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# ALTERNATIVE LIGHTWEIGHT COMPOSITE FACING MEMBERS FOR REINFORCED SOILS

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**Abstract:** Steel reinforced concrete facing members, which are used to fix geosynthetic reinforcements working against tensile forces inside soils and to resist active lateral earth pressures, have certain disadvantages, such as massiveness and corrosion. In addition, the aforementioned conventional panels are not economical since they frequently require maintenance and repair in terms of long-term stability. In this study, the utility of alternative composite panels is evaluated with the various arrangement and type of fiber reinforcements and a typical foam concrete. Panel tests and three-point bending tests are realized to determine the experimental behavior of steel, carbon fiber (CFRP) and glass fiber reinforced (GFRP) specimens, as well as unreinforced examples. Although CFRP wrapped specimens cannot reach expected levels, samples with GFRP present favorable performance as well as being cheaper. Specimens with mat GFRP enhance both strength and deformation capacities according to the results of axial and lateral deformations under diagonal loading condition. In addition, chopped GFRP applied foam concrete specimens have more strength in terms of bending test results, but CFRP reinforcements increase their displacement capacity.

**Keywords:** Bending Test, Panel Test, Foam Concrete, Carbon Fiber, Glass Fiber

**Donatılı Zeminler için Alternatif Hafif Kompozit Panel Elemanları**

**Öz:** Zemindeki çekme kuvvetlerine karşı çalışan ve aktif yanal toprak basınçlarına karşı koyan geosentetik donatıları sabitlemek için kullanılan çelik donatılı beton panel elemanlarının ağırlık ve korozyon gibi bazı dezavantajları vardır. Buna ek olarak, bahsi geçen geleneksel paneller, sıklıkla bakım ve onarım gerektirdiklerinden uzun süreli stabilite açısından ekonomik değildirler. Bu çalışmada, çeşitli dizilim ve tipteki fiber donatılarla güçlendirilen özgün köpük beton ile alternatif kompozit panellerin kullanılabilirliği değerlendirilmiştir. Çelik, karbon fiber (CFRP) ve cam fiber donatılı (GFRP) numunelerin yanı sıra donatısız numunelerin deneysel davranışını belirlemek için panel testleri ve üç nokta eğilme testleri gerçekleştirilmiştir. CFRP sargılı numuneler beklenen seviyelere ulaşamasa da GFRP ile güçlendirilen numuneler daha ucuz olmasının yanı sıra olumlu performans göstermektedir. Keçe formundaki GFRP'li numuneler, diyagonal yükleme koşulları altında eksenel ve yanal deformasyonların sonuçlarına göre hem mukavemet hem de deformasyon kapasitelerini arttırmaktadır. Ayrıca kırpılmış GFRP uygulanmış köpük beton numuneler eğilme testi sonuçları açısından daha fazla mukavemete sahipken, CFRP donatılar deplasman kapasitelerini arttırmaktadır.

**Anahtar Kelimeler:** Eğilme Testi, Panel Testi, Köpük Beton, Karbon Fiber, Cam Fiber

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## 1. INTRODUCTION

Precast reinforced concrete panels have been used as facing elements in reinforced soils or mechanically stabilized earth walls within geotechnical projects, such as highways, railways, bridge piers, slope stability, subways and tunnels. However, a number of problems may be encountered during the transportation and installation of these massive reinforced concrete panels, which can weight up to 1.5 tons. On the other hand, conventional facing elements need maintenance, repair or replacement after damage in only a short time due to external factors, such as vehicle crashes, overload conditions or freeze-thaw cycles in the case of groundwater effect. The main factor that creates this weakness is the typical behavior of reinforced concrete. To solve this problem, several material, geometry and detail including facing members have been used in retaining structures within the scope of carrying lateral earth pressures safely, as well as being resistant to external conditions. In addition, certain requirements must be satisfied, such as type, shape, aesthetic appearance and performance level of facing, as well as connections according to TS-EN 14475 (2006). Therefore, new composite panel proposals can be found in the literature to enhance the properties against impact loads, abrasion and corrosion and, at the same time, requiring minimum maintenance. The tensile strength of reinforced concrete plate elements is more important than compressive strength under impact loading according to Morales-Alonso et al. (2011). Therefore, composite precast concrete members have been produced as a result of fiber reinforcement within pipe lines, sewer lines, beams and facing elements (Banthia et al., 2012) While the effect of glass fiber reinforcement on the shear strength of pre-stressed precast concrete sandwich panels is examined by Soriano (2012), fatigue performance under bending effect on reinforced concrete elements is performed by Lv et al. (2012). Henriksen et al. (2015) emphasize the effectiveness of the pulverization technique producing a fiber containing thin walled concrete members. Yıldız and Arslan (2018) explain the usage areas and advantages of concrete-based precast panels in terms of weight. Kızılkanat et al. (2015) compare the difference between glass fiber and basalt fiber in high strength concrete, with respect to three-point bending test results. Furthermore, glass and nylon originated fiber increase the tensile strength and the bending strength of plate-like concrete members, as well as reducing the formation of early age micro cracks after casting according to Khan and Ali (2016). In addition, glass fiber reinforcement is used to increase the fatigue performance, shear capacity, flexural stiffness and elasticity modulus of concrete bridge decks and sandwich wall panels in a similar manner (Xin et al., 2015; Kim and You, 2015; Yang et al., 2017). Moreover, panel tests and bending tests are the most common experimental procedures to evaluate the in-plane shear strength and flexural resistance of composite panels, precast reinforced concrete plates or masonry walls (Benayoune et al., 2007; Mohamad et al., 2011; Ahmad and Singh, 2021).

On the other hand, a drainage requirement of collected water just behind the retaining structure is a problem in itself. Otherwise, an increasing level of ground water at the active side creates a hydrostatic pressure in addition to lateral earth pressure, which force both the existing structure and the panels. If water infiltrates inside a tension crack, the panel elements of the retaining structures can be subjected to excessive displacement according to a study focusing on the drainage effect on the facing (Koerner and Koerner, 2011). Moreover, a squeezing problem of panels may be seen under a combined effect of rainfall and earthquake within an undrained case (Ren et al., 2020). Viswanadham et al. (2017) suggest a chimney drain application to minimize facing deformation, since it reduces the ground water table in the case of fine grained backfill usage.

Different approaches have been suggested in the literature to increase the efficiency of facing elements during application of modular precast panels, segmental facing or block panels, flexible or semi-rigid panels and hybrid panels. A reinforced segmental block facing members especially has become popular due to its low cost, ease of workability and aesthetic appearance (Lee et al., 2010). Panah et al. (2015) propose galvanized toggles and reinforcement loops for the connection between panel and modular facing members, while polymeric connectors are used between strips and precast panels. Ahmadi and Bezuijen (2018) compare the difference between a flexible facing and a rigid facing within mechanically stabilized earth walls in real scaled tests. Although the maximum lateral earth pressure is higher in a flexible facing, its collapse zone is located at a deeper level than a rigid model. Bui et al. (2020) propose a shotcrete as an effective method due to the results of experimental and numerical studies related to the behavior of anchored modular precast concrete in a special geometry. While it is stated that attention should be paid to appropriate material selection and sizing in scaled facing models, the importance of bending rigidity is also emphasized by Ren et al. (2020). Xu et al. (2020) present seismic performance of abutment facing members for a geosynthetic reinforced soil integrated bridge system. In addition, a number of researchers focus on the effective production of facing elements by examination of the various applications, such as shotcrete, sodding and vegetation, additional confinement with geosynthetic materials, and hybrid implementation (Nicholson, 2015; Lelli et al. 2015). Evirgen et al. (2022) reduce the weight of reinforced concrete panels around 13% by using polystyrene foam. The galvanized steel strips or the geosynthetic elements are fixed to the various shaped metal apparatus (omega, trapezoid, and ring etc.) have been welded to the steel reinforcement inside reinforced concrete panels in reinforced earth applications. Similarly, this type of apparatus can be fixed to the outer polymer coating after producing with carbon or glass-based polymers for the suggested alternative panels in addition to the special connection apparatus proposed by Sarı and Büyük (2023). The connection points should also be strengthened by carbon or glass fibers against the punching effect.

The production of alternative facing panels, which have sufficient strength and deformation capacities, is one aim of this study. Therefore, innovative foam concrete is used to reduce weight, while an attempt is made to increase strength capacity by external reinforcement elements, such as CFRP and GFRP components. The experimental results of the panel tests and three-point bending tests are presented. The aforementioned alternative panels, which offer different solutions in line with real project necessities, are lightweight and easy to install, as well as being maintenance-free in terms of long-term stability.

## 2. MATERIALS

### 2.1. Foam Concrete

Lightweight concrete is a special type of concrete with an average density almost 800 kg/m$^3$ that contains pozzolanic additives or light aggregate in addition to standard raw materials, such as cement, sand and water components. However, an innovative foam concrete with a density about 600 kg/m$^3$ is used to reduce the density of standard concrete fourfold. The concrete mix design includes 180-liter water, 300 kg pozzolanic cement with a 42.5 MPa compressive strength and 100 kg 0-3 mm sand for the production of 1 m3 of lightweight foam concrete. In addition, a herbal additive called ‘soapwort’ is mixed into the water component at a ratio of 0.04 per liter, since it forms a liquid state foam material to reduce weight (Figure 1). After pouring concrete into the metal molds, only a surface finish operation is applied because it does not need vibration. After twenty-eight days curing, the compressive strength and the modulus of elasticity values of the foam concrete specimens are reached at around 2.2 MPa and 1000 MPa, respectively. Although the mechanical parameters of foam concrete are lower than standard concrete, its weight is seriously light. In this way, light concrete production, with a density of approximately 630 kg/m$^3$, is achieved. Therefore, additional fiber reinforcements are used to provide the required level of strength and ductility.

### 2.2. Carbon Fiber Reinforced Polymers (CFRP)

Foam concrete panels without steel mesh reinforcement were wrapped by carbon fiber reinforced polymer (CFRP) strengthening elements in order to increase the capacity, as well as to prevent corrosion and to minimize impact effects. Therefore, the aim is to produce long-lasting composite panels that exhibit high strength and elastic behavior without the need for steel reinforcement and related workmanship. Local cracks encountered in a few concrete samples during the production phase were eliminated using epoxy-based repair mortar. First of all, a special resin called 'primer' with a bending capacity of 20 MPa was applied on the concrete surface in order to ensure smoothness and to increase an adherence level of carbon fiber. Next, the bonding of carbon fiber was achieved with another resin originated liquid called 'saturant', which has a minimum bending strength of 50 MPa and a minimum compressive strength of 60 MPa (Figure 2a). The mechanical properties of 0.111 mm thick unidirectional carbon fiber are given as follows: 230 GPa modulus of elasticity; 2.10% elongation ratio at failure; and 4.9 GPa characteristic tensile strength due to manufacturer.

### 2.3. Glass Fiber Reinforced Polymers (GFRP)

Some samples of unreinforced foam concrete panels were completely covered with mat formed GFRP in addition to the cropped form. After applying a single layer resin on the foam concrete surface, a glass fiber mat with a density of 0.44 kg/m$^2$ was placed on it and resin was applied on it again (Figure 2b). Moreover, another application method was also used, which included chopped glass fiber and resin mix with 100 gr fiber per kg of resin. Within this stage, approximately 2.3 kg/m$^2$ of mixture was poured on the surface as well as a 300 g/m$^2$ additional resin which was applied during final touch (Figure 2c). Each application had a similar amount of fiber and resin.

a. b.

c. d.

***Figure 1:***
*Foam concrete application stages; a. Soapwort additive, b. Mixing, c. Pouring and d. Leveling*

### 2.4. Bitumen

Although glass fiber reinforced polymers have high mechanical properties, they behave in a brittle and fragile form after setting. Therefore, 50/70 class bitumen melted at 160 °C was poured on the front side and lateral faces of the specimens in temporary molds (Figure 2d). It is thought that the use of a flexible damper on a panel surface may reduce impact effects, since precast composite panels are mostly preferred on roadside structures. In addition, one aim is to minimize the hit of adjacent panels between each other that are placed in modular form.

## 3. MATERIALS

### 3.1. Preparation of Specimens

In total, twenty-five specimens were prepared in order to determine the performance characteristics of alternative composite panels within panel tests and three-point bending tests (Table 1). Test specimens were produced inside steel molds having dimensions of 70 x 70 x 10 cm and 35 x 70 x 10 cm for panel and bending tests, respectively. Foam concrete with and without steel mesh were used as reference samples. While CFRP strips of 10 cm width were applied on panel specimens, both transverse and cross arrangement, bending specimens had 5 cm width CFRP strips of the same order. Moreover, resin impregnated GFRP covering was also applied with mat and chopped form.

a. b.

c. d.

***Figure 2:***
*Surface strengthening applications with external reinforcements; a. CFRP, b. Mat style GFRP, c. Chopped style GFRP and d. Bitumen covering*

### 3.2. Panel Tests

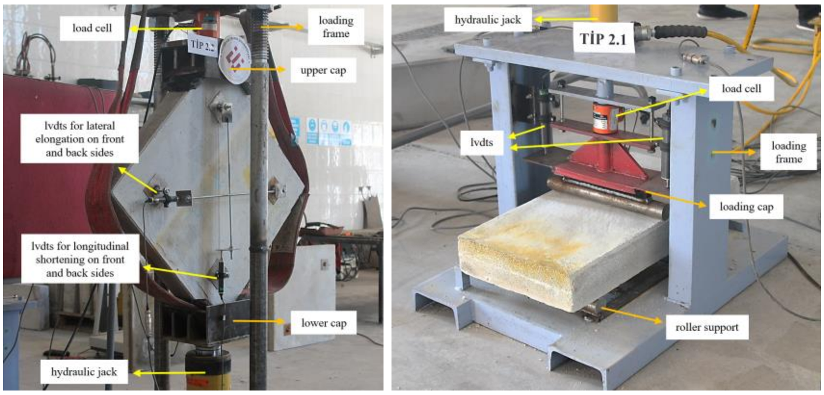
The panel tests were realized to obtain the load-displacement behavior of the composite facing elements according to ASTM E519/E519M (2021) since conjugate panel elements force the nest one if mechanically stabilized earth wall exposed to static or dynamic loading conditions. This test procedure and experimental setup has been used by researchers to attain the in-plane shear resistance during diagonal compression loading mechanism (Corradi et al., 2008; Roca and Araiza, 2010, Tunaboyu, 2017; Longo et al., 2021; Manos et al., 2021) The related loading frame consists of measuring instruments of 300 kN capacity load cell, 300 kN capacity hydraulic jack and 25 mm capacity linearly variable displacement transducers (LVDT) (Figure 3a). The panel specimens placed between the upper and lower caps were subjected to monotonic loading along the diagonal direction, while deformation values were recorded as a shortening in the vertical (loading direction), and elongation in the horizontal direction. Deformation measurements were collected from an average distance of 60 cm between bolts fixed on the epoxy-based mortar, both front and back sides simultaneously.

**Table 1. Type and number of specimens**

| Type of specimen | Details | Panel tests | Bending tests |
|---|---|---|---|
| Type - 2 | Foam concrete + steel mesh | 3 | 3 |
| Type - 4 | Foam concrete + transverse CFRP | 3 | 3 |
| Type - 5 | Foam concrete + cross CFRP | 3 | 3 |
| Type - 6 | Foam concrete + without reinforcement | 1 | 2 |
| Type - 7 | Foam concrete + mat GFRP + bitumen | 1 | 1 |
| Type - 8 | Foam concrete + chopped GFRP + bitumen | 1 | 1 |

### 3.3. Bending Tests

A vertical load was applied at the mid portion to the specimens placed on roller supports having a 50 cm net span between ends, and therefore, a 3-point bending test procedure was carried out (ASTM C293/C293M, 2016). During the experiment, load data was collected via the load cell with a capacity of 100 kN fixed to the hydraulic jack, while displacement data was recorded simultaneously by means of 2 LVDTs with a 50 mm capacity mounted on a loading frame (Figure 3b).




a. b.

***Figure 3:***
*Loading setup; a. Panel test setup and b. Bending test setup*

## 4. RESULTS

### 4.1. Panel Tests

After the panel experiments, the load-displacement graphs, including both axial shortening and lateral elongation, were drawn in Figure 4 and the average numerical results of the raw data are given in Table 2. An equivalent polynomial trend line of each sample was implemented in order to draw meaningful graphs, due to serious fluctuations in the raw curves of the foam concrete. The capacity of unreinforced foam concrete panel specimens was enhanced in all of the reinforced cases without single-sided CFRP reinforcement. Therefore, the transverse and cross shaped CFRP strengthening were applied on both sides for the remaining specimens, since a low ultimate capacity of around 20 kN was achieved in specimens reinforced on one side only (Type-4.1 and Type-5.1). Therefore, ultimate loads reached up to 30-35 kN in other specimens with ductile behavior. In addition, a significant level of enhancement was observed in GFRP with bitumen-coated specimens, both mat and chopped form in terms of load capacity and deformation behavior if compared with unreinforced reference specimens (Type-6) and CFRP specimens. While similar behavior was observed in CFRP applied specimens and steel mesh reinforced specimens, a significant increase in capacity, as well as ductile deformation, was obtained in both types of samples with GFRP application. Although an average lateral elongation of around 0.1 mm was obtained in CFRP reinforced specimens, approximately 50% more deformation was observed in samples with GFRP reinforcement (Figure 5). Finally, an average ultimate load value of 51.15 kN was reached in Type-7 specimens with mat GFRP and bitumen covering, which is the highest level at 1.25 kN/kg according to the unit load value per kg.

The crack patterns for all of the specimens can be seen clearly in Figure 6. However, cracks of Type-7 and Type-8 cannot be seen because of the bitumen. In addition, all of the cracks start from the top of the specimens near the loading caps. The crack path is directly affected by the strengthening procedure and reinforced forms. The formation of cracks is prevented by the reinforcement types for the first stages of loading, but at the progressive steps, hairline cracks are observed with the strength reduction. Mat GFRP with bitumen specimens show good performance for the panel tests. Similarly, the following type of collapse mechanisms are reported in-plane diagonal panel tests within previous studies; the loss of adherence between the composite reinforcement layers and concrete, deterioration of the outer coating, rotation, support sliding, multiple crack formations and crushing at the loading ends (Corradi et al., 2008; Roca and Araiza, 2010; Longo et al., 2021)

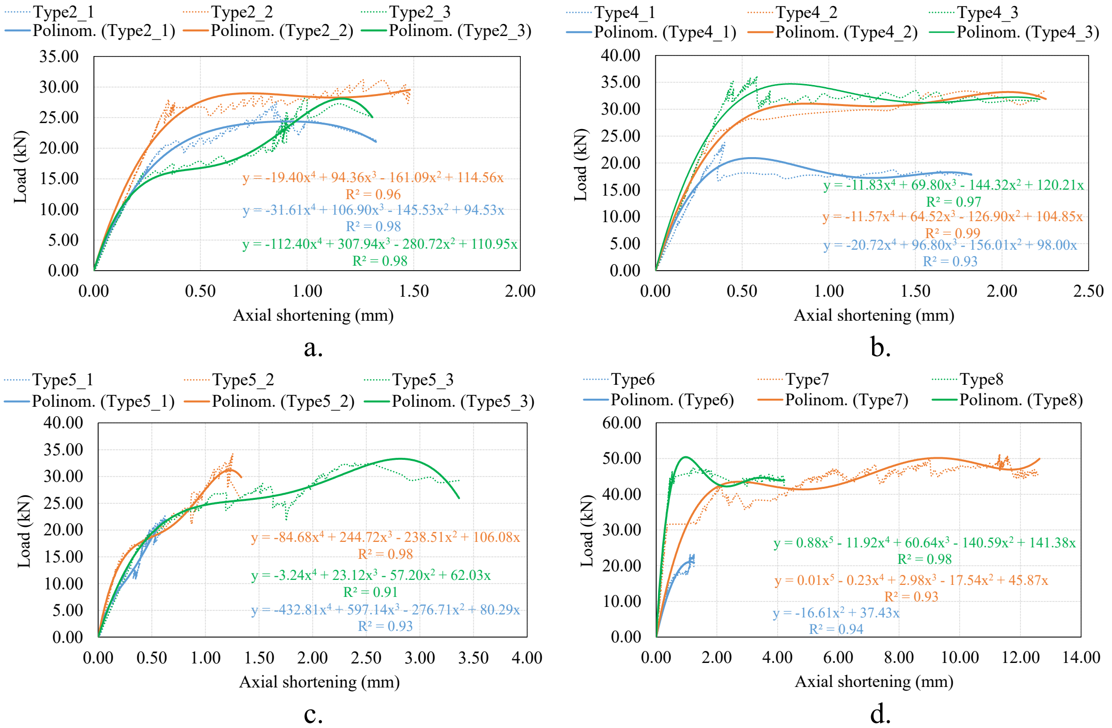



***Figure 4:***
*Load-axial deformation curves of the panel tests; a. Steel reinforced specimens, b. Transverse CFRP reinforced specimens, c. Cross CFRP reinforced specimens and d. Reference and GFRP reinforced specimens*

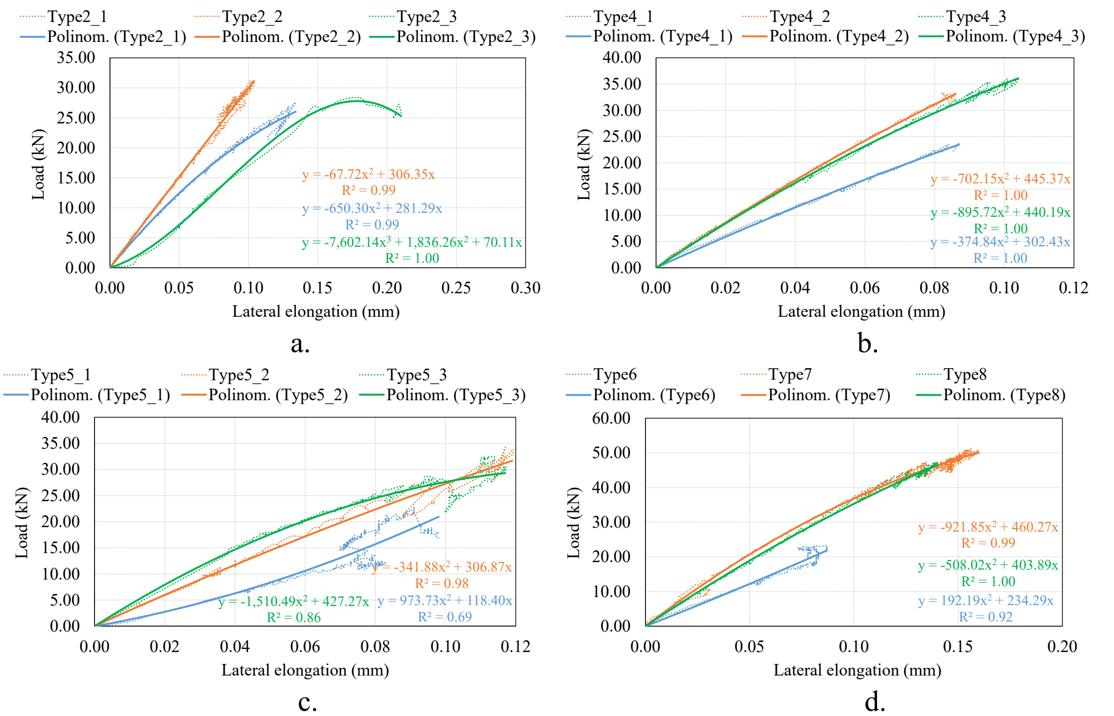
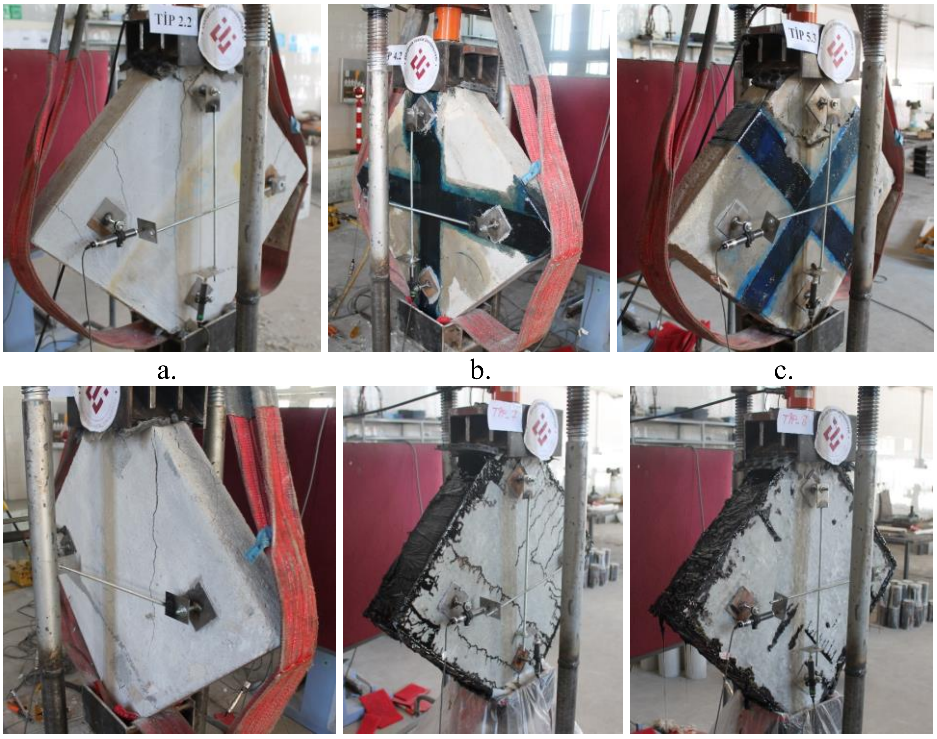



***Figure 5:***
*Load-lateral deformation curves of the panel tests; a. Steel reinforced specimens, b. Transverse CFRP reinforced specimens, c. Cross CFRP reinforced specimens and d. Reference and GFRP reinforced specimens*

**Table 2. Average ultimate values obtained in panel tests**

| Type | Weight (kg) | Ultimate load (kN) | Axial shortening (mm) | Lateral elongation (mm) |
|---|---|---|---|---|
| Type2 | 35.82 | 29.04 | 1.04 | 0.14 |
| Type4 | 33.50* | 23.78* | 0.40* | 0.09* |
| | 39.50 | 34.86 | 1.42 | 0.09 |
| Type5 | 33.64* | 22.88* | 0.62* | 0.09* |
| | 36.98 | 33.32 | 1.83 | 0.11 |
| Type6 | 26.54 | 23.28 | 1.25 | 0.08 |
| Type7 | 40.82 | 51.15 | 11.31 | 0.16 |
| Type8 | 45.00 | 47.45 | 1.22 | 0.14 |

*Single-sided specimens only



a. b. c.

d. e. f.

***Figure 6:***

*Featured failure modes of specimens after panel tests; a. Steel reinforced specimen, b. Transverse CFRP reinforced specimen, c. Cross CFRP reinforced specimen, d. Reference specimen, e. Mat GFRP reinforced specimen with bitumen and f. Chopped GFRP reinforced specimen with bitumen*

### 4.2. Bending Tests

The load-displacement graphs of the three-point bending tests are given in Figure 7. If no reinforcement or any strengthening member was used, the foam concrete specimens denoted by Type 6 collapsed at an extremely low load level of around 1 kN with a 3 mm displacement level. Although a limited performance increase was observed in single-sided strengthening, it gained serious flexible behavior with an average load increase of 3.9 and 2.1 times in the case of transverse and cross double-sided CFRP wrapping, respectively. However, these ranges were located below the performance of Type-2 specimens with a steel mesh reinforcement. Among the reinforced specimens, the best behavior was obtained for GFRP and bitumen coated Type-7 and Type-8 specimens, which had 9.6 kN and 15.2 kN bending loads.

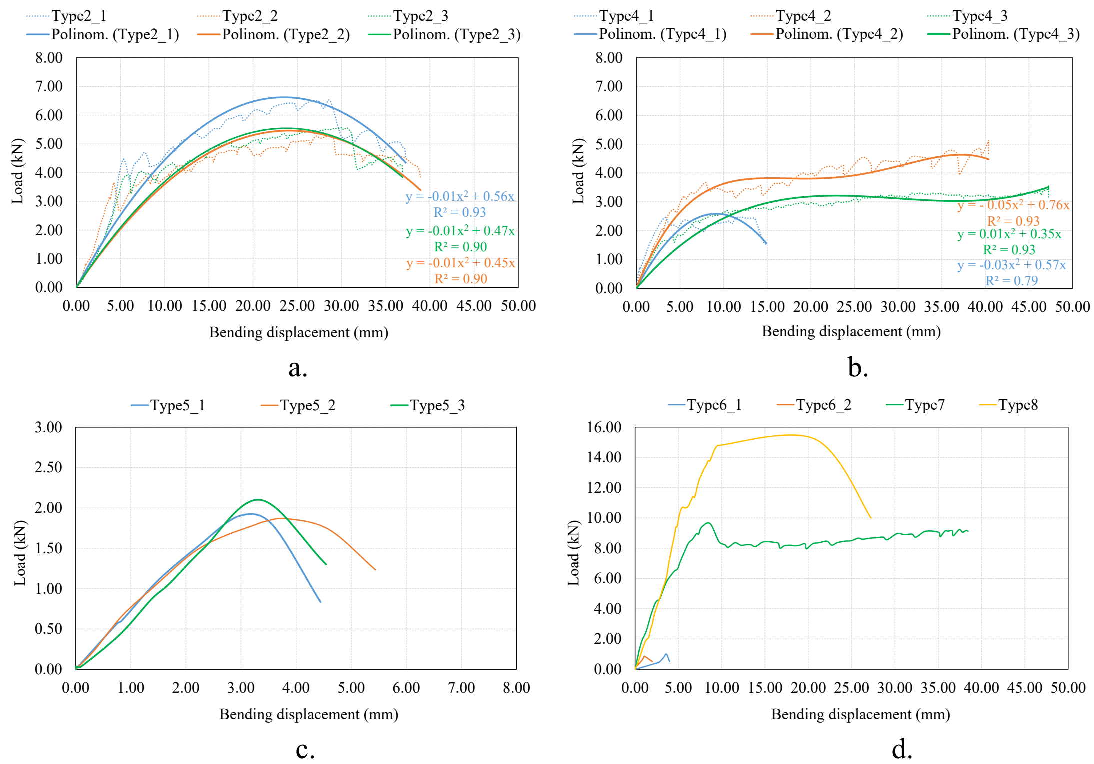


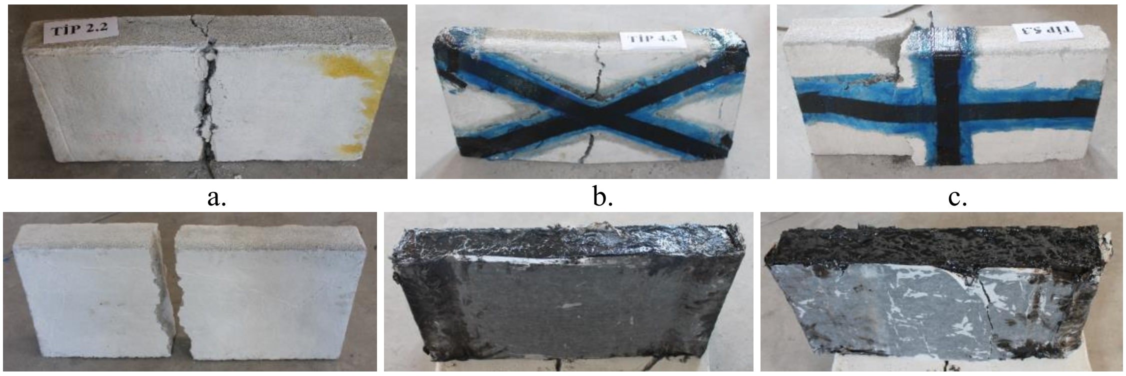

***Figure 7:***

*Load-axial deformation curves of the bending tests; a. Steel reinforced specimens, b. Transverse CFRP reinforced specimens, c. Cross CFRP reinforced specimens and d. Reference and GFRP reinforced specimens*

In addition, the average results of the raw data in bending tests and observed failure modes are given in Table 3 and Figure 8. Carbon fiber, which provides high capacity adherence between standard concrete surfaces, could not adapt to the foam concrete surface due to its porous structure, and unit load levels remained relatively low, at around 0.12 - 0.25 kN per kg. When mat and chopped type of glass fiber were bonded on foam concrete, the highest bending performance levels were reached at almost 0.49 kN and 0.75 kN per kg, respectively. It was noted that shearing or breaking type of collapses occurred as a result of the failure of the fiber, which is individually load carrying due to the low strength of the foam concrete after partial or serious ductile behavior in the entire reinforced cases. Although the chopped GFRP specimens with bitumen had a higher flexural strength, specimens with transverse CFRP had a higher displacement capacity, as can be seen in Figure 7. The displacement capacity of the specimens guides the ductility behavior. The crack patterns for all of the specimens can be clearly seen. However, cracks of Type 7 and Type 8 cannot be seen because of the bitumen. As can be seen in Figure 8e and Figure 8f, the GFRP reinforced specimens are the two specimens that remain in one piece.

Even though the conventional reinforced concrete panels have difficulties in terms of weight, corrosion and workmanship, the remarkable strength values reaching 288.01 kN and 32.77 kN are observed in panel and bending tests, respectively (Evirgen et al., 2022). However, the compressive strength of foam concrete around 2 MPa created fluctuations as seen in load-deformation curves. It is the most important problem in proposed alternative panels, while the foam concrete provides a serious lightweight operation with minimum workmanship and without corrosion problem. If the mixture design is improved and the compressive strength of foam concrete is increased with additives, the production of panels with higher performance can be achieved.

The simple cost analysis of specimens calculated according to the material consumption only is given in last column of Table 3. If these values are compared with the current price of conventional C30 reinforced concrete facing members, which is around 240 TL/m$^2$ due to manufacturer, the most economic foam concrete panel types are reinforced with mat and chopped forms of GFRP in terms of cost-performance benefit. Although CFRP reinforced ones had more rigid behaviour, the epoxy based special chemicals and the carbon fiber drastically increased their price. Even if Type 6 with only foam concrete had a cheaper option, its performance was unacceptable without any reinforcement.




a. b. c.

d. e. f.

***Figure 8:***

*Featured failure modes of specimens after bending tests; a. Steel reinforced specimen, b. Transverse CFRP reinforced specimen, c. Cross CFRP reinforced specimen, d. Reference specimen, e. Mat GFRP reinforced specimen with bitumen and f. Chopped GFRP reinforced specimen with bitumen*

## 5. CONCLUSIONS

In this study, the aim is to produce light and strong composite panels instead of steel reinforced heavy concrete precast panels for reinforced soils. With this purpose, several reinforcements, which include carbon fiber of transverse arrangement or cross arrangement, and glass fiber in a mat and a chopped form, are tried out to enhance the load-displacement performance of characteristic foam concrete under panel tests and three-point bending tests.

**Table 3. Average ultimate values obtained in bending tests and comparison of unit cost**

| Type | Weight (kg) | Ultimate load (kN) | Displacement (mm) | Unit cost of 10cm thick panel (TL/m$^2$) |
|---|---|---|---|---|
| Type2 | 18.15 | 5.77 | 28.62 | 79.70 |
| Type4 | 16.92* | 2.47* | 11.80* | 618.20 |
| | 17.42 | 4.35 | 43.79 | |
| Type5 | 17.18* | 1.90* | 2.97* | 521.50 |
| | 16.95 | 1.98 | 3.59 | |
| Type6 | 12.36 | 0.94 | 2.35 | 75.00 |
| Type7 | 19.40 | 9.63 | 8.65 | 156.15 |
| Type8 | 20.38 | 15.19 | 20.84 | 107.20 |

*Single-sided specimens only

Although foam concrete provides a 4-fold gain of weight compared to standard concrete, it has a low compressive strength at an average of 2 MPa, since it does not contain coarse aggregate. In addition, synthetic resin impregnated carbon fiber does not provide the required amount of adhesion and strength due to the porous structure of foam concrete. If CFRP is applied in a transverse or cross direction along double sides, ultimate load levels reach up to approximately 34 kN and 17 kN, when the specimens are subjected to panel tests and bending tests. These specimens perform better in panel tests than in bending tests with respect to steel reinforced specimens.

The best performance values are obtained with the use of glass fiber reinforcement, both mat and chopped forms, in terms of strength, ductility and cost benefits. While the mat type of GFRP applied specimens have the highest load value, reaching 51.15 kN with a ratio of 1.25 kN per kg in panel tests, the highest bending performance levels are obtained at 0.75 kN per kg for chopped GFRP covered specimens. In addition, the mat and chopped GFRP reinforced specimens are cheaper than conventional C30 reinforced concrete panels with an amount of 35% and 55%, respectively.

It is thought that innovative composite panels will provide a serious contribution in terms of transportation and placement processes, as well as a long-term maintenance requirement compared to conventional steel reinforced concrete panels. Moreover, a modified bitumen coating or a rubber-based elastomer can be used to absorb impact effects, such as those caused by vehicle crashes.

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## CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

## AUTHORS CONTRIBUTION

Burak Evirgen: Determining and management of the conceptualization and design procedures, data curation, analysis and discussion of the results, writing of draft. Onur Tunaboyu: Determining of the conceptualization and design procedures, data curation, analysis and discussion of the results, editing. Barış Büyük: Methodology, reviewing, and editing. Gizem Tuğçe Çil: Methodology, reviewing, and editing.

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