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Autor: Samuelli Ferretti, A. / Zingali, A.

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A Large Span Hanging Roof: The "PALASPORT" in Milan

Un toit suspendu de grandes dimensions: le "PALASPORT" à Milan

Ein weitgespanntes Hängedach: Der "PALASPORT" in Mailand

A. SAMUELLI FERRETTI A. ZINGALI
Istituto di Scienza delle Costruzioni
Università di Roma, Italia

A 11.000 seat Palasport is currently being built in Milan. Figures 2,3,4 show the architectural design. The main hall, including the field, a bicycle track of 265 m and the stands for the audience, is approximately in the shape of a reversed truncated cone. The upper rim of the cone follows a saddle-like profile, while keeping a perfectly circular shape in the horizontal projection; the outside diameter is 140 m. Such an arrangement gives to the roof surface a negative gaussian curvature throughout.

The structure of the reversed cone consists of 38 reinforced concrete ribs supporting on the upper edge the stands, and in the lower one the walls forming the outside face. From the above mentioned architectural arrangement, as far as the action of transmitting to the ground the strong pull of the cable network supporting the roof is concerned, arises quite a problem, because the rib structure should be of an exceptionally large size. It has been preferred to support the beforementioned inward pull by means of a self sufficient structure, which could transmit to the underlying reinforced concrete structure its dead weight and the roof's one, that is vertical actions only.

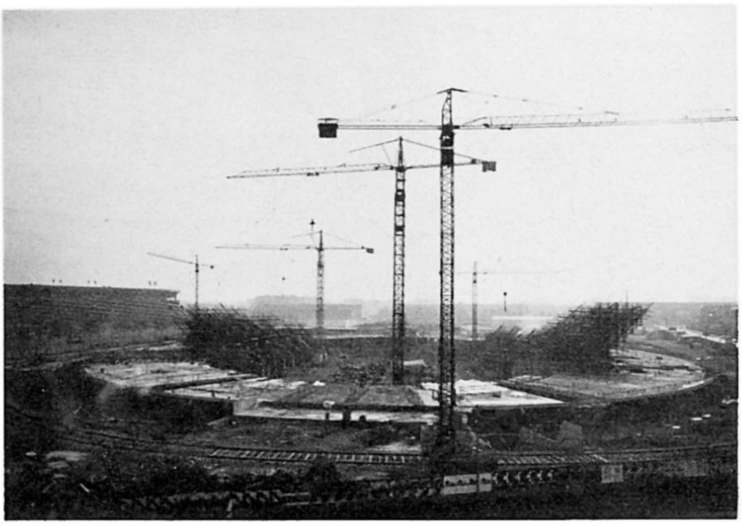

Fig.1 - General view of the building site

The network was thus anchored to the internal edge of a peripheral beam in the shape of a ring, which resists the inward pull of the cables in the various design load conditions, simply supported by the reinforced concrete ribs.

The main geometrical data of the roof are hereunder listed:

- area covered by the network : 11,500 m^2
- maximum camber of the sagging cables : 10.70 m;
- maximum camber of the hogging cables : 7.84 m.

The network consists of high tensile steel cables, spaced 1.50 m each other. Such spacing was chosen in order to allow the cables to support the roof plates consisting of cold formed light gauge steel sheet. The steel sheet supports the insulating and waterproofing coverings.

The cables are anchored at both ends by means of toggles and screws which allow a length regulation for about 500 mm, in order to ease the operation of assembling and prestressing the network.

The ring consists of a box steel girder whose cross section is of about 7.00x3.00 m; the skin plates are reinforced by means of transversal frames and longitudinal stringers. The shop welded elements are assembled in place and jointed by means of high tensile bolts.

The 38 abovementioned supports are simple action ones, that is they allow every rotation and every displacement in an horizontal plane. Special devices have been designed to realize supports which can react downwards as well as upwards.

The horizontal diplacements of the ring as a whole are preven-

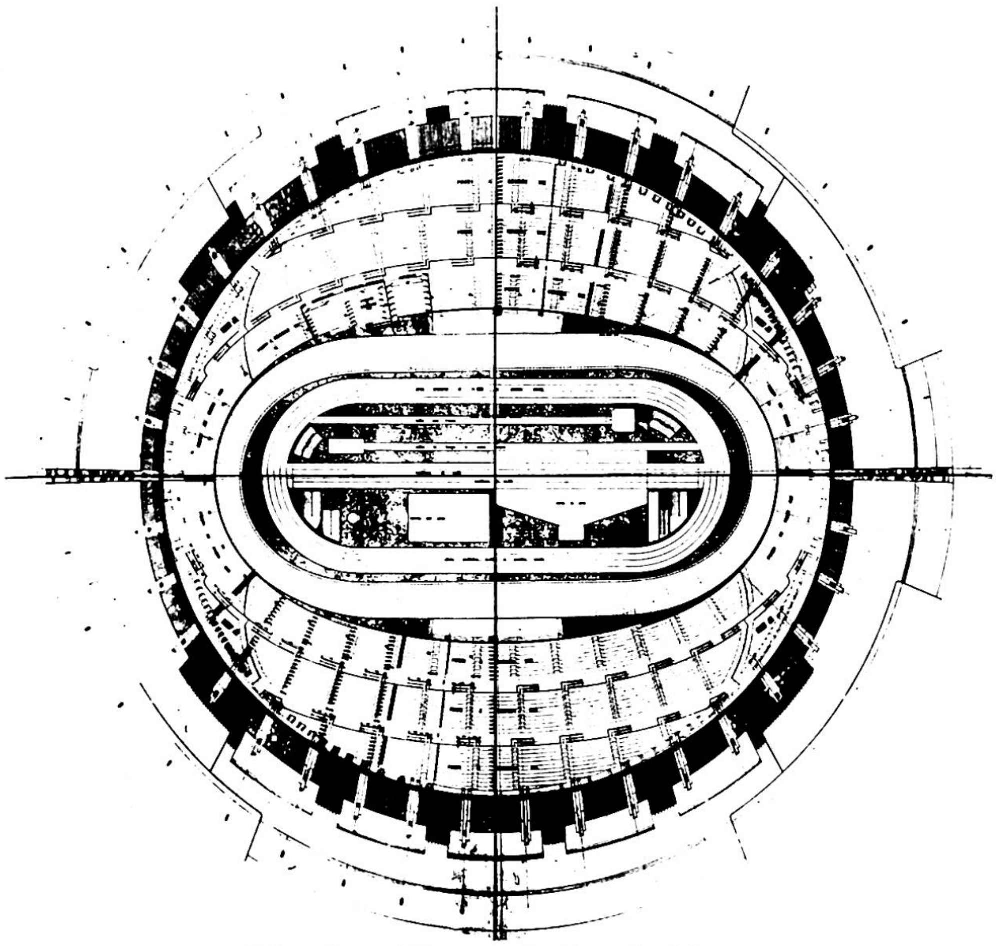

Fig.2 - Plan of the hall

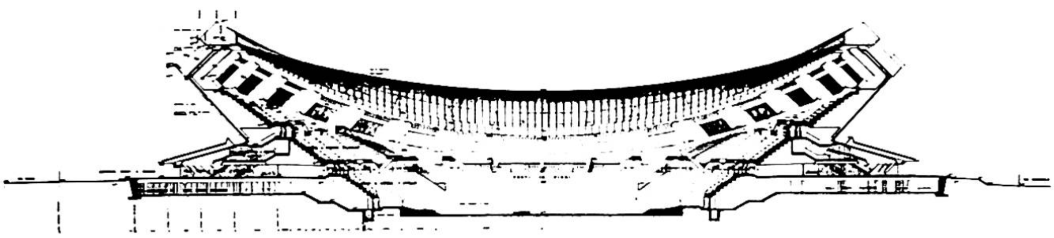

Fig.3 - Section

ted by means of limit stops provided for the supports at the opposite ends of two diameters. Therefore, the thermal ring displacements as well as the elastic ones due to live loads can be distributed between the opposite supports, thus avoiding excessive slippage of the ring with respect to the supporting plates.

The study of the static behaviour of the roof structure put into evidence the great importance of the ring flexibility in the geometrical and static conditions of the network. The influence of the ring flexibility is so important to completely cancel the schema of the fixed-end network, even as first approximation.

It is, therefore, necessary to take into account from the very beginning of the computational work the structure consisting of the network and the ring as a whole; a method envisaging such interaction as well as the non-linear behaviour of the network was specially perfected. The calculation procedure is briefly resumed in the flow-chart shown in figure 6, and its details are currently being published.

The roof shape, not far from an hypar one, was determined by imposing, as known quantities, the coordinates of the outside ring togetherwith the distribution of the prestressing forces in the cables.

As the design live loads can be upwards (suction caused by the wind) as well as downwards (snow load), the ensuing moment distribution in the anchoring ring beam are subjected to reversing.

The initial prestressing of the cables has been designed in order to minimize the bending moments in every section, by splitting their excursion in two almost equal parts.

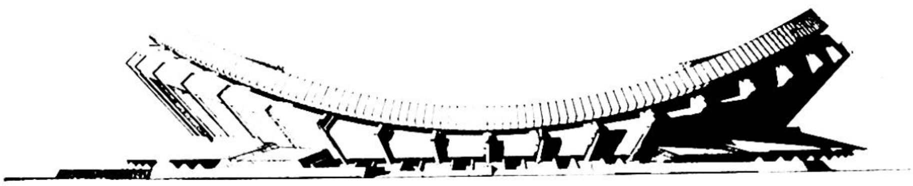

Fig.4 (1°) - Main views

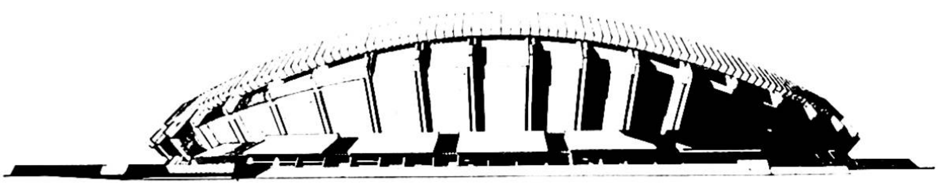

Fig.4 (2°) - Main views

The ensuing stress distribution in the sagging cables is almost constant, and equal to the hogging ones (20 t/m); under such forces the ring is subjected to almost pure compression.

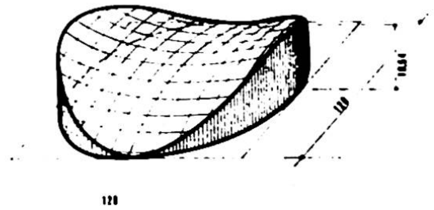

Fig.5 - Shape of the roof

As a matter of fact it has to be pointed out that the distribution of moments around the strong axis (horizontal) of the ring beam, whose center line follows a space curve, is not far from the one obtained by applying an equal system of forces to a flat ring-beam, whose centerline follows a plane curve.

Therefore, the ring being subjected to forces almost radial in direction and constant in value under dead load, the pressure curve is almost coincident with the center line.

Of course, the weak axis bending moment and the twisting moment distribution depends mainly from the altimetric shape of the ring; it has been found out, in particular, that the twisting moments never reach very important values.

As far as the choice of the orientation of the principal axes of the cross section is concerned, the possibility of placing the beam with its strong axis following the tangent of the network along its outside edge has been examined.

A small saving in the maximum moment was thus possible, but this solution has been cancelled for aesthetical as well as assembling reasons.

The most singular consequence of the aforementioned interaction between ring-beam and network can be observed in the behaviour of the cables under the action of an uniform live load such as the snow. In a fixed ends network the effect of such a load is well known: the tension in the sagging cables increases while the tension in the hogging cables decreases. In our case the shortening of the diameter between the points of support of the longest sagging cables is followed, in the ring-beam, by an elongation of the same order of magnitude

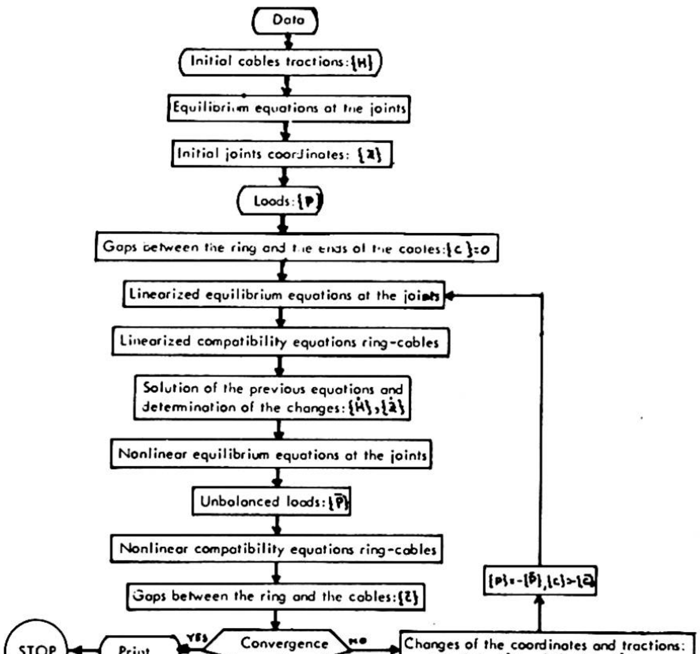

Fig.6 - Flow chart

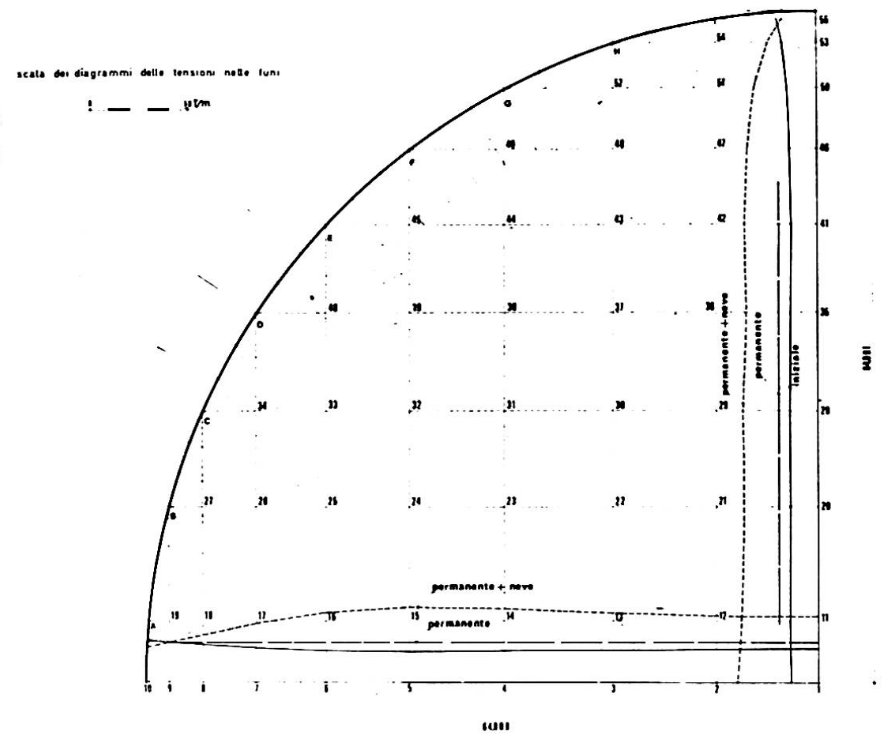

Fig.7 - Tractions of the cables

of the perpendicular diameter, corresponding to the longest hogging cables. Those displacements are large enough to increase the tension in the hogging cables also. Thus the live load is supported, so to speak, by means of a rather large increase in the curvature of the sagging cables. As a consequence, the deflections of the network due to live loads are rather large, as compared to the very small ones that can be observed in a fixed-end network; in the latter case, on the other hand, the variations of the network tensions are much larger, and, consequently, so are the moments in the outer ring.

In order to check the results of the calculations, a model in the scale of 1 : 100 was built and subjected to tests at the Istituto di Scienza delle Costruzioni, of the engineering faculty of Rome. The tests are conducted by A.Gallo Curcio and F.Piccarreta of the aforementioned Institute.

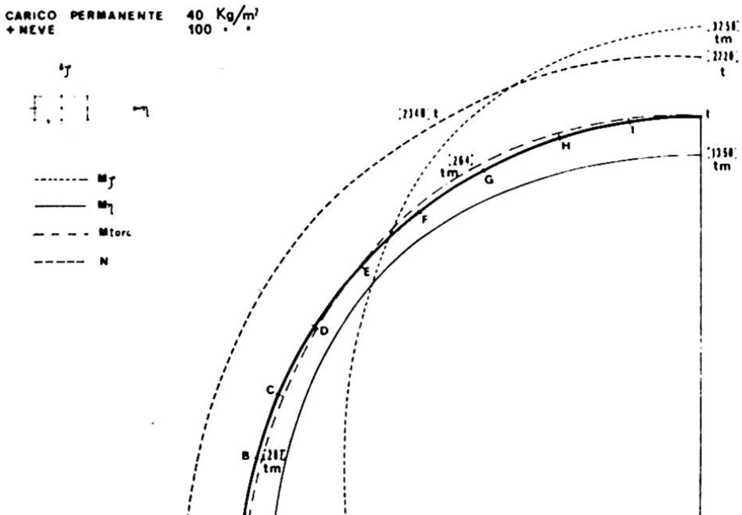

Fig.8 - Moments and normal forces in the ring for the snow load

The ring-beam of the model was made of cast aluminium, the cables of high tensile steel bands, spaced 10 cm and provided with turnbuckles. The supports are made by means of aluminum bars provided with spherical hinges at both ends, and linked to a very rigid steel frame. The bars are provided with dynamometrical devices in order to evaluate the reactions over the supports.

A second model, in the scale of 1:200, is currently being tested for eva-

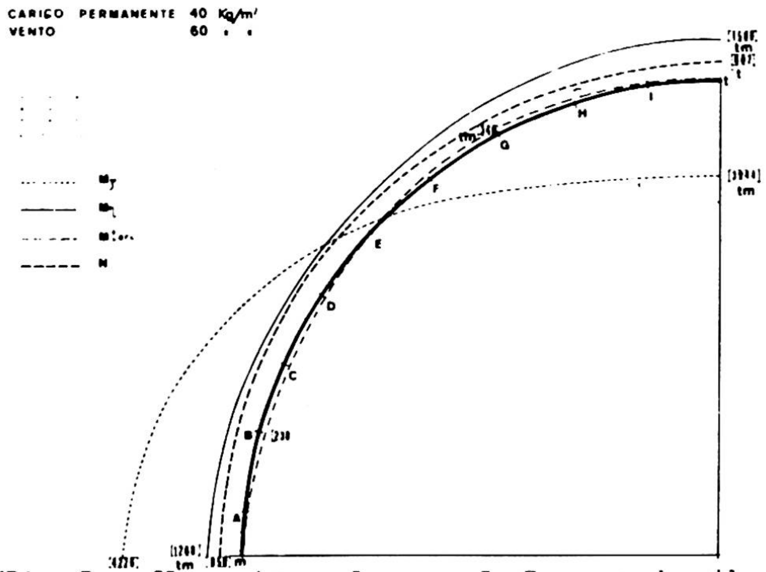

Fig.9 - Moments and normal forces in the ring for the wind suction

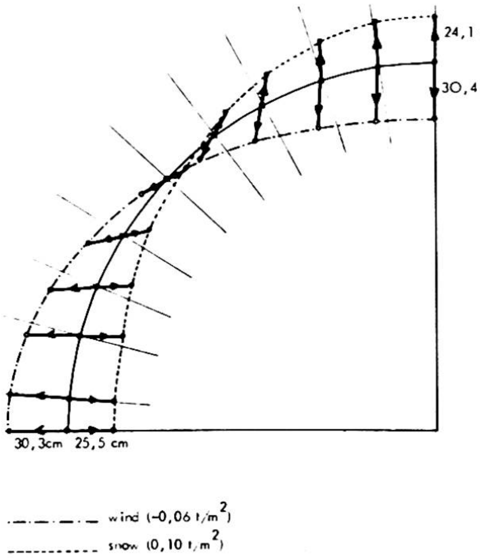

Fig.10 - Displacements of the ring

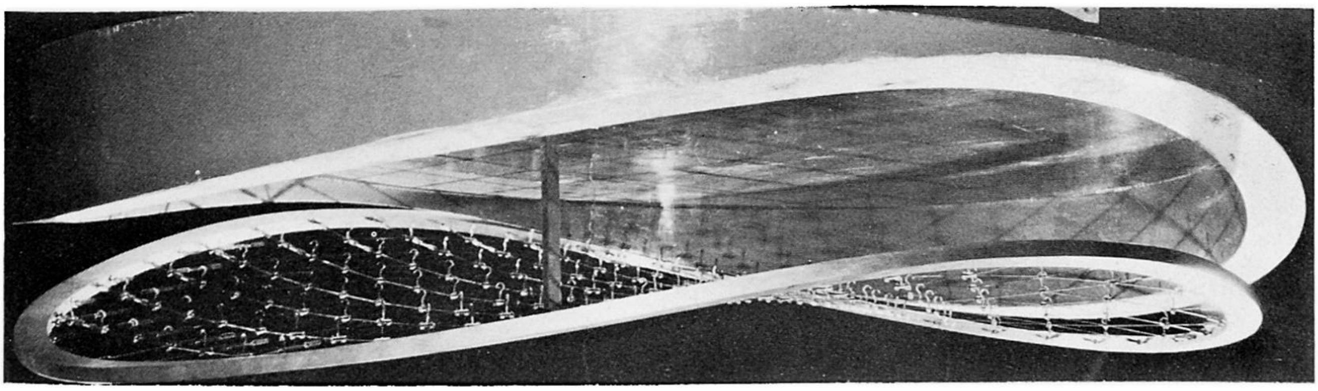

Fig.11 - The Model before being placed on its supports

luation of wind actions, to the faculty of Aerospace Engineering of Milan, (director prof. G.Rotondi).

The building of the Palasport has been committed by the Italian Olympics Committee to the "Società Italiana per Condotte d'Acqua", which was awarded the contract following a national call for bid.

The design has been developed by the Studies and Design Division of the "Società Italiana per Condotte d'Acqua", with the participation of the following consulting engineers and architects:
Architecture : arch. G.e T.Valle;Soc.Italiana Grandi Padiglioni
Calculation of the structure: Società Italiana per Condotte d'Acqua
Calculation of the network and ring-beam: ing. A.Samuelli Ferretti and A.Zingali

SUMMARY

The hanging network roof structure of large span,for the new Palasport in Milan,is described. Design as well as computational criteria are given,with some details about the effect of the interaction between network and peripheral ring.