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HEADED FASTENINGS ACTING IN COOPERATION WITH SUPPLEMENTARY STEEL REINFORCEMENT

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1. Introduction

Composite steel-concrete and precast concrete structural systems are becoming the first choice for many construction designers because of easier and more efficient process of building. This is also achieved by simple, efficient joints allowing quick and easy connection between beams and columns or other membersin concrete structures.The appropriate design and performance of joints are very important preconditions for durability and effectiveness of structures. In current practice, there are many types of fastening systems using in building structures as part of joints. But requirements of high load capacity present preferable advantage especially for cast-in-place anchorage systems.Headedfastenings made of rebar or smooth steel appertain presently to the attractive solution. This type of anchors currently represents a relatively popular technique to create joints in composite structures because it is more compact than other available systems. The proper design and detailing of anchors and joints may be quite complex in some cases. Due to a gap between the design of fastenings in concrete and steel design and missing concerted standardised joint solutions it may lead to unnecessarily conservative results.For designing of anchors could be used available approaches, namely CEN/TS 1992-4[1], fib Bulletin No. 58 2011[2], INFASO[3].The research and studies focused on headed fastening have been executedby the authors of the paper. The theoretical study, experiencefromexperimental research and some conclusions are analysed and discussed in paper.

2. Scope of research

The aimof our research should bea better understanding of the headed fastening behaviour subjected to tension load and identification of some the factors influencing the fastening capacity. In this part of work we try to compare interim results with current methodologiesthat describe the behaviour of anchors.Interim tests are essential forpreparing and calibratingfuture experimentalmore ample testing programme.

Performance of fastenings usually depends on load capacity of the concrete surrounding the fastening. The resistance of the fastening may be increased by using supplementary reinforcement designed in order to prevent or delay the formation of concrete cone. The supplementary hanger reinforcement can be used in form of hooks, loops or stirrups. The studyis focusingon determination of this type of reinforcementcontribution that can be generally taken into account too conservatively.

3. Failure modes of individual headed anchor subjected to tension load

3.1. CEN/TS 1992-4-2[1]

The design of headed fastenings is regulated by the technical specification CEN/TS 1992-4-2[1] that defines a set of verifications for different failure modes of headed fasteners loaded in tension. The load capacity of a fastener is governed by its geometry, position in concrete member and materials properties of concrete and steel. Non-reinforced anchorage typically exhibit five possible failure modes in the case of tension loading. These consist of following:

a) Pull-out failure (Fig. 1(a))
b) Concrete cone failure (Fig. 1(b))
c) Steel failure (Fig. 1(c))
d) Splitting failure (Fig. 1(d))
e) Blow-out failure (Fig. 1(e))

Each of these failure modes is characterised by relevant load-displacement curve.

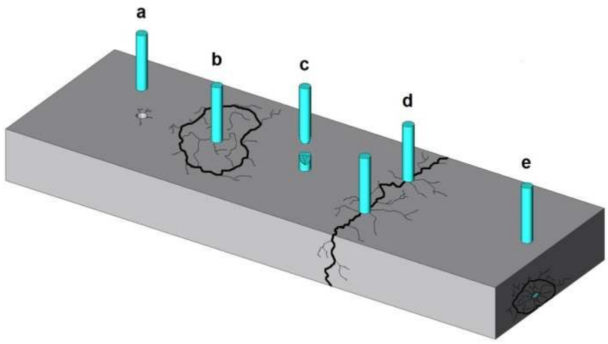


Fig.1. Failure modes of headed anchors.

The majority of cast-in-place anchor systems exhibit concrete cone breakout at failure that is the most representative for fastener subjected to tension. The concrete cone breakout failure mode is characterised by the formation of a cone-shaped fracture surface in concrete, so the full tensile capacity of the concrete can be utilised.The evaluation of anchorage to concrete failure is currently based on Concrete Capacity Method (CC-Method). The method consists in assumption of the development of a failure surface, with a slope of 35º, starting from the head of anchor to the concrete member surface (Fig. 2).

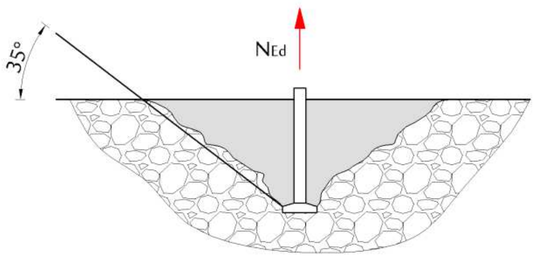


Fig.2. Concrete cone failure.

The resistance of an anchorage system is due to concrete cone failure obtained from the capacity of one anchor without influence of concrete member edges. Insuch conditions, the characteristic resistance of this anchor according to CEN/TS 1992-4[1], is

$$N^{O}_{Rk,c} = k_{cr}\sqrt{f_{ck,cube}}h^{1.5}_{ef} \quad (1)$$

with:

k_{cr} → factor taking into account the influence of load transfer mechanisms forapplications in concrete as a function of concrete situation, especially concrete with or without cracks,
$f_{ck,cube}$ → cubic concrete compressive strength,
h_{ef} → effective embedment depth of fastening in concrete.

In order to increase the resistance of the fasteningagainst concrete cone failure, a common practice is the use of supplementary reinforcement around the fastening. The installation examples of this type of reinforcement are illustrated in Figure 3.

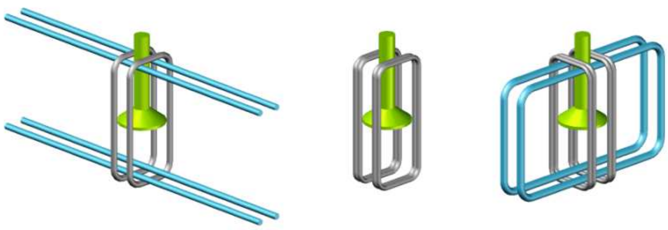


Fig.3. Supplementary reinforcement.

After the concrete cone crack surface is formed, the reinforcement acts on keeping the concrete cone and membertogether. In such conditions not only the resistance of the anchorage is increased but also theductility. So, the supplementary reinforcement delays or prevents the formation of a concrete cone, and therefore two new failure modes may occur:

a) Steel failure of the supplementary reinforcement (Fig. 4(a))
b) Anchorage failure of the supplementary reinforcement in the concrete cone (Fig. 4(b))

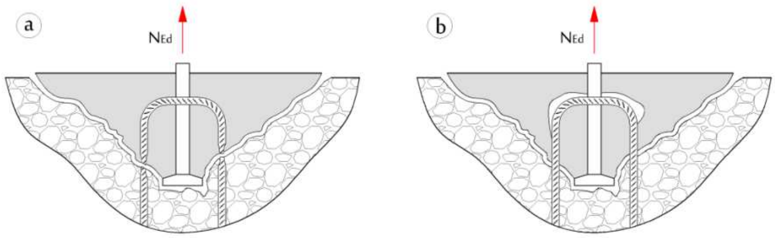


Fig.4. Failure modes of supplementary reinforcement.

The characteristic value of resistance of an anchor withsupplementary reinforcement is governed by the smaller of two failure loads. The resistance connected with steel failure of reinforcement is defined as follows:

$$N_{Rk,re} = n\ A_s f_{yk}\ , \tag{2}$$

with:

n → number of legs of the supplementary reinforcement effective for one fastener,

A_s → cross section area of one leg of the supplementary reinforcement,

f_{yk} → nominal yield strength of the supplementary reinforcement.

The determination of resistance of a fastening system due to anchorage failure of the supplementary reinforcement follows from normal considerations of reinforcement bond length. This resistance can be predicted using the following expression:

$$N_{Rd,a} = \sum_n \frac{l_1\ \pi\ d_s f_{bd}}{\alpha}, \tag{3}$$

with:

l_1 → anchorage length of the supplementary reinforcement in the assumed failure cone,

d_s → diameter of the reinforcement bar,

f_{bd} → design bond strength according to EN 1992-1-1[4],

α → factor that takes into account the effect of the shape of the supplementary reinforcement (α=0.7 – for hooked bars).

3.2. INFASO [3]

Document INFASO (Innovative Fastening Solutions between Steel and Concrete) is a result of European project focused on development of mechanical models based on the component method describing the behaviour of steel-to-concrete joints. The component method allows a detailed optimization of joints. The method, originally developed for steel joints, regards the joint as a set of individual basic components which contribute to its structural response as resistance, stiffness and ductility. For single anchor with supplementary reinforcement in concrete member this components have been defined:

- Concrete breakout in tension

- Supplementary reinforcement in tension
- Pull-out failure in tension
- Steel elongation in tension

Component „Concrete breakout in tension"
This component is described by an analytical investigation and using the existing test results. The aim isto describe the failure mode concrete cone breakout. This is done by a bilinearfunction (Fig. 5(a)).

Component „Pull-out failure in tension"
The pull-out failure of the headed fastenings occurs if the mechanical interlock between head of anchor and the surrounding of concrete is inadequate. The stress under the head of anchor is very high and the concrete is crushed in the anchorage zone. Depending on the load the stiffness of system changes andtherefore two different ranges have been defined (Fig. 5(b)).

Component „Steel elongation in tension"
The steel of tensioned headed anchor elongates up to the yielding strength in a linear elastic way. This displacement can be predicted by using the Hook´s law. When the yieldingstrength of steel is reached, the displacement increases withoutincreasing of the load. The load-displacement curve is given in Figure 5(c).

Component „Supplementary reinforcement in tension"
The component "Supplementary reinforcement in tension" was developed based on empirical studies. The evaluation of tests shows, that the displacement depends mainly on the concrete strength and the diameter of reinforcing bar. The function describing this component is shown in Figure 5(d).

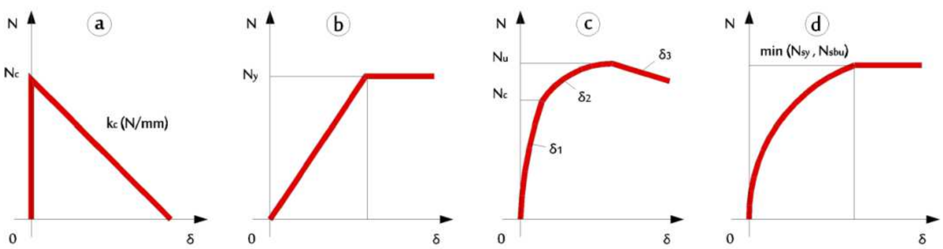


Fig.5. Corresponding components of model.

The definition of resistance of anchor for the combined model usesabove mentioned components. Generally, three failure models are possible. Concrete cone can failure, rupture of supplementarysteel reinforcement might occur and breaking of anchoragesupplementary reinforcement in the concrete conecan limit the carrying capacity. If the concrete cone failure occurs, the ultimate load $N_{u,max}$ can be calculated by the concrete cone failure according to the CC-method using an increasing factor Ψ_{suppor}depending on the position of supplementary reinforcement.

$$N_{u,max} = N_{Rk,c}\psi_{suppor} \tag{4}$$

$$\psi_{suppor} = \frac{x}{h_{ef}} \geq 1{,}0 \quad (5)$$

To calculate the resistance of single anchor, it is crucial to define the „x“distance. Therefore the distance „x“is determined as the distance between the anchor and the crack of the reduced concrete cone on the concrete member surface (Fig. 6). Generally, the crack develops from the stirrupas supplementary reinforcement to the concrete surface with the angle of 35°.

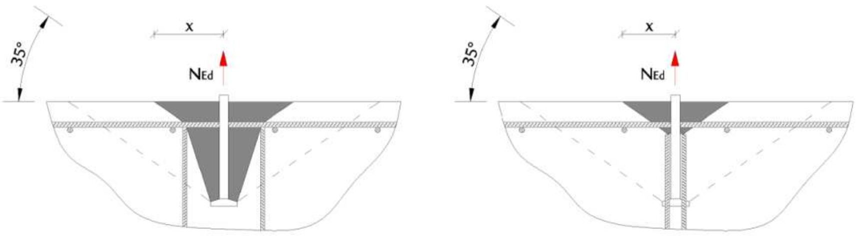


Fig.6. Reduced concrete cone and distance „x“.

If concrete cone develops and the load is transferred to the supplementary reinforcement, the failure of the reinforcement would becritical. In case of steel yielding of reinforcement, it is necessary to know the displacement of the component „supplementary reinforcement in tension“ at the yield point (δ_{sy}) and also stiffness $k_c$that is defined in component „*Concrete breakout in tension*“.The failure load can be calculated according to equation:

$$N_{u1} = N_{sy} + N_{Rk,c} + \delta_{sy} k_c, \quad (6)$$

with:

N_{sy} → Af_y, the load corresponding to the yielding point,
$N_{Rk,c}$ → the resistance of a fastener in case of concrete cone failure,
δ_{sy} → displacement of the component „Supplementary reinforcement in tension“ at the yield point,
k_c → stiffness of component „*Concrete breakout in tension*“.

In case of anchorage failure of the supplementary reinforcement in the concrete cone, the resistance of anchor is defined as:

$$N_{u2} = N_{sbu} + N_{Rk,c} + \delta_{sbu} k_c , \quad (7)$$

with:

$N_{Rk,c}$ → the resistance of a fastener in case of concrete cone failure,
δ_{sbu} → displacement of the component „Supplementary reinforcement in tension“ that corresponds with anchorage failure,
k_c → stiffness of component „*Concrete breakout in tension*“.

The anchorage capacity of supplementary reinforcement (N_{sbu}) is defined as well as CEN/TS:

$$N_{sbu} = \sum_n \frac{l_1 \; \pi \, d_s f_{bd}}{\alpha}, \quad (8)$$

with the factor α=0.49.

4. Experimental investigation

The mission of the interim test study is to determineexperimentally resistances and failure modes of short headed fastenings with supplementary reinforcement, which are cast in small concrete members and to compare the results with presently available methodologies.

4.1. Specimens

Three specimens with cross-sectional dimensions of 280x280 mm and length of 1200 mm were fabricated for determining the load-carrying capacity of the short headed fastenings cast in concrete members. The anchorage depth of the headed fastenings and the system of specimen reinforcing were varied in the three tested specimens. The diameter of the shank of headed fastenings was 25 mm. The part of the fastening outside concrete member was equipped with metric thread M24. This thread portion was used to attach the fastening to the loading jack during testing.All specimens were reinforced by longitudinal reinforcement and in corners by stirrups. Supplementary reinforcement consisting of two Ø12 mm stirrups looped around Ø10 mm longitudinal bars at the bottom and upper surface were used in specimen P3. In the specimens P1 and P3, the headed fastening was embedded in depth of 140 mm and in the specimen P2 in greater depth of 255 mm (Fig. 7).

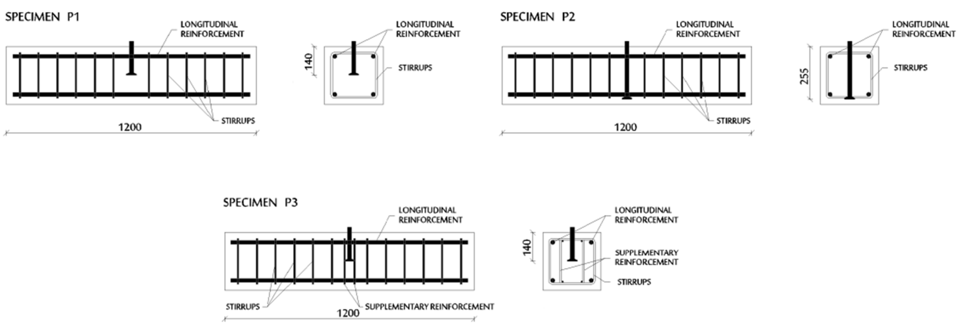


Fig.7. Specimens.

4.2 Test setup

The test procedure was chosen in such a way to correspond as much as possible to requirements ETAG 001 Metal fastenings to concrete. In the beginning, the fastenings were loaded with tension force of 15 kN during 1 minute and thereafter they were loaded to failure with the rate of 80kN.min^{-1}. The load displacement relationship between the fastening and the concrete surface was measured by linear displacement transducers (Fig. 8).

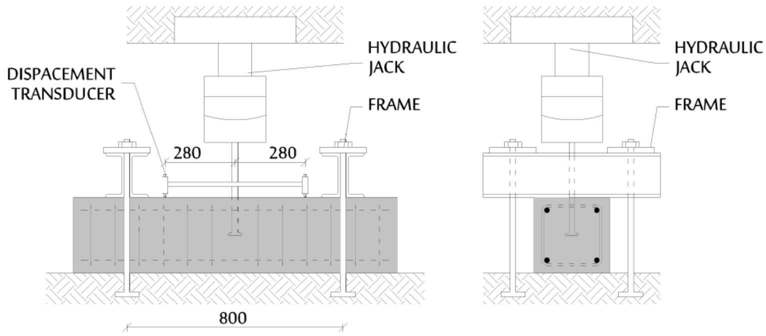
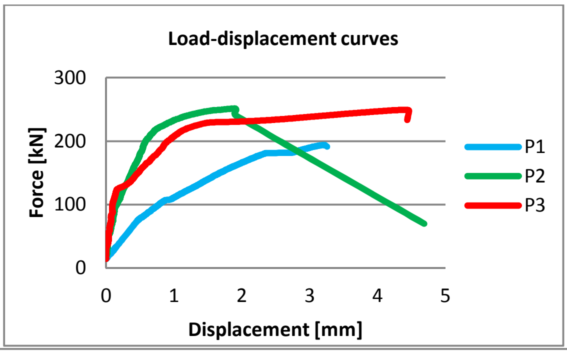


Fig.8. Test arrangement.

5. Results

The load - displacement behaviour of the fastenings is shown in the Figure9(a). The values in the graph are shown from the comparative level of the loading (15 kN).



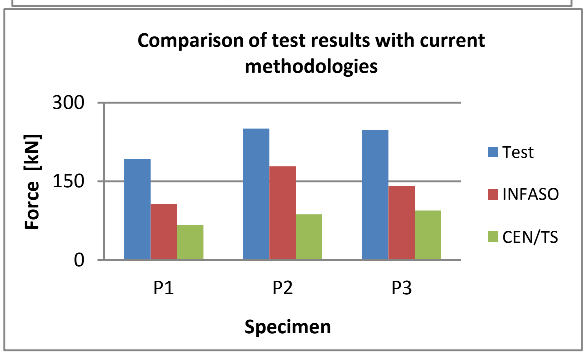


Fig.9. Load-displacement curves (a), Comparison of test results with current methodologies (b).

In the case of the specimen P1, the concrete cone failure occurred. The detached concrete cone was bounded by head of fastening in lower part and by longitudinal reinforcement and stirrups in the level of upper reinforcement. The specimen P2 failed by steel failure of the fastening in the thread M24 without visible cracks on concrete surface.

In the case of the specimen P3, the steel failure occurred too, but local cracks in concrete were observed around the fastening. The cracking was probably initiated by the pressure of the supplementary reinforcement on the concrete surface. Load at failure was compared with resistance according to CEN/TS 1992-4-2[1] and INFASO document[3]. The comparison of measured and calculated values is presented in Figure 9(b).

6. Conclusions

The executed experimental tests have demonstrated that the behaviour of headed fastening strongly depends on the embedment depthand presence of supplementary reinforcements. From the comparison of the experimental results with the technical specification CEN/TS 1992-4-2[1], it can be concluded, that the technical specification takes into account the use of supplementary reinforcement quite conservatively. The document INFASO[3] predicts the failure load better than current technical specification. It seems that inaccuracy between Infaso document and test result is caused by strong influence of narrow member and presence of robust longitudinal reinforcement.

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