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CONCENTRATED LOAD IN ANCHORAGE ZONES OF PRESTRESSED CONCRETE MEMBERS

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Abstract: *In prestressed concrete structural members, the prestressing force is usually transferred from the prestressing steel to the concrete in one of two different ways. For pretensioned members, the force is transferred by bond between the tendon and the concrete. In post-tensioned construction, relatively small anchorage plates transfer the force from the tendon to the concrete immediately behind the anchorage by bearing at each end of the tendon. In most post-tensioned members, the prestressing wires are introduced in cable holes or ducts, pre formed in the members, and then stressed and anchored at the end faces. As a result of this, large forces, concentrated over relatively small areas are applied on the end blocks. This highly discontinuous forces which are applied at the end, develop transverse and shear stresses. This paper in short describes design of reinforcement in anchorage zone of post-tensioned concrete structures according to European standard.*

Keywords: Concrete, Anchorage zones, Anchorage, Tensile bursting forces, Confinement reinforcement.

1. Introduction

There are generally three areas behind an anchor that need to be reinforced. Immediately behind the anchor are splitting forces due to the tendency of the anchor to be driven into the concrete member by the force of the tendon. Adjacent to the anchor, on the end face of the member, are zones of tensile stress known as spalling zones. Finally, as the prestress force disperses into the member, further zones of tensile stress are created. Anchorages are expected to function satisfactorily for tendon forces of around 95 % of the tendon strength, though most of the standards limit the jacking force to about 80 % of the tendon strength. It may be permissible to take the design force for anchorage zone reinforcement as equal to the specified jacking force, but it is preferable to design for a force of 90 to 100 % of the tendon strength as this provides a useful reserve for a deliberate or inadvertent overstressing of a tendon.

2. Anchorage zones in post-tensioned concrete

In commercial post-tensioned anchorages, the concrete immediately behind the anchorage is confined by spiral reinforcement (see Fig. 1), in addition to the transverse bursting and spalling reinforcement (often in the form of closed stirrups). In addition, the transverse compression at the loaded face immediately behind the anchorage plate significantly improves the bearing capacity of such anchorages. Therefore, provided the concrete behind the anchorage is well compacted, the bearing stress given by Eq. (1) is usually conservative. Commercial anchorages are typically designed for bearing stresses of about 40 MPa, and bearing strength is specified by the manufacturer and is usually based on satisfactory test performance. While the anchorages come in many shapes and sizes, the load transfer mechanism of these anchorages remains essentially the same. The stressing operation involves the hydraulic jack pulling the strands protruding behind the anchorage until the required jacking force is reached.

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2.1. Bearing stresses behind anchorages

In post-tensioned concrete structures, failure of the anchorage zone is perhaps the most common cause of problems arising during construction. Such failures are difficult and expensive to repair, and usually necessitate replacement of the entire structural member. Anchorage zones may fail owing to uncontrolled cracking or splitting of the concrete resulting from insufficient well-anchored transverse reinforcement. Bearing failures immediately behind the anchorage plate are also relatively common and may be caused by inadequately dimensioned bearing plates or poor workmanship resulting in poorly compacted concrete in the heavily reinforced region behind the bearing plate (see Fig. 2). Great care should therefore be taken in both the design and construction of post-tensioned anchorage zones.

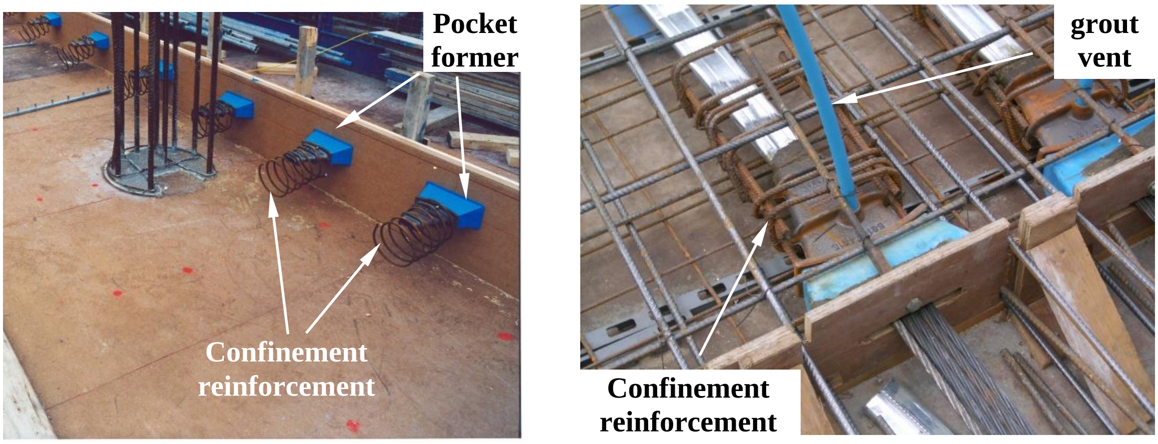

Fig. 1: Live-end anchorage with confining steel.

Fig. 2: Tendon failure at the end of the slab.

2.2. Bearing stresses behind anchorages

Local concrete bearing failures can occur in post-tensioned members immediately behind the anchorage plates if the bearing area is inadequate or the concrete strength is too low (see Fig. 3). The stres σ_{c1} that can be supported on a bearing area A_{c1} is specified in EN 1992-1-1 as:

$$\sigma_{c1} = {F_d}/{A_{c1}} \quad \leq \quad \omega_c \cdot f_{cd} \tag{1}$$

$$\omega_c = \sqrt{A_{c2}/A_{c1}} \qquad max \quad \omega_c \; = \; 3{,}0 \tag{2}$$

where f_{cd} is the design compressive strength of the concrete at the time of the transfer, A_{c1} is the bearing area, A_{c2} is the largest area of the concrete supporting surface, with maximum dimensions as indicated in Fig. 3 (EN 1992-1-1). The centre of the design distribution area A_{c1} is on the line of action of the force F_d passing through the center of the bearing area A_{c1}.

Main stresses σ_1 and σ_2 in 200 mm thick concrete floor slab under two anchorage plates for 5 x Ø 15.7 mm tendons are shown in Fig. 4. High bursting forces exist along the axis of the anchorage plate and, away rom the axis of the anchorage, tensile stresses are induced on the end surface.

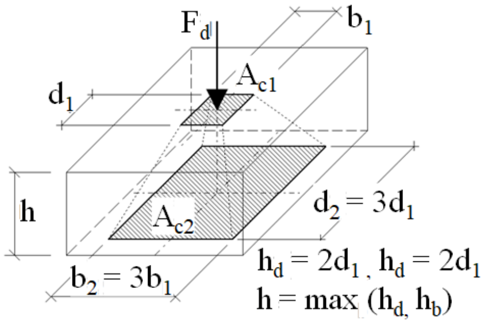

Fig. 3: Design distribution areas for determination of bearing resistance force (EN 1992-1-1).

Tab. 1: Values of coefficient ω_c.

A_{c2}/A_{c1}	1	2	3	4	5	6	7	8	9
ω_c	1.000	1.414	1.732	2.000	2.236	2.449	2.646	2.828	3.000

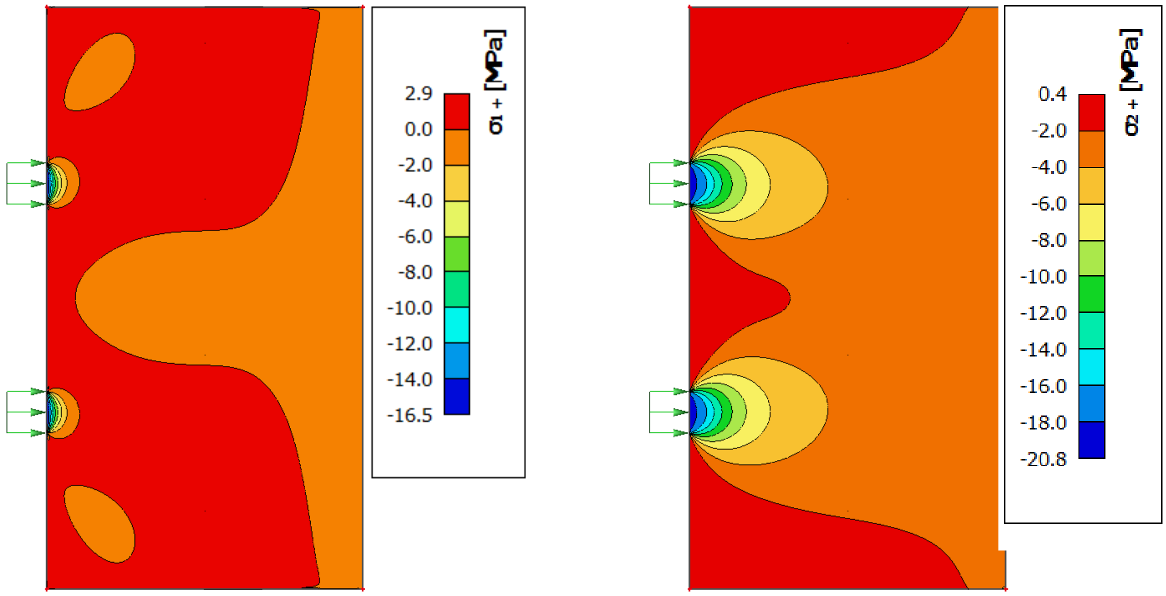

Fig. 4: Stress in concrete under two anchorage plates.

Method of concentrated pressure analysis

1. For concrete with design compressive strength f_{cd}, we first determine the necessary strength increase by means of the coefficient $\omega_c = F_d / (A_{c1}.\ f_{cd})$ while the force F_d acts on the area A_{c1}. If the required value of $\omega_c > 3$, it is necessary to increase the class of concrete, or enlarge the contact area A_{c1}. If the required value of $\omega_c < 1$, it is not necessary to make an expertise of concentrated pressure.
2. We determine the distribution area $A_{c2} = A_{c1} \cdot \omega_c{}^2$, with its minimum value being $A_{c2} = F_d / f_{cd}$.
3. The shape of the area A_{c2} must be the same as the shape of the area A_{c1}. If the area A_{c1} matches the criteria $\beta = b_1/d_1$, the sides of the distribution area $A_{c2} = b_2 \cdot d_2$ must meet the same criteria, i.e. $\beta = b_2/d_2$, or $b_2 = \beta \cdot d_2$. Thus, we can state the following formulas for calculating the measurements of A_{c2} in such a way, that the lateral stress distribution σ_c is equal in the directions of b and d.

$$A_{c2} = b_2 \cdot d_2 = \beta \cdot d_2 \cdot d_2 = \beta \cdot {d_2}^2 \tag{3}$$

$$d_2 = \sqrt{A_{c2} / \beta} \qquad b_2 = \beta \cdot d_2 \tag{4}$$

4. We confirm that the measurements b_2, d_2 meet the criteria of A_{c1} and A_{c2} placement above each other, i.e. if the stress distribution of σ_c from the force F_d is full, in the shape of the modeled pyramid. Full distribution occurs if the borders of the area A_{c1} are further from the edges of the element than the sizes b_1, d_1. If the borders of A_{c1} are closer to the edges of the element, only partial distribution of stresses σ_c

occurs, in the shape of modeled pyramid, but limited by one or two edges of the element (Fig. 3). In that case, the designed distribution in the directions of b and d will not be equal and we must correct the shape of A_{c2} according to the principles of partial distribution, so that we can achieve the required value of coefficient ω_c.

5. In order to analyze the effects of design lateral tensile forces T_{Ed} we determine the height h of design distribution of concentrated pressure below the contact area A_{c1} while taking directions b and d, into account. In the following calculations, we will use the value of $h = \max(h_b, h_d)$, with the partial heights in the directions of b, d will be

$$h_b = b_2 - b_1, \qquad h_d = d_2 - d_2. \tag{5}$$

2.3. Method of performing expertise of the effects of lateral tensile forces T_{Ed}

The effect of lateral tensile forces we analyze separately for each of the directions b, d of the design distribution of σ_c. When considering the possibility of plasticized zones in concrete occurring, as well as the positive effects of shear stress in concrete right under the contact area A_{c1}, we can determine the overall designed and characteristic values of lateral tensile stresses in the zone of σ_c distribution using the following formulas:

for the direction b — for the direction d

$$T_{Ed,b} = \frac{1}{4}\left(1 - 0{,}7\,\frac{b_1}{h}\right) F_d \qquad T_{Ed,d} = \frac{1}{4}\left(1 - 0{,}7\,\frac{d_1}{h}\right) F_d \tag{6}$$

The basic condition, which grants the occurrence of spatial state of stress in the zone below A_{c1} (and related higher compressive strength, which equals $\omega_c \cdot f_{cd}$) is reliable transfer of tensile forces, which cause the appearance of cracks, within concrete. For these lateral tensile forces below the area A_{c1}, reinforcement A_{st} must be calculated, separately for both directions of σ_c distribution. The minimum section area A_{st} of the reinforcement must be 25 % of the opposite direction. Using the design value of reinforcement's yield strength f_{yd} we can determine the required reinforcement that can secure the lateral tensile strength. The area A_{st} has to be bigger than the minimum $A_{st,min}$. This means, that

for the direction b — for the direction d

$$A_{st,b} = T_{Ed,b}/f_{yd} \qquad A_{st,d} = T_{Ed,d}/f_{yd} \tag{7}$$

$$A_{st,b} \geq A_{st,min,b} \qquad A_{st,d} \geq A_{st,min,d} \tag{8}$$

3. Conclusions

The bearing area of the anchorage is only a small proportion of the concrete area associated with an anchorage. The prestressing force, concentrated on the bearing area, spreads through the concrete, and can be uniformly distributed on the concrete section at a suitable distance from the anchorage. The transverse stresses developed in the anchorage zones are tensile in nature over a large length and since concrete is weak in tension, adequate reinforcement should be provided to resist this tension. The main aim of stress analysis in the anchorage zone is to obtain transverse tensile stress distribution o the end block from which the total transverse bursting tension could be computed. Inadequate reinforcement in anchorage zone of post-tensioned prestressed concrete members may leads to cracking or appalling of concrete. In this paper, the design of rebars in anchorage zone of post-tensioned concrete structures according to EC2 are describes.

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References

Abrahoim, I. (2012): Assessment of reinforced concrete members in concentrated pressure according to EN 1992-1-1, In: Proc of 19th Concrete Days 2012 Conference, Hradec Králové, Czech Repulic, 21.-22.11.2012, (in Slovak).

Harvan, I. (2013) Prestressed Concrete Structures, Design According to European Standards. Bratislava, (in Slovak).

Gilbert, R. I., Mickleborough, N. C. and Ranzi, G. (2017) Design of Prestressed Concrete to Eurocode 2, 665 p.

Harvan, I. (2014) Reinforced Concrete Structures, Design According to European Code. STU Bratislava, (in Slovak).

STN EN 1992-1-1 Design of concrete structures, General rules and rules for buildings, 2005, (in Slovak).