CTU in Prague
Faculty of Civil Engineering
Department of Building Structures

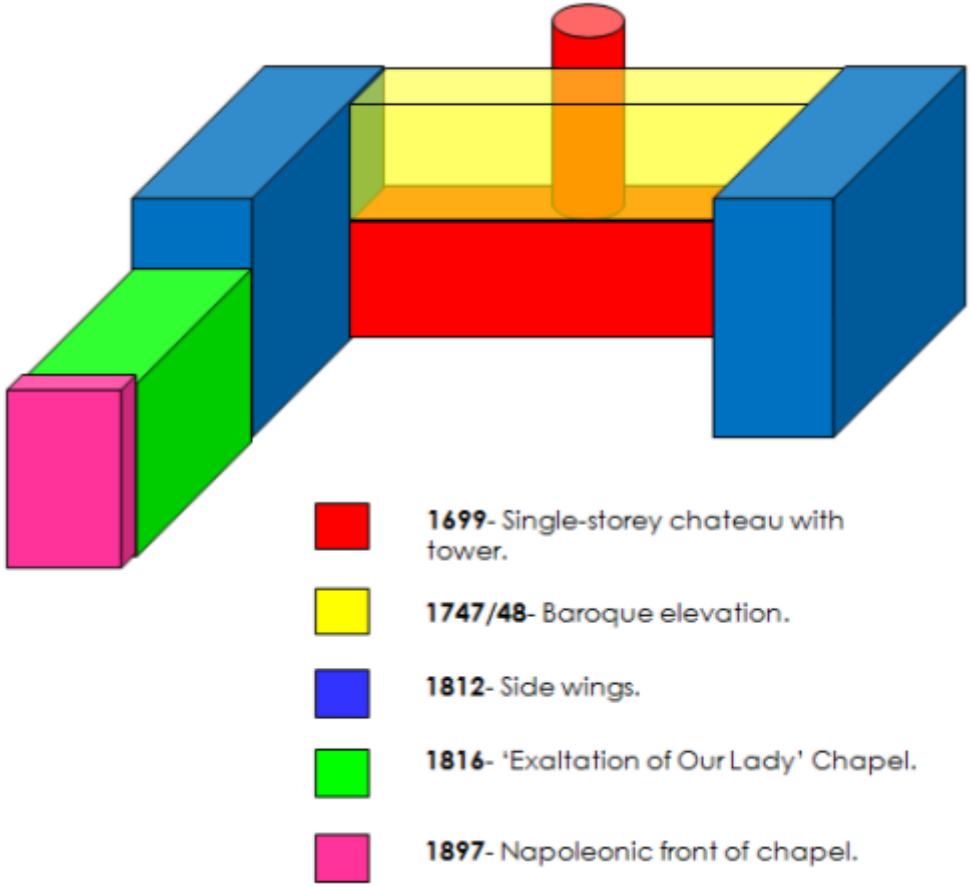
Restoration of load-bearing structures

Buštěhrad

Presentation was created with the kind support of Ministry of Education Grant FRVŠ 2960/2011.

History of the object

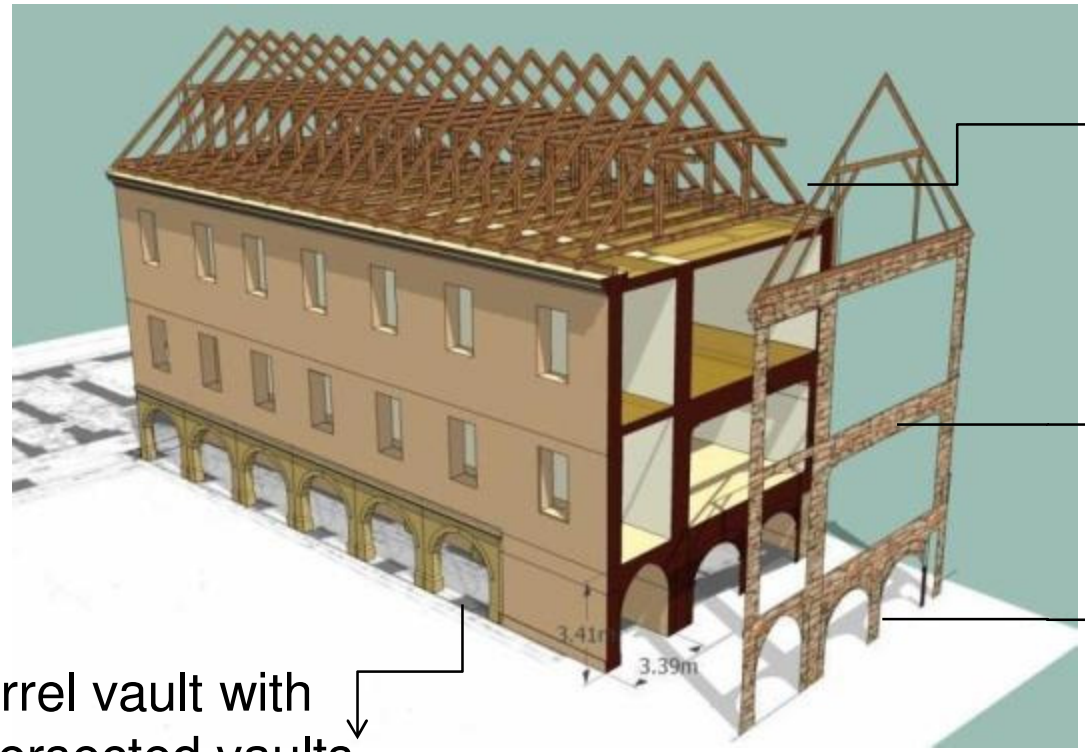
- different parts of the castle by the time construction



Description of the object

- Bustehrad castle in the Kladno surroundings
- look of the facade of the castle

Description of the object

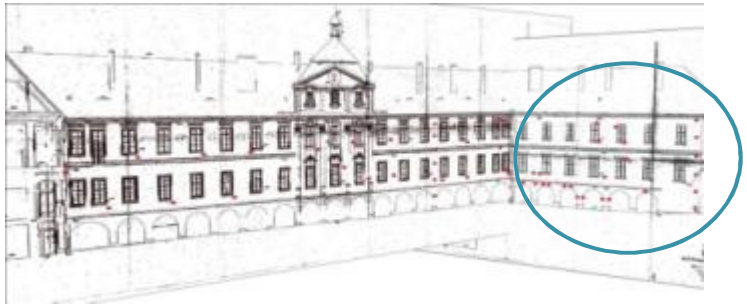


timber truss roof

wooden floors

intersected
cross vaults

barrel vault with
intersected vaults

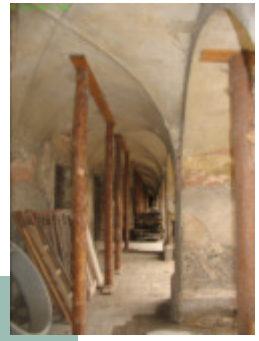


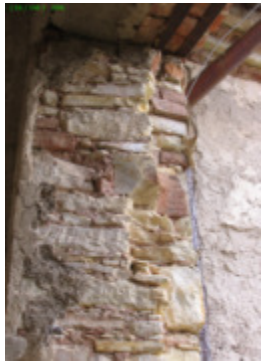
Description of the object

- analysis of the structure

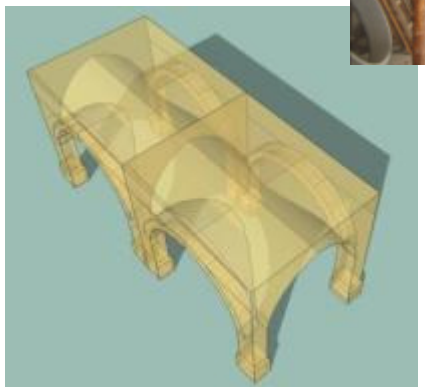
timber
roof
2 kN/m2

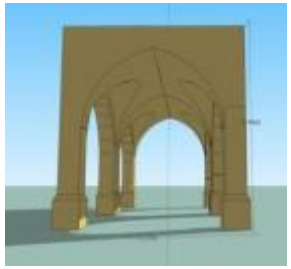
timber floors
1 kN/m2





stone
26 kN/m2





brick
18 kN/m2

Description of the defects

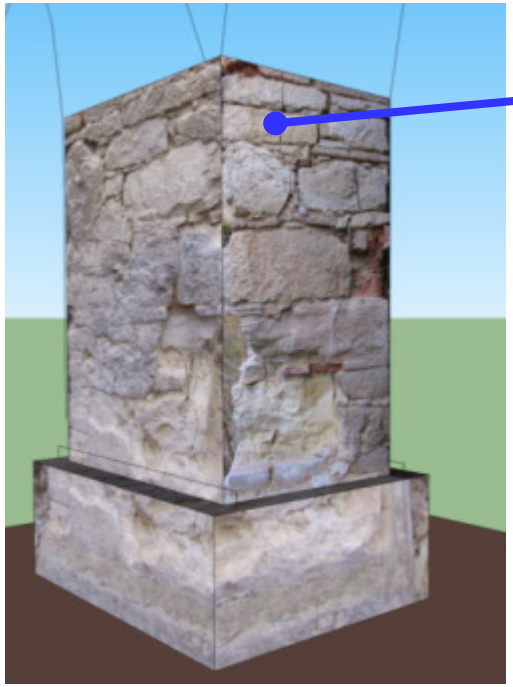
- structural demages
  - arch failure mechanism
  - scaling and spalling
  - diagonal cracs
  - efflorescence

Description of the defects

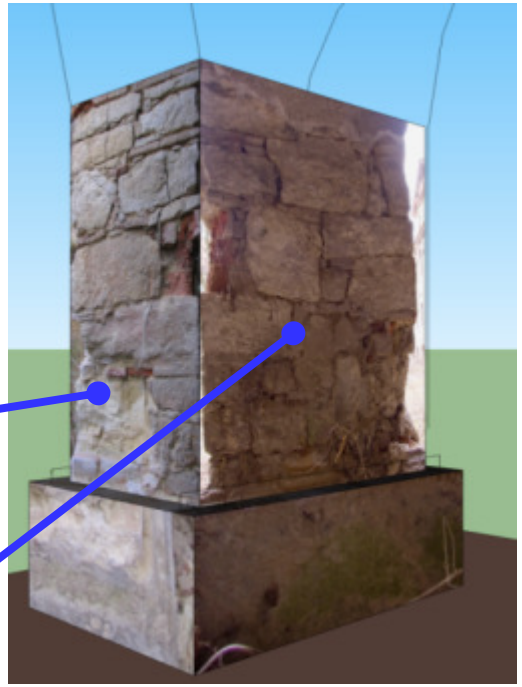
- architectural demages
  - brick – blistering, exfoliation
  - erosion
  - missing elements

Technical analysis of structures

- column 1x0,6 m, height 1,5 m (ground to springing)



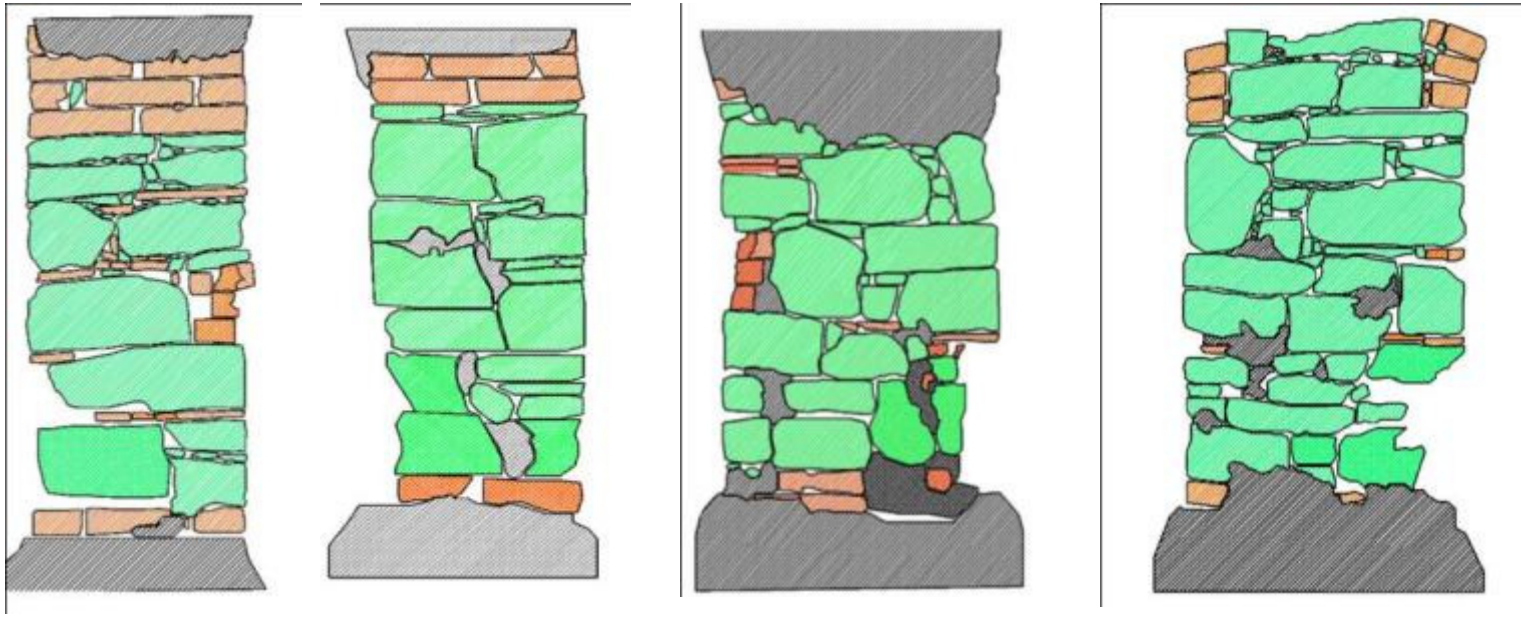
front view



back view

Technical analysis of structures, defects

- material composition
  - composite masonry (opuka + bricks)
  - heterogeneous courses, poor interlocking
- visible demage
  - plaster loss, surface deterioration, reduction of cross section at base



Technical analysis of structures, defects

- cracs
  - in mortar 1
  - at corner of section 2
  - in brick 3
  - in opuka 4

1

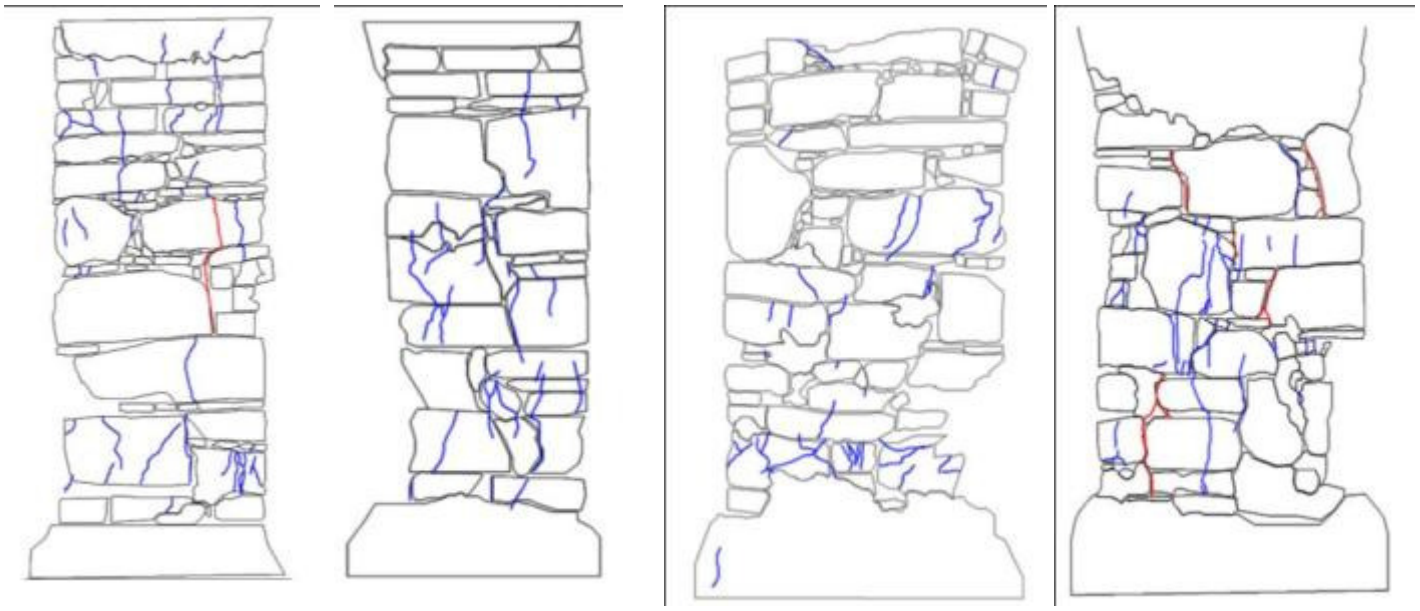
2

3

4

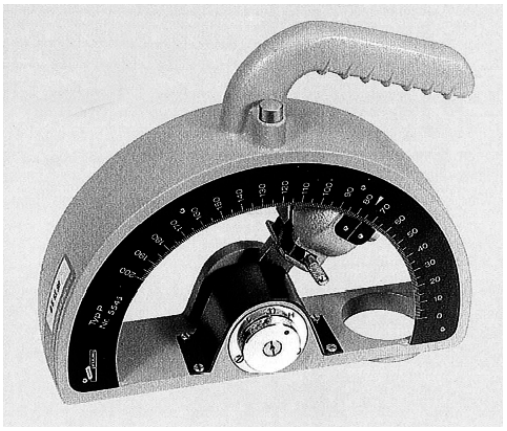
Technical analysis of structures

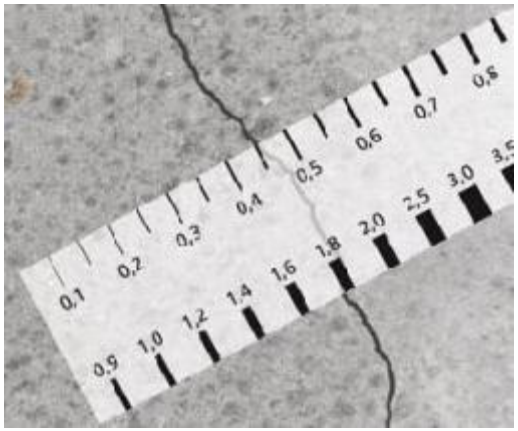
- cracking
  - vertical cracs – lenght up to 80 cm
  - most of cracs active
  - severe cracking through mortat joints
  - concentrated at reduced section of base



Technical analysis of structures

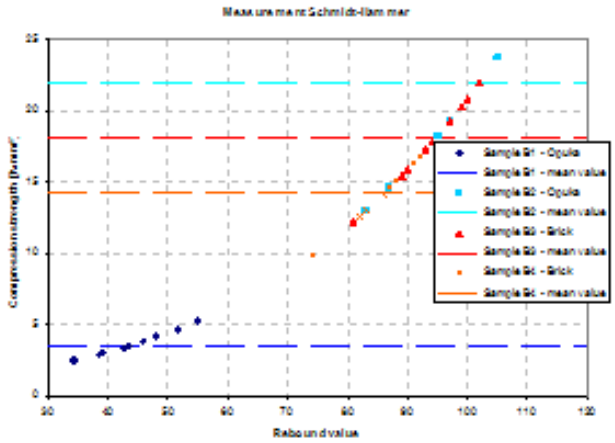
- equipment for inspection in-situ
  - folding rule (2m)
  - tachymeter Leica TCR 303
  - infrared thermography camera
  - Schmidt-hammer type PT
  - crack meter
  - Moisture monitor M49





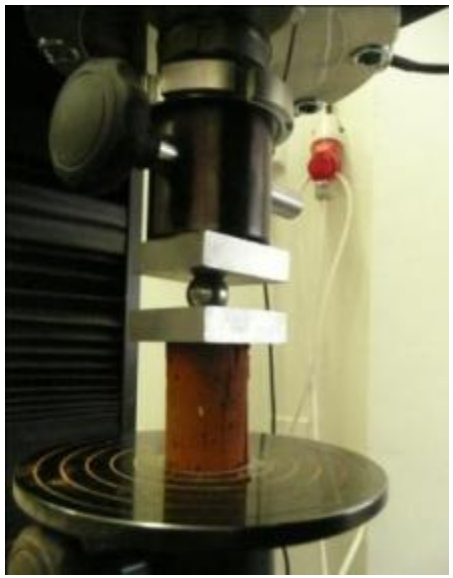
Technical analysis of structures

- Schmidt-hammer type PT
- opuka
  - B1 = 3.6 N/mm²
  - B2 = 22.0 N/mm²
  - Lab = 30.24 N/mm²
  - Big difference between measured values
- brick
  - B3 = 18.2 N/mm²
  - B4 = 14.3 N/mm²
  - Lab = 14.34 N/mm²
  - compressive strenght matches relatively well to the laboratory tests



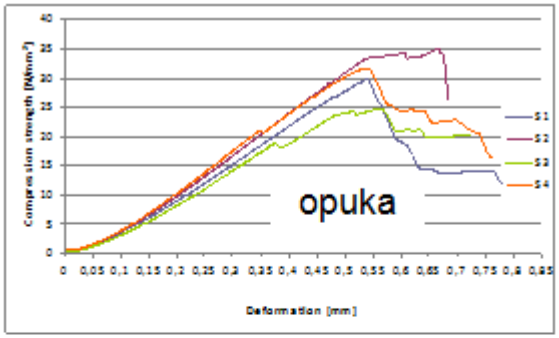
Technical analysis of structures

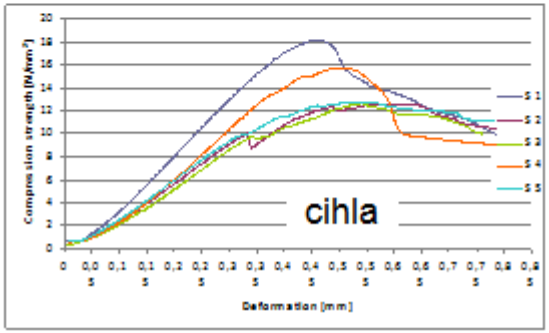
- laboratory tests – compression tests
  - determine the compressive strength of the masonry (brick, opuka)
  - selecting of 4-5 samples for each stone type
  - cutting out cylindrical specimen (d=35mm, h=40mm)
  - perform the compression test until the failure of the material (cracking)
  - results for the compressive strength and the Young´s modulus



Technical analysis of structures

- laboratory tests - results
  - characteristic strength is ≈ 2/3 of the average value
  - maximum compression stress:
    - opuka 19,0 N/mm²
    - brick 8,6 N/mm²
  - modulus of elasticity
    - opuka 2138,0 MPa
    - brick 1133,2 MPa





Technical analysis of structures

- laboratory tests – bending test for opuka
  - determine the tensile strength
  - cutting out a rectangular specimen (distance between supports 100mm)
  - perform the bending test until the failure of the material (cracking)
  - storing the results and evaluate the tensile strength and the Young´s modulus
  - result: tensile strength
    - 0.38 N/mm² - 0.73 N/mm² → negligible for the calculation

Technical analysis of structures

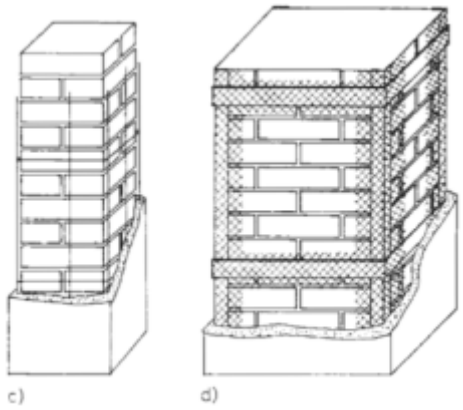
- Laboratory tests – moisture content
  - determine of the moisture content in the opuka and the brick
  - removing the sample for each stone type and put them into airtight bags
  - weigh the samples in the original state
  - drying the specimen in an oven (24h)
  - weigh the samples after drying
  - result: moisture content
    - opuka 2.7%
    - brick 4.1% → can be assumed as 'dry'

Analysis of defects

- failures of the pillar are caused by the decrease of the column strength and modulus of elasticity of masonry elements for long-term exposure effects of humidity and climate change

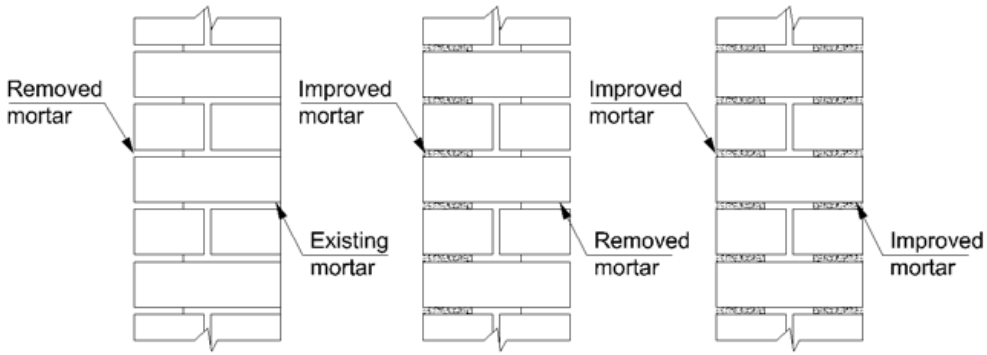
Restoration of defects

- factors to be considered
  - historical building with a cultural value → minimum intervention
  - keep as much as possible from the old building/structure
  - no change of the overall impression
  - safety aspect and nowadays requirements to buildings
  - before any intervention the cause that led to the damage should be abolished (checking by monitoring of the building)
- redevelopment proposal for the optimal solution – steel reinforcing
  - apply vertical reinforcement with steel bars, connected by brackets
  - set in concrete



Restoration of defects

- mortar & joints repointing



- moisture prevention against rising damp
  - mechanical driving of metallic sheets
  - surface finish

    remedial plaster

    system