

# 5 I C C H

## PROCEEDINGS

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Brian Bowen

Donald Friedman

Thomas Leslie

John Ochsendorf, eds.

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**PROCEEDINGS OF THE FIFTH INTERNATIONAL CONGRESS ON  
CONSTRUCTION HISTORY**

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**Edited by**

Brian Bowen  
Donald Friedman  
Thomas Leslie  
John Ochsendorf

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# THE LANGUAGE OF STRUCTURES. THE ITALIAN SCHOOL OF ENGINEERING.

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## Keywords

History of Engineering, Evolution of Structural works, History of the theory of structures, XX Century Italian Engineering

## Abstract

This paper intends to present the most important results of the “SIXXI - 20th Century Structural Engineering: the Italian contribution” Research (ERC Advanced Grant 2011).

The SIXXI research is designed to trace and tell the tale of structural engineering in Italy. It has been an enthralling, sometimes stunning and undeniably unique, tale of progress. Italy had always lagged behind other industrialized nations; yet, in the Twentieth century it was able to start a new trend that would be up to the most advanced European standards. Under the autarchic regime, Italian structural engineering created its own unique identity, and then in the enthusiastic second post-war reconstruction period and the economic booming years it produced outstanding works, and made a name for itself as one of the most prominent schools in the world. In the following years, it faded into oblivion as quickly as it had risen on the international scene.

There is an objective difficulty to see the history of structural engineering against a specific disciplinary context. A structure requires a radically trans-disciplinary approach.

In the development of the Italian school of Engineering, the theoretical contribution made by Menabrea, Castigliano, Danusso, Colonnetti is no less important than the work of designers like Nervi, Morandi, Zorzi and Musmeci. To get the secret of the originality of the great post-War achievements – it is necessary to investigate the close collaboration between scientists and designers. An operator and a theoretician, the protagonist of the Italian school is a multi-faceted figure that is at the same time a scientist, an entrepreneur and a craftsman, a reincarnation of the 19th-century engineer. Based on that strange combination, he finds the conditions for a short, anachronistic survival in the unique setting of Italian (belated and constantly proto-industrial) modernization.

The challenge faced by the SIXXI research is to discover the history of structural engineering by applying the approach that is used by the history of construction. Being this a ‘material history’, it is prepared to recreate the design and construction phases as ‘practices’: definite moments of a material culture. Since any practice is heterogeneous, but essentially unitary, a historian wishing to bring it back to life cannot use an interdisciplinary approach but has to get ready to take transversal paths on his own. The creator of a major structural work passes easily through the great epistemological areas, from sciences to techniques and arts. The investigator wishing to trace his works has to go the same way.

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## INTRODUCTION

During the years of Italy's 'economic miracle', Italian engineering presented itself to the world in the form of an actual School, a prolific workshop producing new structural architecture. It was the heyday of a long string of events that we have described many times and whose fundamental steps can be summed up as follows.

In the 19<sup>th</sup> century most metal structures were imported; then, in the early 20<sup>th</sup> century, with the advent of reinforced concrete, Italian engineering started to achieve its autonomy, especially through the pioneering work on arch bridges carried out together by scientists and builders.

This autonomy became consolidated during the period of autarchy, when the two experimental lines appeared that after the War would relaunch reinforced concrete structures: one based on 'form resistance' that led to thin shell and the other based on co-action that led to the prestressing technique.

By continuing along these paths, in the post-War period Italian engineering was a protagonist in the major reconstruction endeavour of rebuilding road and railway networks. The experimental stage was over and engineering was now taking on a collective dimension: a school was emerging. And not only in the academic sense: in the field, it was now normal practice for the structural designer (a profile that had hitherto been quite uncommon) to lead the reconstruction of thousands of bridges.

In the exceptional operational excitement that characterized the economic booming years, Italian engineering finally managed to express its architectural languages: new, original, perfect languages, and indeed in the minutely undulated domes by Pier Luigi Nervi and in Riccardo Morandi's homogeneous cable-stayed bridge the world acknowledged the advent of a new structural architecture.

And this was only the tip of the iceberg. In the numerous large construction works produced during the period of the economic boom – the Autostrada del Sole, the stadiums for the Rome Olympic Games, the facilities for the 'Italia 61' Expo, the international airports, the skyscrapers – gave rise to a wide array of structural languages, some of which were very diverse from one another, but all encompassed in a general homogeneous trend.

And even after the lightning-quick extinction that was to follow the exploit, the School continued, for several years, to express works of extraordinary efficacy, including, for instance, the 'extruded' viaduct by Silvano Zorzi, or the "nameless form" for the bridge on the Basento River by Sergio Musmeci: 'posthumous masterpieces' that did not succeed in relaunching the School but are very useful from a historic standpoint to reveal hidden implications.

What are the traits characterising the originality of Italian structural architectures? What are the characteristics whereby the School stands out with its distinctive features on the international scene? How is it (a truly very rare case) that engineering works are so poignant in bearing witness to a crucial period in Italy's history?

Keeping these questions in mind let us re-read some of the main structural languages expressed by the Italian School of Engineering.

### PIER LUIGI NERVI, THE ARTIFEX

Let us begin with the *Palazzetto dello Sport*. Externally it looks like a low, spherical dome supported by thirty-six Y-shaped radial struts. Internally, the web of the ribs that mark the intrados of the dome shows the flow of stresses that starting from the top gradually spread out, reach-

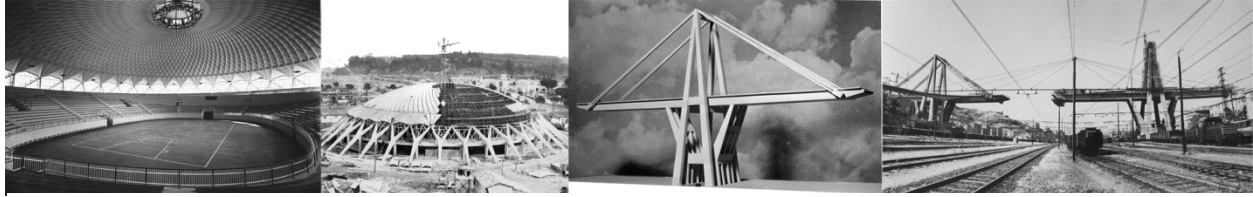


Figure 1 : Palazzetto dello Sport, Roma, P.L. Nervi; Polcevera Viaduct, Genova, R. Morandi (©SIXXI collection)

ing the fans, pass through the open arms of the Y-shaped supports and from there finally reach the ground.

What does this structural language tell us?

First of all we can notice that, with the self-centredness typical of modern engineering, the structure speaks to us of itself. It displays its inherent rationality. It displays the consistency between geometry and static behaviour, typical of form resistant structures.

By revealing its intrinsic structural truth, the building is in perfect harmony with nature (with Nervi's connotation of 'lay' naturalness that does not arise from the imitation of nature but rather flows forth from the mysterious wisdom that is inherent in each thing, whether the product of creation or manmade: trees, leaves, crystals, or umbrellas, lamp shades, chairs).

But besides describing the stress paths, the structure speaks to us of its constructive origin, even though from this aspect the language is less sincere. Indeed, at first sight the dome seems to have come out of a huge mould. In actual fact it is made up of 1,620 small, rhomboidal, hollow tiles that are only 2.5 centimetres thick, built on the ground, one by one, and then welded on site with the help of light scaffolding (this is an exemplary application of the two inventions that constitute the Nervi system: structural prefabrication and 'ferrocemento').

The illusion however does not cause the feeling of a false image because a closer look shows that the effect of continuity of the surface is not the result of a trick, but to the contrary it is based on the intimate truth of the material: reinforced concrete can be cast in different phases and reproduce a perfect monolith without the need for superficial finishing. This is its inherent prerogative. Indeed, it is its most exclusive property. It is the fascination of molten stone that Nervi handles and works with the skill that only an 'artifex' can have.

Through the literal meaning, that reflects the static functioning and the construction technique, the structure also tells us other things: it sheds light on aspects of Italian modernity.

Even though it belongs to the category of thin shell that was very much in fashion in those years (suffice it to think of the double curved shells by Torroja, Candela and Isler), Nervi's domes attract people's attention because they are absolutely original. A distinguishing feature is that they are minutely corrugated, undulated, and shaped.

This is what makes them inimitable: shapes that are so articulated that they would be too expensive for anyone building structures using reinforced concrete in the traditional manner. They become not only possible but miraculously economical only by applying the Nervi system.

The originality therefore reflects the uniqueness of the construction system, and this in turn relays back to the production conditions of the time when they were invented: it is a typical example of Italian brilliant craftsmanship.

In this way the structural language spoken by Nervi tells us about Italy's modernization. And thanks to his pedagogic inclination, it literally 'explains' a core attribute of the 'made in Italy': the possibility for scientific rationalism to peacefully coexist with the pragmatism of craftsmanship within the overall protoindustrial condition.

## **RICCARDO MORANDI, THE VISIONARY**

Another unmistakable logo of the Italian School is Morandi's 'homogeneous' cable-stayed bridge. While Nervi's domes offer a perfect representation of the line of 'naturalness' underpinned by form resistance, Morandi's bridge is the symbol of scientism, the other soul of the Italian School of Engineering, the one based on prestressed elements.

The Polcevera viaduct is a balanced system consisting of a continuous beam on four supports completed by a simply supported central beam, following the Gerber scheme. The span is just over 200 metres in all. An X-shaped support is used for the two internal supports; the external support is provided by two cable-stays, they too in prestressed reinforced concrete, that pass over a 90-m high tower.

This structure too speaks for itself: its static function is on stage but with a language that is very different from that used by Nervi's surfaces where we see the flow of the internal stresses as a system of harmonious balance, with explicit reference to nature. Morandi's structures instead are abstract figures that offer a representation of the contrast of external forces, of weights and counterweights, and of pushes and counterthrusts. The balanced system, in particular, is a diagram of forces that offers a sculptural model of the potential that Science has of challenging Nature.

When the 'homogeneous' cable-stayed bridge was drawn for the first time in Morandi's design for the Maracaibo bridge, it astonished the engineering world (and not only). And yet cable-stayed structures were not at all new at the time (cable-stayed bridges were preferred by German engineers, in particular, in the wake of the three bridges designed by Fritz Leonhardt over the Rhine in Dusseldorf). So why was Morandi's version considered to be an invention? And above all an Italian invention?

Usually cable-stayed bridges are built in steel. Morandi's invention consisted in building it in prestressed reinforced concrete. And this is the surprising aspect: the typical lightness of tie-rod based structures is in contrast with the 'masonry' character of Morandi's structure.

Also in Morandi's case the originality lies in the construction method. The Polcevera viaduct across an area that also includes many railway tracks, had to be built without provisional scaffolding. The continuous beam consists of thirteen 5-m segments symmetrically cast in cantilever (provisionally linked by a bundle of prestressed cables on the deck).

According to this method, the figure of the balanced system (besides representing the static equilibrium) embodies the sense of craftsmanship with which it was built: a sophisticated craftsmanship that in the work site exploits the prestressed solution in many ways. And in the end it gives the impression of a daring unsupported structure hovering in space.

And now, a second and different manner in which the structural language tells us about Italy's modernization. Whereas with the domes that were literally hand-shaped by the 'potter' Nervi, the classical tradition of Italian craftsmanship was revived, Morandi's mechanical structural metaphors were linked to the visionary current, triggered by Antonelli's daring nineteenth-century 'reinforced masonry' and relaunched on a grand scale by Futurism.

## **THE CRISIS OF THE SCHOOL**

But in the mid Sixties, at the peak of its success, the School suddenly died out. The causes were many. The cultural milieu in which the multi-talented designer had grown up had dispelled. Very low-cost manpower was no longer available, an essential condition for the survival of artisanal work-sites, and the advent of the computer had ushered in the third industrial revolution.

And this phenomenon was not limited to the engineering (or construction) sector. If we widen our vantage point we will notice that engineering was caught in the extensive and radical transformation that affected the Country in those years. Overnight, the tradition of material culture that had survived during the twenty years of fascism, revived by reconstruction that had triumphed during the economic miracle, was washed away by the wave of general standardization that submerged the Country.

The consequence of this in the area of large construction works was the diffusion of prefabricated bridges. The economic, bureaucratic and regulatory conditions now took on a deterministic role in structural and architectural solutions. There was no escaping the fact that the viaducts and urban overhead roads built from the Seventies onwards lacked personal touch and were sadly standardized.

Hence another chapter in the history of Italian engineering had begun. The much less glorious chapter that is still present today. In the meantime the School, that had gone off-stage, left some particularly significant trails. While the old masters of the first generation had begun to produce structures all over the world, some of the second-generation protagonists, who were still young, made some more or less desperate attempts to keep the School alive. They did not succeed, but those attempts did produce some 'posthumous masterpieces'. They were important because they generated new languages that reveal other aspects of the School and, more in general, they tell us about Italy's modernization. We would like to present two of them: Zorzi's utopian language, and Musmeci's critical (and prophetic) language.

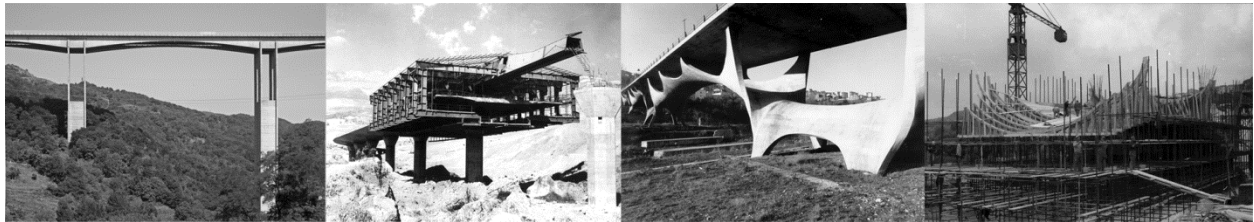


Figure 2: Gorsexio Viaduct, Ligury, and Fichera Viaduct, Sicily, S. Zorzi; Bridge over Basento river, Potenza, S. Musmeci (©SIXXI collection)

## SILVANO ZORZI, THE DESIGNER

Zorzi realistically accepted the new production conditions that led to the adoption of standardized beams that are all the same, but he engaged in the desperate attempt to avoid their being featureless by focusing on the drawing of the elements.

This led to the creation of a language of the School of a totally different nature compared to the past. Nervi's dome is a hand-fashioned form resistant structure. Morandi's cable-stayed bridge is a figure of equilibrium hovering in space. Zorzi's viaduct is a simple design object (and this does not reflect a variation in tone but rather major differences in syntax).

Let us take a look at the Gorsexio viaduct. The modelled deck is monolithically one with the slender piles. The viaduct appears to be a continuous coherent object. What is special about it is that at the fixed joints the piles are not thicker as one would expect in a frame; instead they are tapered until they form a double flexible blade. This could be interpreted as an expedient to prompt an albeit moderate amazement. In actual fact, the choice of the shape is perfectly consistent with the structural behaviour. The different deformability of the parts determines what Zorzi himself defines a 'fixed joint that slides' longitudinally. This hybrid constraint makes it possible to absorb stresses (even those due to shrinking, flueage and temperature deformations) by exclusively exploiting the elasto-plastic characteristics of the monolithic object, thus avoiding

recourse to mechanical devices, hinges, sliding supports, etc. (with the same approach also the dilation joints of the deck are reduced to one out of every five piles).

Another example of the egocentricity of structural language that, in the elegance of its lines, expresses the close correspondence between the shaping of the segments and the masterful tuning of the stresses. And this is done in an understated and discrete way, without revealing the prestressed solution that plays a key role in reaching a sophisticated balance.

Then there is another aspect for which Zorzi's last generation viaducts appear to be the result of a utopian attempt to keep the School alive. Once again design is closely linked also to the construction method: not to the artisan tradition in this case, but to the new construction techniques for large works; techniques that are invented (or even reinvented from experience abroad) on each occasion.

Indeed, Zorzi realizes that the days when artisan methods could be used with the massive employment of manpower are over. But at the same time he refuses the solution of the inevitably impersonal and anonymous prefabricated beams. So he tries to bring industrialization into the work-site by developing sophisticated machines that enable to preserve the flavour of hand-made modelling by adopting the on-site casting method. After some experience based on the use of the cantilever forming traveller system, he fully reaches his goal with an even more extravagant equipment: the movable self-launching scaffolding. This is a real mobile work-site that includes the formworks for the casting of the entire bridge-deck: a huge extrusion machine that, in practice, leaves behind it the deck as it advances.

This is the development of a third way in which structural language tells us of Italy's modernization. With its soft voice it tells of how, in order to achieve high quality work, some engineers follow a path that is parallel to the path that makes a success of 'made in Italy' design. The path that modernizes the product and the process avoiding industrial standardization and preserving the uniqueness and value of a crafted object.

### **SERGIO MUSMECI, THE PROPHET**

Another posthumous masterpiece is the Basento Bridge by Musmeci, a work that offers a concrete and monumental representation of the crisis of the School.

The shape of the bridge arises as a demonstration of a sort of theorem. Musmeci maintains that once the restraints are set (supporting elements of the deck and the supports on the ground) and once the load is known, the unknown is the structural shape, which, according to Musmeci, may be determined with scientific instruments.

The quest for minimal form for the bearing shell is made following two paths: analytically through a mathematical optimization procedure, and experimentally by having recourse to physical models (arranged by soap film and rubber sheet) that allow to make equally tensioned surfaces that are statically and geometrically a mirror reflection of the shape being sought.

If we consider its origin, therefore, the nature of the form is purely static. Indeed, Musmeci maintains that in order not to disturb the pureness of the short-circuit between science and architecture, in the very first step of the design one must clear the ground from all the other conditioning elements: i.e. the more common structural schemes, the limits of classical geometry, but above all one must free oneself from all the technical construction hypotheses (the latter position being truly disgraceful in a country where the engineer is first and foremost a builder).

The built bridge reflects the conception of a form that is the result of a purely scientific action but it tells us also about the rest of the story. When passing from the design to implementation indeed, the fortuitous circumstances, that are not part of the conception, are relentless in im-

posing corrections and modifications to the minimal form. A slow, tormented, but also fascinating, metamorphosis occurs.

In seeking to manage this, Musmeci takes off his scientist-artist's cap and puts on the cap of a pragmatic designer and work-site director. During the development of the final design, also on the basis of tests done on models, he modifies the (otherwise imperceptible) transverse curvature of the "nameless form" and considerably thickens the border arches to prevent instability phenomena. Subsequently he faces the difficulties that are encountered at the work-site, when a wooden centring having an unusually complex shape has to be built, when concrete has to be cast on a surface with constantly varying curvatures.

In the end, costs double; the works are completed well beyond deadline but the most severe consequence is that the form that is built is quite different from what had originally been designed. The light equistressed membrane, the minimal form has turned into a massive shell.

And yet in the troubled transition from conception to construction, the shape was not distorted. Rather it takes on a double connotation: albeit deformed under the blows of the implementation difficulties, whose traces are evident on the visible face of concrete and in the heavier aspect of the outline, it still preserves also the aspect of the tensioned (and then turned upside down) membrane that derives from the scientific conception.

And then there is a fourth way in which the structural language tells us about Italy's modernization, a manner that is uniquely critical. Indeed, with its duality, the bridge does not solve the basic contradiction of Italian modernism - between scientific pureness and artisanal pragmatism - but puts it on stage at the very moment in which it explodes. And in the final image of the bridge, ambiguously suspended between spider web and a pachyderm, we recognize yet another familiar expression of the Italian School, but this time portrayed in its most dramatic moment, that of the final crisis.

## CONCLUSIONS

The interpretations presented in the foregoing provide input for making some hypotheses on the identity of the Italian School of Engineering.

At first glance the Italian School appears to be orthodox in its approach, and fits perfectly in the international picture of modern engineering. This is due to the firm roots it had in nineteenth-century Positivism. Structural sincerity, present in all languages, confirms that scientific rationality is a basic value of modernity. And so, large construction works are in any case a symbol of progress (taken not as an aspiration but as a fully achieved goal): the Eiffel Tower, the Maillart Bridge, the tensile structure by Frei Otto, and also the Italian structures.

Having said this, we must immediately add that the Positivism underlying Italian languages is a *sui generis* Positivism: a positivism contaminated by various humanisms. The cultural atmosphere in which Italian engineering was immersed, indeed, was very different from the culture that fostered the development of Anglo-Saxon or American engineering, for example.

In the Anglo-American world, the 20<sup>th</sup> century is marked by a scientification (and also 'engineeringisation') process that invades also the humanistic sphere. Science and technique are put at the centre of the epistemological framework. In particular in American pragmatism, the engineer, and above all the bridge builder, is indicated as a model for all to follow (for the way in which he implements science in what he builds).

In Italy instead, modernization stimulates the reverse process, a sort of 'humanization' of engineering. Neoidealism on the one hand (for more than fifty years the whole of Italy follows the philosopher Benedetto Croce's teachings) and Catholicism on the other dominate Italian culture.

In this context the engineer, instead of defending himself, becomes the most fervent of the supporters of the superiority of the spiritual and humanistic vision. On the one hand the scientists prefer the spiritualistic vision: Danusso indicated evocative similarities between the principles of mechanics and the moral and social principles; Colonnetti confirms the role of the engineer as "God's assistant". On the other hand, the influence of neoidealism among designers leads more laicly to the centrality of ethics: correctness (in design work) tends to immediately become an aesthetic value.

The coexistence of international and national characteristics could suggest that Italian engineering embodies the idea of a humanistic positivism. We know that in the philosophical debate (that in Italy is the official seat of cultural policy) this thesis, that is however formulated several times, is peremptorily rejected by the representatives of neoidealism. It is our impression that humanistic positivism lives happily in the Engineering School (that keeps clear of the philosophical dispute), and that the engineers normally practised humanistic positivism when they made calculations for structures and when they designed and built bridges. Without the awareness of a full-blown theoretical elaboration, day after day, they silently moulded it into sculptural shapes and structural figures.

But the humanistic positivism of the Italian engineer would not be so concrete if, besides the cultural environment, it did not also reflect the economic and productive dynamics of the Country. In Italy modernization takes place within a capitalism without entrepreneurial concentrations and without revolutions (not only industrial). In the Country there persists a chronic condition of protoindustrialisation in which one could still rely on skilled workers, on low cost manpower, on a low level of mechanization. This is the background in which the artisanal work-site of large structural works is located and which is the same as that in which the advanced 'made in Italy' artisanship flourishes.

The Italian nature of the School is therefore at the heart of our cultural history and of our manufacturing history. From these circumstances there arises a special historic meaningfulness that is quite uncommon in the field of engineering and more typical of architecture. The bond between the School and the events of the Country is very close. The structural architectures by Nervi, Morandi, Zorzi and Musmeci prove to be, both individually and as a whole, among the most authentic products of Italy at the time of post-War reconstruction and of the economic miracle. They are true monuments of the 'made in Italy'. They reflect the Italy of that time and are its most significant documents.

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