Archives of Materials Science and Engineering

Volume 112
Issue 2
December 2021
Pages 55-62

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

DOI: 10.5604/01.3001.0015.6286

Relationship of the interaction load capacity of anchors on their number and anchoring system

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ABSTRACT

Purpose: The article presents the possibilities of using anchoring systems in the walls of three-layer large slab panel buildings. The use of diagonal anchors allows to increase the effective anchorage depth, which significantly increases the durability of the façade textured layer.

Design/methodology/approach: Pilot tests have confirmed the necessity to use an anchor system in various configurations.

Findings: The documents used included the conclusions of the pilot tests on the real object and the main experimental tests carried out on concrete samples.

Research limitations/implications: The design of new anchorage systems and the proposed theoretical models for estimating their theoretical load capacity are based on the Guidelines contained in the European Technical Approvals.

Practical implications: Single bonded anchorages used in engineering practice require evaluation in order to increase the durability of larger areas of the façade textured layer.

Originality/value: The possibility of differentiating system anchors makes it possible to use them in very thin structural layers (diagonal anchors).

Keywords: Interaction load capacity, Bonded anchors, Epoxy resin, Anchoring system, Large slab panel buildings

Reference to this paper should be given in the following way:

A. Baryłka, D. Tomaszewicz, Relationship of the interaction load capacity of anchors on their number and anchoring system, Archives of Materials Science and Engineering 112/2 (2021) 55-62. DOI: https://doi.org/10.5604/01.3001.0015.6286

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The theoretical models for estimating the capacity of anchorages have been the subject of many publications [1-3]. Usually, such estimates are preceded by experimental tests [1,4,5], as well as numerical analysis using MES programs and environments [5]. Numerical analysis may also concern very important phenomena in various types of anthropogenic objects [6]. When it comes to experimental tests, they are often preceded by an on-site inspection of the facility and then technical diagnosis [7]. Thanks to these activities, it is possible to use the facility safety [8]. The stability and area of textured layers requiring repair or reinforcements are influenced by both negligence resulting from measurement deviations at the stage of making wall elements [9], as well as the impact of factors beyond our control [10]. A very important factor among the time-varying factors is the influence of temperature [11]. Design and execution errors in various types of industrial facilities play a significant role in damage to structural elements [12].

Until now, usually single anchors perpendicular to the surface of concrete elements have been tested as unit anchors or as groups of anchors. The analysis of the selection of individual proposed anchor systems depending on the possibility of their application was made. This article also analyses the anchors fixed at an angle (30, 45 and 60 degrees), extended with groups of anchors in two- and three-anchor systems, the load capacity of which was checked simultaneously. The issues discussed in the article concern the safety of use of large slab panel buildings [13]. The anchoring systems proposed in this article are to significantly increase the durability of fastening the façade textured layer in large slab panel buildings [10].

2. Proposed theoretical models

In the experimental tests [14], there were established the ultimate failure load of the joints anchored in the concrete blocks. Due to the nature of the impact of these loads in three-layer models, see Figure 1, the Authors extend formula (1) with the algebraic sum of the shear force of the top textured layer, the displacement of which is the load capacity to the force pull-out the anchors. This model is described by the formula (1):

$$P_{gr} = \sqrt{\left(\pi \cdot d_o \cdot \tau_p \cdot h_{ef}\right)^2 + \left(\frac{V}{\alpha_M}\right)^2} \tag{1}$$

where:

P_{gr} – design ultimate load capacity for connection failure, kN;
d_o – hole diameter, mm;
τ_p – epoxy resin adhesion stress, N/mm^2;
h_{ef} – effective anchorage depth, mm;
V – shear force of the top textured layer, kN;
α_M – anchor fastening factor (shear loads with lever arm α_M = 1.0 or shear loads without lever arm α_M = 2.0) [15].

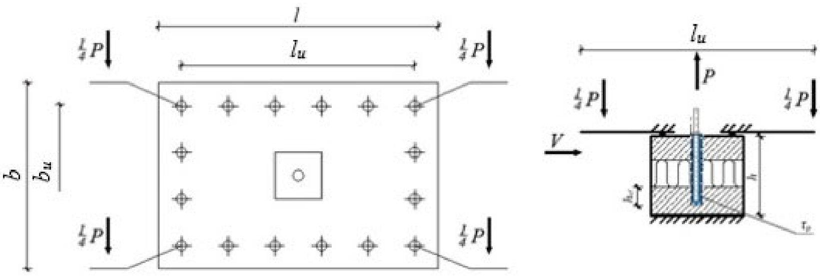

Fig. 1. Due to the nature of the impact of these loads in three-layer models

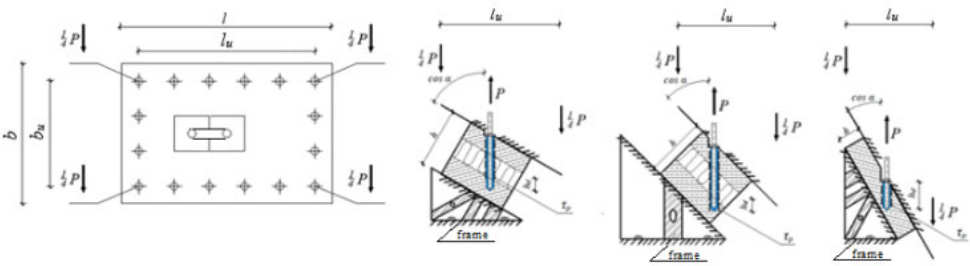

Fig. 2. Sample load diagram with single diagonal anchors at 60°, 45° and 30° respectively

When dealing with single anchors, the authors used the formula (1). However, in the case of anchors concreted in solid concrete elements, it was not necessary to take into account the effect of the shear force. For the group of anchors as it is shown in Figure 2. the theoretical load capacity estimation is given using the formula (2)

The value of the α_M coefficient, depending on the method of fastening and the nature of failure of the anchor, may be taken in accordance with the recommendations [15].

Another theoretical model [16] were discovered to describes the failure of diagonal bonded anchors at angles of 60°, 45° and 30° (Fig. 2). It does not take into account the effect of the shear force of the textured layer due to the lack of experimental verification. The failure load is estimated as:

$$P_{gr} = \pi \cdot d \cdot \tau_p \cdot h_{ef} \cdot \cos\alpha \qquad (2)$$

where α = angle of inclination of diagonal anchors, °.

Moreover, for two-anchor systems (Fig. 3), the failure load was proposed equal to:

$$P_{gr} = \sqrt{\frac{P_{1gr}\cdot s + P_{2gr}\cdot s}{2c+2l_{ef1,2}} + \left(\frac{V}{\alpha_M}\right)^2} = \sqrt{\left(\frac{\pi\cdot d\int_0^{h_{ef1}\cos\alpha_1}(\tau_p\cdot s)ds + \pi\cdot d\int_0^{h_{ef2}\cos\alpha_2}(\tau_p\cdot s)ds}{2c+2l_{ef1,2}}\right)^2 + \left(\frac{V}{\alpha_M}\right)^2} \qquad (3)$$

where:
h_{ef1}, h_{ef2} – effective anchor lengths of individual anchors, mm;
s – distance between the anchors in the axes, mm;
c – thickness of the epoxy resin covers between the anchor and the concrete substrate, mm;
$l_{ef1.2}$ – the length of total anchorage in the samples, mm.

In the case of three-anchor systems, a theoretical resistance is equal to:

$$P_{gr} = \sqrt{\frac{P_{1gr}\cdot s + P_{2gr}\cdot s + P_{3gr}\cdot s}{3c+2l_{ef2,3}+l_{ef1}} + \left(\frac{V}{\alpha_M}\right)^2} = \sqrt{\left(\frac{\pi\cdot d\int_0^{h_{ef1}\cos\alpha_1}(\tau_p\cdot s)ds + \pi\cdot d\int_0^{h_{ef2}\cos\alpha_2}(\tau_p\cdot s)ds + \pi\cdot d\int_0^{h_{ef3}\cos\alpha_3}(\tau_p\cdot s)ds}{3c+2l_{ef2,3}+l_{ef1}}\right)^2 + \left(\frac{V}{\alpha_M}\right)^2} \qquad (4)$$

where:
h_{ef1}, h_{ef2} – effective anchor lengths of individual anchors, mm;
s – distance between the anchors in the axes, mm;
c – thickness of the epoxy resin covers between the anchor and the concrete substrate, mm;
$l_{ef1.2}$ – the length of total anchorage in the samples, mm.

3. Comparison of theoretical models with experimental results

3.1. Comparison of the results for bonded anchors at an angle of 90, 60, 45 and 30 degrees

The most unfavourable situations resulting from the installation of bonded anchors were compared. These situations include: the minimum possible anchoring depth, a combination of epoxy resins with weaker and stronger adhesion stress parameters in concrete with a higher and lower strength class (C 30/37 and C 12/15). The results are presented graphically in the Figures 4-9 and compared in the Tables 1-7.

Small differences in the estimation of the theoretical load capacity of the anchors and the experimental test (Tab. 1 and Fig. 4), despite the unfavourably shallow anchorage, are the result of a higher class of concrete compressive strength than is usually the case in the walls of three-layer large slab panel buildings (C30/37).

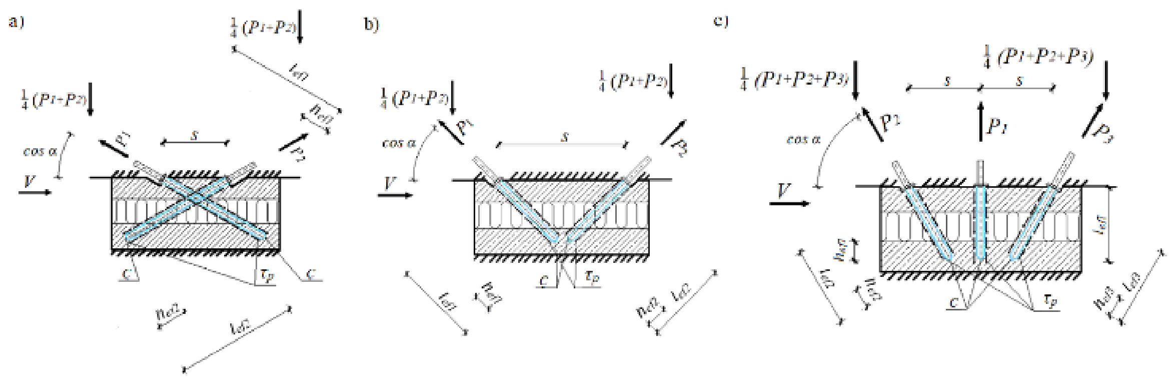

Fig. 3. Diagram of a three-layer sample load in: a) a two-anchor system at an angle of 30°; b) a two-anchor system at an angle of 45°; c) a three-anchor system at an angle of 60°

The difference in the results (Tab. 2 and Fig. 5) is the result of increased epoxy resin adhesion stresses in concrete with a lower strength class.

The big difference in the results was caused by the brittle fracture of the structural concrete layer.

Table 1.
Comparison of the result – steel bonded anchors at an angle of 90 degrees

No	Description	Theoretical estimate	
1.	Parameters	Force, kN	Displacement, mm
2.	The result of the experiment	8.40	0.10
3.	Calculation result	7.17	0.08
4.	Difference	1.23	0.02

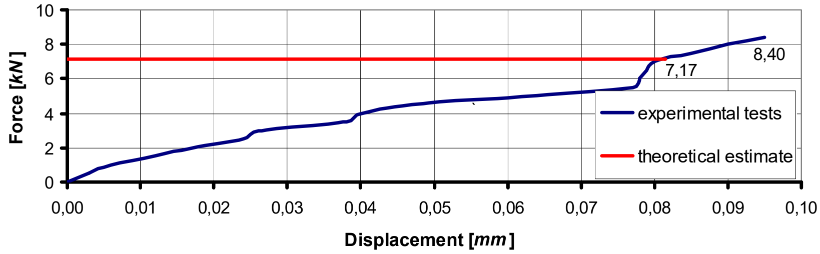

Fig. 4. Comparison of theoretical estimation and experimental tests for an anchor bonded at 90 degrees to the surface of the block model

Table 2.
Comparison of the result – steel bonded anchors at an angle of 60 degrees

No	Description	Theoretical estimate	
1.	Parameters	Force, kN	Displacement, mm
2.	The result of the experiment	9.10	0.10
3.	Calculation result	12.06	0.18
4.	Difference	2.96	0.08

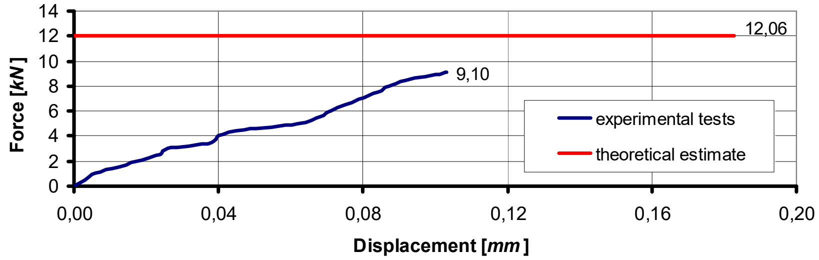

Fig. 5. Comparison of theoretical estimation and experimental tests for an anchor bonded at 60 degrees to the surface of the block model

Table 3.
Comparison of the result – steel bonded anchors at an angle of 45 degrees

No	Description	Theoretical estimate	
1.	Parameters	Force, kN	Displacement, mm
2.	The result of the experiment	4.20	0.05
3.	Calculation result	17.05	0.19
4.	Difference	12.85	0.14

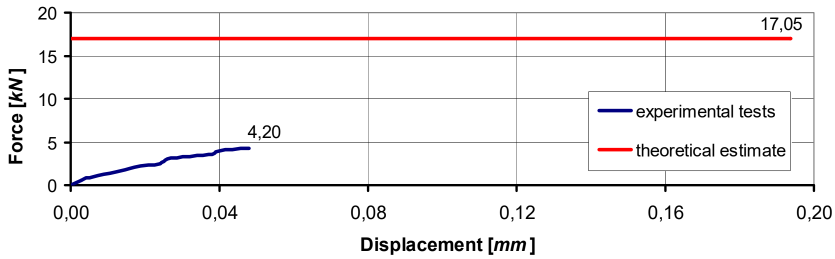

Fig. 6. Comparison of theoretical estimation and experimental tests for an anchor bonded at 45 degrees to the surface of the block model

Table 4.
Comparison of the result – steel bonded anchors at an angle of 30 degrees

No	Description	Theoretical estimate	
1.	Parameters	Force, kN	Displacement, mm
2.	The result of the experiment	17.80	0.20
3.	Calculation result	28.93	0.16
4.	Difference	11.13	0.04

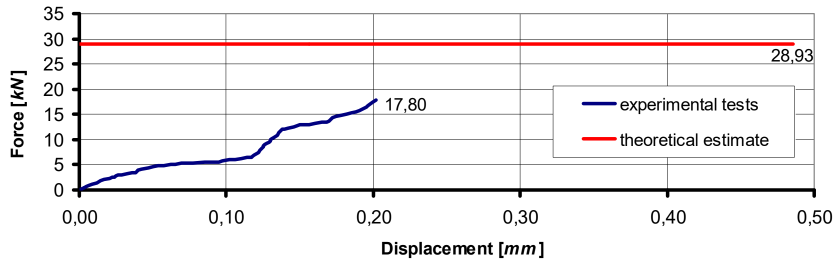

Fig. 7. Comparison of theoretical estimation and experimental tests for an anchor bonded at 30 degrees to the surface of the block model

The difference in the results was caused by the use of a resin with weaker parameters in concrete with a higher strength class.

3.2. Comparison of the results of bonded two-anchors at an angle of 30 and 45 degrees

In the case of two-anchor systems bonded at an angle of 30 degrees (Tab. 5, Fig. 7), a slight difference in the results of 1-1.5% is the result of using a lower class of resin with higher strength parameters in concrete in experimental tests.

In the case of lower class concrete and resin with higher strength parameters, it gives a very high consistency of results. Therefore, it can be concluded that the theoretical models proposed in the article estimate the results of the load capacity with high accuracy.

Exceeding the design limit force shows that the use of two-anchor systems significantly improves the durability of the texture layer attachment.

3.3. Comparison of the results of bonded three-anchors at an angle of 60 degrees

The three-anchors were two steel anchors bonded in at an angle of 60 degrees and one the anchors bonded in at an angle of 90 degrees. The results of a single model are presented in Table 7. The forces in individual anchors obtained in experiment are added, see Figure 10.

The obtained results confirm that the proposed formula for estimating three-anchor systems meets its assumptions.

Table 5.
Comparison of the result – steel bonded anchors at an angle of 30 degrees

No	Description	Theoretical estimate	
1.	Parameters	Force, kN	Displacement, mm
2.	The result of the experiment	12.03	0.14
3.	Calculation result	12.20	0.14
4.	Difference	0.17	0.00

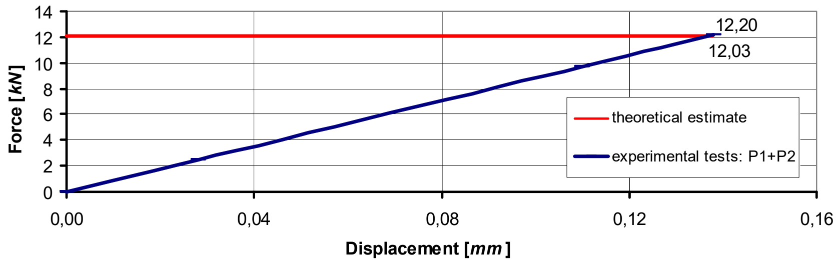

Fig. 8. Comparison of theoretical estimation and experimental tests for an anchor bonded at 30 degrees to the surface of the block model

Table 6.
Comparison of the result – steel bonded anchors at an angle of 45 degrees

No	Description	Theoretical estimate	
1.	Parameters	Force, kN	Displacement, mm
2.	The result of the experiment	16.90	0.19
3.	Calculation result	12.11	0.14
4.	Difference	4.79	0.05

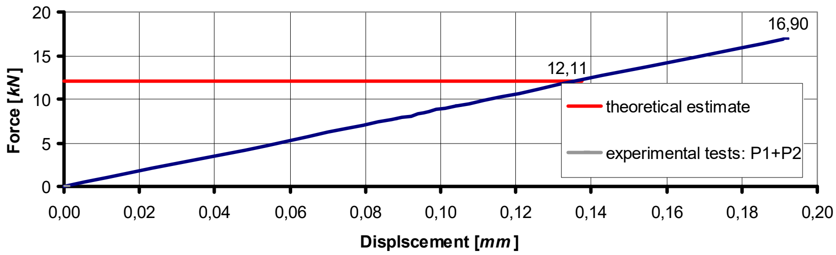

Fig. 9. Comparison of theoretical estimation and experimental tests for an anchor bonded at 45 degrees to the surface of the block model

Table 7.
Comparison of the result – steel bonded anchors at an angle of 60 degrees

No	Description	Theoretical estimate	
1.	Parameters	Force, kN	Displacement, mm
2.	The result of the experiment	14.40	0.16
3.	Calculation result	11.63	0.21
4.	Difference	2.77	0.05

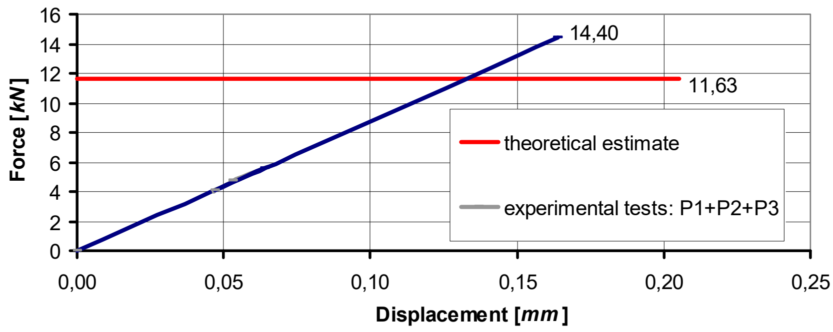

Fig. 10. Comparison of theoretical estimation and experimental tests for an anchor bonded at 60 degrees to the surface of the block model

The greater compliance of the results obtained from the experimental tests compared with the theoretical estimation of the capacity of the anchors is the result of the use of a combination of a higher class of concrete compressive strength and resin with higher strength parameters, or the use of a concrete bonding material of concrete anchors with higher parameters of adhesion stress in concrete with a lower strength class.

A direct comparison of 90 degree bonded and diagonal anchorages are described in [17].

4. Conclusions

The experimental tests were carried out in which the pull-out load capacity of anchors was tested in single-anchor systems at an angle of 90, 60, 45 and 30 degrees, two-anchor systems at an angle of 30 and 45 degrees and in a three-anchor system at an angle of 60 degrees and with the anchor between them at an angle of 90 degrees.

For these elements, mathematical formulas were developed to estimate the theoretical load capacity of anchors, taking into account the interaction of the pull-out force of the anchors and the shear force of the textured layer.

The obtained results were used to verify the systems in terms of the durability of the textured layer fixing.

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