценах) ________ 20__ г	**at base prices** (в базовых ценах) _______ 20__ г		**at current prices** (в текущих ценах) _______20___ г	**at base prices** (в базовых ценах) ______20___ г
Total estimation cost in rubles (Общая сметная стоимость (тыс.руб.)			**The cost of PIR** Стоимость ПИР (без НДС)		
including construction and installation work (в том числе стоимость СМР)					

design documentation or results of engineering survey for construction are made byпроектная документация или результаты инженерных изысканий на строительство объекта разработаны:

____
the whole name(полное наименование)

GIP (name, telephone number) ГИП (ФИО, номер телефона)

____

GAP(name, telephone number) ГАП (ФИО, номер телефона)

____

with a certificate of admission to the design work (certificate of admission to work in the field of engineering surveys), issued
имеющей свидетельство о допуске к проектным работам (свидетельство о допуске к работам в области инженерных изысканий), выданное

____
the name of self-regulatory organization (наименование саморегулируемой организации)

№____________________________ **from** (от**) «**____**»**_______________ (г.)

Basis for design *(Основание для проектирования)*

The name of document *(Наименование документа)*	***The number of document*** *(Реквизиты документа)*	***Book*** *(Том)*	***Pages*** *(Стр.)*
Resolution of St. Petersburg governor (St. Petersburg Administration, the Government of St. Petersburg, Committee on Urban Planning and Architecture of St. Petersburg), targeted program Распоряжение (Постановление) губернатора СПб (Администрации СПб, Правительства СПб, КГА), адресная программа			
Certificate of state registration of rights to property Свидетельство о государственной регистрации прав на недвижимость			
Development plan of site Градостроительный план земельного участка			
Conclusion KGIOP about the status of land Заключение КГИОП о статусе земельного участка			
Design task Задание на проектирование (с ТУ ГУ по делам ГО и ЧС)			
The results of sanitary-epidemiological expertise for environmental factors Результаты санитарно-эпидемиологических экспертиз по факторам среды обитания			
TU services and departments of the city in connection to utility networks ТУ служб и ведомств города на подключение к инженерным сетям			
Special technical conditions agreed with the Ministry of Regional Development(if necessary) Специальные ТУ, согласованные с Министерством регионального развития РФ (при необходимости)			

Approvals (Согласования)

<table>
<tr><th colspan="2">The name of organization
(Название организации)</th><th>Approved at the stage
(Согласовано на стадии)</th><th>The number of document
(Реквизиты документа)</th><th>Book
(Том)</th><th>Pages
(Стр.)</th></tr>
<tr><td rowspan="2">KGA
КГА</td><td>The main architector (extract, GP (PZU) and facades)
Главный архитектор (выписка, ГП (ПЗУ)и фасады)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>OPS (at the stage RP)
ОПС (на стадии РП)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">KGIOP (if necessary)
КГИОП (при необходимости)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">The main departmrnt of St. Petersburg Rospotrebnadzor - sanitary-epidemiological conclusion about the use of land
(Управление Роспотребнадзора по г.Санкт-Петербург – санитарно-эпидемиологическое заключение по использованию земельного участка)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">USPH; the certificate for greenery inspection
(УСПХ; акт обследования зеленых насаждений)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Rosaeronavigaciya (if necessary)
Росаэронавигация (при необходимости)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">District Administration
(Администрация района)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">UGIBDD
(УГИБДД)</td><td></td><td></td><td></td><td></td></tr>
</table>

SZTU "Rosrybolovstva" (if necessary) СЗТУ «Росрыболовства» (при необходимости)				
Technological regulations of construction waste treatment (Технологический регламент обращения со строительными отходами)				

Designer (Проектировщик) ________________________________
full name (полное наименование)

The name of head of design company, telephone number (ФИО руководителя, номер телефона)

____

The address of legal entity (Место нахождения юридического лица)

____

The name of individual entrepreneur (ФИО инд. предпринимателя)

____

Details of the identity documents (Реквизиты документов удостоверяющих личность)

____

Postal address of residence (Почтовый адрес места жительства)

____

OGRIPP (ОГРИПП)____ **INN** (ИНН)___________________________

INN (ИНН) _______________________ **KPP** (КПП) _____________**OKPO code** (Код по ОКПО)______________

Current account (Расчетный счет)____

Correspondent account (Кор. счет)____________________________________

BIC (БИК) __________________

The name of bank (Наименование банка)

____

The project owner company is (Функции заказчика осуществляет)

____
full name (полное наименование)

The name of project owner head, telephone number (ФИО руководителя, номер телефона)

____

The address of legal entity (**место нахождения юридического лица)**

____

The name of individual entrepreneur (**ФИО инд. предпринимателя)**

____

Details of the identity documents **(Реквизиты документов удостоверяющих личность)**

____

Postal address of residence (**Почтовый адрес места жительства)**
____
OGRIPP (**ОГРИПП)** ____ INN **(ИНН)**
____

INN (ИНН) _____________________ **КРР (КПП)** ____________**OKPO code (Код по ОКПО)**_____________
Current account (Расчетный счет)____
Correspondent account (**Кор. счет)**________________________________
BIC (БИК) _________________
The name of bank (Наименование банка)
____

Responsible representative – name, telephone number (*Ответственный представитель (ФИО, номер телефона)*

____
certificate of admission to the building works issued
свидетельство о допуске к строительным работам выдано
____
the name of self-regulatory organization (наименование саморегулируемой организации)

№_____________________________ from (от) «_____» ______________ г.

The developer company is (Функции застройщика осуществляет)
____
Full name (Полное наименование)

The name of developer company head, telephone number (ФИО руководителя, номер телефона)
____
The address of legal entity (Место нахождения юридического лица)
____

The name of individual entrepreneur (ФИО инд. предпринимателя)
____
Details of the identity documents (Реквизиты документов удостоверяющих личность)
____
Postal address of residence (Почтовый адрес места жительства)
____
OGRIPP (ОГРИПП)____ **INN** (ИНН)__________________________

INN (ИНН) _____________________ **КРР** (КПП) ____________**OKPO code** (Код по ОКПО)_____________
Current account (Расчетный счет)____
Correspondent account (Кор. счет)________________________________
BIC (БИК) _________________
The name of bank (Наименование банка)
____

Applicant (Заявитель) **________________________**
full name (полное наименование)

The name of developer company head, telephone number (ФИО руководителя, номер телефона)

____

The address of legal entity (Место нахождения юридического лица)

____

The name of individual entrepreneur (ФИО инд. предпринимателя)

____

Details of the identity documents (Реквизиты документов удостоверяющих личность)

____

Postal address of residence (Почтовый адрес места жительства)

____

OGRIPP (ОГРИПП)____ **INN** (ИНН)___________________________

INN (ИНН) _______________________ **KPP** (КПП) _____________**OKPO code** (Код по ОКПО)______________

Current account (Расчетный счет)____

Correspondent account (Кор. счет)____________________________________

BIC (БИК) __________________

The name of bank (Наименование банка)

____

Acting on the basis (Действующий на основании)

____

Agreement,letter of attorney from developer, project owner in cases when the documents are provided not by themselves

(Договор, доверенность от застройщика, заказчика, в случаях, если документы представлены не ими самими)

I undertake to inform Saint-Petersburg State expertise center about the changes, connected with the information, mentioned in this application. (Обязуюсь обо всех изменениях, связанных с приведенными в настоящем заявлении сведениями, сообщать в СПб ГАУ «Центр государственной экспертизы».)

Applicant (Заявитель)

М.П.

____________________	__________________	__________________	
position /должность/	***signature /подпись/***	***Name /Фамилия,И.,О./***	***the place of stamp***

Application form for STU examination
Форма заявления о рассмотрении СТУ

Form of the applicant
Бланк организации (заявителя)

Ref. № (Исх. №) ___________ **from** (от) ______________

To Minister of Regional Development of Russian Federation

127994, Moscow, st. Sadovaya-Samotechnaya, 10/23, str.1

Министру регионального развития Российской Федерации

127994, г. Москва,
ул. Садовая-Самотечная,
д.10/23, стр.1

____

the name of legal entity, organization form in accordance with documents of association
(наименование юридического лица, организационно-правовая форма в соответствии с учредительными документами)

is the project owner of (является заказчиком по проекту строительства) ____.

the name of construction object (наименование объекта строительства)

In accordance with paragraph 14 of the Order of the Ministry of Regional Development of the Russian Federation from April 1, 2008 № 36 "On the order of development and harmonization of technical specifications for the development of design documentation for the object of capital construction" send the documents for special technical conditions approval

В соответствии с пунктом 14 приказа Министерства регионального развития Российской Федерации от 1 апреля 2008 г. №36 «О порядке разработки и согласования специальных технических условий для разработки проектной документации на объект капитального строительства» направляем документы для рассмотрения вопроса о согласовании специальных технических условий ____,

the name of special technical conditions (указывается наименование специальных технических условий)

developed by (разработанных) ____.

name of development company, organization form
(наименование организации-разработчика, организационно-правовая форма)

Appendices : **1. The project of special technical conditions, signed by contact persons of development company at ___pages in 2 copies.**
(Приложения): 1. Проект специальных технических условий, подписанный должностными лицами разработчика, на ___ л. в 2 экз.
2. Explanatory note to the special technical conditions at ___pages in 1 copy.
2. Пояснительная записка к специальным техническим условиям на ___ л. в 1 экз.
3. A copy of technical task for development of special technical conditions, signed by the head of project owner company or the person performing his duties at ___pages in 1 copy.
3. Копия технического задания на разработку специальных технических условий, заверенная руководителем заказчика строительства или лицом, исполняющим его обязанности, на ___ л. в 1 экз.
4. Scheme of site organization and drawings of architectural and planning decisions at ___pages in 1 copy.
4. Схема организации земельного участка и чертежи архитектурно-планировочных решений на ___ л. в 1 экз.
5. A copy of Ministry of Emergency Situations conclusion at ____ pages in 1 copy.
5. Копия заключения МЧС России на ____ л. в 1 экз.
6. Expert conclusion (original) at ___ pages in 1 copy
6. Экспертное заключение (оригинал) на ____ л. в 1 экз.

______________________	________________	________________________
position of Head(должность руководителя)	**signature**(подпись)	**name**(Ф.И.О.)

the place of stamp
М.П.

Contractor (Исполнитель):
Telephone number (Телефон):