UDC 626.131.34
IRSTI 67.11
RESEARCH ARTICLE

ACTUAL PROBLEMS OF APPLICATION OF COMPOSITE FLEXIBLE CONNECTIONS IN EXTERNAL THREE-LAYER WALL PANELS

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Abstract. *In this paper, the technical problems of using the structures of their three-layer panels with flexible connections made of polymer materials are considered on the example of a residential complex under construction in Astana. The study of three-layer panels with flexible composite bonds was carried out as a result of the appearance of cracks with an opening width of acrc = 0.05-0.1 mm. The main purpose of the study was to establish the causes of cracking and to develop recommendations for the exclusion of such phenomena in the structures of three-layer panels with flexible composite bonds, which was carried out in the following directions: preparatory research (study of technical and design documentation, review of scientific and technical literature (sources) in this field of theory of buildings and structures); full-scale study of external wall three-layer panels with flexible polymer bonds (the actual strength of concrete was determined; the entire technological chain of creation and erection of the structure under study was traced (manufacture, transportation, installation in the design position); actual reinforcement of panels was established); performing panel verification calculations for various design situations (a total of six design calculation options) based on software the Lira CAD complex; identification of the main causes of cracks and development of recommendations for the elimination of future technical problems in the design, manufacture, transportation and installation of three-layer panels with flexible composite bonds.*

Keywords: *wall panels, load-bearing elements, structures, facade, defects and damages.*

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https://doi.org/10.51488/1680-080X/2024.4-10
Received 15 February 2024; Revised 27 March 2024; Accepted 18 July 2024

ӘОЖ 626.131.34
ҒТАМР 67.11
ҒЫЛЫМИ МАҚАЛА

ҮШҚАБАТТЫ СЫРТҚЫ ҚАБЫРҒА ПАНЕЛЬДЕРІНДЕ КОМПОЗИТТІК ИКЕМДІ БАЙЛАНЫСТАРДЫ ҚОЛДАНУДЫҢ ӨЗЕКТІ МӘСЕЛЕЛЕРІ

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Аңдатпа. *Бұл жұмыста Астана қаласында салынып жатқан тұрғын үй кешенінің мысалында полимерлі материалдардан жасалған икемді байланыстары бар үш қабатты панельдердің конструкцияларын қолданудың техникалық мәселелері қаралды. Икемді композиттік байланыстары бар үш қабатты панельдерді зерттеу жарықтардың ені acrc=0,05…0,1 мм ашылу нәтижесінде жүзеге асырылды. Бұл зерттеудің негізгі мақсаты жарықтардың пайда болу себептерін анықтау және икемді композиттік байланысы бар үш қабатты панельдердің конструкцияларында осындай құбылыстарды болдырмау бойынша ұсыныстар әзірлеу болды. Бұл жұмыстар келесі бағыттарда жұмыс жүргізу кезінде анықталынды: дайындық зерттеу (ғимараттар мен үймереттер теориясы саласындағы техникалық және жобалық құжаттаманы қарау, ғылыми және техникалық әдебиеттерді (дереккөздерді) шолу); икемді полимерлі байланысы бар үш қабатты сыртқы қабырға панельдерін табиғи зерттеу (бетонның нақты беріктігін анықтау; зерттелетін құрылымды құру мен тұрғызудың барлық технологиялық тізбегін бақылау (дайындау, тасымалдау, жобалық жағдайға орнату); панельдердің нақты арматурасын орнату; ашылу ені acrc=0,05…0,1 мм кезінде ішкі бетон қабаты бойынша бетон бетіндегі қабырға панелінің жоғарғы және төменгі жиектерінің деңгейінде, сондай-ақ терезе саңылауларының тораптары аймағында жарықтарды анықтау;Лира САПР бағдарламалық кешені негізінде әр түрлі есептік жағдайларға арналған панельдік тексеру есептеулерін (есептеудің алты есептік нұсқасын алу) жүргізу; жарықтардың пайда болуының негізгі себептерін анықтау және икемді композиттік байланысы бар үш қабатты панельдерді жобалау, дайындау, тасымалдау және монтаждау кезінде болашақта техникалық проблемаларды жою бойынша ұсыныстарды әзірлеу.*

Түйін сөздер: *қабырға панельдері, тірек элементтері, құрылымдар, қасбет, ақаулар мен зақымдар.*

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https://doi.org/10.51488/1680-080X/2024.4-10
Алынды 15 ақпан 2024; Қайта қаралды 27 наурыз 2024; Қабылданды 18 шілде 2024

УДК 626.131.34
МРНТИ 67.11
НАУЧНАЯ СТАТЬЯ

АКТУАЛЬНЫЕ ПРОБЛЕМЫ ПРИМЕНЕНИЯ КОМПОЗИТНЫХ ГИБКИХ СВЯЗЕЙ В НАРУЖНЫХ ТРЕХСЛОЙНЫХ СТЕНОВЫХ ПАНЕЛЯХ

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Аннотация. *В данной работе рассмотрены технические проблемы применения конструкций их трехслойных панелей с гибкими связями из полимерных материалов на примере строящегося жилого комплекса в г. Астана. Исследование трехслойных панелей с гибкими композитными связями выполнено в результате появления трещин шириной раскрытия* a_{crc}*=0,05-0,1 мм. Основной целью исследования явилось установления причин трещинообразования и разработка рекомендаций по исключению подобных явлений в конструкциях трехслойных панелей с гибкими композитными связями, которая проводилась в следующих направлениях: подготовительное исследование (изучение технической и проектной документации, обзора научной и технической литературы (источников) в данной области теории зданий и сооружений); натурное исследование наружных стеновых трехслойных панелей с гибкими полимерными связями (определялась фактическая прочность бетона; прослежена вся технологическая цепочка создания и возведения исследуемой конструкции (изготовление, транспортировка, установка в проектной положение); установлено фактическое армирование панелей); выполнение поверочных расчетов панели на различные расчетные ситуации (всего шесть расчетных вариантов расчетов) на основе программного комплекса Лира САПР; определение основных причины появления трещин и разработка рекомендации по исключению в будущем технических проблем при проектировании, изготовлении, транспортировки и монтажа трехслойных панелей с гибкими композитными связями.*

Ключевые слова:. *стеновые панели, несущие элементы, конструкции, фасад, дефекты и повреждения.*

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https://doi.org/10.51488/1680-080X/2024.4-10
Поступило 15 февраля 2024; Пересмотрено 27 марта 2024; Принято 18 июля 2024

ACKNOWLEDGEMENTS/SOURCE OF FUNDING

The study was conducted using private sources of funding.”

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС/ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

One of the primary objectives in advancing large-panel construction technologies is to enhance energy efficiency and energy conservation. This is achieved through the integration of composite polymer reinforcements, which are particularly promising for use in three-layer external wall panels.

To ensure the required reliability of three-layer reinforced concrete panels with composite connections, it is essential to develop appropriate structural solutions and conduct extensive experimental investigations. These include testing both individual panel elements with connections and the panels as a whole. Key aspects of this research involve addressing issues of anchoring, corrosion resistance, and fire safety of the connections, as well as examining the interaction between flexible connections and the concrete layers of load-bearing structures.

2 LITERATURE REVIEW

(Blazhko, 2015), in Flexible Basalt-Plastic Bonds for Use in Three-Layer Exterior Wall Panels, emphasized the necessity of developing an effective and reliable system for quality control of flexible composite connections during production. This system should be incorporated into the technological regulations for panel manufacturing. The study demonstrated that inaccuracies in the installation and embedding of flexible basalt-plastic connections, as well as technological factors during production, significantly affect the load-bearing capacity and durability of panels across various stages, including manufacturing, transportation, installation, and long-term operation.

(Lugovoy, 2014), in Composite Flexible Connections for Three-Layer Panels, identified several key advantages of using composite connections over traditional bonding methods for three-layer panels. Composite connections eliminate thermal bridges, which increases the thermal resistance of wall panels by 20–40% due to their low thermal conductivity (0,55 W/m·°C). This improvement enhances energy efficiency and conservation in large-panel construction. Furthermore, experimental and theoretical studies revealed essential physical and mechanical characteristics of panels with flexible polymer connections, including their strength under various stress-strain states (tension-compression, transverse bending, and shear along and across reinforcement fibers), elastic modulus, creep resistance, and durability in aggressive environments such as acids and alkalis for up to 100 years. The bond strength between flexible connections and concrete or mortar was also confirmed. Instead of increasing the insulation thickness in traditional panel designs, the use of flexible polymer connections eliminates thermal bridges caused by concrete keys or stainless-steel ties, significantly improving the reliability and cost-efficiency of three-layer panels.

In the study, **(Kovrigin, Maslov, and Wald 2017)** investigated the effects of alkaline exposure on flexible composite connections with wound strands. The results showed that such exposure significantly reduces bond strength with concrete—up to 90%. However, flexible connections featuring cylindrical-conical anchor expansions experienced only a 9% reduction in bond strength, ensuring operational reliability and durability of the structure.

The introduction of flexible composite connections in wall panels has significantly enhanced corrosion resistance and material efficiency. These panels also effectively meet regulatory requirements for thermal conductivity and heat resistance, optimizing the consumption of components.

Screw-type connections with periodic profiles, created by bonding strands of basalt and glass fibers impregnated with resin, are deemed impractical. During extraction from the concrete mass, shear failures occur in the contact zone due to the detachment of coarse sand from the reinforcing rod surface. Conversely, the use of anchor elements with cylindrical expansions at the ends of the rods ensures reliable and durable fixation of flexible connections in concrete.

In addition to the design of the anchor interface (e.g., cylindrical expansion at the end of the rod), the reliability of flexible connections depends on the composition of the binding element and the stability of the manufacturing process in terms of quality. Key factors include using raw materials with high initial strength and modulus of elasticity and determining the optimal volume ratio of filler to polymer matrix to achieve a uniform composite structure.

To ensure the required thermal stability of the composite, it is essential to select the appropriate glass transition temperature, ideally between 60–65°C, as verified by relevant testing protocols. Furthermore, quality standards for manufacturing flexible composite connections should include a robust acceptance testing system, with samples from each batch subjected to rigorous evaluation.

The foundation of composite reinforcement in constructions consists of fibers made from basalt, glass, aramid, and carbon, with thermoactive synthetic resin (plastic) serving as the binding agent **(Imomnazarov, Al Sabri, & Dirie, 2018)**. Compared to conventional steel reinforcement, composite reinforcement exhibits certain disadvantages: a low modulus of elasticity, reduced fire resistance, inability to be used as compressed reinforcement, and higher costs.

A significant obstacle to the widespread use of composite reinforcement is the lack of a robust regulatory framework. The low modulus of elasticity reduces the ultimate load capacity of flexural elements without pre-tensioning. Furthermore, traditional calculation methods for reinforced concrete structures with steel reinforcement are unsuitable for designs incorporating composite reinforcement.

Fire resistance is another critical challenge. When heated to 100°C, composite reinforcement made of glass or basalt fibers may degrade, requiring the development of specialized fire protection measures to ensure its viability in high-temperature conditions.

Despite these limitations, composite reinforcement offers notable advantages, including chemical resistance, electromagnetic transparency, and excellent dielectric properties, making it particularly beneficial in certain applications.

Filatov (2017) examined the use of three-layer panels with discrete connections (reinforced concrete walls) based on fiberglass and basalt-plastic reinforcement. The study investigated the temperature distribution within three-layer external wall panels, which consisted of an outer layer of expanded clay concrete (80 mm thickness), an insulating layer of polystyrene foam boards (PPS-25 type, 150 mm thickness), and an inner layer of expanded clay concrete (120 mm thickness). Average surface temperatures of external walls, heat flows, and thermal resistance values were determined. Thermodynamic calculations were verified through thermographic inspections, which confirmed the absence of thermal bridges in all cases.

According to **Kovrigin and Maslov (2016)**, existing GOST standards for composite connections exhibit several critical shortcomings:

1. There are no requirements for the organization of acceptance tests for composite flexible connections. These tests should not only include measurements of sample geometric dimensions but also determine the actual physical and mechanical characteristics of the products.
2. The standards lack requirements for bond strength between connections and the concrete of the load-bearing or facing layer after exposure to appropriate environmental conditions. This factor significantly influences the load-bearing capacity of panels incorporating polymer-composite flexible connections (e.g., glass and basalt fibers).
3. There are no correction coefficients that account for dynamic and climatic impacts on the strength of flexible connections and their anchoring systems within the concrete mass. This necessitates the development of additional calculation methods within the broader framework for composite constructions.
4. Specific (technically justified) schemes for the placement of flexible connections to optimize their inherent strength and ensure reliable and thermally efficient wall panels are absent.

The structural design of the anchoring element in flexible connections plays a pivotal role in their reliability and durability. This includes features such as protruding ribs along the entire length of the rod, square profile expansions formed by milling the composite rod, or cylindrical-conical expansions connected with cylindrical sanded anchor sections. Such features are essential to ensuring the reliable connection of the layers in three-layer panels. Therefore, all flexible connection designs should undergo strength testing in aggressive environments to verify both the connections and their anchoring systems before being approved for use.

Based on international methodologies, the following requirements have been established for testing the load-bearing capacity of flexible connections:

1. The quality of the connections should be assessed in terms of both their own strength and the strength of their nodes when bonded to the concrete mass of constructions.
2. Connections should undergo tests in alkaline environments to evaluate chemical aging under simultaneous static loading. The test duration should be at least 5,000 hours (compared to only 720 hours in Russia).
3. Statistical data on strength reduction over time should be collected, allowing extrapolation for the expected service life of the structure.
4. During testing, failures should occur exclusively within the concrete mass (i.e., the forms and failure modes of flexible connections should be uniform).

Flexible rod connections used in three-layer sandwich panels are sections of composite rods with a circular cross-section and anchor expansions at their ends to improve anchoring performance. These components include suspensions, supports, and braces, which are integral to the structural integrity of the panels.

To reduce shrinkage and deformation of concrete, which create conditions for crack formation during lifting and transportation, this study proposes diagonal flexible connections. These connections are made from high-strength fiberglass with low thermal conductivity and high resistance to alkaline and chemical environments, thereby eliminating thermal bridges and ensuring the corrosion resistance of the panels **(Nikolaev, Stepanova, & Demina, 2018)**.

Lugovoy and Kovrigin (2015) analyzed the application of three-layer reinforced concrete panels with composite flexible connections, including SPA 7.5 connections produced by the Biysk fiberglass factory. Replacing thermally conductive connectors such as metal ties and concrete keys with composite flexible connections effectively addresses the issue of thermal bridges. However, current GOST standards for flexible connections used in multilayer enclosures exhibit several shortcomings. First, they lack technical requirements for the bond strength between flexible connections and the concrete of the load-bearing or facing layer after exposure to alkaline environments, despite this factor being critical for determining the load capacity of the bonding node. Although alkaline testing does not significantly affect the strength of the primary rods of the connections, which retain a margin of safety, the absence of these requirements limits design accuracy. Second, there is no established procedure for statistically reliable determination of correction coefficients that account for dynamic and temperature impacts on the strength of flexible connections and their anchoring nodes. Third, calculation-based and justified schemes for arranging flexible connections within the concrete mass of constructions remain undeveloped.

To ensure the proper operation of panels with polymer composite flexible connections, they must comply with GOST standards and construction regulations, including **SP 63.1333012 Concrete and Reinforced Concrete Structures. General Provisions**, to prevent undesirable cracking processes. When calculating prefabricated structural elements exposed to loads during lifting, transportation, and installation, the load from the element's weight must include a dynamic coefficient of no less than 1.6 during transportation and 1.4 during lifting and installation.

When designing structures with flexible composite connections, operational factors such as freeze-thaw cycles, exposure to high-temperature fields, wind pressure pulsations, and similar conditions must be considered using appropriate reliability coefficients and working conditions. The design of three-layer panels with flexible composite reinforcement must strictly adhere to current standards, including Interstate Standard GOST 31938-22 Composite Polymer Reinforcement for Concrete Structures. General Technical Conditions **(Interstate Standard, 2022)** and Interstate Standard GOST 32486-15 Composite Polymer Reinforcement for Concrete Structures. Methods for Determining Structural and Technological Characteristics **(Interstate Standard, 2016)**.

3 MATERIALS AND METHODS

The scientific and technical assessment of a residential construction project in Astana was conducted in accordance with SP RK 1.04.04-101-2012 Inspection and Evaluation of the Technical Condition of Buildings and Structures **(SP RK 1.04-101-2012, 2015)** by the KazMIRR Institute. The assessment included three main stages: preparatory (preliminary) research, a full-scale investigation of external three-layer wall panels with flexible connections, and verification calculations for the external wall panel under various design scenarios.

The preparatory research established that the structural scheme of the building is a frame structure consisting of monolithic reinforced concrete pylons, shear diaphragms, and floor slabs. The strength, stability, and spatial rigidity of the building are ensured by the combined performance of the pylon system, shear diaphragms, horizontal floor disks, and foundation, as described by **Nuguzhinov et al. (2023), Nuguzhinov et al. (2021), and Mussabayev et al. (2023)**.

The panels used in the project are 3NSg-type panels in accordance with GOST 31310, which are three-layer external wall panels with flexible connections and a single-row cut design. These panels have a total thickness of 285 mm, comprising an internal reinforced concrete layer with a thickness of 80 mm, a mineral wool insulation layer with a thickness of 140 mm, and an external reinforced concrete layer with a thickness of 65 mm, as outlined in **NTP RK 01-01-3.1(4.1)-2017, GOST 14782-86, and GOST 5264-80**.

Flexible connections installed between the internal and external concrete layers ensure the combined performance of these layers in the external wall panel. These connections consist of suspensions, spacers, and braces made of fiberglass rods with a diameter of 7.5 mm. Each connection element performs a specific function: suspensions support the weight of the panel's external layer, spacers maintain the distance between the layers, and braces prevent horizontal displacement of the external layer relative to the internal layer, as described by **Nuguzhinov et al. (2022) and Nuguzhinov et al. (2021)**.

The reinforcement of the external and internal concrete layers of the three-layer external wall panels consists of Vr-1 class wire mesh with a diameter of 5 mm and a spacing of 100 mm, combined with frames containing longitudinal reinforcement made of AIII class rods with a diameter of 10 mm. The transverse reinforcement is made of Vr-1 class wire with a diameter of 5 mm. Additional reinforcement is provided at the corners of window openings using AIII class steel rods with a diameter of 8 mm and a length of 600 mm. Four lifting loops made of AI class reinforcement with a diameter of 10 mm are embedded in the internal concrete layer. To ensure vertical positioning, two loops made of AI class reinforcement with a diameter of 20 mm are installed in the upper part of the panel and are embedded in both concrete layers.

During the full-scale investigation of external three-layer wall panels with flexible connections, cracks with a width of acrc = 0,05–0,1 mm were identified in the internal concrete layer at the top and bottom levels of the wall panel, as shown in **Figure 1**.

4 RESULTS AND DISCUSSION

Selective probing of sections of the internal layer of the external three-layer wall panel, as well as control openings in specific areas, revealed that the reinforcement of the internal reinforced concrete layer complies with the project specifications. The reinforcement consists of Vr-1 class wire mesh with a diameter of 5 mm and frames containing longitudinal reinforcement made of AIII class rods with a diameter of 10 mm. The transverse reinforcement is also made of Vr-1 class wire with a diameter of 5 mm. Additional reinforcement at the corners of window openings was implemented using AIII class steel rods with a diameter of 8 mm and a length of 600 mm.


(a)
(b)

Figure 1 – Crack in the internal concrete layer of three-layer wall panels: a) crack at the top level of the wall panel; b) crack at the bottom level of the wall panel **(Nuguzhinov et al., 2023)**.

Non-destructive tests to determine the strength of concrete in the internal load-bearing layers of the external three-layer wall panels showed that the actual concrete strength corresponds to the design class of concrete B20.

To investigate the causes of cracks in the external three-layer wall panels, a comprehensive field study was conducted across all stages, from production and movement of the panel from the assembly table to its final position at the construction site. Panels are formed in special metal molds, and to accelerate the curing process, thermal and moisture treatment is applied, ensuring that the concrete in the external and internal reinforced concrete layers achieves at least 80% of its design strength.

The reinforcement of the wall panels complies with the working drawings and includes flexible fiberglass connections. The first lifting of the panels from the assembly table was performed using an overhead crane and double-sling cable straps at an angle of 35–40° from the plane. After lifting the panels, cracks with widths ranging from acrc = 0,02–0,03 mm were observed on certain specimens.

Following lifting, the panels are placed in an inclined position onto racks located in the assembly shop and subsequently loaded onto panel trucks. The external wall panels are secured on the panel truck via the upper mounting loops using clamps. The lower part of the internal concrete layer of the external wall panels rests on a solid rubber strip laid on a timber support frame, as per **SP RK EN 1993-1-1:2005/2011 (2015) and SP RK 5.03-107-2013 (2015)**.

Upon the arrival of the panel truck with the examined external wall panels at the construction site, a visual inspection of the concrete layers revealed cracks with widths of acrc = 0,05–0,1 mm. Notably, cracks also appeared on panels that were previously free of such defects.

Based on the investigation results, the authors simulated various scenarios from production to installation of the panels and performed detailed calculations to determine the causes of cracks in the external three-layer wall panels. Verification calculations were carried out for different scenarios, including the moment of the first lift at an angle of 65° using tippers and lifting traverses to ensure force balance in the load slings with 80% concrete strength and a dynamic coefficient of 1,4, transportation of the panel with a dynamic coefficient of 1,6, lifting of the panel with a dynamic coefficient of 1,4, installation of the panel in its design position, and two panel installation variants.

The simulation of the wall panel was performed using the licensed software package LiraSAPR (**Figure 2**). The calculation model for the NS-1 wall panel was based on materials from detailed instrumental inspections and project documentation. The model was constructed through interactive input of load-bearing structures with the creation of a finite element mesh (nodes and elements). The input data included information on cross-sections, materials, support conditions, and loads. In each scenario, the actual concrete strength determined by field testing was considered. The external and internal layers of the wall panel were modeled using universal shell elements, while the flexible connections were modeled using general-purpose rod elements. The calculation model included all loads acting on the panel at a given moment depending on the specific design scenario.

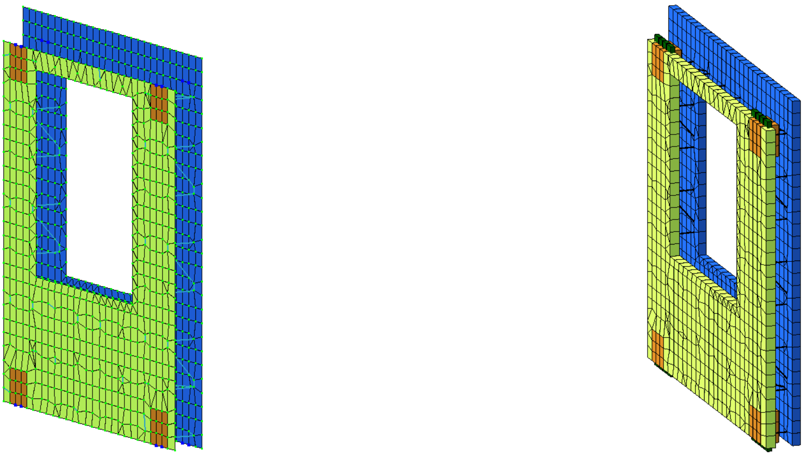

Figure 2 – Finite element model of the analyzed panel **(Nuguzhinov et al., 2023)**.

First Design Scenario: "Initial Lifting of the Panel". The first design scenario (**Figure 3**) is based on materials provided by the client and the results of the field investigation. The panel is lifted from the mold using a tilting device, which lifts the panel not horizontally but at an angle to the horizontal plane. Three angles were analyzed in the calculations: 15°, 45°, and 65°. In this scenario, the displacement constraints of the calculation model are set at the lifting loops and along the lower edge of the external layer.

The only load acting on the panel in this scenario is its self-weight, considered with a load reliability factor γ_f=1,1 and a dynamic coefficient of 1,4. The load from the insulation is distributed evenly across the external and internal layers of the wall panel, with a load reliability factor for the insulation of γ_f=1,2.

Second Design Scenario: "Transportation of the Panel". The transportation of the panel is performed using panel trucks. The panel is placed on rubber supports with the internal layer inclined at an angle of 3–5° to the vertical. In this scenario, the displacement constraints of the calculation model are located at the points of support under the panel and along the upper edge where the internal layer rests on the truck frame (**Figure 4**).

Third Design Scenario: "Lifting of the Panel". The lifting of the panel is conducted using a lifting traverse to ensure the self-balancing of forces in the slings. In this scenario, the displacement constraints of the calculation model are applied exclusively at the lifting loops of the panel (Figure 5).

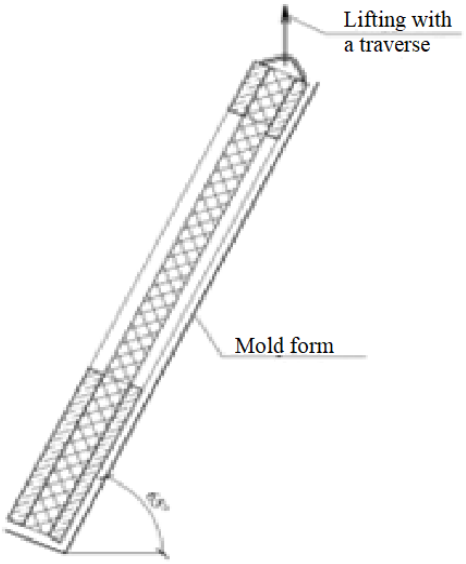

Figure 3 – First design scenario: Lifting the panel from the mold at angles of 15°, 45°, and 65° (authors' materials).

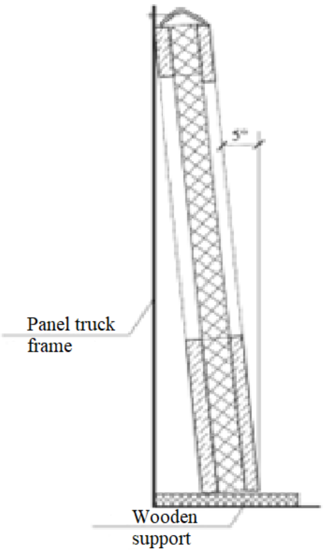

Figure 4 – Second design scenario: Transportation of the panel on a panel truck with an inclination of 3–5° to the vertical (authors' materials).

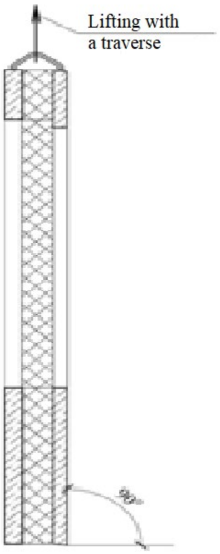

Figure 5 – Third design scenario: Lifting the panel using a lifting traverse (authors' materials).

Fourth Design Scenario: "Panel Installed in the Design Position". The panel is attached to the building's load-bearing structures using embedded parts located along the upper and lower edges of the internal layer, as specified in the construction detail album. In this design scenario, the displacement constraints of the calculation model are located at the points of the embedded parts (**Figure 6**).

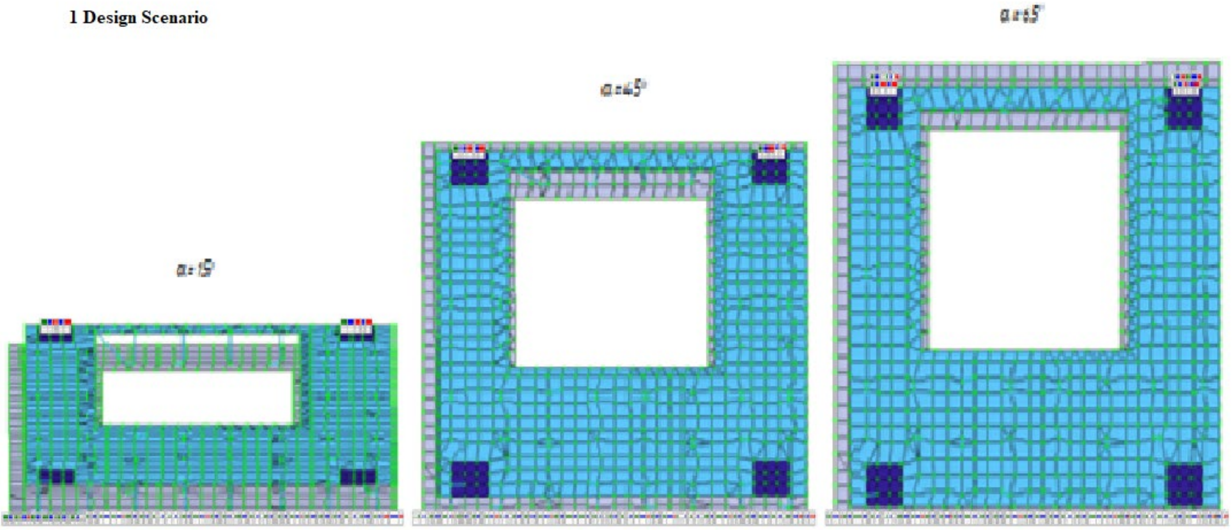

Figure 6 – Panel support fixations **(Nuguzhinov et al., 2023)**.

Fifth Design Scenario: "First Panel Installation Variant". According to the results of detailed instrumental inspections, it was determined that the wall panel has no upper gap between its internal layer and the floor slab. In this scenario, the upper edge of the internal layer of the wall panel is either entirely clamped by the floor slab or only one of its corners is clamped. To install the panel in its design position, non-design forces must be applied to the areas near the mounting loops located around the window opening on the internal side of the panel. The magnitude of these forces cannot be precisely measured, as they are applied outside the plane of the slab and vary widely (from manual force to the force generated by a winch). Additionally, each mounting loop experiences its own force. In this calculation scenario, it is assumed that the wall panel is supported along the lower edge and the right corner is wedged, requiring non-design forces to be applied to the mounting loops to position the panel in its design location. For the calculation, it was simplified that the force applied to each mounting loop is the same, approximately 250 kg.

Sixth Design Scenario: "Second Panel Installation Variant". According to the results of detailed instrumental inspections, it was observed that during installation, wall panels are temporarily supported by the outer surface of the lower panel.

The verification calculations indicated that in scenarios 2, 3, 4, and 6, the reinforcement of the wall panel is sufficient. However, in scenarios 1 and 5, when concrete strength is low and non-design forces are applied to the mounting loops, cracks may form in certain areas of the wall panel. It is worth noting that cracks were observed during the transportation phase of the panel according to the field investigations, although the calculations did not predict this. This suggests that additional dynamic loads, difficult to account for in calculations, may occur during transportation (road unevenness, improper panel fixation, speed of the panel truck, and other factors).

5 CONCLUSIONS

Based on the analysis of the causes of cracks in three-layer panels with flexible polymer connections observed after delivery to the construction site, the following conclusions and recommendations were made:

1. The absence of a technological control system for the installation of flexible connections significantly contributes to the formation of defects in the panels.
2. Violations of transportation conditions, particularly failure to adhere to standard requirements, result in additional dynamic loads that lead to cracking.
3. Insufficient attention is paid to areas of high stress concentration, such as the corners of window openings, during the design and reinforcement processes.
4. Improvement of technical regulations for the use of composite polymer reinforcement is required, including the implementation of a strict quality control system during the manufacturing process.
5. Designers should focus on optimizing the reinforcement structure in the areas surrounding window openings to minimize stress concentration.
6. Transportation of panels must be carried out in strictly horizontal positions in accordance with standard requirements to avoid unnecessary stress and deformation.
7. Advancements in computational platforms, utilizing modern application software and high-performance computing tools, are necessary to accurately model and evaluate the performance of complex and heterogeneous construction objects.

These measures aim to mitigate technical issues such as cracks on the surface of three-layer panels with flexible polymer connections and to ensure improved construction quality in the future.

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