# GFRP Reinforcement for Concrete Facilities to Protect Against Mudflow

*by Valery Hurynovich and Antonio Nanni*

A unique complex of mudflow protection facilities was recently constructed to protect the city of Ashgabat, Turkmenistan, using concrete reinforced with glass fiber-reinforced polymer (GFRP) reinforcement. The project's specifications and design provisions followed current Russian standards for fiber-reinforced polymer reinforcement, and the project was completed on time and under budget.

Ashgabat is the capital and largest city of Turkmenistan. The city is situated at the foot of the Kopet Dag mountain range in Central Asia, with the highest nearby peak standing at 2940 m (9646 ft) above sea level. The slopes of the range facing Ashgabat are steep and ravine-scarred. From March to October, periodical convective precipitation events release a total of up to 400 mm (16 in.) of rainfall. After rare but sometimes heavy rains, massive mudflows sweep down the narrow ravines and over the submountain plains.

In 1991, the Turkmenistan government took significant steps toward revitalizing Ashgabat, turning it into a modern city with public buildings, monuments, and parks. The city is famous for its architecture: white marble-clad buildings, mosques with beautiful golden domes, and high monuments. To protect Ashgabat and its people against the risk of mudflows (Fig. 1), the decision was made to construct a complex of mudflow protection facilities. The construction started in March 2020 and was completed in September 2022. The complex of facilities is in the southern part of Ashgabat and receives water from the Kopet Dag (Fig. 2).

The project called for the construction of mudflow storage facilities (Fig. 3) in the streambeds of the main ravines as well as a system of diversion channels and pipelines carrying cleared water to the existing mudflow diversion channel (the so-called Ashgabat Channel).

The primary purpose of the facilities is to receive and intercept mudflow and stormwater from rains falling in the area. After the complete settlement of detrital deposits in the storage facilities, the discharge of the cleared water that was part of the mudflow starts with flood gates being opened and pump stations being activated.

**Fig. 1: Streets of Ashgabat, Turkmenistan, after a mud stream inundation** *(photo credit: https://centralasia.media/news:1448895/)*


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**Fig. 2: Location of the mudflow protection facilities**

The water diversion facilities are made of reinforced concrete (RC) channels and pipelines that receive and divert the clarified water from the mudflow storage facilities. The water diversion channels receive torrents from the Kopet Dag along their length, thus reducing the amount of rainwater moving to Ashgabat. These massive construction projects included the following:

- Nine mudflow storage facilities;
- Five mudflow channels with a total length of 7 km (4.3 miles);
- Water diversion channels with a total length of 22 km (13.7 miles);
- Water diversion conduits with a total length of 9 km (5.6 miles);
- Restoration of an existing mudflow diversion channel with a total length of 19 km (11.8 miles);
- Seven pump stations;
- Two water outlet structures; and
- Restoration of three bridges.

The group of mudflow protection facilities is unique as it can receive mudflow and stormwater for a total volume of 12.4 million $m^3$ (16.2 million $yd^3$) at a time and withstand a magnitude 9.0 earthquake.

To help ensure the maintenance-free service life of the diversion channels for a total of 100 years, GFRP bars were chosen as reinforcement for the concrete in the project. The selected GFRP composite was in the form of sand-coated bars (straight or with bends) (Fig. 4) made of E-glass corrosion-resistant (E-CR) glass fibers embedded in epoxy resin. GFRP bars are currently becoming more popular because of their properties that allow the extension of service life and reduction of construction costs (Table 1). GFRP bars exhibit no corrosion, have high tensile strength and good fatigue strength, are lightweight, and exhibit electromagnetic transparency. While GFRP bars also have low elastic modulus and transverse shear strength, these properties are not significant factors in uniformly loaded slabs-on-ground. In addition, the low weight of GFRP bars minimizes transportation and placement costs.


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**Fig. 3: Mudflow storage facilities**

**Fig. 4: Sand-coated GFRP reinforcing bars used in the project**

## Material Specifications and Design

The following regulations were used during development of the project for GFRP reinforcement for the channels:

- SP 295.1325800.2017, "Concrete Structures Reinforced with Fibre-Reinforced Polymer Bars. Design Rules"[2]; and
- GOST 31938-2012, "Fibre-Reinforced Polymer Bar for Concrete Reinforcement. General Specifications"[3] (Table 2).

The main calculation criteria included:

- Maximum allowable crack opening width of 0.7 mm (0.03 in.);
- Distance between cracks from 0.5 to 1 m (1.6 to 3.9 ft);
- Stress in bars under long-term load of not more than 330 MPa (47.8 ksi);

**Table 1:**
**Physical and mechanical properties of GFRP and steel bars used in design**

| Property | GFRP | Steel bars A500 (GOST R 52544-2006[1]) |
|---|---|---|
| Characteristic tensile resistance, MPa (ksi) | 1100 (160) | 500 (72.5) |
| Design tensile resistance, MPa (ksi) | 641 (93) | 435 (63) |
| Design resistance to tension under sustained and long-term load, MPa (ksi) | 330 (47.9) | 435 (63) |
| Tensile modulus, not less than, MPa (ksi) | 50,000 (7250) | 200,000 (29,000) |
| Elongation at failure, ε, % | 2.2 | 14.0 |
| Coefficient of linear thermal expansion, 1/°C | $(6.0 \text{ to } 10.0) \times 10^{-6}$ | $(11.5 \text{ to } 14.5) \times 10^{-6}$ |
| Conductivity | Nonconductive | Conductive |
| Magnetic properties | Nonmagnetic | Magnetic |
| Corrosive and chemical resistance | High | Low |

**Table 2:**
**GFRP material specifications**

| Property | GOST 31938-2012[3] | ASTM D7957/D7957M-17[4] |
|---|---|---|
| | GFRP/BFRP | GFRP |
| Fiber mass content, no less than, % | 75 | 70 |
| Nominal ultimate tensile strength, MPa (ksi) | 800 (116) | 533 to 843 (77.3 to 122.3), depending on bar diameter |
| Nominal mean tensile modulus of elasticity, no less than, MPa (ksi) | 50,000 (7250) | 44,800 (6500) |
| Guaranteed transverse shear strength, no less than, MPa (ksi) | 150 (21.7) | 131 (19) |
| Nominal ultimate compression strength, no less than, MPa (ksi) | 300 (43.5) | — |
| Guaranteed bond strength, no less than, MPa (ksi) | 12 (1.74) | 7.6 (1.1) |
| Loss in tensile strength after exposure to alkaline conditions, no more than, % | 25 (30 days at 60°C [140°F]) | 20 (90 days at 60°C [140°F]) |
| Guaranteed bond strength after aging in an alkaline environment, no less than, MPa (ksi) | 10 (1.45) | — |
| Mean glass-transition temperature, no less than, °C (°F) | — | 100 (212) |
| Mean degree of cure, % | — | 95 |
| Operating temperature limit, no more than, °C (°F) | 60 (140) | — |
| Moisture absorption in 24 hours at 50°C (122°F), no more than, % | — | 0.25 |
| Mean moisture absorption to saturation, no more than, % | — | 1 (to saturation at 50°C [122°F]) |


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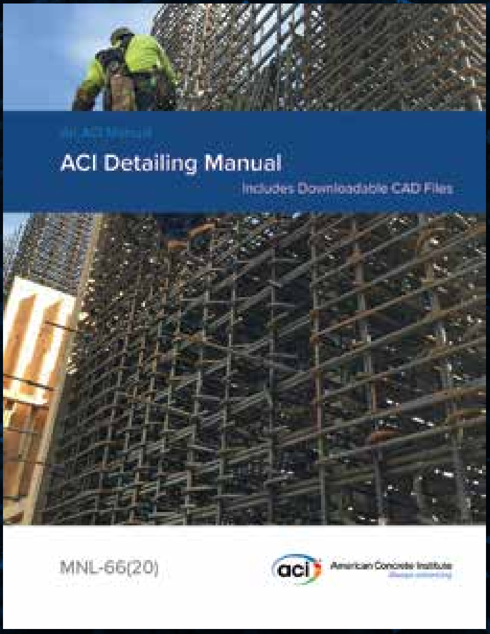


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**Fig. 5: GFRP reinforcement in channel slabs**

**Fig. 6: Channel slab after concrete casting**

### Table 3:
**Total number and weight of GFRP bars used in the project**

| Name | Length, m (ft) | Weight, tonne (ton) |
|---|---|---|
| Straight bars | | |
| GFRP 10 | 151,026 (495,492) | 25.97 (28.73) |
| GFRP 12 | 7,834,137 (25,702,549) | 1997 (2201) |
| GFRP 16 | 6955 (22,818) | 3.23 (3.56) |
| Bent bars | | |
| GFRP 12 | 32,690 (107,250) | 8.92 (9.83) |
| Total | 8,024,808 (26,328,111) | 2035 (2243) |

- Stress in bars under short-term load of not more than 641 MPa (93 ksi); and
- Concrete B25 with compressive strength of 14.5 MPa (2100 psi).

The design strength of the GFRP bars was calculated with consideration of a material resistance factor of 1.2 and an operation factor of 0.7 (structures operated outdoors or on ground).

The following parameters were chosen for the channels (Fig. 5):

- Slab thickness of 400 mm;
- Bar diameter of 12 mm (0.47 in.);
- Spacing of bars in the slab top mat of 250/250 mm (10/10 in.);
- Spacing of bars in the slab bottom mat of 250/250 mm; and
- Bar lap splice length of 600 mm (24 in.).

Based on the calculations for temperature exposure, the dimensions of channel panels were determined as 30 x 30 m (98.4 x 98.4 ft) (Fig. 6).

GFRP bars with diameters of 10, 12, and 16 mm were used in the project; additionally, 12 mm diameter L-shaped bent bars were employed for splicing. Straight bars were supplied in bundles of a maximum length of 13 m (42.6 ft). The total quantities are given in Table 3.

## Economy of GFRP Bar Application

The initial project design called for 12 mm diameter A500 steel bars installed at 250/250 mm in the top and bottom mats of a slab. The total required length of bars was estimated at 7.9 km (4.8 miles), including additions for lap splices. At the time of the construction, the cost for 12 mm diameter steel bars was 0.27 USD/ft, while corresponding GFRP bars cost 0.23 USD/ft.

The project calculations showed that steel bars could be replaced by GFRP bars without changing bar diameter and spacing, leading to a material cost savings of 16% (refer to Table 4).

Costs for the delivery of bars to the construction site

### Table 4:
**Direct comparison of material costs for steel and GFRP bars**

| Material | Bar diameter, mm | | | | | | Total cost, USD | |
|---|---|---|---|---|---|---|---|---|
| | 10 | | 12 | | 16 | | | |
| | A500 | GFRP | A500 | GFRP | A500 | GFRP | A500 | GFRP |
| Length, ft | 495,492 | 495,492 | 25,809,801 | 25,809,801 | 22,818 | 22,818 | — | — |
| Weight per length, lb/ft | 0.415 | 0.116 | 0.597 | 0.171 | 0.812 | 0.312 | | |
| Total weight, lb | 205,431 | 57,269 | 15,400,708 | 4,422,767 | 18,524 | 7119 | | |
| Cost per length, USD/ft | 0.19 | 0.15 | 0.27 | 0.23 | 0.37 | 0.36 | | |
| Cost, USD | 95,134 | 72,837 | 7,089,694 | 5,936,254 | 8522 | 8215 | 7,193,350 | 6,017,306 |
| Difference, USD | | | | | | | 1,176,044 | |
| Savings, % | | | | | | | 16 | |

Note: 1 mm = 0.04 in.; 1 ft = 0.3 m; 1 lb/ft = 1.5 kg/m; 1 lb = 0.45 kg

**Table 5:**
**Comparison of total costs for the project**

| Reinforcement type | A500 | GFRP |
|---|---|---|
| Cost for bars, USD | 7,193,350 | 6,017,306 |
| Number of Euro trailers | — | 101 |
| Number of railroad cars | 110 | — |
| Delivery cost per one Euro trailer, USD | — | 4240 |
| Delivery cost per one railroad car, USD | 8140 | — |
| Transportation cost, USD | 895,400 | 428,240 |
| Cost including delivery, USD | 8,088,750 | 6,445,546 |
| Difference, USD | 1,643,205 | |
| Savings, % | 20 | |

accounted for a significant part of the project's economy. The total weight of steel bars would have been about 7812 tons (7087 tonnes). In contrast, the total weight of the GFRP bars required for the project was about 2243 tons (2035 tonnes).

The total economic efficiency of replacing the steel bars with GFRP bars, including the delivery cost, was 20% (refer to Table 5). While an accurate assessment of costs for unloading, crane operations, and reinforcement cage installation for the project was not carried out, it was also noted that the use of GFRP bars improved construction time and reduced labor costs. The construction of the mudflow protection facilities has been successfully completed, and the owner has decided to apply GFRP bars in new projects.

## References


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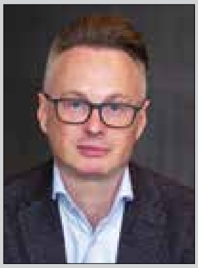


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