

# Reduced-scale testing of historical monuments under explosions: application to the Parthenon

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# Modern and historical structures under explosions



Beirut 2020



<https://news.sky.com/story/beirut-explosion-rescuers-search-for-survivors-after-deadly-ammonium-nitrate-blast-12042827>

Parthenon 1687

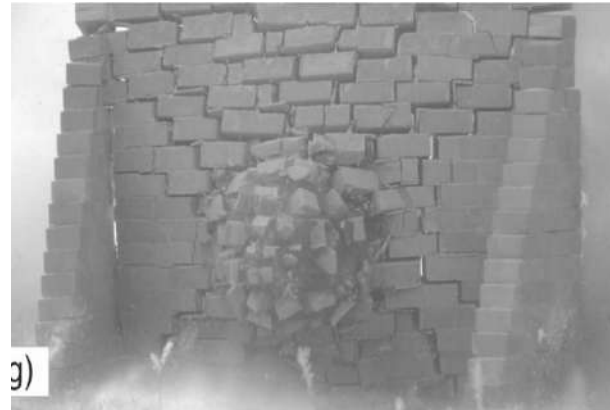


Emmanouil Korres

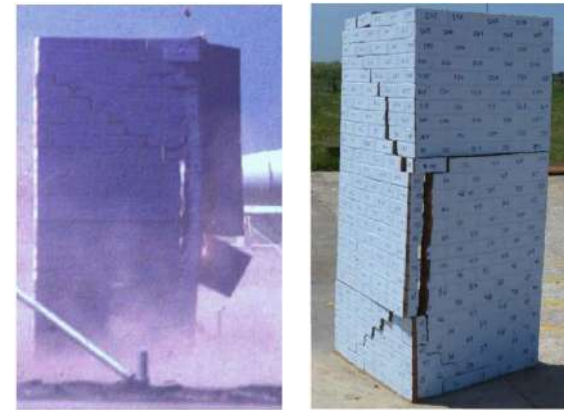


## Full scale:

The experiments are **not repeatable**, **expensive**, and **laborious** (Pereira et al. 2014, Ahmad et al. 2014, Li et al. 2017, Godio et al. 2021, ....).



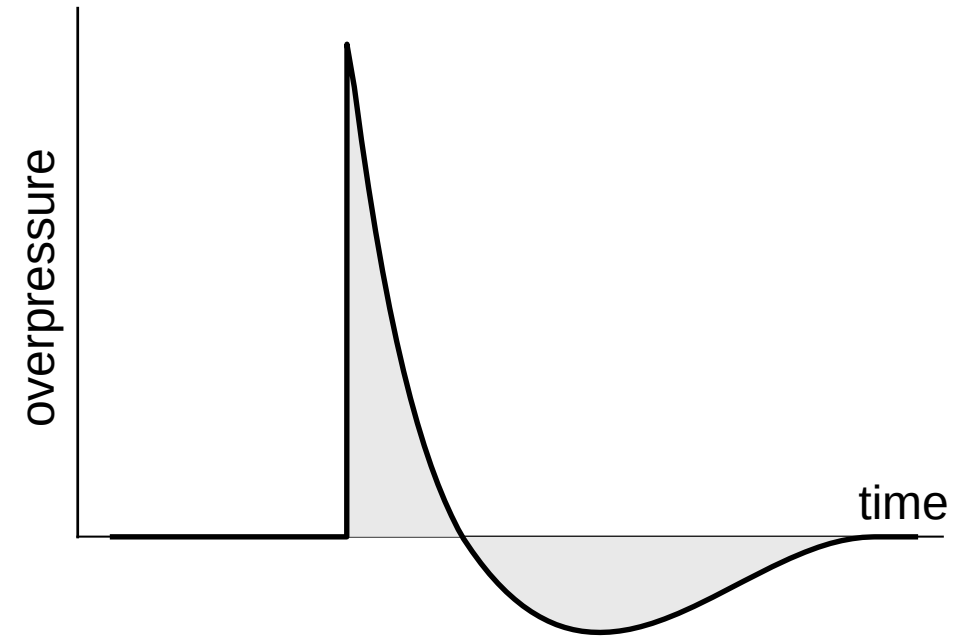
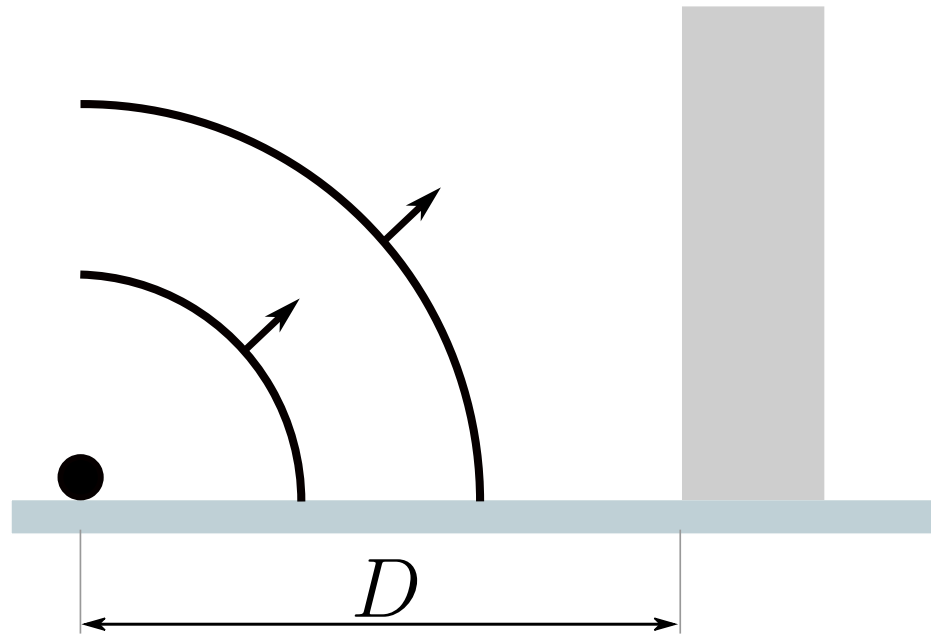
Sielicki et al. 2019



Keys et Clubley 2017

## Reduced scale:

The experiments are focused on studying **shock wave propagation** (Zyskowski et al. 2004, Pennetier et al. 2015, Trelat et al. 2011, Sochet, et al. 2019, ....).



# Scaling laws for reduced-scale testing



## Scaling laws (Masi et al. 2021)

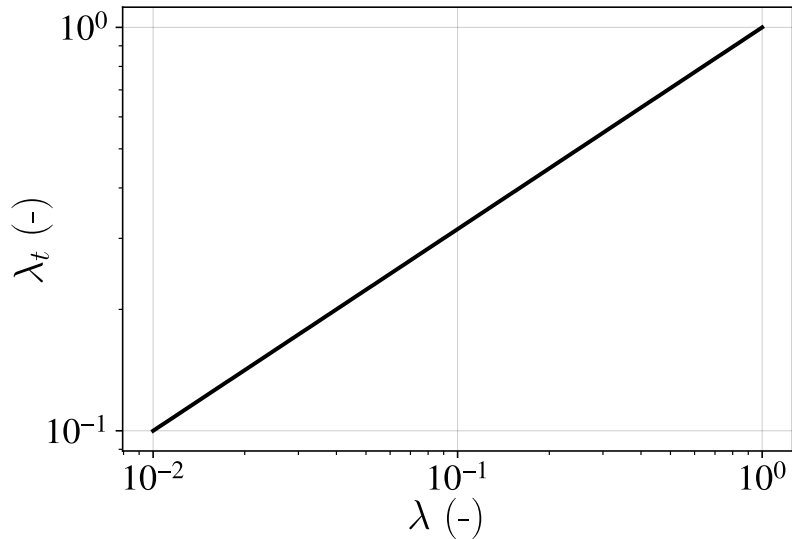
- scaling ratios:

geometric scale factor:  $\lambda = \frac{\tilde{l}}{l}$       density scale factor:  $\gamma = \frac{\tilde{\rho}}{\rho}$        $\frac{\tilde{f}}{f}$  model/prototype

$l, \rho$  Length and density

- scaling factors for the rigid-body response

$$\lambda_t = \lambda^{1/2}$$



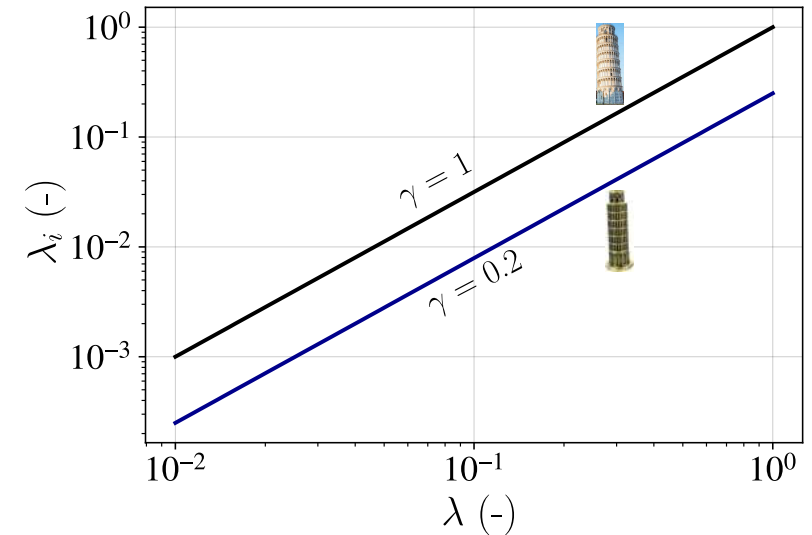
prototype

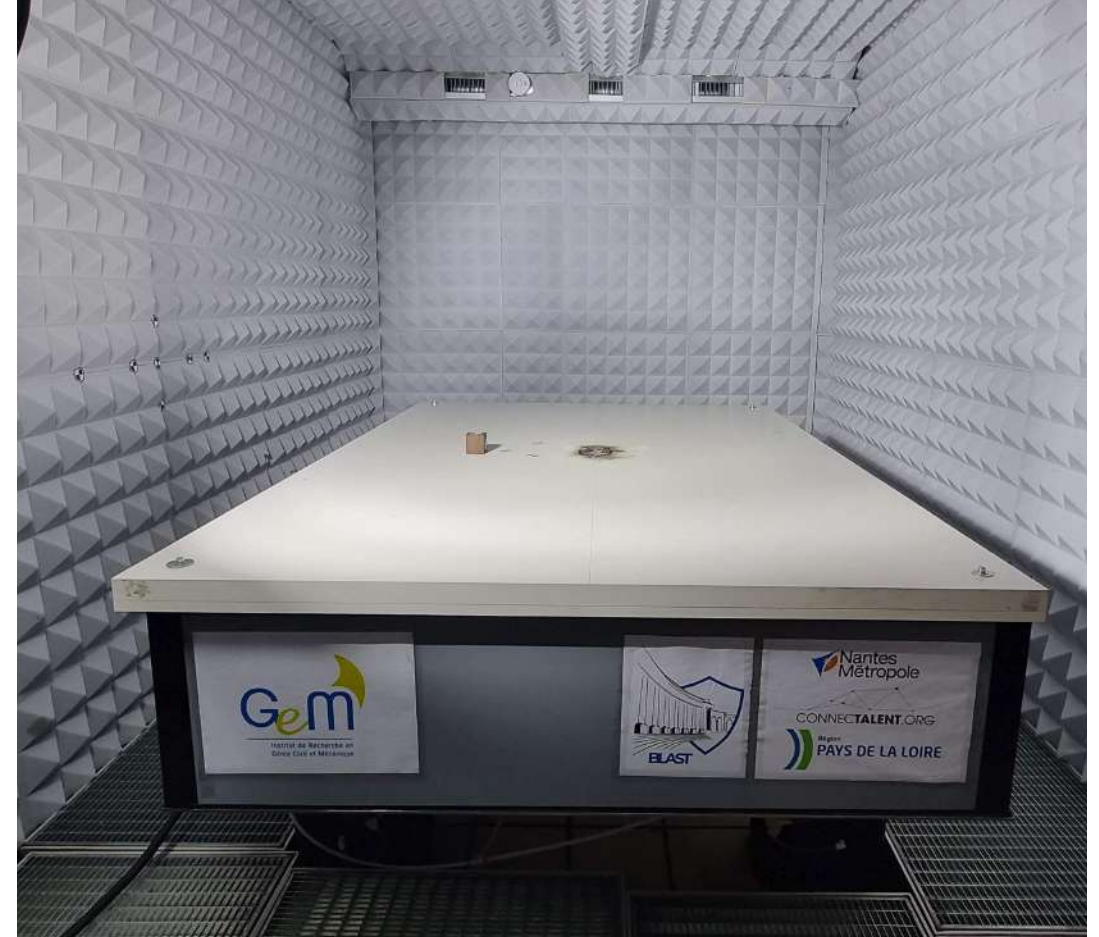
$$\lambda = \frac{1}{100}$$



model

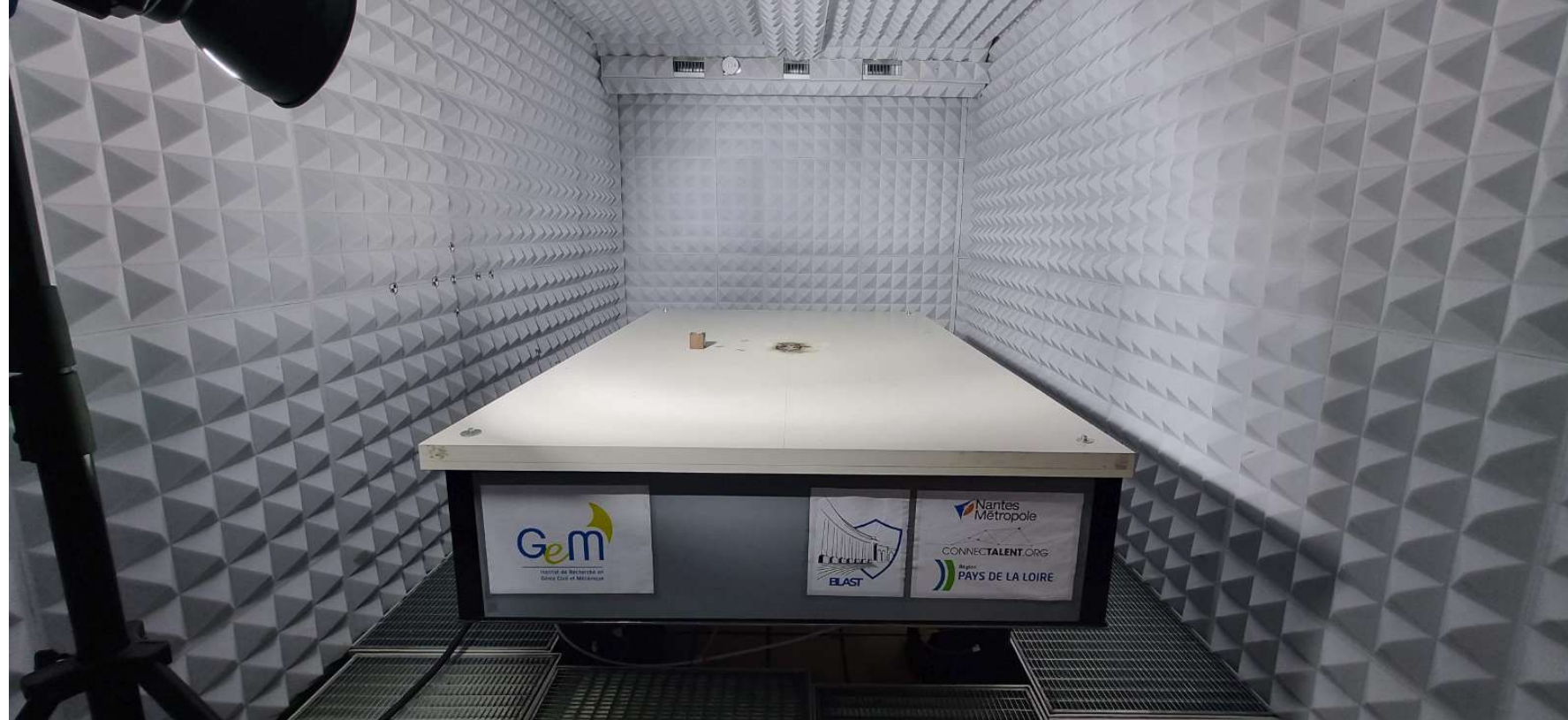
$$\lambda_i = \gamma \lambda^{3/2}$$



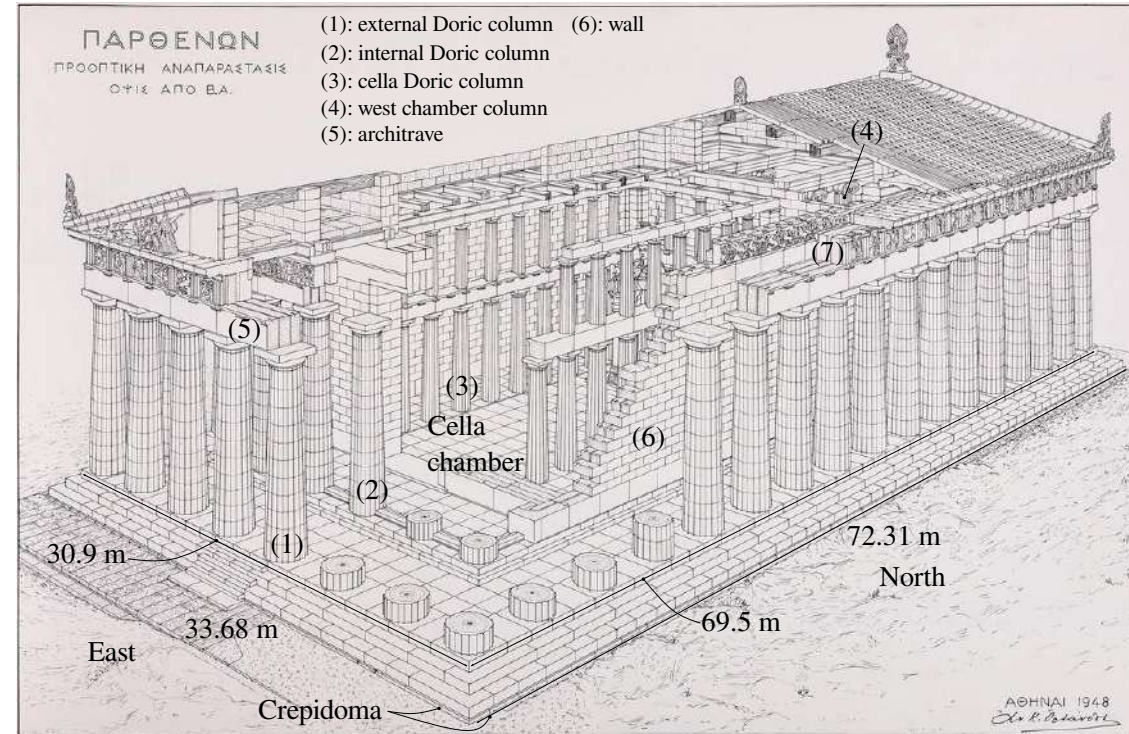
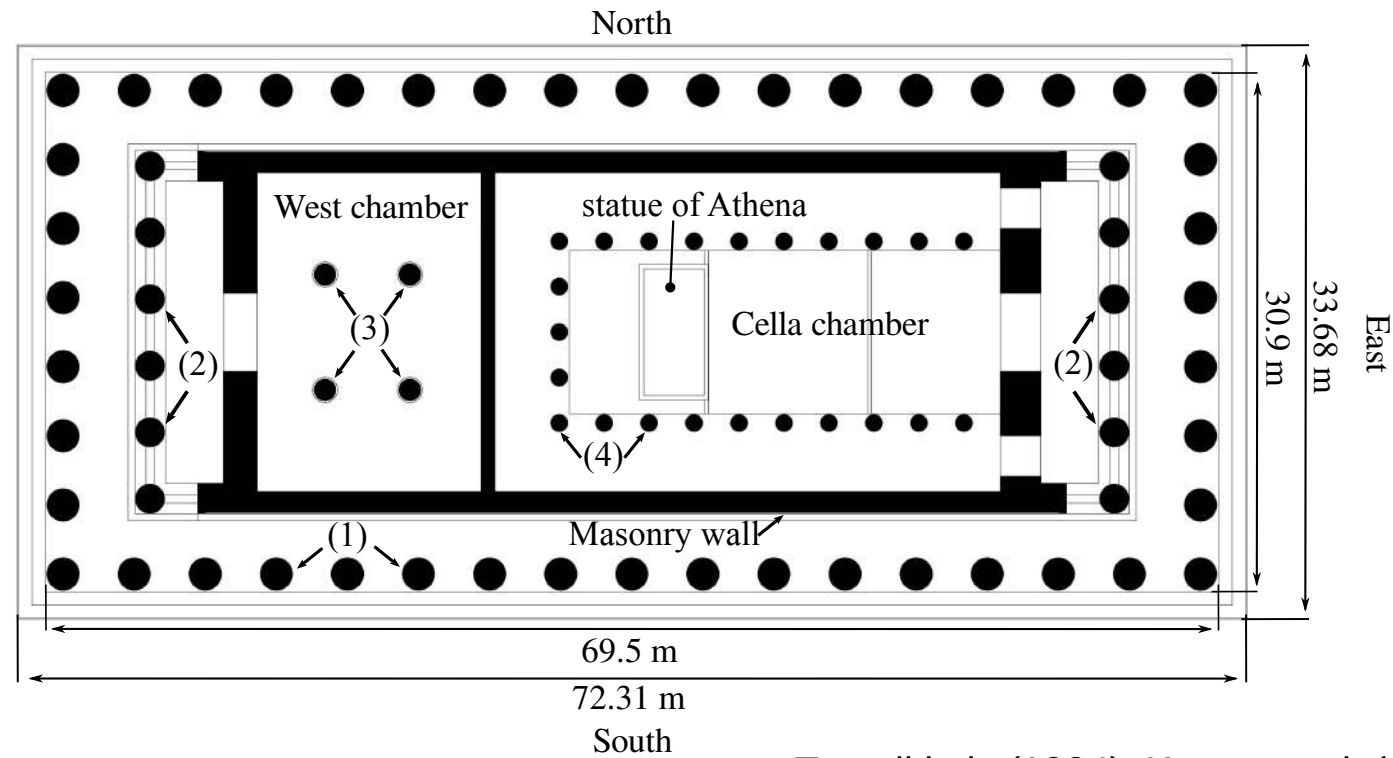




- Explosive source and its components
- Metrology
- Structure prototyping and optical table
- Safety



# Reduced scale modeling of the Parthenon

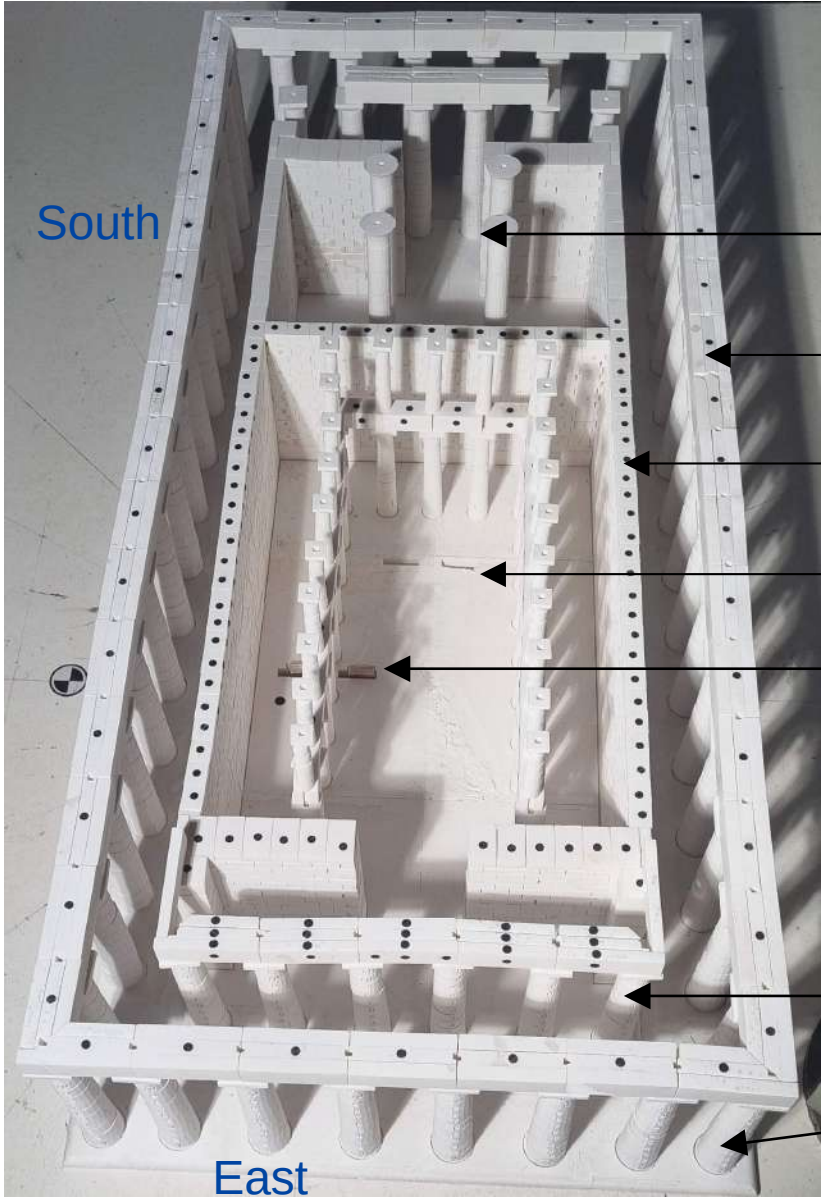


Tournikiotis (1994), Korres et al. (1999), Zambas (1994)

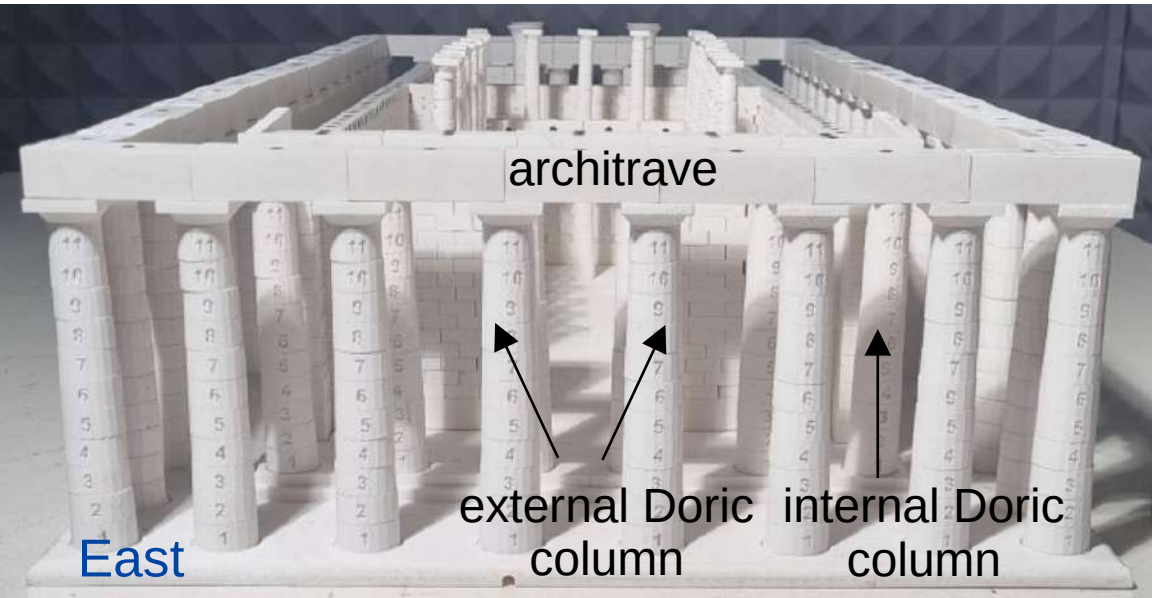
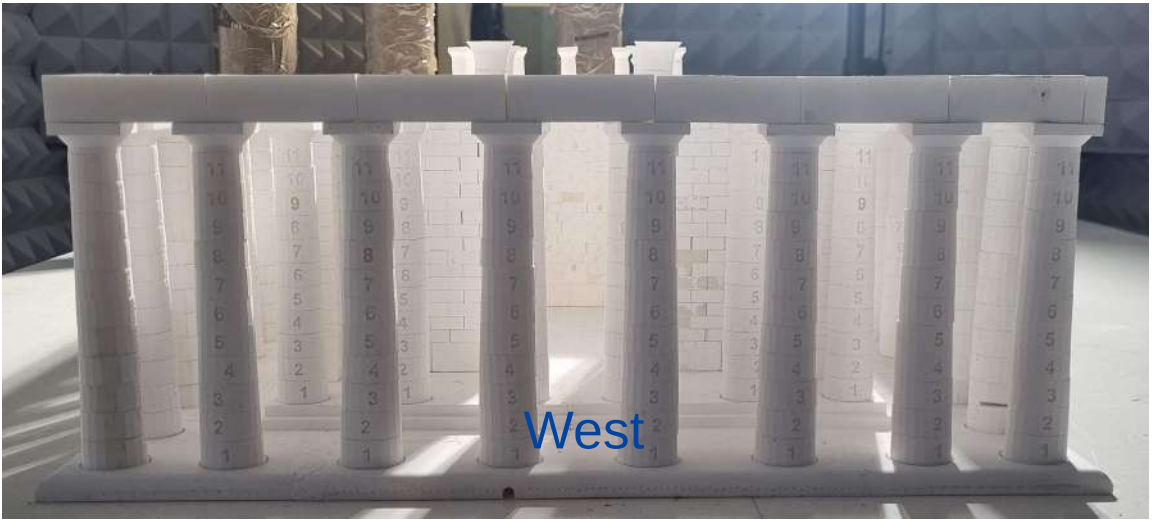
**3D printed with:**  $\lambda = 1/70$  and  $\gamma = 0.667$



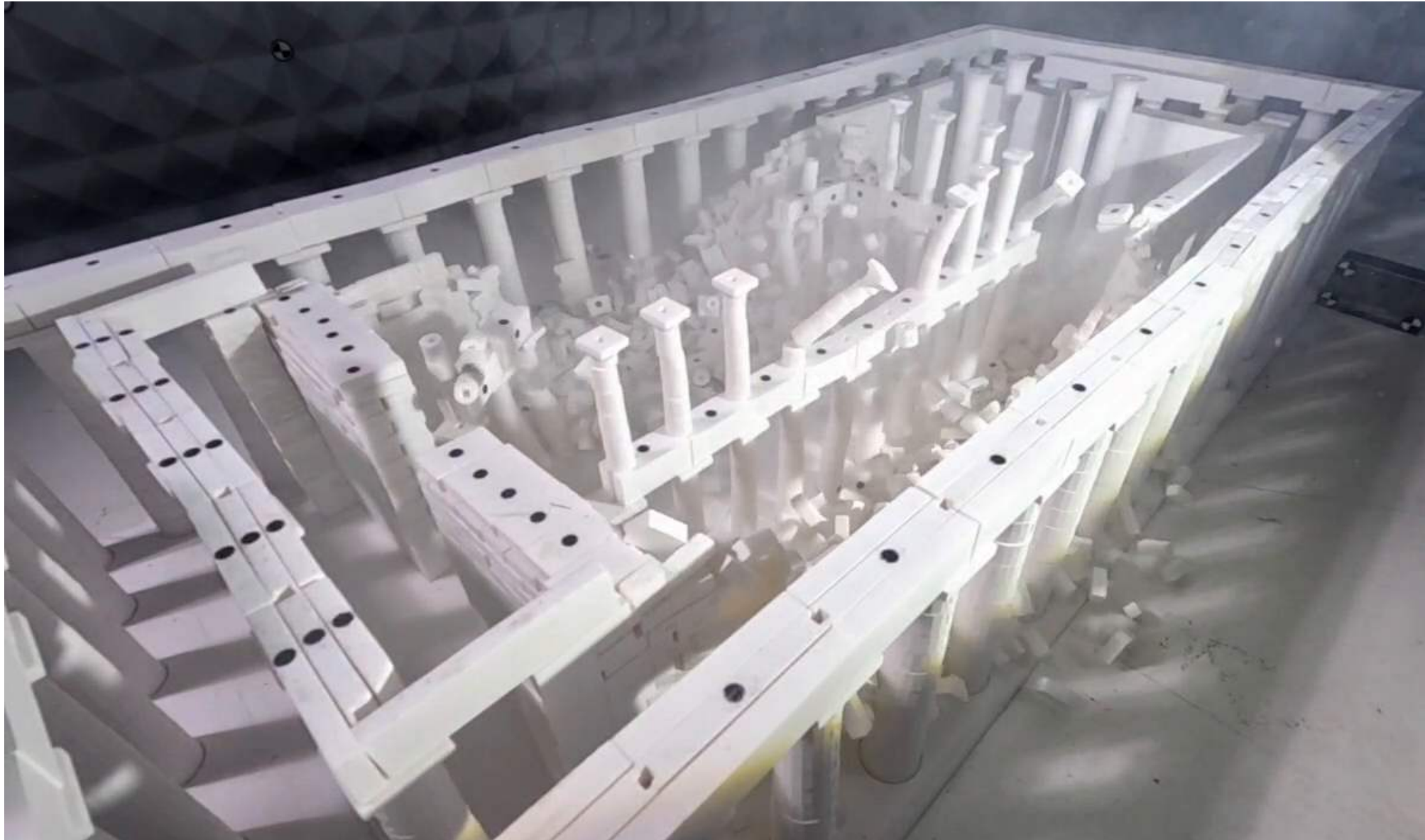
# Parthenon at reduced scale



- West chamber
- architrave
- wall
- Cella chamber
- explosion location
- internal Doric column
- external Doric column

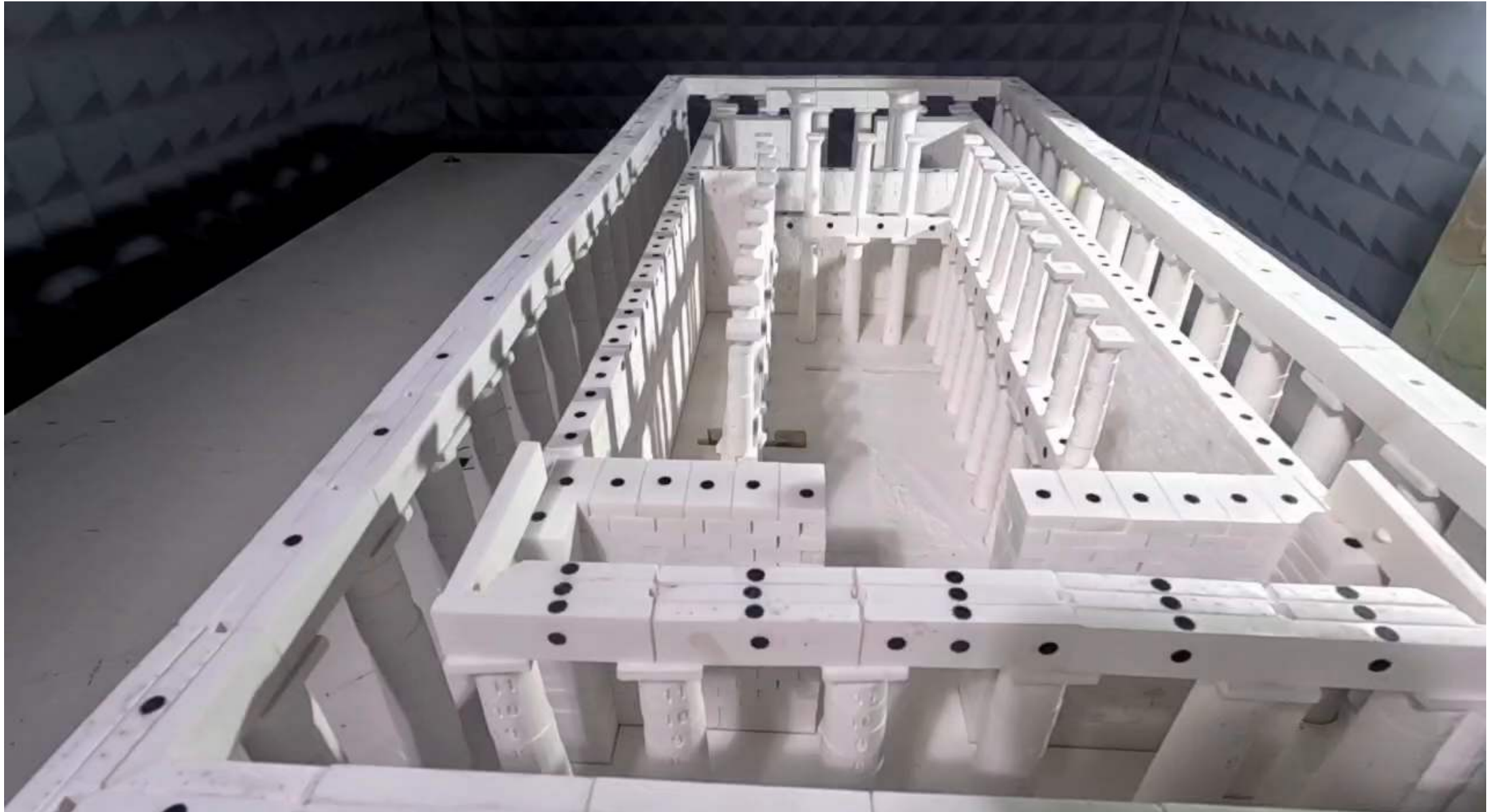


# Parthenon's explosion (C1 - speed 1/8 normal)



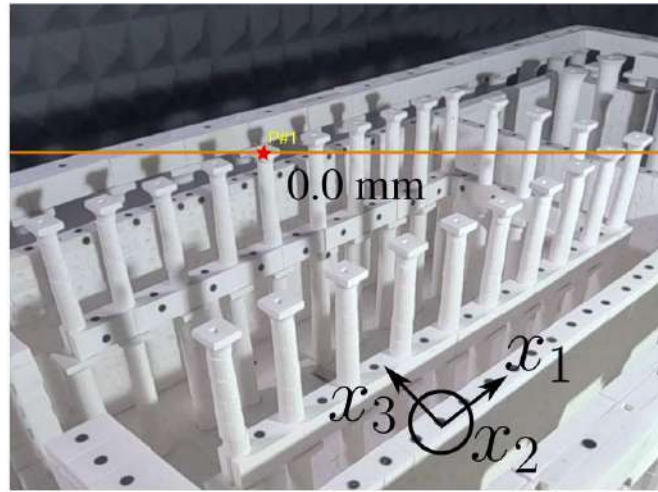


# Parthenon's explosion (C3 - speed 1/8 normal)

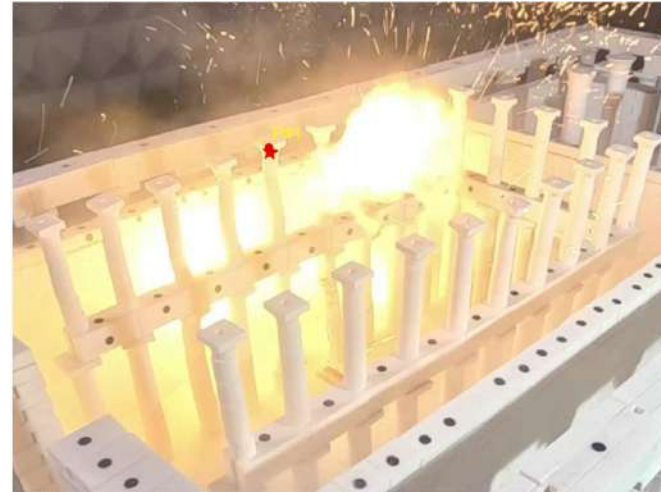




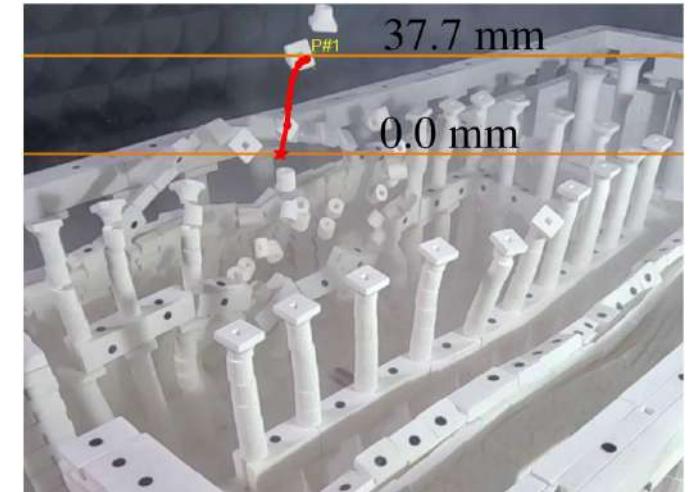
# Tracking



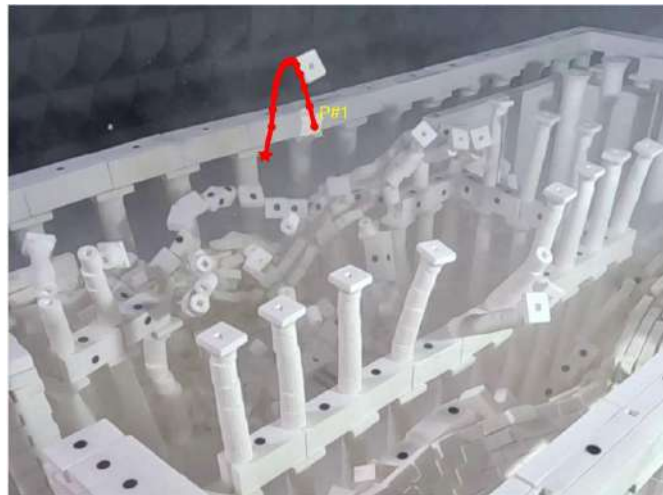
$t = 0.0$  s



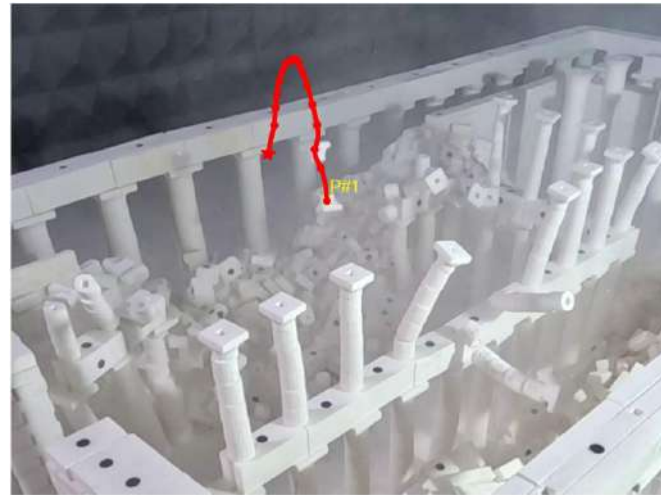
$t = 12.5$  ms



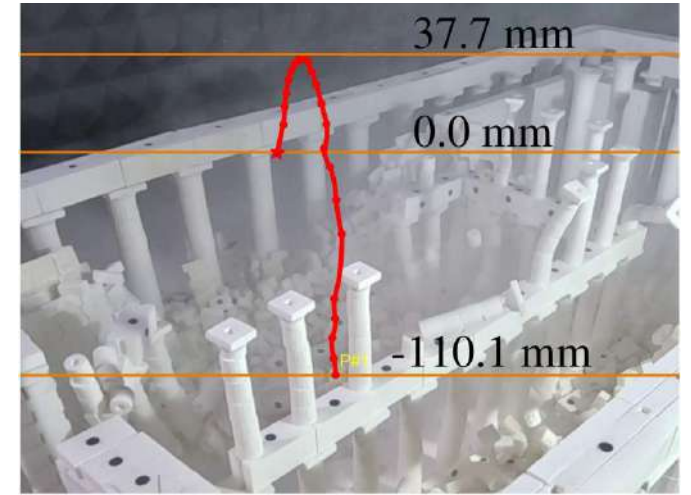
$t = 116.6$  ms



$t = 200.0$  ms



$t = 250.0$  ms



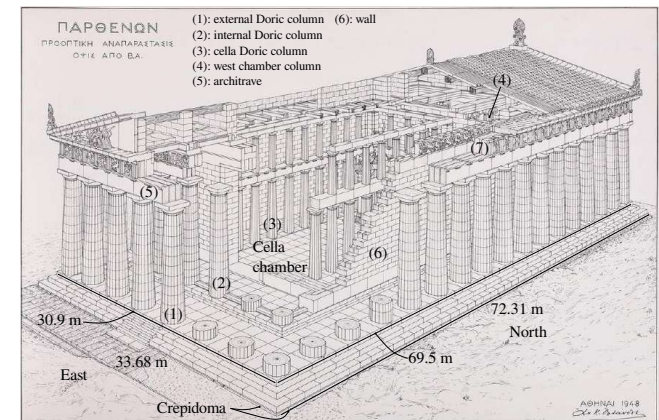
$t = 350.0$  ms

## Main findings (see A. Morsel's PhD thesis for more details)

1. **Novel experimental platform** (miniBLAST) designed and installed
  - **methodology** adopted and reasoning behind the design and installation
  - **safety and metrology**
2. Explosive source analysis
  - **exploding wire mechanism** and study of the **current and voltage evolution**
  - **pressure distribution** measurements and **shock wave sphericity**
  - **TNT equivalency**
3. Study the **dynamic response of structures**
  - first experimental test of the **scaling laws**
  - study the **Parthenon** of Athens at **reduced scale**

## Continue the study of the explosion of Parthenon

- improve the model
- answer to open questions of what happened in 1687....







**Acknowledgments:  
Guillaume Racineux  
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