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Nervi's cantilevering stadium roofs: discipline of economy leads to inspiration

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Summary: Although he came from a tradition that built magnificent palaces and churches, the Italian master builder Pier Luigi Nervi is arguably mostly known for his sports infrastructure. In this paper, we focus on his first (Giovanni Berta Stadium, Florence, 1930-1932) and last (Olympic Flaminio Stadium, Rome, 1957-1959) internationally widely recognized stadium with cantilevering roof. Through literature studies and structural analyses, we compare and contrast these two stadia on the basis of their structural and constructional efficiency, economy and design intent within the specific social-political context of the interbellum and post-World War II era in Italy. The interpretation of these studies shows Nervi's clear progression from imitation, innovation to inspiration in his stadium design. More specifically shortage of construction materials and skilled labor did not constrain his projects but drove Nervi to design and build great structures.

Keywords: Nervi, ferro-cement, prefabrication, stadium, cantilever, grandstand

1. INTRODUCTION

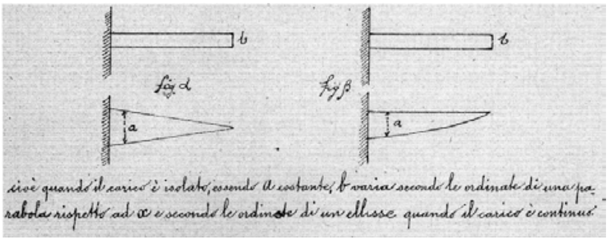
Although he came from a tradition that built magnificent palaces and churches, the Italian master builder Pier Luigi Nervi (1891-1979) is arguably best known for his sports infrastructure. In 1960, at the height of his career, Nervi's Olympic structures were lauded worldwide. The question arises: how did Nervi's structures evolve from his early architectural projects to the engineering inspirational masterpiece found in the Olympic Flaminio Stadium (1957-1959, Rome)? The design and construction success of this widely-recognised stadium was entirely his own. Nervi stated that the series of innovations he developed in the two decades leading up to the Olympic Games formed the basis for this realization [1]. How did constraints, imposed by Italy's socio-political context before and during World War II, influence Nervi's evolution in stadium roofs?

In this light we study the progression from imitation, innovation to inspiration in his two most widely-recognized stadiums with cantilevering roofs. The Giovanni Berta Sports Stadium (1930-1932, Florence) and the Flaminio Stadium are compared and contrasted on the basis of (i) structural efficiency (forked cantilever versus simple pleated beam cantilever system), (ii) material (reinforced concrete (rc) versus ferro-cement), (iii) construction techniques (in-situ versus segmented pre-cast) and (iv) their socio-political context (interbellum versus post World War II Italy). Although Nervi designed many more stadia, the Berta and Flaminio stadiums were selected for this study because both (i) were entirely designed and constructed in an Italian context by Nervi's own family-run firm (see figure 1); (ii) have similar cantilever roof spans, seating capacity and ellipsoid plan; (iii) at the time of their completion they were instantly internationally applauded and (iv) they span Nervi's professional career (Berta early career and Flaminio late career).

Figure 1. Nervi and his sons Antonio, Mario and Vittorio at the Flaminio Stadium (1960, Rome) (book Pier Luigi Nervi: Architecture as a Challenge, 2010)

2. IMITATION: ARCHITECTURAL FORMS AND IDEAS ABOUT REINFORCED CONCRETE

Nervi's life has been intrinsically linked to concrete. One year before François Hennebique filed his reinforced concrete patent in France and Italy, Nervi was born in Sondrio (Northern Italy) in 1891 [1]. He pursued a degree in civil engineering at the University of Bologna. As a young student, he studied and appreciated the correct relationship between structure and shape, a correlation he would later routinely express in his cantilevering roofs over grandstands. Figure 2 shows an abstract from the course notes of Professor Silvio Canevazzi, who taught him Meccanica applicata alle Costruzioni. The figure shows the ideal shape of a cantilever with uniform thickness and variable height (a) under an edge point load, and with uniform thickness and variable height (b) under a uniformly distributed load [2]. In his lectures, Canevazzi instilled in Nervi the notion that engineers should develop an intuitive understanding of structures and be critical of established theories and practices [3].



cioè quando il carico è isolato, essendo a costante, b varia secondo le ordinate di una parabola rispetto ad x e secondo le ordinate di un ellisse quando il carico è continuo

Figure 2. Ideal shape of a cantilever under an edge point load with uniform thickness and variable height (a) and under a uniformly distributed load with uniform thickness and variable height (b) (credit Library of School of Engineering and Architecture, Bologna)

After graduation in 1913, Nervi spent approximately ten years (interrupted from 1915 to 1918 by World War I) with the Societa Anonima per Costruzioni Cementizie under the mentorship of his Professor, Attilio Muggia, who was the only licensee for the Hennebique patent in Central Italy [3]. This invaluable experience with one of the best organizations in Italy in reinforced concrete work, provided a solid foundation for his future work, but also restricted his freedom as a budding structural innovator. In 1923, when he was about to get married, Nervi formed his own design and construction company Soc. Ing. Nervi & Nebbiosi with co-founder Rodolfo Nebbiosi, the financier and entrepreneur of the team. The company's portfolio showcased a wide range of utilitarian projects such as industrial plants, tanks and warehouses. In 1929 Nervi started working on the design of the Giovanni Berta Sports Stadium (which is now called the "Artemio

Franchi" Florence Municipal Stadium), a project that was divided into many subprojects.

During the construction of this stadium, Nervi broke up with his business partner Nebbiosi and founded a small family-run company Soc. Ing. Nervi & Bartoli with his cousin Giovanni Bartoli (1932). The realization of the Florence Municipal Stadium, a reinforced concrete grandstand with a cantilevering roof, was crucial for Nervi's success as the head of a young design-and-build company. The grandstand was highly appraised by Italian and international critics [4]. The bold design for the cantilever roof and the sculptural expression of the winding external staircases appealed to a new generation of young rationalist architects.

Figure 3. *Overall view of the Florence Municipal Stadium showing the oval playing field, straight race track in front of the covered uncovered grandstands and Marathon tower (book Aesthetics and Technology in Building,1965).*

2.1. Socio-political context of the Florence Municipal Stadium

In July 1930, the Municipal Council of Florence published a competition document for a 35 000 seat stadium with a covered grandstand. This new stadium was promoted by the District Fascist Group and named in honor of Giovanni Berta. With only two stadiums in Italy at that time [5], the design posed interesting challenges. The main design requirement for the stadium stipulated the use of reinforced concrete and that it should be "Erected along one of the sides of the playing field for an overall length of 110m, of which the central part is covered and the two lateral parts uncovered. In order not to block the view too much, the upper roof shall be cantilever design, as far possible eliminating pillars or central supports, and should therefore be constructed in reinforced concrete." [6]. The contract was assigned to Soc. Ing Nervi & Nebbiosi in December 1930. During the next few years the scope of the works was extended to include uncovered rectilinear terrace stands, helical staircases and the Marathon Tower. The stadium has a global oval shape that holds a 78m wide and 204.6m long playing field. The oval shape has an asymmetrical layout due to the 200m straight running track required in front of the covered grandstand (see figure 3). The roof over the grandstand is one of the project's outstanding structural features and is discussed in depth in section 2.2. Although the initial design brief dictated a reinforced concrete cantilevering roof system, Nervi managed to demonstrate through the roof design that he knew how to design reinforced concrete structures well. His design intent was to realize an elegant roof geometry that eliminated the need for costly tensile foundations, unavoidably associated with cantilevering roofs, and efficiently used reinforced concrete.

2.2. Structural efficiency of the cantilevering reinforced concrete roof over the grandstand

The roof (shown in figure 4) consists of a thin reinforced concrete shell spanning continuously between 15 curved reinforced concrete cantilever beams with an expansion joint at every third beam. The roof structure region between the exterior and interior columns is referred to as the 'backspan' and the part between the interior column and the roof tip is referred to as the 'cantilever'. The cantilever measures 14.6m and the backspan is 7.4m long. All dimensions used for this study are taken or scaled from the general cross-sectional drawings [7]. The depth of the overhang beam varies from 40cm at the cantilever tip to 2.6m at the interior support before it forks into a tension and a compression chord of 55cm in depth. With no indication of the shell thickness and the roof beam's width at hand, these values were conservatively estimated to be 10cm deep and 40cm wide respectively. To prevent torsional buckling of the slender beams, Nervi introduced two restraints, namely two additional longitudinal beams. One large beam, located approximately at the overhang's midspan, runs longitudinally between the 15 cantilevering roof beams and one smaller one between the tops of the exterior columns. The bifurcating roof system is integrated in the supporting frame below. This series of frames also support a floor. The floor is assumed to have a slab thickness of 25cm. At the ground level the frames consist of two columns (interior and exterior) spaced 9.85m apart. Reinforced concrete is assumed to have a density of ρ=2400kg/m3.

Support reactions at the frame' footprint: By modeling the roof as a cantilever beam supported at point A and point B and the cantilever tip at C under self-weight, the resultant of all loads is found at 7.4m from support A. This location falls well in the span between the two bottom frame columns A and D (figure 5). Nervi wrote "… the fact that the resultant falls within the two columns eliminates the necessity of costly foundation anchorages." [5] Our analysis of the entire grandstand frame with overhang shows that the entire self-weight and any effect of overturning causes only compression forces on the frame's footprint. Nervi would have considered other loading combinations (including wind, snow, temperature and maintenance) in his detailed calculations. Uplift forces on the cantilever due to wind are not as crucial since they would be counteracted by the self-weight of the roof. The self-weight is the dominant load case and thus suffices to conceptually demonstrate Nervi's design intent to arrange the topology of the overhang roof such that costly tensile foundations are avoided.

Axial stresses in the overhang beam: The largest bending moment due to self-weight in the roof occurs at the interior support where the overhang beam bifurcates as shown in Figures 6 and 7. At this position, the curved overhang beam has tapered from 40cm at the cantilever tip to a solid deep beam of 2.6m and experiences a bending moment of 3500kNm. Figure 7 shows how the shape of the curving beam relates directly to the bending moment that varies along the beam's length. Nervi explained: "The variation in section of the main ribs is dictated by the law governing the variation of moments. Purely esthetic considerations inspired the slight curve of the canopy and the haunching of the main ribs." [8]. This engineering principle was instilled in Nervi as a student by Canevazzi (see section 2). Yet, in the detailing of that form, Nervi expresses his talent to design and create elegance in his projects. Instead of continuing the deep beam, Nervi forks the beam into 2 members, one tensile top chord and one compressive bottom chord. When dividing the bending moment (3500kNm) by the lever arm (2.6m-0.55m) we find a compressive and tensile force in the bottom and top chords of 1710kN and an associated stress of 7.7N/mm^2. This stress falls well within the compressive load bearing capacity of concrete and also shows that the large amounts of tensile reinforcement, positioned at the top of the beam, need to be mobilized.

Deflections: Regarding deflections at the cantilever tip, Nervi recalls how physical in-situ tests with loads of 1.2kN/m^2 on a few spans produced a tip deflection of only 0.8cm (span/1825) while Nervi had calculated 3.8cm (span/380) [7]. Our analysis indicates a value of 3.2cm. After completion, Nervi reports how plastic deformations continued but eventually stopped [6].

Figure 4. *The stadium under construction shows the bifurcating cantilevering roof and the support frame. (book Ingg. Nervi & Bartoli, societa per azioni)*

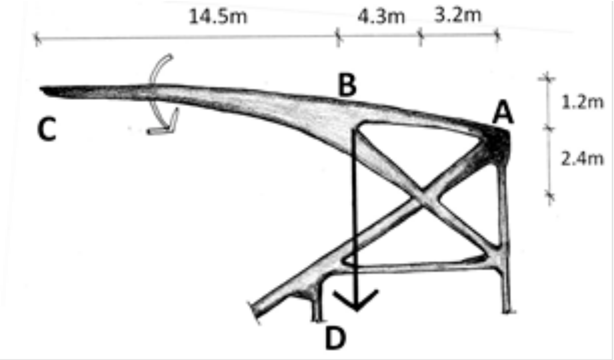


Figure 5. Cross-section with resultant force falling between the two frame columns (A and D).– 25 mm, left/right margin – 20 mm. Apart from the first page a two-column text layout should be maintained.

Figure 6. *Interior view showing the bifurcating beam and its connection to the longitudinal stiffening beam. (book Structures, New York: Mc-Graw Hill, 1955.)*

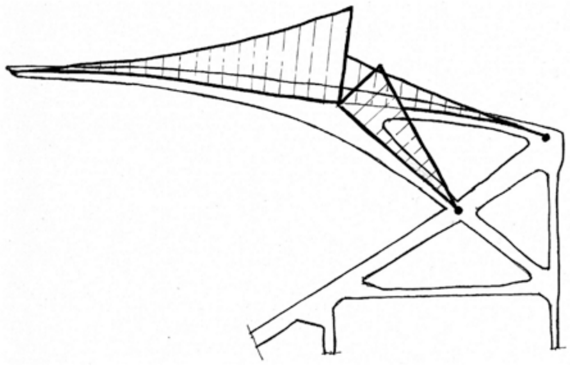


Figure 7. Bending moment diagram under self-weight showing the largest value occurring at the bifurcation point where the roof beam has the largest depth.

2.3. Cost-effective project

The 35 000 seater stadium was built for the economic price of 101 500 USD or 2.9 USD/seat [7] and [9]. A number of factors contributed to this low budget. First, the design and construction of the supporting grandstand frames were kept identical across the uncovered and covered grandstands. Second, Nervi used an integrated approach for his seating and structural system. The terraced steps of the grandstand simultaneously served as seats and beams. Third, he designed the cantilevering roof system over the covered grandstands in such a way that the foundations did not experience any tensile forces, thus avoiding the need for expensive anchorages to resist those forces. Finally, by opting for a thin shell roof supported on cantilevering beams, Nervi substantially reduced the amount of construction material needed for the roof.

2.4. A reinforced concrete esthetic design intent, not entirely free from imitation

This stadium is one of Nervi's own first large scale projects. Unlike in his previous jobs, he was not limited by a fixed, company-imposed design approach. Nervi took the liberty of exploring the formal possibilities of reinforced concrete design without yet being free from preconceived architectural notions of form. The grandstand roof and the seating are impressive integrated structural forms. The roof thickens at its supports and cantilevers out over the grandstand. It articulates the bending moment curve of a cantilever and expresses the forces and stresses within it. A superimposed façade with classical columns, designed by the Florentine architect Alessandro Giuntoli , masks the structural frames along the front of the stadium. Although this façade is constructed of reinforced concrete, it does not explore any of its structural qualities [10]. Also the tower and the spiraling staircases, which were constructed in 1930-31 (three staircases were built in this first phase; the other ones in the 1950's), show no structural relationship to the grandstand. In this project, the young Nervi proved that he understood and mastered how to design, analyse and construct reinforced concrete structures. However he did not integrate this knowledge into all aspects of the stadium's design as illustrated by the classical facade.

3. INNOVATION: NEW CONSTRUCTION MATERIAL AND TECHNIQUE DUE TO DISCIPLINE OF ECONOMY

In preparation for WWII, the dictator Benito Mussolini (1883-1945) started to organize Italy to be economically independent from other European countries. In 1935, Italy invaded Ethopia and the League of Nations sanctioned Italy with an international embargo on all raw materials useable for warfare (specifically metals). Steel was rationed and only permitted for military purposes (such as rejuvenating the army gun arsenal and constructing battleships). In 1939, Mussolini considered concrete reinforced by steel bars as an anti-autocratic material and banned its use despite its widespread application in building projects. This politically imposed constraint of material economy led Nervi to major innovations. He began a thorough investigation into the material cost of all items involved in the construction process [1]. These detailed bills of quantities and associated cost excluded manual labor and design cost. At that time, these two elements had a negligible effect on the cost of a project. This study led Nervi to two conclusions (i) the amount of concrete had to be minimized and (ii) wooden formwork had to be reduced or, better yet, totally eliminated [11].

Ferro-cement: In his 1943 patent, Nervi described a composite material of packed steel meshes (of 1mm diameter or less) saturated with mortar. This technique was pioneered by Joseph-Louis Lambot [12] in France and re-invented by Nervi. The mortar recipe contained water, cement and sand but no gravel because gravel cannot be pressed into the steel mesh with a trowel. Once the mortar was applied with a trowel on one side of the mesh and appeared on the other side, it would be smoothed out. The preparation of the mortar required careful attention; its plasticity was crucial to the making of the material. Without the need for (expensive timber) formwork, horizontal and vertical slabs could be prepared by low skilled laborers. He called this invention 'ferrocement.' Ferro-cement could be very thin (as little as 4cm in the Flaminio Stadium cantilever beams), strong, flexible and inexpensive. Unlike reinforced concrete, this material is homogeneous, isotropic and elastic.

Structural Prefabrication: To eliminate wooden formwork, Nervi envisaged how a structure could be broken down into light and small identical pieces. On site, these elements with protruding bars could be prepared in a series of reusable molds. Once cured, these pieces could easily be lifted and transported by light lifting equipment and assembled by low-skilled workers on scaffolding. A strong connection could then be cast between the pieces to make the system monolithic. In 1939, Nervi patented this technique and called it 'structural prefabrication' [1]. This artisanal construction technique is quite different from our contemporary definition of prefabrication and would prove to be perfect for a traditional building site in a post-war country that lacked skilled labor and machinery, such as the 1960's Rome Olympic infrastructure.

4. INSPIRATION: THE MASTER BUILDER

4.1. Socio-political context of the Olympic Flaminio Stadium

The Flaminio Stadium is one of the four structures designed and built by Soc.An.Ingg. Nervi & Bartoli for the 1960's Olympic Summer Games in Rome (see figure 8). When the project started, Nervi was 64 years old and presented for the first time as his official partner his son Antonio, who had just qualified as an architect in March of 1950 [1]. The brief for the stadium stated that (i) the new soccer stadium footprint should not exceed the old stadium's footprint, (ii) it should additionally house a swimming pool and five gymnasia, and (iii) it should seat 45 000 spectators comfortably [12]. The stadium has an ellipsoid plan with dimensions 85.8m x 153.3m. The short sides of the ellipsoid were designed for standing room, and one side of the long side as a covered grandstand with individual seating. The design and construction of this stadium clearly shows how Nervi built on his 20 years of experimentation with ferro-cement and pre-fabrication to realize an inspirational work of structural engineering. The stadium has three structural systems: the foundations, the ground level structure with incorporated grandstand with 45 000 seats and the corrugated cantilever roof, which arises out of the seating on only one long side of the stadium.

4.2. Design virtuosity and structural efficiency

This section focuses on the design and construction of the grandstand cantilevering roof, which consists of a series of juxtaposed V-beams connected monolithically. The roof region between the exterior and interior columns is referred to as the 'backspan' and the overhang is referred to as the 'cantilever'. Each individual roof beam is 1.42m wide, 27.7m long (14.5m cantilever plus 13.2m backspan) and has a varying height from 117cm at the interior column to 4cm at the cantilevering edge.The webs of the V-section have a thickness of 4cm. Four such V-shaped profile beams (these were Nervi's patented "wave elements") are monolithically joined to form a 5.6m wide structural corrugated section. This section connects to the grandstand at two points. At the exterior of the stadium, the corrugated section rests on concrete supports. Halfway along the length of the corrugated section it is further supported by inclined steel tubes, filled with concrete, that arise from the seating. The interior roof support and the exterior roof support are connected with a square steel section, embedded in reinforced concrete. In order to not obscure the sightlines, Nervi positioned the interior roof support as far back as possible (see figure 9). As a result he created a large cantilever over the covered grandstand. To reduce the effects (high stresses in the concrete and possibly the need for tensile foundations) of an unavoidably large bending moment, Nervi took several rational measures that had visual implications. First, he introduced high-strength low-density ferro-cement (ρ=2130kg/m^3) [13] for the cantilever and normal weight/normal strength concrete (ρ=2400kg/m^3) for the backspan to balance the loads between those two parts. Second, he shaped the longitudinal profile of the roof section in accordance with the bending moment diagram as he had realized in the Florence Municipal design 30 years earlier. Third, he reduced the permanent loads on the cantilever even further by introducing 5 circular apertures in each beam web in the cantilever [13]. And finally, as he had pioneered in the Berta stadium (see section 2.2.), he designed the cantilever roof and supporting grandstand frame such that the foundations only experience compressive loads (see figure 10) [13].

***Figure 8.** An overall view of the Flaminio stadium shows the standing grandstands on the short side of the ellipsoid floor plan and the covered grandstand on one side. (book New Structures, London: Architectural Press, 1963)*

***Figure 9.** Perspective of the cantilevering roof showing the web apertures in the ferro-cement beam and the interior steel column positioned far back. (book Ingg. Nervi & Bartoli, societa per azioni)*

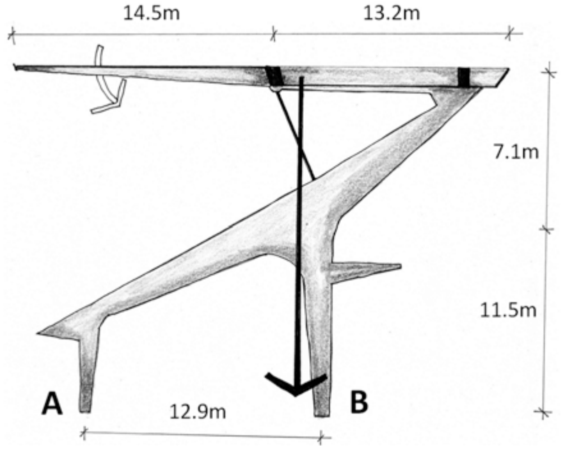


Figure 10. *Structural cross-section shows how the resultant of roof loads falls between the frame supports.*

Avant-la -lettre topology and size optimization in the roof to minimize stresses in the grandstand frames: Nervi wrote that he designed the relationship between the length, the weight of the overhang and the inclination of the interior column to increase as little as possible the stresses in the cantilever section of the rigid frame carrying the grandstands. To evaluate this statement, we determine the axial stresses due to normal forces and bending moments in the frames with and without the cantilever roof. Dimensions are taken from Nervi's drawings [12] and the live load for stadia is assumed to be 5kN/m^2. To demonstrate Nervi's intent, we discuss only the loading combinations (of dead and/or live load on the grandstands) that cause the largest stresses in the frame. For the covered and uncovered grandstands these loading combinations are not the same. Interestingly, our analysis shows that for the rigid frame with a roof, the worst loading combination is due to the factored dead load alone. For the frames without a roof, the maximum axial stress is due to the factored loading combination of dead and live load. The maximum axial compressive stress in the cantilevering end of the rigid frame is 7N/mm^2 and 5N/mm^2 for the uncovered and covered grandstands respectively. These values are well within the allowable stress value for concrete (i.e. < 27N/mm^2). We did not investigate the effect of wind, snow, temperature, creep, asymmetric loads etc. and used limit state design factors . Our design calculations do confirm Nervi's design intent and virtuosity. Since maximum stresses in both frames are very similar, great construction economy could be achieved by repeated identical construction all the way around the stadium. The axial load and bending moment diagrams for both situations are given in figure 11.

4.3. Achieving construction economy in a post-war country

Six factors played in favor of the economic construction of this Olympic stadium: (i) competition design, (ii) design and build company with a substantial track record, (iii) pre-fabrication and lightweight hoisting equipment, (iv) ferro-cement wave elements, (v) identical in-situ frames for covered and uncovered grandstands, and (vi) low cost foundations.

Competition Design: Nervi put in a bid for the Stadium for 1 280 000 USD or 28.44 USD/seat. Other bids came in between $1 900 000 to over $3 000 000 [12]. The jury of the design competition evaluated the appearance of a stadium in addition to its performance, constructability, and mostly cost. In general, design competitions ensure a high level of engineering, but in this case the competition also fostered inspiration in structural design.

Master builder and his design and build company: Unlike Eduardo Torroja and the Zarzuela Stadium [15], Nervi did not devise the Flaminio Stadium solely from the laws of statics or from any belief that efficiency alone would lead to an appropriate structure. Instead, Nervi acted as an engineer and master builder. With his 13-man office [16], he generated this design driven by this novel material (ferro-cement), and only he knew how to build it (prefabrication).

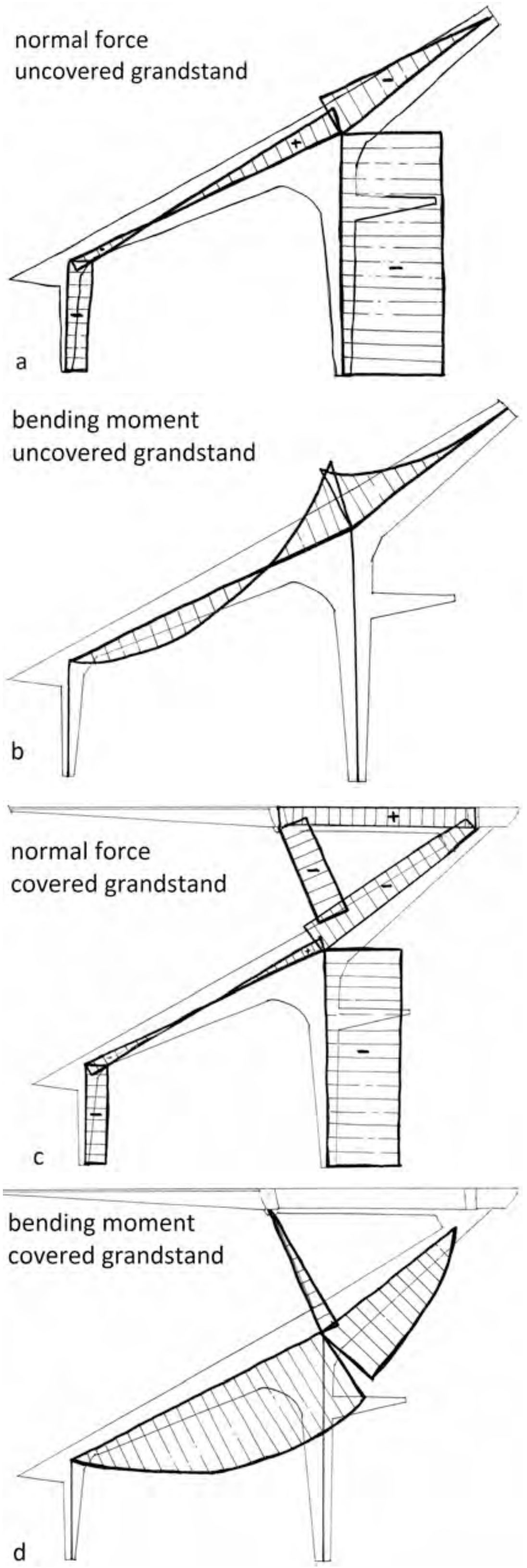


***Figure 11**. Normal force and bending moment diagram for uncovered grandstand under a loading combination due to dead and live load (a*

and b), and covered grandstand due to a loading combination due dead load only (c and d) The bending moment in roof is not shown for clarity.

Prefabrication and lightweight hoisting equipment: With the congested urban fabric of Rome as a construction site, Nervi envisaged the decomposition of the stadium roof into separate elements. The roof beams were prepared directly on-site while the identical rigid frames where cast-in-situ. Those roof beams had to be light (6000kg) and small enough to be lifted into place by lightweight hoisting cranes, the only widely available machinery in post-WWII Italy. The beams' profiles also had to provide sufficient bending stiffness to bear the handling and erection stresses. Once the beams were placed on the scaffolding, ribs were cast in situ to connect the wavy elements and establish a monolithic corrugated section (see figure 12).

Ferro-cement wave elements: For this cantilevering thin roof to be stiff enough during its erection and service life, it had to resist force by form. The "wave elements" patented in 1948 [17] and extensively used in the roof of the Flaminio stadium, gave the roof beams a higher moment of inertia and thus increased bending stiffness and lowered bending stresses. The wavy meshes were fabricated by bending the steel mesh with a brick mold. The mesh was then further prepared with the mortar. To locally ensure the rigidity of the wave elements, transverse diaphragms prevented the slender elements from buckling.

Identical in-situ frames with pre-cast structural seating for the (un)covered grandstands: Nervi arranged the roof topology and elements such that the cantilevering part of the cast-in-place rigid frame supports showed little stress variation between the covered and uncovered grandstands (see section 4.2.). As a result, all grandstands were designed and realized in an identical manner, which further reduced construction cost. Once the frames were cast in situ and had cured, integrated pre-cast beam/steps were placed over the supports.

Foundations: By varying the cross-sections of the cantilever and backspan and carefully selecting the location of the interior columns, Nervi shifted the center of gravity of the entire roof structure (backspan and cantilever) to lie between the two supports (A and B) (more precisely at a distance of 10.1m from A in figure 10). Our analysis of the entire system under self-weight confirms that the frame's footprint experiences only compression forces and thus avoids the need for expensive tensile foundations [11].

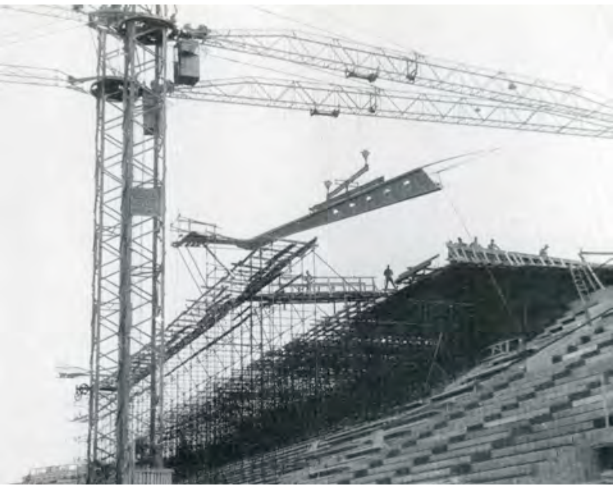


Figure 12. *The lightweight pre-fabricated beams are lifted into place by two lightweight cranes operated by one person. The beam consists of ferro-cement wavy elements, stiff enough to be lifted at two points during construction and to withstand forces during its service life. (book Ingg. Nervi & Bartoli, societa per azioni)*

4.4. Understated elegance through integration and rhythm in form.

Without gaining as much attention as Nervi's other Olympic structures, the Flaminio Stadium really captured the spirit of the 1960 Games. The Palazzetto and the Palazzo dello Sport buildings were designed in collaboration with the architects, Annibale Vitellozzi and Marcello Piacentini, who strongly influenced the architecture of these sport complexes. Unlike the Pallazzo dello Sport, the Flaminio stadium, solely designed by Studio Nervi, does not call attention to itself with elaborate forms and ornament but through integration and its understated rhythm. Nervi created a simple aesthetic by minimizing the number of different forms. The reinforced concrete frames are in essence a diagonal beam supported on two legs. Nervi integrated the indoor architectural program (e.g. swimming pool, gymnasium, etc.) in the space between those frames. These rooms do not disrupt the visual coherence of Flaminio, but they are logically contained within it. The indoor program was not the only brief requirement Nervi elegantly integrated into the stadium form. The pre-fabricated seats, posed on the frames, simultaneously serve as seating, steps and a structural diaphragm between the frames. The roof does not challenge the integrated appearance of the stadium; it complements and shades the seating from which it extends. The connections between the roof and frame appear light. The feeling of lightness is further enhanced by an optimized form that minimizes stresses and is pierced with apertures, letting Mediterranean sunlight flood in.

5. CONCLUSION

Nervi became an innovator and eventually master builder of inspirational works out of economic necessity. Although his early Berta stadium design put Nervi in the (inter)national spotlight as a budding structural designer and his work was fresh, it was not totally liberated from preconceived architectural ideas about the relationship between form and material. The Flaminio Stadium, which he realized 30 years later, was the result of a long process of development, experimentation and innovation of structural and constructional practices in a time and place that imposed severe material restrictions. In this project Nervi showed himself as a master-builder – contractor, engineer and designer with a strong esthetic intent – in a context where materials were expensive and labor cheap.

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