Improvement of the Method for Calculating External Three-layer Wall Panels with Flexible Layer Bonds

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Abstract. This article proposes a theoretical investigation of the contact of composite reinforcement with concrete under the action of an axial tensile load. The purpose of this article is to identify existing methods of specifying stress-strain state of concrete and reinforcement contact zone under the influence of an axial tensile load and proposals of analyses of stress-stain condition of anchoring flexible connections with concrete zones based on the conducted experimental studies. The article analysed methods for calculating the adhesion of reinforcement to concrete by Russian and foreign scholars, and proposes an example of engineering calculations of flexible connections for three-layer wall panels. It was revealed that this method considers limited condition; however, taking into account the actual stage of work on composite flexible connections under calculating and constructing three-layer wall panels makes the most informed project decisions about location and number of flexible connections in the structure, considering the safe exploitation is provided. Based on the results of experimental studies, the article proposes to distinguish three main Stress-Stain State (SSS) of composite glass flexibles bolting resistance in the considered lightweight concrete. The research is carried out within the project funded by Fund for Assistance to Small Innovative Enterprises in Science and Technology Grant, programme UMNIK, contract №11905GU/2017 from 03.07.2017.

1. Main part

Building of panel and frame construction schemes are the most the most common as residential buildings and structures in our country. They occupy up to 40% of the total number of commissioned residential areas. For the Tomsk region, this figure reaches 70%. And one of the most important factors of the quality of these houses is their energy efficiency, which, mainly, provide external enclosing structures. In this, the most popular option is three-layer concrete wall panels that act as external enclosing structures.

The most effective from the point of view of heat engineering parameters while maintaining the technological design of the structures was the decision to apply for three-layered wall panels,
composed of flexible links. The most popular of those are glass composites, as they have low weight, low thermal conductivity and high tensile strength.

When working under the construction of a wall panel, the one can identify two types of flexible links – normally located links and obliquely located suspensions and struts. Suspension links serve to perceive a vertical load, that is to say, they serve against vertical displacement of the outer layer relative to the inner; bond-struts serve against the shift of structural layers in the horizontal direction of the structure; the spacer joints take horizontal loads onto the wall panels in a direction perpendicular to the plane of the structure.

Currently, there are various methods for calculating the number of flexible compounds, the basis of which is usually the verification of flexible bonds for strength and deformation (taking into account the shear of the insulation or without it), and also conditions for ensuring the strength of anchoring flexible compounds in concrete [1-15].

In structural system of composite bonds, which consists of obliquely and normally located rods, inclined links are calculated on the action of shear forces on the weight of the outer layer of the panel, and normally located bonds - on the action of wind load tensile forces and efforts arising in the manufacture of panels (Figure 1).

It is possible to distinguish the following main directions in the calculation of flexible links in three-layer wall panels:

**Calculation of flexible compounds by strength:**

\[
\frac{N}{n \cdot A_f} + \frac{P \cdot l}{2n \cdot W_f} \leq R_f \cdot \gamma_n
\]  

(1)

where \( R_f \) – is the design tensile strength of the tensile bond with the coefficient of working conditions, taking into account the influence of alkaline in the concrete;

\( N \) – is the structure load causing tensile forces in the panel connections;

\( P \) – is the shear force acting on the links in the panel;

\( l \) – is the calculated link length, equal to \( t + 1 \) cm;

\( n \) – is the number of compounds in the panel;

\( A_f \) – is the cross-section area of one flexible link;

Condition (1) determines the minimum number of flexible links in the panel:

\[
n = \left( \frac{N}{A_f} + \frac{P \cdot l}{2 \cdot W_f} \right) R_f^{-1}
\]

(2)
This formula is also valid for calculating the wall panel for the action of forces during the decking of the structure at the manufacturing stage, but without regard to the action of shear forces (second element on the left-hand side of the formula (1) equated zero).

The calculation of deformation links (includes stage of building management) is performed by taking into account the joint operation of the heat-insulating layer of panels on the shear from the condition:

$$\Delta \leq \Delta_{\text{ult}}$$

where $\Delta_{\text{ult}}$ – the maximum permissible value of reinforced concrete layers of the panel mutual displacement relative to each other;

$\Delta$ – is the mutual displacement of the panel layers under the action of a shearing force, equal to the displacement of one end of the compound with respect to the other.

$$\Delta = \Delta_f = \frac{P \cdot l^3}{12 \cdot n \cdot E_f \cdot I_f}$$

where $\Delta_f$ – is the mutual displacement of the bonds ends from the shearing force $P_f$, acting on the compound;

$E_f$ – modulus of elasticity at tension of composite compound;

$I_f$ – is the moment of inertia of the cross section of one compound.

A check is also carried based on the condition of anchoring strength of flexible compounds in concrete:

$$N \leq N_{\text{anch}}$$

where $N$ – is the tensile force acting on the anchoring device;

$N_{\text{anch}}$ – is the ultimate tensile force, which can be perceived by flexible links anchoring.

The value of the ultimate effort $N_{\text{anch}}$ is determined by the results of static tests carried out individually for each type of anchoring part of flexible links, for the type of its surface, as well as the depth of anchoring and strength of concrete, where anchoring is carried out.

Based upon possible forms of destruction, the ultimate tensile strength of the anchoring can be determined from following dependencies:

– when destroyed by pulling on concrete:

$$N^1_{\text{anch}} = \gamma_b \cdot \varphi_1 \cdot R_{bt} \cdot u_f \cdot l_{\text{anch}}$$

(6)

– when broken from pricking out concrete::

$$N^2_{\text{anch}} = \gamma_b \cdot \varphi_2 \cdot R_{bt} \cdot u \cdot l_{\text{anch}}$$

(7)

– when the connection in the anchoring zone is broken:

$$N^3_{\text{anch}} = \gamma_b \cdot \varphi_3 \cdot R_{fp} \cdot u_f \cdot l_{\text{anch}}$$

(8)

where $R_{bt}$ – the calculated resistance of concrete against strength;

$R_{fp}$ – the calculated resistance of the flexible links along the fibers;

$u_f$ – perimeter of flexible links;

$u$ – perimeter of the critical section, where:

$$u_f = \pi \cdot l_{\text{anch}}$$

$l_{\text{anch}}$ – depth of flexible links anchoring in concrete;

$\gamma_b$ – coefficient of working conditions of concrete, taking into account the influence of the environment;

$\varphi_1, \varphi_2, \varphi_3$ – coefficients that take into account the type of anchoring device.
The coefficients $\gamma$ and $\varphi$ are established by experimental studies.

In accordance with the above, before the calculation of three-layer wall panels with composite flexible links, it is necessary to carry out a series of experimental studies, that determine the actual strength parameters of the considered flexible links anchoring in concrete.

These studies should include at least: determination of the strength of flexible links adhesion to concrete, variation of the anchoring depth, determination of the strength for axial pulling out under different strength classes of concrete. Additionally, formulas 1–8 allow the calculation to be performed in the limiting stages of the materials work. To assess the stress-strain state of the anchoring zone of flexible links in concrete at the operational stage, it is necessary to conduct experimental and theoretical research that broadens the notion of their joint work and processes that take place when the effect of external loads increases. In the framework of this article, the results of experimental studies are presented for the following case: anchoring in lightweight claydite-concrete of glass-composite flexible link of Biysk fiberglass plant. These flexible links have a nominal diameter $d = 7.5$ mm, along the body of communication and broadening at the end sections on both sides, with a diameter equal to $1.5d$.

A simplified design scheme for determining the standard effort in flexible links and the design schemes of the glass-composite flexible links of the samples under study are shown in Figure 2.

Generally, despite the arrangement of flexible links in different geometric planes, the calculation is based on the action of an axial tensile load. In accordance with this, a test stand has been designed and patented (patent on invention RU 2605386 dated December 20, 2016), which models the work of glass-composite flexible links in concrete. The tests were carried out on a static load transferred to the structure by a hydraulic automated press UTM 4500, which allows to carry out tests with a constant rate of deformation up to complete destruction. This makes it possible to obtain with the greatest accuracy the strain curve in studying the strength of anchoring of glass-composite flexible links.
Figure 3 – shows the characteristic strain curve obtained from the results of glass-composite flexible links tests. Depth of anchoring of 70 mm in claydite-concrete sample of class B15 in compressive strength

This graph shows a curve corresponding to the slippage of the composite flexible links in concrete, on which several stages of the stress-strain state of the composite flexible link anchoring with the broadening at the end section are clearly distinguished.

The First Stage of SSS - a section of the fiberglass flexible links without broadening is involved in the active process. Strength analysis is carried out over tangential stresses (Figure 4, a, formula 9). Further, as the external load increases, the broadening and redistribution of internal forces are included in the work. There comes Second Stage of SSS. At this stage, the tangential stresses resist the displacement in the body of the concrete sample, the deformation of the contact zone. At this stage, the strength analysis is proposed to be carried out by the ratio of the resulting tangential stresses through the ultimate strength of concrete to crushing (Figure 4, b, formula 9). With a further increase in the external load, there is a violation of the contact zone, the deformation of the flexible link. The total adhesion is defined as the sum of the adhesion along the lateral surface of the broadening and the tangential shear stresses along the boundary of the main crack (Fig. 4, c, formula 10).

![Figure 4](image)

Figure 4 – proposed stages of SSS anchoring in lightweight concrete of the investigated composite flexible compound with broadening at the end section: a) I stage of SSS; b) II stage of SSS; c) III stage of SSS

\[
\tau_{\text{anch}}^J \leq \frac{N}{A_{\text{sq}}} \quad (9)
\]
\[
R_{sh} = 2,2 \cdot (1 + 5 \cdot \frac{\sigma_b}{R_b}) \cdot R_{sh}
\]
\[
\tau_{ecc} = -\frac{R_b}{30} + \left(0,234 - 0,2\right) \cdot \Delta_{sh}.
\]

These analytical dependencies are proposed on the basis of processed results of experimental studies, as well as the studies provided in this article [16]. Recognition of the actual work of composite flexible links in the calculation and design of three-layer wall panels will allow us to take the most reasonable design solutions for the location and number of flexible links in the structure while ensuring safe operation.

References

[1] Kholmyanskiy M M 1959 The main tasks of calculating the adhesion of reinforcement bars of the periodical profile with the concrete in centrally reinforced prismatic elements 1 Dokl. AN SSSR, V. 129
[2] Oatul A A 1969 Theoretical and experimental studies of adhesion to concrete of rod and rope reinforcement Doctoral thesis (Chelyabinsk)
[3] Ovchinnikova N G, Sudakov G N and Dodonov M I 1966 Coupling of the bar reinforcement with a periodic profile with the concrete Proc. of VI Conf. on Concrete and reinforced concrete (Riga)
[4] Karpenko N I 1973 Beton i zhelezobeton vol 1 27-38
[5] Sudakov G N 1982 Method for calculating the reinforcement of a periodic profile with the concrete taking into account internal contact cracks Candidate thesis (Moscow)
[6] Nazarenko P P 1998 Contact interaction of reinforcement in concrete in elements of reinforced concrete structures Candidate thesis (Moscow)
[7] Stolyarov YA V 1941 Introduction to the theory of reinforced concrete (Moscow, Leningrad: Stroyizdat)
[8] Babayan A A 1952 Research of the stress-strain state of bent elements taking into account the adhesion between reinforcement and concrete Candidate thesis (Leningrad)
[9] Baykov V N 1968 Beton i zhelezobeton vol 12 13-16
[10] Rehm G 1957 The fundamental law of bond Symp. on Bond and Crack Formation in Reinforced concrete V.1-11 (Stockholm)
[11] Watstein D 1941 Bond stresses in concrete pull – out specimens JACI. V. 13-1
[12] Watstein D and Parsons D E 1943 Journal of research of the National Bureau of standards 1 1545-1576
[13] Zaliger R 1931 Reinforced concrete and its calculation and design (Moscow, translated from German)
[14] Emperger F 1935 Announcements on experiments conducted by the Austrian Committee on Reinforced Concrete Question vol 16
[15] Shima H, Chou L-L and Okamura H 1987 Journal of the Faculty of Engineering 2 133-194 (University of Tokyo)
[16] Kumpyak O G, Galautdinov D N and Kokorin D N 2016 Strength and deformability of reinforced concrete structures on flexible bearings under short-term dynamic loading (Tomsk, TSUAB)