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CONSTRUCŢII. ARHITECTURĂ

STRUCTURAL BEHAVIOUR OF STRENGTHENED COMPOSITE MATERIALS
EXPERIMENTAL STUDIES

BY

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Masonry represents one of the earliest structural materials used by mankind. A lot of the ancient building structures were made using masonry. A large number of these buildings have been stated historical monuments. Most commonly masonry elements which are able to cover large spans was masonry arches.

The paper makes a detailed presentation on structural behaviour and failure mechanisms of a horizontally loaded masonry arch. The arch model was built at a 1:1 scale using solid bricks and M10Z mortar. It was firstly loaded with vertically acting dead loads and with horizontal load acting in its plane. In this loading hypothesis, a plastic hinge occurred leading to the failure of the arch and loss of load bearing capacity. In the next stage of the experimental program, the arch was strengthened using a composite material membrane at the upper face. The membrane consisted in a continuous, glass-fiber fabric and epoxy resin. After proper curing, the same loading hypothesis was used. The failure mechanisms changed and a larger horizontal loading level was noticed. Further on, the arch was rehabilitated using a different composite material layout, the membrane was applied both on upper and bottom faces as well as partially on the lateral faces of the arch. This new rehabilitation layout leads to a significant increase in the load bearing capacity of the arch. The failure mechanisms were changed causing a significantly better overall structural behaviour of the arch.

1. Introduction

Masonry represents one of the earliest structural materials used by mankind. A lot of the ancient building structures were made using masonry. A large number of these buildings have been stated historical monuments [1]. One of the main advantages of masonry as a structural material is represented by its high compressive strength and its versatility in realizing various architectural shapes. Among these elements arches stand in front as structural members able to cover large spans, because unlike beams little tensile stresses develop. Various types of arches are present in the structural systems of most of the monuments especially in the case of churches [2]. Based on the role in the structure, the arches may have different shapes such as: segmental arches, ribs.

The necessity of finding structural behavioural enhancing techniques for arches rises from the fact that they cannot undertake tensile stresses. Scientific studies reveal that the use of FRP (fibre reinforced polymer) materials has favourable effects upon the load bearing capacity of the arches. Composite materials made of glass fibre fabrics and epoxy resin have the advantage of enhanced tensile stresses undertaking capacity.

In order to observe and analyse the behaviour of a composite materials strengthened masonry arch, an experimental program has been conducted upon a semicircular masonry arch (typically for a lot of churches in Romania).

2. Experimental Analysis of the Masonry Arch

In the frame of a research project, an experimental analysis was conceived and realised; it consisted in testing of a semicircular masonry arch, loaded both vertically and horizontally. Its overall behaviour was observed.

The experimental masonry semicircular arch model was built using normal solid bricks (240 × 115 × 63 mm) and M10Z mortar. After realizing a wooden semicircular, 1.00 m radius scaffolding, and its mounting on a specially designed steel support, the arch was built having a 240 × 240 mm in cross-section. Two supports were placed at the ends of the arch. One of the supports was partially fixed so that translation was blocked. The second support was partially fixed in the direction of horizontal arch pressure, translation being free in the opposite direction, after application of loads.

After building the arch, a 45 days period was provided in order to obtain the maximum of mechanical properties of masonry. After this curing period, the loading devices were applied as follows:

a) for the gravitational loading of the arch as a low loading rate and small variation steps, plastic recipients with 18 L capacity were filled with water; they were placed in five equally spaced points;

b) for the horizontal loading a mechanical acted loading device was used; it consisted in a fine threaded bolt that when twisted, gave a horizontal concentrated load.

For displacement data acquisition strand Linear Variable Differential Transformer (LVDT) were used as for the loading level, a load cell was used too.

Fig. 1 presents the statical loading schema of the model and in the Fig. 2, the real model during the first test may be observed.

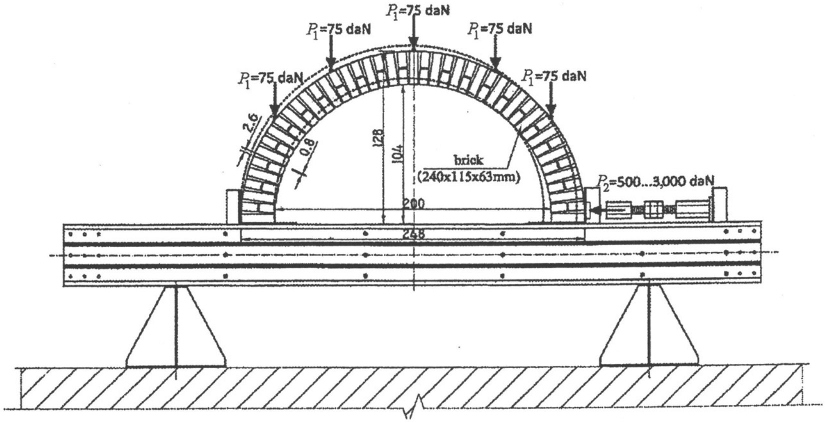

Fig. 1.- Statical loading schema of the experimental model.

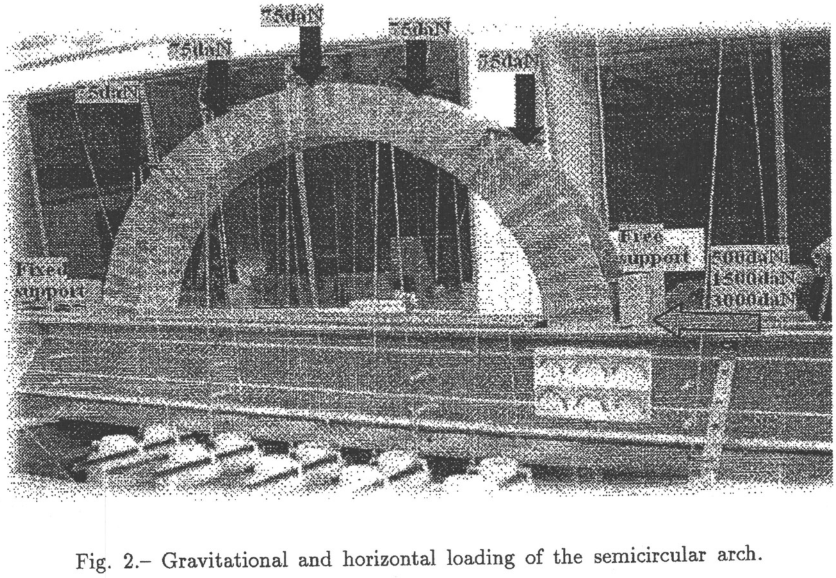

Fig. 2.- Gravitational and horizontal loading of the semicircular arch.

The first test on the model resulted in occurrence as a plastic hinge at a load level of approximate 500 daN. The horizontal displacement at roller support was of approximate 3 mm. Fig. 3 captures the state of the masonry arch at the moment of plastic hinge occurrence.

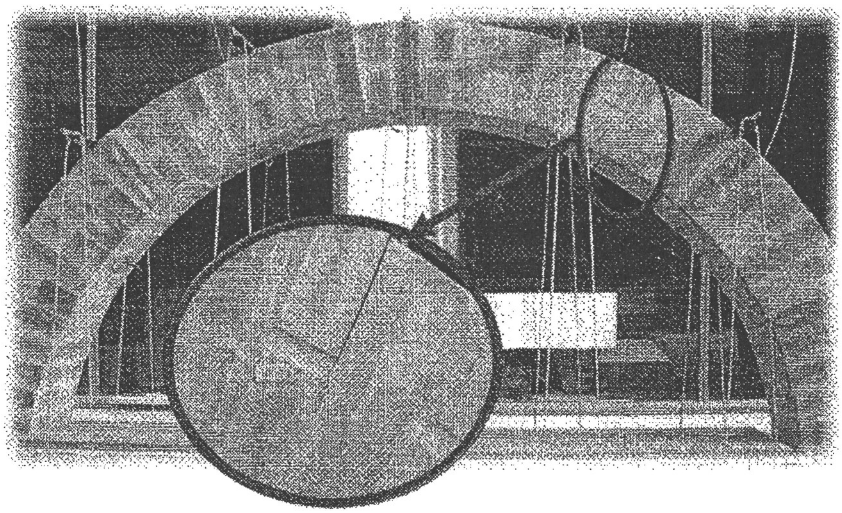

Fig. 3.– Plastic hinge occurrence on first model.

After this step, the arch was consolidated by applying two layers of unidirectional glass fiber fabric and epoxy resin at the upper face of the arch. One week after the consolidation the model was tested again. With this new configuration, the horizontal displacement of the arch was of around 26 mm at a load level of approximate 1,500 daN. The failure was followed by a noise. In Fig. 4, the failed consolidated arch is presented.

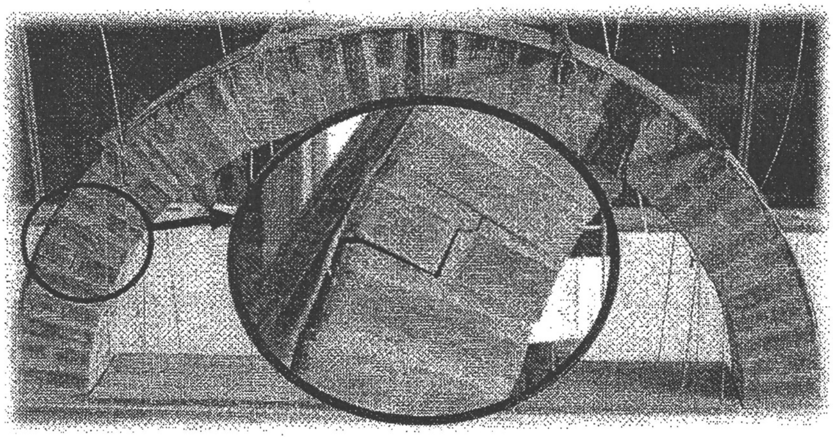

Fig. 4.– Plastic hinge occurrence after the first consolidation layout.

Further on, the bearing capacity of the arch was repaired by applying a new composite material layer on the destroyed area of the arch. On its bottom face a single layer of fabric was applied and in critical zones, transversal sheets of $L = 4 \times 24 + 24$ cm were applied too.

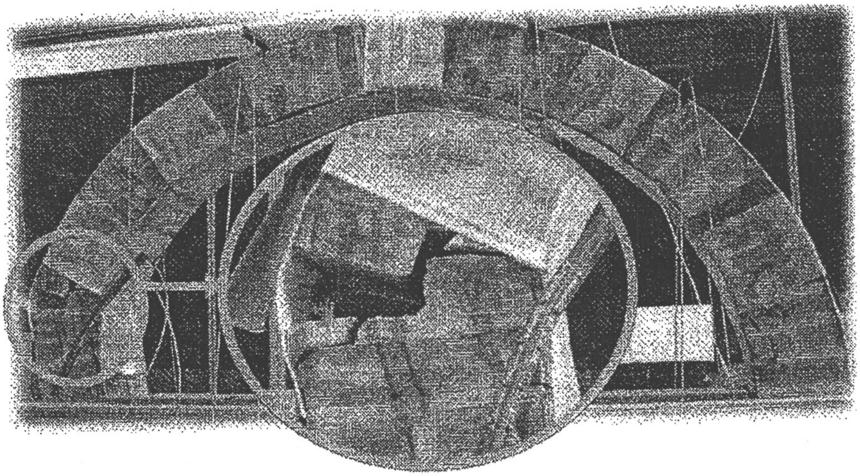

Fig. 5.– Plastic hinge formation in the second consolidation layout.

The newly consolidated model was horizontally loaded again. This time, the load attained the value of 3,000 daN when failure occurred. The section were plastic hinge formed, was close to the section of previous failure. The moment when failure occurred was marked by a very noisy crash. The horizontal displacement was of approximate 57 mm. Fig. 5 shows the arch after failure in the second consolidation layout.

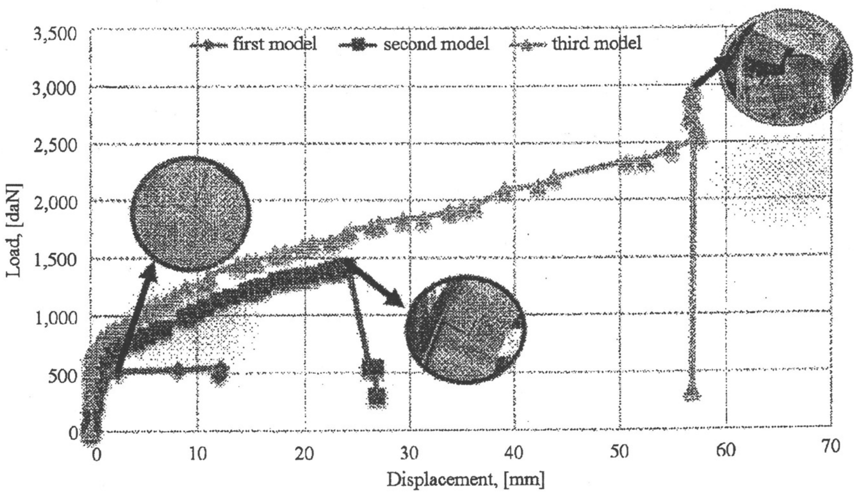

Fig. 6.– Load-horizontal displacement characteristic curve.

3. Conclusions

The following conclusions were drawn after analysing the experimental results:

1. When laterally loaded (seismic loading) in the masonry arch a rapid failure by plastic hinge occurrence is to be expected.
2. The unconsolidated arch losts its load bearing capacity at a load level of 500 daN and a horizontal displacement of 3 mm, with a classic masonry structural behaviour (brittle failure).
3. Using the first composite materials based consolidation layout, 300% enhancement in the load bearing capacity was obtained.
4. The horizontal displacement after second loading of the arch was of approximate 26 mm, and the horizontal load was of approximate 1,500 daN.
5. By using the second consolidation layout a 600% enhancement the load bearing capacity was obtained as compared to the unconsolidated arch.
6. The second consolidation layout ensured a better anchorage of the composite, resulting into a better composite action of the masonry/GFRP.
7. During the loading process, cracks were noticed in multiple sections of the arch and, later on, they extensively developed due to compressive strength surpassing.
8. The horizontal displacement after third loading was of approximate 57 mm, at a load level of 3,000 daN.

The application technologies of the composite materials are not very complicated, these ones may be conducted by an adequately qualified personnel.

By using these composite materials based consolidation methods, the load bearing capacity of the members is substantially increased, as the experiments revealed, and change in the failure modes performed.

At an european level, the composite materials based consolidation methods have already been successfully used in case of over 1,000 historical monuments, most of them from Italy [3],[4]. Among these applications in case of arches various consolidation methods were based on composite materials.

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COMPORTAREA ARCELOR DIN ZIDĂRIE CONSOLIDATE CU MATERIALE COMPOZITE

Studii experimentale

(Rezumat)

Zidăria reprezintă unul dintre cele mai vechi sisteme constructive. Foarte multe construcţii vechi sunt realizate din zidărie. Un număr important dintre acestea au fost declarate monumente istorice. Principalele elemente realizate din zidărie, care acoperă deschiderile, sunt arcele. Datorită diverselor cauze arcele au fost deteriorate, ceea ce impune găsirea unor soluţii de consolidare cât mai eficiente.

Se detaliază analiza comportării şi mecanismele de cedare în urma acţionării orizontale a unui arc din zidărie de cărămidă şi mortar realizat în cadrul unui experiment. Arcul a fost realizat la scara 1 : 1 din cărămidă plină şi mortar M10Z. Acesta a fost lestat după care a fost acţionat cu o forţa orizontală în planul lui. În urma acţionării s-a produs un mecanism de cedare ce a constat în apariţia unei articulaţii plastice, fapt care a determinat pierderea capacităţii portante. În următoarea etapă arcul a fost consolidat prin aplicarea materialului compozit realizat din ţesătură de fibră de sticlă şi răşină epoxidică pe extrados. După această fază arcul a fost acţionat din nou cu o forţă orizontală mai mare decât în etapa precedentă, astfel a apărut un mecanism de cedare diferit de cel anterior. În continuare s-a refăcut capacitatea portantă a arcului deteriorat prin aplicarea unei noi metode de consolidare. Materialul compozit a fost aplicat atât pe extrados cât şi pe intrados şi parţial pe zona laterală.

Aplicarea soluţiilor de consolidare a avut ca rezultat o creştere semnificativă a capacităţii arcului. De asemenea modul de comportare şi mecanismele de cedare au fost schimbate prin aplicarea materialului compozit, îmbunătăţindu-se substanţial comportarea arcului din zidărie.