CDCC-07

DURABILITY AND FIELD APPLICATIONS OF FIBRE REINFORCED POLYMER (FRP) COMPOSITES FOR CONSTRUCTION

DURABILITÉ ET APPLICATIONS DES COMPOSITES EN POLYMÈRES RENFORCÉS DE FIBRES (PRF) POUR LA CONSTRUCTION

EXPERIMENTAL STUDY ON PULTRUDED GFRP DECK UNDER SUSTAINED LOAD

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ABSTRACT

A pultruded cellular GFRP (glass fiber reinforced polymer) deck was tested in doors under sustained load for three years to investigate its creep. The deck is designed for pedestrian bridges with a 4kN/m^2 live load. After obtaining its initial stiffness in static loading test, the deck with a 2.8m long span bolted on supports were loaded to the maximum design load and held during the first year. The creep of GFRP deck is investigated. The deflection did not rise obviously after 200 days. After one year the load was reduced to the normal service load level. In the next two years the deflection kept nearly constant. The experimental results are explained in this paper. It is shown that the deformation of GFRP deck developed significantly in the first 125 days, and the maximal deflection in long term is 124.2% of the instant deflection under the maximum design loads.

1. INTRODUCTION

Fiber reinforced polymer (FRP) is available for use with its advantages in civil engineering applications, which is light-weight, easily transported and installed, and corrosion resistant. However, different from successful FRP applications in the fields such as aviation, aerospace, and automobile, the long-term performance of FRP in civil structures is concerned considerably as it will be exposed to more complex infrastructure service environmental conditions of a range of combinations of stress, time, temperature, moisture, radiation, chemical and gaseous environments and are expected to perform for a longer time of fifty years or more. Although FRP shows an excellent long-term durability in the cases investigated by Halliwell [1], the undesirable long-term deformations appeared in some FRP bridges, some of which even have been abandoned for it, for instance, the first FRP highway bridge in Miyun, Beijing, China [2]. It shows that the creep of FRP elements comes to be more highlighted than other long-term behaviors.

The creep tests for FRP bars [3, 4], FRP sections [5] and FRP frames[6] were carried out, the theoretical models for viscoelastic behavior of FRP were developed [7, 8], and the research works were reviewed and analyzed [9-11]. In this paper, a long-term sustained loading experiment is conducted to investigate the creep behavior of a pultruded cellular GFRP deck according to its actual engineering situation, which will be used in pedestrian bridges. The approach to predict the long-term deflection for design is proposed.

2. PULTRUDED DECKS

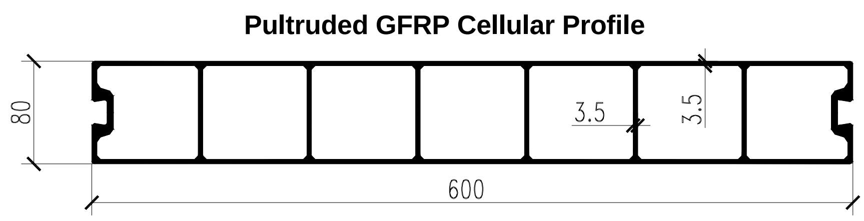


Fig. 1: Section of the pultruded GFRP decks

Table 1: Properties of GFRP decks provided by manufacturer

Properties	**Longitudinal**	**Transverse**
Tensile strength (MPa)	210	72
Tensile module (GPa)	22	10
Compressive strength (MPa)	258	98
Compressive module (GPa)	19.2	7.2
Flexural strength (MPa)	302	76
Flexural module (GPa)	18.6	7.2
In-plane shear strength (MPa)	24.5	-
Poisson ratio	0.29	-
Density (kg/m^3)	1800	

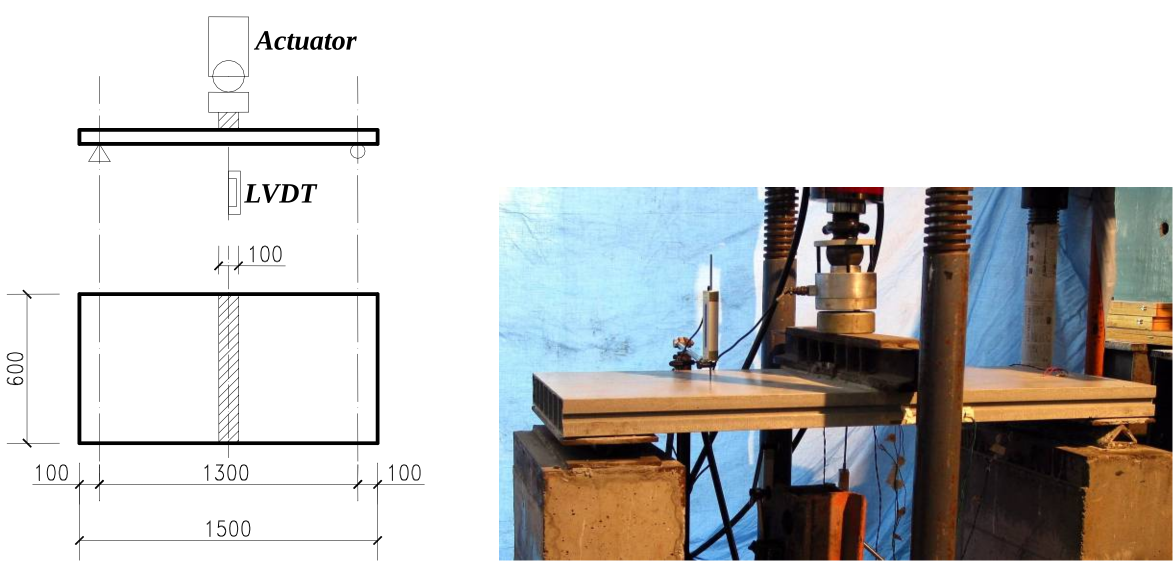
The GFRP modular pultruded deck, named SP as the product, is studied. The section of SP is 600mm wide by 80mm deep as shown in Fig.1, which is composed of seven cavities with 3.5mm thick walls. The total area of the section is 6941mm^2, and the inertia moments are 7.337×10^6mm^4 in primary and 1.222×10^9mm^4 in secondary. There are two grooves along the longitudinal length for joggled connecters on the two sides of the section separately, by which the parallel decks are installed together. The SP was made of E-glass rovings (4800 Tex), continuous strand mat and unsaturated polyester resin. The total fiber volume ratio is 61%. The mechanical properties of GFRP are listed in Table 1, which are determined by the standard tests. The material of the deck is orthotropic. The longitudinal direction is the major, in which the mechanical properties are stronger.

SP was designed for pedestrian bridges, working platforms and enclosure systems of long-span bridges. The major vertical load in service is the pedestrian load of 4.0kN/m^2 according to the China Code [12], for which a quasi-permanent ratio of 25% is considered.

3. TESTS

3.1 Static Failure Test

A SP with a 1.3m long span was loaded to failure to investigate its stiffness and ultimate strength under short-term loading [13]. The specimen was supported simply and loaded on the central line of the span as shown in Fig 2. The SP was failed with sounding loudly at the maximum load. A crack along the top edge of the section occurred on one side and the top plate delaminated and buckled as show in Fig 3. The thickness of delaminated layer was about 3mm and the crack length was about 480 mm. The load-deflection curve is shown in Fig. 4, The FRP deck kept nearly linear until failure. The maximum load reached 80.8 kN, the corresponding flexural moment is 26.3 kNm. As the depth of the deck is much less than its span, the shear deformation may be ignored to determine the flexural stiffness. The flexural stiffness of section, *EI*, evaluated by the stable part of the curve is 133.8 kNm^2.



(a) (b)

Fig. 2: Failure loading test: (a) illustration of test (unit: mm) (b) test setup

Fig. 3: Failure of GFRP deck

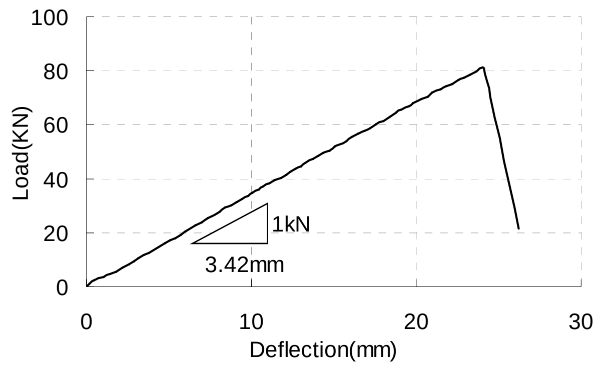


Fig. 4: Load-deflection curve of failure test

3.2 Long-Term Test Setup

Fig. 5 shows a schematic illustration of the deadweights to apply the uniform sustained load. The weights, including 14 concrete blocks and 84 steel blocks, are loaded grade by grade. To keep consistent with the actual condition, the specimen was fixed by eight steel bolts on the supports as shown in Fig 6. The specimen is 3.0 m long with a 2.8 m span. The total mass of the fourteen concrete bricks is 428 kg, which is equivalent to the uniformed load of 2.5 kN/m^2. Each steel block weighs 10 kg. The additional weight of six steel blocks on each concrete bricks is 60 kg. All weight of 1268 kg totally as the sustained load is considered as the uniform load 7.4 kN/m^2, which is the maximum design load in service including the factored dead load and live load. The dead load of 1.5 kN/m^2 is considered as the weight of pavement, handrail, and decoration, and the live load is 4.0 kN/m^2. The design load and the quasi-permanent load are determined as listed in Table 2.

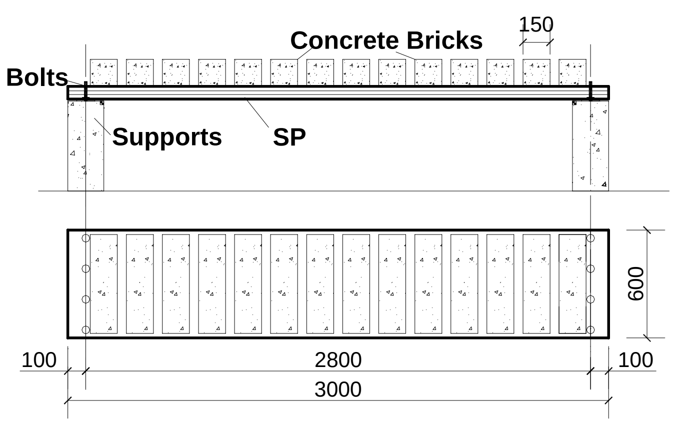


Fig. 5: Long-term loading test setup (unit: mm)

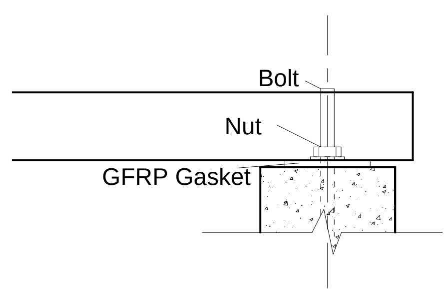


Fig. 6: Supports

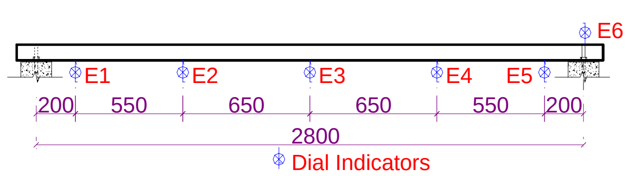


Fig. 7: Measuring setup for long-term test (unit: mm)

Table 2: Design load and quasi-permanent load

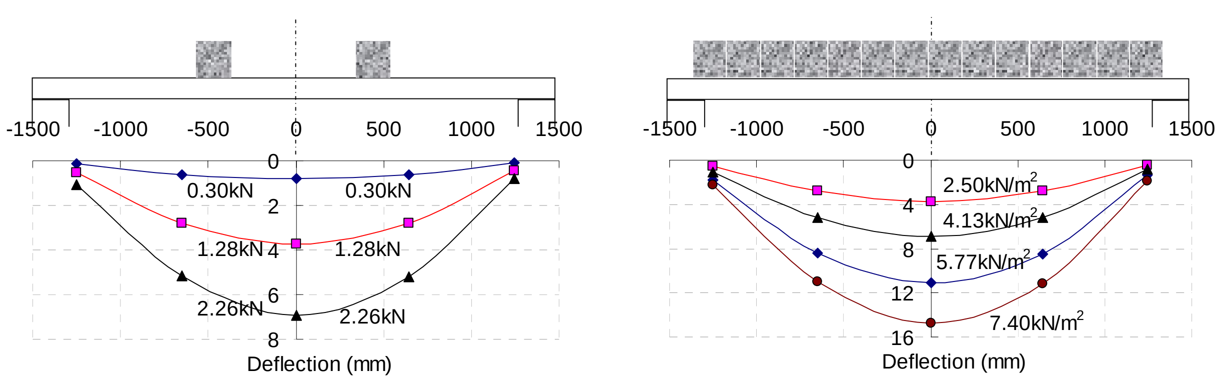
Loads	**Standard load**	**Design load**	**Service load**
Dead load	1.5 kN/m^2	1.2* Standard load	1.0* Standard load
Live load	4.0 kN/m^2	1.4* Standard load	0.25* Standard load
Total		7.4 kN/m^2	2.5 kN/m^2

Six dial indicators were installed to measure the deformation of the specimen as shown in Fig. 7. A thermometer and a hygrometer are placed close to the specimen. All test setup shown in Fig 8 stood in a basement, where temperature and humidity changed gently.

Fig. 8: Long-term loading test

3.3 Short-Term Loading

Before applying the uniform load, the specimen was loaded on the one-third span to get its stiffness. The measured deflection curves in each load step are shown in Fig 9(a). The flexural stiffness of SP is 133.9 kNm^2 determined by the former test. If the SP is simply supported ideally, the maximal deflection should be 13.2 mm under two 2.26 kN loads, and 2.9 mm for the ideally clamped ends. The real boundary condition, which is to be used in the actual bridges, is the semi-fixed support which is provided by the bolts.



(a) (b)

Fig. 9: Deflection of short-term loading: (a) four-points load; (b) uniform load

3.4 Long-Term Loading

The uniform load was applied in one hour as the following four steps:
(1) 2.50 kN/m^2 (concrete bricks only);
(2) 4.13 kN/m^2 (two additional steel blocks on each concrete brick, 28 totally);
(3) 5.77 kN/m^2 (four additional steel blocks on each concrete brick, 56 totally);
(4) 7.40 kN/m^2 (six additional steel blocks on each concrete brick, 84 totally).
The measured deflection curves in each loading step are shown in Fig. 9(b). Then, the SP was loaded as shown in Fig. 8 for one year and nine days, say 374 days totally. The deflections were recorded 11 times in the first day, 5 times in the second day, 1 time per day in the first month, and 60 times in the later days. At the same times, the temperature and the relative humidity were recorded.

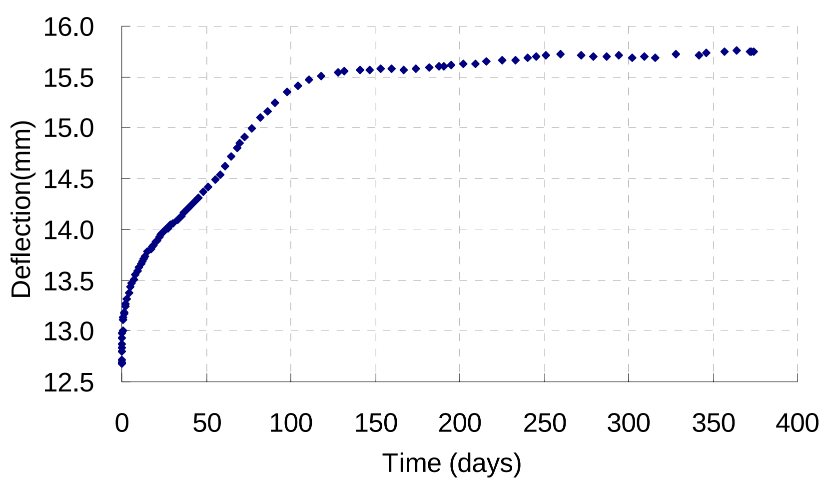


Fig. 10: Creep curve of long-term test: 374 days

The Fig. 12 shows the creep behaviors of SP in 374 days, in which the relative deflection of the midspan point (E3) to the points near the supports (E1 and E5) is investigated. The initial relative deflection is 12.35 mm. It rose to 13.51 mm in the first week, 14.05 mm in the first month, 15.58 mm in the first 150 days. After 150 days, it rose slowly, even stopped. The maximal deflection is 15.76 mm in the 364th day, 124.2% of the instant deflection. The changing rate, say the difference of the creep curve, is illustrated in Fig. 11, which shows that the deflection increase very slowly after the 125th day when the total deflection is 15.55 mm. It can be seen that 93.8% creep deflection occurred in the first 125 days.

As the deflection kept almost constant during the later 150 days, the unloading test was conducted. After the steel blocks were unloaded, the sustained load became the service load of 2.5 kN/m^2. The deflection at the first loading to this grade was 4.13 mm, while it was 7.16mm at the instant after unloading. There was 3.03 mm difference. After 100 days, it returned to 6.03 mm. During the following 500 days, it did not change obviously. The unrecoverable deflection is 1.90 mm only, which is 16.3% of the load increment. The time-deflection curve of the whole loading process is shown Fig. 12.

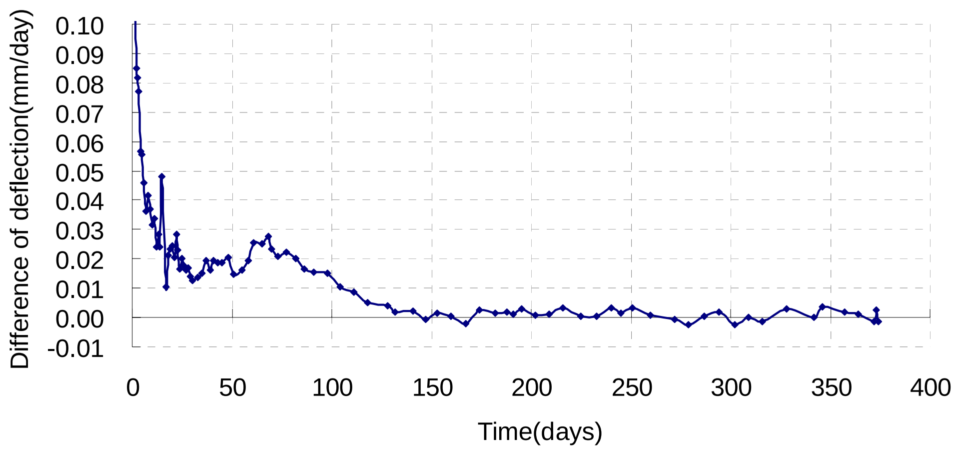


Fig. 11: Difference of deflection

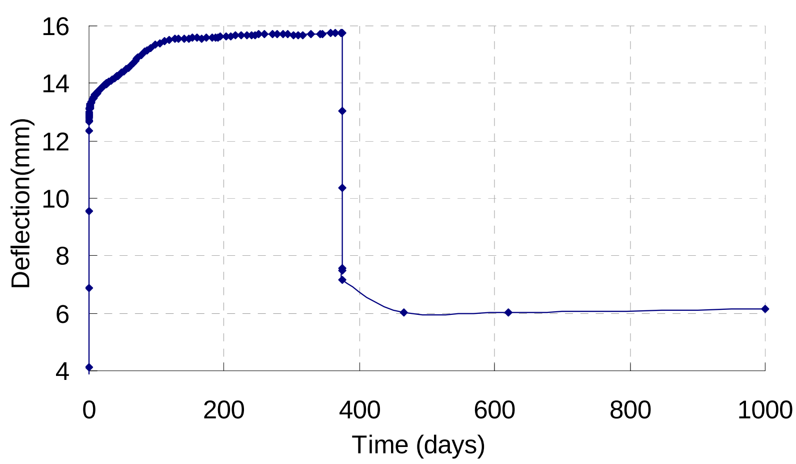


Fig. 12: Time-deflection curve of 1000 days

4. CONCLUSIONS

The behaviors of a pultruded GFRP deck were investigated in short-term and long-term tests. The following conclusions can be drawn: (1) 93.8% creep deformation developed in the first 125 days, and deflection kept constant after the 150th day; (2) 16.3% load increment in long-term is unrecoverable; (3) long-term deflection can be predicted conservatively as the instant deflection by an amplified factor of 1.25.

5. ACKNOWLEDGEMENTS

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