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Multivariate façade strengthening systems of textured layers in large slab panel buildings

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Abstract

This article presents the solutions of bonded anchors used to strengthen façade textured layers in the walls of three-layer large slab panel buildings in Poland. Large slab panel building systems that are found in Poland have been characterized. The use of new bonded anchors is preceded by diagnostics of the walls of three-layer large slab panel buildings. The author presents two-stage diagnostics: non-destructive methods, measurement of reinforcement parameters and its condition using a Profometer type device, and destructive methods by performing an opencast with a drilling rig. A review of previously used bonded anchorages in Poland was carried out. Proposals for the use of anchor groups in various configurations with different angles of inclination of the diagonal anchors were also presented in order to achieve the most durable effect possible.

Keywords: façade, bonded anchors, textured layers, diagnostic tests, large slab panel buildings

1 Introduction

The current state of external textured layers in large slab panel buildings raises some reservations about their durability. There is a high risk of de-bonding façade textured layers in three-layer walls. Therefore, additional reinforcements are made using bonded anchors. They are indispensable especially because thermo-modernization works are carried out on large slab panel buildings.

Many flaws and shortcomings of the system cause that the buildings made in this technology require identification of the current state and modernization [23, 24], above all the basic structural elements, including external walls [28, 30]. In many studies, attention is paid to the assembly methods used: free assembly (e.g. OWT system) and forced installation (e.g. W-70 system), which provided better quality [32–34]. Both cases also take into account the exploitation period of the building, in which the "alterations" related to the change in the function of the rooms, such as apartments for premises, were made without taking into account the loss of spatial durability of the building [35]. Large slab panel buildings are exploited not always in accordance with technical requirements [7, 9], which affects their durability [59]. Damage occurring in large slab panel buildings can be classified into two groups [40, 43]. The first one includes damages, which also occur in traditional construction. These include, for example, damaging partition walls, roof/flat roofing or installation. The second group is damaged resulting from errors in the technology of building elements of large panel buildings, such as external and internal walls, ceilings or balconies. A separate subject is expansion joints. Failure to use them in the structure prevents the free settlement of individual building segments and causes damage [52].

2 Large slab panel building systems in Poland

In large slab panel buildings in Poland, the division of structures includes two systems: closed and open. The first group includes the following systems: PBU, „Domino”, „Dabrowa LSM (Lodz)”, „Fadom”, WUF-T, OWT-67, OWT-67/N, OWT-75, WWP, RzWP, CzWP, NRD Wielka Plyta – system FT/MG (Katowice), RBM-73 (large-block system), RBM-75 (slab system), large slab panel buildings RBM-75 (OWT-67 agricultural version), „Rataje”, „Winogrady” i

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„Szczecinski”. The whole is complemented objects realized in open systems: W-70 and Wk-70. In closed systems, the system of „Przedsiębiorstwo Budownictwa Uprzemysłowionego” (PBU) characterized by layered external walls with insulation in the form of polystyrene in the cross-section of load-bearing walls (version PBU-59) and system PBU-63 with a transverse arrangement of load-bearing walls and external walls of 24 cm thick made of aerated concrete.

System „Domino” it consisted of making external walls of large-block elements. In the "Dabrowa" large slab panel system in Lodz, 5 and 11-storey blocks were built, while external walls were made of 24 cm thick cellular concrete. The "Fadom" system was characterized by layered external walls, 29 cm thick, with insulation in the form of mineral wool.

The WUF-T system in its varieties, WUF-T / 67 and WUF-T/72, was characterized by three-layer walls 25 cm thick (14 cm - construction layer, 5 cm - insulating layer in the form of polystyrene and 6 cm - external layer). In this system, as in the "Dabrowa" system, 5 and 11-storey buildings were implemented.

The OWT systems in their variants have been modernized over time. The OWT-67 system was a continuation of the OWT-1700 and OW-1700K systems. In this system, the thickness of the outer three-layer curtain wall was 16 cm (construction layer - 6 cm, styrofoam layer - 5 cm and the textured layer - 5 cm), and the top walls were 24 cm thick (construction layer - 14 cm, styrofoam layer - 5 cm and the textured layer - 5 cm).

With the development of large slab panel buildings, a new OWT-67/N system was created. It was characterized by an increase in thermal insulation thickness compared to the OWT-67 system. The outer gable walls were 25 cm thick (construction layer - 14 cm, styrofoam layer - 6 cm and the textured layer - 5 cm), while the curtain walls were 17 cm thick (construction layer - 6 cm, styrofoam layer - 6 cm and the textured layer - 5 cm).

The last OWT system group was the OWT-75 system. In this system, the thickness of the walls was also increased. The longitudinal walls had a thickness of 19 cm (construction layer - 7 cm, styrofoam layer - 6 cm and a textured layer - 6 cm) and gable walls with a thickness of 27 cm (structural layer - 15 cm, styrofoam layer - 6 cm and a textured layer - 6 cm). In addition, in the inter-window pillar, the outer cladding was 6 cm thick, while the inner liner was 12 cm thick. The thickness of thermal insulation in the cross-joist pillar is respectively: OWT-67 - 5 cm, OWT-75 - 6 cm and OWT-67/N - 7 cm.

In the area of Lower Silesia, the main large slab panel buildings system is the Wrocław Large Slab Panel, whose basic structure of the walls was the transverse system. The construction gable walls were three-layer large slab panel elements with a thickness of 21 cm (construction layer - 12 cm, styrofoam layer - 4 cm and façade textured layer, e.g. relief - 5 cm). On the other hand, the outer curtain walls were produced in two versions: as a three-layer under-window blocks 16 cm thick, insulated with foamed polystyrene and in a large size version with built three-layer joinery with insulation in the form of polystyrene with a thickness of 6 cm and a concrete façade layer with a thickness of 5 cm.

In the Rzeszow Large Slab Panel system, external walls were made as three-layer. The thickness of the external gable walls was 25 cm (construction layer - 15 cm, styrofoam layer - 5 cm and the textured layer - 5 cm), and the thickness of the longitudinal walls was 17 cm (construction layer - 7 cm, styrofoam layer - 5 cm and the textured layer - 5 cm). Were similar to regional systems of Czestochowa Large Slab Panel.

The FT/MG system was modeled on the German Large Panel system with three-layer exterior walls 24 cm thick in the basic version (construction layer - 12 cm, styrofoam layer - 6 cm and façade layer - 6 cm) and 30 cm thick in the modified version (construction layer - 12 cm, styrofoam layer - 12 cm and façade layer - 6 cm). The gable walls were 27 cm thick (construction layer - 15 cm, styrofoam layer - 6 cm and façade layer - 6 cm) and modernized version 33 cm (construction layer - 15 cm, styrofoam layer - 12 cm and façade layer - 6 cm).

A separate group is the systems of Agricultural Housing. The first variant, RBM-73 (the original name), was made in a large-block system in which the thickness of the gable blocks was 42 cm, and the outer curtain walls in the form of three-layer walls made of clay-clay and expanded clay. The next varieties were RBM-75 board and large-panel systems, which were intended for widespread use in agricultural housing. The construction solutions were based on the Wk-70 system. In both versions, buildings were designed and erected up to three overground storeys. External wall panels in the panel version were 24 cm thick and were made of aerated concrete variant 07 and consisted of an inter-window filler and window sill panel and window sill, while in the large panel version they were three-layer boards and 27 cm thick (construction layer - 15 cm, wool insulation layer) mineral - 6 cm and textured layer - 6 cm). Most of the elements were produced in forms after the withdrawn OWT-67 production system due to the introduction of the modernized OWT-75 system.

When reviewing the large slab panel buildings in Poland, one should mention the system that had its roots in Greater Poland, and more precisely in Poznan. Introduced in 1966, the "Rataje" system assumed the construction of 5, 11 and 13-story buildings. In this system, the outer curtain walls were made of 30 cm thick expanded clay and the top supporting slabs were also made of 42 cm thick expanded clay. Two years later, the construction of the "Winogrady" housing complex began in Poznan. 5, 13- and 16-story buildings were erected according to a bi-directional mixed construction system. External wall panels were made as complete with embedded 35 cm thick joinery made of expanded clay in swing molds. The first time in the country in this system, bottom forming with ready textured from washed gravel was used.

In the "Szczecinski" system buildings were erected in 5 and 11-storey systems. Outer self-supporting walls were made of 36 cm thick expanded clay, along with an external textured made on 2.5 cm thick gravel, and an internal textured made of cement-lime mortar 1.5 cm thick. On the other hand, the external bearing walls were made of 40 cm thick expanded ceramsite with the textured surface as in the case of self-supporting walls.

The open system included practically two W-70 and Wk-70 systems. The W-70 system was characterized by a transverse structural system with the possibility of placing load-bearing walls mutually perpendicular to each other. The system was able to be used in public utility buildings for the erection of facilities with similar utility requirements. Structural elements in the form of external load-bearing walls were made as three-layer with a thickness of 27 cm (construction layer - 15 cm, mineral wool insulation layer - 6 cm and a texture layer - 6 cm) and 40 cm thick expanded clay.

The Wk-70 system was an improved version of the W-70 system. It was characterized by external three-layer walls in the form of gable walls with a thickness of 27 cm (construction layer - 15 cm, insulating layer with polystyrene - 6 cm and a textured layer - 6 cm) and curtain walls with a thickness of 20 cm (construction layer - 8 cm, layer Insulation made of expanded polystyrene - 6 cm and a textured layer - 6 cm) [11, 39, 42, 54].

2.1 Construction systems of large slab panel buildings in Poland

The construction of the large slab panel building consisted of load-bearing (construction) walls, ceilings, and foundations.

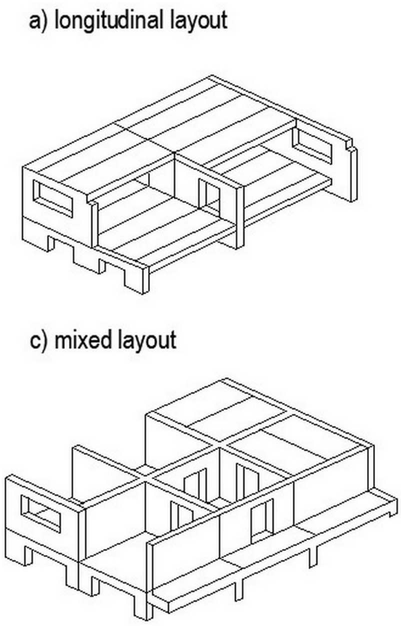

Figure 1. The layout of construction systems of large slab panel buildings [29]

Depending on the direction of the load-bearing walls in relation to the longitudinal axis of the building, four basic layouts are distinguished:

- longitudinal layout – it is a system characterized by the fact that the load-bearing walls are parallel to the longitudinal axis of the building, and the ceilings are stretched perpendicular to these axes; in this system, the spatial rigidity is ensured by longitudinal load-bearing walls (in the longitudinal direction) and transverse walls limiting staircases (in the transverse direction) and ceilings

- transverse layout – it is a system characterized in that load-bearing walls are perpendicular to the longitudinal axis of the building, and ceilings are stretched parallel to this axis; in this system transverse stiffness is provided by transverse load-bearing walls, stiffening walls located in the longitudinal direction and ceilings
- mixed layout – it is a system characterized by having load-bearing walls both parallel and perpendicular to the longitudinal axis of the building, ceilings are based on the entire circumference and cross-braced; in this system, spatial rigidity is ensured by a two-way system of load-bearing walls with ceilings
- cross layout – it is a system characterized by supporting walls located in both directions

Figure 1 shows the layout of construction systems according to which large-panel buildings in Poland was erected.

2.2 Diagnostics of external three-layer walls

Diagnostic tests are carried out in order to assess the condition of components or structures in order to prevent breakdown or construction disaster. Diagnostics can be carried out with non-destructive detection methods so as not to damage the concrete structure and be able to locate the reinforcement system in the wall. Diagnostics [17, 44] is a course of conduct aimed at making a diagnosis. The problems of building structure diagnostics together with the assessment of the technical condition occur most often during renovations, renovations, extensions, reconstructions, and modernization of building objects. There are two types of diagnostics [17]: full and periodic. The condition for a correct assessment of the technical condition of the building walls is to collect as much information as possible. This applies to both full and periodic diagnostics. One of the first steps during a visual inspection of concrete structures is the visual assessment of the tested structure [8, 46]. The person conducting the visual examination should also get acquainted with the technical specification, the construction log, the results of material tests carried out during the erection of the object and the available results of subsequent structure tests, opinions, and expert opinions. In non-destructive diagnostic tests of concrete objects, two types of impulse methods are used as a complement to visual examinations, i.e. an ultrasound method and a hammer method [1, 8, 13, 15–17, 48]. When assessing the technical condition of the construction of large-panel buildings, it is first necessary to check the protection of the structure against the effects of exceptional loads, e.g. by hitting a heavy object into a building or an explosion in its premises. It is important because the constructions of large slab panel buildings, due to the lower degree of "monolithization", have a limited ability to redistribute internal forces and the presence of slow-supported elements, and therefore may be more susceptible to a construction disaster, which occurs as a result of an explosion [51].

Figure 2. Preparation of the Profometer Corrosion for testing.

Diagnostics of external three-layer walls in large-panel buildings results in increased thermal insulation of these walls. However, this is not related to the change of the load-bearing structure of buildings, but increasing the load on the insulation layer makes it necessary to apply new anchors [27]. The diagnosis of large slab panel buildings is necessary and results from the provisions on the maintenance of construction works and their periodic inspections (Journal of Laws of November 29, 2013, item 1409), as well as changes in the standard requirements. Diagnostics is an important factor in the aspect of repairing a structure or its element [10, 53]. An important factor in this diagnostics is the assessment of the protective properties of concrete/ mortar against reinforcing steel, based on the tests listed in articles [49, 50]. In the diagnostic tests of three-layer walls elements in reinforced concrete buildings, reinforcement detectors are used. One of such devices is the Profometer Corrosion (Fig. 2) serving as a reinforcement corrosion analyzer and additionally having the option of detecting the reinforcement. Figure 2 shows the diagnostics of reinforced samples, made on the model of three-layer walls of large slab panel buildings.

Typical reinforcement detectors are Profometer PM-600/PM-630 Al/PM-650 Al devices. During the pilot study, the author of the doctoral dissertation used Profometer Corrosion and Profometer PM-650 for research (Fig. 3).

Figure 3. Preparation of the Profometer PM-650 for testing.

As a result of non-destructive diagnostic tests, information on material discontinuities in objects [44] is obtained.

Non-destructive testing is an alternative to destructive testing, which by using opencast makes it possible to assess the technical condition of hangers and other reinforcement elements in three-layer walls. Non-invasive diagnostic tests are the ability to locate reinforcing bars without damaging the wall structure, and then on the basis of localized reinforcing bars (hangers), you can arrange the space for fixing new bonded anchors. Their task, as already mentioned in this doctoral dissertation, is taking over the loads from the wall construction and additional external influences in order to minimize the loads of existing, often heavily corroded hangers.

Destructive testing involves drilling a well using a drilling rig. The material from the collected sample can be used after polishing the sample to check the actual compressive strength of concrete (Fig. 4).

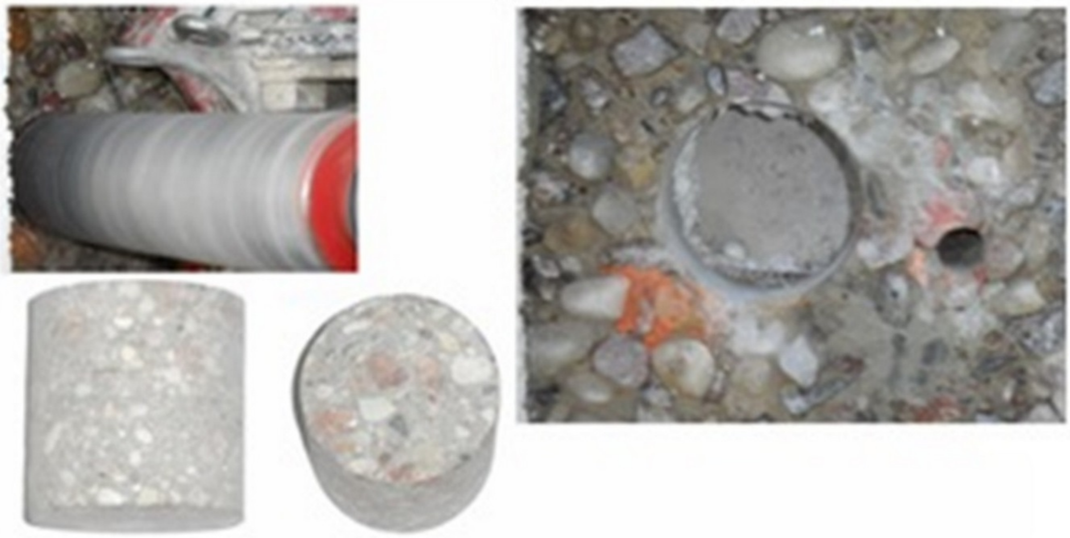

Figure 4. Drilling of a well with a drilling rig to determine on the cylindrical sample the compressive strength of concrete. [ref. own]

In the case of three-layer walls, you can also determine the actual thickness of the wall layers in a given place and check the cohesion of concrete layers with the inner layer of insulation. An example of checking the consistency of layers is shown in Figure 5.

Figure 5. View of the hole made "through" using a drilling rig. [ref. own]

This test was performed on a large slab panel building made in the Polish OWT-67/N system.

This object is called an empty apartment and is used to carry out various diagnostic tests. One borehole was made in the curtain wall and the gable wall. As can be seen in Figure 6, consistency of the external texture layer with the internal insulation layer has been observed at the hole locations.

Due to the basic factor of durability, the assessment of the protective properties of concrete in relation to reinforcing steel is a very important factor in the diagnostics of the construction of large slab panel buildings [58]. This manuscript

Figure 6. View of checking the cohesion of layers in the sample hole. [ref. own]

also presents the possibilities of using modern scanners in diagnostic tests of prefabricated joints, i.e. vertical and horizontal joints.

In non-destructive testing, flaw detection methods are used to detect material discontinuities, and mainly for discontinuities in the macrostructure of objects [31]. When assessing diagnostic three-layer external walls, one should also remember about elements of these walls containing asbestos (window separators) and make a decision as to the safety of their further operation [41].

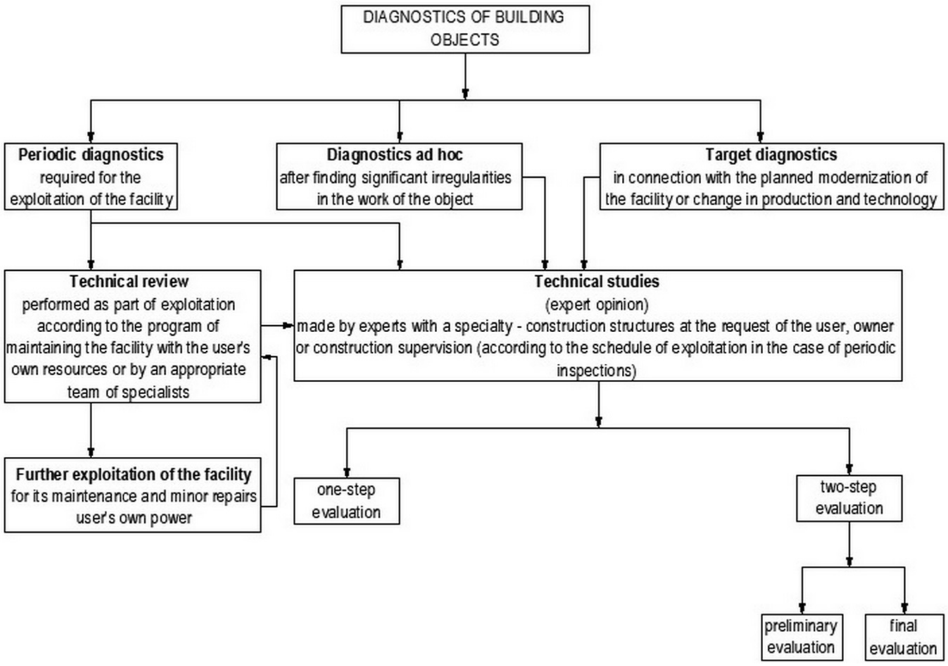

Figure 7. Diagnostic system for building objects [44].

3 Strengthening systems for bonded anchors used in Poland

In order to repair and strengthen the durability of the textured layer, new anchorages are installed in the walls of three-layer large slab panel buildings. Anchoring systems can be divided into bonded and mechanical. The manuscript focuses only on anchors bonded due to the many advantages of using this type of fastenings. The main advantage of bonded anchors, unlike mechanical ones, is that they do not introduce pre-stresses into the concrete base.

Strengthening the external walls of large slab panel buildings, characterized in detail in the industry-standard BN-79/8812-01 [26], consists in embedding anchors in a hole made in a three-layer wall structure. They are links between the textured layer and the structural layer [3].

Some types of anchorages are only used for horizontal fixings (Fig. 8). This is the most popular solution used by most construction companies.

Figure 8. HWB-H bonded anchor Ø 22 x 190 mm for reinforcing external walls in large panel buildings (www.hilti.pl)

The HWB anchor for horizontal fastening is approved for use in all three-layer large panel slab systems such as W-70; Wk-70; OWT; WUF-T or the Szczecin System. It should be installed in concrete with a class not lower than B 15 (C 12/15) (www.hilti.pl). HWB bonded anchors have Technical Approval [4].

The COPY-ECO system [5] consists of two anchors: horizontal and diagonal. They reproduce the work of the hanger, and their design allows installation in walls whose construction layer is only 70 mm thick. The COPY-ECO solution can be used, among others, in buildings constructed in the systems in W-70 and OWT. The COPY-ECO large slab panel building wall reinforcement system has ITB Technical Approval AT-15-6916 / 2014. The view of COPY-ECO anchors for reinforcing balcony slabs as well as curtain and gable walls is shown in Figures 9 and 10.

Figure 9. View of the reinforcement anchor M20 x 330 mm COPY-ECO used for reinforcing balcony slabs.

Figure 10. View of the COPY-ECO anchor system reinforcing the outer wall plates of large slab panel buildings: a) horizontal anchor M12 x 190 mm, b) oblique anchor M12 x 330 mm.

A system of reinforcing the outer sandwich walls of large slab panel buildings with K2 anchors (Fig. 11), mounted in C12/15 concrete, is also used. The K2 anchor has ITB Technical Approval AT-15-8130 / 2009 [6] and is used only as a horizontal fastening.

Figure 11. View of the K2 anchor for strengthening three-layer walls (www.inwestbud.com.pl).

Figure 12 presents the idea of using horizontal and diagonal anchors. The combination of both anchors creates the COPY-ECO system. The task of the diagonal tendon is to transfer tensile loads to the structural layer, derived from the own weight of the textured layer. On the other hand, the horizontal tendon can transfer the tensile loads that would occur if the textured layer detached [3, 27].

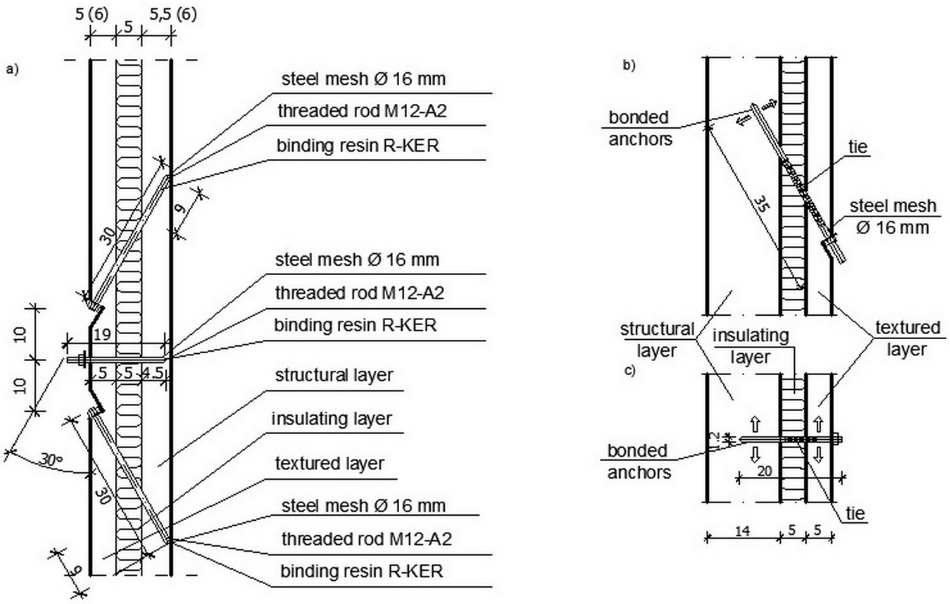

Figure 12. Wiring diagram with steel ties: a) solutions for staircase walls, b) solutions for gable wall panels.

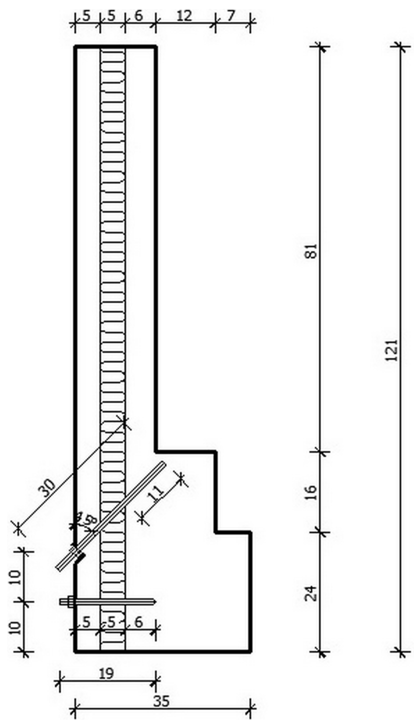

Figure 13. Distribution diagram of COPY-ECO anchors.

Another system that can be used to reinforce three-layer walls in large slab panel buildings is the CHEM-SET system from Trutek (Fig. 14). The system includes: TCS threaded rod with two diameters M20 and M24 with a nut and washer made of steel grade A2 or A4, steel mesh sleeve and system resin selected depending on the drilling technique. The system has technical approval AT/2007-03-2292/1 [25].

Figure 14. View of TCM Trutek bonded anchor (www.trutek.com.pl).

The Fischer FTR M12 x 160 mm bonded anchor (Fig. 15) has the ITB Technical Approval AT-15-8273 / 2010 [14].

Figure 15. View of Fischer FTR M12 x 160 bonded anchor (www.fischerpolska.pl).

An interesting anchoring system is an anchor shown in Figure 15. Due to its conical shape, it allows to achieve high pull-off capacity, i.e. it is used in cracked concrete. The anchoring system has a DoP performance declaration: 0130 for Fischer Highbond-Anchor FHB II (Bonded anchor for use in concrete) - EN [19].

Figure 16. View of the Fischer Highbond FHB II-A L injection bolt (www.fischerpolska.pl).

In the case of the Fischer injection anchor, there are two possibilities for its application in concrete - both with ampoules and with injection mortar. If the FHB II-A L anchor rod is used together with the FHB II-P/-PF ampoule, there is no need to clean the drilled hole, which significantly reduces the installation time of the anchor. Installation of anchorages and tests should be carried out on the basis of Polish and European Guidelines [20–22, 36–38, 45, 55].

4 Proposed variants of bonded anchorages

4.1 Perpendicular and oblique anchorages in two-anchor systems

Anchorages in double-bolt systems are modeled on probably the most popular anchor system in Poland, i.e. the COPY-ECO system (Fig. 17c).

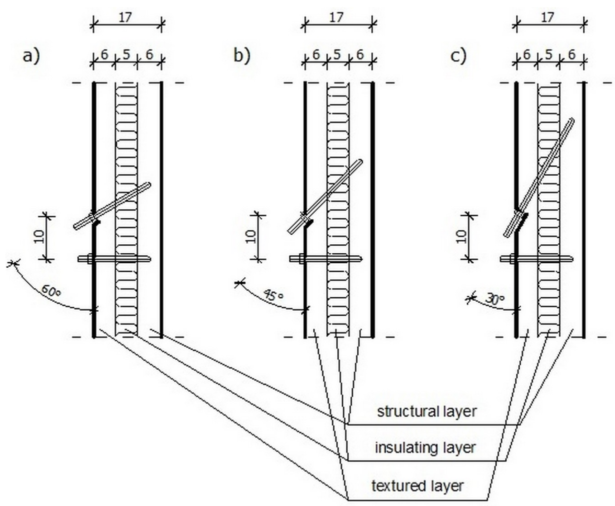

Figure 17. Propositions of a two-anchor system similar to the COPY-ECO system.

It is a set of two anchors: horizontal and oblique, imitating the hanger existing in the walls of three-layer of large slab panel buildings. The anchor groups shown in Figures 17a and 17b are variants proposed by the author. These anchor systems with an increased angle of inclination of the oblique anchor in relation to the surface of the façade layer of the textured layer can be used for a relatively small thickness of the inner structural layer.

Alternative methods for anchoring three-layer walls is the manuscript author's proposal in Figure 18. It is a mirror image of diagonal anchors in two-anchor systems.

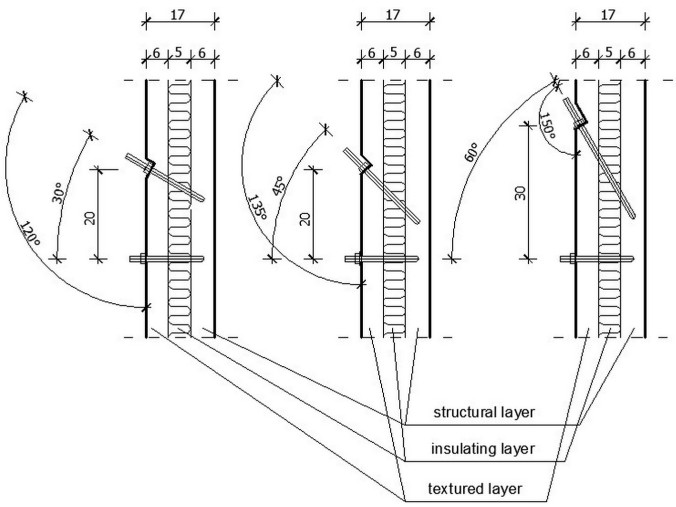

Figure 18. Alternative to two-anchor systems, inverted systems.

4.2 Perpendicular and oblique anchorages in three-anchor systems

This group of anchorages is a mirror image of the COPY-ECO system, i.e. a system of one anchor perpendicular to the façade surface of the textured layer and two diagonal anchors (Fig. 19.).

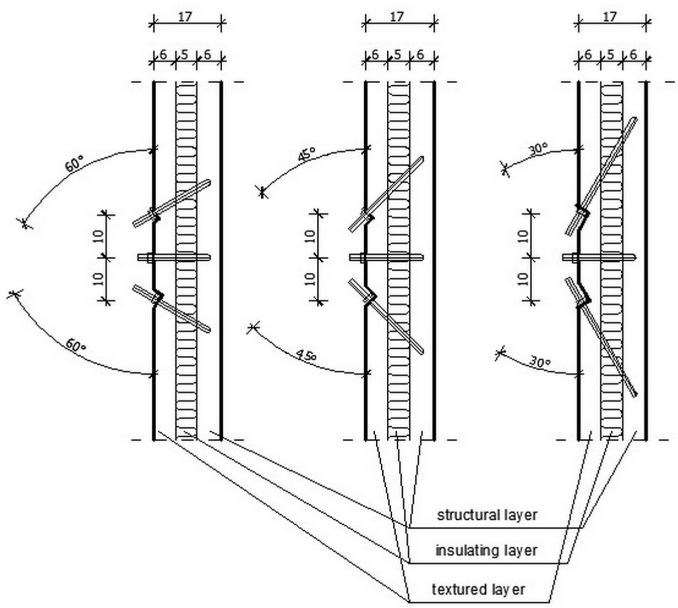

Figure 19. Proposals for the three-anchor systems.

The other two schemes are derived from anchor groups but with a different anchor angle. And the last group of anchorages, as in Figure 18 for two-anchor systems, is the reversal of the anchor angles of diagonal anchors.

Multivariate façade strengthening systems of the textured layer in three-layer walls of large slab panel buildings is

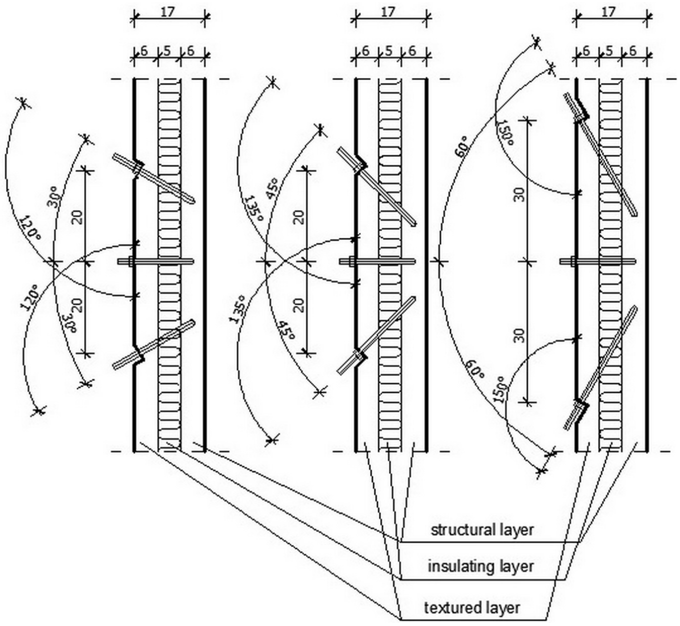

Figure 20. Alternative to three-anchor systems, inverted systems.

checked by the author in terms of the durability of the anchoring, the anchoring system, both way practical [56] and theoretical and numerical [18, 57].

5 Discussion

The most interesting aspect of this chapter is to show the effect of using diagonal anchors, which obviously lengthen the durability of bonded joints due to the possibility of using them in slabs of relatively small thickness with a greater effective anchorage depth than would be the case when using only bonded horizontal anchors. These tests give an overview of the possibilities of the anchor group systems proposed by the author, depending on the needs and applicability. In other papers [2, 47], mainly single adhesive anchors were considered and tested. Groups of anchors were tested only as anchors bonded perpendicularly to the surface of concrete elements [12] without including diagonal anchors. The chapter is a review of anchoring methods as well as proposals and possibilities of using a group of anchors in configurations proposed by the author. The advantage of diagonal anchors is the nature of their work, i.e. the load-bearing capacity. The restrictions apply to the number of anchors used per one three-layer wall slab and the need to assess the technical condition of the textured layer so as not to cause new holes for additional cracks in the structure of the textured layer. Future tests will focus, among others, on the numerical evaluation of concrete fracture mechanics and forecasting of cracking and stress formation in concrete elements.

6 Conclusions

The issue of durability of fastening the facade texture layer in the walls of three-layer large slab panel buildings is still a topical issue. The problem of large slab panel housing development concerns not only Poland. Oblique anchors have the advantage of carrying tensile loads and working as anchors after pull-out.

An important factor is also the possibility of increasing the anchorage depth for diagonal anchors in relatively thin sandwich partitions. The change of the anchoring system (reversal of the anchor angles for diagonal anchors) makes it possible to adapt to the character of the connection reinforcement and the actual effect of achieving the intended durability of connections of external textured layers. The best solution is to use stainless steel anchors because their parameters provide much longer durability of the connection than the parameters of anchors with ordinary carbon steel.

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