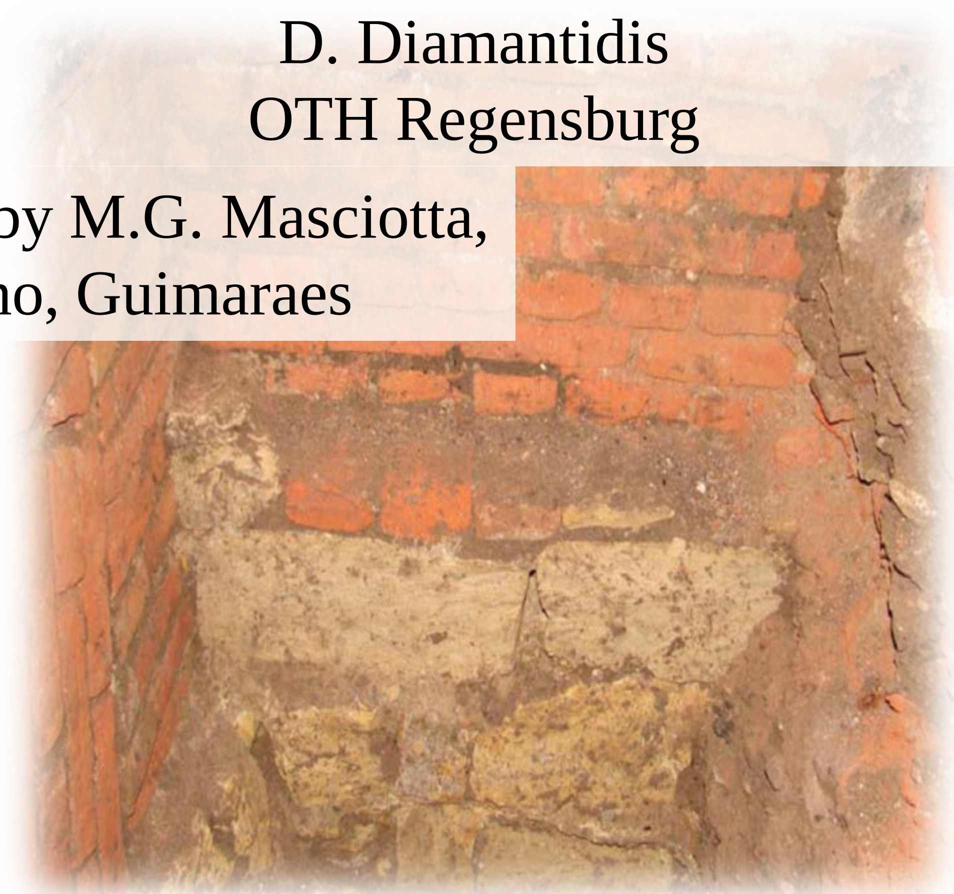
Optimising in-situ testing for historic masonry structures - proposal for a simplified study

M. Sykora & J. Markova
CTU in Prague

D. Diamantidis
OTH Regensburg

with comments by M.G. Masciotta,
Univ. Minho, Guimaraes



General overview

• Masonry construction - long history, scatter of properties (age, region-specific constituents, manufacturing)
→ crucial to obtain case-specific information

• The key material property – **compressive masonry strength**

• For heritage structures, non- or minor-destructive tests (NDTs, MDTs) commonly applied along with a few DTs
uncertainty of spot monitoring?

• “In some cases, destructive tests may be necessary to calibrate NDT” - ISO 13822

Asset information

- ***No information*** or previous measurements related to material properties (guidance for both cases should be provided) – ***at least NDTs needed***
- Hygrometric and salt content information (typically less informative) may be available
- As built information may be available (geometry, construction phases, structural system)
- Demands: permanent loads, imposed and environmental loads
- Codes: Eurocodes, ISO 13822

Structural performance

- Limit state function based on the ***compressive masonry strength*** ***f***
  - Compression with small eccentricity; large eccentricity or horizontal forces – deformation characteristics and tensile strength derived from ***f***
  - Standards - EC6, ISO 13822, DIN 1053
  - R(***f***, b,..) – E(**G**, Q,..) = 0

- The compressive strength of masonry depends on the compressive strength of ***mortar*** and of ***masonry units*** (stone, bricks)

Optimisation of monitoring strategy - ideas

1. Quantification of uncertainties in NDTs validated by several DTs (n_{DT} = 0..~10) for homogeneous material
2. Consideration of measurement uncertainty in reliability analyses of masonry members exposed to imposed and climatic actions (no seismic actions)
3. Simplified optimisation - reliability to comply with a target level β_t given in standards (next slide)
4. A detailed, full risk pre-posterior analysis could later improve the results of the preliminary optimisation.
   Failure consequences over a reference period (both inputs difficult to assess)

Current status

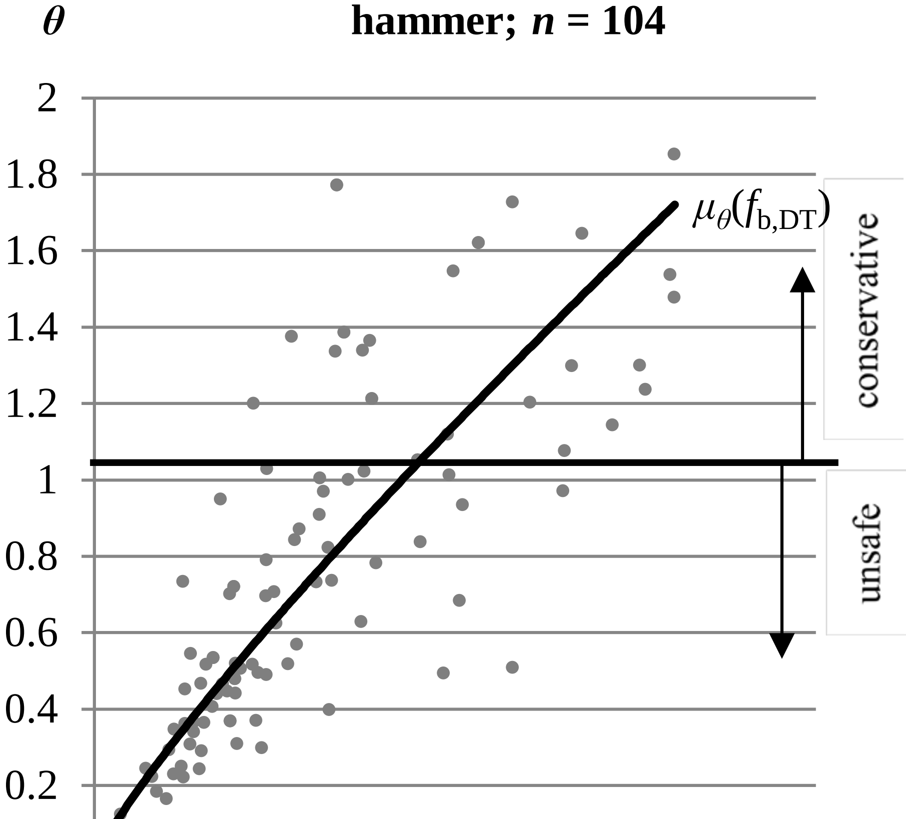
- Database of 14 historic stone and brick masonry structures from the 17th to the 20th century
- Schmidt hammer and modified drill tests verified by DTs of masonry units

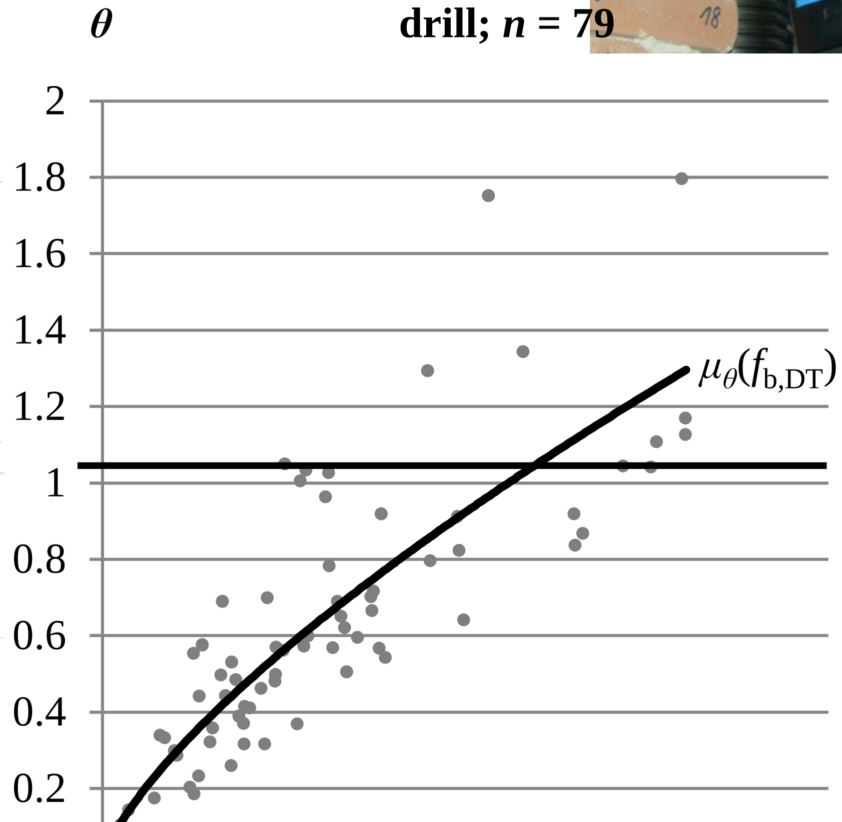
Table 1: Basic information about the experimental database for strength of masonry units.

No.	Use of building	Built in	Masonry units	Number of measurements		
				DT	Schmidt*	drill*
1	vicarage	17th	sandstone	3	3	3
2	church**	17th	sandstone	11	11	11
			bricks	6	6	6
			pudding stone	1	1	1
3	printing works***	1930s	bricks	18	18	17
4	residential	end of 19th	bricks	4	4	4
5	offices, storage	1890	bricks	6	6	3
6	monastery, barrack	1638	bricks	11	10	8
			marlstone	3	3	3
7	offices, archive	early 20th	bricks	4	4	2
			marlstone	2	2	0
8	textile mill	second half of 19th	bricks	6	6	4
9	boiler house	1959	bricks	4	4	1
			unspecified stone	1	1	1
10	water mill	1930	bricks	4	4	4
			unspecified stone	1	1	0
11	residential	1867	bricks	6	6	3
			granite	1	1	0
12	engineering works	1870	bricks	5	5	5
13	residential	1890	bricks	2	2	0
			marlstone	1	1	0
14	residential	1871	bricks	6	6	0

Test uncertainty

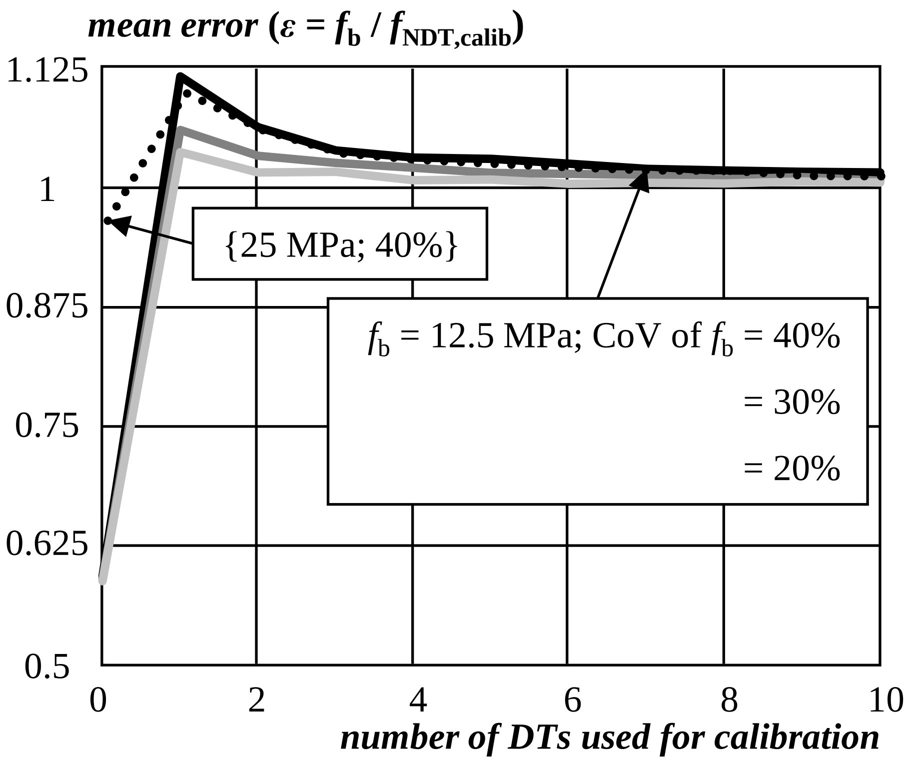
$$\theta = f_{b,DT} / f_{b,NDT}$$

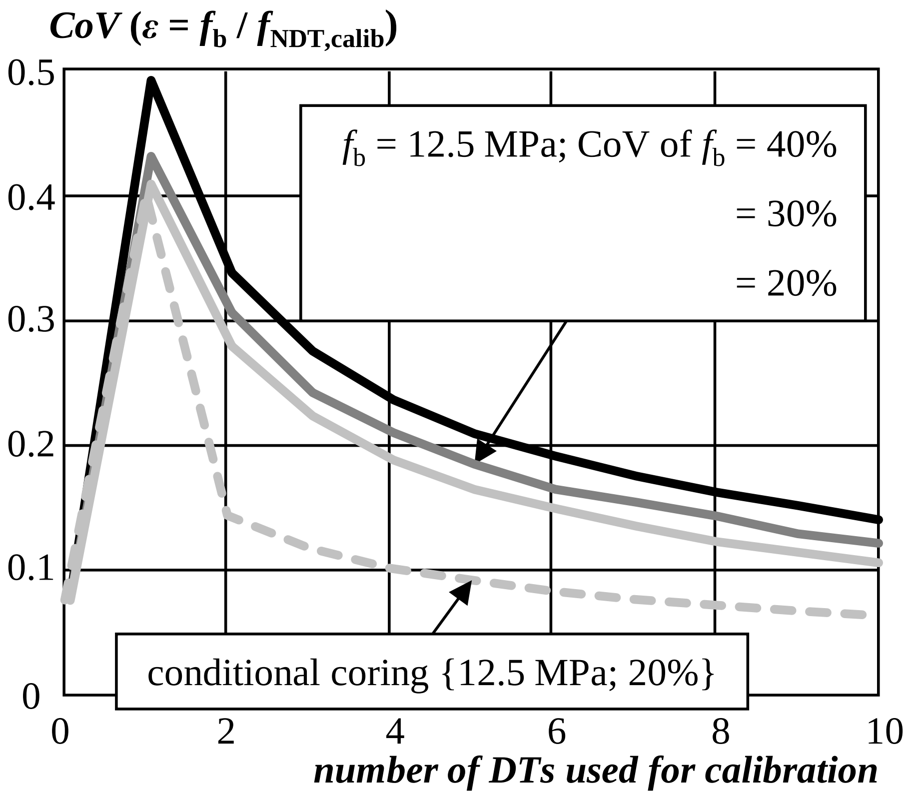




- Both methods poorly calibrated – doubtful to use only NDTs for assessment.
- Outlying observations removed
  DT strengths above 40 MPa beyond NDT calibration curves
  NDT leading to unrealistic zero values (local damage)

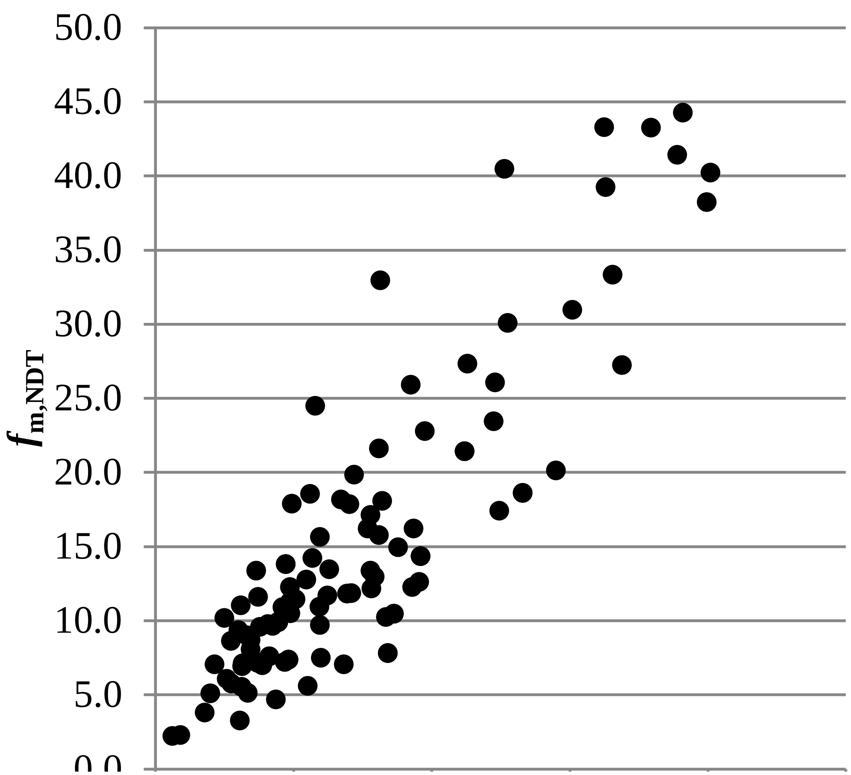
Uncertainty in mean strength estimate – hammer

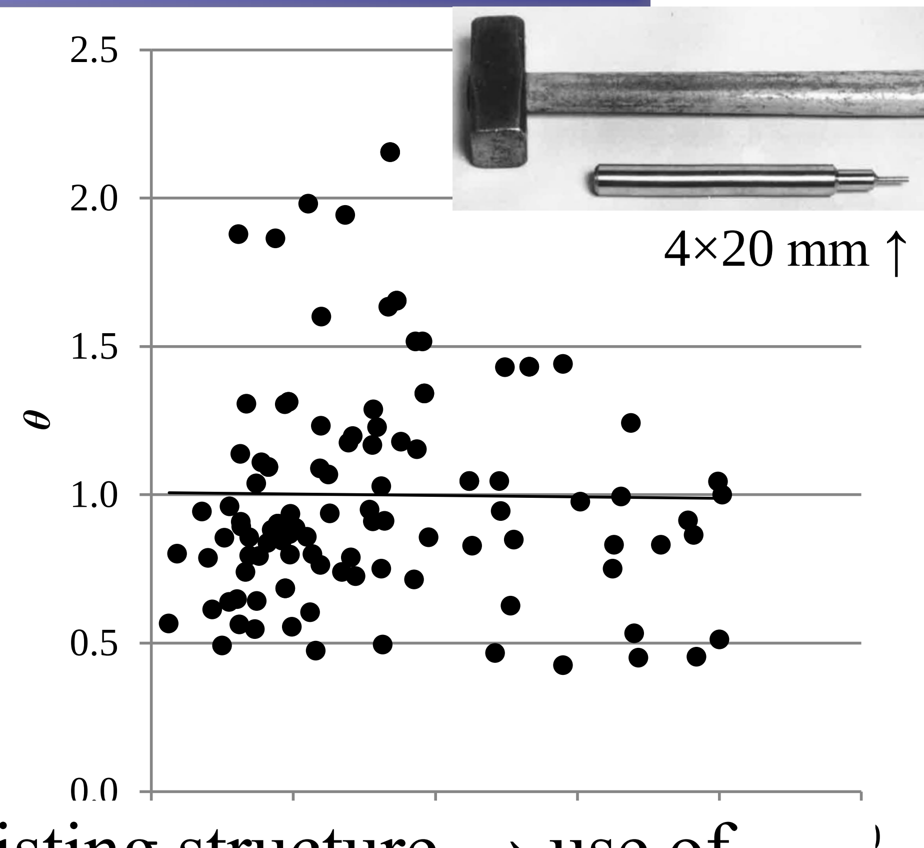




- ε-characteristics independent of mean and CoV of f_b (in ranges of practical relevance)
- Similar results for the drill

Uncertainty in mean strength estimate – mortar

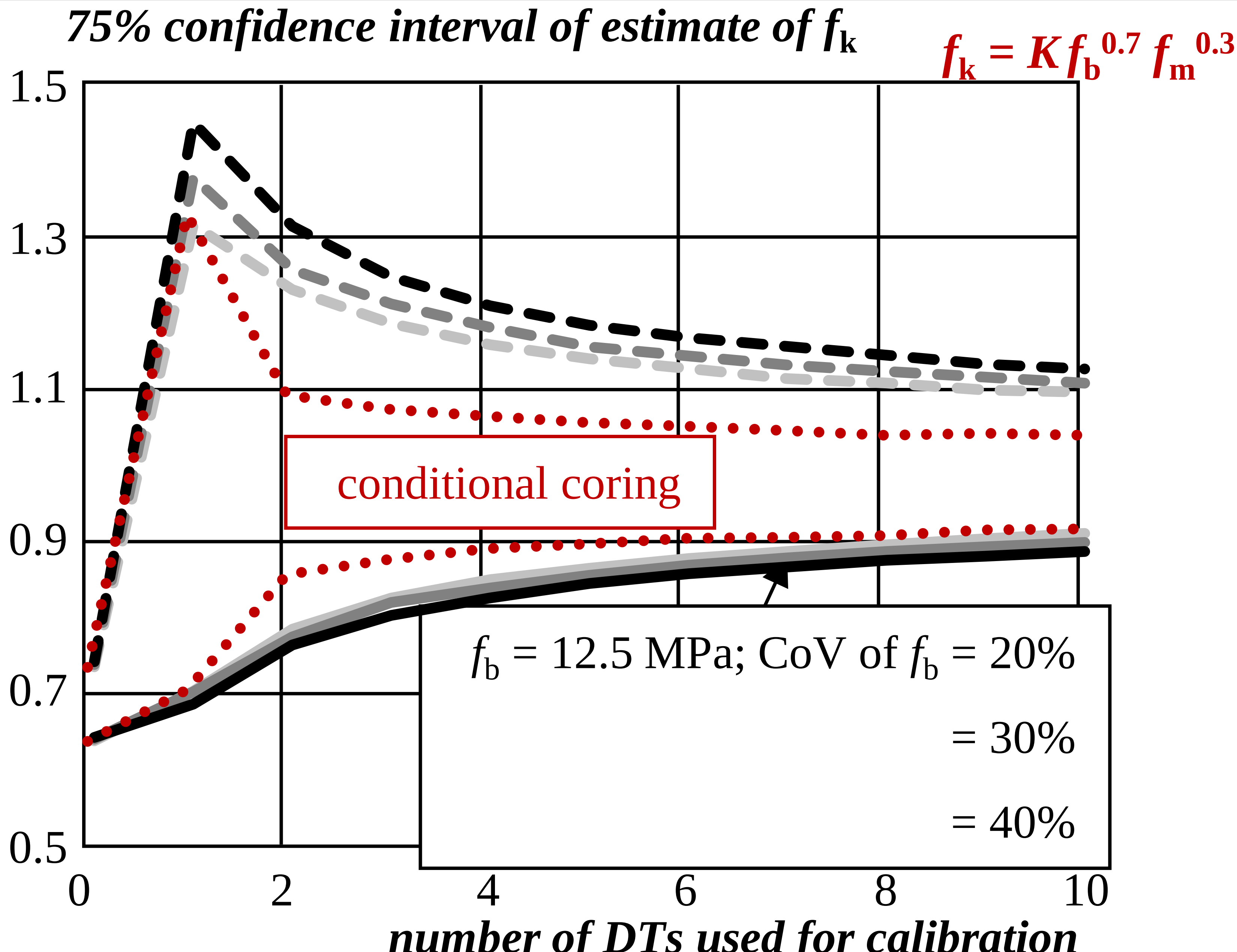




4×20 mm ↑

- No DTs available for an existing structure → use of database for calibration
- Simulations:
  - representative strength f_m = 1 MPa, CoV = 20/30/40%
  - n_{NDT} = 5..30
- Error in mean estimate: $\varepsilon = f_m / [\eta \times \mathrm{mean}(ndt_i)]$

Uncertainty in characteristic masonry strength – hammer



VoI flow chart

Abbreviations
DT destructive test
NDT non-destructive test
ULS ultimate limit state

Remedial actions

- If code requirements are NOT fulfilled, the structure is strengthened (short or long-term perspective)

Indicators

- Compressive strength of masonry units (NDT, DT) and mortar (NDT)
- *Crack widths, deformations; natural frequencies*

Knowledge on decision context

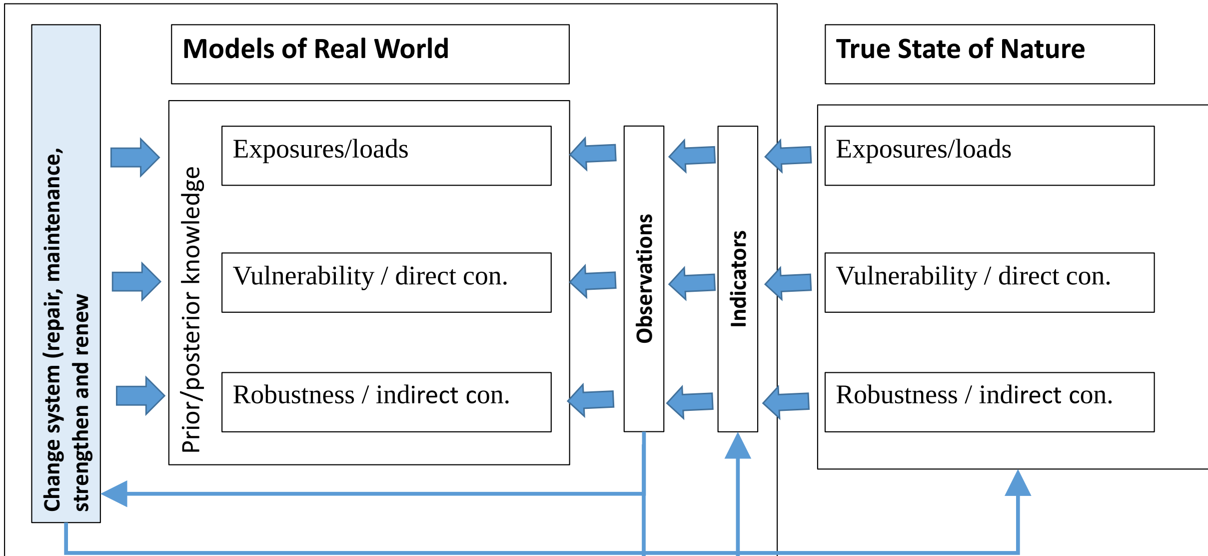
- Decision maker: national authorities for heritage structures in most cases, often church or private owners and municipality
- Constraints: budget, code requirements (Eurocodes, ISO)

Asset information

- No information or previous measurements related to material properties (guidance for both cases should be provided)
- Hygrometric and salt content information may be available
- As built information may be available (geometry, construction phases, structural system)
- Demands: permanent loads, imposed and environmental loads
- Codes: Eurocodes, ISO 13822

Objectives

- Minimizing cost and optimise number of destructive tests to preserve a cultural heritage value



Collect Information

- NDT and DT
- Visual inspection
- Additional detailed measurements: static and/ or dynamic monitoring

Optimization

Objective function(s) based on performance:
- Cost of tests (n number of DTs) and cost of strengthening (n) to be minimized
- For full probabilistic optimisation, failure consequences over reference period are needed (lower bound estimates - insurance, inverse cost optimisation for accepted target level, structural costs to repair or re-build)

Performance

Structural reliability ULS

VoI analysis implementation

1. ***NDTs*** are ***necessary***.

2. Focus on ***one example***.

3. Make assumptions for C_{test}(DT) and C_f → How to estimate ***failure consequences***? For which ***reference period***?
   Lower bound estimates - insurance, structural costs of replicas, inverse cost optimisation corresponding to accepted target reliability

4. ‚No action' alternative: reliability analysis based on ***NDTs*** – LSF: $K\, \boldsymbol{f_b^{0.7}}\, f_m^{0.3}$ geo - E

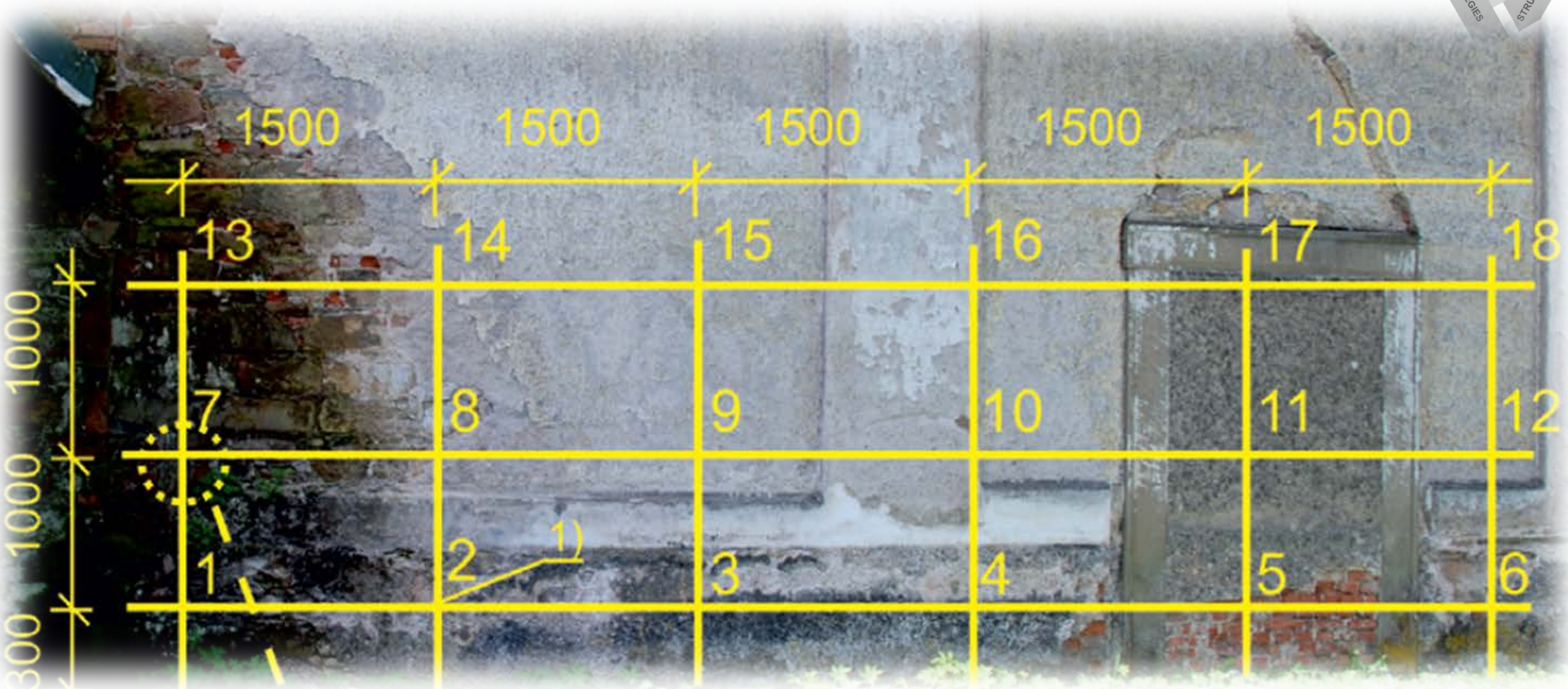
5. ***Optimisation*** of n_{DT}: $K\, \boldsymbol{f_b(n_{DT})^{0.7}}\, f_m^{0.3}$ geo – E
   $C_{tot} = C_{test}(\mathrm{DT}) + C_f\, P_f(\text{ref period})$

CASE STUDY BRIEF

1. It is essential to obtain case-specific information on historic masonry properties.

2. Crude estimates obtained by non-destructive tests NDT can be improved by calibration using DTs.

3. The calibration by two-three DTs significantly improve structural reliability estimates.



Thank you for your attention.