On the use of the Discrete Element Method in the modelling of masonry structures under seismic loads

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1- General Introduction

2- Seismic Vulnerability

3- « MP » - pre processing

4- Simulation Results

5- « MP » - post processing

6- Perspectives & conclusions
General Introduction

Seismic Vulnerability
Simulation Results
Outlook & Conclusions

« MP » pre processing
« MP » post processing

1-

General Introduction

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very heterogeneous material with numerous non linearity

- Dry masonry / mortar
- Material properties (blocks/bonding agent)
- Shape & dimensions of blocks
- Blocs layout

→ Modelling ?
### General Introduction

- **Seismic Vulnerability**
- **Simulation Results**
- **Outlook & Conclusions**

### Structured Choice and Scale of the Analysis

**Equivalent Frame Model***

**Finite Element Model***

**Discrete Model**

#### Structural elements

- **Panels**

#### Continuous media

- **Homogeneity**
  - equivalent material

#### Divided media

- Model of « block to block »

- **Description « masses / springs »**
  - Bulk behaviour of blocks + interaction laws
  - good In-plane & out-of-plane responses

### Discretisation

- **Macro elements**
  - No Out-of-plane response

### Damage

- In each macro element

### Fields

- on the mesh

#### Localisation issues

- Principal inelastic strains

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**Fileds**

**Mechanical information**

at the scale of the block / contact point

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**Workshop Masonry LMA – October, 24th 2013**
1. Generation of discrete models of masonry structures

2. Numerical simulation using DEM (LMGC90)

3. Exploitation of simulation results

Seismic Vulnerability
Seismic Vulnerability
Specific pattern of failure due to seismic actions:

- **In-plane:**
  - Shear → diagonal cracks in panels
  - Compression / Flexion → horizontal cracks in the top/bottom of the panels

- **Out-of-plane:**
  → falling down of masonry panels

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<th>A</th>
<th>B1</th>
<th>B2</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<tr>
<td></td>
<td>VERTICAL OVERTURNING</td>
<td>OVERTURNING WITH 1 SIDE WING</td>
<td>OVERTURNING WITH 2 SIDE WINGS</td>
<td>CORNER FAILURE</td>
<td>PARTIAL OVERTURNING</td>
<td>VERTICAL STRIP OVERTURNING</td>
<td>VERTICAL ARCH</td>
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**FURTHER PARTIAL FAILURES**

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<td>HORIZONTAL ARCH</td>
<td>IN-PLANE FAILURE</td>
<td>VERTICAL ADDITION</td>
<td>GABLE OVERTURNING</td>
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**ASSOCIATED FAILURES**

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<td>ROOF/FLOORS COLLAPSE</td>
<td>MASONRY FAILURE</td>
<td>Insufficient cohesion in the fabric</td>
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Niveaux de dommage des bâtiments en maçonnerie d'après l'EMS98

d'après D. D'Ayala & E. Speranza, Earthquake Spectra, 2003
Post seismic missions

Seismic Vulnerability
Simulation Results
Outlook & Conclusions

General Introduction
« MP » pre processing
« MP » post processing

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Mechanical Approach

Quasi-static

Dynamic

Direct Analysis of the damage state

Agression vs Damage grade

Seismic Vulnerability
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Numerical Approach of the vulnerability with the NSCD method and LMGC90

General Introduction
Outlook & Conclusions

« MP » pre processing
« MP » post processing

Discrete models

Generation of discrete models
Pre processing

Numerical simulation with LMGC90 Calculator

Post Treatment Vulnerability framework
Post processing

Buildings to study

Response curves → statistic treatment of the vulnerability

Discrete models

LMGC90

Damage evaluation of masonry structures
General Introduction
« MP » pre processing
« MP » post processing

Seismic Vulnerability
Simulation Results
Outlook & Conclusions

3-

« Maison Paramétrée » Tool – pre processing –
A structural approach of masonry structures

General Introduction
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Simulation Results
Outlook & Conclusions

Seismic Vulnerability

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Beyond preprocessing...

Gestion of the visualisation & identification interest zones
Deformable macro-elements
(generation with GMSH « on-the-fly »)

Rigid macro-elements
(clusters of rigid blocks)

Beyond preprocessing...
Simulation Results

4-
Mechanical Analysis

BM1

BM3

BM4

Seismic Vulnerability
Simulation Results
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Conclusion

- Variability
  - Enrichment of the parametric space → gestion of irregularities

- Modelling and Behaviour
  - Under estimation of shear behaviours
  - Over estimation of the stability of masonry structures
  - Improvement of the modelling of structural elements: diaphragms, ...

Vulnerability Analysis ?

Modelling masonry with deformable blocks
Local approach by panels inspired by GNDT and adapted to the DEM

Existence et quantification of damage in each vertical element of structure:

→ ∃ 1 carck if \( \delta_{2 \text{ blocs}} > 0.5 \text{ mm} \)
→ Cracks rate = Nb crackss / Nb interfaces
→ mean cracks \( \delta_{\text{mean}} \) ? Cumulated carcks ?
Panels Behaviour

- In-plane « deformation »
- Out-of-plane behaviour

Structural behaviour

Horizontal Diaphragms

- Interstorey drift
- Torsion

Seismic Vulnerability

Vulnerability Analysis & Damage grade identification

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Conclusion

- Local **indicators** + full proposed **strategy**

**Layout...**

- Indicators have to be improved (**suitability ?**)

- **Utilisation of the relevant indicators**
  → from **local indicators to global indicators**

- Generation of **vulnerability curves** linking probability of damage and the characteristics of seismic loads

- Study of a set of real buildings: **comparison** of vulnerability curves numerically obtained with DEM with empirical ones
- Geometrical models « block to block »
  - masonries with regular layers
  - multi layers masonries
  - ...

- Heterogeneity of blocks / mortar
  - bulk behaviour
  - interaction laws
  - ...

Masonry with regular layers composed of non uniform blocks

Mesures in situ (frequential response)

Parametric Space

- variability of the structures
- + variability + gestion of initial state

Probability density function
Thank you for your attention