Challenging Glass 2 – Conference on Architectural and Structural Applications of Glass,
Bos, Louter, Veer (Eds.), TU Delft, May 2010.
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A New Double Glass-Steel Roof for an Auditorium in Cuneo

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A new glass-steel roof for an auditorium of the "ex Sala Contrattazioni" in Cuneo (I) was built in 2009, with a design resulted winner of an architectural concourse. The construction, despite the small dimension, is the result of a design process that involved many interdisciplinary professionals, from architectural conception to the construction phase. The main structure has a non-conventional behavior and the steel girders support the curved glass panes with point devices. This article offers an overview of the design criteria, news on technological solutions, and unusual construction methods applied to this particular application.

Keywords: Bent Glass, Insulating Glass Unit, Steel, Point Fixing, Prestress Steel Cable, Sphere.

1. Introduction

The building of the "ex Sala Contrattazioni" in Cuneo originally was built in the 50s and was used as a "trading floor" to negotiate food products by tradesmen of the city. The floor, bought in 2006 by Fondazione Cassa di Risparmio di Cuneo, has been subjected in 2009 to a complete rehabilitation to have a new auditorium. The new glass-steel roof, about 80 m^2, is the main attraction. The new cover was built on the existing lattice of reinforced concrete beams in order to recover the original natural light. In fact, the original roof was practicable and was made with glass blocks and reinforced concrete. The remaining portion of existing roof is subjected to live load being a terrace, so that is possible to admire the architectural work from close up. Inside the room, a vertical glass partition, with a curved glass and steel structure similar to the cover, functions as filter between the entrance and the main hall. The perfect mechanical symbiosis between glass and steel material has responded, once again, well to the request of the client 'Rice&Dutton [1]'.

2. The Shape

The architectural idea is to reproduce a the natural shapes like an animal chest with glass-steel materials in order to have a transparent suggestive cover for the new auditorium. From inside the hall the viewer sees the outside through three structural layers: the first is the lattice of concrete beams (existing building), the second is the new steel structure with characteristic form and the third is the glass cover. Each layer, being made by a different material, has an increasing lightness (Figure 1) so that is possible to identify new and old structures.

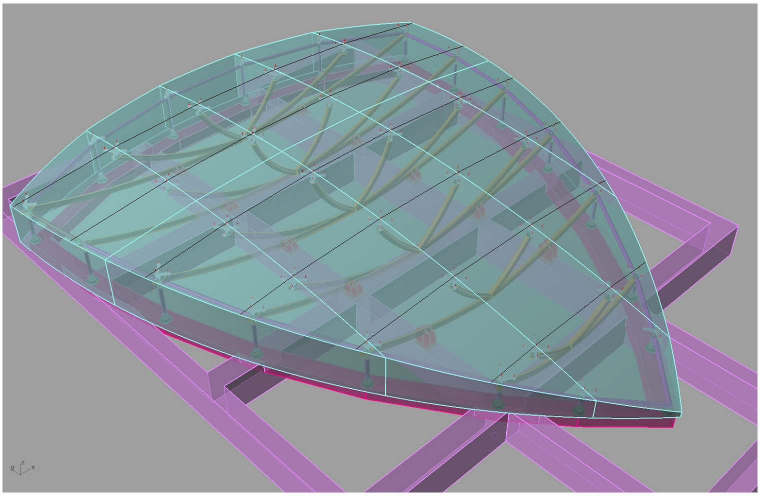

Figure 1: Sketch of the roof.

The geometry of the cover is obtained from a sphere with a radius of 25 meters, so there are many possibilities to realize this regular form with glass panes, each one with virtues and defects. Besides, the insulating glass units can be built with either a bent glass for each unit or a flat glass for the lower unit and a curved glass for higher unit. The typology of steel structure needs to involved quadrilateral glass panels instead of triangular panels, so the problem is: how is it possible to approximate the sphere with quadrangular elements?. The solution adopted in this project is a good compromise between architectural request and economy aspect, the cover is made by glass panes with single curvature for each unit, so on the longitudinal direction the roof has exactly the same curvature of the sphere, and on the transversal direction the curvature is approximated with a broken line. To do this, the panes have not a perfect rectangular shape but two of longitudinal edges were cut with a curved line along meridian line in the intersection of adjacent glass panes. In this way, every panes are different from one other but have the same curvature (Figure 2).

The most important advantage to transform panes with a cylindrical curvature is that the bending phase of glass preserves angles so the function f: $U \rightarrow V$ that transforms flat glass in bending glass is a conforming mapping without deformation of infinitesimal element 'Muskhelishvili [2]'.

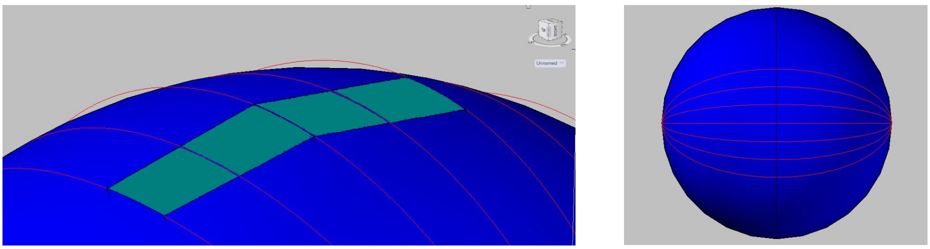

Figure 2: Study of geometry. Approximation of sphere with cylindrical elements

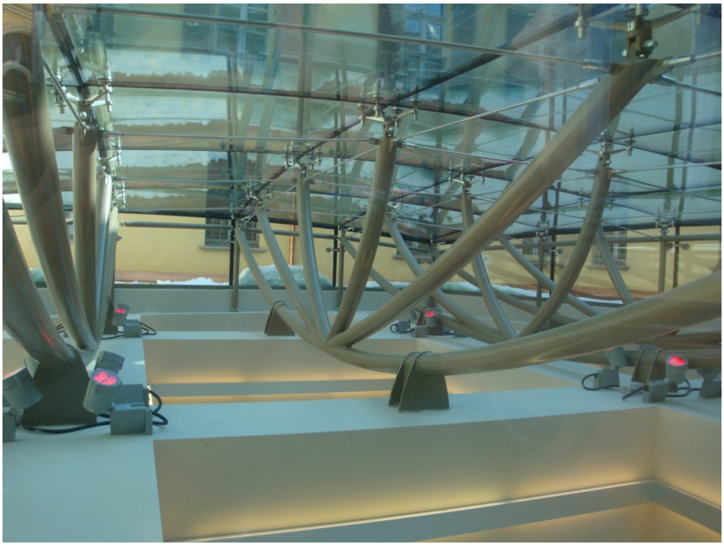

Figure 3: Internal view.

3. The steel structure

The main structure is realized by six girders made of calendered tubular steel beams, ø108 mm, and a system of pre-stressed tension rods, ø14 mm. The materials used are S275 for steel structures and AISI304 for stainless steel parts. The vertical load, in addition to self weight, is due to the snow that, in this alpine area, is 2,10 kN/m^2.

The qualitative structural behavior of this unusual typology, subjected to the vertical loads, is sketched in Figure 4 where it is possible to see the load path with compression and tension members.

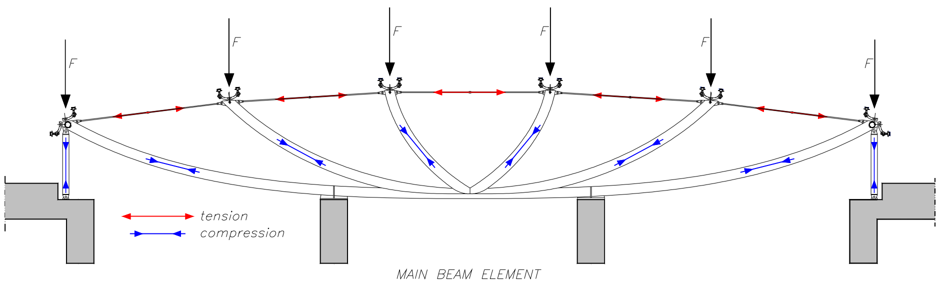

Figure 4: Structural behavior of main beam.

The horizontal loads are induced by structural vertical imperfection and the tendency of beams to buckle out of plane, these actions are evaluated by a non-linear static analysis with a finite element model. The forces acting on the plane of the roof are transmitted by a tension rod to the outside tubular element, and then the compression force are partially discharged to foundation by torsion stiffness of main tubular elements and partially by the horizontal restrain at the lower corner (Figure 5).

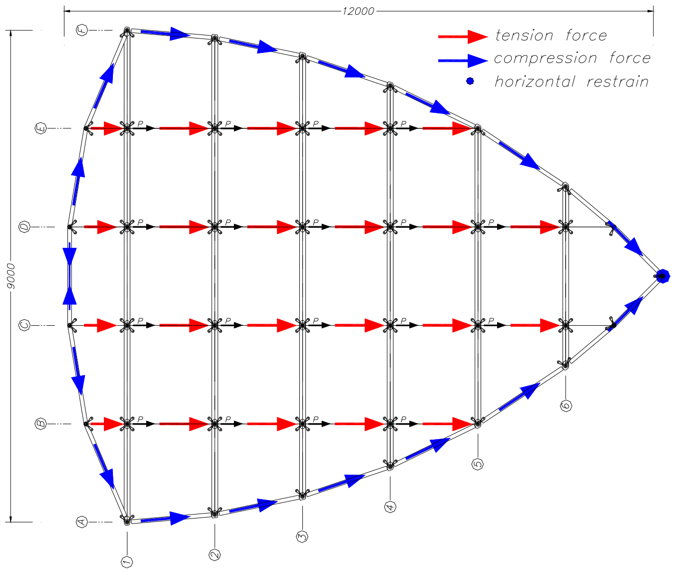

Figure 5: Horizontal load path.

4. The Glass

The glass panes are approximately 1,7x1,6m and are made with bent Insulating Glass Units (IGU). The lower package is composed by a laminated tempered glass with a thickness of 10+10 mm and the other is composed by a monolithic tempered glass with a thickness of 12 mm. The glass panes are designed to withstand the snow load of 2,10 kN/m^2 and 1,00 kN of maintenance load.

The restraint devices are constructed with four articulated bolts (Figure 6). So the system was installed in a way that the glass is able to fit in the movement of a steel structures.

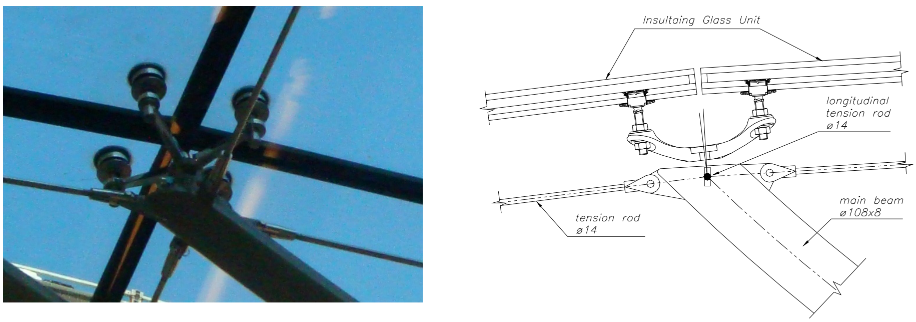

Figure 6: Detail of connection.

Indeed, when bent glass is loaded it is subjected to membrane force like an arch if the horizontal displacements of point device are fixed, so it is necessary to released these displacements to avoid dangerous stresses.

5. The Numerical Analysis

The structural behavior of the roof has been evaluated through a 3-D finite element model. The steel tubulars were modeled with “beam” element (2 nodes, 12 degree of freedom), the struts with “truss” elements (2 nodes, 6 d.o.f.) and the rod with “cut of bar” element (2 nodes, 6 d.o.f.), capable of resisting tensile stress only ‘Irvine [3]’.

A non-linear static analysis was performed to better simulate the real mechanical behavior of the structure ‘Przemieniecki [4]’; the initial form of the structure was affected by geometric imperfection derived from linear buckling analysis.

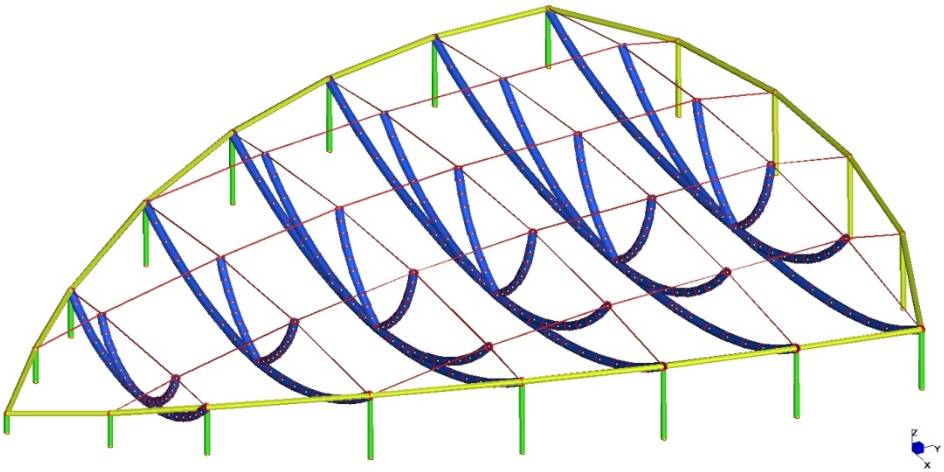

Figure 7: Finite Element Model of the steel structure.

The structural analysis was performed with several load conditions to evaluate the status during the erection and the pretension operation. Furthermore the load combination for Ultimate Limits State and Service Limits State was performed, then the steel design was performed according ‘EN1993 [5]. In Table 1 the load conditions are reported, Phase “0” represents the construction of steel structure and the rod pretension, Phase “1” represents the glass assemblage.

Table 1: Load increment

Load case	Phase “0”	Phase “1”	SLS	USL
Pretension	1	1	1	1
Self weight	1	1	1	1,3
Glass weight	0	1	1	1,5
Snow	0	0	1	1,5

The glass panes were analyzed with a separate model conforming to the French Code 'CSTB 3574 [6]'. In this case, we have a double glaze with thickness h_1=10+10 mm for the lower unit and h_2=12 mm for the upper unit. The partition of external uniform load due to snow and self weight is determined according to the stiffness of lower and upper units. Additionally, the internal load, due to the isochore pressure generated by altitude difference and difference of temperature/air pressure is applied on panes. The external loads act on to the panes supported by point devices and internal loads act on panes restrained by spacer. Figure 8 and 9 shows the principal max. stress acting on surfaces, these are lower than the ultimate stress of tempered glass. The strength of glass, f_d was evaluated according to CSTB 3574 [6].

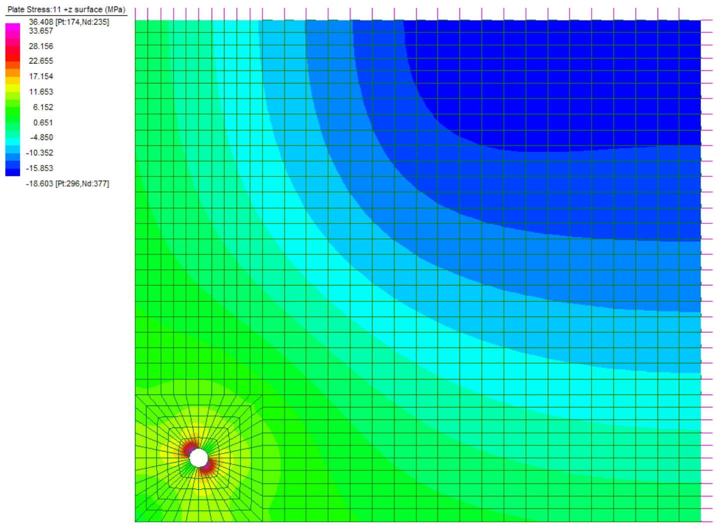

Figure 8: Principal max stress on glass pane (upper side) - σ_{max}=36 MPa < f_d=50 MPa.

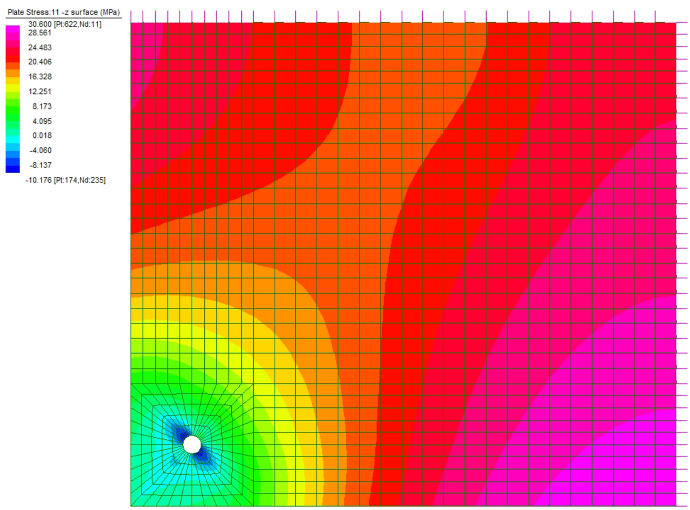

Figure 9: Principal max stress on glass pane (upper side) - σ_{max}=30 MPa < f_d=50 MPa.

6. Conclusion

A new glass-steel roof for an auditorium in Cuneo was built in 2009, the cover resulted from interdisciplinary collaboration between the designer, structural engineer and fabricator. Particular care was taken for the construction details and the cutting of glass panes with CAD/CAM/CAE tools. Three structural layer made of three different materials show how is possible to use advanced technologies to renovate existing building.

Figure 10: The cover.

7. Credits

Owner: Fondazione Cassa di Risparmio di Cuneo;
Architects: Giacomo Doglio, Alfonso e Salvatore Maligno, Guido Lerda;
Structural Engineers: Studio Ass. Ing. Galgani Grazzini Lani;
General Contractor: Fratelli Ferrero srl;
Glass Contractor: Sunglass srl;

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