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Proceedings of the Twelfth International Conference on Computational Structures Technology

Edited by
B.H.V. Topping and P. Iványi

Including special sessions organised by
J.G. Santos da Silva, L.F. Costa Neves, D. Kennedy, S. Ilanko, J.R. Banerjee, A. Sextos, A. Baratta, R.C. Barros, A. Formisano, J. Nemecek, O. Jiroušek, H.-P. Chen, R. Ceravolo, C.C. António, C.F. Castro, D.V. Oliveira, C. Pellegrino, J.V. Araújo dos Santos, H.M. Lopes, P. Moreno-García, A. El-Hami, B. Radi, K. Marti, J. Logo, J. Náprstek, F.A. DiazDelaO, E. Patelli, M. Beer, S.K. Au, N.L. Rizzi, V. Varano, S. Gabriele, J. Awrejcewicz, A. Dall'Asta, W. Salvatore, D. Kvasov, A. Csébfalvi, V. Gattulli, S. Kubo and L.M.C. Simoes

Introduction

Welcome to the proceedings of *The Twelfth International Conference on Computational Structures Technology*, organised by Civil-Comp Press in Naples, Italy from 2-5 September 2014.

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Naples, Italy, 2-5 September 2014

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Preface

This volume comprises the summaries of contributed papers presented at *The Twelfth International Conference on Computational Structures Technology* (CST 2014) held in Naples, Italy from 2-5 September 2014. The CST 2014 conference was held concurrently with *The Ninth International Conference on Engineering Computational Technology* (ECT 2014).

The special sessions included in this volume of Proceedings are:

- Structural Analysis of Steel and Steel-Concrete Composite Structures
  organised by: Professor J.G. Santos da Silva and Professor L.F. Costa Neves
- Eigenvalues of Continuous Systems
  organised by: Professor D. Kennedy, Professor S. Ilanko and Professor J.R. Banerjee
- Computational Earthquake Engineering
  organised by: Dr A. Sextos
- Control of Vibrations in Civil Engineering
  organised by: Professor A. Baratta and Professor R.C. Barros
- Seismic Assessment and Retrofit of Historic and Monumental Constructions
  organised by: Dr A. Formisano
- Multi-Scale Modelling of Materials with Heterogeneous Microstructure
  organised by: Dr J. Nemecek and Dr. O. Jiroušek
- Structural Health Monitoring
  organised by: Dr H.-P. Chen and Professor R. Ceravolo
- Optimization supporting Sustainable Development
  organised by: Professor C.C. António and Professor C.F. Castro
- Analysis and Design for Repair, Strengthening and Retrofit of Heritage Structures
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- Damage Identification Methods
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- Probabilistic Approaches to Structural Mechanics
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- Optimal Design under Stochastic Uncertainty
  organised by: Professor K. Marti and Professor J. Logo
- Numerical and Non-linear Dynamics
  organised by: Dr J. Náprstek and Professor J.R. Banerjee
- Uncertainty Quantification and Management through Bayesian and Imprecise Probability Perspectives
  organised by: Dr F.A. DiazDelaO, Dr E. Patelli, Professor M. Beer and Professor S.K. Au
- Nonlinear Beam and Plate Models with a view to applications
  organised by: Professor N.L. Rizzi, Dr V. Varano and Dr S. Gabriele
- Linear and Non-Linear Dynamics of Structures
  organised by: Professor J. Awrejcewicz and Professor J.R. Banerjee
- Seismic Behaviour of Steel-Concrete Hybrid Structures
  organised by: Professor A. Dall'Asta and Professor W. Salvatore
- Black-Box Global Optimization: Fast Algorithms and Engineering Applications
  organised by: Dr D. Kvasov
- Uncertain Topology Optimization
  organised by: Professor A. Csébfalvi
- Models and Measurements of Masonry Dynamics
  organised by: Professor V. Gattulli
- Inverse Problems
  organised by: Professor S. Kubo and Professor L.M.C. Simoes

- Bridge Engineering: Modelling, Analysis and Design
  organised by: Dr A. Sextos

We are particularly grateful to the special session organisers.

The following sessions are also included in this volume:

- Software Development
- Meta-modelling and Decomposition
- Boundary Element Methods
- Finite Element Modelling
- Extended Finite Element Method
- Fluid-Structure Interaction
- Modelling Biomechanics Problems
- Shell Structures
- Plate and Folded Plate Structures
- Structural Optimization
- Structural Engineering Dynamics
- Control of Engineering Structures
- Seismic Vulnerability Assessment
- Composite Structures
- Modelling and Design of Reinforced Concrete Structures
- Modelling Concrete and Reinforced Concrete Structures
- Assessment of Masonry Construction: Models and Applications
- Damage Mechanics
- Materials Modelling
- Modelling Composite Materials
- Structural Mechanics
- Beam Structures
- Impact Loading
- Timber Structures
- Cable, Membrane and Space Structures
- Multiphysical Mechanics of Membranes
- Geomaterials Modelling

Other papers presented at the conferences in 2014 are published as follows:

- *The Invited Lectures from ECT 2014 and CST 2014 are published in:*
  Computational Methods for Engineering Technology, B.H.V. Topping and P. Iványi, (Editors), Saxe-Coburg Publications, Stirlingshire, Scotland, 2014.
- *The Invited Review Lectures from ECT 2014 and CST 2014 are published in:*
  Computational Technology Reviews, Volumes 9 and 10, Saxe-Coburg Publications, Stirlingshire, Scotland, 2014.
- *The Contributed Papers from ECT 2014 are published in:*
  Proceedings of the Ninth International Conference on Engineering Computational Technology, P. Iványi and B.H.V. Topping, (Editors), (Book of Summaries with online delivery of full-text papers), Civil-Comp Press, Stirlingshire, Scotland, 2014.

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Paper 243

Numerical Models and the Perception of Masonry

E. Della Bella
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Keywords: masonry, groin vault, cross vault, survey, historical buildings, statics.

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During the restoration of ancient constructions that follow a survey; architects and engineers are asked to consolidate the masonry structure. In these cases, more often than not, the use of a numerical model is far from useful. This paper analyses some case studies in which architects and engineers should go 'beyond' the numerical computer model and take a step 'backwards' to a substantial intrinsic knowledge of masonry. To really approach these contingencies, the architect or engineer must distance themselves from being mere technicians, assuming the role of the scholar who is able to 'feel' and 'visualize' the masonry's stress.

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Paper 243

Numerical Models and the Perception of Masonry

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Abstract

During the restoration of ancient constructions that follow a survey; architects and engineers are asked to consolidate the masonry structure. In these cases, more often than not, the use of a numerical model is far from useful. This paper analyses some case studies in which architects and engineers should go 'beyond' the numerical computer model and take a step 'backwards' to a substantial intrinsic knowledge of masonry. To really approach these contingencies, the architect or engineer must distance themselves from being mere technicians, assuming the role of the scholar who is able to 'feel' and 'visualize' the masonry's stress.

Keywords: masonry, groin vault, cross vault, survey, historical buildings, statics.

1 Introduction

Masonry defines and protects the building from the elements, it supports its own weight, the horizontal structures, and external loads. From a mere material point of view, masonry is the union of elements both natural, such as stone, and artificially produced, such as bricks; this union is aided by the use of mortar, which has the task of creating continuity in the wall, and spreads out the load between the various elements. Whatever the resistance of the masonry part, it is the mortar that, more often than not, fails to withstand the load [1].

In this paper, I will show two case studies which deserve to be mentioned. Both come from a building of historical value, which was erected between the 17th and the 19th century in the city centre of Rome. Similar to the majority of roman buildings erected during that period, masonry was very peculiar and was known as muratura a sacco [2]. The original concept of this kind of masonry, often referred to as 'double-skin concrete core', comes from the ancient romans who made this peculiar technique the core of their construction method. It is essentially a masonry structure made of two facades filled with rubblework and concrete. While ancient roman concrete, often made with *pozzolana*, is known to be of the best quality possible, 17th century roman rubblework is known to be the worst of its kind. Though papal laws on buildings were very strict, and included beheading for building poor masonry, it is very common to find extremely strange cases such as the use of earth and wood logs instead of well compacted rubblework filled with mortar.

2 Analysis of ancient structures

As mentioned, the building in this case was built during a time span that includes many centuries so that it is possible to find a very heterogeneous situation in which several masonry types penetrate and entwine each other. In cases such as this, the use of a static model is far from accurate and useless or, at best, inappropriate. As a matter of fact, a computer generated model is both useful and productive if it can easily simplify a complex contingency. It is very important to stress the word ‘easily’, as building a model that requires more energy and is more time consuming is far from useful compared to the canonic load analysis. I feel that many architects and engineers have abdicated to computer generated results, forgetting and neglecting the principles of static, the lore of the building processes, and the ‘feeling’ of the structures. Those architects and engineers who depend solely on the calculation of the computer: to which my old professor of static referred to as ‘the stupid slave’, have become mere technicians. In effect, it is so easy to make this subtle mistake; as every aspect of contemporary life is managed by high powered computer systems, how may we even think that they can fail in such a simple task? The answer to this question is binary. On one side, we have the constant thought that a computer may ‘think’ and that it cannot fail, while, as mentioned before, it is just a mindless perpetrator of a task. On the other side, even if perfectly instructed – and that could be both inaccurate and time consuming – the computer may not reckon with a series of anomalies that go from unseen poor building techniques to the use of unorthodox materials [3].

What is needed in these circumstances are both the knowledge of the structure, and of the materials used, and the history of the building. It is never enough to stress the importance of a major survey project anytime you want to work on a historical building [4,5].

3 Case studies

Let us see the first case study. As we have learned by accurate research based on old land registers, the building in this case was erected between the 17th to the 19th century. What, today, appears to be a huge complex, known to be the residence of a noble roman family, was erected one piece at a time by various owners, some extremely wealthy, some less so. Of course, greater or lesser economic means is reflected on the quality of the masonry. As with the majority of roman buildings from the city’s historical centre, parts of the structure have been erected on previous constructions. It is essential to know how and when this happened to have a complete scheme of what to expect. In this particular case, some problems occurred in a relatively new part of the building which was erected during the first half of the 19th century. A shop assistant who worked in the premises declared that she had heard a sinister sound coming from the vaults.

Figure 1: A hair like sign on a vault's intersection

3.1 Understanding hair like signs

On an inspection, it was found that on the intersections of the cross vault there was a thin sign on the plaster, so thin that it was almost impossible to see it without the help of some kind of tool. Surely that tiny hair like sign shown in Figure 1 was not enough to sound an alarm; as a matter of fact, hair like signs are almost everywhere, both in new and old constructions, and as a rule of thumb they don't mean anything serious.

It is very common to see some signs on the plaster even after inserting a nail for hanging a painting. I seriously doubt something so trivial would give rise to a static survey. Here, the knowledge of the scholar comes into play once again. What is plaster and how is it made? More importantly, how was it made in the early 19th century? Nowadays, plaster is made from various premixed products, usually with a higher or lower percentage of lime and cement or plaster of Paris. These types of plaster are very fragile; as with any crystal like structure they tend to crack very easily. It is obvious then that a hair like sign is not acknowledged as a problem. But the matter is that old plaster was made with lime which is surely more adaptive to stresses, and tends to crack only when the masonry underneath has reached a high value of stress [6]. In Figure 2, is it possible to see what happened underneath the plaster hair like sign of the previous figure after having removed part of the plaster.

3.2 Knowing the structures, feeling the stresses

3.2.1 Groin Vaults

As expected, though the whole structure was well made, as both the bricks and the mortar were in excellent shape, the crack on the masonry was extremely serious. Once again, there is no need for any computer generated model to understand what the cause is.

Figure 2: A serious crack found underneath a hair like sign along the vault groin

Figure 3: A hair like sign on the plaster of the outer skin of the *a sacco* masonry

A well educated architect or engineer may immediately ‘feel’ the reason that caused the resulting crack in that particular place. The geometric genesis of a cross vault is the intersection of two barrel vaults that have the same height both of the springer and of the key. The intersection of the two barrels, that is the groin, is the line through which the loads are transferred to the foundations. If the two barrels of the cross vault are subjected to differential subsidence, the groin will crack because of the tension between the two semi-structures. Obviously, the tension along the groin cracked the weaker material; that is the mortar [7]. The question to ask now is how did this happen? From the preliminary survey, we know that this part of the building was erected when the owners had a significant amount of money and that, to mark their power in the society, they wanted to build a new aisle of the family property in extreme haste. We also have confirmation from the better masonry that lies under the plaster, but what about the foundation of this side of the palace? Once again, the survey we made earlier is helpful because from the documents we have found, we know that the new isle was build on a complex of very old and decaying structures. Thus we have good masonry on a poor substructure, and it is the latter that lacks the ability to distribute the loads evenly because of differential subsidence [8].

3.2.1 Double-skin concrete core masonry

The second case study comes from the same building but on a different part which was erected between the 17th and the 18th century. While the masonry of the first case study was extremely well constructed and preserved, the structure of this part is a very poor *a sacco* or 'double-skin concrete core' masonry. In Figure 3, we may see a thin vertical sign on the plaster of the outer skin of the masonry. The same wall had a series of vertical and horizontal signs that suggested a crush stress [6]. Usually, this kind of stress is the symptom of huge loads, and this could be the case if only the same kind of signs, or even small traces, were present in the inner skin as well as in the proximity of perpendicular structures. The stress signs were only visible on the red part of Figure 4 without involving the ground floor of the structure which, if crush stress was involved, should have absorbed the load of the above storeys so that at least some little signs would be seen [9].

Figure 4: Signs are only visible on the outer skin of the masonry of the first storey

The ground floor, which today hosts a series of top brand shops, was used as stables for the horses and carts of the noble family while the first and second floors were used as a residence. This means, fireplaces and chimneys were only present on the residential floors. In this case, fireplaces, of which we have no sign today, were built between the windows, thus reducing the structure of the masonry. But it was not the slimming down of the masonry that caused the stress otherwise we should expect the same problem on the upper storey. The cause of the stress was the poor quality of the bricks and mortar of the chimneys that, after a prolonged exposure to high temperatures, crumbled down opening ‘wounds’, making the structure uneven and inconsistent [1,6]. This may be seen in the collage of Figure 5 where the mortar has crumbled from intense heat and the chimneys have been exposed.

Figure 5: Collage of two parts of the masonry. Extreme heat has crumbled the mortar making the structure uneven and inconsistent

4 Conclusions

Ancient masonry constructions come in many kinds. Almost every century, as well as every specific site, developed a peculiar and unique way of building, further affected by the economic resources of the owners and the technical preparation of the masons. In recent years, structural design has come to be viewed in terms of limit states, a method that is based on a good knowledge of the building considered to be heterogeneous in its nature. If this were not true, and the two case studies have shown that this contingency happens only seldom, it will correspond to the realization of a difficult, time consuming, and often highly unreliable mathematical model. In cases such as these, when the buildings behave more as a living being rather than a crystallized object, from time to time favouring and reacting to the stress, I would like to emphasize once again the need to know, understand and ‘feel’ masonry and the stress involved. An accurate knowledge of the building; a deep understanding of the structures, their strength, stiffness, and stability, as well as a meticulous survey, are the keys to a winning approach. By being able to ‘see’ the geometry of the stress lines of a masonry building , architects and engineers should think as masons rather than mere technicians, thus going beyond the numerical computer model.

References

[1] S. Mastrodicasa, *Dissesti statici delle strutture edilizie*, Hoepli Editore, Milano, 1958.
[2] L. Matarazzo, *La statica degli edifici esistenti: indagini e monitoraggi, gruppo editoriale esselibri*, Napoli, 2005.
[3] B. Furiozzi, C. Messina, L. Paolini, *Prontuario per il calcolo di elementi strutturali*, edizioni Le Monnier, Firenze, 2010.
[4] A. Defez, *Il consolidamento degli edifici, Liguori Editore*, Napoli, 2002.
[5] A.A.V.V., *Tecnica e pratica del recupero edilizio, alinea editrice,* Firenze, 1982.
[6] G. Rizzi, *Lesioni, dissesti, controlli, rimedi,* Vol. I, edizioni Meschini editore, Roma, 1994.
[7] J. Heyman, *The stone skeleton structural engineering of masonry architecture*, Cambridge University Press, 1997.
[8] V. Franciosi, *Scienza delle costruzioni*, edizioni Liguori, Napoli, 1983.
[9] G. Cigni, *Il consolidamento murario*, edizioni Kappa, Roma, 1978.