Some Thoughts on FC Reinforcement Design

* FC reinforcement is many times considered to be an engineering problem. As a result the average person wishing to build with FC may be reluctant to design his or her own reinforcing scheme. The following offers some thoughts on reinforcement design for non-engineers.

When one looks at injection molded products from the plastics industry one can see the use of a minimum amount of material to produce a maximum strength, shell-type structure. Examination of items such as plastic chairs, exercise equipment, custom molded EPS packaging inserts, etc. show how certain areas of the object can be selectively thickened to produce maximum strength in all three dimensions.

One can also look to examples from nature. Close examination of the design and structure of a leaf show the fractal like arrangement of the veins in a leaf. These provide strength so that a leaf can stand out from the plant and gain maximum sunlight, yet is still flexible enough and strong enough to stand up to high winds.

In FC we can accomplish the same thing in a similar manner. By increasing the amount of reinforcing in selected areas all manners of ribs, beams, columns, trusses, arches and other shapes can be directly incorporated in the walls and roofs of curvilinear or conventional rectilinear buildings.

Increasing the amount of reinforcement in selected areas can be accomplished by adding additional layers of the same size mesh used in the primary reinforcement, by using larger diameter wires or bars, by using strips of mesh of larger diameter wire, by using mesh composed of more, closely spaced wires, or any combination thereof.

This additional reinforcement can be oriented in the same plane as the shell or oriented 90 degrees to the shell surface. If positioned

90 degrees to the shell the additional reinforcement creates a rib, column or beam integral with the shell. The rib, column or beam can be located on the inside or outside of the shell surface.

Quotes from P.L. Nervi:

"All the promising developments [of reinforced concrete structures] are made possible by the progressive liberation of reinforced concrete from the bonds of wooden forms. Until these bonds are totally removed, the architecture of concrete structures are bound to be, even if briefly, an architecture of wooden planks."

"Reinforced concrete beams lose the rigidity of wooden beams or metal shapes and ask to be *molded according to the line of the bending moments and shearing stress*." [italics mine]

This type of visualization can be used to model where additional reinforcement is needed in FC elements and structures. The most efficient reinforcement for shell structures follows the isostatic stress lines of the shape. Beyond creating a visually dynamic pattern, this form explicitly expresses the flow of forces through the structure or object.

"…isostatic stress lines…These lines depend exclusively on the loading conditions of the structure and it was amazing to find that by thus limiting our task to the interpretation of a purely physical phenomena we were able to discover unexpected and new forms…"

From 'Paolo Soleri's Earth Casting' author, Paolo Soleri: "The very large earth mold for this structure was piled and shaped into the form of the planned structure. I then carved V-shaped indentations into the mold that crisscrossed from one side of the mold to the other. These indentations had two purposes. First, they are structural and hold steel reinforcing bars. Secondly, they are really part of an architectural mold. This involves articulating the lines of structural stress in such a way that they appear as aesthetic details."

"The mold for the North Studio not only had structural ribs carved into it, but also other details such as light fixtures, posts and even sections of support beams extending from the ceiling."

"Thus, a pattern of structural ribs, light fixtures, flying beams that contain light fixtures and structural posts were carved in negative into the earth mold, just as similar features were carved into the molds for Earth House and the Ceramics Studio. The structural posts were dug in negative, into the earth mold halfway to the planned interior floor level."

"Once again, steel reinforcing bar was laid into the grooves that had been cut into the mold. Steel mesh was laid onto the mold and a gunite concrete mixture was sprayed using a gunite machine."

Fractals

If one thinks in terms of fractals one sees how FC reinforcement can be designed on an intuitive and experiential level.

Fractals are defined as: "a complex geometric pattern exhibiting self-similarity in that small details of the structure viewed at any scale repeat elements of the overall pattern."

"A self-similar structure whose geometrical and topographical features are recapitulated in miniature on finer and finer scales."

One of the natures of fractals is that they move from larger elements to smaller elements in a progressive manner. The same holds true for FC reinforcing. Reinforcement should always transition from the largest to the smallest in a progressive manner.

Testing

Starting with scale models and doing empirical testing can readily test reinforcement designs. Loading FC scale models and full size components or structures with bags of sand or cement or other heavy materials can readily determine if additional reinforcement is needed in certain areas. Simple, practical tests can be done to explore design limits for tension, compression, point loading, etc.

Disclaimer: The thoughts given here are not intended to supplant the use of engineering calculations in FC construction. Anyone building a structure used for humans or animals is encouraged to seek and use as much input as possible from all sources in the design of that structure..