II–21. On the Possibility of Reusing Old Masonry

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ABSTRACT

Among the problems concerning the reuse of historical centers, an aspect of significant importance is to be found in conservation and functional re-covering of masonry structures in old buildings.

Authors examine the structural behaviour of some types of masonry vaults from a theoretical point of view in comparison with the actual behaviour of the same ones on according loading tests.

Mechanical characteristics of materials constituting such masonries are also studied experimentally, so as to gather reliable data for further research.

Parmi les problèmes relatifs à la récupération des centres historiques, un aspect de toute première importance concerne la récupération conservatoire et fonctionnnelle des structures en maçonnerie des vieux édifices.

Les auteurs examinent le comportement statique de certains types de voûtes en maçonnerie, du point de vue théorique, pour le comparer par la suite aux résultats obtenus à l'aide des essais de charge.

L'enquête théorique est réalisée moyennant la méthode des éléments finis, se basant sur la discrétisation des voûtes en éléments tridimensionnels. Les caractéristiques mécaniques des matériaux constituant ces maçonneries sont en outre déterminées expérimentalement, dans le but d'obtenir les données de départ pour l'accomplissement de l'étude théorique.

Pour terminer, l'enquête fait usage de la méthode des échantilonnages des vieilles maçonneries, pour l'obtention de données significatives, pouvant être tirées même d'un nombre limité d'échantillons de petites dimensions à prélever, par exemple, de vieux édifices à récupérer. C'est dans ce sens que sont fournis les premiers résultats d'une campagne d'essais actuellement en cours, visant à éclaircir les rapports existants entre des échantillons de petites dimensions et des échantillons ayant les dimensions qui sont généralement adoptées pour les nouvelles constructions en maçonnerie.

Unter den vielen Problemen, die die Erhaltung der historischen Zentren belangen, nimmt dasjenige, das die funktionelle Instandhaltung der Struckturen aus Mauerwerk der alten Bauten albelangt, einen ganz besonders wichtigen Platz ein.

Die Verfasser untersuchen das statische Verhalten einiger Gewölbetypen aus Mauerwerk vom theoretischen Standpunkt aus und vergleichen dasselbe mit den aus den Belastungsproben hervorgehenden Resultaten.

Für die theoretische Untersuchung wird die Methode der Fertigelemente angewandt, die auf der Unterteilung der Gewölbe in dreidimensionale Elemente beruht.

Darüberhinaus werden experimentell die mechanischen Eigenschaften der Materialien, die dieses Mauerwerk bilden, bestimmt, wodurch die Anhaltspunkte für das theoretische Studium gegeben werden.

Schliesslich wird an einer Probenmethode des alten Mauerwerks gearbeitet, die in der Lage ist, aus auch nur kleinen Proben, wie sie aus den zu erhaltenden alten Bauten entnommen werden können, brauchbare Angaben zu liefern.

In dieser Richtung werden die ersten Resultate einer laufenden Probenkampagne laut, die zum Zweck der Bestimmung des Verhältnisses zwischen Proben von kleinem Ausmass und Proben mit den Ausmassen, die im allgemeinen für neues Mauerwerk angewandt werden, durchgeführt wird.

Tra i problemi afferenti il recupero dei centri storici, un aspetto di particolare importanza riguarda il recupero conservativo e funzionale delle strutture in muratura dei vecchi edifici.

Gli autori esaminano il comportamento statico di alcuni tipi di volte in muratura dal punto di vista teorico e lo confrontano con i risultati desunti dalle prove di carico.

Per l'indagine teorica viene ultilizzato il metodo degli elementi finiti basato sulla discretizzazione delle volte in elementi tridimensionali.

Si determinano inoltre sperimentalmente le caratteristiche meccaniche dei materiali che costituiscono tali murature al fine di ottenere i dati di partenza per lo studio teorico.

Infine si indaga su di un metodo di campionatura delle vecchie murature, tale da fornire dati significativi anche con pochi provini di piccole dimensioni, quali quelli che possono essere prelevati dai vecchi edifici da recuperare. In tale direzione vengono forniti i primi risultati di una campagna di prove in corso, volta a chiarire le relazioni tra campioni di piccole dimensioni e campioni con le dimensioni generalmente adottate per le nuove murature.

INTRODUCTION

Among problems concerning building reusing in historical centers, which made themselves acutely felt in Italy during last years, an aspect of particular importance deals with the conservation and functional recovery of masonry structures that characterize old buildings.

To give contribution in this field, we started studies according two main lines:

a) The interpretation of structural intuition and constructional traditions of ancient architects and builders, by means of an appropriate screening of bibliographical contributions..
b) The gathering of a sort of "data bank" concerning:
   —behaviour patterns of structural elements normally found in 700's and 800's buildings in Piedmont (Italy) area;
   —results of experimental tests aimed at determining physical and mechanical characteristics of materials to be found in old masonry;
   —comparison between the static behaviour of today's masonry and the ancient one;
   —statements and suggestions concerning characteristics of masonry made by assembling ancient bricks with fresh mortar.

In the field b) themes the present paper takes into consideration two masonry buildings of remarkable quality, as far as structural meaning and executional soundness are concerned, since for both of them a change is under way: the "Cascina Marchesa" will host a cultural center (Phot. 1); the "San Giovanni Hospital" will be used as a center for a Regional Museum of Natural Sciences (Phot. 3,4).

In particular the results of theoretical-experimental research are related to masonry vaults and constructions materials belonging to both buildings.

POLICENTRAL BARREL VAULT (Cascina Marchesa)

The first case concerns a barrel vault with polycentral directrix spanning 8 mts, dimensions in ground of about 8×46 m (Photo 2).

Vault texture shows two ways of brick laying or: bricks laid "on edge" in the central part (12cm thick) and bricks laid according to their biggest dimension in springers zones (24cm thick): the workmanship seems extremely regular and of the utmost quality.

A structural bay of about 4.20 m is apparent; in fact according to such spans ties and stiffening ribs were placed. Other elements of structural meaning are so said "frenelli" or stiffenings aimed at bracing arch ends between ties anchors.

The thrust of the vault is taken by strong piers of excellent masonry and by the above mentioned ties. The latter show an original cross section of 12 × 50 mm in some zones reduced by corrosion effects (cross section to 2 ÷ 3 × 45 mm : in the calculations has been taken a "balanced" value of cross section – 300 mm²).

Figure 1. shows the cross section of the vault.

The analytical study was carried on by using the finite element method: calculation mesh was selected according to the structural bay and its pattern. The same figure shows mesh pattern (three dimensional elements) and edge assumptions: the assumption of a supporting restraint on a pier shows the effect of a reinforced concrete structure propping from outside.

Vault loads taken into account are dead load and a live load of 5225 N/m² (according to experimental test).

In figure 3 are shown forces acting on piers (dead load of upper masonry and of the roof).

Assumption concerning mechanical characteristics of materials are related in the next section of present paper.

Experimental research on the structure was performed through a loading test, gradually increasing the load to 5225 N/m²; in order to avoid perturbation effects in boundary zones, load was applied on a surface far bigger than the basic bay or four times the same (which corresponds to an overlapping of half a bay by each side).

The following instruments have been employed to get displacements and deformation effects (Fig. 1):

—n° 7 one meter equally spaced Messner dial gauges on the chain directrix;
—n° 7 gauge bases (Whittemore deformeter) placed on the intrados at the same points of dial gauges, and one on the extrados at middle span;
—n° 4 gauge bases with a base on the pier and the latter on a support independent from the structure (two on each side) to evaluate the horizontal displacements;
—n° 8 gauge bases (Staeger deformeter) placed on two points of the chain (with the same cross section area) on every side.

The comparison between the deformation curve according to the calculations and according to the test is related in Fig. 2; a substantial correlation of values is apparent and a rigidity of real structure higher than expected.

Table 1 shows horizontal displacements of piers: a good correlation between experiment and calculation values is apparent.

Stresses according calculation (vault between ribs) are shown in Fig. 3 (dead load plus live load) where the thrust line is also been drawn. Tension zones are represented in Fig. 4; the partialisation of masonry in tension zones is confirmed by the presence of failures between stiffening elements ("frenelli") and vertical masonry, easy to be seen in the real structure.

Table 2 reports the confrontation between live loads stresses according to calculation and strain gauges data confirming the aforesaid agreement.

BARREL VAULT WITH LUNETTES (San Giovanni Hospital)

The second case is peculiar to the court side of the "San Giovanni" Hospital: it covers the full length of three floors in the east wing (Photo 5).

As regards morphology, the structure is a polycentral barrel vault with large lunettes built on stone architraves supported by twin columns. The lunettes have a chord

spanning 2,90 m and meet in the centre of the barrel vault to form a pseudo cross-vault at their intersection.

A structural bay of 4,20 × 5,04 m is apparent: it includes the whole "crossvault" and a half polycentral arch on each side (fig. 5). For such a span four ties were placed: two, in the lower part, are rods with a cross section of 700 m^2, whereas the two in the upper part are flats with a cross section reduced to 2,5 ÷ 3 × 50 mm by corrosion.

Vault texture shows bricks laid "on edge" with 20 ÷ 30 mm thick mortar joints; in the lower parts of the vault there are stiffenings ("frenelli") also shown in Fig. 5.

We are conducting an analytical study using the finite element method with regard to this structure too: Fig. 5 shows the calculation mesh.

The loads taken into account are:

—dead load;
—permanent load of over-filling;
—live load of 3000 N/m^2 (as per experimental testing).

The assumptions concerning the mechanical characteristics of materials are given in the next section of this paper.

Experimental research on the structure was carried out by means of a loading test in which the load was gradually increased to 3000 N/m^2 over one day; in this case too, to avoid perturbation effects on boundary zones, load was applied on a surface four times the basic bay on each side.

Nineteen Messner dial gauges, as shown in Fig. 6, were employed to evaluate displacement effects. Two pairs of Staeger gauge bases were placed on each of the lower ties to evaluate tensile deformation effects.

The comparison between theoretical and real displacement is shown in Fig. 6: whereas a substantial agreement can be seen in the values at certain points, structural behaviour is far more rigid especially in the middle of the bay on the diagonals.

In order to get at a more accurate explanation of the true behaviour of the structure and evaluate the stress layout satisfactorily, we are carrying out a further analysis on a pattern enabling us to make a suitable evaluation of the greater rigidity of the vault.

TESTS ON MATERIALS

Drawing of the Specimens

Compression tests carried on structure materials have been the following:

—teste on single bricks (N° 8 bricks belonging to the stiffening elements of the vault of "San Giovanni");
—tests on 5 specimens of masonry, for each structure; in the case of "Cascina Marchesa" samples have been drawn directly from the vault.

In this last case the possibility of a sampling "in situ" upon the masonry structure has given results of good reliability; on the other hand, the first case called for a close investigation of material, since samples were drawn from structural areas of secondary importance. Data gathered from this set of tests, slightly wider, showed nevertheless useful indications for calculations enough to be exploited in our study.

First Set of Tests

Tests on bricks concern some specimens drawn, as already stated, from the structures of "San Giovanni".

The first set of tests carried on single bricks indicate different values of Elasticity modulus E, according to the direction of application of the load (long side or short side). In order to get homogeneous and comparable data five bricks have been cut according to the scheme of Fig. 7. (A way which allows us to test each brick according to three directions, further arranging tests as per Fig. 8 scheme. Table 3 shows the tests results).

Pictures 6, 7, 8 show the mode of failure in various specimens.

Such data, difficult to be related to usual ones, out of lack of specifications in this peculiar field, indicate a remarkable difference in values of Elasticity modulus between case A (or C) and B cases. Such a difference most probably derives from the way of moulding and curing of old bricks (hand shaped, roughly pressed, levelled by scraper and heat hardened without burning control).

Second Set of Tests

Tests on undisturbed samples have been performed on 5 elements belonging to "Cascina Marchesa".

Samples to be tested have been cut from masonry pieces as prisms of square cross section (area 5000 mm^2) made out of two brick parts with original mortar between them. (Samples cutting proved a very delicate operation). Load was applied by self centering heads and deformations were read by means of Staeger and Huggenberger tensometers arranged in such a way as to get reading on bricks as on mortar.

"Cascina Marchesa": E_b = 3433,50 N/mm^2
E_j = 284,50 N/mm^2
E_m = 1464,93 N/mm^2

"San Giovanni": E_b = 4179,10 N/mm^2
E_j = 431,60 N/mm^2
E_m = 1946,40 N/mm^2

where:

E_b = Elasticity modulus of bricks
E_j = Elasticity modulus of mortar
E_m = Elasticity modulus of masonry

Diagrams (Fig. 9,10) show stress-strain ratios for average values corresponding to both sets of tests (theoretical and experimental).

CONCLUSIONS

Tests and data underline the necessity of a deeper knowledge of mechanical characteristics of materials used in ancient masonry buildings.

The limited number of tests, owing to the impossibility of getting a big amount of suitable testing samples in buildings due to be recovered surely lends uncertainty to evaluation of results.

To the end of a wider contribution in this field our Institute has now under way a large scale examination of specimens drawn from a building which we consider particularly fit for this kind of research. That is a XIX Century masonry building of peculiar structural meaning, admirably designed and built with exceptional skill i.e. the "Old People Retirement House" (Architect C. Caselli).

Though this experimental examination is still under way, we wish to show some partial results obtained from early tests.

a) n. 30 compression tests on single bricks crushed transversally to the bedding layers.
 The tests were carried out according to the Italian Code; the uneven surfaces of the laying sides were levelled with cement mortar and the load applied by self-centering heads.
 The average compressive strength was:

$$f_{me} = 26{,}41 \text{ N/mm}^2$$

 and the mean standard deviation:

$$s = 6{,}90 \text{ N/mm}^2$$

b) n. 120 compressive tests on specimens cut as shown above in fig 8, n. 30 each for patterns a), b), c), d)-(Photo 6).
 The following table shows the average compression strength and Young modulus with respective mean standard deviations for each pattern (Table 4).

Tough a comprehensive evaluation of these early results is not yet available, we may note a close agreement between the strength values of the two sets of tests. We may also confirm the difference between the "b" case and other Young moduli.

Tests are currently being carried out on square cross section (5000 mm^2) prism samples as shown in Ph. 7–8 and on masonry specimens five bricks high and two bricks long.

This series of tests should allow us to define some correlations between ordinary masonry tests and tests carried out on the aforesaid small samples.

Tests are also being carried out on:

—dimensional variations of old bricks;
—physical properties (specific gravity, absorption, etc.);
—tensile strength of bricks;
—physical–chemical and mechanical properties of old mortars.

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Photo 1. Cascina Marchesa, Turin. General view

TABLE 1—Comparison Between Horizontal Displacements of the Piers. (mm.)

measurement points	data	
	test	calculation
W_9	0,545	0,473
W_{10}	0,357	0,00
W_{11}	0,035	0,003
W_{12}	0,020	0,00

Displacements positive outwards.

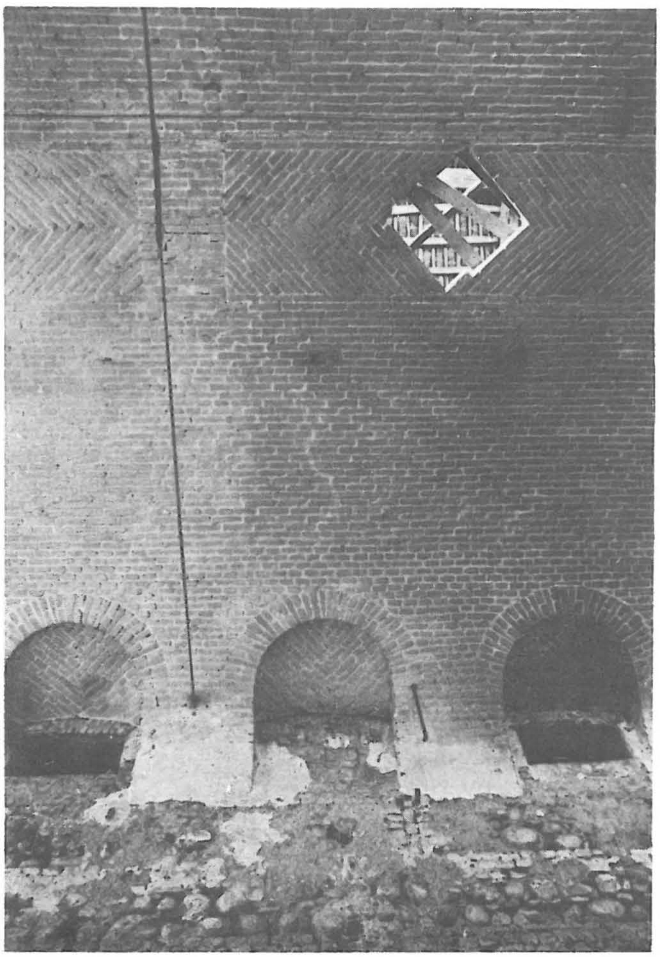

Photo 2. The vault of Cascina Marchesa

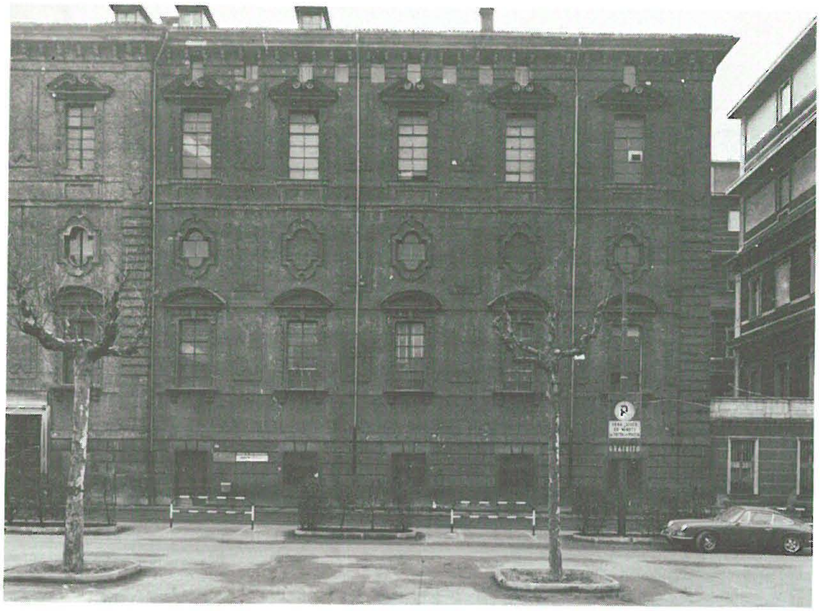

Photo 3. San Giovanni, Turin. External view

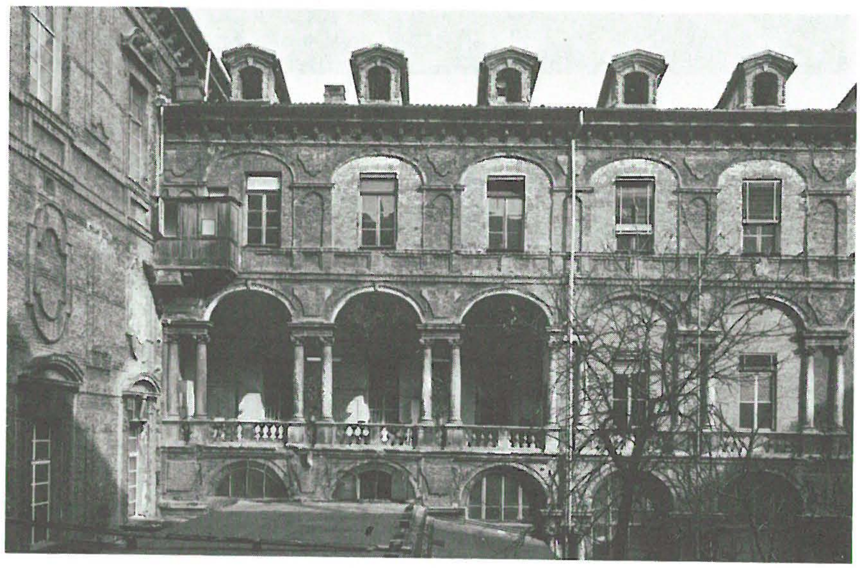

Photo 4. San Giovanni, the inside. Tested vaults cover the loggia in the background

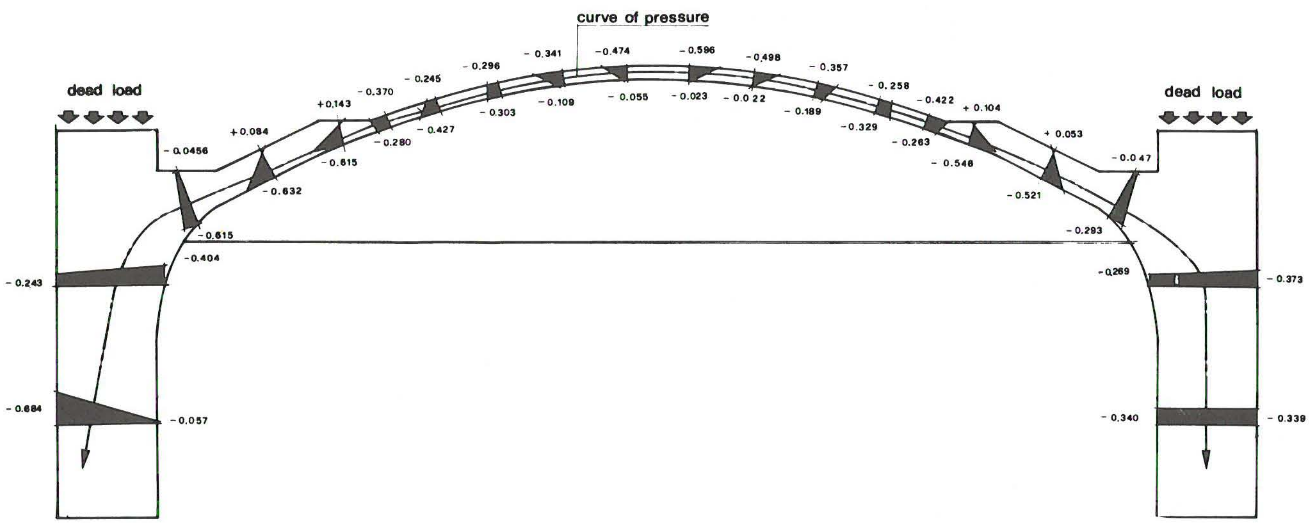

Figure 3. Stress diagrams in the vault. (N/mm²)

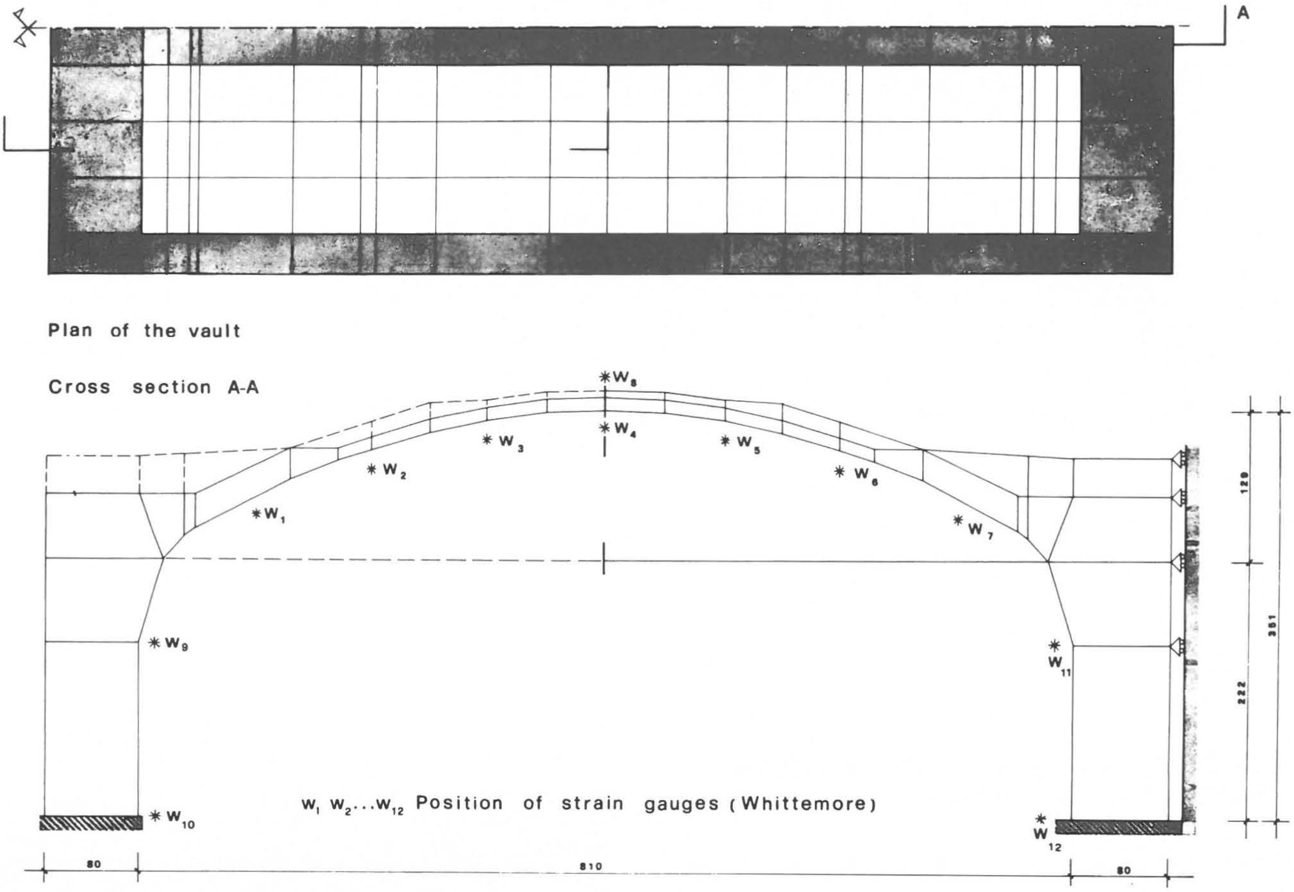

Figure 1. Finite element model

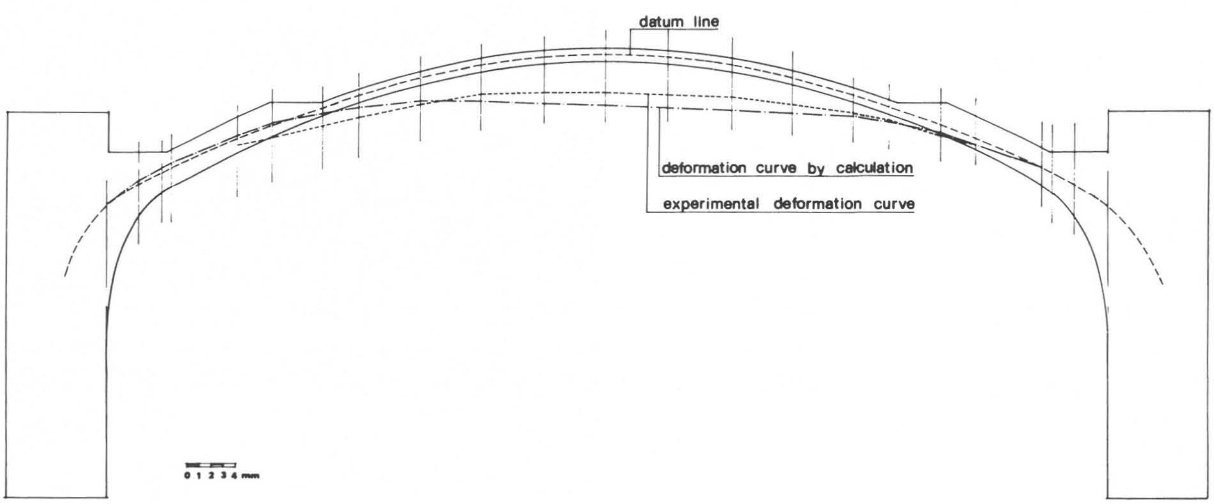

Figure 2. Comparison between deformation curve from calculation and experimental data.

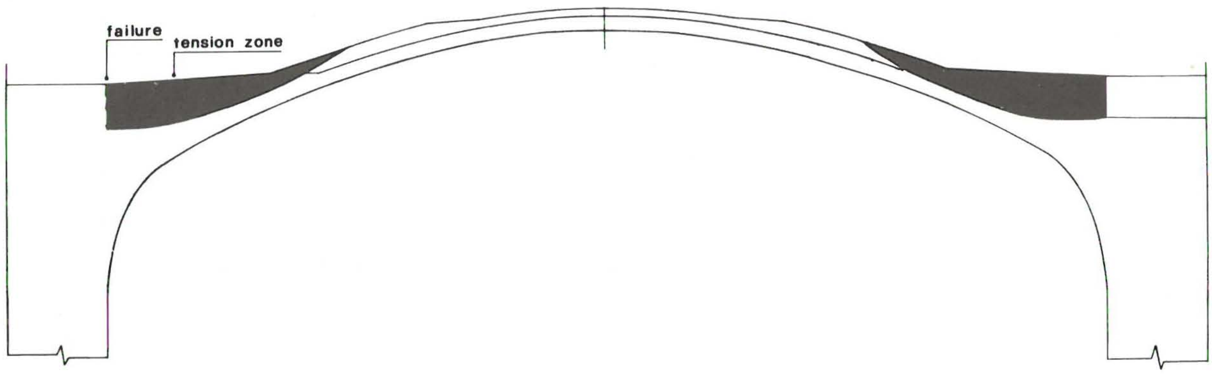

Figure 4. Tension zone in the vault.

TABLE 2—Comparison Between Stresses Resulting from Test and Calculation. (N/mm²)

measurement points	data	
	test	calculation
W_1	− 0,163	− 0,404
W_2	− 0,154	− 0,219
W_3	− 0,092	− 0,120
W_4	− 0,003	+ 0,003
W_5	− 0,032	− 0,044
W_6	− 0,148	− 0,248
W_7	− 0,180	− 0,346
W_8	− 0,330	− 0,496

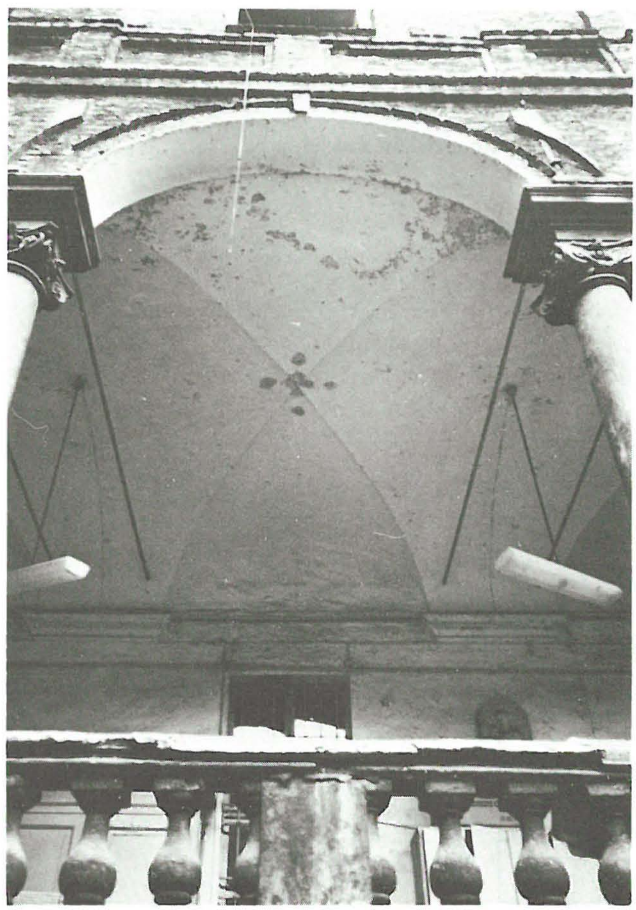

Photo 5. The vault of "San Giovanni"

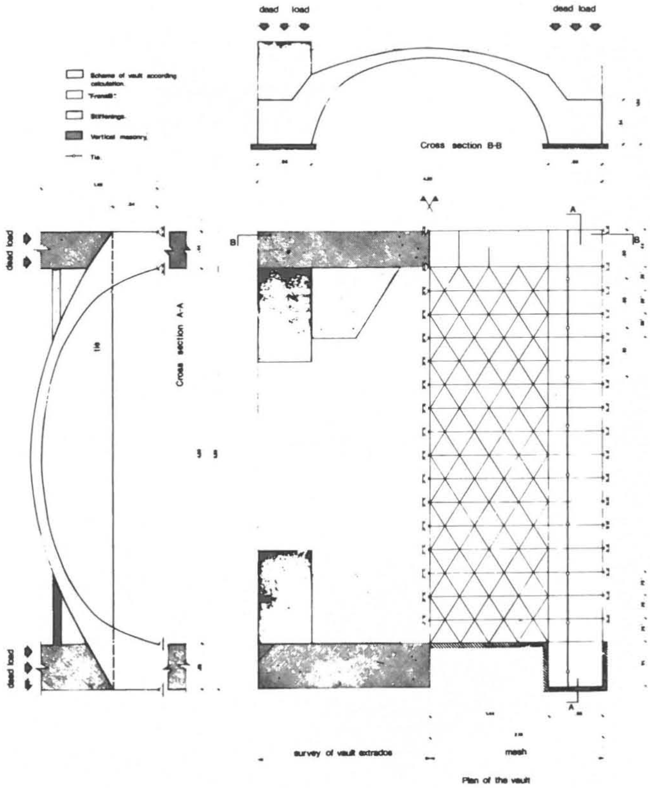

Figure 5. Finite element model of San Giovanni's vault

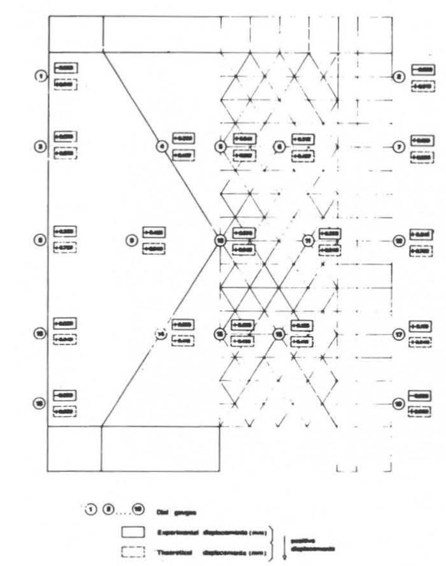

Figure 6. Comparison between experimental ad theoretical displacements (live load 3000 N/m²)

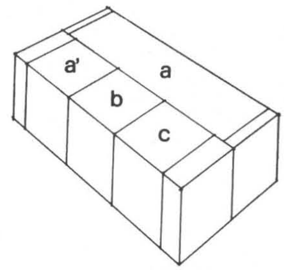

Figure 7. Cutting scheme of samples

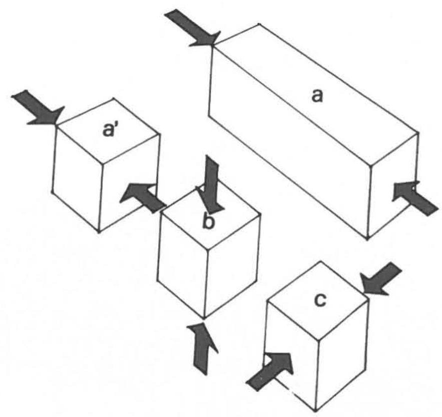

Figure 8. Load conditions of samples

TABLE 3—Experimental Data on Bricks of S. Giovanni

N°	LOAD CONDITIONS	COMPRESSIVE STRENGTH N/mm²	MODULUS OF ELASTICITY N/mm²
1	a	27,69	8474,24
	a'	30,55	8877,82
	b	20,57	4316,83
	c	27,41	9163,08
2	a	13,56	8267,52
	a'	15,02	8467,58
	b	13,06	4029,63
	c	19,42	952453
3	a	17,28	5 646,04
	a'	15,07	7131,87
	b	18,52	4384,29
	c	16,84	7388,40
4	a	13,03	7677,31
	a'	15,15	6765,52
	b	12,70	3748,89
	c	13,97	6122,42
5	a	13,83	6740,94
	a'	15,04	7104,89
	b	14,19	4455,51
	c	15,92	6839,04

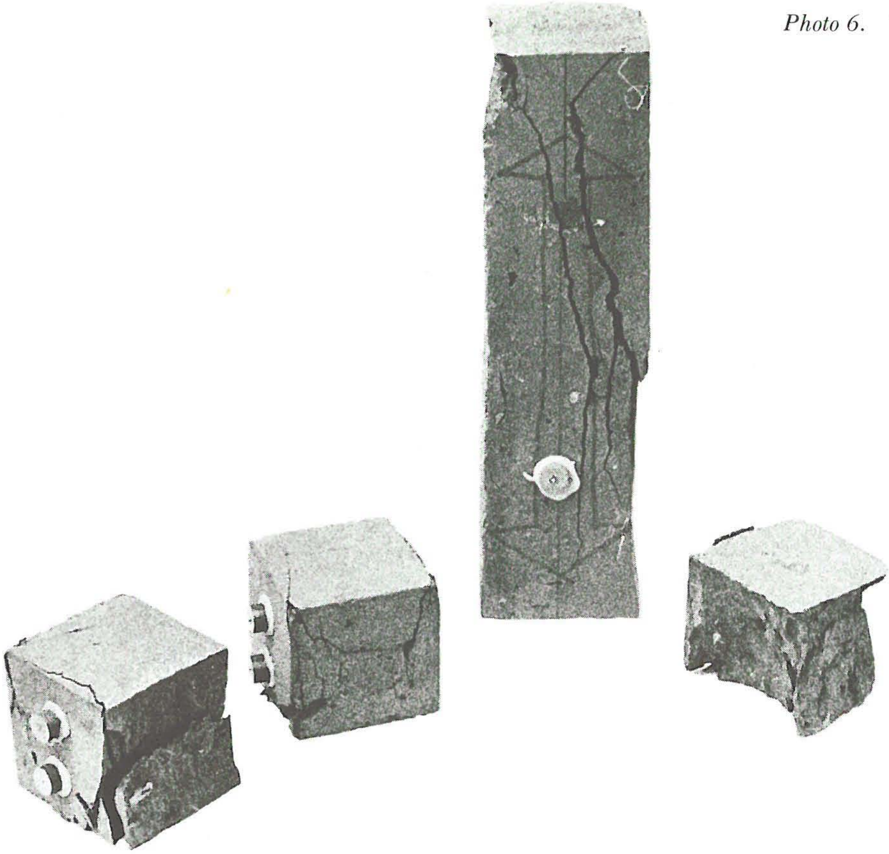

Photo 6. "San Giovanni"— The samples of bricks after failure.

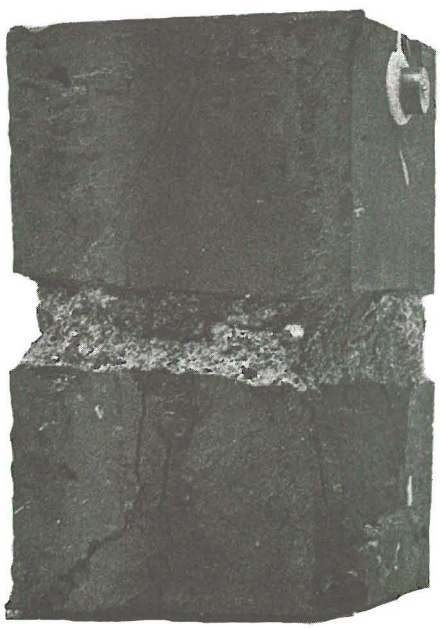

Photo 7. "San Giovanni"—Sample of masonry after failure.

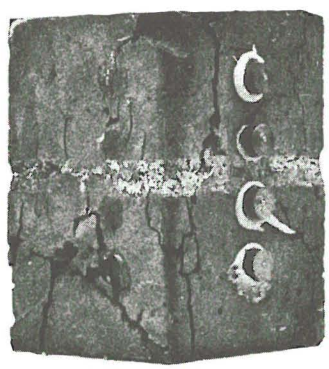

Photo 8. "Cascina Marchesa" Sample of masonry after failure.

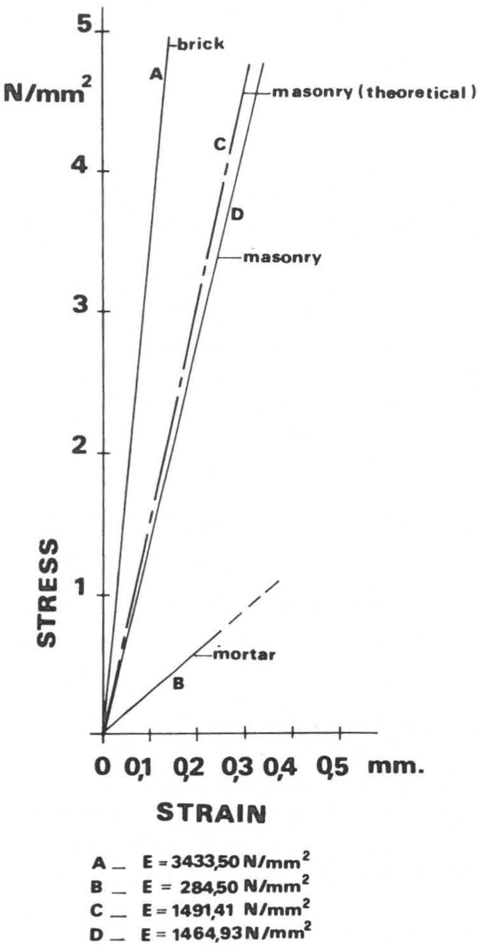

Figure 9. Stress-Strain diagrams for bricks, mortar and masonry of CASCINA MARCHESA

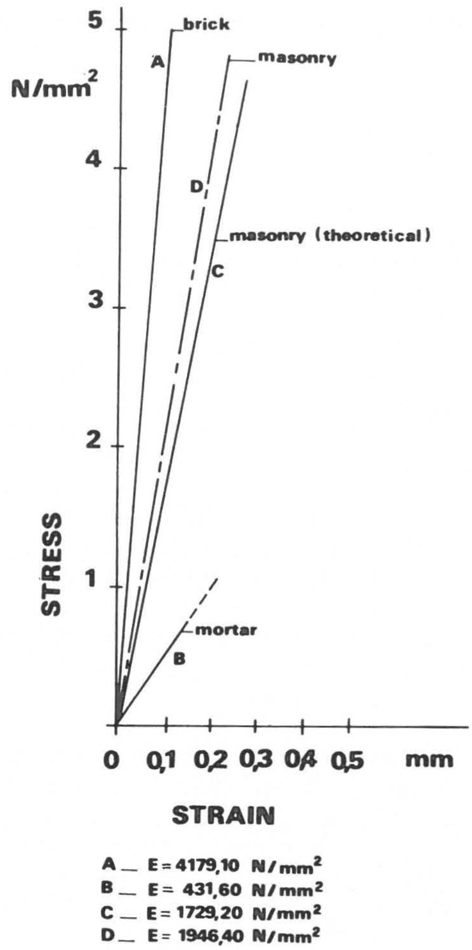

Figure 10. Stress-Strain diagrams for bricks, mortar and masonry of S.GIOVANNI

Table 4—Old People Retirement House: Results of Compressive Tests on Specimens

	a	a'	b	c
fme	22.45	23.14	24.97	23.02
s	6.37	5.55	8.86	6.68
Eb	7191	7067	5529	6823
s	1497	1611	1671	1721

where:

fme: average compressive strength
Eb: elasticity modulus of bricks
s : mean standard deviation