Art and Science of Building in Concrete: The Work of Pier Luigi Nervi

International exhibition and ACI Spring 2012 Convention sessions are dedicated to this grand master of concrete structures

by Mario A. Chiorino

Palazzo del Lavoro in Turin, Italy *(photos courtesy of Istituto Sperimentale Modelli e Strutture (ISMES) archives, MAXXI archives, M. Carrieri, and/or D. Chemise)*

Described by Nikolaus Pevsner as "the most brilliant artist in reinforced concrete of our time," Pier Luigi Nervi (1891-1979) (Fig. 1) was one of the greatest and most inventive designers and builders of the 20th century. He shared the cultures of architects and engineers, operating at the very intersection between the art and the science of building. With his masterpieces scattered the world over, Nervi contributed to the creation of a glorious period for structural architecture.

His personality comprised many facets, including designer, builder, researcher, and creator of new construction techniques. He was also a Professor and Lecturer at prestigious universities around the world and author of books debating the conceptual and technological fundaments of construction, with particular regard to concrete construction.

He has been described as having an engineer's audaciousness, an architect's imagination, and a businessman's practical realism. His use of the most advanced technical solutions always went hand-in-hand not only with the pursuit of formal elegance but also with an equally strong attention to the technical and economic aspects of the building process.

In 2009, on the 30th anniversary of Nervi's death, a broad research and educational program was promoted with the intent of disseminating Nervi's cultural legacy and exploring the complexity of his extraordinary stature as a structural artist. The program culminated in the international traveling exhibition, "Pier Luigi Nervi–Architecture as Challenge," highlighting some of his most celebrated works of genius. This article presents a brief synthesis of this comprehensive exploration of his life's work. It also serves as a preview to presentations at the International Lunch and two technical sessions at the ACI Spring 2012 Convention in Dallas, TX.

Fig. 1: ACI Honorary Member Pier Luigi Nervi, 1891-1979

The International Exhibition: Pier Luigi Nervi—Architecture as Challenge

A broad research-educational program on Nervi's life and work started in 2009, and it culminated in the international traveling exhibition, "Pier Luigi Nervi—Architecture as Challenge." The work was promoted by the Pier Luigi Nervi Project Association (PLN),* the foundation devoted to the dessimination of Nervi's cultural legacy. The program has the scientific support of the Politecnico di Torino, the University of Rome, and La Cambre-Horta School of Architecture of the University of Brussels. The exhibition was organized by PLN and the Centre International pour la Ville et l'Architecture (CIVA), Brussels, in cooperation with the Italian National Museum of the Arts of the 21st Century in Rome (MAXXI) and the Study Center and Communication Archive (CSAC) of the University of Parma, Italy, under the auspices of the President of the Italian Republic and of other prominent institutions, including the Vatican City, the European community, and the International Olympic Committee. ACI co-sponsored the exhibition in recognition of the ACI Honorary Membership awarded to Nervi in 1969 and in consideration of the significant number of his celebrated works in North America.

Accompanied by a catalog assembling the results of the research program,† the exhibition started its extremely successful tour in Brussels, Belgium, in 2010. The subsequent venues in Italy included the Venice Biennale, the MAXXI, and the Turin Exhibition Hall—a building designed by Nervi himself (as shown in Fig. 8). After visiting other venues in Denmark, Germany, and Switzerland, the exhibition is expected to visit venues in North America in 2013. On this occasion, the reprint by PLN of the Charles Eliot Norton Lectures given by Nervi at Harvard‡ in 1961 will be available.

On the eve of the North American tour, it is appropriate to dedicate presentations to Pier Luigi Nervi during sessions on "Structural Concrete: An Art Form" at the ACI Spring 2012 Convention in Dallas, TX, in March, particularly because the general convention theme is "Art of Concrete." The author will deliver the keynote lecture, bearing the same title as this article, at the convention's International Lunch. In two technical sessions, additional speakers will review the work of other eminent pioneers and discuss recent trends in the merging of architecture and structural engineering.

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*www.pierluiginervi.org

†*Pier Luigi Nervi: Architecture as Challenge*, C. Olmo and C. Chiorino, eds., Silvana Editoriale, Cinisello Balsamo, Italy, 2010, 240 pp.

‡Nervi, P.L., *Aesthetics and Technology in Buildings*, The Charles Eliot Norton Lectures, Harvard University Press, Cambridge, MA, 1965, 210 pp.

Early Influences

Pier Luigi Nervi graduated with a degree in civil engineering at the University of Bologna, Italy, in 1913, during a fertile period for scientific, technical, and architectural ideas. Thanks to the contribution of a few pioneers, builders, and designers such as Wayss, Hennebique, and Maillart, the new technology of reinforced concrete was fast developing in the early years of the 20th century. From the very beginning, the new field was associated with a conscious search for artistic results.[1]

It is against this background that Pier Luigi Nervi's professional career began. After an initial period of training in the technical office of a construction company, Nervi set up his own design and construction business in 1920. Nervi was to maintain this dual role of designer and builder throughout his life.

Early Works

The stadium in Florence (1930, Fig. 2) was Nervi's first great work that attracted the attention of critics and the public—both in Italy and abroad. Besides the intrinsic beauty of the project, characterized by the elegance and strong visual impact of the curved tapered corbels of the cantilevered roof and the spatial sculptural forms of the helicoidally warped stairs, Nervi's design was chosen because of the low construction cost.

From 1935 through 1940, a series of great hangars was built for the Italian air force at Orvieto (Fig. 3) and Orbetello. Probably inspired by hangars and temporary exhibition halls constructed in steel and laminated wood (primarily in Germany), Nervi designed a daring, yet dramatically simple in structure, geodetic roof with intersecting arched ribs. The first group of hangars was built using traditional scaffolding and wooden forms for the concrete structure. Those that followed were built using ribs consisting of precast elements that were connected on-site. From that time on, the use of precast components would become a constant in Nervi's work, as he sought to exploit and maximize the outstanding compositional and structural freedoms offered by this technology.

The hangars were also the first structures for which, in addition to static calculations, Nervi relied on tests of

Fig. 2 (left and right): Nervi's first great work: the stadium in Florence, 1930

Fig. 3: Hangar at Orvieto, 1935

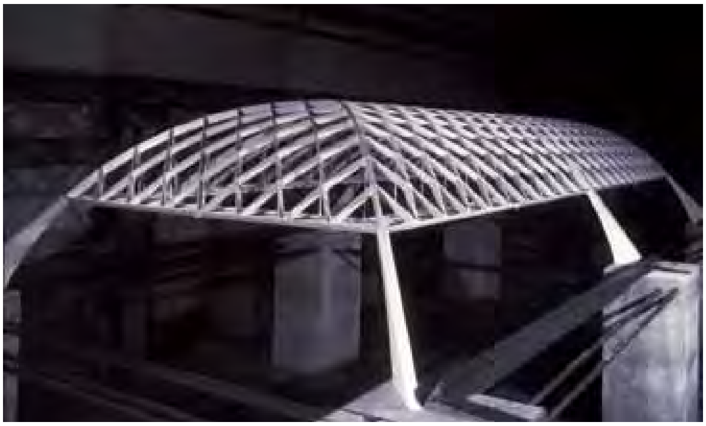


Fig. 4: Celluloid model of hangar at Orbetello tested at the Model and Construction Testing Laboratory, Politecnico di Milano, Italy

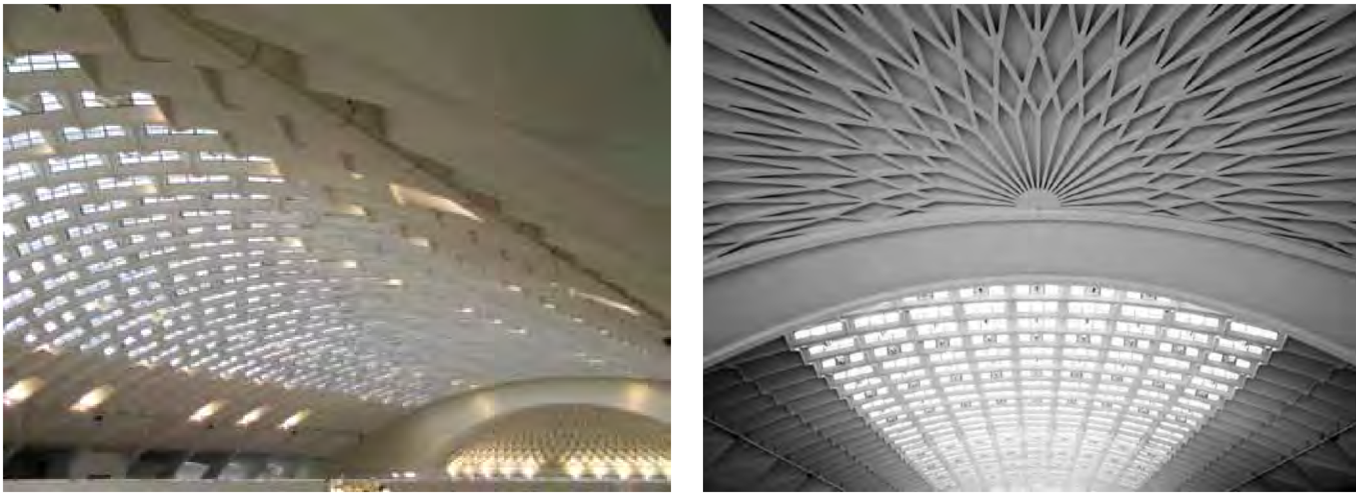


Fig. 5 (left and right): Central hall (Hall B) of Turin Exhibition Complex, Turin, Italy, 1948

reduced-scale models. The tests were performed by ACI Honorary Member Guido Oberti (1907-2004) at the Politecnico di Milano, Italy, in the Model and Construction Testing Laboratory created by Arturo Danusso (1880-1968), using celluloid elastic models on a 1:30 scale (Fig. 4). Nervi would maintain this procedure for most of his later works.[2]

Ferrocement Reinvented

In his first important post-war work—the astonishing central hall of the Turin Exhibition Complex built in 1948 (Fig. 5)—Nervi used ferrocement to make the precast elements for the hall's magnificent, transparent, 94 m (308 ft) span barrel vault. This technology had been originally adopted by Jean Louis Lambot in 1846, at the very dawn of reinforced concrete, to produce a "ferciment" boat hull. The hull comprised a thin layer of concrete reinforced with a thick mesh of small-diameter wires, and it exhibited remarkable ductility and resistance to cracking.[3]

After using it for an experimental warehouse at the site of his construction company at La Magliana, near Rome, Italy, and also for the hulls of small ships (Fig. 6), Nervi made extensive and innovative use of ferrocement in the majority of his most daring and fascinating projects. He is thus credited as the reinventor of this technique.

Fig. 6: Nervi reintroduced the use of ferrocement: (left) experimental warehouse in ferrocement, La Magliana, Rome, Italy, 1945; and (right) Pier Luigi Nervi in front of one of his ferrocement boats

Fig. 7: Sports Palace in Rome, Italy, 1958-60, P.L. Nervi with Marcello Piacentini

Fig. 8: Hall C of Turin Exhibition Complex, Turin, Italy, 1950, while hosting the International Nervi Exhibtion, 2011

Fig. 9: The small Sports Palace in Rome, Italy, 1957, P.L. Nervi with Antonio Vitellozzi. The elegant pattern of the concrete ribs seems to be inspired by the geometrical network of a sunflower core

Ferrocement can be used to mold elements of any geometric shape. The shapes can then be connected by cast-in-place concrete. The geometric shapes can be undulating—as in the case of the vault of the Turin Exhibition Complex and in the great ribbed spherical cap dome, with a diameter of almost 100 m (328 ft), of the large Sports Palace in Rome (1960, Fig. 7)—or they can be simple tile shapes.

For the 55 x 157 m (180 x 515 ft) dome of Hall C of the Turin Exhibition Complex, designed and built by Nervi in 1950, the precast ferrocement elements are in the form of 20 mm (0.8 in.) thick, diamond-shaped tiles that were assembled and then served as formwork for cast-in-place concrete on their upper surfaces and within the contact channels formed at the tile edges. The result is a particularly elegant mesh of reinforced intersecting ribs (Fig. 8). The same pattern characterizes the structural fabric of the vaults and domes of some of Nervi's most famous later works: the Kursaal at Ostia (1950); the Ballroom at the Chianciano Spa (1952); the small Sports Palace in Rome (1957, with Antonio Vitellozzi, Fig. 9); the Leverone Field House and Thompson Arena at Dartmouth College in Hanover, NH (1962, with Campbell and Aldrich, and 1976); the Norfolk Scope Arena in Norfolk, VA (1965-71, with Williams and Tazewell & Associates)—at the time, the largest dome in the world with a diameter of 135 m (443 ft); and St. Mary's Cathedral in San Francisco, CA (1963-71, with Pietro Belluschi, Fig. 10). In this last work, the ferrocement tiles and the mesh of concrete ribs adapt to the elegant hyperbolic paraboloid surfaces of the dome.

In the Gatti Wool Mill (Rome, Italy, 1951), the precast tiles are used to build a flat floor. The design of the rib pattern on the ceiling is derived from the lines of the principal bending moments, again resulting in a particularly refined formal effect that is found in a number of Nervi's subsequent projects.

Later Works

Nervi's first important work outside Italy was the UNESCO Headquarters in Paris, France (1953-58, in

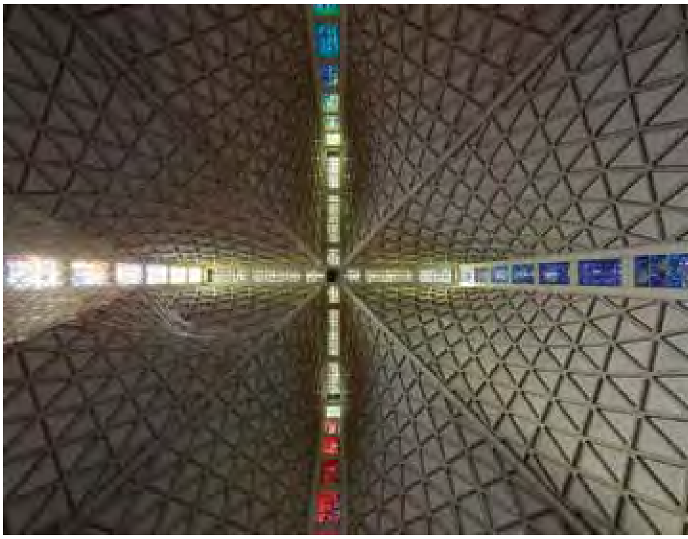


Fig. 10 (left and right): St. Mary's Cathedral, San Francisco, CA, 1963-71, Pier Luigi Nervi with Pietro Belluschi, Mc Sweeney, Ryan & Leew and Leonard F. Robinson (structural engineer)

cooperation with Marcel Breuer and Bernard Zehrfuss). The signature feature of this building is the fascinating folded structure of the exposed concrete of the walls and roof. A series of other prestigious commissions followed. Besides those mentioned previously, the list includes: George Washington Bridge Bus Terminal in New York, NY (1962); Montreal's Victoria Square Tower, Canada (1961-66, with Luigi Moretti, Fig. 11)—at the time, the tallest reinforced concrete building in the world at 145 m (475 ft); Australia Square and MLC Center Towers in Sydney (1964-72, with H. Seidler); the hyperbolic paraboloid umbrella roofs for Newark International Airport, NJ (1971); the B.I.T. headquarters building in Geneva, Switzerland (1972); and the Italian Embassy in Brasilia, Brazil (1979).

Fig. 11: Victoria Square Tower, Montreal, QC, Canada, 1961-66, Pier Luigi Nervi with Luigi Moretti

Fig. 12: Pirelli Tower, Milan, Italy, 1955-58, Pier Luigi Nervi with Arturo Danusso and Gio Ponti

Fig. 13 (left and right): Palazzo del Lavoro in Turin, Italy, 1959-61, Pier Luigi Nervi with Antonio Nervi and Gino Covre

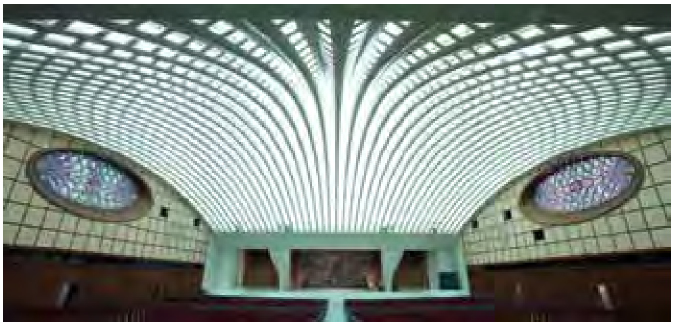


Fig. 14 (upper and lower): Papal Audience Hall, Vatican City, Rome, Italy, 1963-71, Pier Luigi Nervi with Antonio Nervi

In Italy, the most celebrated works of his later period include: the 135 m (443 ft) tall Pirelli Tower in Milan (1955-59, with Arturo Danusso and Gio Ponti, Fig. 12); the facilities for the 1960 Rome Olympics, including, besides the two mentioned Sports Palaces, the Flaminio Stadium, and the Corso Francia Viaduct; the Palazzo del Lavoro in Turin (1959-61) (Fig. 13), with its geometrically fascinating columns featuring striped slanting surfaces covered by a steel umbrella-like structure (designed by Gino Covre); the Ponte Risorgimento in Verona (1963-68); and the Papal Audience Hall in the Vatican (1963-71, with Antonio Nervi, Fig. 14). The latter project recalls the themes of the Turin Exhibition Hall (from 20 years earlier) while enhancing them to create an imposing composition also characterized by the sculpturally highly effective shapes of the main supporting columns and of the ribbed ceilings of the proscenium.

Experimentation

Experimentation, including scale models and full-scale prototypes and constructions, continued to play a major role in Nervi's work. The scientific collaboration between Nervi and Oberti, initiated at the Laboratory of the Politecnico di Milano before the war, continued after 1950 within the new research laboratory of *Istituto Sperimentale Modelli E Strutture* (ISMES), founded by Danusso in Bergamo with the support of Italcementi, the leading Italian cement corporation.

Nervi and Oberti considered experimentation to be the best strategy to overcome the practical impossibility, at that time, of basing safety checks of complex constructions on adequately accurate and computationally feasible theoretical models.[4] This strategy was also followed—not coincidentally—by other leading exponents of structural architecture in the 20th century, including Eduardo Torroja, Franz Dischinger, Antoine Tedesko, Felix Candela, Heinz Hossdorf, and Heinz Isler, to name a few.

While the numerical modeling techniques that increasingly appeared in the late 1960s would have gradually

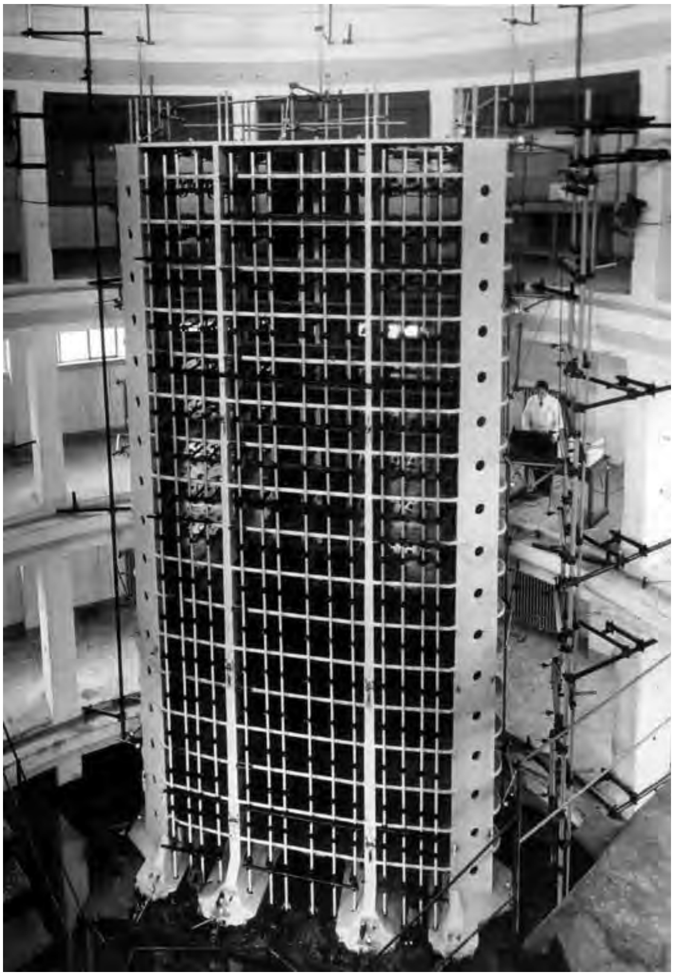


Fig. 15: Microconcrete large-scale model (1:15) used for tests to failure for the Pirelli Tower, Milan, Italy

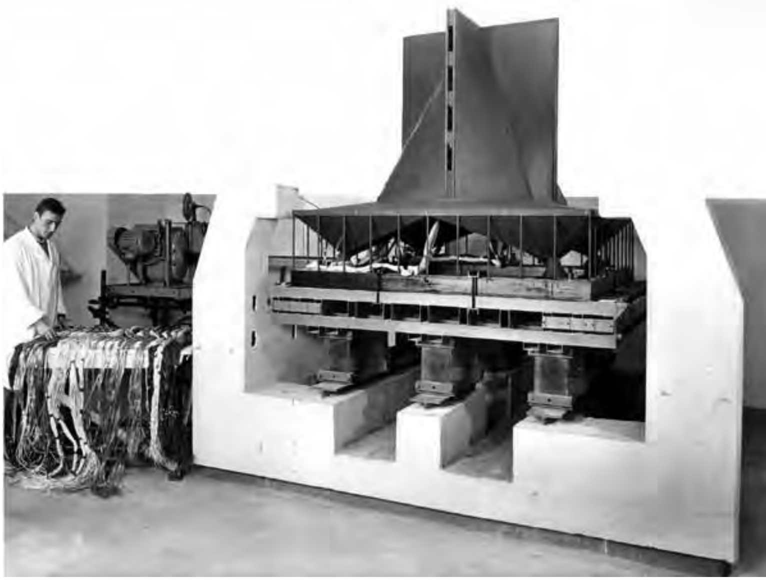
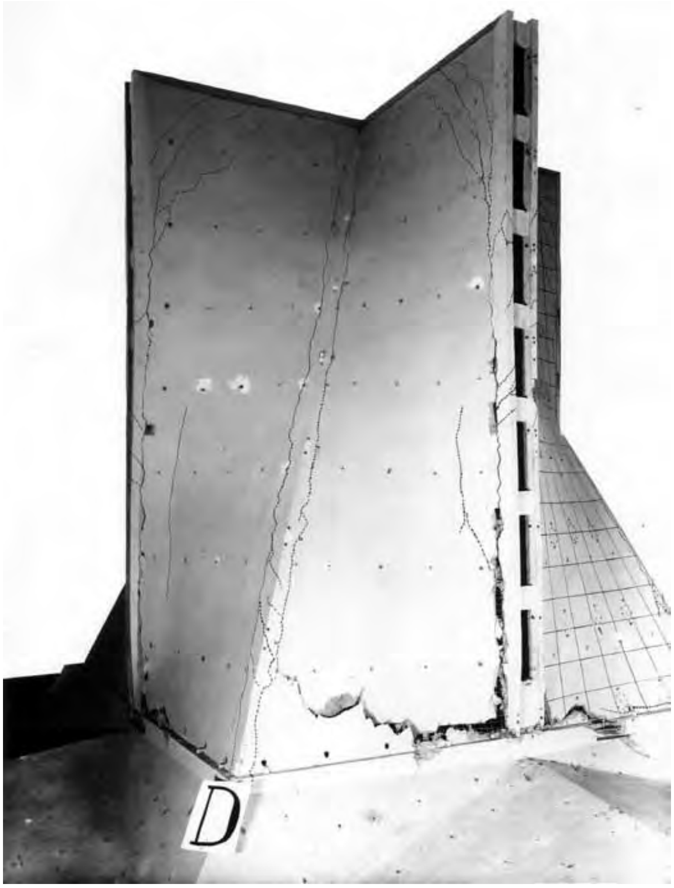


Fig. 16: St. Mary's Cathedral, San Francisco, CA: (above) elastic model (1:37) under dynamic test; and (below) microconcrete model (1:15) shown following the ultimate limit state tests



opened new frontiers, it's fair to say that experimentation using models became an extremely refined art form and an essential phase of the design path for Nervi and other eminent protagonists. Creating physical models was an art form that required, almost in the same way as in real construction, the designer to be able to combine technological expertise and imagination—perhaps justifying Oberti's frequent citation of the adage attributed to Michelangelo by Vasari: "The most blessed monies that are spent by those who would build are on models."

One of the most complex models produced and tested within the ISMES facilities was of the reinforced concrete frame of the Pirelli Tower in Milan, Italy, (modeled in 1955-56). The nearly 10 m (33 ft) tall, 1:15-scale model (Fig. 15) was produced in microconcrete of pumice stone and portland cement and tested beyond service conditions up to failure, after a series of tests in the dynamic field to check the effects of wind.

Other ISMES testing programs included models of the Victoria Tower in Montreal, QC, Canada, and St. Mary's Cathedral in San Francisco, CA. In the latter case, a small-scale (1:100) model was used for the wind tunnel tests, two medium-scale (1:40 and 1:37) resin models were used for static and dynamic tests in the elastic field (with special attention to seismic tests due to the building's location), and a large-scale (1:15) model constructed in microconcrete was used for tests to failure (Fig. 16). It's of interest to note that the elastic tests for St. Mary's were accompanied by checks using numerical models based on early applications of elastic finite elements analysis, made by the U.S. engineering studio of Leonard Robinson, the firm responsible for the final design.

Nervi's concrete towers in Sydney were tested in Australian laboratories and were the only two structures for which model testing was performed outside of ISMES.

Philosophy of Structures

Nervi's most famous book was published in 1945.[5] Its title—*Scienza o Arte del costruire?* (*Is Building an Art or Science?*)—is also a fundamental question. With his profound knowledge of construction techniques, Nervi's answer to the question emphasizes the priority of the intuitive moment on the conception of structural architecture, yet it does so without underestimating the importance of the mechanics of structural systems: "The conception of a structural system is a creative action only partly based on scientific data; static sensitivity entering in this process, although deriving from equilibrium and strength considerations, remains, in the same way as aesthetic sensitivity, an essentially personal aptitude." His vision was shared by Torroja, the other great master of structural architecture of the 20th century, who declared in *Razón y Ser de los Tipos Estructurales* (*Philosophy of Structures*)[6] that, "the birth of a structural complex, the result of a creative process, the fusion of art and science, talent and research, imagination and sensibility, goes beyond the realm of pure logic to cross the arcane frontiers of inspiration." In this vision, Nervi essentially expresses his fear that forced requirements to use analytical models for reliability assessments of structures might limit a designer's inventiveness. He believed that structural imagination frequently transcends the possibilities of analytically rigorous verification (which was then confined by the lack of modern computerized structural analysis tools). This struggle for a design freedom was also the principal justification for his keen interest for experimental research on mechanical-scale models.

These concepts were at the base of Nervi's extensive and interesting writings focusing especially on the language of architecture and the relationship between structure and form, and on the ethical value of building in a correct manner. These were also the typical themes of the university teaching he regularly carried out at Rome's School of Architecture and of some of his important speeches and lectures at prestigious universities from Buenos Aires (1951) to Harvard (Norton Lectures, 1961-62).[7] They also characterized his exchanges of ideas and professional collaboration with those who shared his culture and mindset, such as Mario Salvadori, Structural Engineer and Professor at Columbia University.

The true art of Nervi is the ability to close the gap between art and technology to create spaces that border on poetry without renouncing, in the conversion of the inspiration into a design and of the design into a construction, the modus operandi of engineers, but rather emphasizing engineering procedures with original and innovative contributions.

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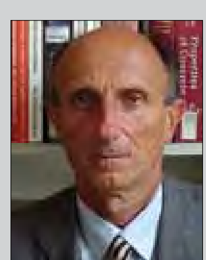

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