Analytical Evaluation of Fibre-Reinforced Plastic Corrugated Sheet

C.K. Gautam and R.C. Pathak

Research & Development Establishment (Engrs), Pune-41 015.

ABSTRACT

Fibre-reinforced composites play a lead role as advanced materials in modern day structures. This paper reports fabrication and testing of fibre-reinforced corrugated sheet employing 4-point bend loading. An in-depth analysis has been carried out using ANSYS, a finite element method package. The theoretical results obtained are compared with the experimental values. The values of both inputs showed similar results conforming at a particular boundary condition. However, more similar experiments on such fibre-reinforced plastic corrugated sheets have been suggested for better comparison.

1. INTRODUCTION

Modern technology and recent developments have seen a wide range of fibre-reinforced plastic (FRP) composites for various structural applications in automobile, military, aerospace and other fields. These composites offer great promise as lightweight, corrosion-free, high strength structural materials and there is a growing demand for these composites in lightweight primary structures as well. The basic needs of these corrugated sheets which are used in the fabrication of shelter are lightweight, corrosion-resistant and sufficiently strong to carry the designed loads. It is envisaged to use FRP composite sheets in lieu of steel sheets, since FRP material is expected to closely fullfil these requirements. Corrugated sheet tests reported by Siddall, *et al.*[1] have shown that yielding in the zone of maximum corrugation takes place well before the ultimate load carrying capacity is reached. Sheet failure may be assumed when the yield point is reached in the zone of shallow corrugation or when the expected limit of plastic deformation is reached in the deepest

corrugation[2]. Because of the high residual stresses and the unpredictable nature of the local buckling, it is necessary to determine or confirm failure prediction by full scale testing of the corrugated sheet. This paper describes the analysis and experimental aspects of FRP corrugated sheet.

2. FABRICATION OF FRP COMPONENTS

In the fabrication of FRP composite components, it is necessary to ensure uniform distribution of reinforcement in the matrix[3] and that the reinforcing fibres are fully coated to ensure proper bonding with the matrix. It is also important to prepare the matrix containing appropriate amount of resin and hardener. In this process, epoxy resin araldite LY-556 with hardeners HT-972 and HY-951 was used. The proportion of resin and hardener depends upon the type of hardener used. These values were taken from the company's product manual[4].

In case of flat plate, epoxy, i.e. araldite LY-556 with hardener HY-951 was used. These were mixed in the ratio of 100:(10-12) for proper strength and

curing at room temperature. In case of FRP corrugated sheet, the matrix system was prepared with resin (araldite LY-556) and hardener (HT-972) in the ratio of 100:27. This mixture/composition was cured at high temperature. Both the mixtures give approximately equal strength. However, the latter is good for high temperature applications. The flat plate and FRP corrugated sheet were fabricated using E-glass woven fabric (stain) and epoxy resin. Hand lay-up process was adopted for the present experimental work.

desired thickness (5.2 mm - by 14 layers) was achieved. All the layers were placed in the same direction (i.e. 0° and 90°). After the last layer was coated with resin, another steel plate coated with releasing agent (facing downward) was placed on it. Pressure was applied on the upper surface of the top plate with the help of concrete blocks and the whole composite was left for curing at room temperature for 24 hr.

FRP corrugated sheet/component was processed using similar procedure and using steel
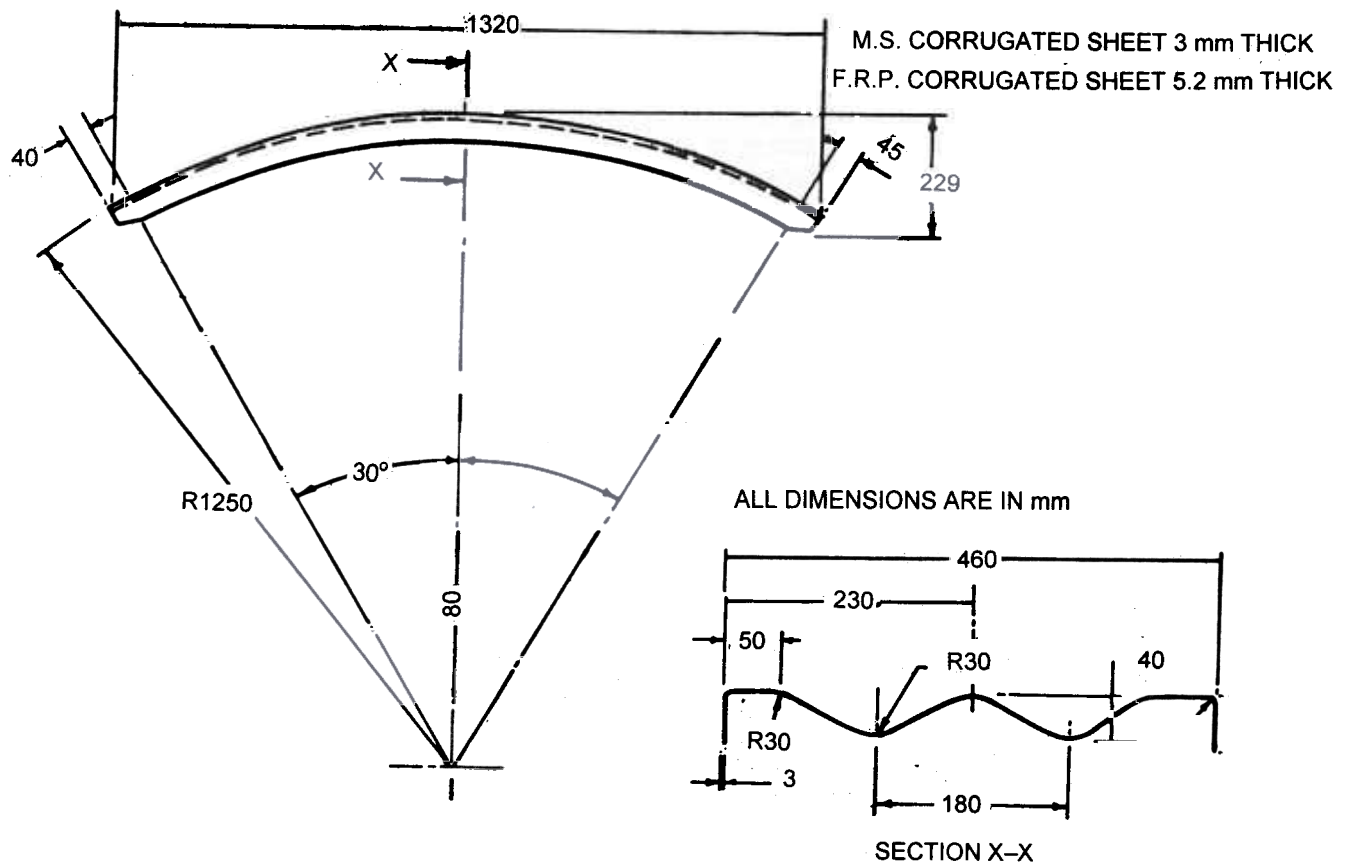

Figure 1. Details of corrugated sheets (mild steel mould and FRP component)

A steel plate free from rust, grease, etc. was used as a mould for FRP plate fabrication. Five coats of release agent, i.e. polyvinyl alcohol (PVA) were applied on the upper surface. After drying the final coat, epoxy resin was prepared and applied on PVA surface. A layer of E-glass-woven fabric was cut to the mould size. This fabric piece was placed on the resin layer. This process was repeated till the

mould. Mild steel corrugated sheet (Fig. 1) of desired dimensions and specifications was fabricated and tested for various designed loads. This mild steel corrugated sheet was used as mould for fabrication of FRP composite sheet, whereas gel coat was used as releasing agent in place of PVA for the fabrication of FRP corrugated sheet. Alternate layers of epoxy and glass fabric were laid until the

Table 1. Fabrication details of fibre-reinforced plastic components

Components	Matrix			Reinforcement		Weight fraction*	Curing Temperature (°C)	Time (hr)
	Epoxy	Hardener	Ratio	Type				
Flat plate	LY-556	HY-951	100:(10-12)	WF**	14	40:60	25	24
Component	LY-556	HT-972	100:27	WF**	14˚	40:60	100	4

*   Ratio of matrix to reinforcement
**   Woven fabric

required thickness was achieved. After laying the last layer, one poly vinyl chloride (PVC) sheet coated with PVA was placed and pressure was applied with the help of dry sand. The whole assembly was then kept inside an oven at 100° C for a curing period of 4 hr. After curing was over, pressure was released and component was taken out from the mould. The details of fabrication are summarised in Table 1.

3. RESULTS & DISCUSSION

3.1 Mechanical Properties of FRP Composite

Strength and elastic properties of FRP composite were measured by tensile and flexural specimen testing. These properties were used for
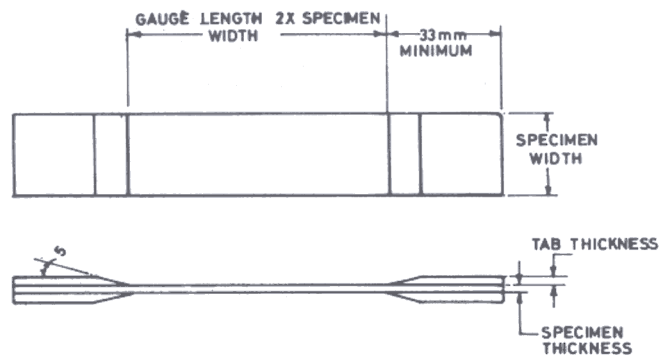

Figure 2(a). Tensile test specimen geometry (ASTM Standard D-3039 M)

analysis of FRP corrugated sheet. Actual 4-point bend test was also carried out on FRP corrugated sheet.

Test specimen for the measurement of tensile and flexural properties were prepared as per ASTM, D-3039 and D-790[5,6], respectively. For tension and flexural testing, specimen were cut from flat plate. All specimen were machined to required geometry

using milling machine with high speed tools. Machining was done with proper care to avoid any defect/delamination. All tests were carried out at room temperature on Universal Testing Machine. Tensile and flexural test specimen are shown in Figs 2(a) and (b), respectively. For tensile testing, specimen's dimensions are

Gauge length	178.0 mm
Specimen length	254.0 mm,
Specimen width	25.4 mm, and
Thickness	5.2 mm

For 3-point flexural test, specimen's dimensions are

Support span (L)	200.0 mm,
Specimen length	240.0 mm,
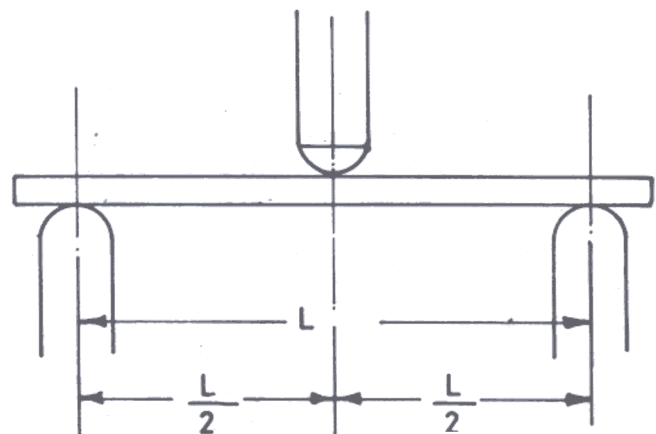
Figure 2(b). Flexural test specimen geometry (ASTM Standard D-790 M).

Specimen width	10.0 mm, and
Thickness	5.2 mm.

These dimensions of specimen were taken as conforming to respective ASTM standards.
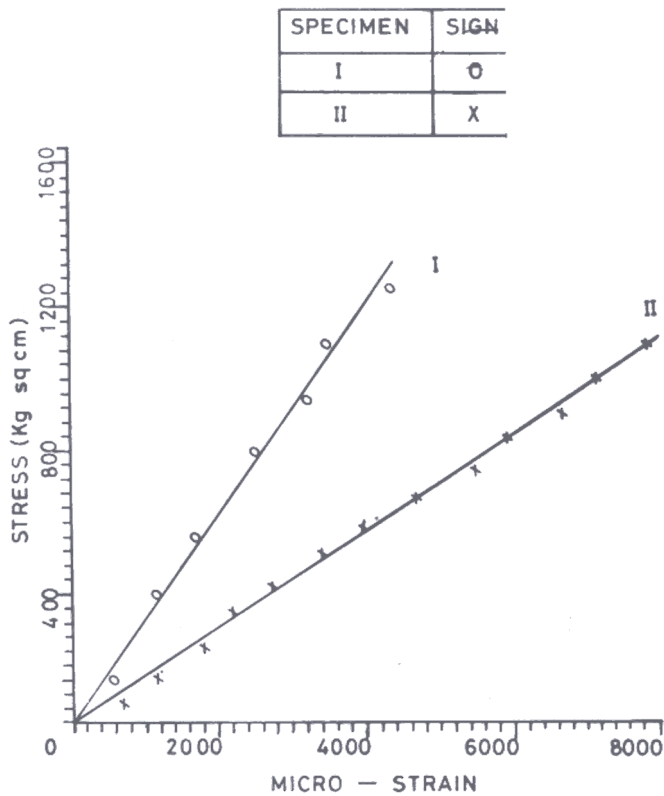
SPECIMEN	SIGN
I	O
II	X

Figure 2(c). Tensile test of two FRP composite specimen and their corresponding stress-strain curves (ASTM Standard D-790 M).

Figure 2(d). Flexural test of 3 FRP composite specimen and their corresponding low-deflection curves.

Two foil type strain gauges of 5 mm length and 350 Ω resistance were fixed on each tensile test specimen to measure longitudinal and transverse strains. A dial gauge was used for measuring the displacement (i.e. percentage elongation) of test specimen under tensile load. Tabs were made from the same plate. Load on the tensile specimen was given steps of 1 kN (100 kg) at a time and with each increment of load, dial gauge reading (deflection) and strain gauge reading (strain) were recorded. The loading rate was kept at the lowest possible, within experimentation limitations and also maintained constant. Two specimen were tested in duplicate. The stress-strain curve of tensile test specimen are shown in Fig. 2(c). Based on these results, tensile strength, modulus of elasticity and Poission ratio of FRP composite were calculated. These values were used in the analysis of FRP corrugated sheet.
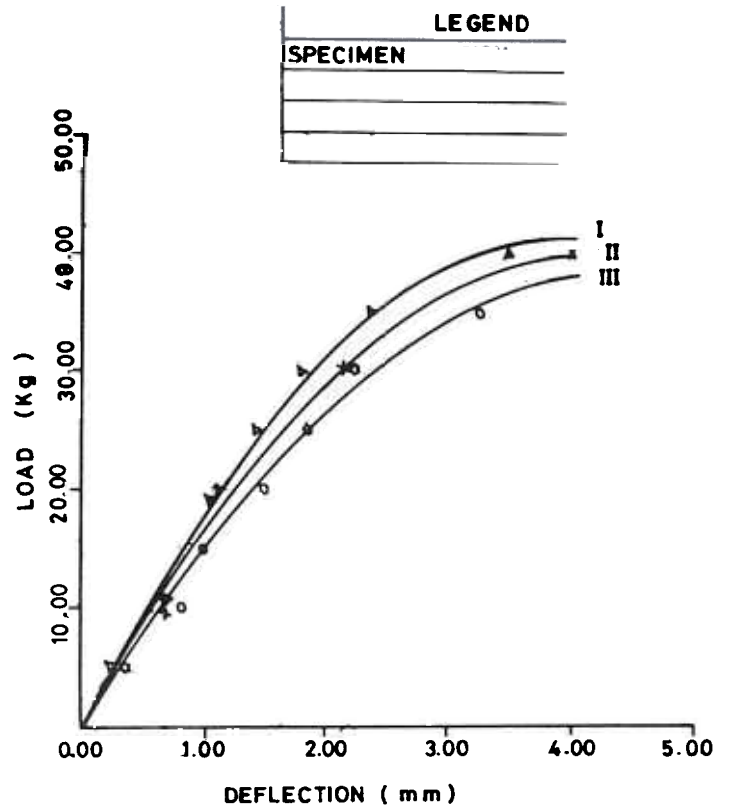
In case of flexural tests, deflection was measured by two dial gauges placed under the specimen at equal distance from the centre on both sides. Load-deflection curves were plotted for all the three flexural specimens and are shown in Fig. 2(d). In this case, loading in the steps of 50 N (5 kg) was applied and dial gauge values (deflections) on both sides were recorded for each loading step. From 3-point flexural specimen tests, flexural properties like flexural strength and modulus of FRP composite were calculated. These values were used to validate the results obtained from tensile tests and used in the analysis of FRP corrugated sheets. The mechanical properties of glass/epoxy composite evaluated are given in Table 2.

3.2 FRP Corrugated Sheet Testing

FRP corrugated sheet was tested under 4-point bend loading (Fig. 3). Supports and loading fixtures were prepared using teakwood planks of size
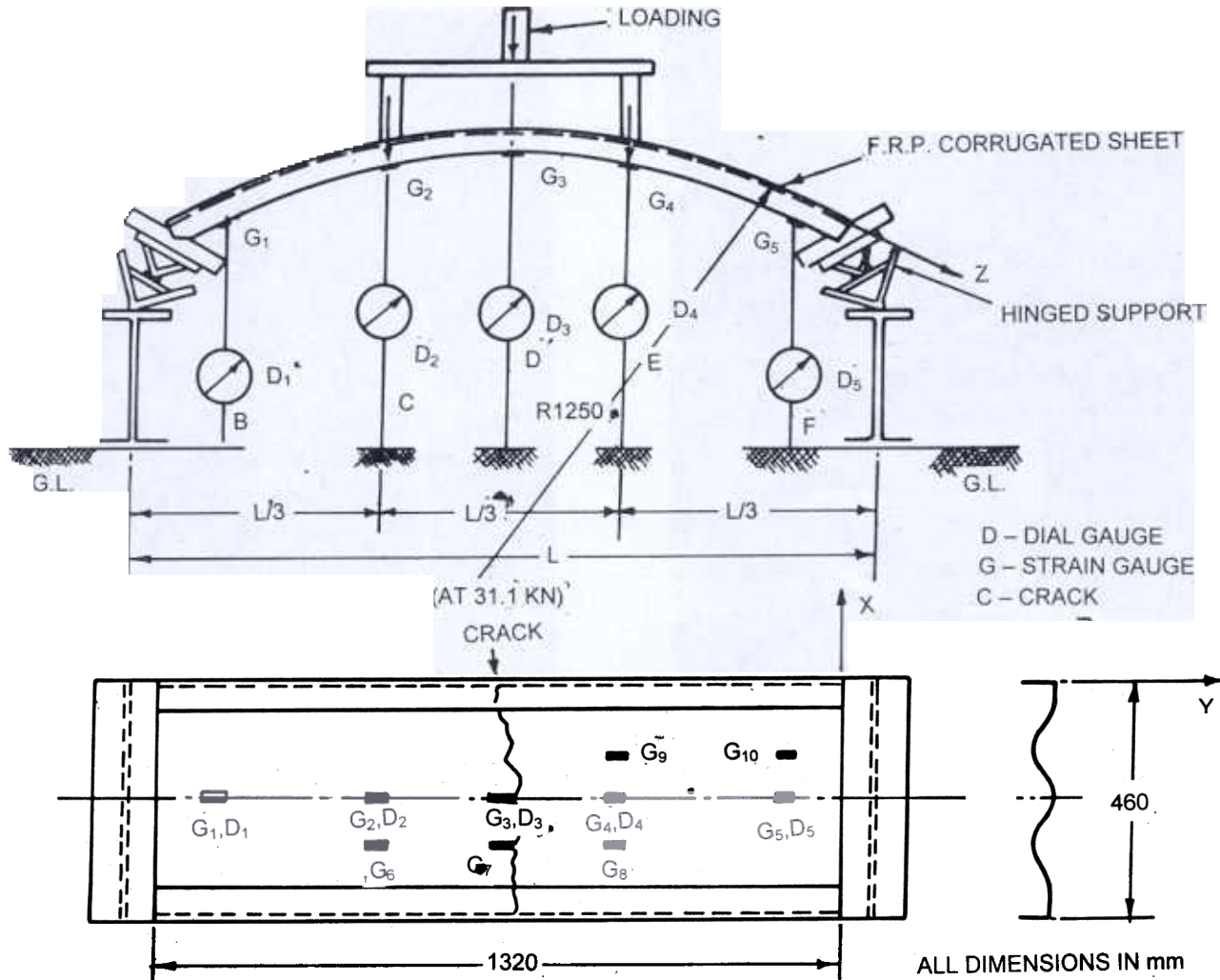
Figure 3. Line diagram of 4-point bend test setup of FRP component testing.

500 mm x 100 mm x 38 mm. Both the edges of corrugated sheet were inserted in these rectangular timber planks which were supported on angle edges. Grooves (10 mm) of the same profile as the corrugated sheet were made on one side of the plank (100 mm width). On the back side of each plank, one steel flat supported on angle was fixed. This

sheet, was loaded along two lines across the length (Figs 4 and 5). To retain a horizontal lower surface, the wooden planks were also given the same slope as that of the corrugated sheet. Rubber paddings were used to take care of any unevenness in the

Table 3 : Deflection values under 10 kN load

Boundary conditions	Deflection (mm)
Experimental value	
Analytical values	
both ends Uz are fixed	1.41
one end Uz is free	39.47
one end Uz (deflected by 10 mm)	17.99
one end Uz (deflected by 5 mm)	9.31
one end Uz (deflected by 1 mm)	2.94

Table 2. Mechanical Properties of fibre-reinforced plastic composite

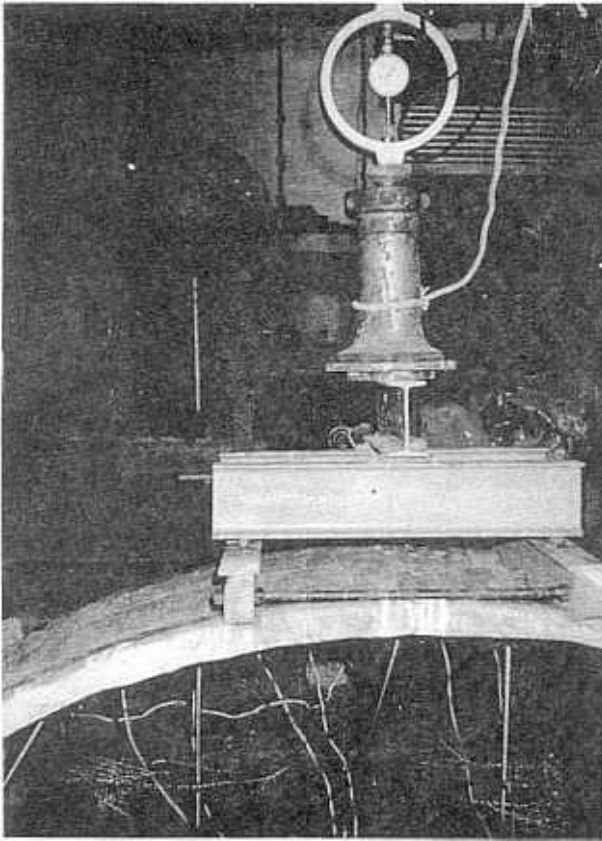| Property	Value
Tensile strength	
Young's modulus	
Poisson's ratio	
Flexural strength	
Flexural modulus	

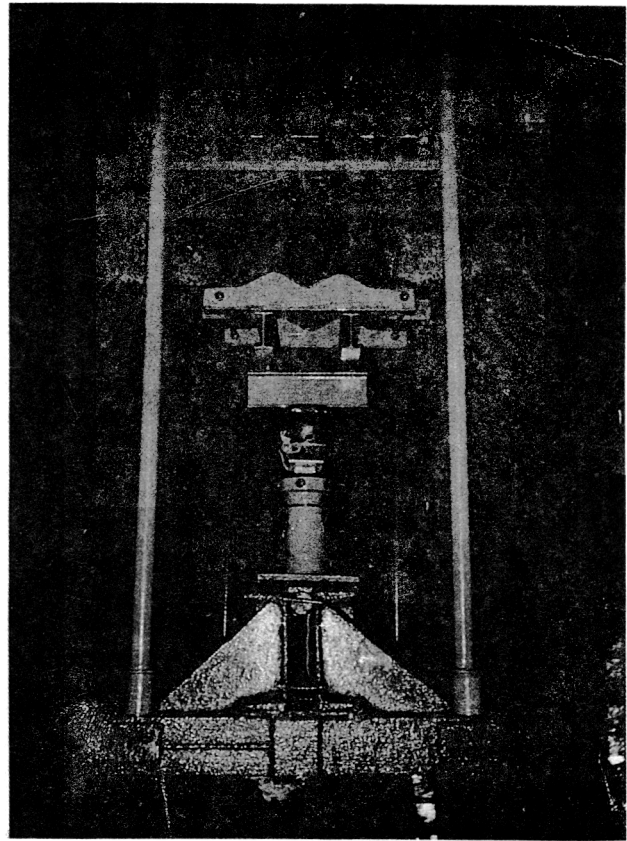Figure 4. Front view of experimental setup for the testing of FRP component.

Figure 5. Side view of experimental setup for the testing of FRP component.

profiles. Two I-sections were placed across the wooden planks. One I-section was placed across these two I-sections. Loading was done with the help of a screw jack and the load was measured with the proving ring.

Dial gauge and strain gauge readings were recorded at constant load interval of 1 kN. Load-deflection data obtained are shown in Fig. 6. FRP corrugated sheet made of glass woven fabric failed at a load of 31.1 kN. From the deflection values of B and F dial gauges near supports, it becomes clear that F support has shifted, causing more downward deflection. At two different load values, deflections at B and F are given below :

Load (kN)	Deflection at back (mm)	Deflection at front (mm)
10	1.89	3.83
29	4.93	8.17

3.3 Finite Element Analysis of Fibre-Reinforced Plastic Components

ANSYS package[7] was used for stress analysis of FRP corrugated sheet. Due to symmetry, only one half of the sheet was considered. Loading was also taken equal to half of the total value. Rotation in 'X' direction (parallel to the horizontal) was allowed on the edges while all other translations and rotations were arrested (Fig. 7). Besides the mechanical properties of FRP composites (Table 2), the following properties of FRP corrugated sheet were used for the analysis:

Specific gravity (S)   1.83
Number of layers   14.00
Thickness (t)   5.2.01 mm, and
Element surface pressure   0.24 MPa

The boundary conditions employed were: (i) symmetry along one side, while other side along

the flange was kept free and (ii) other two edges were connected with 3-D solid beams whose ends were constraints, such that only rotation about

➝ B - DIAL GAUGE NEAR RIGHT SUPPORT
➝ C - DIAL GAUGE UNDER LOAD
➝ D - DIAL GAUGE AT THE CENTRE
➝ E - DIAL GAUGE UNDER LOAD
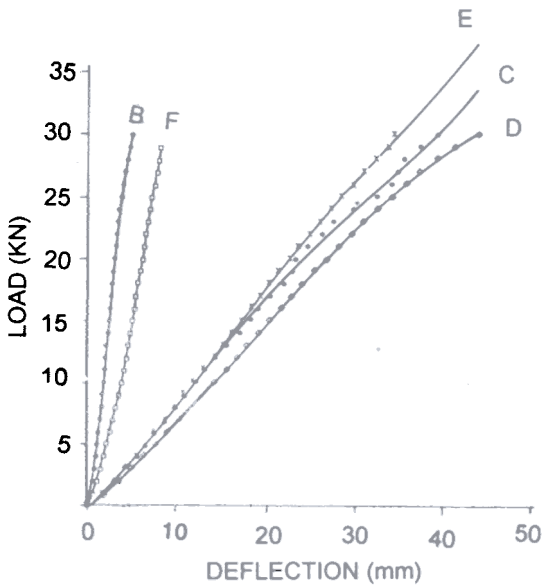➝ F - DIAL GAUGE NEAR LEFT SUPPORT

Figure 6. Load-deflection data of FRP corrugated sheet obtained at different locations.

$U_x = U_y = U_z = 0$
ROTY = ROTZ = 0

u = DISPLACEMENT
ROT = ROTATION
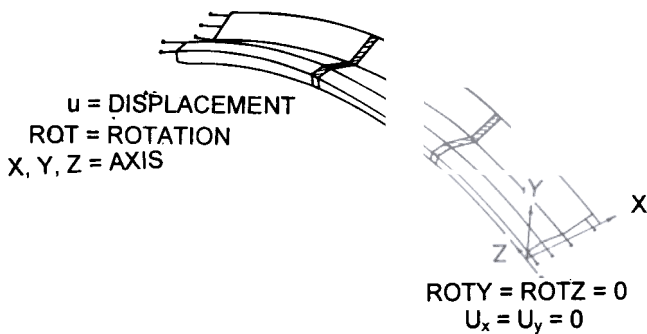X, Y, Z = AXIS

ROTY = ROTZ = 0
$U_x = U_y = 0$

Figure 7. Line diagram showing boundary conditions and position of loads for analysis.

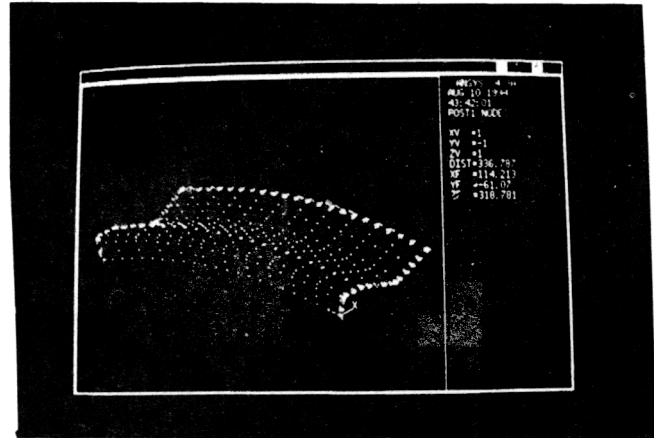X-axis was allowed. However, displacement along

Figure 8. Finite element analysis showing nodes and boundary conditions.

Z-axis was also partially allowed on the edge. An 8-noded shell element was used for the analysis.

Figure 7 shows the coordinate axes and boundary conditions for the analysis of FRP corrugated sheet. Figures 8 and 9 show the nodal plot and stress contour of corrugated sheet, respectively. From the stress contour (Fig. 9), it is clear that the maximum value of stress is 15.096 N/mm^2 (=15.1 MPa) under the element surface pressure of 0.24 MPa. This is safe since the ultimate tensile strength of FRP composite is 135 MPa (Table 2). Similarly, maximum deflection value is also very less (i.e. 3.55 mm) as compared to the dimensions of FRP corrugated sheet. (length:
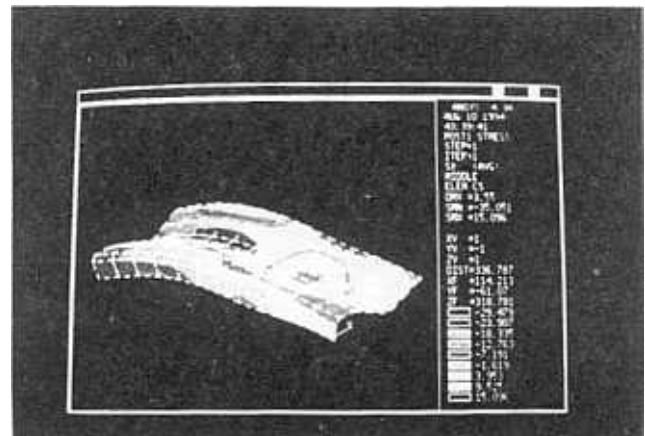

Figure 9. Finite element analysis showing stress contour of the FRP sheet.

1320 mm and width: 460 mm) (Fig. 1). Figure 9 clearly show the higher stress area in FRP corrugated sheet under one load. This was due to unequal settlement and shifting of one support.

4 RESULTS & DISCUSSION

Analysis of FRP corrugated sheet was done for different boundary conditions by comparing the deflection values with the corresponding experimental values. Firstly, both ends of corrugated sheet were hinged (no movement was allowed in the Z-direction, (Fig. 7). The deflection under 10 kN load was 1.41 mm, which is less than the experimental values. Secondly, one support was allowed to move in Z-direction. In this case, deflection under the same loading conditions was 39.47 mm, a value which exceeded the experimental value. By allowing one support to move by 7 mm, matching deflection value was obtained. Comparison between analytical and experimental values is given in Table 3. From the data in Table 3, it is clear that a slight shift/deflection in Z-direction, changes the results drastically. During experimentation, there were chances of slight shift (approx 7 mm) in one of the support along the corrugated sheet, which could cause deflection (12.5 mm) in vertical direction. However, more number of corrugated sheets are to be tested for further verification and precise definition of boundary conditions.

7. CONCLUSION

A sample experimental case of FRP component of a shelter/structure was analysed for its salient stress/strain and deflection characteristics. The experimentally obtained deflection values showed resemblence with those predicted using ANSYS, a finite element package.

ACKNOWLEDGEMENTS

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Countributors

Mr CK Gautam obtained his MTech (Materials Science) from Indian Institute of Technology (IIT), Bombay, in 1995. He joined DRDO at the Snow & Avalanche Study Establishment (SASE), Manali. His areas of research include design/development of many avalanche control stuctures. Presently, he is working as Senior Scientist at the Research & Development Establishment (Engrs), Pune, where he is involved in the development of blast-resistant structures.

Col (Dr) RC Pathak obtained his MTech and PhD (Geotechnical Engg.) both from Indian Institute of Technology (IIT), Delhi, in 1984 and 1988, respectively. Presently, he is working at the Research & Development Establishment (Engrs), Pune and is heading Field and Cold Region Engineering Group. His areas of research include geotechnical engineering, blast-proof structures and cold region engineering. He also took part in one of the Indian Antarctic Expeditions. He has published over 57 papers in national/international journals and also attended many conferences/seminars in India and abroad.