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Load-carrying capacity of a composite architectural cornice with built-in water drainage

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Abstract:

The object of research is a load-bearing capacity of an architectural cornice made of glass-fiber-reinforced composite (GFRC) with an integrated drainage gutter, supported by steel cantilevers. The paper presents the results of an experimental investigation into the structural performance of the composite cornice under static loading. **Method.** The testing methodology was based on axial compression of the multilayer composite material. Due to the large dimensions of the full-scale specimen and test rig, the experiment was conducted indoors but outside of a laboratory setting to better simulate real-world structural interaction conditions. During the test, both load and mid-span deflection were monitored. No failure or significant deformation of the cornice or its fixings was observed. **Results.** Deflection values under the design service load were determined, and a load–deflection curve was obtained. The experimental findings confirm the feasibility of employing this composite cornice system in construction practice. In addition, potential directions for further research into GFRC architectural cornices with integrated drainage channels were identified.

1 Introduction

Composite materials are among the most promising materials in construction due to their low weight, low thermal conductivity, high strength, and excellent corrosion resistance. Glass-fiber-reinforced plastics (GFRP) have gained popularity owing to their favorable mechanical properties and cost-effectiveness, making them suitable for use in both load bearing and enclosure structures of buildings and civil engineering works. Of special interest are façade system components such as cornices with integrated drainage gutters, which provide protection against precipitation, enhance the aesthetic appearance of the façade, offer a wide range of color options, and exhibit high strength, durability, and corrosion resistance.

Despite these obvious advantages, composite materials require thorough investigation of their mechanical behavior, particularly regarding load-bearing capacity and deformation performance. This is especially relevant in the design of structural elements subjected to long-term service loads.

In study [1], a three-point bending test was performed on a single-wave segment of a fiberglass laminate. Numerical modeling and bending simulation of the composite segment were carried out, followed by experimental verification of the results. It was also noted that the Element_75 (Bilinear Thick Shell) provides results that are closest to the experimental data, both qualitatively and quantitatively.

In study [2], the maximum transverse deflections of multilayer sandwich panels (both flat and curved) with cut-outs under uniformly distributed loading were investigated using a mathematical model.

The model was developed based on higher-order shear deformation theory in combination with the finite element method.

In work [3], the authors investigated the effect of repeated tension–compression cycles on the strength of glass-polyester laminates. The results indicated an exponential decrease in material strength under repeated loading. A mathematical model was developed to predict the durability of glass-polyester structural elements under service conditions.

Study [4] focuses on the flexural characteristics of composite leaf springs manufactured by pultrusion and modified with aluminum oxide and silicon carbide fillers. The authors found that the fillers improve mechanical properties up to a certain threshold, beyond which strength begins to decline.

In article [5], bending tests were conducted on glass-fiber-reinforced plastic (GFRP) grating structures intended for pedestrian walkways. Failure zones were analyzed using scanning electron microscopy, which revealed the dominant damage mechanisms. The most significant damage occurred in the interlaminar shear zone.

Study [6] analyzes the influence of glass fiber content (up to 60%) and fiber length (60 mm) on the mechanical performance of composites under bending. The maximum modulus of elasticity reached 4 GPa, and tensile strength was 3.4 MPa. According to the authors, panel thickness plays a key role in enhancing structural strength and resistance to failure.

The authors of study [7] investigated the impact behavior of glass-polyester composites when subjected to 9 mm caliber bullets at velocities of 210–365 m/s. The optimized fiber composition reduced penetration depth. It was found that hybrid composites absorb impact energy more effectively than pure GFRP.

Study [8] presents the results of comparative tests on glass-polyester composites manufactured using different layer sequences and fabrication methods. Particular attention was paid to flexural strength and interlaminar shear. The type of filler was shown to significantly affect both interlaminar shear strength and bending resistance.

In work [9], the behavior of glass-polyester composites under repeated impact loads was investigated. A specially designed pneumatic test rig was used, allowing for accurate recording of impact count and specimen deflection.

Study [10] explores the influence of material structure, reinforcement type, and polyester resin type on the interlaminar strength of glass-polyester composites. The results showed a strong dependence of delamination resistance on the variation in laminate composition.

In article [11], the mechanical properties of composites with different fiber lay-up configurations were analyzed. Infrared spectroscopy was used to examine the bonding between glass fibers and the polyester matrix. An uneven distribution of resin among the fibers was identified, leading to weakened interfacial adhesion.

Study [12] focuses on the degradation of glass-polyester composites under cyclic changes in temperature and humidity. The findings showed a 19–27% reduction in interlaminar shear strength depending on the number of cycles applied.

In work [13], strength properties of glass-polyester composites with various fiber-to-resin ratios were investigated using a universal testing machine in accordance with ASTM standards. The results indicated that optimal mechanical performance is achieved with increased glass fiber content; however, excessive fiber loading leads to reduced ductility

Study [14] examines the behavior of multilayer glass-polyester panels under low-velocity impacts. Experiments were conducted using the Instron 9250HV test system, and numerical simulations were carried out in ANSYS LS-DYNA. A comparison of ultrasonic diagnostics and simulation results revealed discrepancies in predicting damage zones.

Study [15] focuses on the behavior of glass-polyester box beams under loading. Four-point bending tests were conducted to identify structural weaknesses and provide recommendations for improving load-bearing capacity. The authors noted that composite beams exhibit nonlinear behavior under high loads, particularly in connection zones.

The performance of laminated composites containing cut-outs largely depends upon the fiber arrangement, number of layers, shape and corner radius of hole and type of loading. The study [16] investigates the effect of these parameters on the stress concentration around polygonal shaped cut-out in symmetric laminated plate subjected to bending loading.

Study [17] investigates the adhesive bonding of glass-polyester beams to other materials, such as steel. The conducted tests demonstrated that the use of polymer adhesives significantly increases shear strength and structural durability. A design methodology for such hybrid beams is also proposed.

In work [18], the structural properties of matrix composites based on a polyester matrix reinforced with glass fibers were investigated. The glass fiber content ranged from 9 to 33% by weight. To evaluate structural performance, a series of Charpy impact, tensile, flexural, and hardness tests were conducted. Microstructural analysis was performed using optical microscopy and scanning electron microscopy (SEM).

Article [19] presents the results of mechanical testing of a full-scale composite podium frame element filled with foam glass, designed for use in a transparent atrium roof structure. The test setup included specialized equipment to study the interaction between the supporting steel framework, the composite cladding element, and its connections. During the tests, load, structural behavior, and specimen deflection were recorded.

In article [20], a review is presented highlighting the main challenges associated with the use of polymer composite (glass-fiber-reinforced plastic) materials and structures in the design and construction of buildings and facilities. The scope of application of polymer composite materials and structures was defined in accordance with fire safety regulations outlined in national building codes.

The authors [21] analyze facade systems made of GFRC, focusing on energy efficiency, production technologies, and aesthetic adaptability. Special attention is given to the potential of 3D printing and the use of environmentally sustainable fibers.

Study [22] presents an experimental investigation of the flexural strength of hybrid laminated beams reinforced with glass fibers under a three-point bending scheme. The stress–strain behavior, failure modes, and the influence of layer configuration on ultimate performance are analyzed. It was found that the reinforcement type and fiber orientation significantly affect flexural resistance. The findings align with numerical simulations.

Paper [23] describes an experimental study on the mechanical properties of composite structures produced via 3D printing. Specimens with various fiber configurations and fillers were tested. The orientation and print density were shown to critically influence strength and stiffness. Recommendations are provided for optimizing print parameters to improve structural reliability.

Study [24] investigates hybrid composite beams with ultra-high-performance (UHP) concrete permanent formwork and sea sand concrete cores. Experimental and analytical bending tests demonstrate enhanced stiffness and strength under optimized configurations. Predictive models for core–shell interaction is proposed.

Article [25] presents flexural testing of GFRP beams filled with a gypsum-based core. It was found that infill enhances load-bearing capacity while reducing deflections and alters the failure mode due to stronger interlayer interaction.

In study [26], a new anchorage method for GFRP sheets used in the flexural strengthening of concrete beams is proposed. Experimental results show a significant reduction in deflection and improved resistance to brittle failure under sustained loading.

Article [27] introduces a non-destructive monitoring technique for GFRP-strengthened concrete beams using acoustic emission (AE) and digital image correlation (DIC). The method enables real-time detection of cracks and localized deformations.

Study [28] analyzes the effect of fiber orientation and reinforcement ratio in hybrid FRP systems on flexural performance. Results confirm that fiber alignment and volume fraction significantly affect the strengthening efficiency of composite systems.

Review article [29] focuses on the mechanical properties, environmental durability, and applications of GFRC in architectural and structural components. The potential of GFRC in facade systems and harsh environments is highlighted.

Work [30] outlines the production and application of custom GFRC cornices. Key topics include design flexibility, durability, color customization, and ease of installation. Comparisons with metal and concrete alternatives are discussed in terms of aesthetics and technical performance.

Study [31] analyzes the stress–strain behavior of a triangular membrane panel subjected to uniform, concentrated, and linear transverse loads. Through comparative numerical simulations, the authors demonstrated how the type and configuration of loading affect the distribution of stresses and deflections. The findings are particularly relevant for the design and analysis of thin-walled composite structural elements, where load distribution plays a critical role in overall stiffness and stability.

Article [32] presents the results of experimental investigations on a model of a radial-beam dome with a membrane roof. The research analyzes the deformation characteristics of the dome shell under various loading schemes. It was established that the membrane component has a significant effect on the redistribution of internal forces within the beam system. The obtained data are used to refine computational models of spatial roof structures.

Paper [33] compares the results of numerical modeling and experimental testing of a radial-beam dome structure with triangular membrane core-shells. The analysis demonstrated a strong correlation between the calculated and experimental data regarding stress distribution and deflection behavior. The study emphasizes the importance of validating numerical models through physical testing to ensure the reliability of strength assessments in complex thin-walled systems.

The article [34] focuses on the experimental investigation of the stress–strain state of radial-beam domes subjected to different loading configurations. The authors identified characteristic stress concentration zones in the beam and shell elements and refined the parameters of the computational models based on the obtained results. The findings contribute to improving the accuracy of structural analysis and the reliability of dome systems under complex loading conditions.

Study [35] explores the numerical analysis of piled-raft foundations on multilayer soil, accounting for settlement and swelling effects. The simulations were performed using the PLAXIS 2D finite element software to evaluate the interaction between the foundation and the surrounding soil. The results demonstrate that incorporating nonlinear soil behavior and moisture variation significantly influences the redistribution of loads between the raft and the piles, improving the accuracy of structural performance predictions.

Paper [36] investigates the stress–strain behavior and crack formation in three-layer bendable reinforced concrete elements subjected to combined longitudinal and transverse forces. Using numerical modeling and experimental testing, the authors identified the regularities of crack development and stress distribution across the outer and inner layers. The study provides insights into the influence of longitudinal force on crack resistance and overall structural performance of multilayer concrete elements.

Study [37] examines the mechanical characteristics of polymer composites based on epoxy resins filled with silicon carbide. Experimental testing showed that the inclusion of silicon carbide particles increases the compressive strength and hardness of the material while maintaining its workability. The results highlight the potential of such composites for use in structural applications exposed to abrasive and mechanical loads, demonstrating improved durability and surface resistance.

In work [38] showed that fiber reinforcement effectively improves the performance properties of the composite.

The article [39] examines the thermophysical properties of variable-temperature composite concrete. It demonstrates the importance of structural heterogeneity (anisotropy, gradient) for the material's thermophysical and strength characteristics, which significantly impacts the behavior of the structure under load.

Study [40] proposes a universal method for calculating the strength of massive structural elements using parametric equations of the strength surface to predict the performance of composite materials under operating conditions.

Paper [41] develops a kinematic approach to assessing the strength of massive structures, considering complex stress states. It is shown that the choice of calculation method (parametric or kinematic) critically impacts the prediction of the structure's load-bearing capacity.

The article [42] presents an overview of the properties of various types of fibers (steel, polymer, basalt, etc.) and their influence on the behavior of composite concrete structures.

Work [43] examines the strengthening of concrete structures with carbon fiber-based composite materials. It demonstrates that carbon fiber additives can improve the strength and crack resistance of structures.

Study [44] demonstrated the synergistic effect of combining different types of fibers in fine-grained concrete to improve the strength and deformation properties of the material.

The article [45] systematizes data on the impact of fiber reinforcement on the strength, stiffness, and durability of composite concrete. Improvements in the performance characteristics of structures are demonstrated.

In summary, the reviewed studies demonstrate that glass fiber reinforced composites exhibit high mechanical performance and are suitable for use in structural applications. However, the considerable diversity of composite configurations—including hybrid systems designed to improve functional performance—highlights the need for further development of both numerical modeling techniques and experimental validation. These tools are essential for accurately predicting structural behavior under real-world service conditions. In this context, the present study offers a valuable contribution to the scientific understanding of the flexural performance of GFRP cornice elements

The object of this study is the load-bearing capacity of an architectural cornice made of glass-fiber-reinforced composite with an integrated drainage gutter, supported by steel cantilevers.

Figure 1 shows the technical drawing of the test specimen.

Fig. 1 – Technical drawing of the test element
The image provided by the authors

The cornice under consideration was designed for the year-round mountain resort “Lagonaki,” located in the “Upper Village” area (Maykop, Russian Federation). This region has a poorly studied meteorological profile, characterized by significant snow accumulation and frequent changes in wind direction and intensity. In 2024, the Federal Research Center Institute of Geography of the Russian Academy of Sciences (Moscow, Russian Federation) conducted a study to assess the meteorological conditions of the construction site. Based on the findings, the design load acting on the cornice element was determined to be 600 kg/m².

The objective of the present study is to determine the full-scale deflections of the cornice under a design load applied in conditions approximating actual service conditions. The study presents the results of an experiment conducted using a test methodology developed specifically for this structural element. To achieve this objective, the following tasks were formulated:

1. Analyze current literature on the investigation of glass-fiber-reinforced composite materials and structural elements made from them.
2. Prepare and conduct static testing of the cornice under a load corresponding to the design service load (600 kg/m²).
3. Record and analyze the relationship between the applied load and the resulting deflection of the structure.
4. Evaluate the strength and deformation behavior of the structure under conditions approximating real service conditions.
5. Formulate conclusions regarding the practical applicability of this type of cornice in construction and identify potential directions for further research.

2 Materials and Methods

The sample under investigation is a composite cornice with an integrated drainage gutter, manufactured from a multilayer glass-fiber-reinforced composite (GFRC). The composite material has a thickness of 5 mm. The matrix consists of a fire-resistant polyester resin filled with non-woven mats containing randomly oriented E-glass fibers. The GFRC was produced using a manual lay-up technique, including hand placement, spraying, and resin impregnation of the reinforcement.

The cornice comprises two segments joined together using an adhesive bond layer and rivets spaced at 200 mm intervals. The cornice is supported by steel cantilevers bolted to the primary load-

bearing roof structure. The test setup includes auxiliary equipment consisting of steel I-beams to simulate the actual structural supports of a building roof, as well as support frames to anchor the composite cornice during loading. These supporting frames are composed of welded rectangular hollow-section steel profiles, providing the necessary stiffness and stability under load.
The experimental evaluation focused on the following aspects:

- Load-bearing capacity (maximum applied load);
- Deflection of the structure at key fastening points.
- Onset of failure or damage to structural elements.

Due to the large size of the specimen and the required auxiliary fixtures, the experiment was conducted outside the laboratory environment. A dedicated test rig was developed and assembled specifically for this investigation. The test rig is a rigid support frame replicating the real installation conditions of the cornice mounted on a building façade.

A photo of the test setup is shown in Figure 2, and a corresponding technical drawing is presented in Figure 3.

Fig. 2 – Photo of the test stand (prepared by the authors)

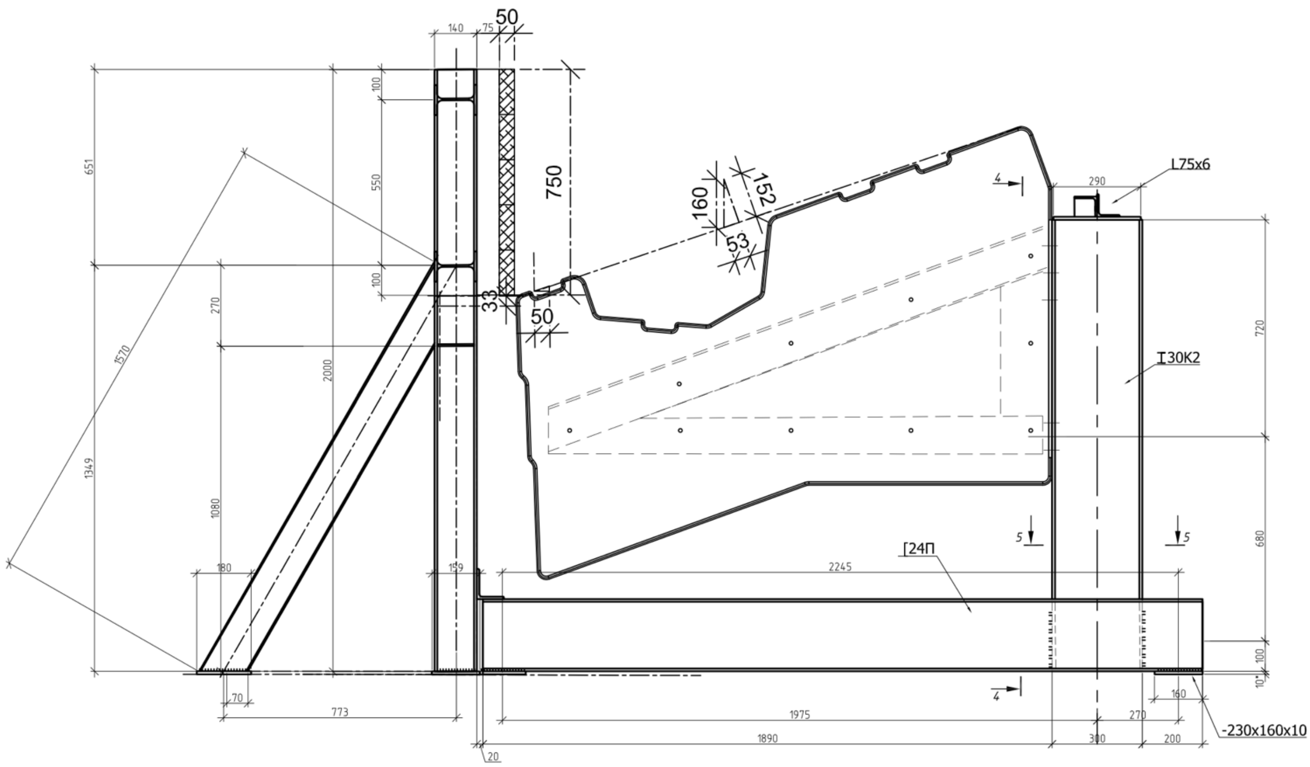

Fig. 3 - Drawing of the test stand (prepared by the authors)

The testing procedure was based on a custom-designed methodology employing the principle of static compression applied to multilayer composite materials.

The following equipment and tools were used in the experiment:

1. Aistov–Ovchinnikov dial gauges, model 6-PAO (manufactured by JSC “Izmeron,” Russia): devices for measuring linear displacements with an accuracy of up to 0.01 mm within a working range of 0 to 50 mm. The gauges feature a rigid, impact-resistant housing and a digital readout system that allows real-time monitoring of deflection changes.
2. Dead weights, including sandbags (50 kg each), reinforced concrete beams, and slabs.
3. Custom-built test rig with rigid fixation points.

Loading procedure of the tested structure included the following steps:

1. Mounting the cornice onto the test rig and securing it at designated fastening points.
2. Calibration of measurement devices and verification of sensor positioning.
3. Initial zero measurement — recording the baseline parameters of the structure prior to loading.
4. Incremental loading in 1000 kg steps.
5. Sustained load holding at each stage for a predetermined period (ranging from 8 to 19 minutes depending on the load level).
6. Recording deflection values at three control points at each loading step.
7. Gradual increase of load up to the maximum of 16,200 kg, followed by observation of critical structural responses.
8. Final measurement of residual deflections and deformations after unloading to assess permanent structural changes.
9. Analysis and processing of collected data, graph construction, and interpretation of results.

Deflection sensors were installed at three points on the structure to capture both vertical and horizontal displacements. Their placement is illustrated in Figure 4:

- Sensor 1 — outer left section
- Sensor 2 — mid-span section
- Sensor 3 — outer right section

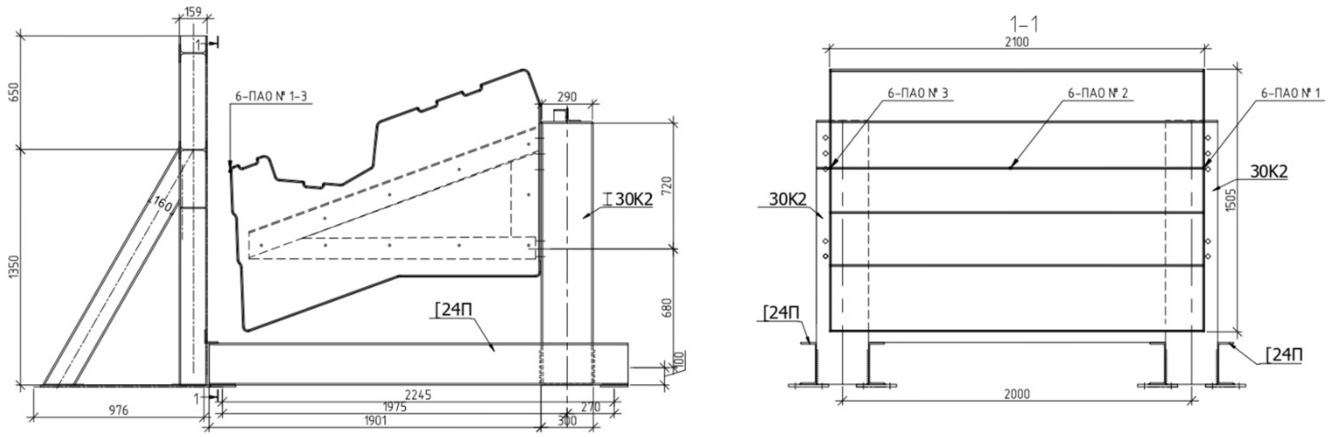

Fig. 4 - Layout of deflection measurement points (prepared by the authors)

3 Results and Discussion

During the experiment, applied loads and corresponding deflections were recorded at each loading step. The results are presented in Table 1,2.

Table 1. Measured Deflections at Different Load Stages (prepared by the authors)

Loading Stage	**Applied Load (kg)**	**Deflection at Sensor 1 (mm)**	**Deflection at Sensor 2 (mm)**	**Deflection at Sensor 3 (mm)**	**Hold Time (min)**
0	0	0.00	0.00	0.00	-
1	1000	2.39	2.01	2.16	12
2	2000	3.64	3.47	3.43	14
3	3000	3.26	5.00	4.50	18
4	3600	3.84	5.54	5.03	10
5	4600	4.36	6.06	5.51	10
6	5800	4.66	8.35	5.45	8
7	8000	6.36	10.21	7.23	10
8	10200	8.10	11.96	9.27	19
9	11700	9.91	13.74	11.03	18
10	12700	11.10	14.79	12.00	9
11	13700	12.39	15.92	12.94	19
12	14700	13.35	16.81	13.89	9
13	15700	14.52	17.65	14.94	7
14	16200	15.16	18.16	15.54	6

Table 2. Maximum Load and Deflection (prepared by the authors)

Specimen ID	Maximum Applied Load (kg)	Measured Deflection (mm)
1	16200	15.6 – 18.16

The resulting load–deflection curve is presented in Figure 5

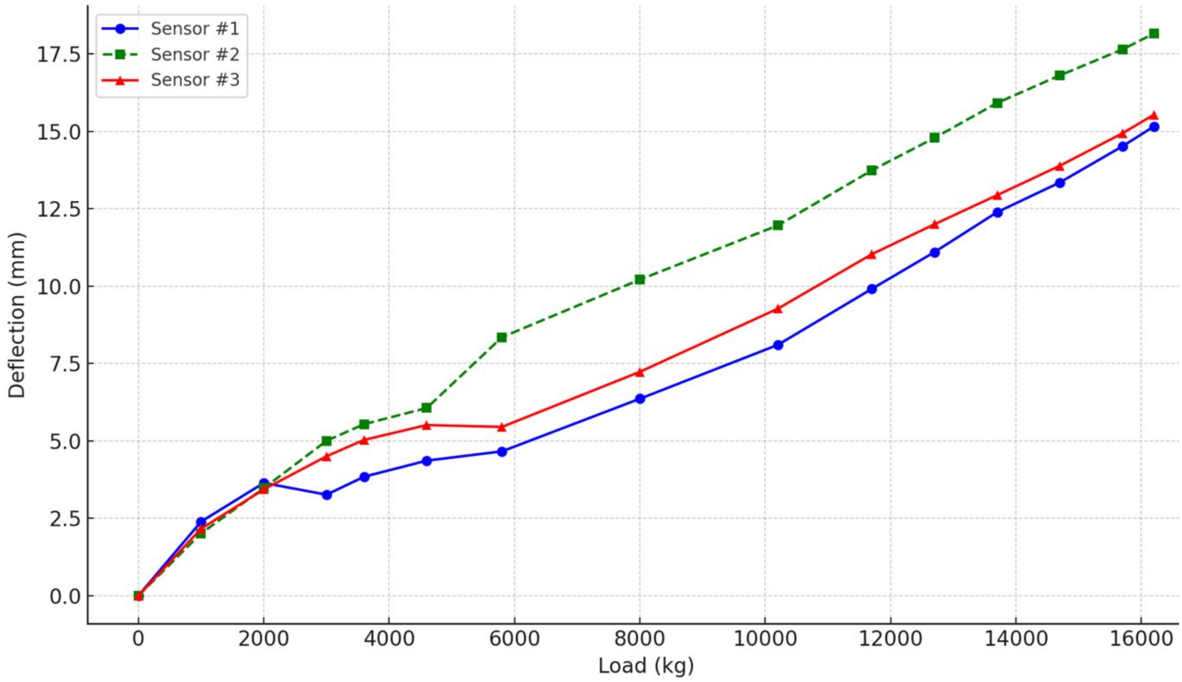

Fig. 5 - Load–Deflection Curve (prepared by the authors)

The analysis of the load–deflection curves for all three sensors reveals a nonlinear deformation pattern as the applied load increases. At early loading stages (up to approximately 3000–4000 kg), the deflections exhibited a near-linear trend, indicating elastic behavior of the composite material.

Starting from 4600–5800 kg, an increasing divergence between the sensors becomes evident, particularly at the mid-span (Sensor #2), suggesting the onset of localized stress concentration and intensified deformation in the central span of the cornice. This trend continues with pronounced acceleration of deflection growth from 8000 kg onwards, clearly indicating a transition from the elastic to the quasi-plastic phase.

At the maximum applied load of 16,200 kg, the deflection values were as follows:

- Sensor 1 (left edge): 15.16 mm
- Sensor 2 (mid-span): 18.16 mm
- Sensor 3 (right edge): 15.54 mm

The resulting distribution demonstrates a symmetric yet localized deformation response typical for cantilever-supported beam elements under increasing static load. The dominant deflection at mid-span corresponds well to the expected behavior of the cornice under service conditions, thus validating the reliability of the adopted testing methodology and supporting the structural integrity of the element.

Several studies demonstrate the importance of an integrated approach to investigating the stress–strain state of building structures to enhance their durability and reliability. According to the authors, such an integrated approach should combine numerical analysis, full-scale testing, and laboratory investigations, which enables the most comprehensive prediction of the structural behavior under service conditions.

Acknowledging the importance of an integrated approach, the authors intend to perform a comparative analysis of the experimental results and numerical simulations.

Research analysis shows the need for an integrated approach to the design and strength assessment of structural composite materials. It has been shown that the use of fibers and the variation of their properties significantly enhance the strength and durability of materials, including both concrete and polymer composites. Experimental and theoretical investigations highlight the importance of considering climatic and service conditions, as well as the need to further develop numerical modeling methods to predict structural behavior. These findings are consistent with the results of the present study, emphasizing the practical significance of combining experimental and numerical research for analyzing deflection and load-bearing capacity of GFRP cornices to predict the behavior of composite structures more accurately under service conditions.

4 Conclusions

The test results confirmed that the architectural cornice made of glass-fiber-reinforced composite (GFRC) with an integrated drainage gutter can withstand a load of up to 16,200 kg. The measured deflections under maximum loading ranged from 15.16 to 18.16 mm, which falls within the acceptable limits for serviceability.

All research objectives were successfully accomplished:

1. A review of recent publications on composite materials and structural applications was conducted.
2. A methodology for static testing of a full-scale cornice under a design load of 600 kg/m² was developed and implemented under conditions closely simulating actual service.
3. Load–deflection relationships were recorded and analyzed at key sections of the structure.
4. The strength and deformation behavior of the structure was evaluated, demonstrating reliable performance under the applied loads.
5. Recommendations for future research directions were formulated.

The experimental data confirm the feasibility of using this structural solution in real construction practice. Future research will focus on long-term and environmental effects, as well as on optimizing the cornice design to improve manufacturability and reduce self-weight.

5 Acknowledgements

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6 Conflict of Interests

The authors declare no conflict of interest.

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