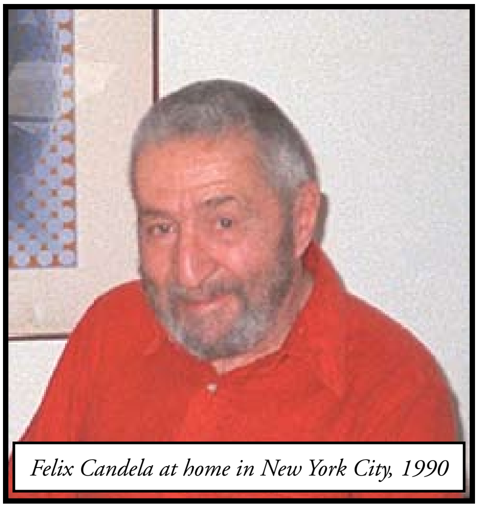
Felix Candela: Creator of Poetic Structures 1910-1997

By Lorraine Lin, Ph.D., P.E.



Felix Candela at home in New York City, 1990

Great structural engineers are often not recognized by the general public as the multi-talented innovators they truly are. Felix Candela's contribution to structural engineering is immense.

His legacy for future generations is the elegant design and construction of a wide variety of thin concrete shells, primarily in or near Mexico City, and also as an advocate for "stereo-structures", structures which actively change the direction of applied loads through a three-dimensional geometry. Stereo-structures require the intelligent selection of form, such as a barrel vault, an elliptical dome, or the form Candela mastered with no equal, the hyperbolic paraboloid shell.

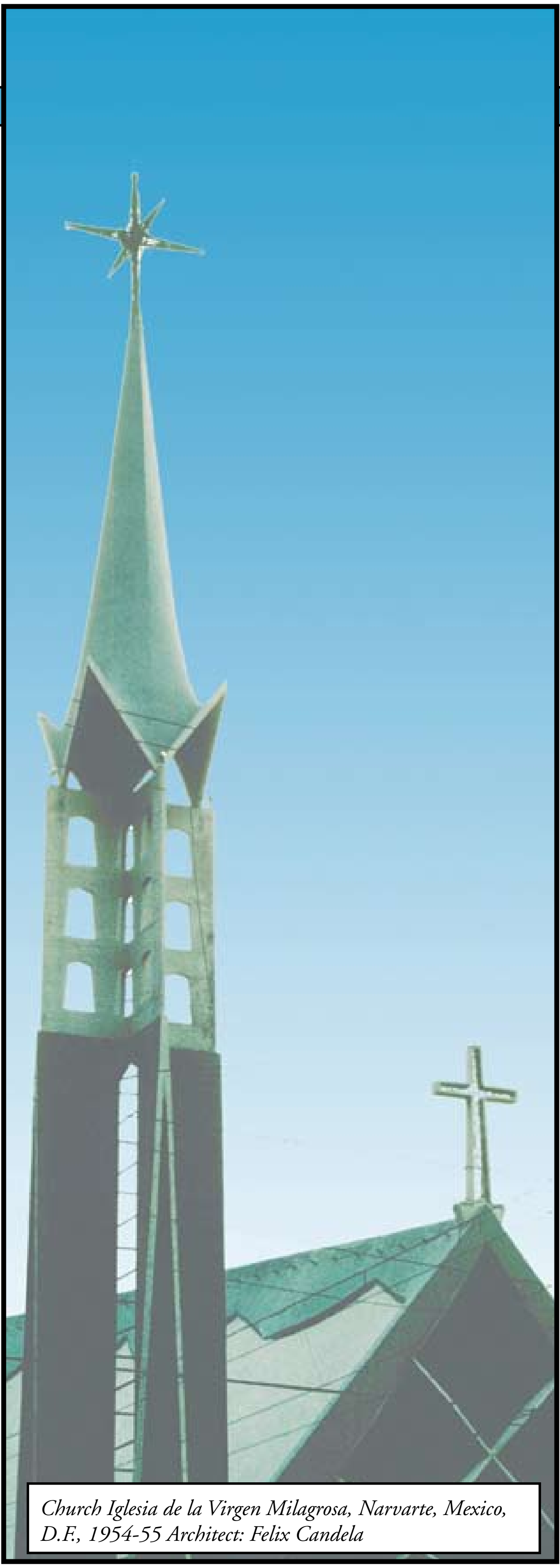
During the 1950's and 1960's in Mexico, Candela was already considered a *maestro* for his skill as an engineer, architect, and contractor when it was still possible for a single person to embody all disciplines. He said that starting his own construction firm was the only way he was able to realize the structures he built.

Candela elevated the hyperbolic paraboloid, also known as the "hypar", to a new art form. Hypars have many wonderful properties. Their anti-clastic or saddle shape is formed by a series of upward and downward parabolas with inherent resistance to global buckling. It is well-known that parabolas carry uniform dead loads primarily as axial stresses, reducing the amount of bending action, thus allowing for lighter structures. An example is the tall thin parabola of the Gateway Arch in St. Louis, which carries its self-weight almost entirely in pure compression. When inverted, the parabolic shape of the main cables of many suspension bridges allows them to carry the weight of the deck in pure tension. Because his hypars made full use of their three-dimensional laminar form and geometric stiffness, Candela was able to create long concrete spans over 100 feet and use shell thicknesses which at times were only a couple of inches. Applied loads were primarily carried as membrane stresses.

Cut the hypar at another angle, and the resulting section is a perfect series of lines. Candela made good use of this mathematical property of hypars by aligning the timber planks of his formwork with the straight line generators of the shell. This helped make the construction of concrete shells affordable.

The concepts sound simple, but Candela's portfolio of shell structures is large and diverse: He was able to create over 300 shells in 10 years. He is best known for his hypar shells, but he also constructed folded plates, cylindrical vaults, and elliptical domes in reinforced concrete. He believed a factor contributing to his success was that thin shell construction was one of the most inexpensive ways to build in Mexico City at that time. By selecting the right structural forms, he was able to minimize material costs.

Candela's early shells included hypars with edge beams. Later by playing with the differential equations — when structural calculations were performed almost entirely by hand — he discovered on his own the mathematical formulation for allowing a free edge in a hyperbolic paraboloid. One of his favorite projects was the Iglesia de la Virgen Milagrosa built in 1954-55 in Narvarte. The roof shells and interior columns merge together with surfaces so warped that their hypar



Church Iglesia de la Virgen Milagrosa, Narvarte, Mexico, D.F., 1954-55 Architect: Felix Candela

Capilla San Vicente de Paul, Coyoacan, Mexico D.F., 1959, Architect: Enrique de la Mora

geometry is difficult to read. With his structural masterpiece, Restaurant Los Manantiales in Xochimilco built in 1957-58, Candela intersected four hypars to create an octagonal groined vault with hidden ribs at the intersection of the surfaces. The shell's free edges are created by cutting the hypars at such unusual angles that only careful inspection of the formwork indentations of the concrete shells reveals the hypar's straight line generators. As he explained, "Free edges are only possible when there are certain rigid members within the structure capable of taking the unequilibrated stresses, although these members need not be obvious or visible."

Candela's interest in shell structures began when he was still a student growing up in Spain with the great German shell designers and the Spanish builder, Eduardo Torroja. However, at that time he came to believe that designing shells would be too difficult due to the complicated mathematics required. In his late thirties, after enlistment with the Republican cause in the Spanish Civil War and internment in a concentration camp, he immigrated to Mexico and picked up his interest in shells again. This time, he began translating technical papers on thin concrete shells in the evenings. "It was as though all the previous events in my life began to make sense and to have meaning. I began to feel 'in form' like an athlete, but mentally as well. I felt the moment had arrived to do something."

Candela's first concrete shells were experiments: "I was learning as I was doing things". His early forms were constructed of burlap fabric draped between concrete arches to create anti-clastic shapes. From the beginning, he was reusing the formwork required to construct the shells, sometimes as often as 10 times. The forms were primarily moved manually by construction workers. Later, when he built some warehouses in Texas,

Candela's Structures to Visit in and Around Mexico City:

❖ *Iglesia de la Virgen Milagrosa* ❖
(Church of Our Miraculous Lady),
Matias Romero & Ixcateopan, Narvarte, D.F.

❖ *Capilla de Nuestra Senora de la Soledad* ❖
(Our Lady of Solitude Chapel), (El Altillo) Av. Universidad No. 17000, Coyoacan, D.F.

❖ *Capilla San Vicente de Paul,* ❖
Francisco Sosa No. 117, Coyoacan, D.F.

he adopted more sophisticated mechanical means. He found the method used to de-center formwork less important for hypar umbrellas than he was initially led to believe. Later, when his projects included constructing formwork for unusual shapes, Candela generously acknowledged his debt to his team. "The construction workers taught me a lot. We started pouring concrete in practically vertical surfaces. I didn't know how to do it . . . they knew how, they did it. We didn't make a second form, just the inside form. Then I put the steel a little closer in order to support the concrete when it was wet. They taught me many things . . . how to use narrow or wide boards for the formwork. All these things we had to try the first time we did it."

When asked in 1990 which designers most impressed him, Candela responded: Mies van der Rohe because he was a "serious kind of person" who carried his ideas through to completion; the Swiss structural engineer Robert Maillart for his facility with concrete forms; and his friend, Frei Otto, then Director of the Institute for Lightweight Structures in Stuttgart, whom he "admired very much".

Although he remained committed to the principles for which he stood in the Spanish Civil War, Candela denied that his structures were any type of political statement characteristic of other architects and artists of his generation in Mexico. However, he conceded that the relatively inexpensive cost of construction made a social statement by improving the condition of many people's lives in Mexico.

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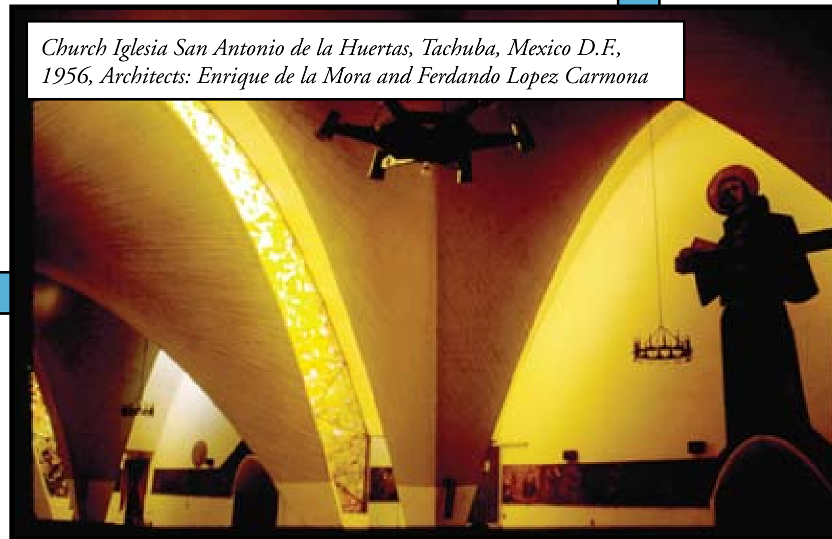
Restaurant Los Manantiales, Xochimilco, Mexico D.F., 1957-58, Architects: Joaquin and Fernando Alvarez Ordonez

Candela was a master builder who understood the meaning of an elegant structural solution, as opposed to one forced to fit a preconceived idea. He believed that designers must not be afraid to allow a shell structure to be thin, given the right geometry. Candela estimated that half his working time was spent doing structural calculations, thus he understood the value of detailed analysis yet was well aware of its limitations.

Why aren't more thin concrete shells being constructed today? Candela's shells performed very well during the two major earthquakes in Mexico City in 1958 and 1985. In 1990, he believed it was because people were no longer interested in shells and that they weren't so easy to construct anymore — there were too many "inconveniences".



Church Iglesia San Antonio de la Huertas, Tachuba, Mexico D.F., 1956, Architects: Enrique de la Mora and Ferdando Lopez Carmona

With characteristic humility, he sometimes described himself as just a contractor. "I am a contractor, working at something I really like to do, which is a very happy situation."

Felix Candela was awarded the Charles Eliot Norton Professorship in Poetry at Harvard University in 1961-62 for his shell structures. Candela — the contractor, structural engineer and architect — shares this honor with the poet T.S. Eliot and the conductor and pianist, Daniel Barenboim.▪

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Information provided in this article was obtained in a personal interview with Felix Candela, New York City, on March 17, 1990. Additional references include:

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Cosmic Ray Pavilion, Ciudad Universitaria, Mexico D.F., 1959, Architect: Jorge Gonzales Reyna