Earthquake Resilience:
Lessons from the 2016 Central Italy Earthquake Sequence

- CASE STUDIES OF CRITICAL FACILITIES -

Carmine Galasso
c.galasso@ucl.ac.uk
University College London, UK
Joining the team from London...
Contents of today’s talk

- Background
- Performance/Recovery of Bridges/Roads
- Performance/Recovery of School Infrastructure
- Performance/Recovery of Cultural Heritage Assets
- (Some) Lessons learned...
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Background

Mw 6.1

Mw 5.9

Mw 6.5

EEFIT
Earthquake Engineering Field Investigation Team

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MSc Earthquake Engineering with Disaster Management

LFE Webinar - Earthquake Resilience: Lessons from the 2016 Central Italy Earthquake Sequence
Amatrice, October 2016
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Background

Questionnaire survey of relief workers in Amatrice and Arquata del Tronto (6-7 weeks after Aug 24th 2016). 57 valid responses.

*multiple answers allowed (> 100%)

Curtesy of David Alexander (EEFIT)
The Case of Amatrice
Ponte a Tre Occhi

Curtesy of Andrea Todaro (EEFIT)
LFE Webinar - Earthquake Resilience: Lessons from the 2016 Central Italy Earthquake Sequence

Curtesy of Andrea Todaro (EEFIT)
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Curtesy of Andrea Todaro (EEFIT)
Accessibility issues
Earthquake Resilience: Lessons from the 2016 Central Italy Earthquake Sequence

Temporary Road
Accessibility issues
Ongoing work...
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- Performance/Recovery of Cultural Heritage Assets
- (Some) Lessons learned...
Devastating effect of natural hazards and climate change on children’s life & education ...

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Country</th>
<th>No. of schools effected</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Earthquake</td>
<td>India</td>
<td>1,864 (collapsed)</td>
</tr>
<tr>
<td>2005</td>
<td>Earthquake</td>
<td>Pakistan</td>
<td>7,000 (collapsed)</td>
</tr>
<tr>
<td>2007</td>
<td>Cyclone</td>
<td>Bangladesh</td>
<td>6,000 (collapsed)</td>
</tr>
<tr>
<td>2008</td>
<td>Earthquake</td>
<td>China</td>
<td>7,400 (collapsed)</td>
</tr>
<tr>
<td>2009</td>
<td>Cyclone</td>
<td>Philippines</td>
<td>3,417 (damaged)</td>
</tr>
<tr>
<td>2010</td>
<td>Earthquake</td>
<td>Haiti</td>
<td>1,350 (collapsed)</td>
</tr>
<tr>
<td>2013</td>
<td>Earthquake</td>
<td>Philippines</td>
<td>2,300 (collapsed)</td>
</tr>
<tr>
<td>2013</td>
<td>Typhoon</td>
<td>Philippines</td>
<td>2,500 (damaged)</td>
</tr>
<tr>
<td>2015</td>
<td>Earthquake</td>
<td>Nepal</td>
<td>5,000 (collapsed)</td>
</tr>
<tr>
<td>2016</td>
<td>Earthquake</td>
<td>Ecuador</td>
<td>1,000 (damaged)</td>
</tr>
<tr>
<td>2016</td>
<td>Hurricane</td>
<td>Haiti</td>
<td>730 (damaged)</td>
</tr>
</tbody>
</table>

World Bank - GFDRR
Need for safer and resilient schools

- Millions of public school buildings worldwide constructed prior to adequate building codes;

- Unsafe schools in hazard-prone regions can incur the loss of the lives of hundreds of school children;

- Collapse of a school building is particularly devastating to communities, as schools can hold an entire generation, a community’s future.

- Safer schools can save valuable lives, provide a safe haven for the local community, serve as a temporary shelter and help to bring normalcy back to society in times of disaster.

- Urgent need to minimize disruption as well as prevent loss of life or assets.
Need for safer and resilient schools

Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030.

... To promote the resilience of new and existing critical infrastructure, including water, transportation and telecommunications infrastructure, educational facilities, hospitals and other health facilities, to ensure that they remain safe, effective and operational during and after disasters in order to provide live-saving and essential services ...
The situation in Italy

• **2002 M5.7 Molise Earthquake**: 27 children died due to the collapse of the Scuola ‘Francesco Jovine’;

• **2003**: New seismic zonation and a new seismic code.

OPCM 3274, 2003

DM2008
The situation in Italy

- Since 2003, several projects have assessed the seismic vulnerability of Italian schools (large-scale methodologies, detailed assessments, ...);

PGA deficit for schools designed in 1984-2003

- Open Database of information related to all Italian schools, in principle including structural information.

This is still not enough!

Curtesy of Flavia De Luca (EEFIT)
Scuola Capranica (Amatrice)

- Two parts, an original masonry unit extended by two RC units ('70s)
- The RC part was retrofitted in 2012

Sources: Bing map, Google street view
• The masonry part of the school collapsed after the August 24 2016 earthquake

Sources: http://www.huffingtonpost.it/2016/08/28/scuola-amatrice-crollata-_n_11746166.htmlview
http://www.ilpost.it/2016/09/01/crollo-scuola-amatrice/
Scuola Capranica (Amatrice)

- Only interventions to increase the shear capacity of the RC part of the school, that is the only part left of the building (personal communication M. Nicoletti, DPC)
Scuola Primaria (Norcia)

- RC building built on slope, built in 1960 and retrofitted in 2012;
- Fifty-six elastic-plastic hysteretic BRAD (Buckling-Restrained Axial Dampers) devices and fibre reinforcement in the external plaster were installed.
• After the August earthquake, the school was fully functional, with very limited damage...
Scuola Primaria (Norcia)

- After the October 30th earthquake, some substantial non-structural damage was observed.

EMS 98 DS2
Medium Damage

Curtesy of Alessandro Fulco and DICA UniPg
The School First!

LA SCUOLA PRIMA DI TUTTO

http://www.protezionecivile.gov.it
The School First!

Amatrice, 09/16

http://www.protezionecivile.gov.it
The School First!

http://www.protezionecivile.gov.it

Acquasanta Terme, 11/16
The School First!

Norcia, 07/17
Data Collection...

1. Rapid Visual Survey form
2. AEDES form
3. FAST form
ReLUIS + DPC work

http://www.protezionecivile.gov.it

TOTELE ESITI SCHEDE AEDES (SCUOLE)

27%
709 PARZIALMENTE O TEMPORANEAMENTE INAGIBILI

0%
6 SENZA ESITO

66%
1733 AGIBILI

1%
28 INAGIBILE PER RISCHIO ESTERNO

TERREMOTO CENTRO ITALIA - FONTE: DIPARTIMENTO DELLA PROTEZIONE CIVILE

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For schools classified as ‘E’ in the AeDES form, a second-level survey/study to assess their reparability (OPCM 14, 2013);

A ‘functionality level’, out of five (B-C and $E_i$ with $i = 0, 1, 2, 3$) and a corresponding parametric cost of repair/reconstruction (given the total area) is assigned to each school;

Such a ‘functionality level’ is function of a damage state (with four possible damage states) of the structure and a vulnerability level (with three possible vulnerability levels);

Structures classified as B-C or $E_0$ can have a ‘light repair’ while structures classified as $E_1$ or $E_2$ can be repaired and strengthened (up to 60% of current code); structures classified as $E_3$ typically need to be rebuilt.
ReLUIIS + DPC work

![Graph showing the number of schools across functionality levels B-C, E0, E1, E2, E3 with RC and Masonry categories.](image)

*Curtesy of ReLUIIS*
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- **Performance/Recovery of Cultural Heritage Assets**
- (Some) Lessons learned...
Need for safer and resilient CH

- Cultural Heritage (CH) assets are a distinctive feature of many regions worldwide, particularly Italy

- Cultural Heritage (CH) assets include both:
  - single buildings
  - cluster of buildings (historic urban city centres)

- Very vulnerable to natural hazards

- Importance of CH recognized in the Sendai Framework for DRR....
Damage to Cultural Heritage Structures

- San Benedetto (Norcia)

Tower: 1st Mode ~ 0.63 sec
Church: 1st Mode ~ 1.5 sec
The recovery process

• Tagging
• Debris clearance, documentation and storage
• Shoring / Demolition
• Documentation + Monitoring
• Review and definition of new/continued function
• Preliminary design of restoration and strengthening
• Approval process + Funding
• Detailed design
• Construction and modifications of the design on site
• Monitoring

WEEKS

MONTHS

1

2

2 YEARS

TIME

INTEGRITY LOSS
Some conclusions...

- **BRIDGES/ROADS (i.e., accessibility issues)**
  - Masonry bridges suffered the heaviest damage during the 2016 Central Italy Earthquake Sequence, while RC and composite viaducts performed relatively well;
  - The road network in the affected areas was severely affected and disrupted by the damage to bridges/roads and urgent temporary works were needed. Given the specific geographical setting, even small bridges/secondary roads can be vital to the emergency services response;
  - Several, well-coordinated repair/restoration/strengthening projects are ongoing across the affected Regions to increase the seismic resilience of the road network.

- **SCHOOL INFRASTRUCTURE**
  - Overall good performance in terms of damage and functionality, highlighting the importance of retrofitting/strengthening in several cases;
  - Resilience of school infrastructure set as a top priority in the Civil Protection post-emergency agenda (through rapid provision of temporary schools, detailed damage assessment and repair of damaged schools, etc).

- **CULTURAL HERITAGE ASSETS**
  - CH assets experienced significant cumulative damage due to subsequent seismic events;
  - Resilience of CH assets should account for structural authenticity and integrity, structural safety, and compatibility, durability, and reversibility of interventions...
Acknowledgements

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- Silvia and Jay!