

# Fiber Composite Bar for Reinforced Concrete Construction

H. SAADATMANESH\* AND M. R. EHSANI\*\*

Department of Civil Engineering and Engineering Mechanics  
University of Arizona  
Tucson, Arizona 85721

\*Received June 16, 1989  
Revised January 22, 1990

**ABSTRACT:** Behavior of concrete beams reinforced with Glass Fiber Reinforced Plastic (GFRP) bars was experimentally investigated. Two types of reinforcements were considered: longitudinal or flexural reinforcement and transverse or shear reinforcement. For each of the two types of reinforcements, three concrete beams were tested to failure. The behavior of each beam was characterized by its load-deflection response to failure. The study was mainly focused on experimentally determining the feasibility of GFRP bars as reinforcement for concrete structures. The results indicated that the plastic bars performed reasonably well in the beams tested.

## INTRODUCTION

CONCRETE IS THE most widely used construction material in the world today. Because of its low cost, availability, and good mechanical properties, concrete will be an integral part of bridge and building construction for many years to come.

The relatively high compressive strength of concrete makes it an ideal material for resisting compressive forces resulting from the applied loads on a structure. However, the tensile strength of concrete is not as good as its compressive strength; normally, the tensile strength of concrete is about one-tenth of its compressive strength. Because in almost all types of structures both compression and tension forces are present, in order for concrete to effectively resist the applied loads its tensile strength must be upgraded. Traditionally, steel reinforcing bar has been used in concrete construction to carry the internal tension forces resulting from the application of external loads. This method of construction is explained in a simple example that follows.

The cantilever beam, shown in Figure 1(a), is subjected to a concentrated load at its end. The bending moment resulting from the actions of the concentrated

\*Assistant Professor  
\*\*Associate Professor

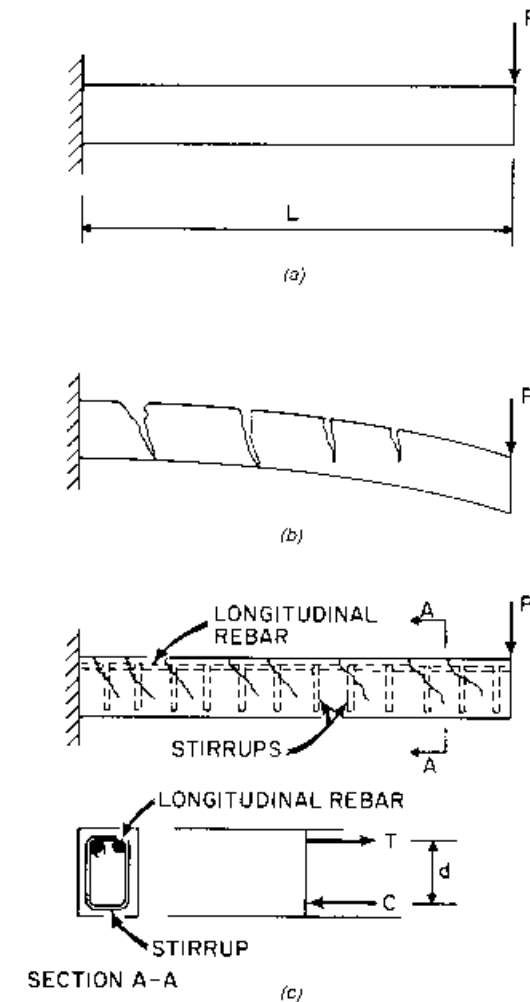


Figure 1. Plain and reinforced concrete cantilever beam.

load and the weight of the beam creates tension stresses normal to the cross section of the beam above the neutral axis and compression stresses below the neutral axis. The combination of shear and bending stresses above the neutral axis results in principle tension stresses on inclined planes with respect to the plane of the cross section. As soon as the magnitude of the principle tension stresses exceed the capacity of the concrete in tension, the concrete will crack perpendicular to the direction of tension stresses and the beam will fail catastrophically [Figure 1(b)].

In order to prevent such a catastrophic failure, steel reinforcing bars and stirrups are placed inside the concrete beam to carry the internal tension forces and to prevent excessive opening of the cracks after they have formed [Figure 1(c)]. The longitudinal reinforcements prevent flexural failure of the beam; the transverse reinforcements or stirrups prevent shear failure of the beam. It is noted that even with longitudinal and transverse reinforcements the beam will crack. However, in this case, the cracks are very fine and do not present any danger to the load carrying capacity of the beam as shown in Figure 1(c). In the reinforced concrete beam, the moment created by the applied load,  $P$ , and the weight of the beam,  $\omega L$ , is resisted by an internal moment developed by the combined actions of the compression force in the concrete,  $C$ , and the tension force in the longitudinal steel rebar,  $T$  [Figure 1(c)].

$$\text{Moment created by the applied load} = Pl + \frac{\omega L^2}{2} \quad (1)$$

$$\text{Internal resisting moment} = Cd = Td \quad (2)$$

Equilibrium of the applied and resisting moments requires that

$$PL + \frac{\omega L^2}{2} = Cd \text{ or } Td \quad (3)$$

where

- $P$  = applied load
- $L$  = length of beam
- $\omega$  = weight of beam per unit length
- $C$  = compression force in concrete
- $T$  = tension force in steel
- $d$  = distance between the lines of action of compression and tension forces

Knowing the strength properties of steel and concrete and using Equation (3), a designer can calculate the required amount of longitudinal steel rebars to be used in the beam. The principles of equilibrium can also be used to obtain the required amount of transverse reinforcements. The full discussion of design of reinforced concrete beams is beyond the scope of this paper and will not be discussed here. However, this subject is discussed in detail in References [1] through [3].

### CORROSION OF STEEL REINFORCEMENT

Even though steel reinforcement has been used in concrete structures for many years, there has always been a major problem with this type of construction; namely, the corrosion of the reinforcement. The corrosion problem is particularly of concern in structures located in aggressive environments such as coastal and marine structures, bridges (especially where salt and deicing chemicals are

used), chemical plants, water and wastewater treatment facilities, etc. Corrosion of reinforcement can result in costly repairs and safety hazards. Rust from the corroded rebar takes a larger volume than the iron from which it is formed, resulting in expansive forces that cause cracking and spalling of concrete and ultimately the failure of the structure. Billions of dollars are spent every year to replace or repair concrete structures that are deteriorated due to the corrosive effects of salt, acids, and other aggressive elements [4].

The corrosion phenomenon became of tremendous concern when extensive salting of bridges and highways began in the late 1960's [4]. Salting has drastically reduced the service life of many of the bridges in the United States. According to the eighth annual report of the Secretary of Transportation to the Congress of the United States on "Highway Bridge Replacement and Rehabilitation Program," (HBRRP) more than 40 percent of the nation's 575,607 inventoried highway bridges are classified as either structurally or functionally deficient [5]. The deterioration in many of these bridges has been caused by corrosion. The deficient bridges must be either replaced or reconstructed in some manner to adequately serve the present and future traffic needs. The estimated cost of bringing all deficient bridges up to current standards is reported at \$52.4 billion dollars. Prudent and efficient use of available funds for reviving the nation's transportation systems requires that every effort be made to prevent premature deterioration of structures caused by corrosion.

### FIBER COMPOSITE REBAR FOR CONCRETE CONSTRUCTION

An effective approach to eliminate the corrosion problems in concrete structures would be to employ corrosion-resistant plastic rebars instead of steel rebars. The recent advancements in the fields of plastics and fiber composites have resulted in the development of fiber-reinforced plastic rebars that surpass the strength and fatigue properties of steel. Other features of these rebars include low weight (1/4 that of steel) and economy. The cost of Glass-Fiber-Reinforced-Plastic (GFRP) rebars is about the same as that of epoxy-coated steel rebars. In addition, plastic rebars possess excellent electrical insulating properties. Therefore, they are ideal for use in airports to help solve radar interference problems and other places where presence of steel could cause interference with electrical or magnetic fields.

### EXPERIMENTAL STUDY

In order to investigate the feasibility of using plastic rebars in lieu of steel in concrete construction, an experimental study was conducted on several concrete beams reinforced with plastic bars. The following sections describe the materials, tests, and the results.

#### Plastic Rebars

Glass-Fiber-Reinforced-Plastic (GFRP) rebars and stirrups were used as reinforcement. These rebars are manufactured using the pultrusion process. The bars

contain approximately 76 percent E-Glass by weight and 24 percent resin. The individual fibers have a tensile strength in excess of 500,000 psi (3,450 MPa) and range from 3 to 5 microns in diameter [6]. The fibers are bonded with a thermosetting vinyl ester resin. The data on the mechanical properties of the rebars was provided by the manufacturer [6]. Based on tests of a large number of bars with different diameters, a mean tensile strength of 1180 MPa (171 ksi) and a mean modulus of elasticity of 53.6 GPa ( $7.7 \times 10^3$  ksi) were obtained for the rebars. The standard deviations for the tensile strength and modulus of elasticity were 38.6 MPa (5.6 ksi) and 8.8 GPa ( $1.28 \times 10^3$  ksi), respectively. The stress-strain behavior was linear to failure. Figure 2 shows a typical stress-strain relationship for the bars with the mean tensile strength and modulus of elasticity. To improve the bond behavior of GFRP rebars to concrete, additional strands of glass fibers are wound around the bars in a spiral during the manufacturing process to create a rough (ribbed) surface. Figure 3 shows a typical GFRP rebar and a stirrup.

### Test Specimens

The static strength of concrete beams reinforced with GFRP bars and stirrups was investigated with tests of five rectangular beams and one T-beam. Figures 4(a) and 4(b) show a typical rectangular beam and the T-beam. Tables 1 and 2 summarize the design details of the beams. In order to separately observe the behavior of longitudinal (flexural) reinforcements and transverse (shear) reinforcements, beams F1, F2 and F3 were constructed with GFRP longitudinal rebars and conventional steel stirrups; beams S1, S2 and S3 were constructed with longitudi-

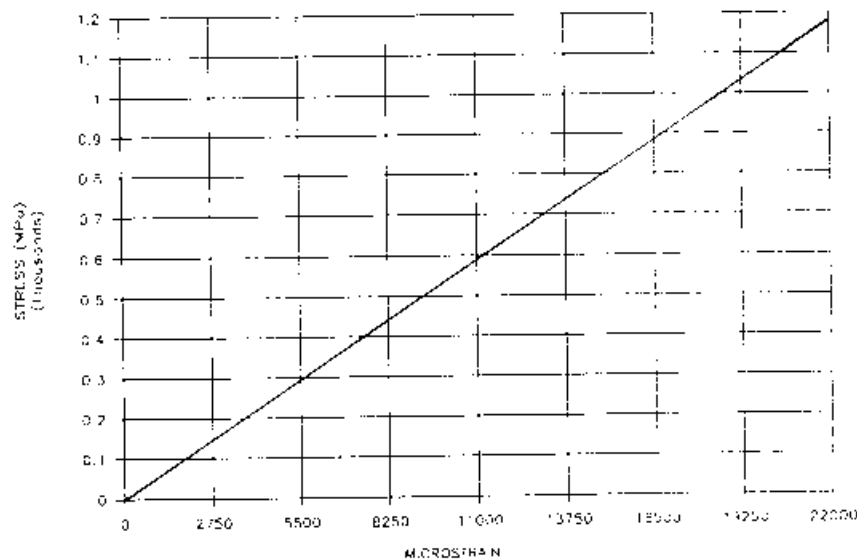


Figure 2. Stress-strain relationship of GFRP rebar.

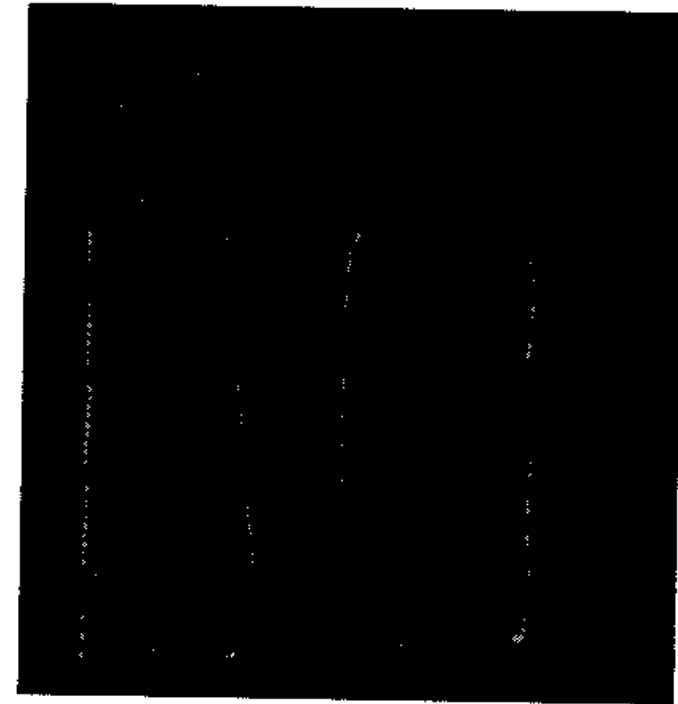


Figure 3. Typical GFRP bar and stirrup.

nal steel rebars and GFRP stirrups. Grade 60 steel with a measured yield stress of 480 MPa (69.5 ksi) was used in all beams.

### Instrumentation and Test Procedure

All beams were simply supported and were subjected to two equal concentrated loads 400 mm (18 in.) apart, and symmetrically placed about the midspan. The load was applied by means of a hydraulic jack in small increments up to failure of the beam. The deflection at midspan of each beam was measured using two Linear Variable Differential Transducers (LVDT). After each increment of the load the deflection and the load were measured and recorded.

### Test Results

The behavior of each beam was characterized by its load vs. deflection response to failure. A comparison was made between the theoretical or predicted maximum load and the measured maximum load to investigate the effectiveness of the plastic rebars as reinforcement for concrete beams.

The load vs. deflection curve for beam F1 is shown in Figure 5. The behavior was initially linear elastic. At a load of 40 kN (9 kips), concrete cracked in ten-

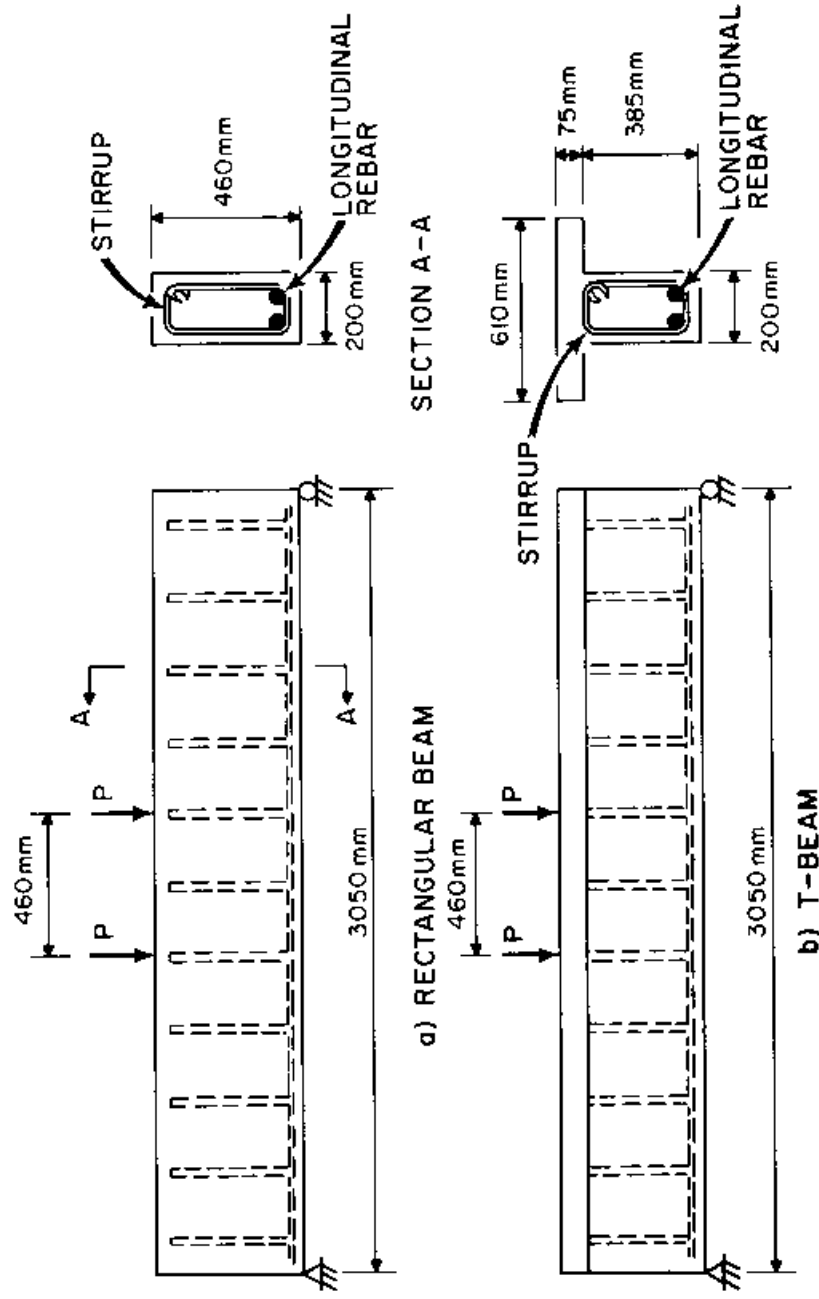


Figure 4. Typical reinforced concrete test beams.

Table 1. Design details of test beams with longitudinal GFRP bars and steel stirrups.

Beam	Longitudinal Bar Diameter mm (in.)	No. of Bars	Stirrup Diameter mm (in.)	Stirrup Spacing mm (in.)	Concrete Compressive Strength MPa (ksi)
F1	20 (0.8)	4	13 (0.5)	100 (4)	31 (4.5)
F2*	20 (0.8)	4	13 (0.5)	100 (4)	33 (4.8)
F3	13 (0.5)	2	13 (0.5)	100 (4)	31 (4.5)

\*T-beam.

Table 2. Design details of test beams with longitudinal steel bars and GFRP stirrups.

Beam	Longitudinal Bar		No. of Bars	Stirrup Diameter		Stirrup Spacing		Concrete Compressive Strength	
	Diameter mm (in.)	Diameter mm (in.)		mm (in.)	mm (in.)	Strength MPa (ksi)	Strength MPa (ksi)		
S1	22 (0.87)	10 (0.4)	2	75 (3)	33 (4.8)				
S2	22 (0.87)	10 (0.4)	2	150 (6)	33 (4.8)				
S3	22 (0.87)	10 (0.4)	2	300 (12)	30 (4.3)				

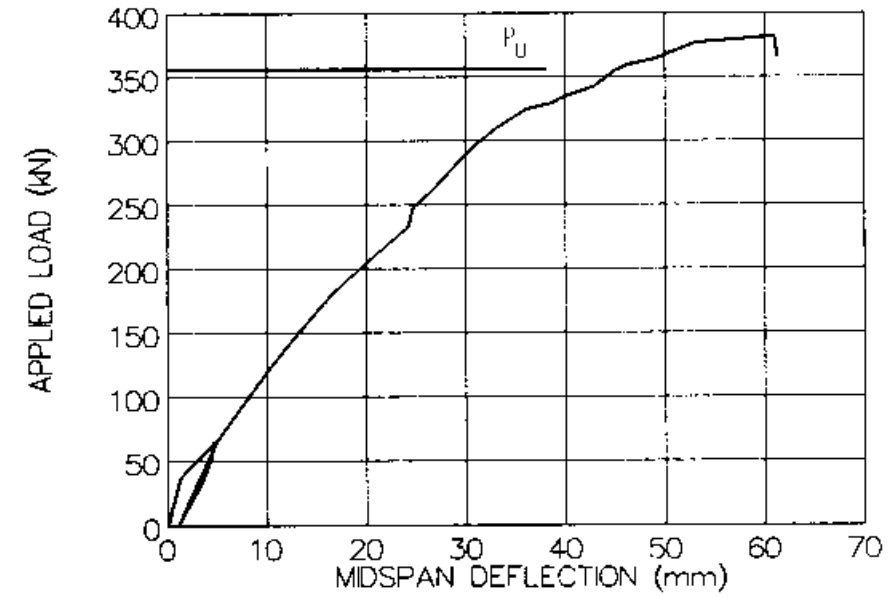


Figure 5. Load versus midspan deflection of beam F1.

sion (bottom face of beam) and the stiffness of the beam reduced, resulting in larger deflections. The loading was continued until the concrete crushed in compression at a load of 378 kN (85 kips). The theoretical maximum load,  $P_u$ , is shown on the same figure with the horizontal line. This load was calculated based on the theories for the analysis of concrete beams reinforced with steel bars, but using the mechanical properties of GFRP rebars. The theoretical and measured maximum loads were reasonably close, indicating that the plastic bars effectively reinforced the beam and also that the classical theories for analyzing concrete beams reinforced with steel bars can be used with good accuracy to predict the behavior of concrete beams reinforced with plastic bars. Tension cracks were uniformly distributed along the beam. The actual width of the tension cracks were not measured, however, they seemed to be slightly larger than those for beams reinforced with steel rebars. This is attributed to the lower modulus of elasticity of GFRP rebars. The large number of fine distributed cracks indicated a good mechanical bond between the GFRP rebars and concrete. Figure 6 shows the failure of the beam at the conclusion of the test.

The load vs. deflection to failure of beam F2 (T-beam) is shown in Figure 7. The behavior was generally similar to that of beam F1. The stiffness reduced after the concrete cracked at a load of 31 kN (7 kips). The loading was then continued up to 222 kN (50 kips); at that point the beam was completely unloaded and then reloaded. The load-deflection curve exhibited a slight hysteresis loop upon unloading and then reloading, but the loop closed almost at the same point at which the beam had been unloaded, indicating that under cyclic (repeated) load-

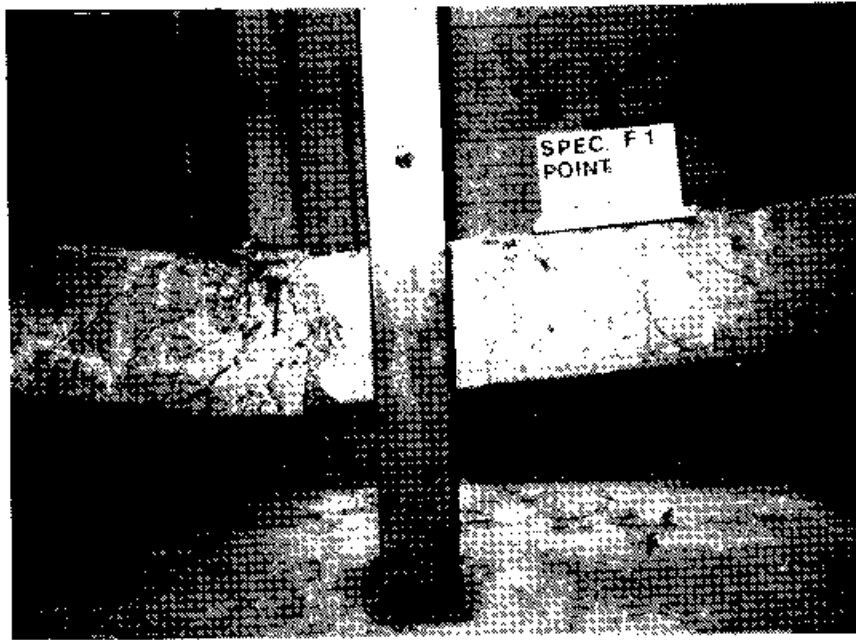


Figure 6. Beam F1 at failure.

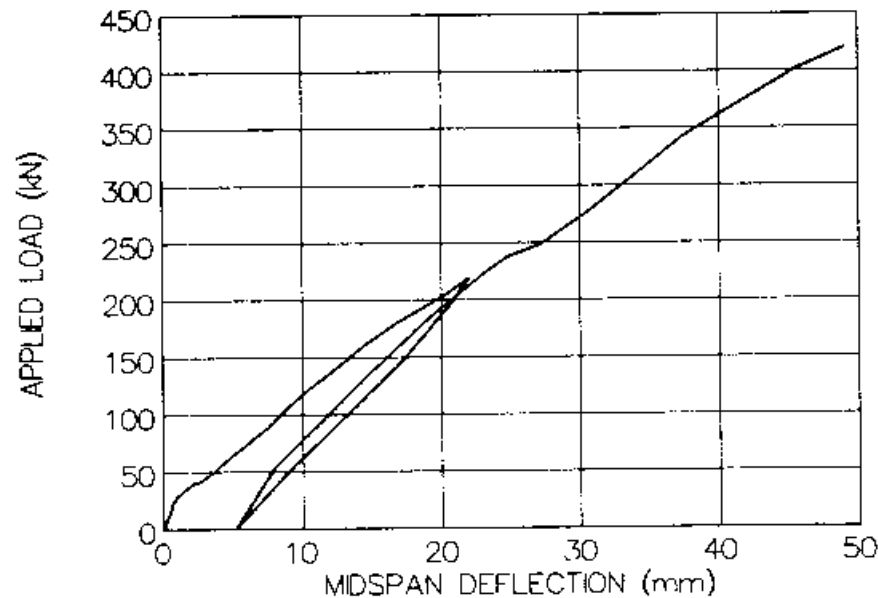


Figure 7. Load versus midspan deflection of beam F2 (I-beam).

ing the load carrying capacity of the beam does not decrease significantly. In addition, due to the perfect linear elastic behavior of the plastic rebars, substantial deflection recovery was observed upon unloading of the beam. A complete investigation of the behavior of this type of beam under cyclic loading requires fatigue testing. This was beyond the scope of the present study. The loading was then continued until failure was reached at a load of 423 kN (95 kips). The theoretical maximum load is not shown on the figure because the T-beam failed prematurely when a section of the outstanding part of the flange broke locally in tension under the load point. This occurred due to the accidental omission of the transverse rebars in the top flange during the construction.

Figure 8 shows the load vs. deflection response of beam F3. The area of reinforcement in this beam was significantly smaller than the first two beams. The stiffness of the beam reduced after concrete cracked in tension at a load of 24 kN (5.4 kips). After cracking, the load vs. deflection response was almost linear until the failure was reached at a load of 134 kN (30 kips). The theoretical maximum load,  $P_U$ , shown with the horizontal line, is reasonably close to the measured value. The failure of this beam was reached when the plastic bars ruptured, as shown in Figure 9. The cracking behavior of this beam was different from that in beams F1 and F2. The cracks were larger in size and fewer in numbers. Two cracks, near the loading points, became sufficiently open to result in the rupture of bars and splitting of the beam in three segments as can be seen from Figure

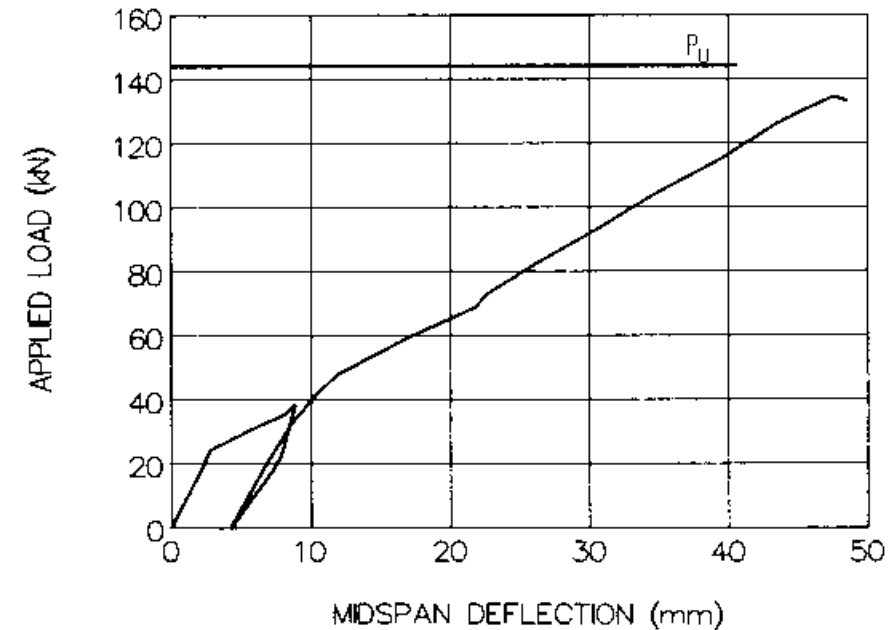


Figure 8. Load versus midspan deflection of beam F3.



Figure 9. Beam F3 at failure.

9. This failure mode in the underreinforced beam F3 was due to the low ductility of GFRP rebars. Satisfactory design procedures need to be developed to prevent failure of beams by rupture of GFRP bars.

All S-series beams were reinforced with longitudinal steel rebars and GFRP stirrups. The closed-loop GFRP stirrups, with a leg diameter of 10 mm (0.4 in.), were placed at 75 mm (3 in.), 150 mm (6 in.), and 300 mm (12 in.) intervals in beams S1, S2 and S3, respectively. Plots of load vs. deflection for beams S1, S2 and S3 are shown in Figures 10 through 12, respectively. The load deflection curves of all beams were initially linear. After each beam cracked at a load of approximately 36 kN (8 kips), the stiffness reduced resulting in larger deflection. The linear behavior then continued until the longitudinal steel rebar yielded at about 200 kN (45 kips). This resulted in further reduction in stiffness and a progressively nonlinear load-deflection response until failure was reached by crushing of concrete in compression. None of the beams failed in shear, indicating that the GFRP stirrups effectively resisted the shear forces in all beams. In addition, no major distress due to shear stresses or large shear cracks were observed. The number and pattern of shear cracks were similar to those in beams F1 and F3 which had conventional steel stirrups. The actual crack widths were not measured, however, they were comparable to those in beams with steel stirrups. The theoretical maximum load,  $P_u$ , is shown with the horizontal lines in Figures 10 through 12. Because strain hardening of longitudinal steel was ignored in calculating the theoretical maximum load, the calculated loads are slightly smaller than the measured values. All S-series beams failed when concrete crushed in compression. A typical beam (beam S2) is shown at failure in Figure 13.

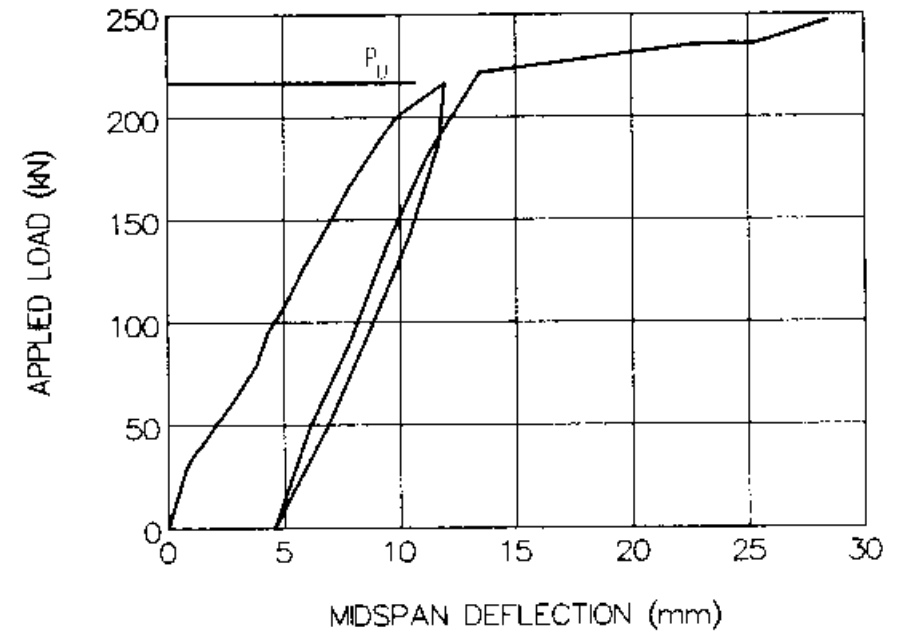


Figure 10. Load versus midspan deflection of beam S1.

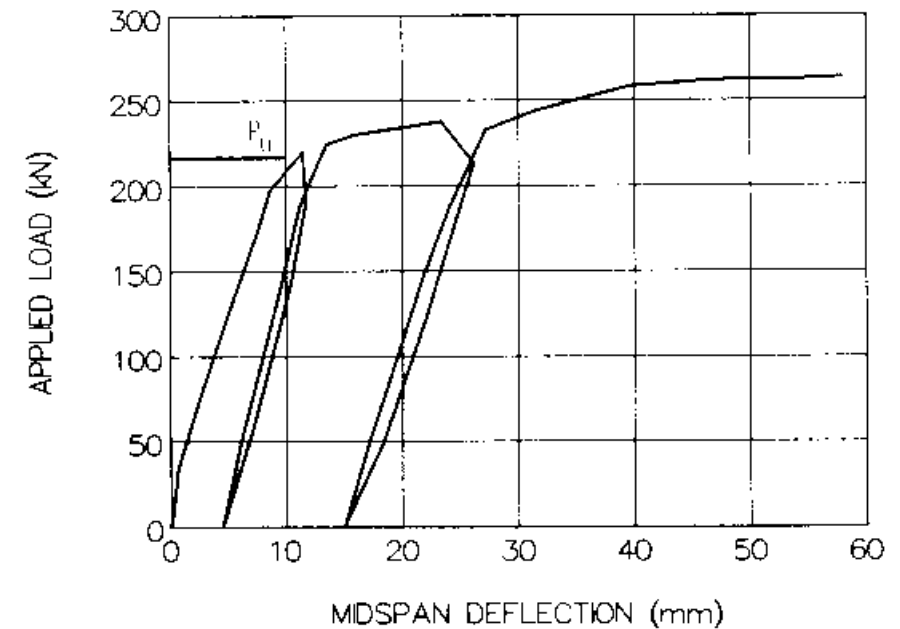


Figure 11. Load versus midspan deflection of beam S2.

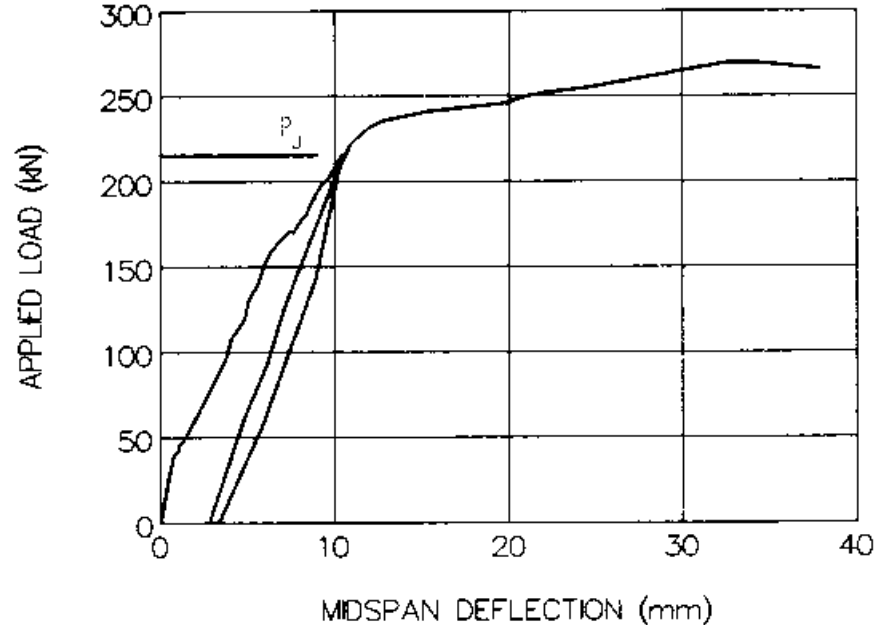


Figure 12. Load versus midspan deflection of beam S3.

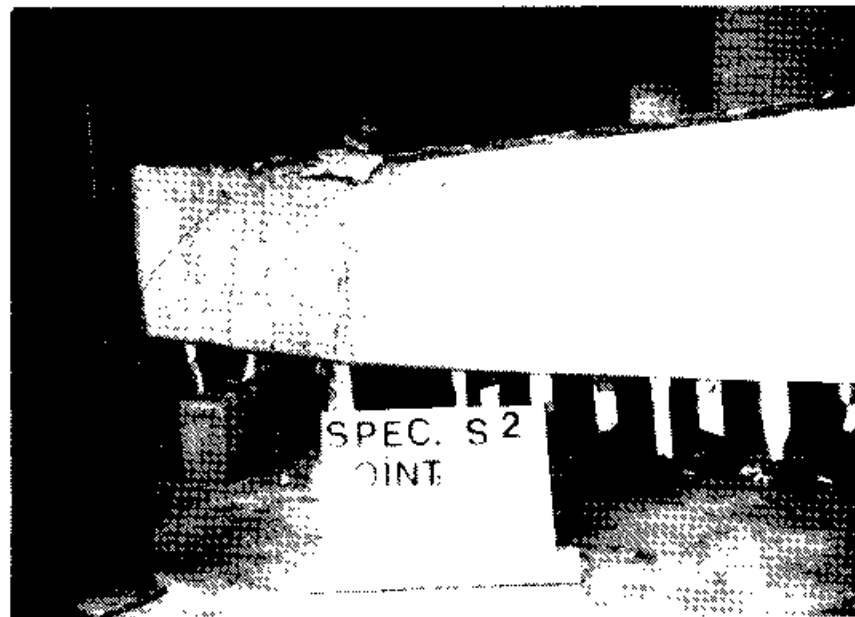


Figure 13. Beam S2 at failure

## CONCLUSIONS AND FUTURE STUDIES

The preliminary results from the tests of concrete beams reinforced with fiber composite rebars and stirrups indicate that great potential exists for the use of synthetic rebars in concrete structures, especially in areas where corrosion is a problem. Because the modulus of elasticity of GFRP rebars is about one-fourth that of steel, plastic rebars deflect four times as much as steel. Therefore, deflection might become the limiting design criterion for certain structural elements. The bond between the GFRP rebars and concrete was good in the beams tested, and no failure was observed due to debonding of the rebars and concrete.

Before field application of fiber composite rebars, however, additional studies must be undertaken to address several key issues such as creep, relaxation, and fatigue behavior of concrete members reinforced with GFRP rebars. Other studies may include a comprehensive investigation of the bond behavior of GFRP bars and concrete as well as establishing a rational approach for determining the minimum required development length of these bars. In addition, the success of fiber composite materials for civil engineering applications requires a close collaboration between materials scientists and civil engineers. Such collaboration should result in the development of fiber composite materials with the desired properties for civil engineering type applications.

## NOTATION

- $P$  applied load
- $L$  length of beam
- $w$  weight of beam per unit length
- $C$  compressive force in concrete
- $T$  tension force in steel bar
- $d$  distance between the lines of action of compressive and tension forces

## REFERENCES

1. Nilson, A. H. and G. Winter. 1986. *Design of Concrete Structures*. Tenth Edition, McGraw-Hill, Inc.
2. MacGregor, J. G. 1988. *Reinforced Concrete—Mechanics and Design*. Prentice Hall.
3. Ferguson, P. M., J. E. Green and J. O. Jusa. 1988. *Reinforced Concrete Fundamentals*, 5th Edition. Wiley.
4. Gibson, F. W. 1987. *Corrosion, Concrete and Chlorides—Steel Corrosion in Concrete: Causes and Restraints*. American Concrete Institute, SP-102.
5. "Highway Bridge Replacement and Rehabilitation Program," 8th Annual Report of the Secretary of Transportation to the Congress of the United States, Bridge Division, Office of Engineering, Federal Highway Administration, Washington, D.C. (1986).
6. Pleimann, L. G. 1987. "Tension and Bond Pull-Out Tests of Deformed Fiberglass Rods," Final Report, Vega Technologies, Marshall, Arkansas.