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DESIGN AND CONSTRUCTION REQUIREMENTS IN CONCRETE PRESTRESSED STRUCTURES

Abstract

The basic principles for the design of prestressed concrete structures including the requirements for phase of fabrication, transportation, installation and operation are discussed. Failure to comply with these requirements makes the theoretical assumptions considered in the design differ from the actual parameters of operated compressed construction. In the present of technological progress and the overall availability of high-quality materials keeping a tight relationship between the design assumptions and execution is crucial. It often happens that, for example too slender roof beams suffer buckling during transport or installation and must be repaired or re-fabricated.

Material requirements for this type of construction and immediate and delayed loss of prestressing force appearing at various stages of operation are discussed in the paper.

INTRODUCTION

From the point of normal operation of the construction, including the prestressed construction, design assumptions should reflect the real work conditions of the structure. The final effect of the realized object is the result of variables matched in the following stages: pre-design activities, preliminary design, final design, preparation of drawings, preparation of contract documentation, provision of design advice during construction.

The investment process is therefore the optimization process at the design stage and implementation. It is not enough to design properly but implementation must comply with the established standards

1. THE STAGES OF THE PROCESS OF IMPLEMENTATION OF PRESTRESSED STRUCTURES

Compression of structural elements is increasingly being used in all kinds of objects, including frames. Supported by the increasing desire to achieve long spans between columns and reduce their number, while low weight slabs. By reducing the height of the construction of these slabs give a lower height of the object. In high-rise buildings can thus be additional space for the next floor.

The use of compression may also have economic aspect. Less weight structure associated with reduced loads on foundations, and therefore the cost of implementing the foundation can be reduced.

The most advantage of compressed structures is also durability by eliminating cracks. Deflections are further reduced compared to reinforced concrete structures, with equal loads. Compression is also used where it is necessary to transfer significant loads, eg. from overhead cranes in industrial buildings. Frames structures are designed as partially or completely compressed [1].

The objective of the preliminary design stage is to investigate feasible options for structure the site in sufficient detail to enable reliable comparative estimates of costs to be made. This is the stage where most engineering judgement is exercised. Using the known information and constraints, a suitable location, length and span configuration is determined for the structure and one or more structural solutions investigated [2].

2. MATERIAL AND CONSTRUCTION ASSUMPTIONS

Process of design of concrete prestressed elements is less standarized than e.g. hot-rolled steel sections. The larger the eccentricity of the prestressing at the midspan the smaller is the need of prestressing force, but on the other hand for a larger eccentricity, a large concrete area at the top fibers is required. So that is the reason of ‘I’, ‘T’ or double ‘T’ section with wide flange is required.

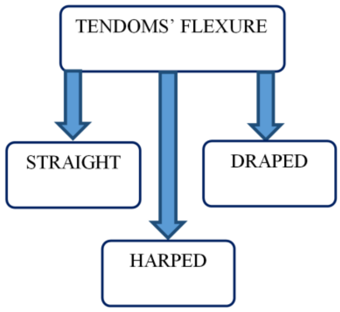

Fig. 1. *Tendoms flexure*

Straight tendoms are used e.g. in the prestressed slabs in the case of uniform moment distribution and moderate span. Draped tendoms have most often the parabolic forms and harped one are used in elements subjected to concentrated tranverse loading. The aim of the design is path of the tendoms that results limited or no tension at the extreme fibers of the element.

Another important issue is reduction of prestress near supports due to absence of moment and high tensile stresses in the concrete fibres. Changing the eccentricity of some tendoms by rising then towards the suport or sheathing some cables by plastic tubing are two main metods to reduce the tenile stresses in the concrete.

During the design phase analysis of prestressing forces that value can change over of period of usage of the element. Reduction of prestressing force is a progressive proces over the period of approximately of five years. This reduction of prestressed force can be grouped as immediate elastic loss during the fabrication or construction proces and time dependent losses.

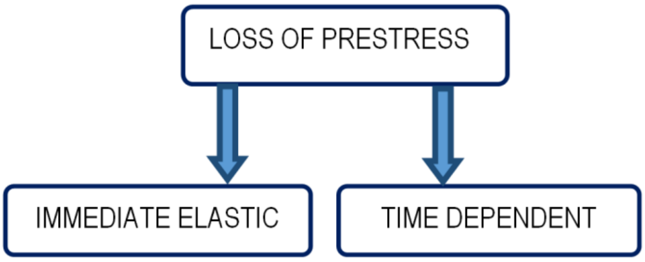

Fig. 2. *Losses of prestressed*

At the design stage of prestressed structures a few key elements should be taken into consideration: concrete, prestressing steel, with protection against corrosion, the anchorage zone, cable channels in the case of post-tensioned structures along with their connections and route of tendons in prestressed concrete structures.

2.1. Concrete

Concrete shoud meet several requirements, such as resistance to weathering and chemicals [3], [4]. This is achieved by appropriate cement type, low w/c ratio, proper curing, alkali-resistance aggregate, suitable admixture, sometimes air entrainment, as well as use of superplasticizers or polymers as admixtures. During the preparation of concrete the proportions are controlled. Just to receive the durability of prestressed concreto structure appropriate cement type with low C3A, MgO, free lime and low Na2O and K20 need to be chosen. Especialy for bridges and other structures with high value of shear forces the resistance to wear deterioration is the important feature. To achieve his high parameters the design and consructed concrete shoud meet low w/c ratio, proper curing conditions, sufficent dense and homogeneous structure as well as high strength, wear resisting aggregate and good surface texture.

Because of high value forces in the tendons, the same high requirements are required for concrete. That was the reason to develop high strength concrete that cylinder compressive strength exeeds 45 MPa and achieved using stone aggregate size of 9.5mm and pozzolamic partial replacements for the cement such as silika fume.

Strains of concrete are another important parameter that should be considered at the stage of design, especially the design of concrete receipt. According to the preseent investigations, concrete total strains can be described as a summary of elastic strains, creep and shrinkage:

$$\varepsilon_T = \varepsilon_E + \varepsilon_C + \varepsilon_S \tag{1}$$

where ε_T – total strains, ε_E – initial elastic strains, ε_C – creep strains, ε_S – shrinkage strains.

Elastic strains ε_E appears during the initial phase of work due to load, creep strains are when the strains appear due to sustained load, and shrinkage when the volume of concrete decrease due to loses of its moisture. There are two types of shrinkage: plastic and drying shrinkage. Plastic one occurs after placing fresh concrete in the formwork and the drying shrinkage occurs during the chemical hydratation process. The opposite situation is when swelling occurs during water absorption by the concrete element. One of the factor that influences on magnitude of drying shrinkage is aggregate – the concrete with high aggregate content is less vulnerable to shrinkage and another is water-cement factor and the higher w/c ratio gives the higher shrinkage. Another factor is ambient condition, such as high states of relative humidity gives the lower shrinkage and in the low temperatures the shrinkage is stabilized. Higher amount of reinforced causes the less shrinkage. Admixtures also influence the level of the shrinkage, such as calcium chloride that accelerate the hardening of the concrete increases the shrinkage at the first stage of curring, but pozzolans increase the drying shrinkage, the same as rapid-hardening cement that shrinks more than other types. Another facor of shrinkage is carbonation as the carbon dioxide is present in the atmosphere and in the cement paste.

Shrinkage and creep increases deflections of concrete elements causing loss of prestress.

Remaing question i show to model the behaviour of strain development in the prestressed elements. There are several models describeing this behawior and the problem is to define this one which reflect the limits of the creep. One of the model is Burger and another one is Ross model.

The Burger model describes the recoverable strain, the delayed recoverable elastic strain and the irricoverable time-dependent strains. The model does not reflect the real dependence in the concrete regarding the limits of creeping.

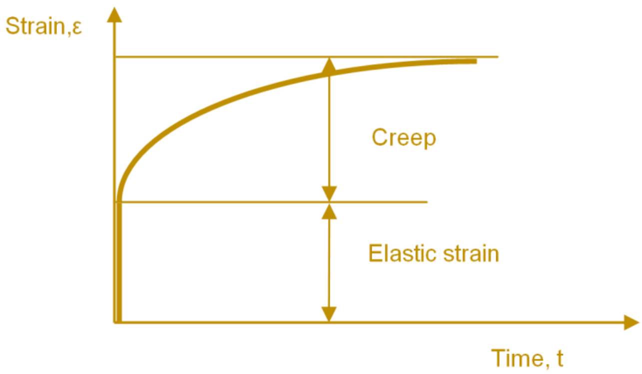

Fig. 3. *Time-strains relations in the concrete*

The Ross model is built of spring element describing the proportional dependence between strain and stress, dashpot and another spring element transmitting the applied load to the enclosing cylinder walls by friction.

According to literature [4] requirements for concrete are:

- high compressive strength; due to the presence of large prestressing forces in cross-section good quality of concrete is required.

It also has economic significance, because it also affects the cross-sectional dimensions, and therefore the amount of material used is reduced.

Higher strength is further guarantee more stability of the structure by providing suitable tightness.

Minimum required class for the construction of post-tensioned concrete is C25/30, while for pretensioned is C30/37.

- rapid strength; the requirement for concrete in a short time is related to the possibility of quick accession to the compression without scratches. The speed of the increase in strength of concrete depends on the type of used material. High-strength concrete more quickly obtain the appropriate degree of strength than ordinary concrete.

Strength of the concrete should be at least 70% of the final value for compressing,

- high elastic modulus;

It is directly linked to minimizing loss of prestressing force by reducing short-term loss of compression and deformable structure (less deflection).

For high value of this module should be used crushed aggregate.

- small strains of concrete

Creep and shrinkage affect the value of loss of the compressed force. The low-shrinkage cement, low water-cement coefficient, casting in suitable external conditions, higher concrete class are required to reduce the creep and shrinkage.

- good adhesion of concrete and steel. It is needed when the transfer of force to the concrete is achieved by the adhesion of both materials to each other, which is usually in the pre-tensioned and post-tensioning prestressed concrete tendon with adhesion. It is related to the strength of concrete for tension. The attenuation is affected by the use of coatings for steel.

2.2. Prestressing reinforcement

Because of the high reology losses in concrete, proper prestressing can be achieved by using high-strength steels of 2000 MPa. This stress in steel can counterbalance losses that appear in the first stage of prestressed structure and during next few years of activity.

Prestressing steel can be in the form of single wires, strands composed of wires forming the element and high-strength bars. Important thing is protection against corrosion. Corrosion reduce the strength of the section and lead to the failure of the system. The protection against corrosion is provided by the concrete cover and in post tensioned members the full grouting of the ducts after prestressing is completed.

The requirements for prestressing steel are:

- high tensile strength. High tensile strength can be achieved by use of steel of suitable composition and their proper handling.

During the compression the proper value of compressed force is required after deduction of immediate and delayed losses.

- prestressing steel with high stress

Steel used in the prestrressed constructions has high elastic strength, strain-stress relationship is almost linear. This allows for the introduction of high stress in the steel, eliminating distortion. Large stress negatively affect the sensitivity of the steel to corrosion. In addition, they are partially reduced by relaxation of material, which must be included in the calculation.

- adequate ductility. It protects against brittle rupture, emerging suddenly, which notes, for example when overloaded tendons during tensioning. It is also significant in the case of dynamically loaded structures.

- high resistance to fatigue. Required for construction of highly stressed in the operating phase.

- low sensitivity to corrosion. The prestressing steel is subject to corrosion during transport, storage and compression process. Since the formation of corrosion is highly influenced by humidity, elements should be dry before embedding in construction. They should be stored in places regularly ventilated. After performing compression, cracks in the concrete are potential areas for the appearance of corrosion.

In the prestressed structures with steel adhesion to concrete, corrosion protection is ensured by grout injection or alkaline concrete environment. However, in cables without adhesion, the channels must be filled with corrosion inhibitors. Corrosion protection also provides the use of galvanized wire or multi-layer construction of the conduit.

2.3. Anchorages

There are few issues that should be taken into account in the design of anchorage zones. Among others this is the place for the press for anchoring and suitable amount of reinforcement in the anchorage area and the alignment of the concrete mix [5]. The amount of reinforcement and its distribution in the area of the anchorage is often given in catalogs of compression systems. It is therefore important to adhere to these recommendations. Too much reinforcement in this zone and the formation of voids in the anchorage area during compression moves reinforcement deeper into the structure. Bad composition of concrete mix can lead to the decrease of concrete strength. This type of neglect manifests itself often scratches concrete during tensioning of cables [6].

When a compressive force is applied to the construction too early, that is, when the concrete has not the sufficient strength, it can lead to crushing of that zone.

When multiwires tendons are used the single press equipment should not be used as in that case is difficult to achieve the proper tension, because during the tensioning the wires not tensioned are pressed. This situation requires to repeat the tensioning to obtain the assumed parameters. Another important thing is to use the resistance block perpendicularity to the axis of the cable. Failure to this may result in shearing of tendons.

Fig. 4. *Anchorages*

2.4. Jacking systems

Jacking systems are the units where the prestressing forces are transferred to the tendons. Capacity of hydraulic jacks are up to 20 tons per one tendon.

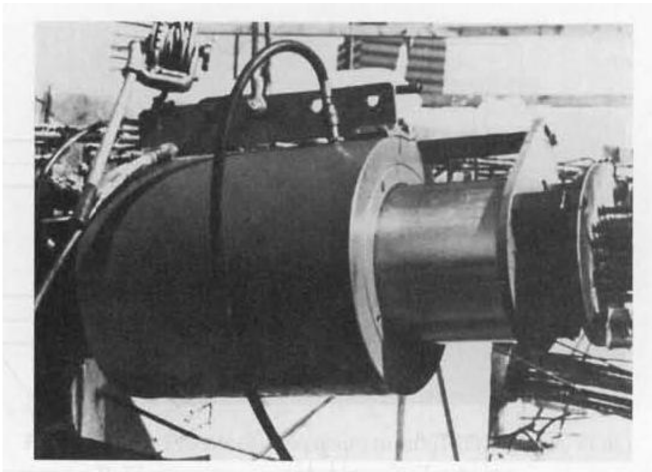

Fig. 5. *Prestressing systems*

2.5. Cable channels

In the case of post-tensioned structures, the size of the prestressing force and accuracy of mapping the theoretical assumptions are affected by an appropriate diameter of channels, correct support of cable route and installation of vent channels.

The producers of prestressing systems instruct which requirements should be met as filling the channel section by wires, should not be more than 50%, on an average 1.3 cross section.

Appropriate support and fixing of cable channels should be made to avoid their displacement.

Spacing of fasteners should not be larger than 1.5 m.

The vents are necessary during injection and they allow to escape the air from the interior canals filled with cement grout. They are mounted in the channels on the outside of the structure.

2.6. Technical documentation

Depending on the type of compressed construction, the documentation should include specific information regarding technology.

In the case of prestressed construction should be provided: the type of tendons and tensioning devices, sequence of stretching tendons when tendons are tensioned in stages, the maximum pressure in the pump unit or value of the maximum force that the press can generate, the final value of the prestressing force introduced into the tendon, acceptable lengthening of tendons, as well as limit of slip in the tensioning device and the strength of concrete at the time of transfer of the prestressing force. In the case of post-tensioned cable construction the documentation should include: way of compressing, the species and the variety of prestressing steel, the number of bars or strands found in one cable, the strength of concrete at the time of compression, sequence compression of cables, as well as how the cables are compressed as one-side or two-side tension, the final value of the prestressing force, value of extending of the cable, the allowable slip in cable anchorage, number, type and location of cables switches, if required the information should include time of overloading of cables [7].

CONCLUSIONS

The prestressing force undergoes the proces of reduction over the period of approximately five years.

As the proces of design starts with the choice of geometry and converges to the final section after taking into consideration possible losses of compressed force and other requiremnts coming from construction of elements and their detailes. At the final stage of design each section of the element meets the stage of stresses connected to bending, shearing, torsion, deflection and cracking during the fabrication, transportation or constrction phase depending on time of prestressing before or after the curring of the concrete. Especially failure at shear or combined shear and torsion caused very dangerous effects because those fails are without advance warning and the diagonal cracks are wider than those coming from flexural stage of stresses.

One of the biggest benefits of precast systems is in their design: tight controls mean more efficient designs, resulting in smaller structural members and longer spans. Construction waste is reduced because the exact amount of necessary components is delivered to the site. By crafting systems that not only look great, but also act as structural walls and support floor loads, designers can reduce material redundancy—and project costs.

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WYMAGANIA PROJEKTOWE I WYKONAWCZE DLA BETONOWYCH KONSTRUKCJI SPRĘŻONYCH

Streszczenie

W artykule zostały omówione podstawowe zasady projektowania sprężonych konstrukcji z betonu z uwzględnieniem wymagań fazy prefabrykacji, transportu, montażu i eksploatacji. Nieuwzględnienie tych wymagań powoduje, że założenia teoretyczne uwzględnione w fazie projektowania odbiegają od parametrów rzeczywistych eksploatowanej konstrukcji sprężonej. W dobie postępu technologicznego i ogólnej dostępności materiałów wysokowartościowych zachowanie ścisłej relacji między założeniami projektowymi i wykonawstwem ma kluczowe znaczenie. Zdarza się, iż np. zbyt smukłe dźwigary dachowe doznają zwichrzenia już w fazie transportu lub montażu i wymagają naprawy lub ponownej prefabrykacji tych elementów.

W artykule zwrócono uwagę na wymagania materiałowe dla tego typu konstrukcji oraz straty doraźne i opóźnione pojawiające się na różnych etapach eksploatacji.

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