Research Article

Dariusz Tomaszewicz*, Agnieszka Jablonska-Krysiewicz, and Jerzy K. Szlendak

The effect of the stress distribution of anchorage and stress in the textured layer on the durability of new anchorages

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Abstract: The paper estimated the effect of the distribution of edge and shear stresses occurring in the façade texture layer of three-layer walls of large slab panel buildings, as well as the variability of these stresses depending on the anchorage strength of the anchorage. Bonded anchors with seven different diameters M8 ÷ M30, selected based on catalogues, were analysed. The traction stress was determined based on the destructive force, which is determined by the catalogues of manufacturers of bonded anchors. Depending on the choice of the method of repairing the connections between the textured layer and the structural layer, we give the three-layer walls a new character of work. One of the methods of strengthening the textured layer is the popular COPY-ECO system in Poland. It is a system of two anchors (horizontal and diagonal), reflecting the shape of the work of existing hangers. The article also analyses the variants of oblique anchorages for the M12 anchor with inclination angles of 30°, 45° and 60°. The extent to which the anchorage inclination angle has been assessed influences the higher parameters of the anchor's bearing capacity due to the shearing of the textured layer.

Keywords: Bonded anchors, shear stress, adhesion stress, diagonal anchors, textured layer

1 Introduction

The technical condition of façade cladding of the textured layers as well as the layers themselves requires treatments to improve their durability. Large slab panel buildings, contrary to some opinions, are safe, and their state when it comes to spatial development does not raise major objections. Additional fasteners are used in the form of bonded anchors. The manager of the housing estate is choosing the type of anchorage. However, cases of the detachment of the external textured layer caused that it was necessary to think about how to prevent such events. In case of elements connecting layers of external walls with each other, i.e. the hangers problem was their corrosion. Hanger could crack when exposed to the weight of the textured layer. In the case of hangers with smaller diameters than $\varnothing 12$ mm and with the use of a protective coating (latex-cement, asphalt-cement, zinc coating with a protective layer thickness), the problem was not so serious. Constructional hangers without a protective coating, based on conducting expert reports with pits to the places of critical panel joints, in this way it was possible to determine the speed of the carbonation process, which leads to corrosion of the reinforcement and weathering of concrete. This process is very dangerous for the durability of façade textured layers because the hanger rods rust and swell, thus causing the concentration of high stresses around the hangers, any defects must be repaired before the thermo modernisation phase [20]. After the works in the large-panel buildings are carried out periodically, mandatory technical checks and inspections of their current status [1, 2].

In this article, the topic of the use of new bonded anchors and the adhesive stress caused by their presence in the structural layer of a three-layer wall and edge stresses in the façade textured layer, which occur as a result of the dead load of the textured layer of bonded anchors.

Many authors consider the issues of adhesion stress both analytically [3], experimental [4–7], as well as numerically modelling [9, 10, 16–18]. All considerations are

*Corresponding Author: Dariusz Tomaszewicz: Higher School of Agribusiness in Lomza, Agricultural and Engineering-Technical Sciences, Studencka 19, 18-402 Lomza, Poland; Email: dariusz.tomaszewicz@poczta.wsa.edu.pl

Agnieszka Jablonska-Krysiewicz: Białystok University of Technology, Faculty of Civil and Environmental Sciences, Wiejska 45 E, 15-351 Białystok, Poland

Jerzy K. Szlendak: State School of Higher Professional Education in Suwałki, Teofila Noniewicza 10, 16-400 Suwałki, Poland

based on European ETAG Guidelines [11], Technical Report EOTA TR 023 [11] and British Guidelines [13–15].

The authors of this manuscript, in addition to the obvious and most important from the point of durability, anchorage depth [7], also focused on the transmission of stress through the bonded anchor in the internal structural layer to the external textured layer in the walls of three-layer large slab panel buildings, constituting apartments for about 12 million people in Poland.

The article [8] proposes theoretical models, developed on the basis of experimental research carried out on field.

According to the ITB guidelines, if the designer provided the original two hangers (for slabs with a short under-window) or three hangers for slabs with a long under-window and confirmed in preliminary tests, it is recommended to strengthen the walls before the insulation, regardless of the condition of hangers and other elements slabs.

This article describes the theoretical estimation of stresses occurring during operation of new adhesive anchors.

2 The genesis of the durability of the textured layer

One of the main factors that ensure the correct functioning of the external walls of a prefabricated building is the proper condition of joining connections. They are subject to external influences, which include: wind, atmospheric precipitation, temperature variability and their derivatives, for example, concrete contraction. An additional factor that acts destructively on weakened hangers is the weight of the textured layer slab panels.

Other factors contributing to the faster degradation of connections are errors at the stage of making elements in prefabrication plants and errors during the construction of large slab panel objects.

The basis for estimating the stresses occurring both in the anchor in the structural layer and the edge stresses in the façade textured layer were the input data of the building made in large slab panel technology according to the OWT-67/N system. The input data are summarised in Table 1.

Table 1: The juxtaposition of input data.

Name of the façade slab	Slab dimensions $l \times h$ [m]	Steady load G_d [N] [kN]		Slab weight G_w [kg]	Dead load c_{wp} [kN/m ²]	Calculated wind pressure w_e [kN/m ²]	Calculated moment M_c [kNm]
textured layer of the gable wall	4.97×276	16922.25	16.92	1725	1.23	6.63	17.82
textured layer of slab short under-window	2.68×1.29	4151.59	4.15	423.2	1.20	5.74	4.62
textured layer of slab long under-window	5.38×1.29	7581.17	7.58	772.8	1.09	5.74	9.28
textured layer of a balcony slab	5.38×1.29	6723.77	6.72	685.4	0.97	5.74	9.28
textured layer of the staircase slab	2.68×276	7536.04	7.54	768.2	1.02	6.63	4.62
Name of the façade slab	Radius of anchor r [mm]	Moment of inertia I_p [mm]		Maximum and minimum temperature affecting the façade of the textured layer [°C] $T_x(max)$ $T_x(min)$			
textured layer of the gable wall	4	8.71		64.4 19.2			
textured layer of slab short under-window	5	0.48		65.6 19			
textured layer of slab long under-window	6	0.96		65.6 19			
textured layer of a balcony slab	8	0.96		65.6 19			
textured layer of the staircase slab	10	0.96		65.6 19			

2.1 External effect affecting the durability of the textured layer

External influences are listed in point 2. Parameters affecting the durability of the textured layer, including factors such as wind pressure force, or thermal influences have been selected to determine edge stresses for a building implemented in the OWT-67/N system according to [22].

The effect of variable loads over time, which have a large impact on the durability of the façade textured layer, was estimated based on Eurocodes, according to the following relationships:

Calculated wind pressure on the external surfaces of the structure:

$$w_e = q_p(z_e) \cdot c_{pe}, [\text{kN/m}^2] \quad (1)$$

In case of thermal loads, the average temperatures occurring in Poland and cases of extreme weather conditions were taken into account at the same time.

$$T(x) = T_{in} - \frac{R(x)}{R_{tot}} \cdot (T_{in} - T_{out}) \quad (2)$$

where:

T_{in} – indoor air temperature

$R(x)$ – thermal resistance on the inner surface and the element from the inner surface above point x

$$R(x) = R_{in} + \sum_i \frac{h_i}{\lambda_i} \quad (3)$$

where:

R_{in} – heat transfer resistance on the internal surface, $[\text{m}^2\text{K/W}]$

h_i – layer thickness i , $[m]$

λ_i – heat transfer coefficient, $[W/mK]$

R_{tot} – the total thermal resistance of the element, taking into account the resistance of both surfaces, $[\text{m}^2\text{K/W}]$

$$R_{tot} = R_{in} + \sum_i \frac{h_i}{\lambda_i} + R_{out} \quad (4)$$

where:

T_{out} – external environment temperature, $[^\circ\text{C}]$

R_{out} – heat transfer resistance on the outer surface, $[\text{m}^2\text{K/W}]$

3 Prediction of anchoring stresses and stresses occurring in the textured layer

3.1 Stresses in anchorages

Tension in the anchorages, otherwise called the adhesion stress, can be determined based on [20] from dependence (5):

$$\tau_{pr} = \frac{P}{U \cdot l_z}; [\text{MPa}] \quad (5)$$

where:

τ_{pr} – adhesion stress, $[\text{MPa}]$

P – the force of pull-out anchors from concrete, $[\text{kN}]$

U – circuit created after breaking the anchor, $[\text{mm}]$

$h_{ef} = l_z$ – anchorage length, $[\text{mm}]$

To assess the stresses in the walls of three-layer large slab panel buildings, the least favourable anchoring parameters were adopted, which are summarised in Table 2.

Table 2: Anchoring parameters for anchoring depth $6 \times d$ according to the manufacturer's catalogue.

Anchor symbol	M8	M10	M12	M16	M20	M24	M30
total length of the anchor l_f [mm]	160	190	220	260	300	300	380
effective anchorages anchor depth h_{ef} [mm]	60	70	80	100	120	140	165

Based on dependence (1), the adhesion stresses for seven anchor diameters were determined: M8, M10, M12, M16, M20, M24 and M30. Interpretation of the increase in adhesion stress depending on the diameter of the anchor

Figure 1: Increase in the value of adhesion stresses depending on the size of the anchor.

and, as a result, the effective anchorage length is shown in Figure 1.

3.2 Edge stresses of the textured layer

In order to estimate the value of edge stresses in a single slab panel of the textured layer, the influence of factors that significantly has contributed to the degradation of the façade of the textured layer was taken into account. Edge stresses in a single slab panel of the textured layer can be determined from the dependence (6):

$$\sigma_{ctop} = \left(c_{wp} + w_e + \int_0^{hef} \frac{M_{Ed} \cdot r}{I_p} \right) \cdot \left| \frac{T_{(x) \max}}{T_{(x) \min}} \right|; [MPa] \quad (6)$$

where:

σ_{ctop} – edge stress, [MPa]

c_{wp} – a dead load of a single textured layer calculated for $1m^2$ of surface, [kN/m²]

w_e – calculated wind pressure on the external surfaces of the structure, [kN/m²]

hef – effective anchorages anchor depth, [mm]

M_c – the calculated moment from the steady load for a given slab of the textured layer, [kNm]

r – the radius of the anchor, [mm]

I_p – moment of inertia of the cross-section of the slab, [m⁴]

$T_{(x) \max / \min}$ – maximum and minimum temperature affecting the façade of the textured layer, [°C].

Figures 2-6 present the relationships between edge stresses in the outer slabs of the textured layer and the adhesion stresses of individual anchorages.

The factor determining the differences in calculating the values are the dimensions (area) of the slab panels and their dead load.

Figure 2: Dependency edge stress – adhesion stress for M8 ÷ M30 anchors in the gable wall.

Figure 3: Dependency edge stress – adhesion stress for M8 ÷ M30 anchors in slab short under-window.

Figure 4: Dependency edge stress – adhesion stress for M8 ÷ M30 anchors in slab long under-window.

Figure 5: Dependency edge stress – adhesion stress for M8 ÷ M30 anchors in a balcony slab.

Figure 6: Dependency edge stress – adhesion stress for M8 ÷ M30 anchors in the stairwell slab.

3.3 Shear stresses of the textured layer

The shear stress of the textured layer results directly from the edge stresses (2) and it is the most important factor determining the durability of connections in the walls of three-layer large slab panel buildings, both existing joints (hangers) and new bonded anchors.

Weakness caused by the process of degradation of hangers connecting external wall layers in large slab panel buildings with each other layers, and therefore is the high probability of shearing (vertical displacement) of the textured layer in relation to other layers is the main reason for using new bonded anchors.

The shear stresses of the textured layer are determined in the middle of the length of the slab panel and can be determined according to formula (7):

$$\tau_{\max} = \frac{1}{2} \cdot \frac{l}{h} \cdot \int_0^l \sigma_{ctop}, [MPa] \quad (7)$$

where:

$\tau_{\max}$ – shear stress, [MPa]

l – length of the textured slab, [m]

h – the height of the textured slab, [m]

σ_{ctop} – edge stress, [kN/m²]

Figure 7: Dependency shear stress – edge stress for M8 ÷ M30 anchors in the gable wall.

Figure 8: Dependency shear stress – edge stress for M8 ÷ M30 anchors in slab short under-window.

Figure 9: Dependency shear stress – edge stress for M8 ÷ M30 anchors in slab long under-window.

Figures 7-11 present the relationships between stresses in only the textured layer.

Other examples of the work of the three-layer system of external walls in large slab panel buildings are shown in Figures 12-16, depending on the distribution of shear stresses and adhesion stresses. These are the most impor-

Figure 10: Dependency shear stress – edge stress for M8 ÷ M30 anchors in a balcony slab.

Figure 11: Dependency shear stress – edge stress for M8 ÷ M30 anchors in the stairwell slab.

Figure 12: Dependency shear stress – adhesion stress for M8 ÷ M30 anchors in the gable wall.

Figure 13: Dependency shear stress – adhesion stress for M8 ÷ M30 anchors in slab short under-window.

Figure 14: Dependency shear stress – adhesion stress for M8 ÷ M30 anchors in slab long under-window.

Figure 15: Dependency shear stress – adhesion stress for M8 ÷ M30 anchors in a balcony slab.

Figure 16: Dependency shear stress – adhesion stress for M8 ÷ M30 anchors in the stairwell slab.

tant relations in the correct work of the façade of the textured layer via anchorages.

According to the dependence (3), calculations were made for the gable peak texture layer and the remaining plate elements in the entire facility. If the anchors are mounted at the angle, the relationship between the stress of adhesion of such anchors and the stresses created in the façade texture layers, are shown in Figures 17 and 18. The presented dependencies are only for M12 anchors.

The values of the destructive force needed to determine the values of the adhesion stresses were adopted on the basis of experimental investigations. How complex the problem of durability of external textured layers is presented, among others, in the works [19, 22].

Figure 17: Dependency edge stress – adhesion stress for diagonal anchors.

Figure 18: Dependency shear stress – adhesion stress for diagonal anchors.

4 The two- and three anchorages system based on the COPY-ECO system

The inspiration for the tests of such groups was the bonded anchors system, called COPY-ECO system, which was very popular in Poland. The idea of this system were two anchors: horizontal and diagonal, mounted at the angle of 30 degrees in slab panel wall.

Variants of two- and three-anchorages considered in the article are a change in the angle of the diagonal anchorages in relation to the concrete surface, i.e. their additional installation at 45 and 60 degrees angles.

The use of diagonal anchors significantly increases the effective length of the anchor and increases the durability of fixing the façade textured layer.

5 Results and discussion

In addition to the obvious factors affecting the durability of the façade textured anchor, i.e. anchor diameter, anchor depth and resin strength parameters, the decisive mechanisms supporting the durability of joints are: panel dimensions, distance between anchors, steel anchor diameters and epoxy resin adhesion stress.

As the diameter of the steel anchor increases, all the strength parameters of steel adhesive joints increases: shear stress, adhesion stress and edge stress.

The results shown in Figure 17 and Figure 18 shows that increasing the angle of inclination of the steel diagonal anchor generates smaller stress values in the textured layer.

6 Conclusions

The article confirmed the fact that the selection of the diameter of anchors bonded, regardless of the resin parameters and the concrete base concrete class together with the increase of the anchor diameter and at the same time the effective anchorage depth h_{ef} influences the increase of adhesion stress τ_{psr} .

The relationship between the values of edge stresses and shear stresses is shaped linearly.

The most-loaded textured slabs concentrate shear stresses depending on the adhesion stresses are the textured layers of long under-window slabs and balcony slabs.

In case of individual diagonal anchors, the best results of stress dependence on each other in terms of the durability of the bonded anchors were obtained at the angle of inclination of 30° .

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