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Contents

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Design between Architecture and Structure: Case Studies of Pilot Interventions on Italian Monumental Buildings

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Abstract: Two case studies, referring to historic Italian buildings housing city halls, provide an opportunity to investigate the design of non-standard elements aimed at protecting masonry vaults, with particular reference to the preliminary works prior to the actual structural restoration work. There is in fact a phase in which it is a priority to secure the vault to avert possible risks to the users of that portion of the building. This phase is temporarily intermediate between the detection and aggravation of injuries and the renovation and consolidation project. Although these are provisional works, they are intended for buildings that are often public and therefore intended for a wide range of users, such as schools, offices or monumental buildings. In analyzing traditional techniques and systems used in similar cases, the possibility of developing evolutionary aspects with respect to, above all, simple shoring techniques emerged. In these areas, hybrids between a structural and architectural project, it is possible to reconcile static requirements with architectural techniques of space management, attentive to the quality of the interior and the integration of the provisional work with the reference context.

Key words: Non-standard, temporary design, vaults protection, innovation, historical buildings.

1. Background

The vault is one of the oldest and most recurrent constructive-architectural elements in construction. It derives directly from the arch, which in fact is also defined as a vault whose thickness is the depth of the wall. The type of vault is derived from static and geometric matrix, that is, from the way it discharges weights on the masonry walls (Fig. 1) and the position of the center or centers of the arches that generate its characteristic curvature.

Static, constructive or usability aspects, on the other hand, determine the shape of the extrados, which may differ from the former in shape and curvature, also generating variable thicknesses from impost to key. Interesting in this regard are the rules of construction cited by Breymann [1], including, for example, the following: when in a vault of uniform thickness a straight line can be drawn internally within the thickness of the vault from the key of the extrados to the footing as well of the extrados, no rupture of the vault takes place (Fig. 2). From the point of view of materials, remaining within the framework of historical construction, stone or brick masonry is the most frequently used construction technology. In particular, brick, because of its extreme practicality of use, the exactness of construction that it allows, its adaptability to the chosen form, and its use invalidated even in non-specialized workers. The use of brick also allows a differentiation in the type of equipment, which can be knife, sheet, double row, etc.; usually (but not always) the laying is done starting from the shutters and proceeding towards the key.

Understanding the static characteristics and construction procedures of the vault as well as the geometric data is crucial in designing the consolidation process.

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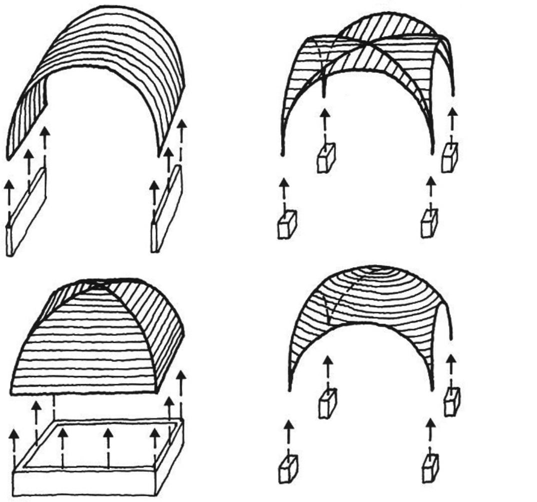

Fig. 1 The discharge supports in the various types of vaults [2].

A characteristic and typical aspect of vaults is the realization in them of an organic fusion between the elements of vertical support and those of coverage, giving rise to an architectural space that is morphologically richer than common horizons...it has constituted, in addition to being the most suitable constructive means of overcoming considerable support distances or covering large spaces, the morphological element capable of producing stupendous architectural results [2].

Due to such constructive and architectural characteristics, vaulted covered rooms are often located within historical buildings intended for public use (town halls, hospitals, museums, churches...).

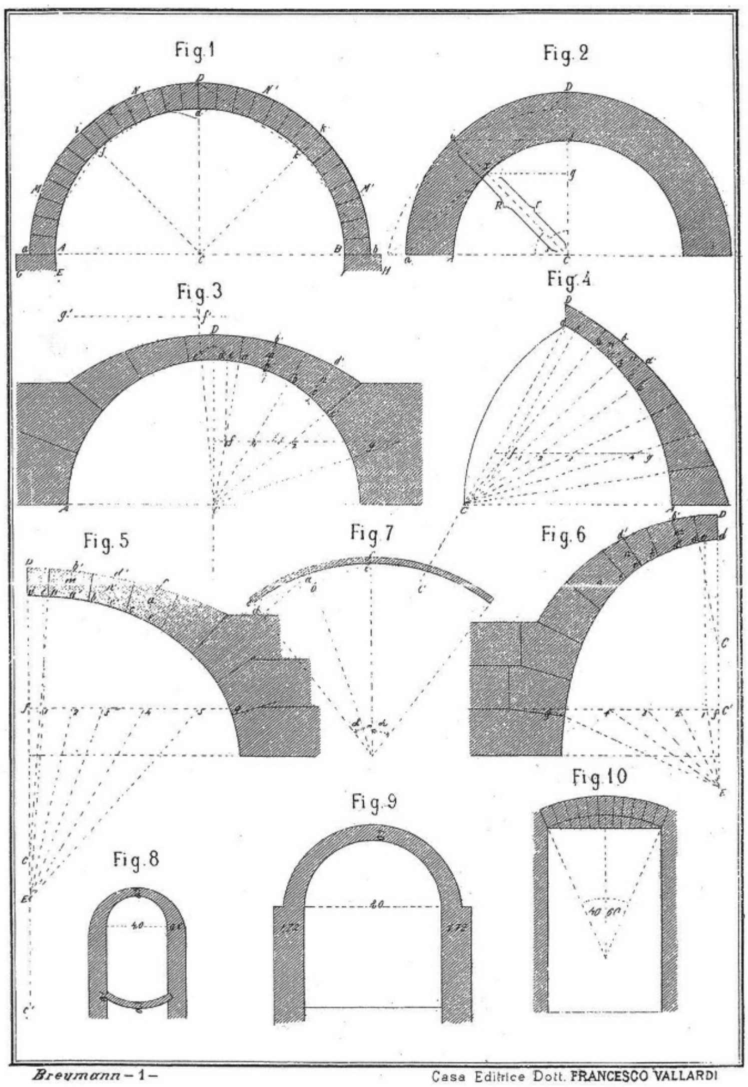

Fig. 2 Static and construction features in vaults [1].

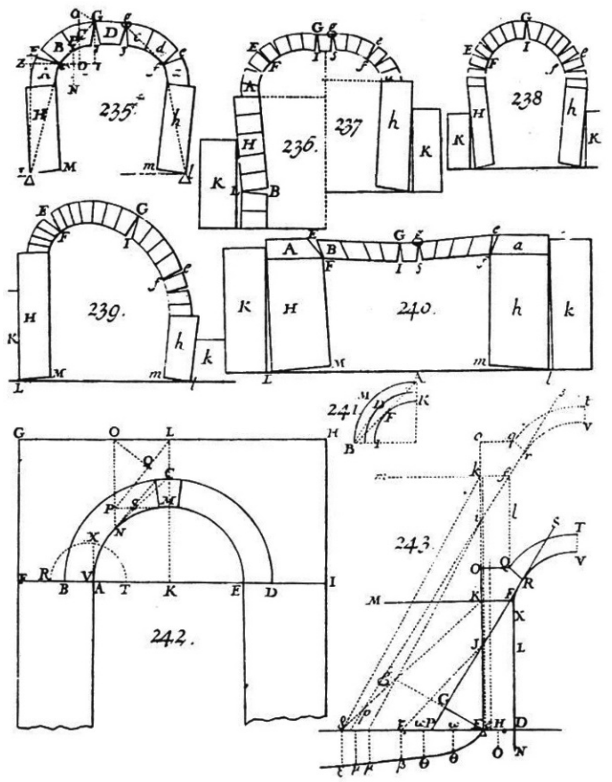

Fig. 3 Formation of collapse kinematics in arches and vaults [3].

In relation to their prevailing function such rooms are intended for reception, representation, service... by reason of their location within the distribution system of the building, for functional reasons or by historical tradition.

If the damage affects marginal compartments, it may be decided to close their access as a precautionary measure, at least temporarily. In cases where vital compartments are involved, whose closure is impractical for the normal performance of the building's functions, then the solutions for securing them are essentially reduced to two: immediate consolidation or the construction of temporary passive protection structures.

The failure of vaults or portions of them is often a consequence of damage to the underlying structures such as foundation subsidence, displacement of the vault outlet wall septa, and static failures, or as a result of excessive and poorly distributed loads on the extrados slab. Changes and new intervening overloads, also due to unplanned or changed uses over the years, together with rainwater infiltration, or other causes are factors that disequilibrate the static system (Fig. 3).

A satisfactory comprehensive restoration can only be effective by working at the root of the problem. This inevitably involves considerable time and costs that are difficult to reconcile with the contingent needs of securing the area. The possibility of intervening selectively, separating the two problems, therefore brings the advantage of immediately avoiding risks to the users (even the simple detachment of pieces of plaster can lead to serious damage) and simultaneously allows an extension to the project timeframe with the implementation of the structural consolidation intervention.

2. Case Study Description

The case studies mentioned in the opening are both related to vaulted covered salons located inside buildings housing Italian municipalities. The first concerns the Municipality of Cecina (LI), and in particular a hall, located on the second floor, which is vital from a distributional point of view because it is the junction of both multiple activities open to the public and offices of municipal officials. For simplicity we will call this case A (Fig. 4). The second case, which we will call B (Fig. 5) is located in the municipality of Imola (BO), very similar to the first one in terms of distributional characteristics and location: a beautiful hall, disengagement of multiple activities, on the first floor and with decorative features accessed, as in case A, by means of a wide monumental staircase.

The damage that occurred to the vault structure alarmed those in charge of the municipal offices in both cases, since the risk of collapse of plaster fragments and portions of the vault was indeed high and such as to give priority to localized safeguarding intervention over general building consolidation.

In fact, these were foundation failures in case A and changes in the static arrangement of 2 of the 4 load-bearing walls of the vault, built in false, in case B.

Fig. 4 Case study A—Cecina, Italy: overall view of the realized structure.

Fig. 5 Case study B—Cecina, Italy: overall view of the realized structure.

Fig. 6 Case study B—Structure assembly steps.

The protection realized was in both cases a steel counter-vault, placed at the intrados of the vault, with the function of non-pushing shoring, which is more evolved from a constructive, logistical and aesthetic point of view. In both cases, the aim was to avoid overloading the underlying floor with vertical shoring structures that would also have been an encumbrance to the use of the spaces.

Masonry vaults often had iron elements as a natural complement to the building element, such as chains, hoops, iron brackets, tie-rods, bracing or supports.

With this logic, the design of the securing intervention pursued the dual objective of achieving the necessary structural reliability with the architectural quality of the result even while providing for the non-immediate removal of the provisional work.

The two cases, although treated with the same construction technology, generated different design results, and required specific calculation methods and surface finishes related to the context.

In the design phase, the idea of reconciling structural requirements with the possibility of creating a qualifying architectural design was pursued. The two experiences (particularly in case B: Imola) confirmed that although the structural result was also achievable through the simple use of traditional shoring, the value of the architectural design enriched the work with design elements. Attention to proportion, aesthetics, and color gave the completed work the architectural quality of an appropriate, site-integrated, well-sized, and proportionate intervention. The architectural completeness of the overall result, even though it is a provisional work, was also appreciated and explicitly liked by the client. An intervention that could have violated the place with the invasive presence of technical elements was instead an opportunity to give that space a new upgrade of meaning layered in the history of that hall. This experience confirms, with interesting perspectives, that interventions that reconcile design approaches and methods of different matrix can contribute to the evolution of the design of temporary consolidation structures.

3. The Design and Realization

Project decisions depend on a number of factors that are not only structural but affect another range of issues. These include the not-so-simple logistics operations (accesses, routes, compartment crossings, possible mechanical connections, access and practicability to vehicles for the external and internal construction site, possibility of stationing trucks or other vehicles without interfering with local public events such as weekly markets, traffic). Equally decisive is the possibility of temporarily storing material on neighboring attics without further damaging the already fatigued building structures. All of these factual elements become an integral part of the project, and it is necessary to acquire them and make them compatible in order to design in detail the manner of assembly.

With the preliminary survey, elements for initial assumptions are acquired.

In the two cases there were vaulted halls of rectangular shape; in case B (Imola) the geometry had planimetric irregularities with considerable out-of-square and out-of-plumb; in the other case the shapes were more regular. In both cases the dimensions reproduce the ratio of sides of one to two, with these measurements: Cecina (A)—12 m × 5.2 (plan) with max *h* in key 7.5 m and skylight in roof; Imola (B)—10.5 m × 6.3 (plan) with max *h* in key 7 m.

Common feature in both interventions is the type of vault, hipped, and the presence of a perimeter chalk cornice at the impost of the vault.

The cause of the lesion was the first design input: where the ceiling covered by the vault was reputed to be in good condition, it was preferred to encumber the ground near the walls with interconnected footings with distributed load at the base (case A). In case B, since only the two longitudinal resisting walls could be used, a more invasive intervention was opted for, through the attachment of wall brackets with bars drowned by epoxy resin.

A common feature of the two interventions is the assembly of a perimeter beam-cord, resting on piers in case A and on brackets in case B, with the recovery of the irregularities of the floor elevations and the verticality of the walls.

This equipment constitutes the reference frame that regularizes the geometry from the shutters. It also functions as a retaining curb for lateral thrust effects of the centrings during assembly. It performs at the same time the fundamental function of dimensional guide and perimeter beam for the positioning of the individual ribbed elements and gives the structure as a whole dimensional compatibility between the individual parts and the whole work. It is made by the coupling of two equal and spaced profiles whose central space performs the function of a guide on which to engage the elements in elevation, with millimeter adjustment.

The centrings were made with different construction methods, depending on the different configurations and geometry of the work. In Cecina, a system of key-coupled semi-centrings was chosen, and anchored to the perimeter beam. Each semi-centring was made with a tube core and flat-iron wings at the extrados and intrados.

A top beam served as the backbone of the structure and as the primary connection between the centrings in the longitudinal direction. The short side was served by 3 semi-centring, 2 of which were diagonal and one on axis with the top beam.

Visually, the result is a series of parallel arches stiffened by the top beam that acts as an elevation reference. The choice of leaving the material to the natural color of worked iron (bluish-black) contrasting with the white color of the walls and vaulting gives the structure an even more imposing appearance. The recurrence of strongly structurally characterizing architectural elements (the arches), their construction in lattice form and serial repetition enhances the perceived structural strength of the whole. These three construction features define the visual impact and perception of the user. These are those architectural solutions that have strength in the explicit relationship between the form of the building element and the structural function, such as trusses, drainage arches, and simple entablature.

In Imola (case B), on the other hand, a typology was chosen that, starting with the cornice, involved the use of whole shop-made centrings consisting of a sheet metal core and flat irons as upper and lower wings. The centrings in this case were custom-made, one for each section of the vault, at 50 cm spacing (Fig. 6).

The short sides were covered with small ribs also at 50 cm spacing, connected to each other and to the nearest transverse centrings.

The connection and stiffening of the structure was made with transverse elements, also every 50 cm. The overall effect in this case was of a bidirectional structure distributed with the curved coffered type, consisting of the regular 50 × 50 cm mesh of sheet metal.

The perception of the interior space of the hall involved in the intervention has a strong connotation of an organic and well-integrated intervention in the vault and the hall. The dimensional and compositional characteristics of the elements used, the prevalence of sheet metal and plates (unlike in Cecina where the prevalence was tubular and profiles), with the elements designed and placed at close distances due to their structural characteristics creates an effect of depth that follows the curvature of the vault. The ivory color (executed with great care by means of epoxy powder coating) gives the whole a stroke of elegance appropriate to the decorations and stuccoes in the room. For this finish it was necessary to consider the size of the ovens already at the design stage.

These features as a whole give the intervention, given the structural function for granted, an explicit expressive force that is perceived in a more natural and less invasive way. The fractionation of the entire system into small elements constitutes its distinctive architecture, which finds its full meaning in the continuum of components.

The steel structure thus created was in both cases completed with the placement of sheets of lightweight plywood, between the extrados of the centrings and the intrados of the vault, to contain the fall of any fragments.

The erection techniques were also different: in A, two manually moved mobile scaffold towers were used, with handling and erection supports such as ladders and pulleys. In B, on the other hand, a work surface was mounted on scaffolding, leaving a central opening for lifting the centrings (footprint in length about 6 m each), then closed again once all the elements were hoisted up.

From the point of view of structural verifications, in case A: Cecina, the single-directional curved floor construction type was adopted, with the assumption of a central beam and 2 side beams as the primary warp and with the semi-corners as the secondary warp.

In B: Imola, on the other hand, a bidirectional curved floor was assumed to be a continuous structure, consisting of single sheet metal elements of moderate thickness, and rigid due to the mutual connection of the elements in the two directions.

4. Summary Sheet of the Interventions Presented

Clients: Municipality of Cecina (LI), from 2010; Municipality of Imola (BO), from 2012.

Architectural Project: Prof. Arch. Vincenzo Legnante, Arch. Marco Mancini.

Structural Project: Eng. Sergio Mancini (iMancini studio, Cortona—AR).

Realization: ATLAS srl, Florence.

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