

# Glass-Fiber-Reinforced Composites in Building Construction

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Glass-fiber-reinforced plastic composites have had limited use as structural components in building construction. To realize the full potential of these materials and increase their use, their outstanding features must be emphasized. In developing composite components, it is essential to combine expertise in the disciplines of plastic and reinforcing materials, structural design, and fabrication techniques. Efficiently designed composite components and a case history are presented to demonstrate typical practical applications.

The unique building shown in Figure 1, the first of its kind, is constructed entirely of glass-fiber-reinforced materials. Because the building is used as a radio-frequency testing station, all components above the ground are required to be nonmetallic so that they do not interfere with electromagnetic waves associated with the operation. Therefore, the components such as rigid frames, columns, purlins and girts, accessories, connections including bolts and nuts, and cladding (building side panels and roof panels) are all made of glass-fiber-reinforced composites. The building is designed like a stressed-skin aircraft structure using torque-box type rigid frames, purlins, and girts.

This unprecedented use of advanced composites as primary structural components met the structural requirements with minimal weight and number of members, thus minimizing overall costs. The composite structures rely on the strengths while recognizing the limitations of the composite materials, without attempting to duplicate standard sections made of rolled or light gauge steels (Figure 2). The structures are designed on the merits of the mechanical properties of the composite material. Control of the stress levels and deflection to within the allowable limits of the composite materials is achieved by the design of the reinforcing scheme, the geometry of the cross section, and the thickness of the skin. The disciplines of structural design, composite materials, and fabrication are linked together to achieve a workable, cost-effective, finished project.

## WHY COMPOSITES?

Plastic composites are excellent for corrosion-resistant applications, besides being nonmagnetic and electrically nonconductive. Considering the devastating cost of damage done by corrosion to metal parts in industrial buildings, glass-fiber-reinforced components (e.g., panels, purlins, and girts) are

viable, attractive alternatives because of their favorable life-cycle cost. Their light weight reduces installation time and costs. In addition, the degree of light translucency or color tones can be varied.



FIGURE 1 Interior of building made entirely of glass-fiber-reinforced composites.

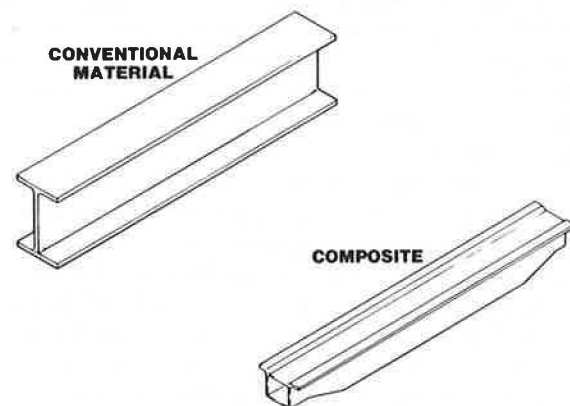


FIGURE 2 While free or unsupported edges in beam design are acceptable with steel shapes, low Young's modulus composite materials require captive elements to resist buckling.

Currently composites are only used in applications where conventional materials such as steel fail to function effectively.

### WHY NOT BEFORE?

The plastic composites industry celebrated its 42nd anniversary at the 42nd SPI Annual Conference and Expo '87 held in Cincinnati, Ohio, in February, 1987. There have been some plastic composites structures built in the past—The Monsanto House of the Future (1957), geodesic domes, shell roofs, and buildings using wide-flange beam shapes and sandwich panels. However, those structures were showcases with little potential for use in the mainstream of the building industry. When it came to meeting the requirements for a standard structure for an industrial building (20- to 25-ft bay spacing and 40- to 60-ft clear spans), none were available. Components suitable for long spans, when feasible, were too expensive because of material and fabrication costs.

Lack of communication between composites industries and building construction industries has caused a great deal of delay in development of composites as building construction materials. In order to build a product such as a preengineered composite building from its conception to final product, expertise in all related disciplines is needed. This requires a designer who works with a stress analyst and composite engineer to come up with the final design for fabrication. Integrating the design of the composite material to the production process is another difficult task. A full-scale test to verify the integrity of the structure is often required (Figure 3). All of these prerequisites, in addition to financial support, are required to make the project a reality.

### DESIGNING PERFORMANCE INTO THE COMPOSITE

Plastic composites use high-strength fibers, usually glass fibers because of their favorable cost and high tensile strength, for reinforcing components in a plastic-based matrix as a corrosion protective and stress transmission medium. Engineered composites are reliable structural materials that possess desirable inherent characteristics such as high strengths, corrosion resistance, nonelectromagnetism, and integral coloring. Composites for building construction applications require predictable short- and long-term behavior within the expected environments. These characteristics are achieved by using a functional resin system, reinforcement design, and a suitable structural shape (Figure 4).

The plastic resins include polyesters for cost and overall performance, vinyl esters for superior bonding, toughness and greater elongation, and long-term characteristics, and other special-purpose resins for chemical resistance. Various forms of fiber reinforcements include unidirectional rovings for high-unidirectional strength and stiffness; woven rovings for good orthotropic properties; and chopped-strand for continuous-strand mats for semi-isotropic properties, good shear strength, and bulk thickness.

In advanced composites, a reinforcing scheme based on the combination of mats and continuous rovings in relevant directions and positions is used. A plastic resin is selected on the



**FIGURE 3** This rigid frame is being tested with an 8,000-lb lateral load at the eave to check for stiffness of the frame and fixity of the base. Box section yields good stiffness in both planes, therefore, lateral support is not needed (a real advantage in erecting operations).

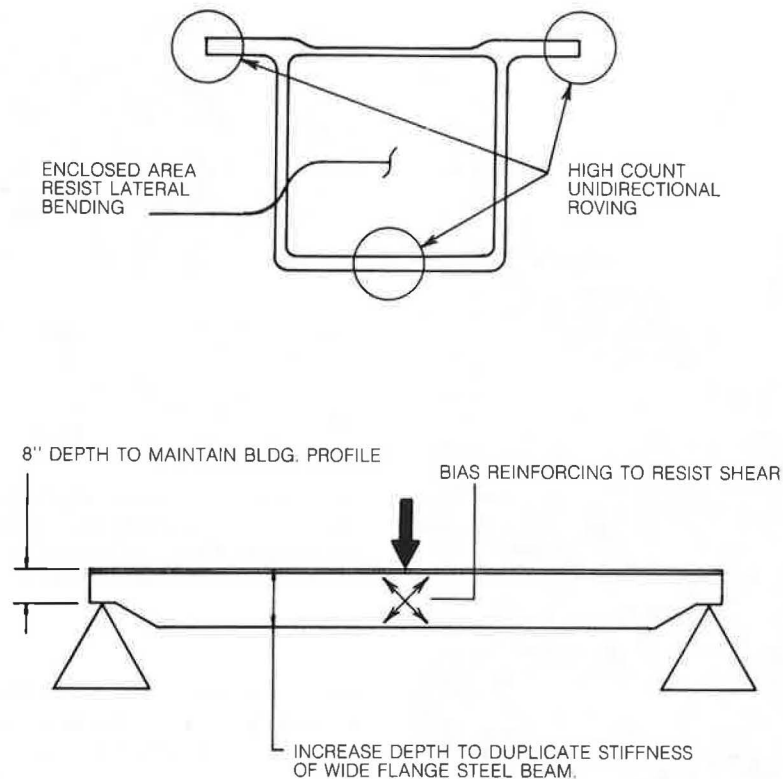
basis of service conditions and its interfacing compatibility with the reinforcing fibers so that the mode of failure is not controlled by the resin, which is the weak or limiting constituent in the composite.

The design of reinforced plastic components for building construction is mainly controlled by deflection limits and stability rather than strengths. Therefore, the structural shapes and fiber placement are designed to obtain the optimum stiffness. The technique is similar to the placement of steel rebars in a reinforced-concrete section. Maximum stress levels are kept relatively lower than those of conventional materials to prevent creep and stress rupture.

### HOW TO INCREASE AVAILABILITY OF COMPOSITES

A concerted effort by building construction and composites industries is needed to establish a direction for expanding the use and application of composite materials to take advantage of their primary benefits. Designer engineers in composites are required to be knowledgeable in the disciplines of plastics and reinforcing materials, structural design, and also fabrication techniques. Training provided by engineering schools is essential to optimize performance of these products.

Standard codes of practice for design and applications of plastic composites are urgently needed, or else design efforts will be limited to a small elite group of experts. Codes for



**FIGURE 4** Low stress levels and low deflections in beam design are obtained by placing primary reinforcement at maximum distance from the neutral axis and using a large enclosed area for lateral stability.

composites also must be integrated into standard building codes.

Materials used in construction must have reliable data for predictable performance of the products. The properties for which data are needed by designer engineers and fabricators are basic design mechanical properties in relevant directions, joining methods and their allowable loads, creep and stress rupture properties, weathering and aging properties, environmental (corrosion) effects, thermal properties, behavior in resisting fire and spread of flame, and in smoke generation.

The inherent nature of these materials causes combined stress to be more significant than in a homogeneous material. Furthermore, classical linear elastic methods of analysis are not always applicable; therefore, full-scale testing to determine ultimate performance in critical cases is warranted.

At the present time, there is sufficient data to be incorporated into product designs. However, only the small inner circle of specialists can interpret it with confidence and also have the facilities to verify the design from conception through fabrication and large-scale testing. Relevant data must be scientifically gathered and presented in a usable form so that the information can be readily interpreted by structural engineers.

After these needs are remedied, composites can be widely used and designed like other conventional building materials.

## FUTURE

Plastic composites will have much wider application when they are accepted as materials in their own right, when they are used

in a form that has synergism with their elastic properties and strengths, and when their weaker characteristics are excluded from the design (Figure 5). For example, timber structures and concrete structures are not considered in the same manner or shape as steel structures.

A challenging, new construction material is available and waiting for architects and engineers to cultivate to its full potential. It is not a replacement for conventional materials but an alternative when special situations dictate its use. It has proven itself as a viable, permanent structural material.

The systems and disciplines described here have been in use since 1975. Composite beams, cladding, and decking with sound structural design have experienced a growing acceptance in coastal regions and in industries where building components are exposed to corrosive elements. The long-term structural performance and durability of the materials in numerous installations have demonstrated their suitability for these applications.

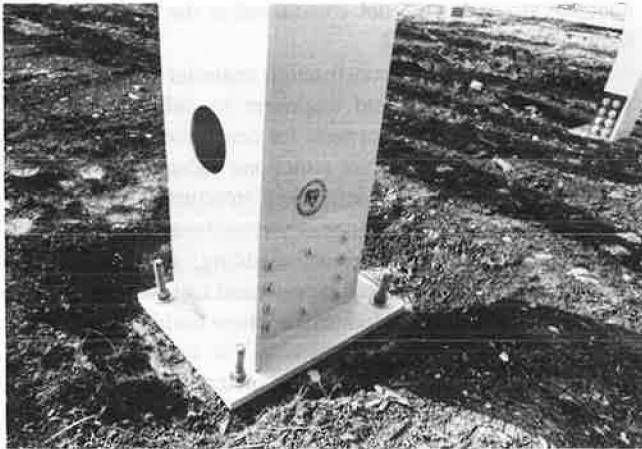
## CASE STUDY

**Required:** Electrically nonconductive, nonmagnetic structure for electronic test facility. Elevations of the building to blend in with the countryside and local environment; erection to be simple with as few members as possible.

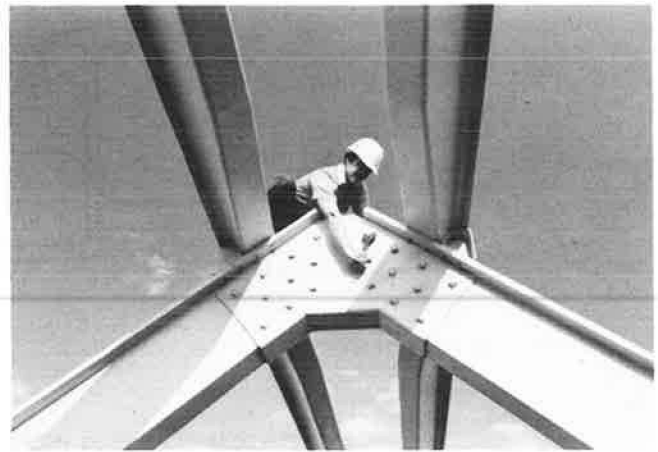
**Solution:** A two-piece rigid frame with fixed ends was selected to keep lateral deflections within local codes (Figure 6). The rigid splice (Figure 7) was selected over a knee splice because this area had lower bending moments than the knee.



**FIGURE 5** Deep rigid-frame knee without splice or connections reduces stress levels and eliminates problem of fasteners at high-moment corner.



**FIGURE 6** Rigid-frame base is fixed to help reduce overall deflection. Rotation of base is resisted by the clamping action of bolts and backing plates bonded on the inside of section. This yields stiff frame with  $1\frac{1}{8}$ -in. deflection at 16-ft eave height with an 8,000-lb lateral load.



**FIGURE 7** Ridge splice showing composite threaded rods and nuts in conjunction with splice plates used exclusively at low-moment joints. High-moment joints are avoided by opting for continuous components.

This choice was important for keeping unit shear stress low in the fiberglass bolts at the ridge splice. Using only two pieces also helps overcome the joining problem by eliminating connections.

The section is a box to increase allowable buckling of flanges and lateral buckling resistance of the frame. Web thickness was increased near the base for shear resistance and to provide resistance to shear buckling.

The rigid frame knee has no joints or splices (Figure 7). Continuous fiberglass rovings maintain uniform strength from one end to the other.

Purlins and girts are 20-ft clear span and use the torque-box system to develop resistance to buckling and lateral bending. No lateral bracing is required.

Fiberglass continuous-strand core and mat skin all-thread rod provides the highest unit strength for fasteners.

Cladding is profiled fiberglass panels that were pigmented beige and coated with an acrylic polymer. The use of non-woven continuous straight fibers provides low deflection. This property overcomes weakness of high bearing loads on fasteners found on conventional fiberglass panels with large deflection.

Fasteners were tested for torque limits, tensile strength, and shear strength. Cladding was tested to determine its resistance to membrane loads, as well as positive and negative wind loads. All primary structural members were tested to determine stiffness, ultimate strength, and load path at the reaction (Figure 3).