

Oporto's Sports Pavilion - Aspects of the design, construction and renovation.

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Abstract

The Oporto's Sports Pavilion was inaugurated in 1952 occupying the place of a Crystal Palace dated 1865 that was demolished. After performing well as a sports and multifunctional arena during more than 50 years, this remarkable building is now going to be renovated to become a modern multipurpose facility. The Sports Pavilion's main feature is the roof that is a dome made of ribbed reinforced concrete forming a spherical cap covered by copper sheet giving it the characteristic green colour. The structure is now being studied and evaluated prior to rehabilitation. A structural assessment and inspection of the building is being conducted to evaluate the structure present condition. Supplementary to these observations a structural analysis is carried out by means of numerical models to find out if the concrete elements are in agreement with current safety standards. Based on original documents and statements of the personnel involved with its construction between 1951 and 1952 and having the unique opportunity to work with the architect of the original design, that is still participating enthusiastically in this renovation project, the aim of this paper is to divulge some aspects of this building that is a noteworthy example of an era when the reinforced concrete and its construction techniques were being explored to its limits.

Keywords: concrete dome, sports pavilion, rehabilitation, renovation, inspection plan

1. Introduction

The Oporto's Sports Pavilion was inaugurated in 1952 to host a Hockey World Championship, before having the roof finished. This iconic building was built occupying the place of a Crystal Palace dated 1865, inspired by London's original, which was demolished.

The building denotes the talent of its creators: architect J. Carlos Loureiro and structural engineers A. Santos Soares and J. Delgado de Oliveira.



Figure 1: Oporto's Sports Pavilion, aerial view

The pavilion has a useable area, at the main floor, of 6 500 m² and a capacity to accommodate 5000 seated spectators in demountable stands and was built to host sports competitions, exhibitions and other venues.



Figure 2: Internal view

The Sports Pavilion has a basement, a main floor, four galleries and a dome shaped roof. The building has a 90m diameter circular plan. The main structural feature is a dome made of ribbed reinforced concrete elements that forms a spherical cap.

Its apex concludes with a 13,4m wide skylight made of “transparent concrete” (10cm thin concrete shell with glass elements).



Figure 3: skylight made of “transparent concrete”

2. Structural design

A rather complete set of information on the original design was found in the municipality archives including original design drawings and calculations. It was also available information concerning results obtained on a dome's scale model made of *Perspex* tests performed in 1952 by the Laboratório Nacional de Engenharia Civil – LNEC (National Laboratory for Civil Engineering).

The entrance level slab (elevation 3.3m) is divided into 9 parts by expansion joints; one is circular and defines the central stage and the other 8 are radial and exist without duplication of structural elements. The two way slabs are 25cm thick and are supported by a grid of beams. These slabs applied a technology known as *Stahlton* slab system that was developed in the United Kingdom in the 1950's. The system developed around a high strength extruded ceramic tile with formed grooves open to the top surface into which longitudinal reinforcement (stressed high tensile wires) and steel ties or stirrups were placed and then the grooves were grouted using a portland cement grout. In the other direction the reinforcement is made of mild steel.

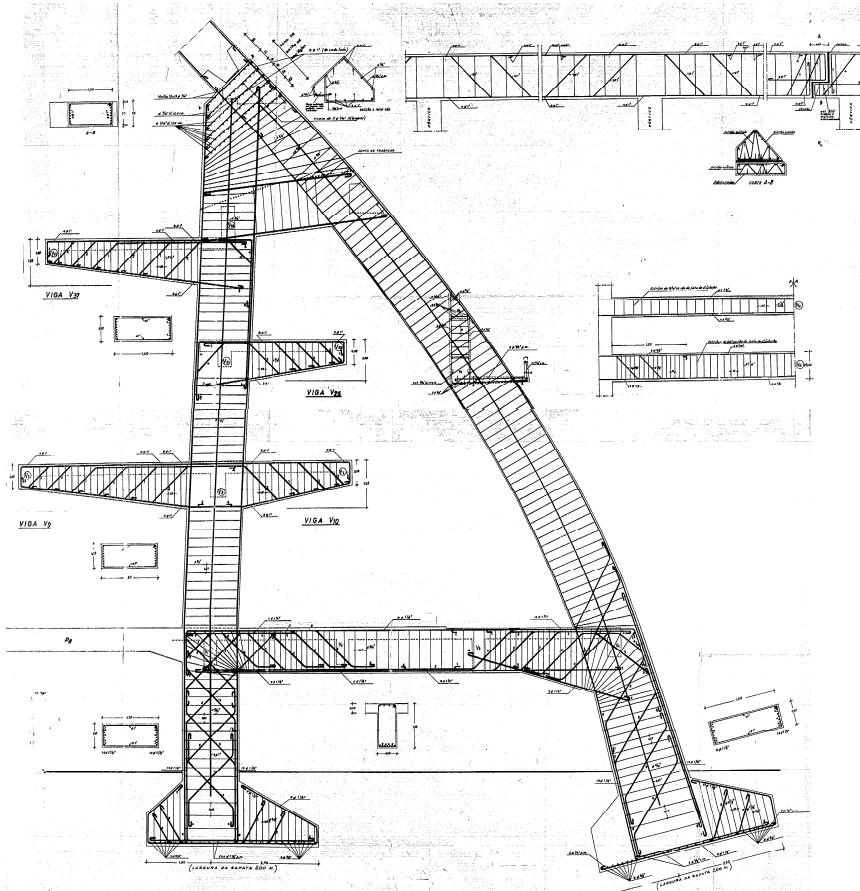


Figure 4: original drawing of triangular frame's concrete detailing

There are four levels of access galleries above level 3.3m. These galleries are supported by the column inside the triangular frame. Its unidirectional slabs are also 25cm thick pre-stressed and supported by a grid of beams. The galleries are also divided by eight radial expansion joints on the same vertical planes of the joints in the 3.3m level.

The roof is a dome made of ribbed reinforced concrete elements that forms a spherical cap. This is formed by thin (8cm to 5cm) two way reinforced slabs supported by 32 radial beams - the meridians - and 8 circular beams - the parallels. These slabs have circular skylights.

The dome is connected to the structure by a pinned support at the end of the triangular frame. The dome spans 72m being 15m height.

All elements have shallow foundations.

In the original design the live load was considered to be 5 kN/m^2 except for level 3.3m where 10 kN/m^2 was the imposed live load. This is justifiable because the stage located at this level has the slab to support the weight of the demountable stands and the loads from the use of the stage itself.

It is interesting to note that given the type of slab adopted, the punching shear resistance was determined experimentally. According to the description found on the calculation report several loads were tested and the report says explicitly that a load of 9 tonnes on a $0.40 \times 0.40 \text{ m}^2$ area can be safely applied on the centre of the slab panel.

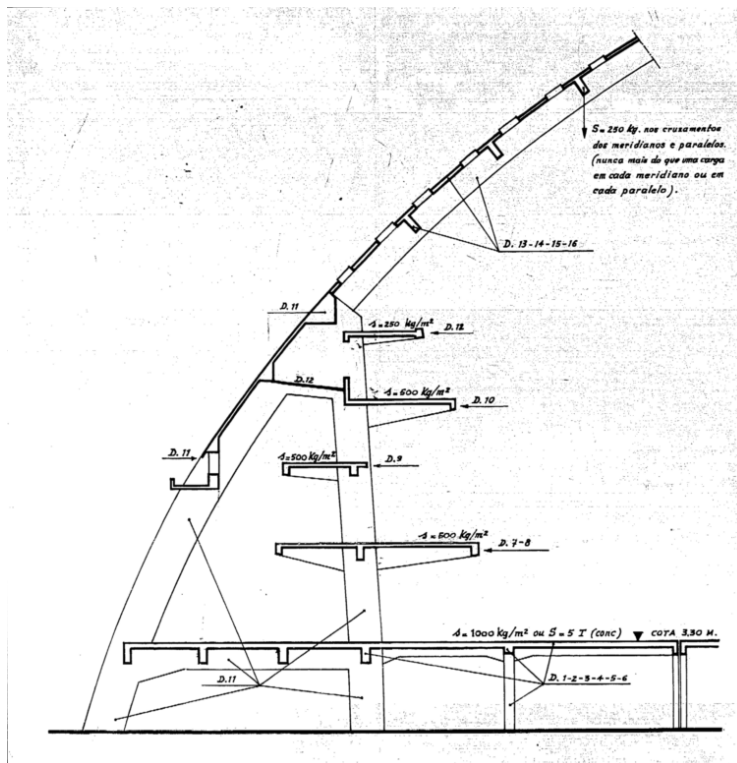


Figure 5: original drawing showing the live load distribution

According to the same report the concrete used in the structure is comparable to a C25/30 (the f_{cd} referred was 16500 kPa) and the steel had a yield point of 24 kg/mm^2 which can be considered similar to an A235.

The construction, as far as it was possible to determine, had two phases. The first ended after completion of the triangular frame and all the slabs. Then the inauguration took place during an international sport event. Latter the roof was finished with the dome construction.

The removal of the shuttering was expected to be a key moment but it turned out that the dome was already supporting its weight before it happened according to LNEC's report and the personnel involved with its construction.

Based on the information provided by the available documentation a preliminary analysis was carried out by means of numerical models. This served as an initial approach to understand the structural behaviour and will serve as a reference for analyzing the impact of the intervention to be undertaken.

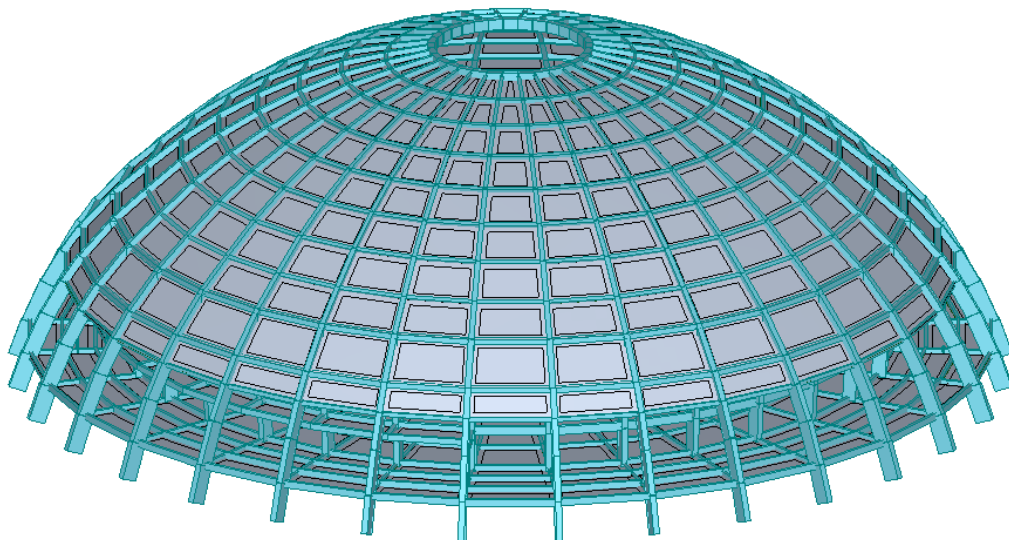


Figure 6: Perspective of the numerical model adopted

The preliminary results showed, as expected, the good performance of the structural design adopted.

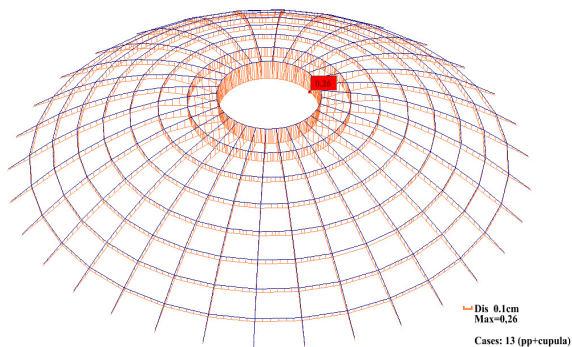


Figure 7: Deformation diagram due to the self weight and dead load

The deformation results due to self weight and dead load were near 3 mm and quite similar to those predicted by the scale model tests. The axial load, due to self weight and dead load, is nearly 800kN at the foundation level, being the level of axial stress below 8.5 MPa and is almost constant along the meridians due to the variable cross-section.

More detailed analysis will be performed based on the findings of the detailed investigation.

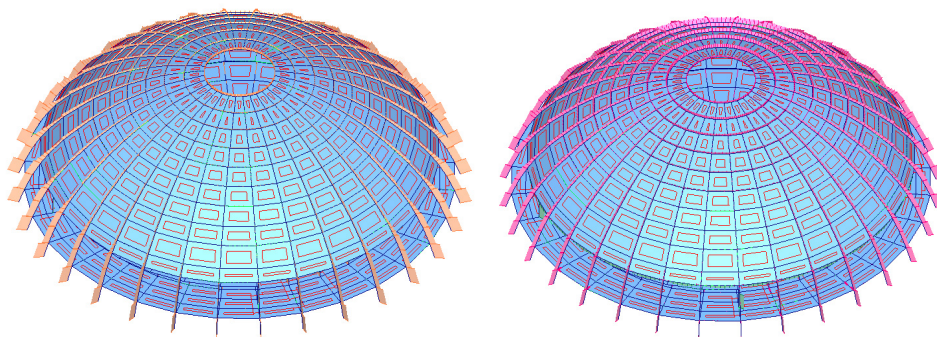


Figure 8: meridians' axial forces and stresses diagrams due to the self weight and dead load

3. Renovation

The project for the renovation of the building involves the construction of new structures outside the perimeter of the existing building and some alterations on the existing structure. The main alteration is the demolition of the central area of the 3.3m level to allow for the increase of seating capacity being the stage moved to the lower level. The impact of this change is little since this area is already delimited by an expansion joint with the duplication of structural elements.

Other alteration is the installation of permanent stands that imply the construction of steel frames attached to the existing structure to support the terrace units.

On the dome the main alteration is the need to support a suspension grid over the stage that can be on different positions and introduces an unbalanced loading.

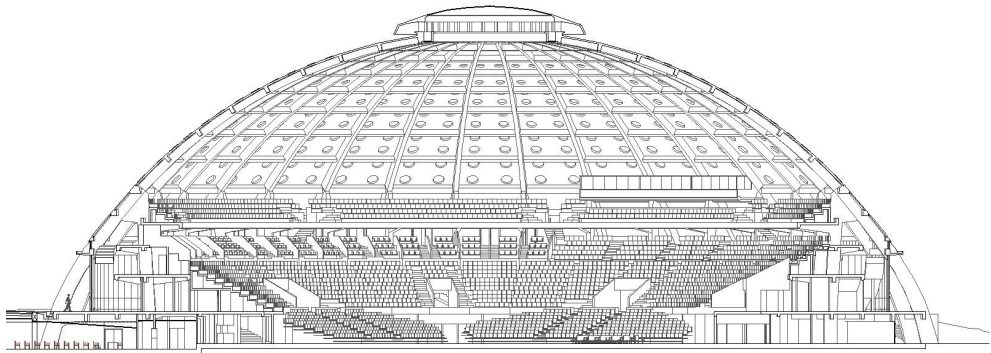


Figure 9: section of the sports pavilion's new design

4. Inspection and rehabilitation

The conversion of existing buildings requires a proper characterization of their conservation status and assessment of building condition by carrying out an inspection plan. This research aims to determine the margins of safety and to define the residual life of the structure.

General procedures for evaluation of concrete structures before rehabilitation were adopted in this inspection. Among the subjects covered are: investigating existing conditions, material properties in the reinforced concrete structure, load and dynamic testing and building envelope assessment.

The structure is now being studied and due to some constraints, as the height of the dome, some works demand to employ temporary structures and especially skilled staff to perform the job.

After evaluation of rehabilitation alternatives the intervention will have two main aspects: repairing deteriorated concrete elements and strengthening structural systems for the new loadings or whenever they do not meet the present safety standards. All intervention must observe the principle of reversibility, which allows the added elements to be easily removed if necessary, given the uniqueness of this building.