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STEEL FRAME AS THE BASIS FOR CHECKING THE PULL-OUT CAPACITY OF BONDED DIAGONAL ANCHOR BOLTS

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Abstract: The paper concerns a device for testing diagonal anchorages, designed by the author. This device constitutes the basis for the testing equipment used for the performed test. No such research has been conducted so far. The article describes the way the rack was designed and what components it is made of. The possibilities and practical examples of the device are also indicated.

Key words: steel frame, capacity, pull-out, diagonal anchor bolts, hydraulic cylinder, bonded anchors.

1. Introduction

The idea to design and create the device was evolving in the course of author's research when it turned out necessary to check the pull-out capacity of diagonal anchor bolts in a three-layer wall of a field facility. There was no possibility to test this type of anchor bolts earlier, as there was a risk of damage to the research apparatus. A device that has not been used so far, has the ability to evaluate the anchor bolts load capacity and provides the basis for verifying the role of the diagonal anchor bolt in the system with a horizontal anchor bolt. On the other hand, many authors have already tested the load capacity of horizontal and point anchor bolts (perpendicular to the surface of a concrete element), whether by computer simulations based on the Finite Element Method and allowing for nonlinear fracture mechanics (Červenka et al., 1991) or by laboratory and field testing (Saleem and Tsubaki, 2010; Karmazínová and Melcher, 2012; Nakano et al., 2012).

During the pull-out test the device used for diagonal anchor bolts is fixed to the wall surface by means of mounting pins. However, for destructive tests (greater destructive power), the frame performs better as a fixing element (Fig. 1).

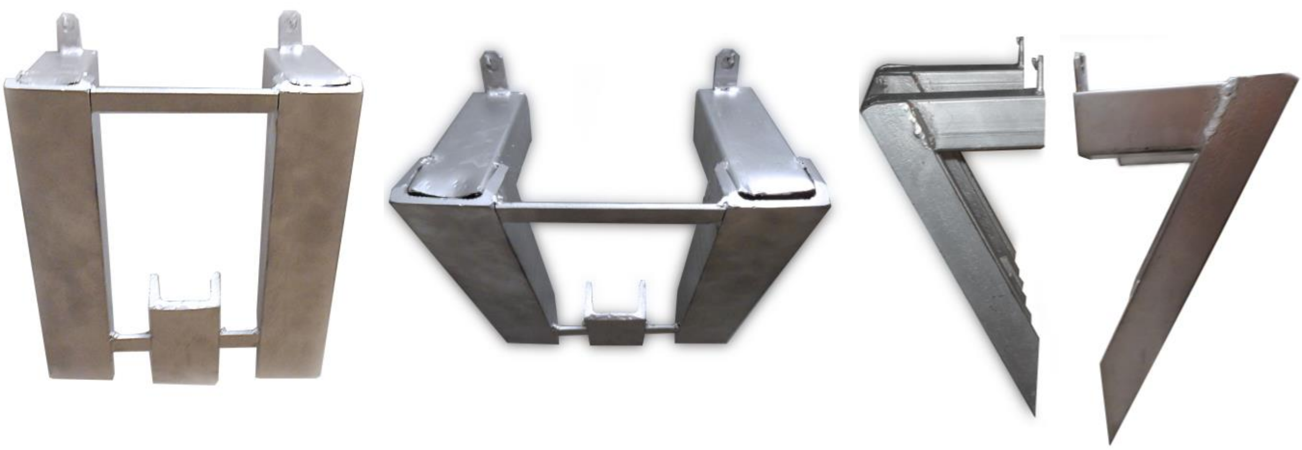

Fig. 1. View of the steel frame reported in the Polish Patent Office.

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2. Description of the device and its scope of application

The frame is designed from steel sections. The arms under the feet of the device are made of structural channels, and the backrests for the arms are made of square thin-walled profiles with flat bars with ø8 mm holes for mounting the frame to the wall surface. Each diagonal anchor bolt test is carried out according to a specific procedure. First there is the so-called "fitting" for a specific anchor bolt to indicate the ø8 mm mounting holes under the frame and adjust the angle of the arms of the frame surface relative to the single anchor bolt (Fig. 2).

This is a basic and essential operation, as it is necessary to maintain the orthogonality of the frame surface with respect to the mounted anchor. The scope of use is virtually unlimited. Due to pivotally adjustable arms the bonded anchors can be tested in the ranges of 30°, 45° and 60° (Figs. 3 and 4).

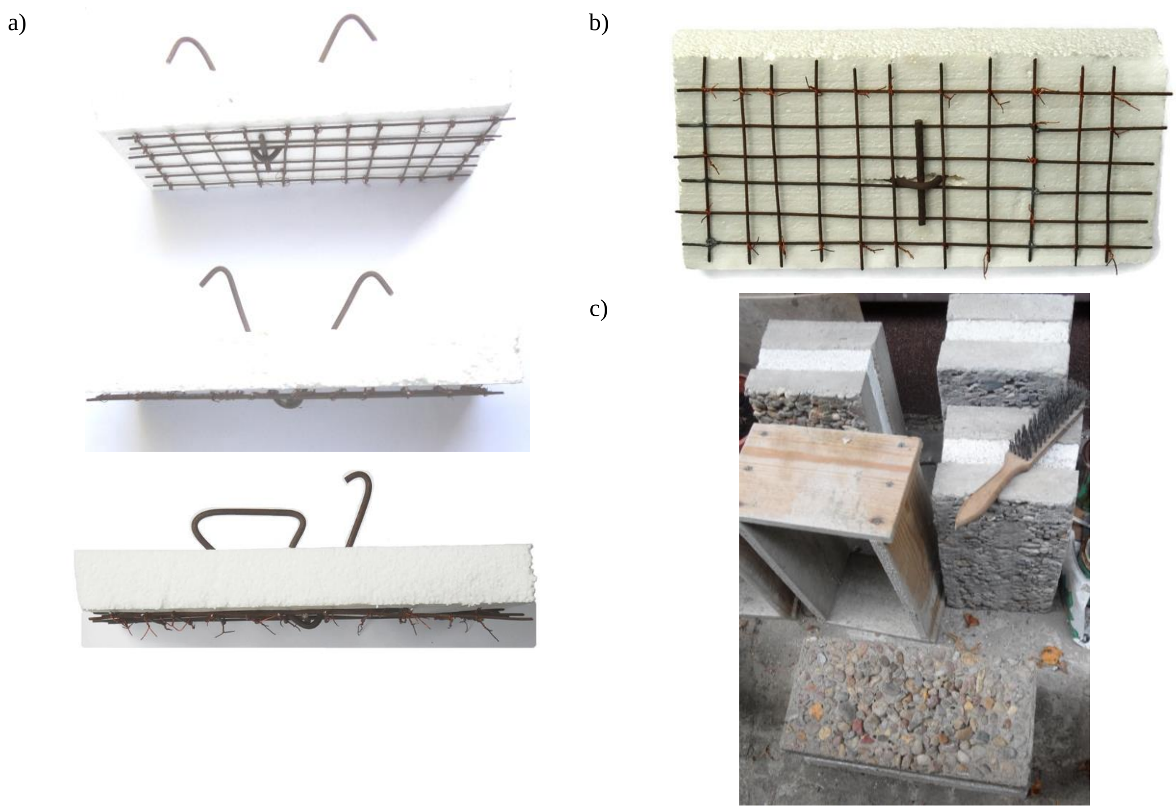
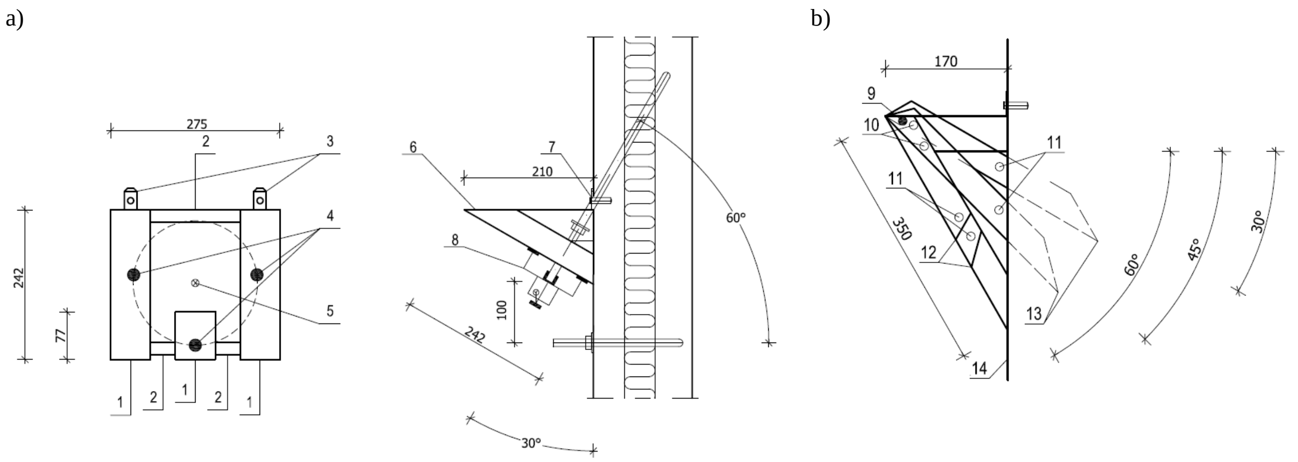


Fig. 2. Design and construction of the samples: a) and b) view of the reinforcement, c) prepared samples.



1 - Arms made of structural channels [65×42×5 mm, extreme length 202 mm and length 77 mm in diameter; 2 - flat bar connecting the arms; 3 - mounting brackets for quick fixing pins; 4 - feet for pull-out anchor bolts; 5 - anchor bolt being removed; 6 - sketch of the frame; wall-mounted, thin-walled profiles (stationary parts) measuring 50×50×170 mm welded to the extremities; 7 - fixing the frame for the test; 8 - angularly adjustable arms of the frame, 9 - cotter for adjusting the desired angle; 10 - holes stabilizing the given angle; 11 - holes for arm length stabilization; 12 - arm profiles with the edge adjacent to the wall surface; 13 - Sliding parts of the arms to adjust a given angle; 14 - outer surface of the wall.

Fig. 3. Diagram of steel frame: a) front view and side view, b) side view of device maneuvering angles.

Fig. 4. View of steel frame with anchors.

3. Examples and applications

There are many ways to use the device. It is possible to check the load capacity of anchor bolts at varying mounting angles in the maneuver range from 30° to 60° with 15° spacing. The frame is necessary to carry out the load testing of diagonal anchor bolts due to the possibility of adjusting the angle towards the anchor bolt to provide the right angle between the frame arms and the axle of the anchor bolt mounted in the wall. It is also possible to check the diagonal anchor bolt in the layered wall with the bevel down, when the frame is rotated 180° from the diagonal anchor bolt mounted with the bevel up.

Furthermore, it is possible to check the load capacity of the anchor bolts mounted parallel to the length of the plate in case of reinforcement of the joints. Then, for the time of this test, the frame must be fastened by first turning it clockwise by 45° and then by 45°, however in the opposite direction towards the mounted frame in Figure 5.

Fig. 5. Example of application frame with hydraulic cylinder.

Figure 6 shows an example of two- and three-way anchors, where the device can be used to check their load capacity. An example of damage to the anchor fixing is shown in Figure 7. It was conducted in stages. Destruction of the fixing at the depth of 6 cm was probably due to inaccurate cleaning of the hole at the depth of attachment to the wall construction layer. Next, a cone (concrete failure) with a top surface of 4×4.5 cm was formed towards the outside of the wall on a 9.5 cm section. A 6.5 cm anchor bolt was not anchored in concrete.

Fig. 6. Anchoring COPY-ECO system and three anchor system.

Fig. 7. A view of destruction fixing anchor with concrete substrate.

Another example, which occurred during the field research (Fig. 8), is the destruction of adhesion by pulling-out the anchor bolt. This happened due to the lack of the hole cleaning after drilling. There was no adhesion between the resin and the concrete surface. The theoretical approach to model destruction shown in Figure 7 has been presented by German (2011). Table 1 shows the results of the load capacity tests of the anchor bolts fixed into the three-layer walls of a multi-plate building. Figure 9 shows the dependant stress-deformation of anchor with Figure 7.

Fig. 8. Destruction caused by pulling-out the anchor of concrete surface.

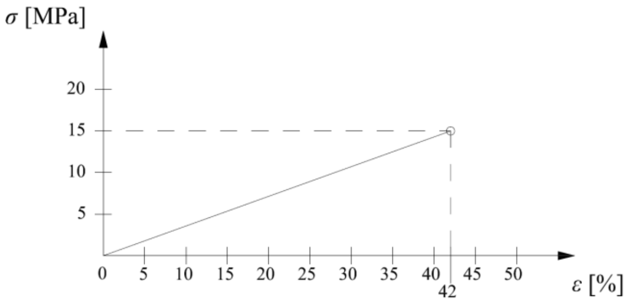


Fig. 9. The dependant of the stress on the deformation of the anchor of Figure 7.

Tab. 1. The results of the pull-out capacity of bonded anchors.

Sample number	Breakout force anchor [kN]		Notes
	Anchor point	diagonal anchors	
two-anchor system COPY-ECO (AT-15-6916-2009, 2011)			
1	27,0	6,0	cone wrench
2	47,1	13,2	
3	13,3	14,7	

The theoretical capacity value of the destructive force is calculated according to the formula:

$$P_n = A_p \cdot f_{yd} \,[\mathrm{kN}] \qquad (1)$$
$$P_n = 113{,}1\,\mathrm{mm}^2 \cdot 350\ \mathrm{N/mm}^2 = 39585\ \mathrm{N} = 39{,}59\ \mathrm{kN}$$

where: P_n is capacity value of the destructive force, A_p is a cross section area for the anchor ø12 mm, f_{yd} is design value of the steel strength.

Please note that any attempt of the pull-out capacity is used to determine the greatest stress of the adhesion $\tau_{pśr}$

$$\tau_{pśr} = \frac{P}{U \cdot l_z} \,[\mathrm{kN/m^2}] \qquad (2)$$

where: $\tau_{pśr}$ is a ultimate adhesion shear stress, P is the breakout strength of anchors in concrete, U is a circuit which would form the hole after pulling away from the anchor, and l_z is anchorage length of anchor.

Figure 10 shows a cracked concrete sample during the test. Tensile strength values of the point anchor bolt (equivalent to the horizontal anchor bolt on the building) has reached the same value of 9 kN which is less than the standard value of 10 kN, and Figure 11 shows drawn anchors after pull-out tests. There are few reasons for this. The main one is that the concrete was prepared with a relatively low strength (below the C 12/15 class). The results of the anchor pull-out capacity test in laboratory are shown in Table 2.

Fig. 10. View of a single sample of concrete cracks during the attempt capacity anchor for pull-out.

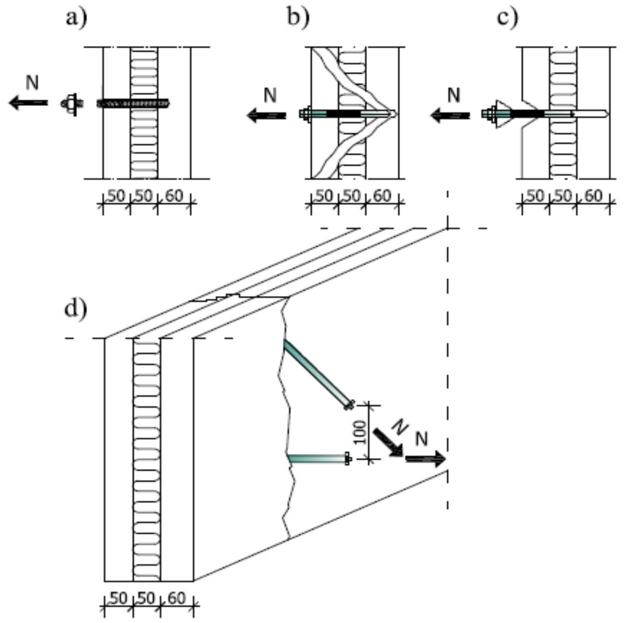
Tab. 2. The results of the anchor pull-out capacity in terms of laboratory.

Sample number	Breakout force anchor [kN]		Notes
	anchor point	diagonal anchors	
two-anchor system COPY-ECO (AT-15-6916-2009, 2011)			
1	9,0	during the test	rupture of the sample
2	9,0	during the test	rupture of the sample
3	9,0	during the test	rupture of the sample

Fig. 11. Drawn anchors after the pull-out test.

3.1. Effects that may occur during testing the capacity pull-out of bonded anchors

When attempting to remove the anchor bolt, four types of damage may occur (Fig. 12). The models of anchor damage during pulling tests for longitudinal force are shown below. Figure 12a is the damage of the fixing due to the broken anchor bolt; Figure 12b damage caused by pulling the anchor bolt out of the concrete surface; Figure 12c is an example of damage by tearing the concrete cone, and Figure 12d is the damage caused by splitting the concrete surface. In the research the author intends to examine the interaction effect of the tensile and shear forces on the fixed anchor bolts.



Explanations: N – pull-out force in kN

Fig. 12. Schemes of pull-out force of destroy anchors (ETAG No. 001).

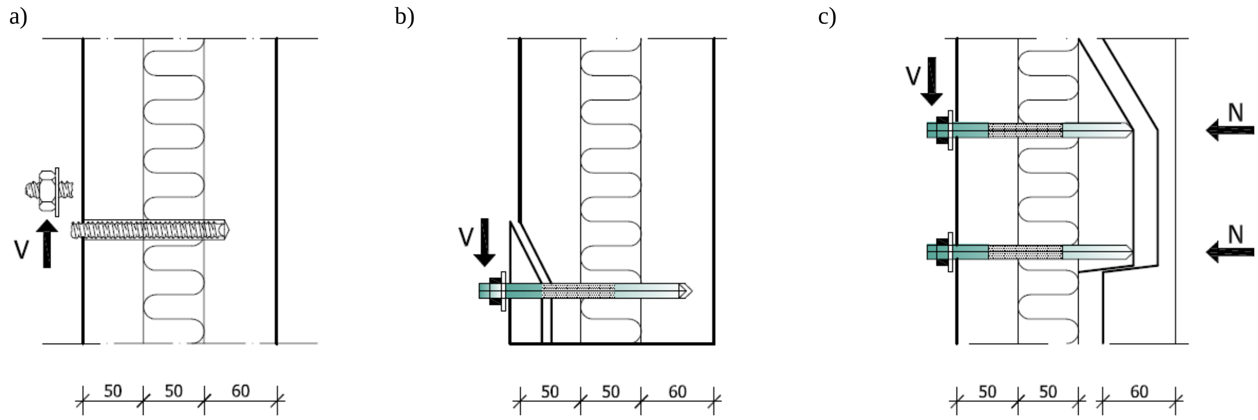
Models of damage that may occur as a result of transverse forces on the anchor bolt and the nature of the shearing force of the anchor bolts are shown in Figure 13. The first type of the model, Figure 13a, is the damage caused by cutting the anchor bolt, the second type of the model, Figure 13b, is the damage by breaking the edge of the concrete surface and the third type of the model, Figure 13c, is the damage caused by prying the anchor bolt. Many authors have undertaken the topic of three-layer external walls. The authors have already addressed the issue of evaluation capacity, which combines old anchor bolts in three-layer walls (Pająk et al., 1986) and new anchor solutions (Starosolski and Zybura, 1992).

Currently, three-layer walls are being described by (Pahn and Hanz, 2012), as well as texture layers, concrete surface repair and adhesion testing (Garbacz et al., 2013). The architecture of the large panel system was also discussed (Gronostajska, 2010; Wójtowicz, 2011; Dębowski, 2012). The problem of numerical analysiswas demonstrated by Ozbolt and Eligehausen (1990), while the composite layer during the finite element bending test was showed by Mazurkiewicz et al. (2013). A calculation model based on regression analysis was developed by Yildirim and Kantar (2014). When developing the research, the authors of the article based on the standards contained in the literature to investigate the problem of pull-out anchor bolts from concrete.

The new anchor computational models proposed by the author focus on two- and three-way anchor systems and evaluation of their role in the construction of a three-layer wall, burdened with the own weight of the textured layer, the influence of wind and temperature.

4. Conclusions

The innovative method of checking the load capacity of bolted anchors is to obtain the perpendicularity between the frame arms and the center of the anchor bolt mounted in the three-layer wall so that the axes of the hydraulic cylinder (or other tester) and the frame arms form a straight angle. Thanks to this device we obtain an imitation of the "inclination" of the wall surface with respect to the mounted anchor bolt to achieve the same effect as when pull-out the horizontal anchor bolt. In this way, due to the ability to maneuver and position the device at a given angle, the effect of the ability to remove the anchor bolt is similar to that of a horizontal anchorage. The angular maneuverability and tilt angles of the anchor bolts determine the thickness of the curtain walls in OWT-67/N system (the gable wall – 25 cm, the curtain wall – 17 cm), where the research was conducted. The author believes that there is a real risk of separating the textured layer in large panel buildings, because "the hangers" in the panels carry heavy load of the structure and this affects their stability, especially in the humps, where the anchor rods are located.



Explanations: N – pull-out force in kN; V – shear force in kN

Fig. 13. Schemes of shearing force of destroy anchors (ETAG No. 001)

Among the widely available bonded anchors, the author was most interested in the COPY-ECO system (AT-15-6916-2009, 2011). It is a system of two anchors – horizontal and diagonal, which reproduces the shape and work of the so-called "hangers". The author is currently carrying out research tasks, in which he determines the bonded anchors capacity for pull-out. The research is conducted in the object and in the laboratory. In addition, the study included a three-way anchor system (with two diagonal and one horizontal anchor bolts). Analysing both anchor systems, the following conclusions were made:

- It is more advantageous to reinforce the layered walls with diagonal anchor bolts, as they can be better adapted to the transfer of loads (bending, stretching).
- It is more effective to use two- or three-way anchor bolts because of the increased load capacity and durability of fixing of the textured layer with the rest of the walls.
- Diagonal anchor bolts better counteract the effects of wind suction, which adversely affects the durability of the anchoring of the wall texture layers.

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ETAG No. 001 Annex C. Methods for the design of anchorages.