TIME TABLE

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	July 26	July 27	July 28	July 29	July 30
9.00 - 9.45	Registration	Lemos	Angelillo	Block	Lemos
9.45 - 10.30	Workshop	Lemos	Angelillo	Block	Block
11.00 - 11.45	Workshop	Aita	Lemos	DeJong	DeJong
11.45 - 12.30	Angelillo	Aita	Lemos	DeJong	Angelillo
14.00 - 14.45	Bagi	Bagi	Angelillo	Block	
14.45 - 15.30	Bagi	Bagi	Angelillo	Block	
16.00 - 16.45	Aita	Aita	DeJong	DeJong	
16.45 - 17.30	Aita	Aita	DeJong	DeJong	
18.00	Welcome Aperitif				

ADMISSION AND ACCOMMODATION

The registration fees are:
- Participation in presence, 600.00 Euro + VAT*
This fee includes a complimentary bag, four fixed menu buffet lunches (on Friday upon request), hot beverages, downloadable lecture notes.
- Participation online, 250.00 Euro + VAT*
This fee includes downloadable lecture notes.

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through the following web site: http://www.cism.it. A message of confirmation will be sent to accepted participants. Applicants requiring assistance with the registration should contact the secretariat at the following email address: cism@cism.it.

Applicants may cancel their course registration and receive a full refund by notifying CISM Secretariat in writing (by email to cism@cism.it) no later than two weeks prior to the start of the course.

Cancellation requests received during the two weeks prior to the start of the course will be charged a 50.00 Euro handling fee. Incorrect payments are also subject to a 50.00 Euro handling fee.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered lodging and/or board, if available, in a reasonably priced hotel or student guest house.

Requests should be sent to CISM Secretariat by **May 26, 2021** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

Information about travel and accommodation is available on the web site www.cism.it, or can be mailed upon request.

* where applicable (bank charges are not included)
Italian VAT is 22%.

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ACADEMIC YEAR 2021
The Erwin Stein Session

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

DISCRETE COMPUTATIONAL MECHANICS OF MASONRY STRUCTURES

Advanced Professional Training
coordinated by

Katalin Bagi
Budapest University of Technology and Economics
Budapest, Hungary

Maurizio Angelillo
University of Salerno
Fisciano, Italy

Udine ***July 26 - 30*** **2021**

DISCRETE COMPUTATIONAL MECHANICS OF MASONRY STRUCTURES

Masonry structures – collections of individual solid blocks with dry or mortared contacts – appear everywhere around us, from architectural heritage through historic or contemporary civilian buildings to traffic infrastructure. The assessment of their structural integrity poses serious challenges: due to their discrete built-up, usual continuum-based calculation methods are often incapable to reflect the mechanical behavior. In cases when the failure is caused by some kind of a local effect (cracks opening up between voussoirs, individual blocks sliding out etc.) the mechanics of the problem may better be captured by methods that consider the structure as a collection of discrete bodies. Such methods are available in a wide variety today. The aim of the course is to give a detailed introduction to their theoretical fundaments, advantages and preferable fields of application, but also calling the attention to their limitations and disadvantages so that the participants of the course would build up a critical view of the choices they have when attacking a masonry mechanics problem. An explicit aim of the course is to give a sound basis for the participants to become able to develop their own methods, inspired either by classical graphical statics, or by any modern technique they find promising. The course will focus on four main topics:

1) Computerized graphical statics methods
Graphical statics seemed to lose practical importance in the 2nd half of the XXth century when continuum-based numerical techniques and Limit State Analysis methods became widely applied in computerized manners. However, the recent decades brought a renaissance to the application of graphical statics in masonry analysis: powerful computer codes have been developed part of which are commercially available and part of which can be found as research tools.

2) Discrete element methods
DEM was born at the end of the 1960ies as an alternative to FEM. DEM considers the simulated material or structure not as a continuum but as a collection of separate bodies being able to detach, slide, partly or completely separate, and form new contacts when large displacements may lead to the rearrangement of contact topology. Possibilities to partial cracking and sliding makes DEM particularly advantageous for masonry failure problems.

3) Blocky models
The main drawback of DEM is that the analysis of whether new contacts are born in the system, simulations can be very computationally expensive. To avoid this, different blocky models have been suggested recently for problems when rearrangements of the topology are not expected, but the discrete built-up of the system is relevant (e.g. formation of partial cracks). These novel methods are considered as being in-between FEM and DEM.

4) Discrete dynamics
Masonry structures are sensitive to earthquakes: seismic analysis is a crucial issue in masonry mechanics. Damping and contact sliding are significant in their energy dissipation and in the ability to adjust to ground displacements. Hence, special lectures will be devoted to the dynamics of masonry structures. In particular, lectures will focus on damping and large displacement dynamics which characterize the dynamic collapse of masonry structures.

Targeted audience: young researchers (including PhD students); engineers interested in high-level computational tools for masonry analysis.

PRELIMINARY SUGGESTED READINGS

Aita D, Barsotti R, Bennati S (2019): Looking at the collapse modes of circular and pointed masonry arches through the lens of Durand-Claye's stability area method. Archive of Applied Mechanics https://doi.org/10.1007/s00419-019-01526-z.

Angelillo M, Fortunato A, Gesualdo A, Iannuzzo A, Zuccaro G (2018): Rigid block models for masonry structures. Int. J. Masonry Research and Innovation 3(4), 349-368.

Bagi, K (2014): When Heyman's Safe Theorem for Rigid Block Systems Fails: Non-Heymanian Collapse Modes of Masonry Structures. Int. J. Solids and Structures 51, 2696-2705.

Block Ph, Ochsendorf J (2007): Thrust network analysis: A new methodology for three-dimensional equilibrium. J. International Association for Shell and Spatial Structures 48(3), 155, 167-173.

DeJong MJ (2012): Amplification of rocking due to horizontal ground motion. Earthquake Spectra 28(4), 1405-1421.

DeJong MJ, Dimitrakopoulos EG (2014): Dynamically equivalent rocking structures. Earthquake Engineering and Structural Dynamics 43(10), 1543-1564.

Foce F, Aita D (2003): The masonry arch between 'limit' and 'elastic' analysis. A critical re-examination of Durand-Claye's method, in Proceedings of the first international congress on construction history (Madrid, 20-24 Jan 2003), Vol. II, 895-908. ISBN 84-9728-072-5.

Lemos JV (2007): Discrete element modeling of masonry structures. Int. J. Architectural Heritage 1, 190-213.

Sarhosis V, Bagi K, Lemos JV, Milani G (2016): Computational Modeling of Masonry Structures Using the Discrete Element Method. ISBN 9781522502319, IGI Global, Hershey, USA. Chapters 2.-6.

Wolfe, WS (1921): Graphical analysis. A textbook on graphic statics, 1st edition, McGraw-Hill Book Company, New York. Chapter I.: General Methods.

LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted participants.

INVITED LECTURERS

Danila Aita - Università di Pisa, Italy
6 lectures on: Classical graphical statics. Fundamentals are recalled and introduction is given to those techiques (Méry, Eddy-Lévy, Wolfe) that inspired modern computerized versions in masonry mechanics. Particular emphasis is on the Durand-Claye method and its generalization to domes. Applications to masonry mechanics issues and on historic structures are shown.

Maurizio Angelillo - Università degli Studi di Salerno, Fisciano, Italy
6 lectures on: The basic ingredients of a method based on unilateral equilibrium and rigid block kinematics, which may allow the implementation of Heyman's model for masonry on a computer, are introduced. The method is based on energy minimization and allows for the evaluation of the combined effect of loads and settlements on real masonry structures treated as assemblies of rigid blocks.

Katalin Bagi - Budapest University of Technology and Economics, Hungary
4 lectures on: After an introductory overview of the different discrete computational approaches, the definition and main types of DEM are introduced. Theoretical fundaments of those techniques most often applied in the engineering practice and masonry research (3DEC, DDA, Non-Smooth Contact Dynamics, Munjiza's FEMDEM) are presented with special emphasis on their limitations.

Philippe Block - ETH Zurich, Switzerland
5 lectures on: Thrust Network Analysis is a 3d method for obtaining lower-bound solutions by finding equilibrium force networks within the masonry vault's geometry. It is a powerful tool for visualizing and understanding the equilibrium of compression-only structures and for finding their collapse mechanisms. Wide variety of attractive architectural applications exist that are also presented.

Matthew DeJong - University of California, Berkeley, CA, USA
7 lectures on: Elements of dynamics of rigid block systems are presented, with scale effects, collapse mechanisms, and particulars – like damping, an important aspect of masonry behaviour – related to earthquake engineering. These are introduced in contrast to the dynamic behavior of typical elastic and inelastic structures. Finally, aspects of DEM modelling of dynamic collapse are discussed.

Jose V. Lemos - Laboratorio Nacional de Engenharia Civil, Lisboa, Portugal
5 lectures on: The most widespread DEM software in practical analysis of the mechanics of masonry structures is 3DEC. Features of the method like contact recognition and representation, damping possibilities, numerical stability issues and the application of structural elements like cable or beam reinforcements are to be introduced. Case studies and application advice will finally be given.

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