THE "FERRO-CEMENTO" OF PIER LUIGI NERVI THE NEW MATERIAL AND THE FIRST EXPERIMENTAL BUILDING

C.GRECO
University of Rome " TOR VERGATA", Italy

ABSTRACT

In 1943 Pier Luigi Nervi tested and presented in his papers, a new structural element, an extremely thin plate of concrete made of layers of small diameter wire mesh and cement mortar with sand used as the binder.

Two years later, in 1945, he built with this thin structure, an experimental storehouse for his own Company in Rome.

The storehouse, is the first application in building construction of the ingenious intuition of Pier Luigi Nervi which made it possible, later on, the realization of his large coverings.

The building, with its absolute originality, has a role in the evolution of thin structures of reinforced concrete. These thin structures made optimum use of the original characteristics of reinforced concrete first patented in the 19th century - the malleability and its monolithic nature.

Nervi introduced two new factors; the distribution of the iron and its subdivision, and the elimination of wooden forms for casting.

The first factor gave birth to a new composite material - the "ferro-cemento", and the second factor enormously simplified the construction of thin structures as experimented for the first time in the storehouse in Rome.

Construction drawings, file and today's pictures will be shown with test data obtained at the time of the construction stage compared with the present situation of the building 50 years later.

1. INTRODUCTION

In 1943 Pier Luigi Nervi registered his patent of "ferro-cemento", an extremely thin structural plate, made of small diameter wire netting layers fixed on steel bars of a wider diameter, with cement mortar used as the binder.It was during war time. Pier Luigi Nervi was 52 years old and he had already had a successful career; his name, associated with the Florence stadium, with its well known helicoidal stairs, and with the Orbetello hangars, had become renowned worldwide.

The first phase of his career, in which the pioneering enthusiasm of this designer engineer had produced some fundamental projects in the history of reinforced concrete as supportings rib system, was over.

Nevertheless Nervi began to notice the limits of this system and two fundamental contributions to his following work arose from these observations: one was the impossibility of a rigorous calculation for complex structures, hence the necessity to turn towards intuition and experimentation, the other one, was the difficulties in the realization of free complex shapes and namely in building forms for casting.

During the war he concentrated on his experiments treating cement as a fluid and malleable element perfectly suitable for innovative shapes and ideas.

2. THE NEW MATERIAL

Nervi began to consider the problems created by the lack of material during the post-war period and the ones related to naval construction that he had been studying for a long time. He realized that the potential of concrete would be further developped and he tried to modify the ratio between the two basic elements "exalting beyond any reasonable limits the amount of steel, thus reducing the cement as simple binder (Nervi, 1945a). The goal first envisaged and finally reached, was of creating a "new material"; not only a fluid and malleable reinforced concrete but the "Ferro-cemento" flexible and shapeable that is a combination of the two materials strictly bound together with the specific characteristics of first a greater stretching capability and secondly a less important crack sensitivity.

The basic concept was to distribute the steel in the mortar in such a way as to increase the contact area between the two materials.In fact it is known that in this area the cement is able to "follow" the elongation of the steel.

He experimented with thin concrete slabs, 10 to 60 mm thick, reinforced with layers of usual steel meshes (Fig.1). The steel meshes were stacked up one on the top of the other, to obtain the same thickness as the final slab which was then filled with mortar of high resistence cement (10 ql/mc), and siliceous sand.

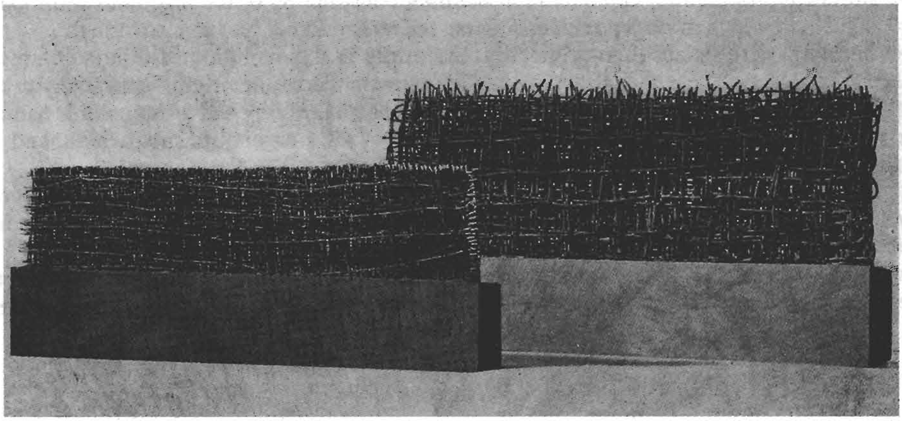

Fig.1 Thin slab samples reinforced with differents layers of meshes
(taken from Nervi,1943?, cit.)

Provino	N	p kg/m^3	d mm	L mm	s mm	γ %	ε_rx 10^3	σ_r^e kg/cm^2	σ_r^f kg/cm^2
1	3	0.4	0.57	10	17	0.45	12.5	25	270
2	6	0.4	0.57	10	16	0.95	11.5	20	250
3	4 2	0.4 1.0	0.57 0.90	10	17	1.35	11.5	20	250
4	20	0.4	0.57	10	18	1.42	60	42	1290
5	10	1.0	0.90	10	17	3.75	66	60	1420
6	10	1.0	0.90	10	17	3.75	67	60	1440

TAB.1

Legenda :
N = number of steel mesh layers
p = weight " " "
d = diameter of the single wire in the mesh
L = dimension of the single mesh element
s = thickness of the sample
$\gamma = A_f/A_0$, where A_0 is the total steel area in the tensile stress direction
e_r = elongation corresponding at the fissuration stress in the concrete
σ_r^c = fissuration stress in the sample, assuming it as composed of homogeneous material
σ_r^f = steel stress at the fissuration point for the concrete

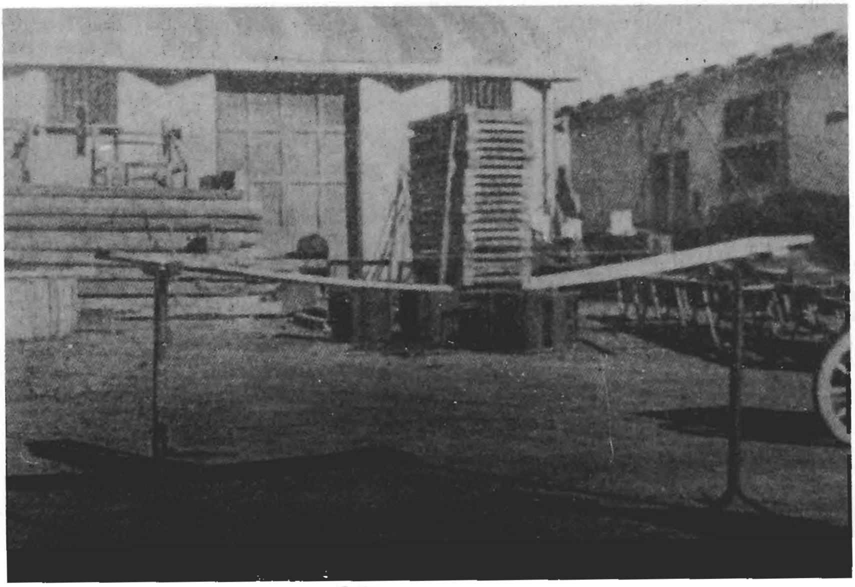

Fig.2 Slab sample tested during the storehouse construction (Archivio Antonio Nervi)

Nervi reported that "first cracks were noticed when tension loads, carried out from the bending moment related at the whole resistent section, were more then 400kg/sq m" (Nervi, 1943?). He noticed that the new material's behaviour was just like a homogeneous material able to resist to similar tension and pressure stresses (Fig.2).

Further tests made by G.Oberti and G.Grandori, professors at the Politecnico di Milano, with 150 mm thick slabs, reinforced with several layers of meshes, proved also that the best characteristics of the new material were strictly linked to the local plasticity phoenomenon (Oberti, 1948). (Tab. 1).

This discovery and the first positive tests so enthused Nervi that he called the event "a true revolution from both the construction point of view and the aesthetic as well".

He envisaged two possible uses - for large corrugated coverings and for thin surfaces of revolution- and produced two illustrative projects: a roofing 300 meters wide big enough to cover the entire colonnade of S.Peter's sqare in Rome (Fig.3) and a Pavillon for the Universal Exibition in Roma ,1942 (Fig.4). Details of the first structure shown that it was to be made with a 100 mm thick corrugated ferro-cemento surface, using two sectors with nets similar to the tested thin slabs and some support bars in the middle.

The major innovation, however, was to be seen in the construction process itself, in fact, quote,".the metal frame placed in that way is capable of retaining cement mortar pressed with a trowel until it comes out from the other side" (Nervi,1945b). Thus, the casting form became useless and Nervi achieved his much sought after goal, the freedom from casting.

Ferro-cemento was tested in 1943 in the construction of three cargos and one 400 ton motorship not completed due to the ongoing war. Right after the war, the 145 ton motorship "Irene" was built and tested, but the first use of Ferro-cemento in civil engineering was the construction of a small experimental storehouse.

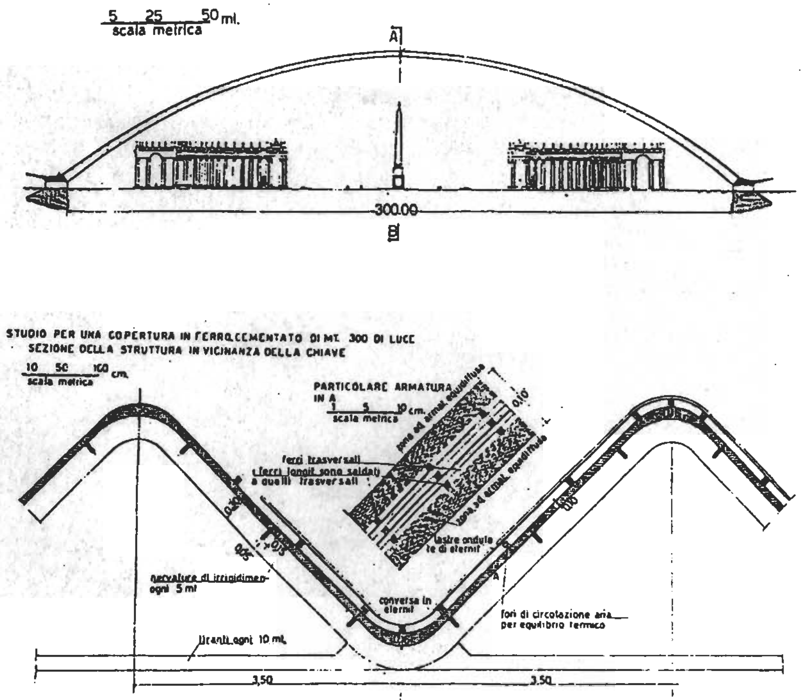

Fig.3 Large covering 300 m wide (taken from Nervi,1945, cit.)

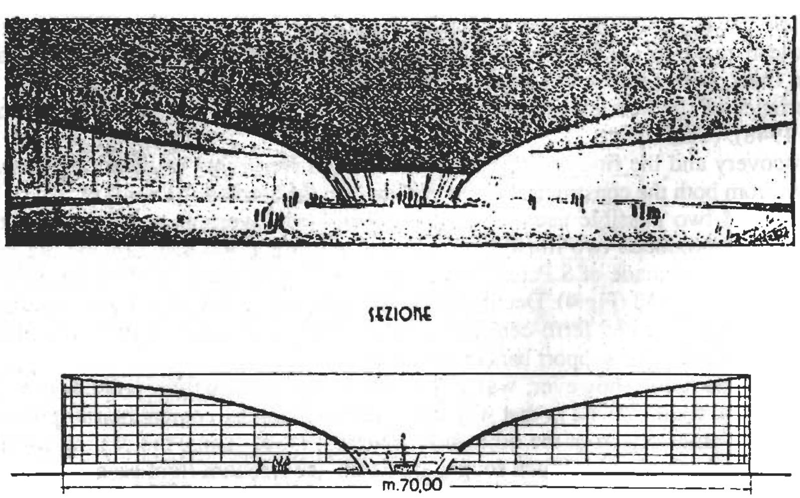

Fig.4 Pavillon for the Universal Exibition in Rome,1942 (taken from Nervi, 1945, cit.)

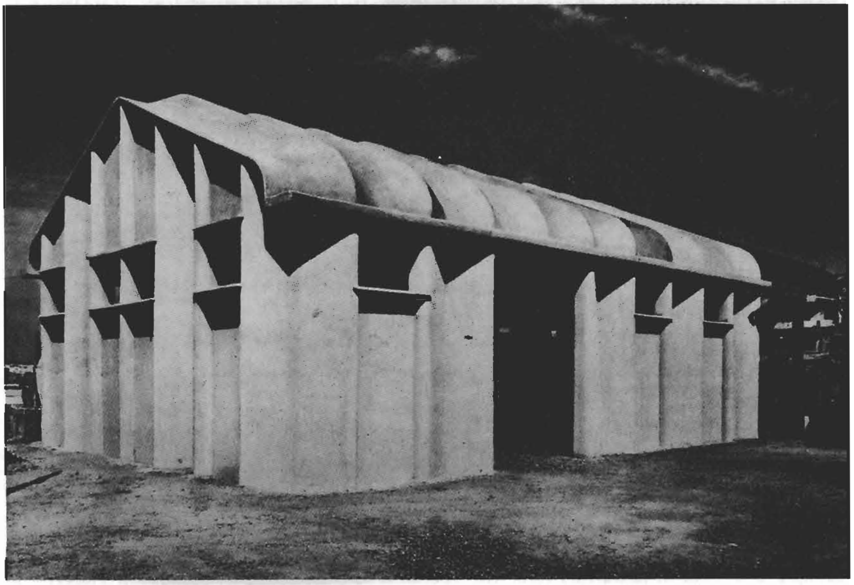

Fig.5 File view of the storehouse in construction,1945 (A.A.N.)

3. THE FIRST EXPERIMENTAL BUILDING

The building is a storehouse 21mt x 12 mt on Nervi & Bartoli Company property land in the Magliana area, Rome (Fig. 5). The ferro-cemento thin slabs (30 mm thick) had to be moulded to obtain the vertical and horizontal necessary resistences through their shapes.

Given that he no longer needed to use wooden forms, Nervi designed for the walls a special corrugated profile, alternated with linear parts that allowed the insertion of windows or wide entrance doors.

These ondulated profiles represented the true intelligent synthesis of his famous "static sensitivity" and his innovative construction process of building. As a matter of fact the first step consisted in placing some vertical wooden posts, rounded to follow the wall curving; these pillars acted as contrast points from which the steel frame, previously shaped on a wooden moulding, unfolded; then the thin wall, following its shape in plan, became orthogonal to the facade, in order to allow the positioning of the window frames. (Fig. 8)

Special wall profiles were designed for the corners and for the middle of the short fronts where a reinforcing element had been inserted.

The ondulation of the ferro-cemento for the roofing was simpler and it repeated itself according to the pattern of the more complex vertical walls.

The steel reinforcement was made of two horizontal iron bars 50 mm of diameter, placed every 200 mm, and separated by small vertical wooden ledges; and by steel-meshes weighing one kilogram per square meter, in a number varying from two for the walls, to four for the roof.

A vertical reinforcement madè by bars of 8 mm of diameter, was added just at the point where the steel frame curved around the wooden pillars .

The reinforcing layout of the thin structure derived from the illustrative project of the 300 mt covering but using much fewer layers of meshes.

Fig. 6 Picture of construction site during mortar laying (Archivio Antonio Nervi)

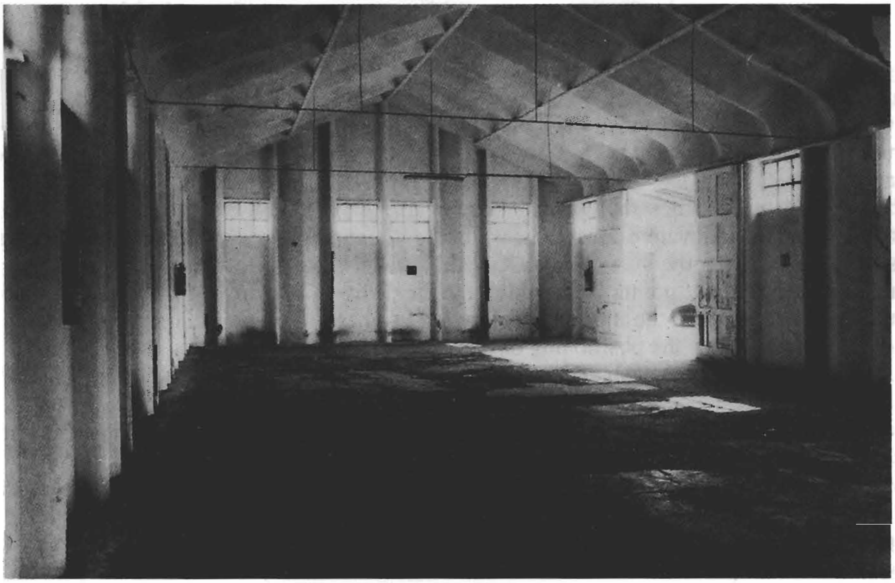

Fig.7 View of the interior of the storehouse today

This tight iron structure was covered by hand with a sand and cement mortar of good quality; the mortar pressed on one side filled up the spaces of the steel frame penetrating to the other side only so much as to require a simple shaving to obtain the wanted thickness of 30 mm, and a good finish (Fig. 6).

In this small building Nervi looks for the maximum of the design consistence using the standard thickness of 30 mm even in the architectural details: the gutter (Fig.9), the windows sills and the reinforcing hollow pillar on the short fronts (Fig. 10). This goal is strongly aimed even in the face of technical difficulties (Greco,1994).

The storehouse still exists and together with other old ones belonging to the Nervi & Bartoli Company, is used as a garage.(Fig.7)

After 50 years, it is in good condition and there are only a few damaged areas due mainly due to water infiltration: not many areas, in fact, considering that, for testing reasons, no water proof system has been used for many years.

Several tests over a structure sample have shown the excellent condition of the mortar and an almost complete absence of cracks.

3. CONCLUSIONS

In the storehouse structure, as in the corrugated element of the later large coverings built by Pier Luigi Nervi, layers of meshes are fewer then in the slabs tested in 1943.

This seems to be in contrast with the results of the experiments; in fact these experiments evidentiated the fundamental influence of the steel distribution and the effects of the local plasticity.

Further tests on new sample and on the storehouse structure will clarify the different behaviour of the two situations.

Our assumption is that the true potentialities of the Nervi new material could be developped even further, especially studying its behaviour as a composite material, prototype of the modern fiber-reinforced concrete.

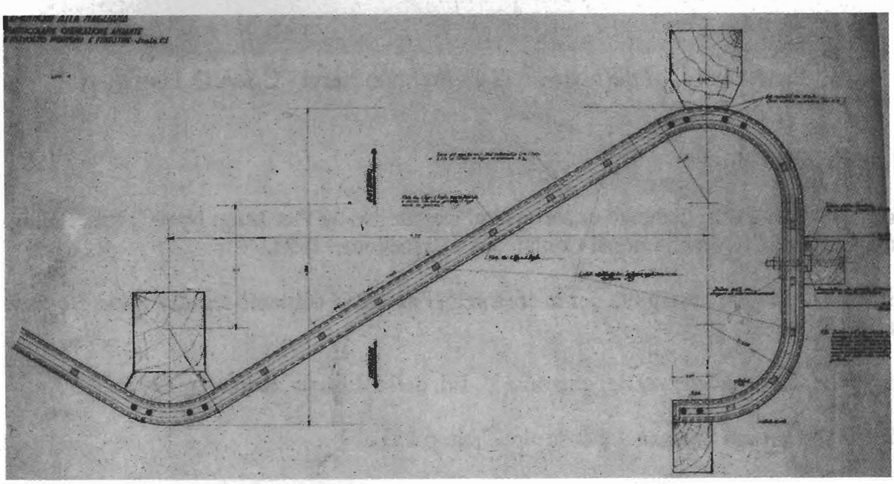

Fig.8 Details of the wall element (Archivio Nervi - C.S.A.C. Parma)

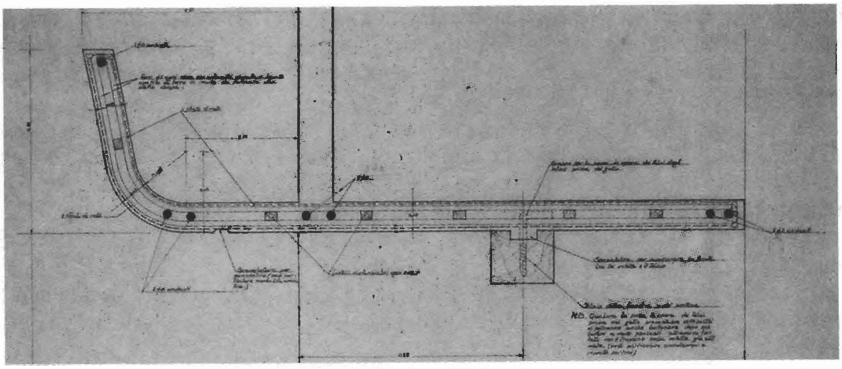

Fig.9 Detail of the gutter element (Archivio Nervi - C.S.A.C. Parma)

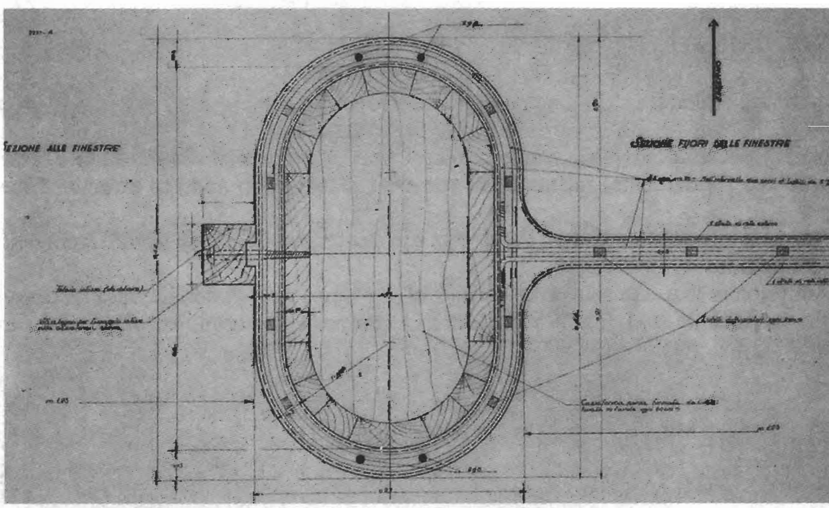

Fig.10 Detail of the hollow pillar (Archivio Nervi - C.S.A.C. Parma)

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