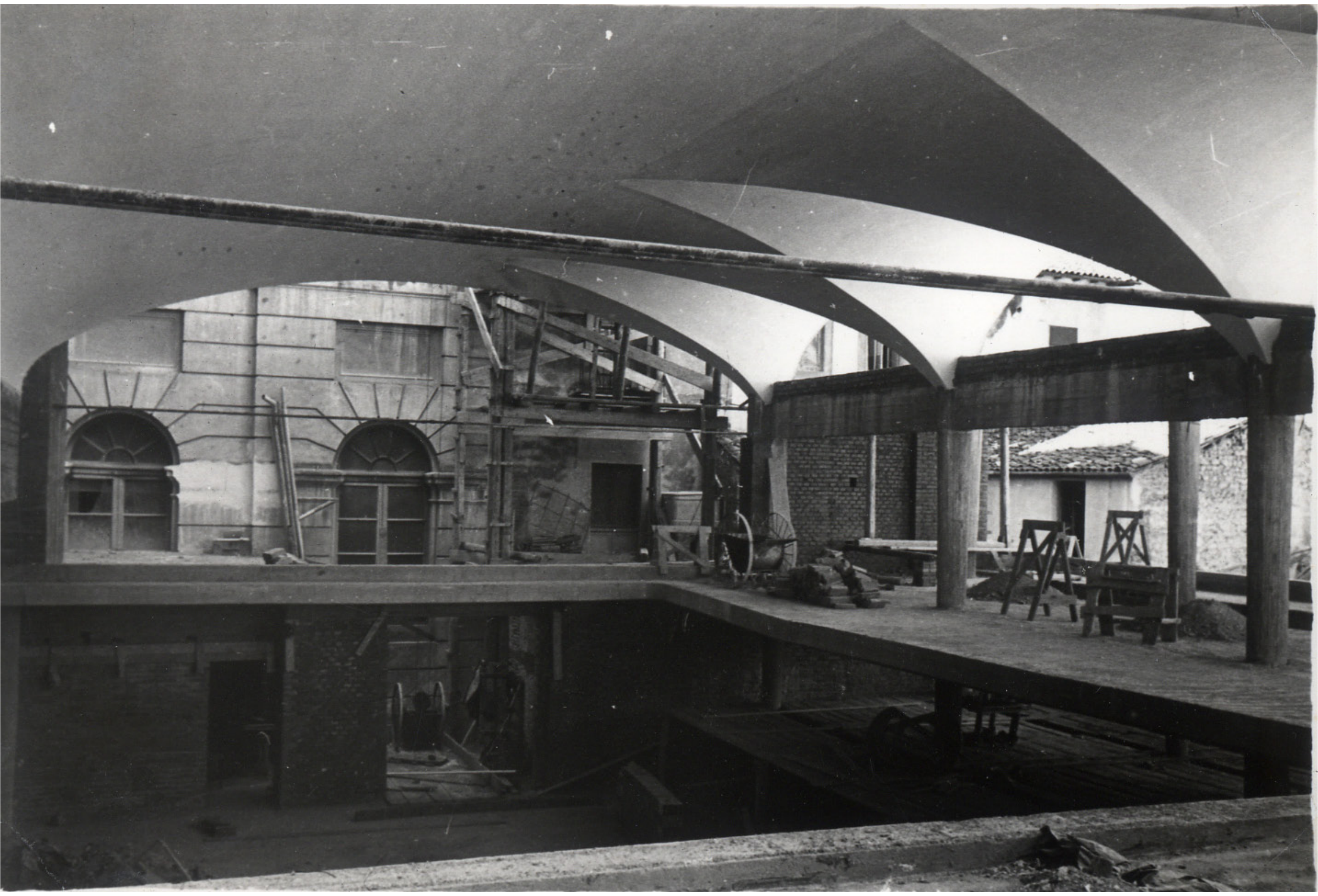

The reinforced concrete thin vault for the reinforced concrete ceiling of the Public Hall of the Cassa di Risparmio Bank headquarters in L'Aquila. Building site picture (source: Carispaq Archive).

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Design and construction of the thin vault for the reinforced concrete ceiling of the Public Hall of the Cassa di Risparmio Bank headquarters in L'Aquila.

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ABSTRACT

The present article wants to report on the technological and constructive aspects related to the realization of the thin reinforced concrete vault for the reinforced concrete ceiling of the Cassa di Risparmio Bank Public Hall of L'Aquila; this work was carried out in the early 1950s on the occasion of the enlargement of the bank headquarters, built in the nineteenth-century . The intervention is seen peculiar because it can be considered representative of the application of the reinforced concrete technique to realize a small structural thickness reinforced concrete ceiling. In particular, the use of complex-shaped vaulted systems in reinforced concrete, in the post-war Italian period, was substantially reserved for the construction of road bridges in the post-war reconstruction context of the infrastructure system, less used in civil construction. The application of such construction systems, in architectural works, refers to buildings with a predominantly tertiary use, such as offices and exhibition halls. Among these, although of minor importance, there is the Public hall of the Cassa di Risparmio of L'Aquila which testifies that some reinforced concrete works, demanding from the constructive point of view, were carried out in the peripheral territorial areas as well, like the provincial ones. In particular, from the analysis of the archive sources, the re-enactement of the project phases as well as the construction ones, confirms the use of a building technique, which in that particular historical period, saw the transition from the structural calculation theories to the construction site practice and, its application not only in large Italian cities, but also in minor contexts.

KEYWORDS

construction techniques history , thin vaults, reinforced concrete, execution procedures

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1. INTRODUCTION

The construction of the building, headquarters of the Cassa di Risparmio, located along Corso Vittorio Emanuele II in the city of L'Aquila, took place between 1885 and 1889 on the occasion of a series of interventions to reconfigure the urban fabric that characterized the historic center of the city.
The building, organized on two levels plus a ground floor with mezzanine and a basement, was built in a 'C' shape, with an internal courtyard on the rear side. It presents a spatial system and a distribution one, resolved within the typical typology of the Palace.
The Palace type building is reinterpreted in its constituent elements such as the entrance hall, the courtyard and two side stairways. The main front, located on Corso Vittorio Emanuele II, is characterized by, the alternation of solids and voids resolved according to the rules of the massive construction, with attack on the ground and by the double-height porch in which also overlooks the mezzanine floor. (Fig. 1). The spatial and distribution systems, that characterize the building today, are the result of a series of interventions that over time have led to the current definition of the architectural body; among these, there is the construction of the Public Hall in the internal courtyard , intervention that was realized in the 1950s with the main objective of satisfying the needs that constantly evolve and update themselves with respect to market demands (Fig. 2, 3, 4).[1]

Figure 1.
Glimpse of the main façade on Corso Vittorio Emanuele II.

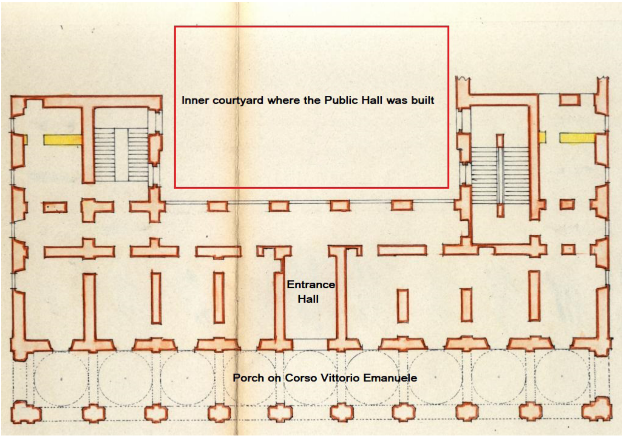

Figure 2.
Ground floor plan of the bank headquarters before the construction of the Public Hall. The part in red is the internal courtyard in which the extension was made (source: Carispaq Archive).

2.THE PROJECT OF THE THIN VAULT FOR THE REINFORCED CONCRETE CEILING OF THE PUBLIC HALL

2.1 THE DESIGN COMPETITION

On December 10, 1949, the phases for a national design competition started in order to create a hall for public services able to solve all aspects of management, related to the bank counter activities and, at the same time, to give a new figurative structure to the building aimed at increasing the

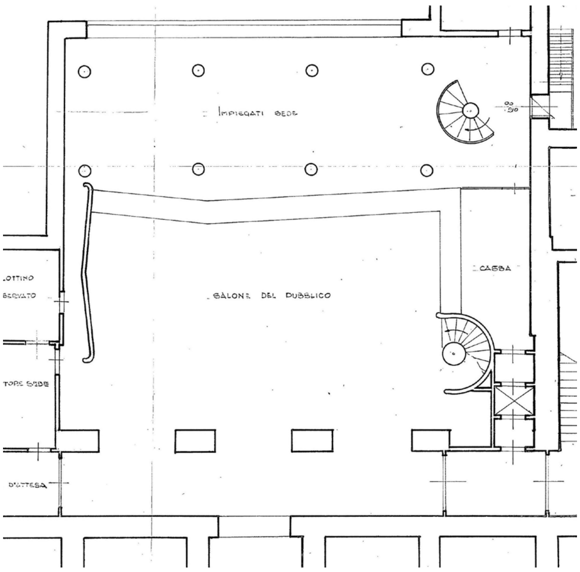

Figure 3.
Excerpt of the Public Hall, plan on the ground floor (source: Carispaq Archive).

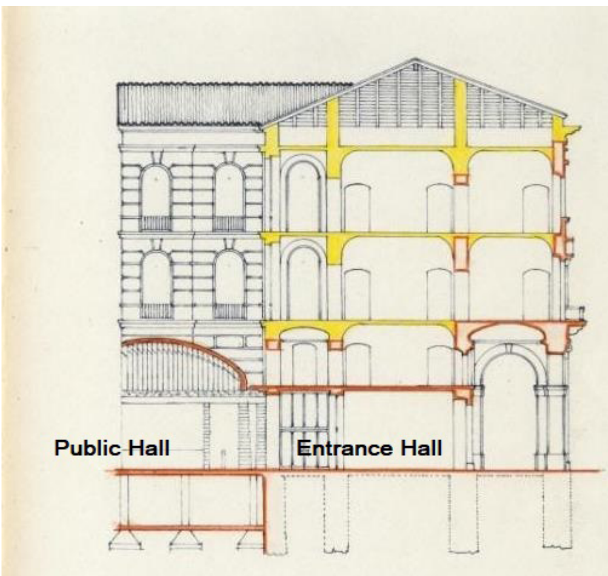

Figure 4.
Excerpt of the Public Hall, cross section (source: Carispaq Archive).

prestige of the Bank. The competition notice required the competitors a discreetly detailed project together with a curriculum that had to include the most relevant information about professional activity carried out up to then, with particular reference to achievements related to the ones , object of competition.

The project had to follow the following directions: occupy the entire surface of the inner courtyard; organize the space in such a way as to draw the area with 12 bank counters, provide an office for the Headquarters Director and reserve a space for toilets, changing rooms and archives. It also required to propose design solutions able to guarantee: the entrance of the public to the new hall directly from the main door of the building; a conformation of the reinforced concrete ceiling to ensure a suitable lighting to the space below and at the same time "…. be of least possible harm to the facades facing the courtyard…." As regards to linguistic and decorative characterization elements, the competition notice gave the designer a wide range of freedom, provided that he satisfied "…. the artistic side, without exceeding in the expenditure, which was to be indicated roughly in the report that would accompany the written work."[2]

On April 21, 1950, the Jury of the Competition, chaired by Prof. Arch. Pasquale Carbonara, after evaluating: the competitors' professional titles, the functional characteristics of the project in relation to the specific use of the construction, the technical-constructive and architectural characteristics of the project, declared that the winners of the competition were Mr Pietro an Engineer and Mr Massimo Parboni an architect.[3] (Ciranna S., 2009).

The project proposed the construction of a hall with a reinforced concrete curved vault , supported by a series of punctiform elements with circular section placed at the longitudinal sides of the volume to realize. (Fig. 5)

The intention was to aim for a new identity of the ancient building, where the use of "modern" construction techniques contributed to connote recognizable effects of space as opposed to the original ones. (Fig. 6)

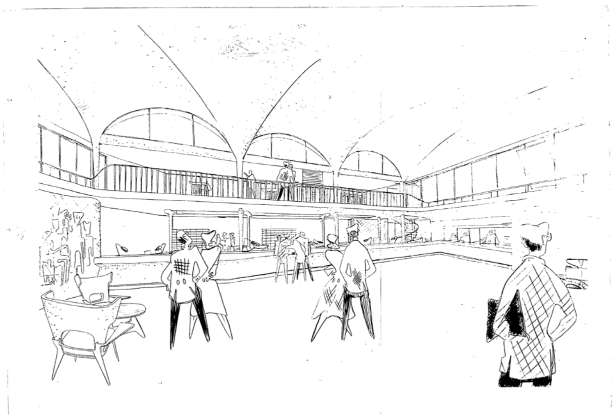

Figure 5.
The winning project of the competition. Internal view of the Public Hall (source: Carispaq Archive).

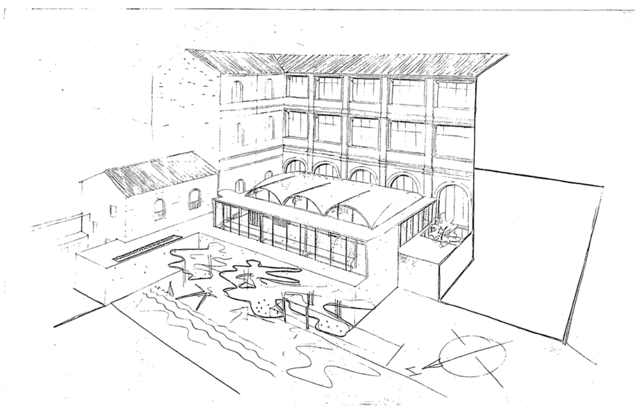

Figure 6.
The winning project of the competition. External view with the new room located in the internal courtyard of the historic headquarters of the banking institution (source: Carispaq Archive).

2.2 THE DEFINITE AND EXECUTIVE PROJECT

The design started at the end of June 1950 through the drafting of the 1:50 scale design plans. The final project was delivered in mid-July of the same year. The drawings 1/20th scale of the reinforced concrete structures executive design, signed by Eng. Sergio Musmeci[4], were forwarded in August, whereas in September 1950 the executive project was concluded with the transmission of the documents relating to the construction details and the technological systems.
From the early design stages, the conformation of the room required a careful and, at the same time, refined study, given that the executive project, in addition to solving the static-construction aspects related to the reinforced concrete thin vault construction with a total surface of 180 square meters, and thickness varying between 8 and 12 cm, also had to manage the inevitable interference that could have occurred between the new reinforced concrete resistant elements and the wall structure of the ancient building (Centofanti M. et al, 2011). In fact, from these contingencies, emerged the need to provide an autonomous system capable of absorbing the horizontal thrusts and vertical loads of the new reinforced concrete structure without affecting the wall elements of the original building[5].
It was for these needs that Sergio Musmeci entrusted the organization of the structural hierarchy to several technical integrated solutions, which necessarily referred to an accurate analysis of the safety and performance expected from the technical elements, in order not to alter the spatiality of the design solution that was based on the vault figurative lightness to which was assigned the role of qualifying the architectural space below it.
The first technical solution concerned the control of vertical loads and the choice of a resistant system capable of supporting the reinforced concrete ceiling and at the same time not interfering with the transparent vertical closures, necessary to ensure a suitable level of illumination of the public hall (Fig. 7). For these reasons, it was chosen to use a reinforced concrete frame to be connected to a 3-span continuous beam, to support the vault: these elements were integrated into the reinforced concrete structure

Figure 7.
The Public Hall after work is completed. Note the lunette vault and the transparent wall with the sunshades where the stabilization tie-beams of the resistant system are inserted (source: Carispaq).

already planned to support the concrete slabs of the hall, of the mezzanine and of the flat roofing adjacent to the impost beams of the curved roof[6].
Other resistant elements were instead assigned the role of absorbing the horizontal actions deriving from the pushing system of the reinforced concrete ceiling. As you can see from the file of calculations of the reinforced concrete structure, the stability of the vault was verified against: the permanent loads, which were equal to 350 Kg / sqm; the vertical overload equal to 120 Kg / sqm; the seismic actions "as per regulation for 2nd category areas" and the wind equal to "150 Kg / sqm in vertical action".
The static analysis of the vault was performed considering the following loads combinations: permanent load – load condition 1); vertical overloads - load condition 2); action with vertical earthquake , evaluated "…. superimposing the load conditions 1) with a third of the 2) and increasing the sum by 25% …." – load conditions 3; with the horizontal seismic action

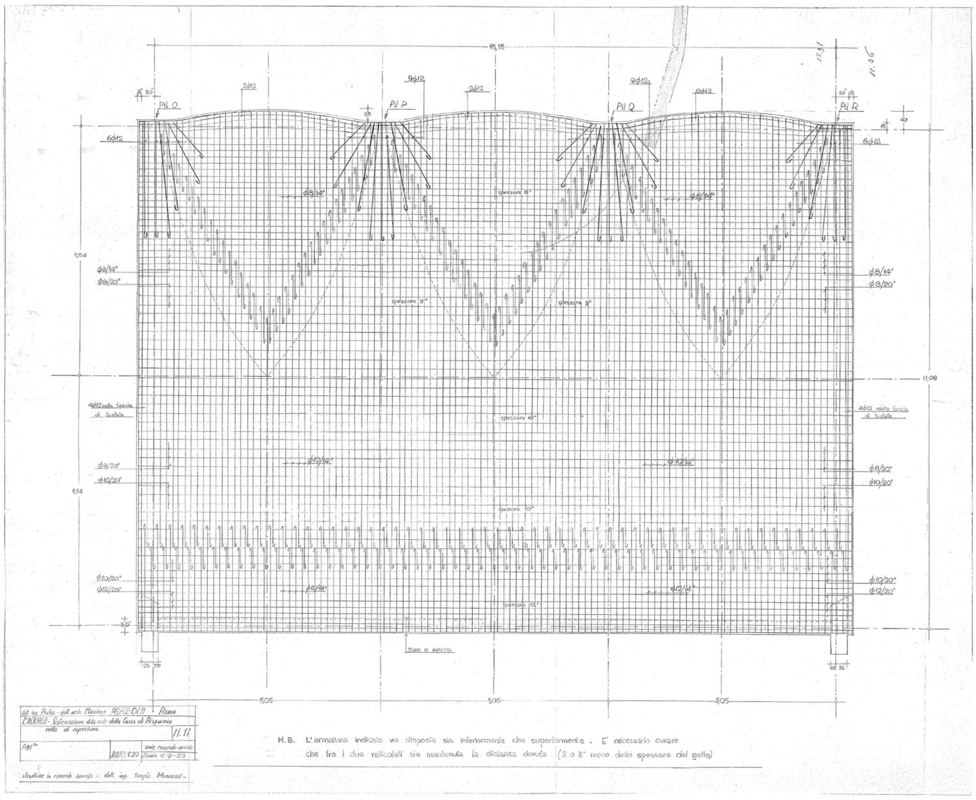

Figure 8.
The design structural work of the thin vault (source: Carispaq Archive).

assuming "... forces equal to 9% of the permanent loads plus 1/3 of the overload ..."- load condition 4), as well as with the action of the wind – load condition 5). The stress calculation was performed through the discretization of the vault in 10 segments, for 1 m strips of width. Then the sections test and the metal reinforcements design were carried out. The static analysis also calculated the vault thrusts on the impost beams for 5 load conditions. The greatest thrust, resulting from the analysis, was the one relating to the load condition 3), that is, with a sussultatory earthquake action, equal to 5,410 Kg / lm, with a 3,060 Kg / lm vertical component and 4,460 Kg / lm horizontal component[7].

If the thrust vertical component could be absorbed, without particular design actions by the vault support beam of 30 x 55 cm in size and 505 cm in lenght, it was the horizontal component of the thrust that aroused particular attention, since the vault support beam, compared to the horizontal forces, would have had a section on the horizontal axis of 55 x 30 cm in size so with insufficient inertia.
For this reason, the 16 + 6 cm thick reinforced concrete and hollow tiles mixed floor, adjacent to the vault support beam , was provided in the perimeter area, as a solid reinforced concrete slab with increased thickness up to 35 cm. so as to function as a "horizontal beam" of 35 x 120 cm. in size , in order

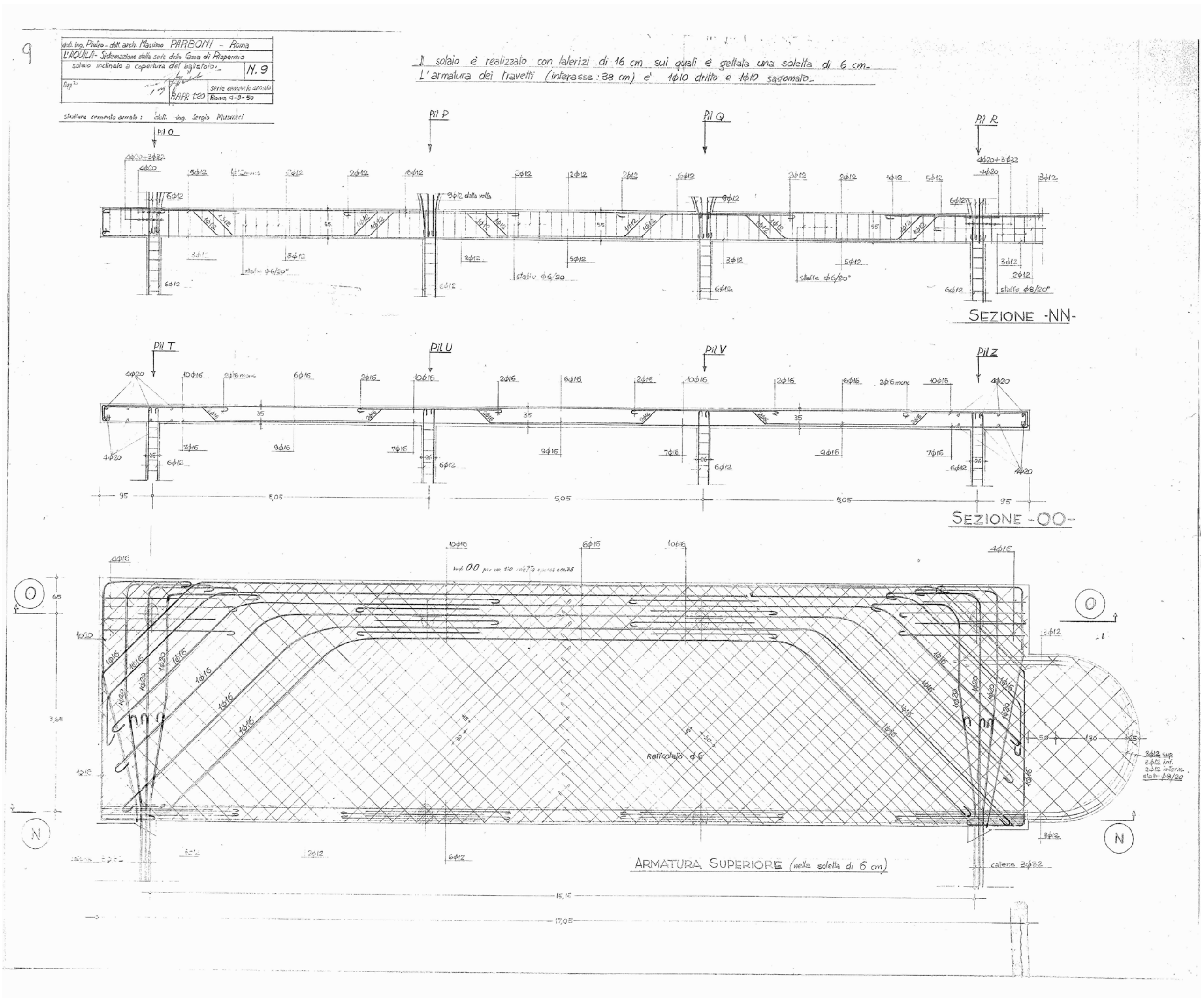

Figure 9.
The structural work of the flat roofing slab with the stiffening "Horizontal beam" of the vaulted system, -OO- Section. The shaped reinforcements and the connection with the side tie-beams are evident in the drawing (source: Carispaq Archive).

to stiffen the entire system planned and therefore capable of resisting to the component horizontal of the vault thrust .
Finally, two orders of tie-beans , were inserted to stabilize the entire resistant system with respect to the sum of the horizontal forces, consisting of three 32 mm diameters cables each and arranged on the transverse external sides of the public hall. (Fig. 9).
In the definition of the structures design , as it can also be seen from the structural work, it is evident as Eng. Sergio Musmeci who was the reinforced concrete designer, in solving the formal particularities inherent in the project, works alongside the designers, Eng. Peter and Arch. Massimo Parboni, about structural forms and architectural languages (Poretti S.2008), according to the approach to the project that in the '50s recorded a large production of representative buildings and significant architectural quality[8].

3. THE CONSTRUCTION OF THE THIN VAULT

3.1 THE PREPARATION OF THE FORMWORK AND THE REINFORCED CONCRETE CASTING

For the execution of the works and in relation to their special nature and in view of their artistic importance, the Cassa di Risparmio decided to execute them in direct economy and therefore invited, by letter dated 19 May 1950, the following Companies: Ettore Barattelli, Fratelli Iorio, La Chioma Umberto, Feneziani and Di Tommaso, this in order to submit bids for the materials supply, for the works execution and for the labour force, as well as for the means of construction to carry out the work. As a result of the examination of the bids, the works were awarded to the Ettore Barattelli Company of L'Aquila. The works began in early August 1950 and were temporarily suspended at the beginning of the winter season because of the cold temperatures that did not allow the execution of the reinforced concrete works .
In Spring 1951 the main works were resumed in full and among them, the preparation of the wooden formworks, for the realization of the vault. Considered that the public hall had to be equal to 7,60 m. high to the key vault and 5,65 m. to the impost line, according to the design, a first floor of a 3,40 m high timbering scaffolding at an was planned, on which to support a second order of chestnut wood struts in support of the centerings.
The first order of the temporary supports was sustained by a 30 cm side props system with square section, placed at a more or less 1,20 m wheelbase. They were flanked by a system of boarding laid diagonally and woven in both directions in order to obtain a wind-brace structure able to stabilize vertically the scaffold, considering the height of the casting plane.
The second order of the props, always arranged with the same wheelbase, had to support the wooden reinforcement of the vault instead. The structure of the centerings was organized in such a way as to ensure the exact configuration of the vault to be built, characterized by a parabolic shape , articulated much more by three circular lunettes, placed in the west side of the building.
Particular attention was also given to the need to make a robust formwork system so as to be able to withstand, any concentrated loads, that would occur during the casting phases, in the areas of discharge, of accumulation and distribution of the cement conglomerate, without recording the slightest structural failure (Fig. 7).The laying of the metal bars did not affect the assembly procedures at all, as the entire system had to be reinforced with a 14 x 20 cm double mesh.
In particular in the transverse direction, that is with respect to the curvature, the design prescribed 10 mm diameter bars placed every 14 cm each; in longitudinal direction, according to the generatrix of the vault, the design provided 8 mm diameter bars placed every 20 cm each. Only in correspondence to the perimetral area, a 4 mm diameter every 12 cm was expected.
Particular care was taken in the areas of intersection between the three lunettes where it was planned to integrate the basic metal reinforcement with an additional longitudinal one consisting of 9 bars in 12 mm diameter to be assembled with a fan-like shape so as to follow the curvature of the vault (Fig. 8).

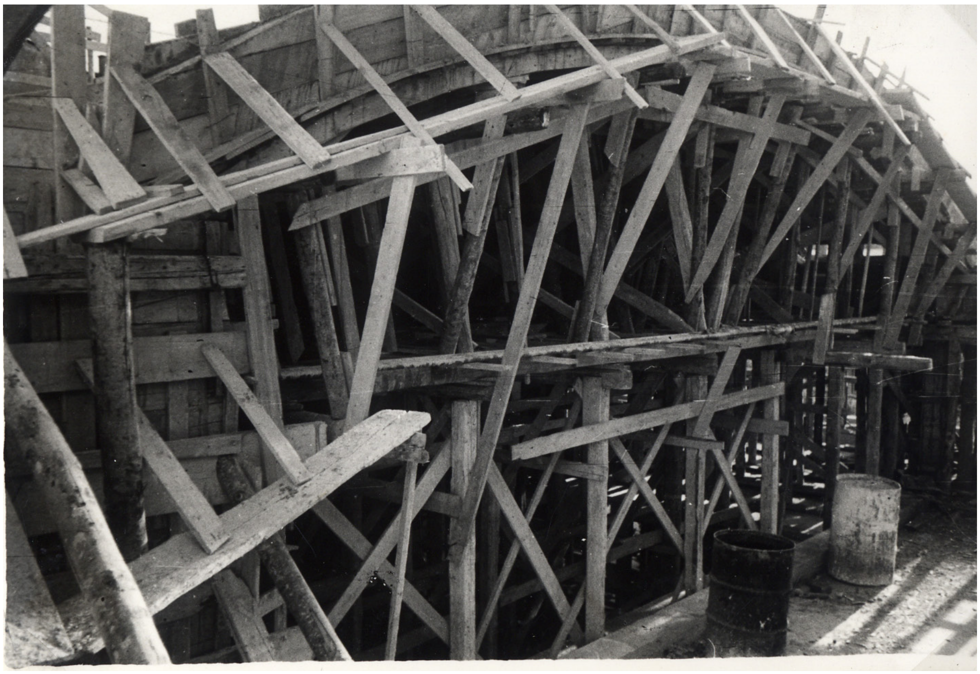

Figure 10.
The powerful system of scaffolding and centerings of the vaut (source: Carispaq).

The metal bars assembly required special attention instead, in correspondence with the connection with the tie-beams, these last ones consisted of a bundle of 3 bars with 32 mm diameter each, passing through the inside of the vault impost beam, in order to be anchored to the 35 x 120 cm size 'horizontal beam' which had the role of stiffening the cealing-beam and absorbing the horizontal thrusts resulting from the vault.
As can be seen also from the structural design and from the pictures of the building site (Fig. 9, 11), the 6+7 with 16 mm diameters bars that constituted the reinforcement of the 35 x 120 beam, in proximity of the connection zone with the chains, where the shearing stress would be concentrated, were skillfully shaped to ensure the proper distribution within the reagent section.

The arrangement of the formworks finished with the tie-beam draught. In the last week, before the casting, the external surface of the formwork was wetted daily in order to avoid any deformation and swelling of the boarding. The realization of the entire scaffolding system and wooden centerings in support of the formworks, was a very demanding activity: it took three months to complete the preparation of the formwork and the assembly of the metal reinforcement, these last ones preparatory phases to the concrete casting which began on June 20, 1951 and went on for four consecutive days, under the constant supervision of the works management. On July 26 ,1951, thirty-six days later, the forms removal phase began.

3.2 THE FORMS REMOVAL

The forms removal operations were directed by the works managers, architect Massimo Parboni and engineer Pietro Parboni as well as Eng. Sergio Musmeci who planned a series of activities and procedures to be carried out. In particular it was required: to carry out the crushing test of reinforced concrete specimens, to be done the day before the beginning of the form removal ;to arrange a pair of deflectometers ; to draw up, at the top of the extrados, a wooden stadia to be aimed with a theodolite from an adjacent building ; to provide two scaffolds next to the tightening screws of the tie-beams in order to allow the labor force to carry out easily the tie-beams draught during the different steps of the form removal[9].
In this regard, Musmeci calculated that the tie-beams, after the forms removal, would have stretched by 7 mm , deformation that should have been recovered by means of the tightening screws, during the gradual decomposition of the wooden supports. Therefore, the forms removal had to be carried out according to six phases so organized: step 1) Coordinated positioning of the tightening screw of both tie-beams; step 2)- Removal of the impost area of the vault; step 3)- recover of the tie-beams' tension half of the expected lengthening ; step 4)- Detachment of the formworks in correspondence of the central zone and removal of the wooden props; step 5) Resumption of tie beams' tension until the lengthening is recovered and restoration of the system equilibrium conditions ; step 6) Complete removal of the formworks and the centerings. After the removal, a sagging in correspondence with the vault key of 2,5 mm was seen, a strain that was recovered through the gradual draught of the tie-beams: after a first quarter of a turn of the tightening screw , 1 mm. was recovered;

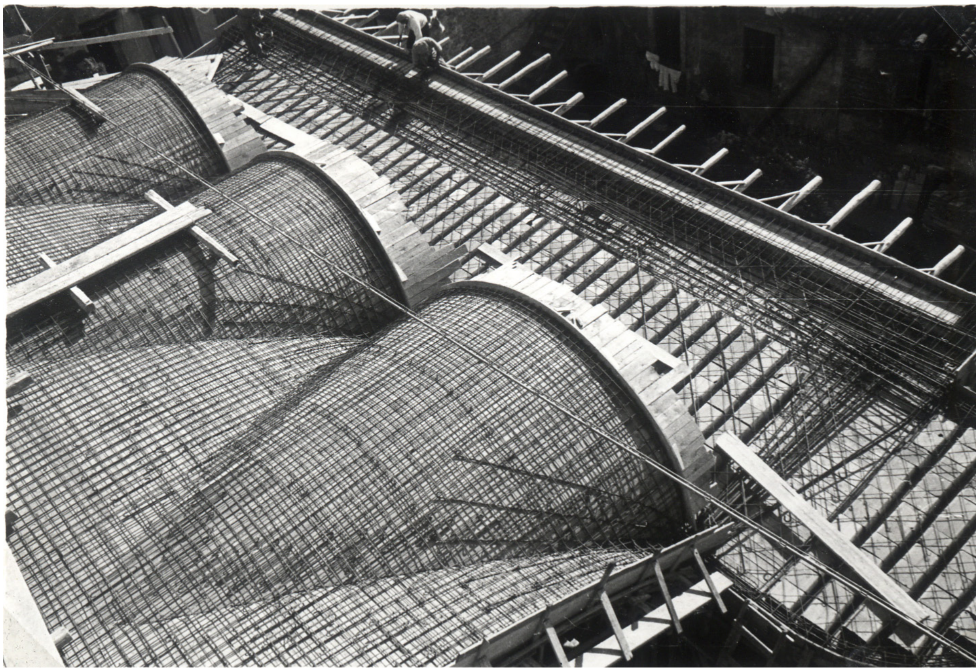

Figure 11.
The arrangement of metal reinforcements. Particular of the lunettes reinforcement and the stiffening "horizontal beam" (source: Carispaq Archive).

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Figure 12.
The Public Hall
(source: author 2009).

within the remaining three-quarters of a turn it was recovered not only all the strain, but also, it was achieved a value greater than 0,5 mm., compared with the initial position, as it was seen on the leveling rod. After this action on the tightening screw , the tie-beams length planned was fully recovered.
The forms removal was also an opportunity to carry out a load test because, once the props were removed , the centerings and their formworks remained united by friction to the intrados ,because of the swelling of the wooden elements and the presence of smudges of the casting, thus loading uniformly the whole structure: in such condition no deformation was detected.
This circumstance allowed Musmeci to evaluate, in action, the potentialities of the designed vaulted system, which presented a reduced deformability according with its design intentions. In fact, in the form removal report regarding the large vault and the test certificate of the vault itself, in transcribing the results found in action , compared to the ones expected from structural analysis, he reported a series of reflections about the vault system behavior of the thin vault systems ; in particular from the minimum settlement of the vault , recorded under work load, he noted that the constructed structure behavior fully reflected the one of a structure that resisted thanks to its shape, and worked with axial stress mainly. So this structure allowed to limit ,even for span greater than 10 meters, the value of the sagging. In addition, the reduced elastic strain of the structure was also due to the presence of the "horizontal ceiling-beams", placed in adherence to the vault support beam, which used to contribute to stiffen the entire resistant system, also providing additional stability reserves. That was the condition which resulted at the time of the forms removal. From these reflections it is clear that the construction of complex shaped reinforced concrete structures results, for the designer, a particular moment of synthesis, between structural calculation and construction site difficulties, necessary to broaden the knowledge between theoretical and implementation aspects; these are assessments that will characterize much more complex experiments on the thin vaults that the young Musmeci will elaborate in the years to follow[10] (Poretti S., 2008).

4. CONCLUSIONS

From what emerged, the construction of the thin vault for the public hall of the Cassa di Risparmio Bank headquarters in L'Aquila, of which Sergio Musmeci is the structures design author and Massimo and Pietro Parboni are the work designers , refers to that particular historical moment, after the war, which saw the Italian architecture characterized by the use of reinforced concrete, also taking advantage of experiences already gained in the construction of bridges with a thin concrete vault and stiffening slab. (Poretti S., 2008) It is also clear how the approach to the research on the structural form (Capomolla R., 2007) and the rational use of the material were aimed at connoting the Italian architecture of this historical period[11]. The Public Hall construction of the Cassa di Risparmio Bank headquarters of L'Aquila although of minor importance, can be associated with those realizations where, the transition from the theoretical experimentation of the structural calculation to the site construction practice one, accompanied the design of thin reinforced concrete curved elements, that were resistant thanks to their shape and that distinguish Musmeci himself's works, Nervi's ones and other engineers' ones who worked in Italy at that time[12] (Iori T., 2007).

NOTES

1. This contribution is the result of a wider research performed by the university of l'Aquila for the study of seismic adequacy and behavior during the L'Aquila earthquake of 6 April 2009 at the Carispaq headquarters building, within which the author has collaborated in archival research and in the elaboration of the constructive analyzes of the architectural organism.
2. From the competition notice for the "Design of the new public hall in the courtyard of the Cassa di Risparmio bank of L'Aquila ".(Carispaq bank Archive).
3. Eng. Pietro Parboni Arquati and Arch. Massimo Parboni Arquati , owners of the Parboni Arquati design studio in Rome, were the winners of the design competition.
4. Eng. Sergio Musmeci (1926-1981), dealt with the study of reinforced concrete structures design. Student of Riccardo Morandi and Pier Luigi Nervi, he carried out his professional activity through the reinforced concrete structures design , with particular reference to bridges. Since 1969 he is professor of " Bridges and big structures" at the Faculty of Architecture in Rome.
5. For further information about the entire building of the Bank's headquarters, Cf. Centofanti M. et al, Palazzo della Direzione generale Carispaq, (2011) Milano L. et al. (edited by) in L'Università e la ricerca per l'Abruzzo. Il patrimonio culturale dopo il terremoto del 6 aprile 2009, Textus edizioni.
6. The geometric grid of the reinforced concrete structure has a 5.05 x 3.70 m rectangular mesh and it consists of: 5 frames, in transverse direction, placed at the 3.70 m. weelbase and of 4 frames, in the longitudinal direction at 5.05 m wheelbase.
7. From the technical file (Carispaq Archive)
8. For more information about this topic cf. Sergio Poretti, Srtuttur(e)alismi, in Modernismi Italiani. Architettura e costruzione nel Novecento.2008, pp. 255-269.
9. The designers' deductions concerning the structure behavior , in action, are reported in the forms removal report signed by Eng. Pietro Parboni Arquati, Arch. Massimo Parboni Arquati and Eng. Sergio Musmeci (Carispaq Archive)
10. Cf. Sergio Poretti, L'exploit dell'ingegneria, in Modernismi Italiani. Architettura e costruzione nel Novecento.
11. 2008 ,pp.209-235.
12. Cf. R.Capomolla. Le forme organiche strutturali. Materia e spazio nelle opere di Sergio Musmeci, in Rassegna di Architettura e Urbanistica Anno XLI 121/122 – Ingegneria italiana. 2007, pp.135-148.
13. For more information about this topic cf. Tullia Iori. L'ingegneria del miracolo italiano, in Rassegna di Architettura e Urbanistica Anno XLI 121/122 – Ingegneria italiana. 2007 , pp. 33 – 59.

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