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Major Repairs to Frank Lloyd Wright's Largest House: Wingspread, Racine, WI, USA

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Summary

Frank Lloyd Wright's design for Wingspread was a brilliant conception but contained several inherent structural deficiencies. These did not manifest themselves significantly for the first 56 years of the house's life, but in 1994 large displacements occurred due to heavy snows. Repairs were made using a carbon fiber-epoxy thin shell laminated directly to the timber roof to form a composite structure. This shell was built up *in situ* from 13 layers of quad-axial carbon fiber.

Project Description

Wingspread, built in 1938 in Racine, Wisconsin, USA, the largest house ever designed by Frank Lloyd Wright (over 4,000 m^2 floor area). The roofs and walls are framed almost entirely of small dimension lumber (50 x 100 mm to 50 x 250 mm nominal), spaced closely (generally 40 cm on center). At the center of the house is the octagonal Great Hall (15 x 18 m) supported in the center by a very large brick chimney and on four of the sides by seven brick piers on each. The sloping wood roof of the Great Hall is interrupted by three concentric rings of glass skylights each stepped slightly lower than the one above. Radiating out from the Great Hall in orthogonal directions are wings containing bedrooms, kitchen, garage, etc. -- thus the name: Wingspread.

Over the years small cracks had appeared in the plaster and wood ceiling of the Great Hall as well as the East Wing. The heavy snows during the winter of 1993-94 however caused a major displacement near the skylight rings in the Great Hall with cracks larger than 40 mm opening. In addition the exterior walls of the East Wing were noticed to be considerably out of plumb due to thrust at the top of the wood stud wall caused by load from the gable roof rafters. Clearly immediate action was necessary to stabilize and repair this structure, now used as a conference center for the Johnson Foundation.

Temporary shoring was installed and the roof tiles were removed (they were not original in any case, having been replaced in 1993). The permanent repair for the great Hall sought to achieve several objectives. First it should never be visible in the completed work. Second it should minimize disturbances to the existing interior finishes. And third it should be as economical as possible while still conforming to the rules of historic preservation.

After extensive computer modeling using Finite Element Analysis, it was decided to create a shell structure out of the lower roof by coating the bare wood sheathing with 13 layers (12 mm total thickness) of quad-axial carbon fiber fabric set in a 50%-50% matrix of epoxy resin which was bonded to the wood. Prior to the first layer of carbon fiber installation the wood was thoroughly cleaned and large diameter screws were installed through the sheathing into the rafters at 15 cm on centers in oversized holes flooded with epoxy. Thus the carbon fiber was bonded to the wood sheathing which was in turn acting compositely with the rafters. Each layer of carbon was offset approximately 7-8 cm from the layer below to provide a scarf joint at every lap of fabric. Vacuum bagging was not practical for this on site installation so air bubbles were forced out using toothed rollers. The entire operation was conducted inside an environmentally controlled temporary timber framed structure built over the top of the roof. Upon completion, the composite membrane was post cured at 60° C for 24 hours.

Extensive testing was conducted prior to installation, particularly to determine the modulus of elasticity of the composite membrane. Stiffness, not strength was the chief characteristic sought after in the design. Test specimens showed a compressive modulus of E = 34 mPa.

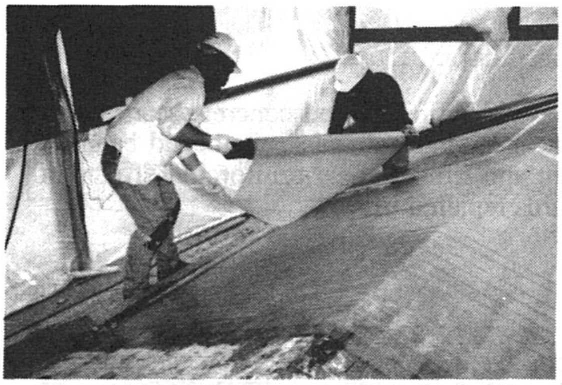

Fig. 1 Installation of Carbon Fiber Fabric

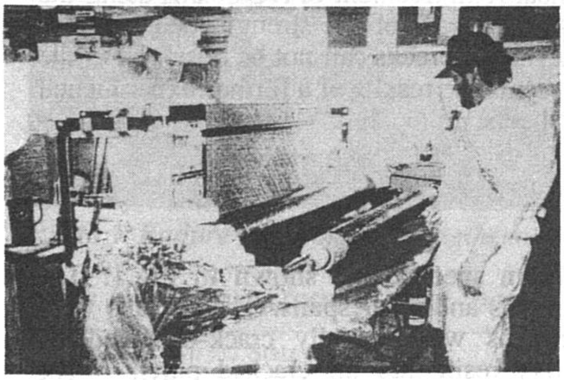

Fig. 2 Impregnating Fabric with Epoxy

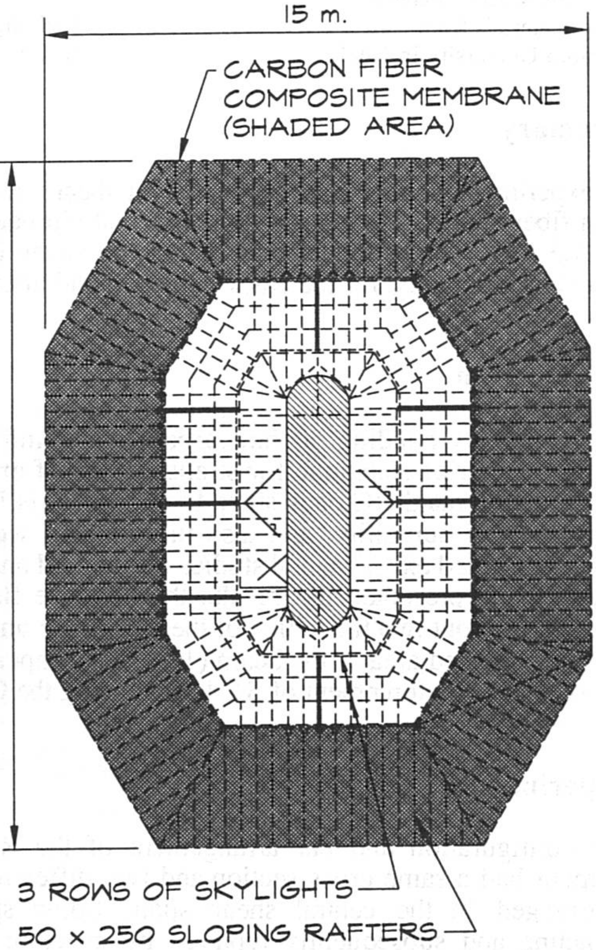

Fig. 3 Roof Framing Plan