Comparative Analysis of Oblique Bonded Anchors with Point Anchors Fixed in the Concrete Structural Layer of Buildings of a Large Slab

Jerzy K. Szlendak 1, Agnieszka Jablonska-Krysiewicz 1, Dariusz Tomaszewicz 2

1 Faculty of Civil and Environmental Engineering, Białystok University of Technology, Białystok, Poland
2 Higher School of Agribusiness in Lomza, Technical Faculty, Lomza, Poland

a.krysiewicz@pb.edu.pl

Abstract. The subject of the article is derived from the current problem, the scope of which applies to the whole of Poland, namely the risk of detachment of the external textured layer in external three-layer walls. Works are being carried out to increase the durability of fixing the textured layer before thermal insulation. The issues discussed in the article are aimed at determining the variant ensuring the longest durability of fixing. The subject of this article is bonded anchors at 60°, 45° and 30°. The load-bearing capacity of these anchors was compared with the results of point anchorages obtained from previous experimental tests. The tests were carried out on samples made of two concrete classes: C12/15 and C30/37. Two types of resin were also used: R-KER and Sika AnchorFix-1. A total of 12 samples were tested, 4 for each angle. In the case of anchors at 60° and 45° angles, three-layer samples with two concrete layers and thermal insulation in the form of expanded polystyrene were used (a 5 cm thick texture layer, a 6 cm thick thermal layer and a 6 cm thick construction layer). Samples with 30° anchorages were made as one-layer (construction layer 6 cm thick). In samples of concrete class C 30/37, only partial anchoring of the anchorage was made only in the construction layer, which is the fixing factor for the textured layer. The test results were quite varied, which was influenced not only by the concrete and resin parameters, but also by the angle of inclination and the length of the anchorage. For 60° anchorages in C 12/15 concrete, breaking forces of 11.25 kN and 9.1 kN respectively were obtained with anchors glued through the Sika AnchorFix-1 resin. In the case of C 30/37 concrete, the breaking forces were very low due to "Partial" fixing with R-KER resin resulting in a lack of greater resistance and had values of 0.6 kN and 2.9 kN. In the case of 45° anchorages fixed with Sika AnchorFix-1 resin in C 12/15 concrete, breaking forces of anchorages were obtained: 3.5 kN and 4.2 kN, while in class C 30/37 concrete using R-KER resin values: 1.7 kN and 1.3 kN. Tests of anchors fixed at an angle of 30° were checked only in the structural layer of the gr. 6 cm without additional layers in a cross-shaped way, i.e. both resins were applied to both classes of concrete samples. The results were as follows: for the Sika AnchorFix-1 resin in C 12/15 concrete, the value of 10.6 kN was obtained, whereas in concrete C 30/37 27.6 kN. Using R-KER resin was obtained: in C 12/15 11.9 kN concrete, while in concrete C 30/37 30.5 kN. All attempts resulted in the destruction of the concrete surface. The results of anchoring studies have led to the conclusion, that the use of a resin with better strength parameters in samples from lower-class concrete gave better results of testing the anchoring capacity of the anchors than in the opposite case.
1. Introduction
The problems of large panel construction are global, as exemplified in the article [1]. In Poland, this problem was described in publications from international conferences [2] and in numerous articles, among others in [3, 4, 5].

The first large-panel buildings were built in 1961-1963 in Warsaw. Access to determining the technical condition of external three-layer walls was hampered by the lack of documentation of the components of prefabricated elements. The subject of the research is single and three-layer samples, which serve as a section of a three-layer wall of a large-panel building. They used systems of anchors tested as single diagonal, working in the panel as a set with a horizontal anchor (COPY-ECO system). Examples of the selection criteria for anchorages are presented in the article [6]. Samples for testing were anchored at 60°, 45° and 30° angles. Two types of resin were used in two series: Sika AnchorFix-1 and R-KER. Samples in which the anchors were mounted at 60° and 45° angles were made as three-layer. In the previously carried out studies of anchors fixed at an angle of 90° in the case of three-layer samples, the total impact on the sample surface forces was tested: tearing concrete anchors and shearing force of the top texture layer. Research conducted in this area, including numerical analysis of the results obtained, was presented in paper [7].

The subject of the article is research on the load-bearing capacity of anchors bonded to pluck at different angles and compare their results with each other. The obtained results were also compared with the anchorages perpendicular to the concrete surfaces of the samples.

2. The state of the subject under investigation
The aim of the study is to examine the adhesion of different systems of bonded anchors in samples of concrete class C 12/15 and C 30/37. The inspiration to carry out this type of research was the need to strengthen the external walls of three-layer large-panel buildings.

Making new anchor anchors is preceded by a local vision and the development of a research program, which results in an expert opinion. All this, is preceded by the gathering of output data. The demand for large-panel buildings is global [1].

![Concrete wythe](image1)

**Figure 1.** Strain distribution in PCSP under flexure [1]

With the passage of time, the technical condition of over half a century old blocks of land deteriorates. One of the stages of work improving the functionality of large-panel housing resources is to strengthen, through the use of new bonded anchors, the durability of the connection of the textured layer with the structural layer. Numerous expert opinions are being carried out to determine the actual condition of attaching the façade of the textured layer, which is undoubtedly diversified. This is mainly due to the steel grade from which the so-called "Hangers", as well as their diameter, which in the case of diameter lower than Ø12 mm as given in the manual [8] should be surrounded by a latex coating. According to the instructions [8], the program of such tests includes: assessment of the external condition of the boards of the textured layer and the location of the crack and cracks distribution in the concrete, determining the location of the reinforcement, hangers and anchor rods.
through the made outcrops. Modelling of adhesion of anchorages glued in various types of concrete solid elements in both experimental and numerical form is presented in articles [9-15]. The article [9] presents the results. Theoretical analytical models have been described in the article [10] as an arrangement of anchors in the team under the direction of their own research. However, in the article [16] a new flexible model for designing anchorages was developed. A comparison of the work of anchors in cracked and uncracked concrete is presented in the article [11]. The problem of load carrying capacity of anchors was presented on concrete samples in the works [13, 17]. Other tests were performed in [12], where the load-bearing capacity of steel rods in a cementitious composite was checked. Variants of the destruction of the anchorage glued as one of the assumed destruction models are presented in [14]. The article [15] presents research for compressed concrete structures. This article shows, how important this factor is in the case of the durability of three-layer walls in large-panel buildings. How important it is to ensure the durability of the façade of the textured layer is presented in the article [18]. Regardless of the research conducted by various authors, the main question is the adhesion of reinforcement or steel rods to concrete [17, 19-22]. The research described in this article is based on information contained in the Polish standard [23] and worldwide standards [24-27].

3. Description of the conducted research

The research was carried out in the Bialystok University of Technology in Bialystok on the HYSDOZOK hydraulic load system. In the case of testing oblique anchorages, it was necessary to design and make auxiliary equipment in the form of an upper retaining plate, causing the test sample to be restrained by means of racks with 60°, 45° and 30° inclination angles to the beam of the research stand. The tensile load was set uniformly with a constant increment of 0.5 kN/s. Each individual experiment was programmed to reach a limit force of 80 kN, so its duration could not be longer than 160 seconds. Figure 2 shows the view of the anchorage survey glued at an angle of 60°. In this case, the joint was destroyed due to the concrete cone breakage. The study was conducted in four variants, similarly more.

![Figure 2. View of the test sample for an anchorage of 60°](image)

Figure 3 shows the view of the sample set on the rack with the inclination of the anchor at an angle of 45°.

![Figure 3. View of the test sample for an anchorage of 45°](image)
All tested samples with anchors located at an angle of 45° resulted in the same effect of destruction of the fastening, i.e. destruction by pulling out the anchor.

![View of the test sample for an anchorage of 30°](image)

**Figure 4.** View of the test sample for an anchorage of 30°

In the case of anchors at an angle of 30°, they were fixed only in the construction layer. In two attempts, the sample rupture occurred, and in the next two samples, the concrete cone broke off.

![View of the test specimen with an anchorage perpendicular to its surface](image)

**Figure 5.** View of the test specimen with an anchorage perpendicular to its surface

Figures 5 and 6 show the view from the previous tests, where the load capacity was checked for pulling anchors placed perpendicularly to the surface of the sample, i.e. at a 90° angle.

![View of the test specimen with an anchorage perpendicular to its surface](image)

**Figure 6.** View of the test specimen with an anchorage perpendicular to its surface

In the examples shown in Figures 5 and 6, two different destruction models were obtained. Figure 5 shows the model of destruction due to rupture of the anchor bolt, while Figure 6 shows the destruction caused by pulling the anchor out of the concrete surface.

4. Results of the tests carried out

As a result of the obtained results, a comparative analysis of each anchorage variant with each was made and reference was made to anchors perpendicular to the surface of the samples to compare these
anchorages with diagonal anchorages. The results depend on the concrete class, the type of the sample (single-layer, three-layer) and anchor mounting angle are shown in Figures 7-12.

Table 1. Comparison of results of single-layer samples with MES analysis

| Sample type | Concrete class | Angle of anchorage | The result of laboratory test, kN | Angle of anchorage | The result of laboratory test, kN | Difference [%] |
|-------------|----------------|--------------------|----------------------------------|--------------------|----------------------------------|----------------|
| single-layer | C 30/37        | 60°                | 0.6                              | 45°                | 1.7                              | 64.7           |
| single-layer | C 12/15        | 60°                | 11.25                            | 45°                | 3.5                              | 68.9           |
| single-layer | C 30/37        | 60°                | 2.9                              | 45°                | 1.3                              | 55.2           |
| single-layer | C 12/15        | 60°                | 9.1                              | 45°                | 4.2                              | 53.8           |

Table 2. Comparison of results of single-layer samples with MES analysis

| Sample type | Concrete class | Angle of anchorage | The result of laboratory test, kN | Angle of anchorage | The result of laboratory test, kN | Difference [%] |
|-------------|----------------|--------------------|----------------------------------|--------------------|----------------------------------|----------------|
| single-layer | C 30/37        | 45°                | 1.7                              | 30°                | 27.6                             | 93.8           |
| single-layer | C 12/15        | 45°                | 3.5                              | 30°                | 10.6                             | 66.98          |
| single-layer | C 30/37        | 45°                | 1.3                              | 30°                | 30.5                             | 95.7           |
| single-layer | C 12/15        | 45°                | 4.2                              | 30°                | 11.9                             | 64.7           |

Table 3. Comparison of results of single-layer samples with MES analysis

| Sample type | Concrete class | Angle of anchorage | The result of laboratory test, kN | Angle of anchorage | The result of laboratory test, kN | Difference [%] |
|-------------|----------------|--------------------|----------------------------------|--------------------|----------------------------------|----------------|
| single-layer | C 30/37        | 60°                | 0.6                              | 30°                | 27.6                             | 97.8           |
| single-layer | C 12/15        | 60°                | 11.25                            | 30°                | 10.6                             | 5.8            |
| single-layer | C 30/37        | 60°                | 2.9                              | 30°                | 30.5                             | 90.5           |
| single-layer | C 12/15        | 60°                | 9.1                              | 30°                | 11.9                             | 23.5           |

Table 4. Comparison of results of single-layer samples with MES analysis

| Sample type | Concrete class | Angle of anchorage | The result of laboratory test, kN | Angle of anchorage | The result of laboratory test, kN | Difference [%] |
|-------------|----------------|--------------------|----------------------------------|--------------------|----------------------------------|----------------|
| single-layer | C 30/37        | 60°                | 0.6                              | 90°                | 43.5                             | 98.6           |
| single-layer | C 12/15        | 60°                | 11.25                            | 90°                | 31.5                             | 64.3           |
| single-layer | C 30/37        | 60°                | 2.9                              | 90°                | 44.0                             | 93.4           |
| single-layer | C 12/15        | 60°                | 9.1                              | 90°                | 15.0                             | 39.3           |

Table 5. Comparison of results of single-layer samples with MES analysis

| Sample type | Concrete class | Angle of anchorage | The result of laboratory test, kN | Angle of anchorage | The result of laboratory test, kN | Difference [%] |
|-------------|----------------|--------------------|----------------------------------|--------------------|----------------------------------|----------------|
| single-layer | C 30/37        | 45°                | 1.7                              | 90°                | 43.5                             | 96.1           |
| single-layer | C 12/15        | 45°                | 3.5                              | 90°                | 31.5                             | 88.9           |
| single-layer | C 30/37        | 45°                | 1.3                              | 90°                | 44.0                             | 97.0           |
| single-layer | C 12/15        | 45°                | 4.2                              | 90°                | 15.0                             | 72.0           |
Table 6. Comparison of results of single-layer samples with MES analysis

| Sample type | Concrete class | Angle of anchorage | The result of laboratory test, kN | Angle of anchorage | The result of laboratory test, kN | Difference [%] |
|-------------|----------------|--------------------|----------------------------------|--------------------|----------------------------------|----------------|
| single-layer | C 30/37        | 30°                | 27.6                             | 90°                | 43.5                             | 36.6           |
| single-layer | C 12/15        | 30°                | 10.6                             | 90°                | 31.5                             | 66.3           |
| single-layer | C 30/37        | 30°                | 30.5                             | 90°                | 44.0                             | 30.7           |
| single-layer | C 12/15        | 30°                | 11.9                             | 90°                | 15.0                             | 20.7           |

Figure 7. Dependence displacement-force in relation to the angle of inclination of the anchor 45° and 60°

Figure 8. Dependence displacement-force in relation to the angle of inclination of the anchor 30° and 45°

Figure 9. Dependence displacement-force in relation to the angle of inclination of the anchor 30° and 60°
For the results obtained, an experiment plan was also planned using the regression function. Based on diagonal anchorages, the boundary interpretation of object-oriented means is illustrated in Figures 12-14.
Yi.. - angle of 60 degrees

Figure 13. The average object value of samples anchored at an angle 60°

Y.j. - angle of 45 degrees

Figure 14. The average object value of samples anchored at an angle 45°

Y.j. - angle of 30 degrees

Figure 15. The average object value of samples anchored at an angle 30°

On the basis of the obtained values from the object-average charts, the following observation model was assumed:

\[ y = b_0 + b_1 x_1 + b_{11} x_1^2 + b_2 x_2 + b_{22} x_2^2 + b_3 x_3 + b_{33} x_3^2 \]  

(1)

After calculations on the independent variables observation matrix and the regression function parameter evaluation vector, the final observation model was obtained:
\[
\hat{y} = 2.675 + 4.729x_2 - 2.365x_3 + 10.381x_3^2
\]  
(2)

Coefficient of determination:
\[
R^2 = \frac{SSR}{SSC} = \frac{29301.131}{29435.321} = 0.9954 \quad (0 < R < 1)
\]  
(3)

Multiple correlation coefficient:
\[
R = \sqrt{R^2} = 0.9977
\]  
(4)

An attempt to optimize the model:
\[
\frac{\partial \hat{y}}{\partial x_1} = \frac{\partial (2.675 + 4.729x_2 - 2.365x_3 + 10.381x_3^2)}{\partial x_1} = 0
\]  
(5)

\[
\frac{\partial \hat{y}}{\partial x_2} = \frac{\partial (2.675 + 4.729x_2 - 2.365x_3 + 10.381x_3^2)}{\partial x_2} = 4.729
\]  
(6)

\[
\frac{\partial \hat{y}}{\partial x_3} = \frac{\partial (2.675 + 4.729x_2 - 2.365x_3 + 10.381x_3^2)}{\partial x_3} = 20.762x_3 - 2.365
\]  
(7)

\[x_{1,\text{optym.}} = 0\]

\[x_{2,\text{optym.}} = 4.729\]

\[20.762x_{3,\text{optym.}} - 2.365 = 0 \Rightarrow x_{3,\text{optym.}} = 0.1139\]

5. Conclusions

The article presents various systems of oblique anchors and compared them with each other and with the results of anchors perpendicular to the surface of the tested samples obtained in earlier studies. Based on these results, it is possible to estimate the theoretical load-bearing capacity of new anchorages and its derivatives, which include the angle of inclination, anchorage length and careful cleaning of the hole before anchoring. The research shows that 99.54% of the differences observed in the sample were explained by linear regression. The remaining 0.46% are uncontrolled factors in the study. This diversity is treated as random.

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References

[1] A. Benayoune, A. A. Abdul Samad, D. N. Trikha, A. M. Abang Ali Akhand. Precast reinforced concrete sandwich panel as an industrialised building system. International Conference on Concrete Engineering and Technology University Malaya; pp. 1–6, 2004.

[2] Ściślewski Z., Woyzbun I., Wójtowicz M., Safety and durability of external sandwich walls; Technical possibilities of modernization of large-panel buildings against their current state. Conference Mragowo 3÷5 November 1999, pp. 121-136, 1999, (in Polish).

[3] W. Ligęza, Technical issues synthesis related to the revitalization of the ‘great panel’ buildings. Builders Review (Przegląd Budowlany) 6/2015, pp. 60-66, 2015 (in Polish).

[4] J. Obolewicz, D. Tomaszewicz. Identification of the technical condition and forecasting a safe durability the construction of buildings of large slab, Modern Engineering 1/2016, pp. 1-13, 2016 (in Polish).

[5] D. Tomaszewicz. Reinforcing of the external wall in the buildings of large slab, Civil and Environmental Engineering (Budownictwo i Inżynieria Środowiska), vol. 5, no. 3, pp. 125-130, 2014, (in Polish).
[6] S. Hamel, Behavior and Design of Steel Anchor Systems in Cementitious Concrete, University of Colorado Department of Civil Engineering CVEN 6831, 2004

[7] W. Jung, M. Kwon, J. Kim, B. Ju, Performance Evaluation of the Post-Installed Anchor for Sign Structure in South Korea. Constr Build Mater 44: pp. 496–506, 2013.

[8] Building Research Institute No. 360/99, Research and evaluation of concrete sandwich panels in residential buildings, 1999 (in Polish).

[9] A. Spada, P. Rizzo, G. Giambanco, Elastoplastic Damaging Model for Adhesive Anchor Systems. II: Numerical and Experimental Validation, JOURNAL OF ENGINEERING MECHANICS, pp. 862-876, 2011.

[10] J. K. Szlendak, A. Jablonska-Krysiewicz, D. Tomaszewicz, Analytical modelling of a threelayer wall system of strengthening for large-panel slab buildings by means of bonded anchors, ECCE Opole, 2018.

[11] J. Nienstedt J., R. Mattner, Three-dimensional modeling of anchoring systems in concrete. Fracture Mechanics of Concrete Structures, ISBN 902651 8250, pp. 1021-1026, 2001.

[12] A.K.F. Cheung, C.K.Y. Leung, Finite element study on bond behavior of steel bar and HSCH/HSFRCC. In: Proceedings of the 7th International Conference on Fracture Mechanics of Concrete and Concrete Structures, pp. 592–599, 2010.

[13] J. Barnat, M. Bajer, Analysis of Bonded Anchor in Combined Concrete-Bond Failure Mode, Recent Researches in Geography, Geology, Energy, Environment and Biomedicine, pp. 364-367, Corfu Island, Greece - July 14 - 16, 2011.

[14] T. Huer, R. Eligehausen, Splitting failure mode of bonded anchors, Proceedings of 6th International Conference on Fracture Mechanics of Concrete and Concrete Structures, IAFraMCoS, 17.06.-22.06., Catania, Italy. UK: Taylor & Francis, Vol. 2, pp. 753-760, 2007.

[15] F. Puigvert, A. D. Crocombe, L. Gil, Static analysis of adhesively bonded anchorages for CFRP tendons. Construction and Building Materials 61: pp.206–215, September 2014

[16] P. A. Prieto-Muñoz, H. M. Yin, R. B. Testa, An Elastic Analysis That Predicts the Pull-Out Capacity of Adhesive Anchors, Materials Science and Engineering 10, pp. 1-10, 2010

[17] J. K. Szlendak, A. Jablonska-Krysiewicz, D. Tomaszewicz, Assessment of the load capacity of the anchorage system connecting the textured layer with the structural wall of large slab buildings in the lights of experimental research and FEM analysis, ECCE Opole (2018)

[18] D. Tomaszewicz, Impact of fixed and variable load during the elevation layer of textured in OWT-67/N system, Building Materials (Materialy Budowlane) 1/2015, pp. 48-50, 2015, (in Polish).

[19] M. Bajer, J. Kala, J. Barnat, Modeling chemical anchor placed in concrete using different FEM systems, The 9th International Conference “MODERN BUILDING MATERIALS, STRUCTURES AND TECHNIQUES”, Brno University of Technology, 2007

[20] M. Kijania, The methods for computation of the bond stress between concrete and steel reinforcement, Builders Review (Przeglad Budowlany) 6/2015, pp. 38-42, 2015, (in Polish).

[21] M. Raith, Ch. U. Grosse, T. Kränkel, Pullout Experiments on Bonded Anchors Monitored via Acoustic Emission Techniques, 31st Conference of the European Working Group on Acoustic Emission (EWGAE) – We.3.A.1, pp. 1-6, 2015.

[22] U. M. Mahran, Theoretical Study For Bond Between Reinforcement Steel And Concrete, IJSBAR, Vol. 12, No. 1, pp. 93-192, 2013.

[23] PN-EN 12504-3:2006, Research of concrete in structures - Part 3: Determination of pull-out strength, 2006, (in Polish).

[24] Model Code for Concrete Structures. CEB Bulletin d’Information No 195 and 196, First Draft, March 1990.

[25] Model Code 2010, First complete draft – Volume 1. FIB Bulletin 55.

[26] Model Code 2012, Final draft – Volume 1. FIB Bulletin 65.

[27] EOTA: ETAG for Anchors (Metal Anchors) for Use in Concrete, Part 5: Bonded Anchor, amended edition November 2006, second amendment February 2008.