# 論文 Static and Fatigue Flexural Behavior of GFRP－Concrete Composite Beam by Epoxy Resin Adhesive

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**ABSTRACT:** The flexural behavior of glass fiber reinforced plastic (GFRP)-concrete composite beam by epoxy resin adhesive was investigated under two kinds of loads (static and fatigue loading). The GFRP-concrete composite beam consists of RC slab and H-shaped GFRP beam. The RC slab and the GFRP beam connected to each other by using epoxy resin adhesive. Three identical beams were prepared; two of them were examined under static loading, while the third was examined under fatigue loading. The experimental results of all the specimens are introduced and the conclusions based on the experimental and analytical studies are presented.
**KEYWORDS:** glass fiber reinforced plastic(GFRP), GFRP-concrete composite beam, rehabilitation, concrete slab, bond failure, shear failure.

## 1.INTRODUCTION

Use of fiber-reinforced plastic (FRP) in structural constructions has been rather limited compared to that of steel and concrete. Some of the attractive and unique features of FRP are their low specific gravities, high strength-to-weight ratio, durability, resistance to marine environment, toughness particularly at low temperature and magnetic transparency. Manufacturing of the GFRP in very wide shape varieties such as angles, channels and H-shaped enhances the possibilities of using these materials in combination with concrete to be used as structural members.

This study is an attempt to put the GFRP-concrete beam in practical use for the purposes of maintenance and rehabilitation of existing concrete structures. Firstly, The mechanical properties of GFRP, concrete and epoxy resin adhesive were summarized, then the flexural behavior of GFRP-concrete composite beam under static and fatigue loadings were experimentally and analytically investigated.

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## 2. SPECIMEN DETAILS AND MATERIAL PROPERTIES

The GFRP-concrete composite beam was composed of GFRP H-shaped beam and RC slab. The GFRP beam was connected to the RC slab by using epoxy resin adhesive. 8 rectangular GFRP pipes were attached to the web of the GFRP beam as stiffeners to prevent local buckling. Details of the specimen are shown in Fig. 1. Three identical GFRP-concrete composite beams were prepared; only two of them were loaded statically up to failure, while the third was loaded with fatigue loading. All of the three specimens have 1800 mm span and 600 mm constant moment zone.

### 2.1 H-SHAPED GFRP BEAM

H-shaped GFRP was composed of the lamination of continuous strand mat (CSM), yarn cloth and roving of glass fibers, impregnated with unsaturated polyester resin as shown in Fig.2. The volume content of glass fiber was form 45 to 60%, and roving occupied the most part. The dimension of H-shaped GFRP was 140 mm of width; 200 mm of height, and the thickness of the flange and the web were 10 mm and 14 mm, respectively.

Tension test was carried out for better knowledge of the GFRP properties by Sekijima et.al[1]. The specimen of the test was cut from the flange, and its dimension was 15 mm in width and 10 mm in thickness.According to results presented by [1], the outer part of the tension specimen, which composed of CSM and yarn cloth, delaminated of the inner part that composed of roving arranged in the longitudinal direction, because the elongation of the former was smaller than that of the latter. The test results are shown in Table 1.

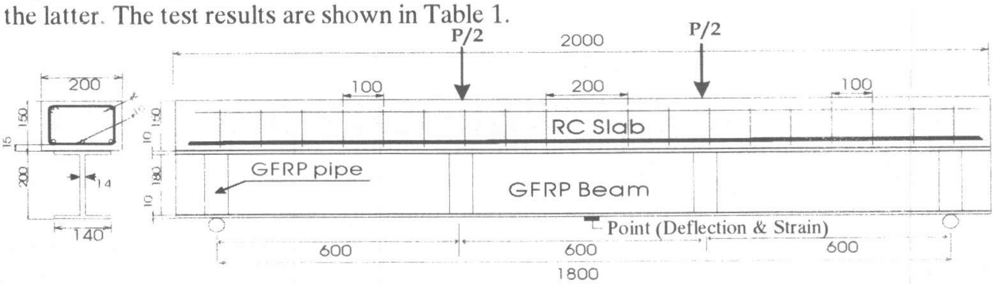


Fig.1 GFRP-Concrete Composite Beam

Table 1 Mechanical Properties of GFRP

| Tensile Strength (N/mm$^2$) | Ultimate Strain | | Young's Modulus (Gpa) | Poisson's Ratio |
|---|---|---|---|---|
| | Longidudinal (%) | Transverse (%) | | |
| 424 | 1.15 | -0.28 | 37 | 0.255 |

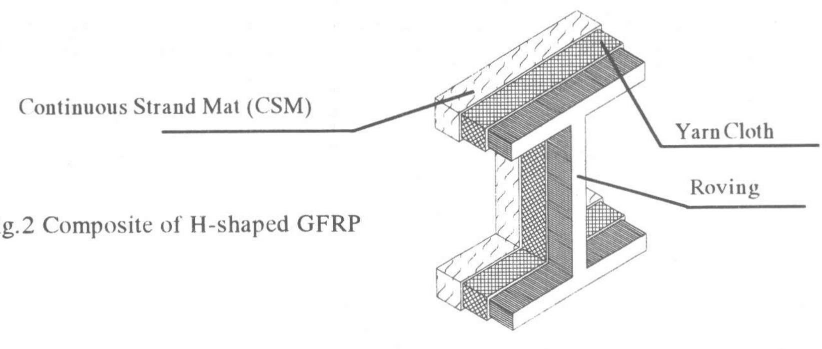


Fig.2 Composite of H-shaped GFRP

Table 2 Properties of Concrete and Epoxy Resin Adhesive

| | Concrete | | | Epoxy Resin Adhesive | | |
|---|---|---|---|---|---|---|
| Specimen | No.1 | No.2 | No.3 | No.1 | No.2 | No.3 |
| Compressive Strength (Mpa) | 38.9 | 38.5 | 39.8 | 61.6 | 62.6 | 75.7 |
| Young's Modulus (Gpa) | 27.6 | 29.0 | 29.2 | 9.0 | 8.9 | 12.4 |
| Possion's Ratio | 0.187 | 0.203 | 0.224 | 0.256 | 0.252 | 0.29 |

## 2.2 RC SLAB

Three identical RC slabs were prepared to be the concrete decks of the test specimens. The slab depth was 150 mm and the width was 200 mm. The slab was reinforced with 3D10 steel bars spaced at 70 mm, which had yield strength of 343.4 Mpa. The mechanical properties of the concrete in the time of loading the specimens are shown in Table 2.

## 2.3 EPOXY RESIN ADHESIVE

The epoxy resin was mixed with fine sand and the mixing percentage was 1/7. The mechanical properties of the epoxy resin adhesive in the time of loading the composite beams are shown in Table 2.

# 3. ANALYTICAL PROCEDURE

Analytical study was completed using FE package (LUSAS Version 13.1) to simulate the behavior of the GFRP-concrete composite beam under static loading. Material properties of concrete, steel and epoxy resin adhesive were determined experimentally (Table 2) and incorporated into the model. A recent report on engineering practice ("Structural" 1984, chapter 3)[2] and a state-of-art report on advance composite material in bridges and structures (Mufty et al. 1991)[3] indicate that reinforced plastics generally behave linear-elastically up to failure. The GFRP mechanical properties (Table 1) were incorporated into the model. The stress-strain relationship for the concrete is shown in Fig.3.

Due to the symmetry of GFRP-concrete composite beam, only half of it was modeled by F.E.M.. The composite beam was discretized into a mesh consisting of 3-D solid continuum elements, 3-D thick shell elements, 3-D joint elements and bar elements. The 3-D solid continuum elements were used to model the concrete, while bars elements were used to model the steel reinforcing bars. The GFRP H-shaped beam was modeled by using 3-D thick shell elements, and 3-D joint elements were used to model the epoxy mortar. Fig.4 shows the mesh view of the composite beam.

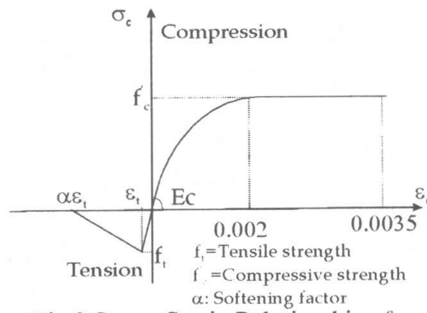


Fig.3 Stress-Strain Relationship of Concrete

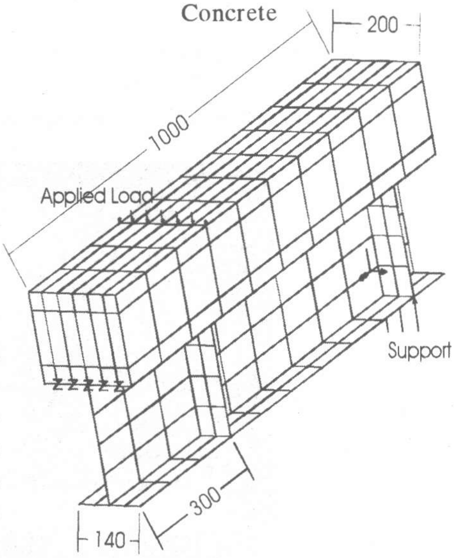


Fig.4 Mesh of FEM Analysis

## 4. RESULTS AND DISCUSSION

### 4.1 STATIC TEST

The load was increased gradually up to failure while measuring the deflection and the strain. When the applied load reached approximately 225 kN, bonding failure occurred in the epoxy resin adhesive along one side of the beam up to the position of the applied load, while completing the loading process the epoxy resin adhesive failure occurred again in the opposite side of the beam. The bond failure of the epoxy mortar was associated with cracks in the concrete slab, finally an approximate horizontal crack occurred in the left shear span of the beam in the web. Summary of experimental results is presented in Table 3. Fig. 5 shows the load-deflection relationship of the composite beam No.1. Fig. 6 shows the load-strain relationships of lower flange in the GFRP beam No.1. Letters A, B indicate the first and second epoxy resin adhesive failures, and letter C indicates the shear failure at the web in the GFRP beam. Photo.1 shows a view of the specimen after failure.

Table 3 Ultimate Strength of Composite Beam

| Specimen | Ultimate Load (kN) | Ultimate Bending Moment (kN.m) | Failure Mode |
|---|---|---|---|
| No.1 | 225 | 67.5 | Bond Failure of Epoxy Resin Adhesive |
| No.2 | 233 | 70.0 | Bond Failure of Epoxy Resin Adhesive |

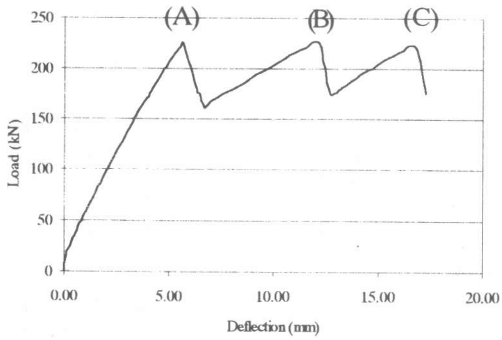


Fig.5 Load-Deflection Relationship (No.1)

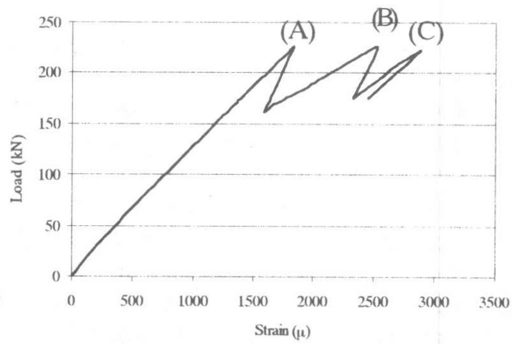


Fig.6 Load-Strain Relationship of the GFRP Beam Lower Flange (No.1)

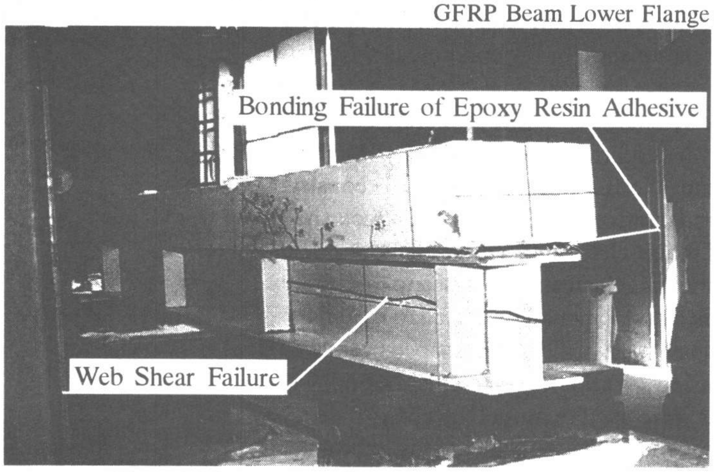


Photo.1 View of Specimen after Failure (No.1)

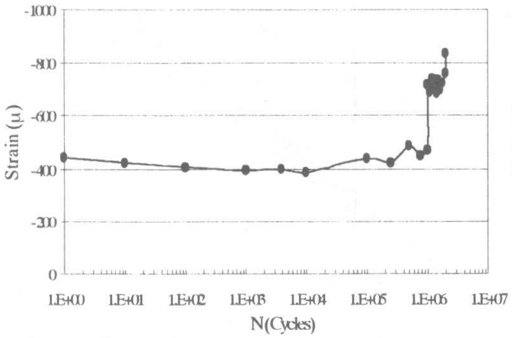

Fig.7 S-N Curve of the RC Slab Upper Face

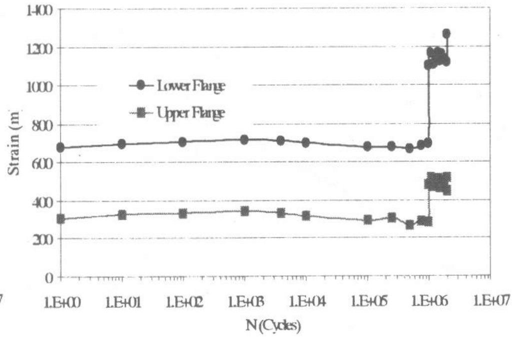

Fig.8 S-N Curve of the GFRP Beam

## 4.2 Fatigue Test

Figs. 7 and 8 show the S-N curves for the RC slab upper face and the GFRP beam. The applied cyclic load was divided to three stages. Firstly cyclic load with a range of 29-98 kN was applied for one million load cycles, in which the upper limit of the applied load was equal to the allowable bonding stress of the eopxy resin adhesive. After the first million cycles, no major change in the strain or deflection was noticed. In a second stage, the range of the applied load was increased to be 29-157 kN; the upper limit of the applied load was equal to 70% of the failure load applied to specimen No.1. Also after one million cycles in the second loading stage, no major change in the strain or deflection was noticed with the exception of some cracks in the concrete slab. In a third loading stage, the upper limit of cyclic load was increased to be 180 kN, which equal to 80% of the failure load. After twenty thousand cycles in the third loading stage, epoxy resin adhesive failure occurred along one side of the beam up to the position of the applied load. The epoxy mortar failure was associated with approximately big concrete crack, which went in the depth of the RC slab making 45 degree with the normal of the RC slab upper surface in the point of the applied load. The continuation of loading the specimen with third stage caused a horizontal crack in the left shear span of the beam in the web.

Fig.9 shows comparison between the analytical and experimental load-deflection relationships.Comparison between the analytical and the experimental load-strain relationships for the concrete upper face, GFRP upper and lower flanges are shown in Figs. 10, 11 and 12, respectively.

The measured and the calculated results are in good agreement, any slight difference between

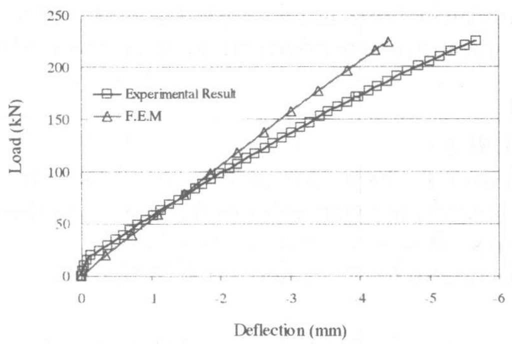

Fig.9 Experimental Vs. Analytical Results for the Central Span Deflection

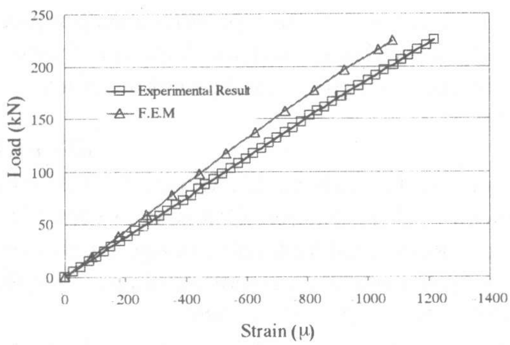

Fig.10 Experimental Vs. Analytical Results for RC Slab Upper Face

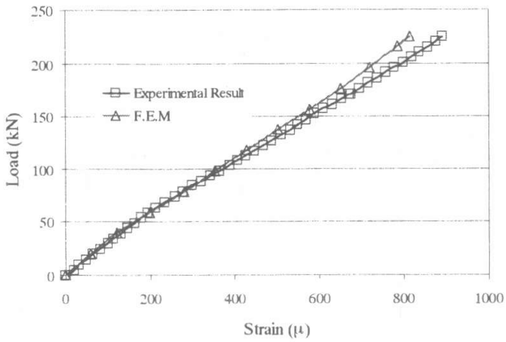


Fig.11 Experimental Vs. Analytical Results for GFRP Upper Flange

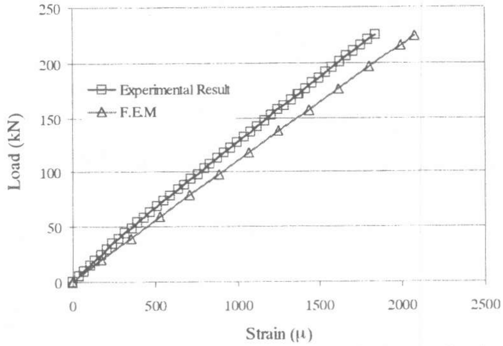


Fig.12 Experimental Vs. Analytical Results for GFRP Lower Flange

them is due to the difficulties to make the spring elements behavior exactly the same like the epoxy resin adhesive in producing the composite action between the RC slab and the GFRP H-shaped beam. The difficulties to model the springs elements in the plastic level prevented the occurance of the bonding failure between the RC slab and the GFRP beam, as a result, the ultimate load could not be predicted.

## 5. CONCLUSIONS

The exploratory study has presented the feasibility of using GFRP H-shaped beam for the applications of maintenance and rehabilitation of existing concrete structures. According to the experimental and analytical studies, the following conclusions can be made;

(1) Using the GFRP H-shaped beam in the field of structural engineering can be consider a promising technique for enhancing the flexural capacities of the existing concrete structure.

(2) The GFRP-concrete composite beam behaves approximately linear-elastically up to the partial bond failure of the epoxy resin adhesive layer.

(3) The flexural behavior of the GFRP-concrete composite beam was stable under fatigue load.

(4) The analytical results were in good agreement with the experimental results. Any slight divergence between the two results can be attributed to the finite elements modeling approximations that were made when constructing the numerical model.

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