Multiscale Analysis of Ballistic Damage in Stone Heritage

Oliver Campbell[1a], Tom Blenkinsop[1], Lisa Mol[2], Charlotte Brassey[3], Owen Green[4], Oscar Gilbert[2]

[1]School of Earth and Ocean Sciences, Cardiff University [2]Department of Geography and Environmental Management, University of the West of England

[3]School of Science and the Environment, Manchester Metropolitan University [4]Department of Earth Sciences, University of Oxford

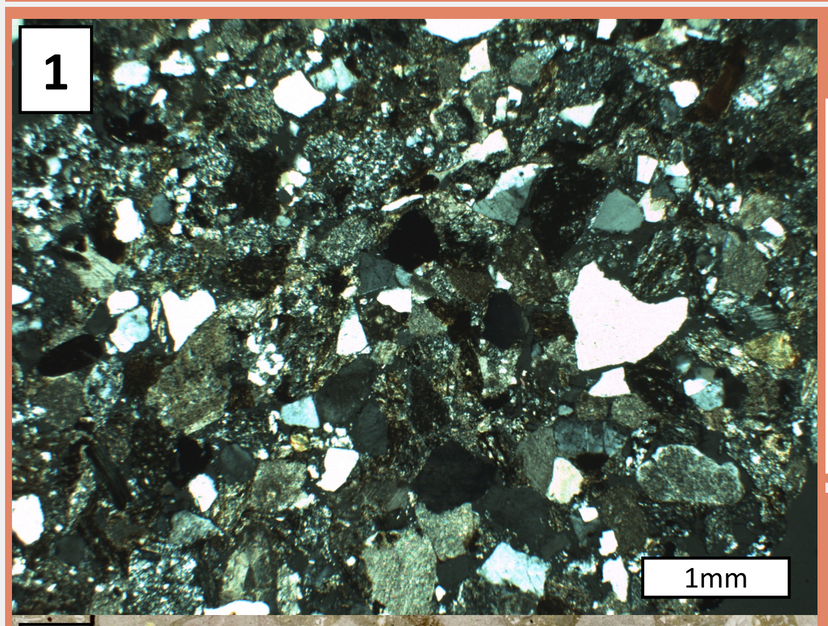
[a]campbellor@cardiff.ac.uk

1. Overview

Headlines of contemporary conflicts are often dominated by the ideologically-driven destruction of cultural heritage, such as the sacking of Mosul and Palmyra by ISIS/Daesh[1]. The impact of ballistics on stone heritage is part of the wider spectrum of imposed damage, which has serious implications for the structural integrity and strength of masonry. Quantifying the extent and severity of internal damage using non-destructive methods is very limited. We will utilise experimental samples to investigate the role of constituent elements in the partitioning and development of impact damage. By also investigating the observable surface damage, and exploring the possibility of numerical models, we hope to generate a comprehensive method of assessing the severity and extent of damage imposed by ballistic impacts in stone heritage.

2. Sample Generation

Blocks of sandstone 15×15×7.5cm, from the Huesca region of NE Spain, were shot with a 7.62×39mm round from an AK-103 assault rifle at a range of 200m. The sandstone was selected for its suitable homogeneity in matrix distribution, minimising the risk of results due to variations within the sandstone[2].



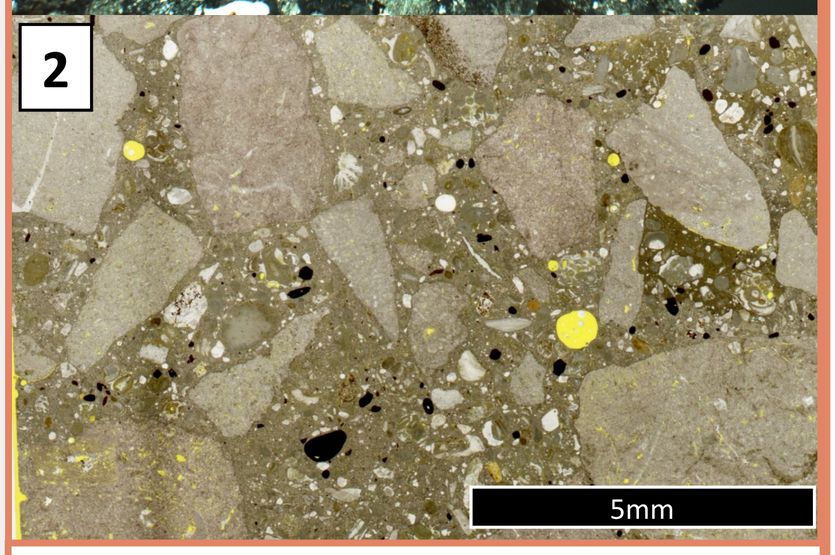


Figure 1: Thin section of a medium grained, well sorted, quartz sandstone under cross polarised light. It is grain supported with interstitial quartz cement

Figure 2: Thin section of concrete composed of coarse and fine, quarried limestone aggregate with traditional Portland cement. This is poorly sorted and cement supported[4].

3. Role of Material Properties

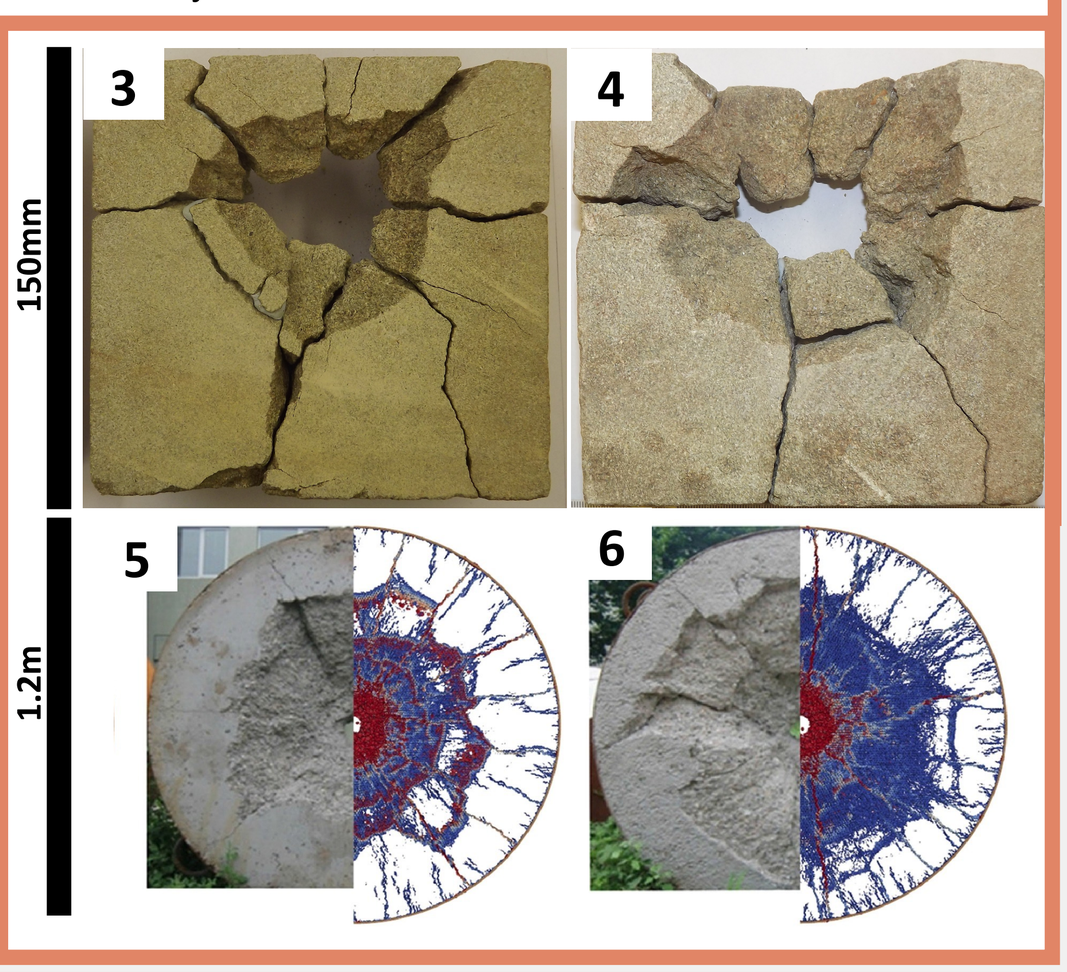
- The most common natural building stones used in built heritage are **sandstone**, **limestone** and **dolomite**. These are comprised of framework grains, pore spaces and a binding cement (Fig.1). The basis for **concrete** is the same, composed of an aggregate (the framework), a binding cement and a proportion of void/pore spaces (Fig. 2).
- The material properties of individual components will vary, impacting the overall bulk properties of the stone or concrete. Aggregate particles in concrete can be up to 4x as strong as the surrounding cement[3].

4. Concrete Comparisons

- Our samples show a resemblance to studies focussing on the resistance of concrete to ballistic impacts (Fig. 3-6).
- Radial fractures originate from the impact site and concentric fractures bound the crater. These features are visible in both entry and exit craters from both our experiment and those seen in figure 5 and 6[5].
- Numerical modelling of impacts may provide comparable data supplementing observations and allowing for a cost effective way of studying more variables.

Figure 3-4: Entry and exit craters respectively from our sandstone experiment.

Figure 5-6: Front and rear damage comparisons (respectively) of experimental observations and Lattice Discrete particles Model (LDPM) simulations. Note radial fractures originating at impact site and concentric fractures defining crater edges[5].



5. Fracture analysis

- Our goal is to characterise the internal fracture networks through a combination of X-ray tomography and petrographic sections.
- The study of fracture surfaces will inform on dynamic fracture processes and the partitioning of fractures between constituent parts.

6. Final Remarks

- Through comprehensive and multiscale methods we hope to quantify damage imposed on natural building stone by ballistic impacts.
- We welcome any collaboration and suggestions of new or developing methods that may support this.

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References

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