DESIGN OF TWO-WAY PRESTRESSED SLABS

Piotr Sokal[1]

Abstract

The article is about design of prestressed slabs. It shows possible solutions of two-way prestressed floors depending on different factors. The design process is briefly described. Some probable difficulties of it are mentioned. Also a punching problem solution and suggestions of common critical areas for limit states verification are presented.

Keywords

Prestressed slab, slab-column system, two-way prestressing, flat slabs, punching problem, design of slabs, monolithic slabs, prestressed slab deflection, prestressing systems, losses of prestressing force.

1 INTRODUCTION

Nowadays in the structures of floors the dominance of reinforced concrete or composite steel and concrete slabs are easily seen and in the case of single-family residential buildings – precast slabs. In industrial or commercial buildings it is possible to see a lot of prestressed slabs. These floors are usually made of prestressed and precast concrete elements. The rarest solution are monolithic prestressed floor slabs. These floors can be prestressed in one or two directions. The choice of the right option depends on the architectural concept, the setting and support spacing. In this paper the attention is drawn to slab-column structures. It should be noted that two-way prestressed slabs have the following advantages over the one-way prestressed slabs with transverse beams:

- possibility of realization of a flat slab,
- smaller slab thickness,
- smaller amount of normal reinforcement,
- better structural layout for equal support spacing in both directions is achieved,
- an easier way of setting various installations under the slab structure,

Prestressed floors comparing to other structural solutions have other advantages [1], [2]:

- smaller deflection than reinforced concrete slabs,
- reduced cracking – it usually occurs over the supports where structure is often protected from exposure to corrosive agents by finishing layers. Cracks usually does not occur in the middle of the span. The conclusion is that due to the lack or smaller cracks, structures have better durability,
- due to bigger distance between the supports there is a smaller number of beams and columns,
- higher strength for punching (in the case of slab-column system),
- better tightness of the structure,
- better possibilities of arranging the space,
- faster stripping of formwork after pouring concrete.

2 POSSIBLE SOLUTIONS OF PRESTRESSED FLOORS

Now it is possible to find many solutions of prestressed slabs [1]. Besides typical flat and mushroom slabs, floors with drop panels, beamed floors, there are banded flat slabs, ribbed or waffle slabs. Most of these floors may be made as a two-way prestressed version. The choice of the number of prestressing directions depends on the spacing of supports in different directions. Beamed, banded and ribbed floors can be done as a one-way floor.

The selection of specific solutions listed above depends on several factors. In this article, typically loaded structures with an orthogonal column grid are discussed. The two main factors are: the spacing of supports and the live load acting on the ceiling. Table 1 shows the typical places of application of types of floors. Table 2 presents possible solutions for floors, depending on the length of the span.

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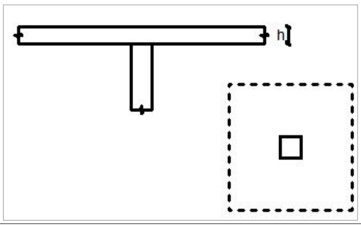
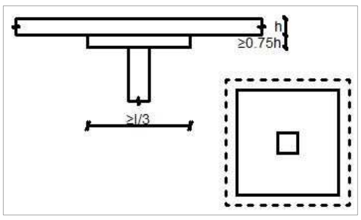
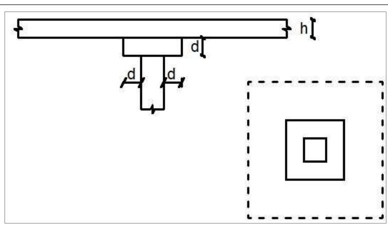
type of system	application
slab-column system	residential buildings, office buildings, public buildings, hotels, car parks for passenger cars
mushroom slab, solid flat slab with drop panels	similar to those of slab-column system
banded flat slab	systems in which spacing of columns in one direction is bigger, conference rooms, car parks for passenger cars, schools, public buildings, office buildings
solid slab with narrow beams	similar to those of banded slab with the same spacing in both directions
ribbed floor	libraries, warehouses, industrial buildings, conference halls, dance halls, airport buildings

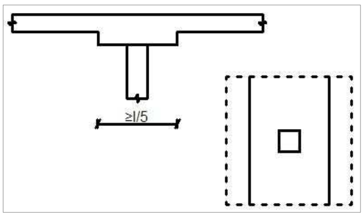
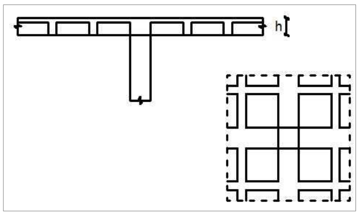
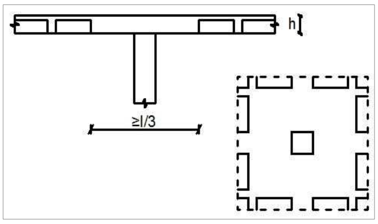
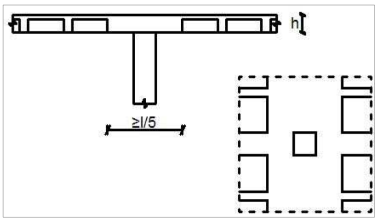
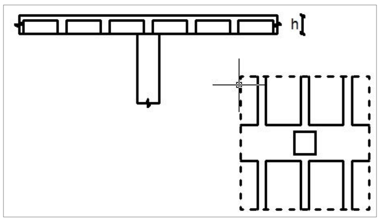
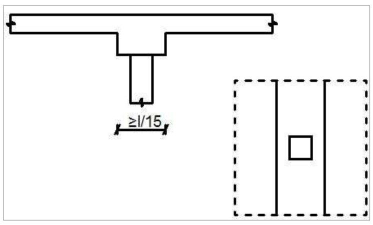
Tab. 1 *Application of prestressed slabs [1]*

type of system	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
slab-column system	■	■	■	■	■	■	■	■								
mushroom slab, solid flat slab with drop panels	■	■	■	■	■	■	■	■	■	■	■	■				
banded flat slab	■	■	■	■	■	■	■	■	■	■	■	■				
solid slab with narrow beams						■	■	■	■	■	■	■	■	■	■	■
ribbed floor						■	■	■	■	■	■	■	■	■	■	■
waffle flat slab						■	■	■	■	■	■	■	■	■	■	■

Tab. 2 *Recommended spans of prestressed slabs [1]*

The recommended dimensions of the structure can be found in the materials of Freyssinet [1], CLL Stressing Systems [2]. Some of them come from a technical report of Concrete Society [3]. They are presented in table 3.

section type	drawing	total imposed load (without self-weight) (kN/m^2)	span/slab height ratio	span/beam height ratio
flat slab		2,5	40	-
		5,0	36	-
		10,0	30	-
solid flat slab with drop panels		2,5	44	-
		5,0	40	-
		10,0	35	-
mushroom slab, solid flat slab with drop caps		2,5	40	-
		5,0	36	-
		10,0	32	-

section type	drawing	total imposed load (without self-weight) (kN/m^2)	span/slab height ratio	span/beam height ratio
banded flat slab		2,5	45	25
		5,0	40	22
		10,0	35	18
waffle flat slab		2,5	25	-
		5,0	23	-
		10,0	20	-
waffle flat slab with solid panel		2,5	28	-
		5,0	26	-
		10,0	23	-
waffle slab with band beams		2,5	28	-
		5,0	26	-
		10,0	23	-
ribbed floor		2,5	30	-
		5,0	27	-
		10,0	24	-
solid slab with narrow beams		2,5	42	18
		5,0	38	16
		10,0	34	13

Tab. 3 *The proposed size of the prestressed slab elements depending on the solution and load [2], [3]*

3 PRESTRESSING TECHNOLOGIES

Technologies of prestressing tendons for prestressed floors can be divided into two types: bonded and unbounded.

In Europe, there are unbounded prestressing systems: the BBR VT CONA CMM, the Freyssinet type F unbounded cables and anchorages, the ALGA SLAB unbounded system, the CCL Stressing Systems monostrand.

Popular bounded systems: PTS Tensiacciai, VSLAB, the Freyssinet type F bounded cables and anchorages, the CCL Stressing Systems bounded multistrand. The above-mentioned systems consist of cables (strips) arranged on one level. This arrangement is efficient in situations where the designer wants to achieve eccentricity of tendons as big as possible in the construction. In the case of the waffle floor application of a bounded round cross-section cable system may be reasonable. The legitimacy of that solution results from the reduction of the breadth of each rib in the waffle slab.

Systems used in the slabs consist of (depending on system) 1-5 (exceptionally 6) strand cables and flat anchorages. A brief comparison of bounded and unbounded systems is shown in table 4.

feature	bounded	unbounded
friction coefficient	approximately 0.10 - 0.19 [4] [5]	approximately 0.05 - 0.06 [5] [6]
coefficient k	approximately 0.005 - 0.010 rad/m [4]	approximately 0.005 - 0.010 rad/m [4]
corrosion protection	depending on the system: a duct, a filling material (eg, cement grout)	depending on the system: HDPE-sheathing, the protective grease
transfer of force to concrete	through anchorages, along the cable	through anchorages and deflectors [7]
strength in the ultimate limit states	100%	85%-91% [4],[8]
weakness due to presence of cables in concrete	50% effectiveness of grouted duct	lack of effectiveness of the duct, additional weakness due to splitting

Tab. 4 *Comparison of bound and unbound prestressing systems*

4 DURABILITY REQUIREMENTS AND FIRE PROTECTION

In order to ensure good durability, it is necessary in the design process to ensure compliance with the conditions of serviceability limit state of crack opening and to provide the adequate concrete cover. Only the fulfilment of these two conditions will provide sufficient durability in a particular environment. In determining the concrete cover, the recommendations contained in EN 1992-1-1 [7] can be used. It should be noted that the unbounded cables usually do not require to fulfil this condition.

An important factor for determining the position of prestressing and normal reinforcement in the element are fire protection requirements. They state the minimal distance from the concrete edge to axis of normal and prestressing reinforcement and also set minimal dimensions of the elements. They are dependent on the required norm fire resistance R, fire integrity E, fire insulation I, type and size of elements and also type of steel. Relevant guidelines can be found in EN 1992-1-2 [9] or in [10]. Prestressing steel is more sensitive than normal steel on the growth of temperature. This fact makes it necessary to increase distance between the concrete edge and axis of prestressing strand by 15mm comparing to normal steel.

For this reason in many cases of prestressed structures the concrete cover is determined by requirements for fire protection. For example, in slab-column system, which is located in dry or constantly wet environment (XC1 by EC2), made of concrete C40/50 and with requirement for REI120, and with unbounded BBR's 20mm-heigth cables the required concrete cover (taking into account the deviations) is 25mm. The concrete cover in the same conditions resulting from the fire protection requirements is 40mm. During designing and constructing of prestressed structures it is crucial to protect anchorages against fire. The designers should carefully check whether recommendations contained in technical approvals comply with fire regulations and in the case they do not, they should correct the solution. This is particularly important for unbounded systems, in which the prestressing force is transferred through the anchorage and the destruction of it excludes strands from work.

5 PRELIMINARY DESIGN OF PRESTRESSED SLABS

Design of slabs can be done using various methods. Currently, due to the development of computer programs it is possible to prepare the project and carry out statics calculations using the finite element method. Another good way is an equivalent frame method. However, it should be approached with great caution. American Standard ACI 318-02 [11] does not recommend the use of the approximate distribution of moments to column and middle strips for prestressed structures. In order to obtain good distribution statics analysis should be made by more accurate methods (eg FEM).

In the case of prestressed slabs and the use of FEM, it is preferable to design in a two-step approach. At the first stage sizes of the elements and the amount of prestressing (the size of the prestressing force) are pre-selected. The approximate verification of limit states in the most critical places are also done at this stage. In this article, particular attention is paid to the solution of flat and mushroom (also with drop panels) slabs. This method with some modifications can also be applied to other types of structural systems.

The first and very important step is to estimate thickness of the slab and check structure above the columns due to punching. This verification is dependent on the proposed solution for punching problem. Selected thickness depends on whether the designer provides additional reinforcement against punching or decides that only concrete works against punching. A very simplified (not accurate) calculation of the force which goes from floor to the column can be done. In the case of slab with equal spans in both directions and in the 2x2 field system, the force (in interior column) can be calculated from the formula (1):

$$V = 1.55 \cdot ql^2 \tag{1}$$

where: q – total uniform load over the slab, l – orthogonal distance between supports,

In the case of slabs with a greater number of fields a factor of 1.55 is smaller. Depending on the applied code the force should be increased due to the moments in the column. After calculating the punching force the structure should be verified according to the applied standard. In the case of non-compliance of conditions the structural solution (usually thickness of the slab) should be changed.

The first step to determine the amount of the prestressing is to set the initial geometry of prestressing tendons and their distribution in the plan. The structure should be divided into the appropriate column and middle strips for each orthogonal direction. For the internal frame width ratio is 1:2:1 (middle strip, column strip, middle strip). As the shape of the cable way, the best are folding parabolas. In the mid-spans cables should be placed (in most of the cases) in the lower part of the plate and over support (and column strips) they should be in the upper part of the plate. Ratio of half of the length of a concave parabola (passing in the column strip) to half of support spacing should be about 0.10 - 0.15. For all types of cables a minimum radius of curvature should be kept. Information about this is given in the appropriate technical approval.

Selection of prestressing forces can be done in several ways. A relatively simple method is the choice of amount prestressing using equivalent loads from prestressing. The forces in this method are modelled as loads applied to the anchorages and loads from the curvature of the cable. In most cases, the floors are loaded uniformly on the surface. Prestressing should carry some part of the dead loads. A ratio of loads from curvature of prestressing tendons to the dead loads is can be called χ. Its value should be between 0.8 and 1.0. Wherein when the ratio of live to dead loads is 0.5 or less, the value of the coefficient χ should be about 0.8. If the ratio is 1.0, the value of χ should be about 0.9 and increase with the participation of live loads. Calculations should be carried out on the characteristic values. This assumption definitely helps during verification of the serviceability limit states, especially deflection.

Transmission of loads in the two-way prestressed slabs has two stages. In the span loads acting on the floor (field A in figure 1) are transmitted by cables of one directions to column bands (fields B and C) to prestressing reinforcement, which is located there and which run in the perpendicular direction. Because of that, bands B and C are loaded by perpendicular prestressing and basic loads acting on the ceiling. In the case of two-span or three-span or last but one bands of multi-span fields B and C can be assumed that the load passing through the cables of A fields overload equal to the ratio of successively 1.25, 1.1 and about 1.15. Then the load from the fields A and B is transferred to the columns.

Distribution of amount of loads which are taken over by the prestressing cables in each direction depends on the spacing of supports in different directions. If the distance of the supports in both directions are similar, each prestressing direction takes over similar amount. When one span is shorter than the cables parallel to the shorter dimension take over (in field A) more loads. Another part of loads from each field is transferred to external columns.

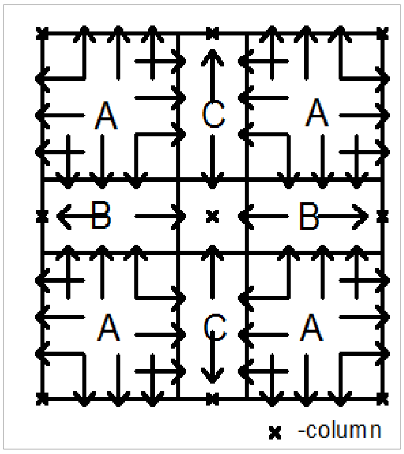


Fig. 1 *The transmission of forces in the ceiling of between fields*

In order to calculate the amount of prestressing force formula (2) should be used:

$$P = q \cdot r \tag{2}$$

Where q – the relevant part of the load acting on the field, possibly with loads from cables which run perpendicularly for 1m of width, r is the average radius of curvature of the cable in the considered segment. It depends on the system, i.e.:

- type of cables (bound – unbound),
- strength and relaxation of prestressing steel,
- number of spans,
- moment of prestressing,
- type and class of concrete.

In case of usage unbound low-relaxation cables with the relatively low coefficient of friction and length 30-40m (2-3 spans) and the prestressing after about 7 days, a good approximation formula is given [12]:

$$A_p = \frac{P}{0.95 \cdot 0.65 \cdot f_{pk}} \tag{3}$$

where: f_{pk} – characteristic stress value at yield stresses.

These calculations use the approximate value of the stresses after all losses of prestressing force (in the presented situation). In the case of bounded cables with it probably would be small decrease in the level of stress after all losses.

In the initial calculations, estimated forces do not have to match specific amount of prestressing strands. Calculated prestressing must be applied to the structure in the form of forces or the forces and moments in the anchorages and the load q_{pst} from the curvature of the cable.

A finite element method is a good method used in the calculation of statics. In the modelling process the appropriate size of finite elements should be selected. Adequate measures should be taken to obtain the correct values of the bending moments over the supports. Recommendations for this can be given by the computer program manufacturer.

After the calculation of statics limit states of punching and flexure ought to be verified in critical areas. Usually these points are the areas near internal columns. These verifications can be done using simplified methods. In case of problems with limit states, the design solution should be changed.

6 DISTRIBUTION OF PRESTRESSING TENDONS

The next stage after the initial verifications is selection of the final number of prestressing tendons and their spacing. For prestressing, cables having from 1-5 (or 6) strands can be used. The use of multistrand cables can definitely speed up the work related with the laying of prestressing. The use of monostrands allows to bypass the designed openings in the floor, because the cables are less rigid in the horizontal direction. A good recommendation [13] is the distribution of prestressing tendons with the spacing which is greater than 8 heights of slab and 150cm.

7 LOSSES OF PRESTRESSING FORCE

The next step is to calculate the losses of prestressing force in each cable. It is a relatively complex issue, because in order to make very precise calculations, it is necessary to repeat the calculation several times. It should be noted that the final result from a practical point of view may have some inaccuracy. It follows from the fact that in the prestressed structures prestressing force which is applied to the anchorages spreads to the entire slab. Determination of compressive stresses in the particular point depends on the amount of prestressing in other places as well as on the acting forces in the prestressing tendons. Because of this influence of prestressing on other cables as well as the impact of losses on the loss of other cables, the unambiguous determination of the final loss is almost impossible. The approximate losses can be calculated by applying some rules, which will be discussed below.

Losses of prestressing force can be divided into two types: initial and delayed or time dependent. Table 5 presents the losses and equations for their calculation. Equations come from the PN-EN 1992-1-1 [7] and [4].

initial losses	equation
losses due to friction	$\Delta P_{\mu} = P_{max}\left(1 - e^{-\mu(\theta + kx)}\right)$
losses due to elastic shortening of concrete	$\Delta P_{el} = A_p E_p \frac{j\Delta\sigma_c(t)}{E_{cm}(t)}$
losses due to anchorage slip	$\Delta P_{sl} = 2a_{sl}\frac{x_0 - x}{x_0^2}E_p A_p$ [1)]
time dependent losses	
losses due to shrinkage of concrete	$\Delta P_{c+s+r} = A_p \frac{\epsilon_{cs}E_p + 0.8\Delta\sigma_{pr} + \frac{E_p}{E_{cm}}\phi(t,t_0)\sigma_{c,QP}}{1 + \frac{E_p A_p}{E_{cm}A_c}\left(1 + \frac{A_c}{I_c}z_{cp}^2\right)\left[1 + 0.8\phi(t,t_0)\right]}$ [2)]
losses due to creep of concrete	
losses due to relaxation of steel	

[1)] the equation is suitable for situations where the range of slip does not exceed the length of the cable
[2)] the equation shows the total value of the time dependent losses

Tab. 5 *Prestressing losses [4], [7]*

where:

θ - the sum of the angles of curves on the way of cable,

μ - coefficient of friction between the strands and the duct,

k – wobble coefficient, sum of angular displacements over the distance x

x - distance from the point where the force is equal to P_0 (P_0 - force on the active end shortly after the prestressing), measured along the tendon,

P_{max} - the force on the active end during prestressing,

j - a factor of (n-1) / (2n) (n is the number of actions of prestressing per one meter of slab width)

a_{sl} – slip of a tendon in the anchorage,

x_0 - the range of slip

ε_{cs} – shrinkage strain of concrete,

$\varphi(t, t_0)$ - creep coefficient,

z_{cp} - distance from the central plane to the axis of the cable,

E_p, E_{cm}, $E_{cm}(t)$, I_c, A_c, A_p – the relevant characteristics values associated with the material or cross-section,

$\Delta\sigma_c(t)$ – the value of changes of stresses in concrete at the moment of prestressing at the level of the centre of the gravity of the tendon. The exact calculations of this value in slabs are difficult. A good approximation is $\Delta\sigma_c(t) = (P_{max} - \Delta P_{\mu} - \Delta P_{sl})/A_c$.

$\Delta\sigma_{pr}$ – the value of changes of stresses in the tendon due to relaxation. The EC2 recommends to calculate this loss with regard to the initial stresses after prestressing and the impact of quasi-permanent loads. This solution is very troublesome in the case of slabs. It therefore seems reasonable to calculate the losses in a simplified manner as a change of stresses in steel only due to prestressing without taking into account the moments which come from calculations of a indetermined structure.

$\Delta\sigma_{c,QP}$ – the value of changes of stresses in the concrete next to the tendon, caused by self-weight, the initial prestressing forces and quasi-permanent loads. The exact calculation is impossible in the slabs. A good and quite safe approximation can be $\Delta\sigma_{c,QP} = P_{m0}/A_c$.

During calculating the time dependent losses of bounded tendons the value $\Delta\sigma_{pr}$, $\Delta\sigma_{c,QP}$ in the specified point should be used. They should be values in a given place in the structure. For unbounded tendons the value should be an average along the length of the cable.

Stresses in the prestressing steel should satisfy the following conditions:

$\sigma_{p,max} \leq min(0.8f_{pk}, 0.9f_{p0,1k})$ - the maximum stress in the tendon (in some cases, these values may be different),

$\sigma_{pm0}(x) \leq min(0.75 f_{pk}, 0.85 f_{p0,1k})$ - stresses in the tendon immediately after the prestressing..

In concrete, it should be ensured that stresses do not exceed the level of $0.6f_{ck}(t)$.

After calculating the initial losses of prestressing force the statics analysis should be done with loads acting at the time just after prestressing. A verification of some places should be done. It is essential to verify whether due to the absence of the live loads any cracks have occurred. Then we proceed to analyse the statics at final situation with regard to the prestressing loads after all losses. A comparison of the initial and final value of the prestressing force can be done at some points. In the case of modelling and applying loads to the structure in computer programs some small rounding down (0.5 – 1.0 kN/m^2) can be done in order to simplify the design process. Such rounding will increase security for the situation of final vertical location of cables. It especially helps structures with unbounded strands.

8 ULTIMATE LIMIT STATES (ULS)

After obtaining the results of statics calculations the next stage of the project is to verify the ultimate limit states. The standards require checking the ultimate limit states in all areas of the structure. Normally it is enough to check:

- bending with compression (eccentric compression) over the columns and probably near the capitals, the places where slab thickness changes, in the spans of the slabs and also spandrel beams (if any) in the mid-span and over the support,
- punching over the columns and near the edges of drop panels and capitals,
- shear of the slab, beams and bands,
- torsion of spandrel beams,
- shear between the beams and the slab,
- anchorage zones due to: pressures under the steel plate, deep-tensile stresses, head tensile stresses, corner tensile stresses.

During verification and dimensioning the structure for flexure with the axial force it is good to consider the effect of torsion in the slab. Torsion occurs near corners of the supports, in corners of drop panels and column capitals and in corners of the slab near beams. It is safe to add torque to bending moment.

When dimensioning the structure some rules connected with prestressing should be taken into account. It is good to treat prestressing tendons as a force in the structure and as reinforcement. This means that during verifying the ULS prestressing is taken into account in the calculation of statics. This helps to avoid the calculation of moments which appear due to indeterminacy of a structure. Additionally, in the case of bounded tendons difference between the design value of yield stress and stresses in prestressing steel after all losses (the deformation of the concrete must be taken into account), and for unbounded tendons the stress increment value in ULS (100 MPa) can be used like a normal reinforcement.

One of the main problems is punching. Often there is a need for some special solutions to protect the floor against punching. These are:

- stirrups and bent bars,
- stiff steel shearheads,
- stiff hidden steel capitals,
- drop panels,
- steel flanges,
- FRP strips,
- steel studs.

EC2 presents methods for calculating solutions using drop panels, traditional solutions with stirrups and bent bars. In these calculations prestressing has an impact in two ways. Prestressing increases the strength of the control perimeter and cables located within a distance of 0.5*d* from the edge of the supports, the punching force is reduced because of the vertical component of the force which acts in these cables. The standard also allows the use of the product of some companies, but the appropriate European Technical Approvals ([14], [15] and [16]) must be used. In the case of studs it should be noted that the punching force can be reduced by prestressing, but the technical approvals do not mention anything about the increase in strength due to the appearance of compressive stresses. The reasoning for the work of concrete against punching in the EC2 and technical approvals are very similar. This allows you to predict that the compressive stresses effect like it is described in the EC2.

Spandrel beams when they are used acquire a substantial torque value. There also exist in large bending moments and shear forces. On their side there are the anchorages of cables, which work in the perpendicular direction. The EC2 standard recommends to reduce the strength against the pressure in the zones of high shear forces. It seems that it is in those areas with anchorages concrete works worse. Also in these zones prestressing works against head stresses and deep-tensile stresses.

9 SERVICEABILITY LIMIT STATES (SLS)

During designing the prestressed slabs the serviceability limit states should be also verified. They require a recalculation of statics, using as characteristic values of loads and in many cases almost quasi-permanent load combination. Prestressed floors usually have no problems in meeting the requirements.

Prestressing by introducing compressive stresses to the structure reduces the possibility of appearance cracks and reduces their width. Crack width limit values depend on the type of prestressing, exposure environment and may also result from other factors. They are presented in the EC2. During the verification of crack width the work of prestressing should be considered. Unbounded tendons give beneficial compressive stresses to the structure, while bounded tendons work also as reinforcement.

Prestressing reduces the deflection because it counteracts the dead loads, which are a major part of quasi-permanent loads. Additionally, due to the smaller number of cracks, stiffness of individual elements is greater, what is beneficial in deflection reduction. The exact determination of the deflection in the design process is difficult, beyond the situation when the entire structure is not cracked – it is enough to calculate the elastic deflection, which is influenced of rheology. When structure works as cracked in most of areas it is expected that the deflection will be large and it should be calculated as for reinforced concrete elements. A situation, in which sections over the supports will be cracked is relatively common. A safe verification of the deflection limit state in that case is to use ratio of uncracked support cross-section stiffness to the stiffness of cracked cross-section support stiffness influenced by rheological effects. Then the ratio must be multiplied by the elastic deflection at the critical point.

10 ADDITIONAL DESIGN INFORMATION

In the final version of the project design basic information of a typical reinforced concrete slab should be included. Additionally, the project should include plans of prestressing cables and the relevant details of prestressing and important cross-sections. In areas where normal reinforcement is not required minimum reinforcement should be applied using appropriate spacing of bars given in EC2. Prestressing cables should be placed on a specially prepared props. The coordinates of the bottom of the prestressing cables depending on the distance from the anchorage and the forces of prestressing and the extensions on the cables during prestressing should be placed in the drawings. In the case of dense prestressing around columns, there is a necessity of analysing for prestressing tendons penetration. Some the appropriate adjustments must be done. They can influence the values in the tables with the coordinates of the bottom of cables. However, when it is necessary to move the cable to a greater distance, eg approximately 5cm, designer should make sure that it will not have a significant impact on the results of statics. For single cable it usually does not cause big problems. In areas over the columns it is crucial to not forget about the correct placement of cables and reinforcement for punching.

11 SUMMARY

Designing prestressed floors engineers can meet many difficulties, which in the first projects can complicate job. However, with experience, designing of these floors will become much easier. Each designer will be able to precisely determine an impact of some changes on the structure. During designing process a stage of choosing adequate structural system can be very time-consuming. It is crucial to set some structural assumptions – especially connected with a punching problem and a prestressing system. Fire protection requirement are also very important. In the drawings it is essential to precisely located the cables and studs for shear to avoid problems with them. Prestressed slabs allow to reduce amount of concrete. Due to smaller height of slabs it is possible to use less space comparing to reinforced concrete structures. Prestressing allows builders to disassemble formwork of the floor and helps to achieve a sufficient strength of the slab. It is easily seen in case of constructing buildings with repetitive floors. Prestressed concrete structures are made of materials of better quality. Due to that they do not need often repairs and are more durable.

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