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The treatment of masonry vaults through the Monge-Ampère equation (Article)

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Abstract

It is recognized that, apart from a few cases, the No- Tension assumption yields a effective model for structural assessment of masonry structures. The theory is briefly illustrated, and its application to vaults is explained in detail, leading to a Monge- Ampere equation ruling the static regime through a membrane stress surface.

Author keywords

Masonry vaults; Monge-Ampère equation; No-Tension model; Stress analysis

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The treatment of masonry vaults through the Monge-Ampère Equation

Alessandro Baratta and Ottavia Corbi

Abstract—- It is recognized that, apart from a few cases, the No-Tension assumption yields a effective model for structural assessment of masonry structures. The theory is briefly illustrated, and its application to vaults is explained in detail, leading to a Monge-Ampere equation ruling the static regime through a membrane stress surface.

Keywords— Masonry vaults, Stress analysis, No-Tension model, Monge-Ampère equation.

I. INTRODUCTION

Masonry is not properly a "material" in the strict sense of the word. It consists in the (generally man-made) assemblage of a basic component (the stones) simply laid on each other or, more often, jointed by mortar. Stones and mortar may have very variable mechanical properties, and the way in which the stones are organized in the masonry volume may (the masonry "texture") may be very different, and is subject to the skill and the creativity of the designer and/or of the builder.

So, "masonry" has not a uniquely defined object, and it is very difficult to set up a mechanical model able to closely reproduce the properties of masonry, fitting all the possible variety of masonry assortment and texture. Anyway, in all structural analyses the engineer is forced to balance the trend to reproduce the material (and consequently the structural behaviour) as closely as possible, with the practical manageability of the analytical tools. Linear theory of structures applied to steel, reinforced concrete and even to masonry, is a successful example of such effort. In all cases the basic theory should include the major features of the behaviour, possibly neglecting many details that poorly influence structural safety assessment, and/or are uncontrollable.

The first step is then to identify the major properties, that are more or less common to all masonry types. The basic knowledge can be achieved through simple experiments. Uni-axial compression/tension tests can be performed on some Representative Volume Element (RVE) of a typical masonry.

After some experiments, it is possible to conclude that: i) the masonry has different elastic moduli in tension (E_t) and compression (E_c); ii) the masonry has different limit stresses in tension (σ_t) and compression (σ_c); iii) the limit stress in tension is much smaller than the limit strength in compression ($\sigma_t << \sigma_c$); iv) the behaviour at failure in compression has some degree of ductility; v) the behaviour at failure in tension is definitely brittle, so tensile strength cannot be recovered absolutely.

Moreover, surprisingly the limit strength in compression of masonry is larger than the strength of the weak element (the mortar) and is bounded from above by the limit strength of the strong component (the stones); this is due to some complex phenomenon of stress interaction and transverse deformation of mortar with respect to stones. It is also easy to understand that if the axis of the stress is rotated by an angle, say 90°, the results of the experiment may significantly change, in particular as regards the tensile strength. Some similar conclusions can be drawn from biaxial tests (see e.g. [1,2]). Experimental limit strength domains show a high capacity in compression and a very poor limit in tension without ductility.

Summing up, masonry is a non-linear material, strongly hetero-resistant, anisotropic with respect to tensile strength, with compliance coefficients depending on the orientation of the stress axes and different in compression and tension, and with brittle failure at a very low tension threshold.

Therefore, the prevalent feature that characterizes masonry structures, and makes them dissimilar from modern concrete and steel structures, is quite definitely their intrinsic inability to resist tensile stresses. So, it is natural that the material model, that is intended to be an "analogue" of real masonry, in principle cannot resist tensile stress, but, possibly, behaves elastically under pure compression, or plastically if some degree of ductility is ascertained. No-Tension solutions for masonry structures are a very significant reference point and a powerful tool for reliable structural assessment, for many reasons. The first reason is that the NT model is a stable behaviour, poorly subject to uncertainty and aging. Tensile strength is in any case small, uncertain, highly variable in the mass of a structure, not durable in time and so on; anyway neglecting tensile strength leads to a safe assessment. In other words, no doubt that the NT model is a simplified behaviour, that in some cases does not give account of some surprisingly good performance of masonry buildings, but it is also true that if a masonry structure does not pass through a NT check it remains a suspect structure.

The basics for the foundation of a NT material theory are illustrated in [3], where the relevant principles for structural

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