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Pre- and Post Collapse Emergency Interventions on Historic Load-Bearing Structures

Case studies in Belgium

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The load-bearing capacity of our built cultural heritage is not infallible. Recent collapses in Belgium demonstrate the vulnerability of our historic buildings. In other cases, the need for intervention is identified on time and preventive measurements are proposed and (on the verge of being) executed. Referring to a collection of case studies, the paper focuses on the post collapse emergency interventions taken as well as on a critical appraisal: structural interventions, monitoring, documentation, and the need for thorough investigation, research and steps towards definitive consolidation or strengthening. Attention is paid to the effect of changing boundary conditions for which all case studies seem to be unique, the need for documentation and their requirements.

Introduction

Several (partly) collapses of historic structures have taken place recently in Belgium. A short overview is given of 4 examples in which (partial) collapse occurred. As such the emphasis is on the reason why their collapse could not be prevented and the post-collapse (emergency) interventions that took place. In a second phase 5 examples are given in which pre-collapse interventions took place or are on the verge of being executed. Some of them are (urgent) temporary interventions awaiting permanent interventions or are part of the planned permanent interventions. In that the background is given that led towards the decisions made. After listing these examples a general discussion is provided fed by the examples outlined.

Post disaster (emergency) intervention

Tower at St. Donatus public park in Leuven (B)

Fig.1 Tower at St. Donatus public park in Leuven (B)

Case study description (Schueremans and Van Gemert, 2004):
- building history: one of the remaining towers of the Romanesque city wall of Leuven, 13th century – listed building;
- owner: city of Leuven;
- collapse date: August 25, 2004;
- short description of collapse: partial collapse of natural stone masonry façade functioning as soil retaining wall – the tower shaft was filled with soil and a façade was constructed in front (18th cent.) - due to masonry deterioration and excessive biological growth within the soil infill;
- available pre-disaster information:
photogrammetric survey of building;
visual inspection reports stating the decay (2002);

post-disaster interventions:
(reversible) temporary shoring of remaining part of façade (December 2004) – design based on available photogrammetric information;
arheological excavations at the shaft of the tower removing the infill material and uncovering one of the best preserved towers of the medieval city wall of the city of Leuven (January 2005 – April 2005);

mid-long-term (planned) actions: consolidation of ruins – opening the site to the public for visits in small groups (2008).

Tower “Maagdentoren” in Zichem (B)

Case study description (Ignoul and Van Gemert, 2007):

building history: residential tower (donjon) constructed by Renier Van Schoonvorst the 2nd, 13th century. Probably never used for its intended housing function, but only served for a display of power from the Count of Orange.

owner: Flemish Government;
collapse date: June 1, 2006.
short description of collapse: partial collapse of external wall and vaults.
available pre-disaster information:
a 3D laser-scanning of both the inside and outside of the building were available, performed in December 2005 (exterior) May 2006 (interior);
reports of Monument Watch Flanders were available reporting the state of the building and its decay;

post-disaster interventions:
decision to leave the collapsed wall in its resulting state of ruin (August 2006);
consolidation study (August 2006 – January 2007[8]);
pre-stressing the masonry with post-tensioned tangential steel cables, preventing further collapse of wall parts and vaults (June 2007);
monitoring the wall deformations (started: June 2007 – on continuous basis);

mid-long-term (planned) actions:
a new function is planned for the building, including public access;
replacement of temporary interventions by permanent internally drilled circular anchors for ring reinforcement and lateral anchorage to ensure the connection of the internal and outer masonry leaf with the rubble core.
Injection of the rubble masonry core to increase its internal cohesion;
- construction of a permanent steel frame structure within the opening of the collapsed part of the structure connected to the internal steel reinforcement.

Bell tower of Church of St. Willibrordus in Meldert (B)

Case study description (Ignoul and Van Gemert, 2006):
- building history: date of construction of bell tower: 14th century;
- owner: local government;
- collapse date: 07/07/2006;
- short description of collapse: collapse during lunch break when emergency interventions were started, shortly after measuring increased and alarming crack. The collapse is due to increased decay of the load-bearing masonry structure and the adaptations made during the history of the tower to enhance accessibility (enlargement of frontal gate, connection with church nave).
- available pre-disaster information:
  - first call to engineering office and visual inspection: 13/02/2006;
  - acceptance of offer for structural monitoring of crack: end /05/2006;
  - starting of initial reference measurements: 12/06/2006;
  - during installation of monitoring already a second visual inspection revealed significant crack opening based on comparison with photographic material dating from 13/02/2006, closure of church was envisaged based on visual inspection;
  - closure of tower, church and surrounding parking lot after 14 days (23/06/2006) based on alarming crack opening measured on a period of 2 weeks;
  - 28/06: urgent emergency intervention requested and design of emergency interventions ready;
  - 06/07: start of emergency interventions for safeguarding the tower;
- post-disaster interventions:
  - visual inspection of remains, for reconstruction of collapse mechanism;
  - laboratory tests: material testing on load-bearing masonry elements;
  - shoring of remains;
  - stability study;
- mid-long-term (planned) actions: construction of a new façade and bell tower (to support the façade)
Case study description (Figeys and Van Gemert, 2005):
• building history: construction date 1955-1956;
• owner: private owner – Antwerp Harbor Enterprise;
• collapse date: 24/12/2004;
• short description of collapse: severe cracking of barrel vault and supporting column due to impact of a forklift on one of the supporting columns;
• available pre-disaster information: set of engineering plans showing the exact layout of the reinforcement and geometry and thickness of the thin shell structure roofing;
• post-disaster interventions: Immediate – after 1 week - temporary shoring of the column to prevent further collapse of the supporting vault;
• mid-long-term actions:
  o On-site investigation and control of concrete dimensions and layout of the reinforcing bars 08/2005;
  o Lifting and repositioning of column and vault with hydraulic jacks (01/2007);
  o Reconstruction of bottom part of reinforced concrete column (02-05/2007);

Emergency intervention at imminent danger
Castle ‘Terlenen’ in Geetbets (B)

Case study description (Ignoul and Van Gemert, 2006):
• building history: listed building – 18th century;
• owner: private;
short description of imminent collapse: central masonry wall demonstrated severe vertical cracking, due to overloading caused by gradual increase of openings made within the central load-bearing walls, combined with moisture decay of soft terra cotta bricks;

available pre-disaster information:
  o geometrical information was available from a master thesis (2005/2006). The author was later re-contacted as architect by the building owner: 05/2006;

pre-disaster interventions:
  o 05/2006: first visual appreciation by architect, and call for expert;
  o 05/2006: on the first contact of the expert engineer, the dwelling house was immediately declared no longer usable for living (although the inhabitants set aside this decision and stayed). Temporary shoring was requested immediately, the contractor was contacted the same evening and the shoring was executed within 2 days;
  o 01/2007: segmented and controlled reconstruction (concrete block masonry) of one of the endangered load-bearing masonry walls in the basement;
  o discrete monitoring of crack-widths are ongoing on a 3-monthly basis for a period of 2 years to check the effectiveness;

mid-long-term (planned) actions: reconstruction of basement; consolidation of upper floors.

13th Century Romanesque city wall of Leuven – Handbooghof

Case study description (Schueremans and Van Gemert, 2004):

- building history: part of the 13th century Romanesque city wall of Leuven (B) awaiting structural strengthening;
- owner: city of Leuven;
- short description of imminent collapse: part of the wall demonstrates a significant leaning that increases as a function of time and biological growth results in increasing decay of the natural stone masonry walls;
- available information before intervention:
  o geometrical survey of the slant of the walls dd. 12/1994;
  o a photogrammetric survey, dd. 07/2002;
- pre-disaster interventions:
evaluation of structural safety based on available information and new on site survey of soil conditions, foundation geometry and geometrical information and proposal for consolidation of masonry and strengthening of the foundation pillars (06/2003);

reversible and intermediate shoring – 3 years later - of the most endangered part of the wall. The shoring is designed in such a way that it can be used for the temporary support when the foundation strengthening is executed (06/2006);

mid-long-term (planned) actions:

Execution of consolidation of masonry walls and strengthening of foundation: presumed date of execution: xx/2008;

This part of the historic city wall will be reopened for the public.

Saint Jacob’s Church in Leuven (B)

Case study description (Schueremans et al., 2007; Schueremans and Van Gemert, 2007):

building history: construction started in 1230. Main parts of the church date from the 15th-16th centuries;

owner: church fabric – the city of Leuven holding it on long lease for 99 years;

short description of imminent collapse: already during history the church demonstrates structural problems. The main causes are related to the increased proper weight due to an increase of the height of the main nave and replacement of wooden vault by a masonry vault in combination with the limited load bearing capacity of the subsoil since the church is constructed on a former swamp reclaimed by monks. This resulted in large differential settlements;

available information before intervention:

church closed down for public: 1963;

temporarily a steel tube and reinforced concrete shores were added (1971). These actions were based on limited geometrical information and structural analysis. In addition, the temporary shoring was only part of the planned strengthening of both the foundation (enlarged reinforced concrete slabs) and replacement of pillars (with reinforced concrete core and natural stone external leave). The latter part was never executed due to the lack of funding;

mid-long-term (planned) actions:

a first study was performed: 1995;

the remaining flying buttresses were removed (2000) and horizontal loads from the vaults are counteracted by tensioning rods with monitoring devices;

urgent roof repair and renewal of sewer system were executed (2005);

available documentation is collected and archived, a stability study is performed for which extensive on-site surveys, long-term monitoring campaigns and laboratory tests are performed (2007). This study gives more profound insights in the load-bearing behavior of
the church and the causes of severe cracking and differential settlements, partly renouncing the causes quoted 40 years ago, based on limited information;
- funding will be looked for by the city of Leuven when a new and promising active use of the building can be found (20XX);

**Basilica of Our Lady in Tongeren (B)**

![Fig. 8 Basilica of Our Lady in Tongeren (B)](image)

**Case study description (Brosens et al., 2007):**
- building history: the Gothic Basilica of Our Lady is built on a former Roman church and surroundings. In several subsequent phases, archeological excavations are performed within the church. The depth of the excavations exceeds the foundation depth of the main pillars of the Basilica. Therefore, a foundation underpinning and consolidation of the existing stone masonry foundation are provided.
- owner: Church Fabric;
- short description of imminent collapse: during excavation, the distance in between the main pillars is monitored by means of on-site distinvar measurements. Relying on the relative horizontal displacements, the stability of the pillars is judged. Based on excessive displacements measured within phase I of the archeological excavations, additional horizontal shores were added to prevent possible collapse. Based on the insights gained in the first phase, a more extensive monitoring was installed as preparation of phase II – 7 years later. In that the movements of the church were already recorded one year before the starting of the excavations. This resulted in a better understanding of the structural behavior of the church and its movements related to changes in temperature and humidity. This information was not readily available in the first phase, possible affecting the judgment of the responsible engineer.
- available information before the intervention:
  - plans with overall geometry of Basilica;
  - within phase I: a proper validation of the distinvar measurements was not available;
  - within phase II and III: the monitoring was already set up one year before the excavations started. The required reference frame demonstrating the seasonal effects of temperature and relative humidity on the overall structural behavior was available at the start.
- mid-long-term (planned) actions: after consolidation and underpinning of the foundations and construction of the new archeological and technical cellar, the shores are removed. Finally, the cellar will be opened for the public as an archeological site.
Eastern aisle of Park Abbey in Leuven (B)

Fig. 9 Eastern aisle of Park Abbey in Leuven (B)

Case study description (Depickere et al., 2007):
- building history: construction started in 1129;
- owner: Abdij van ‘t Park (Park abbey);
- short description of imminent collapse: strong increase in measured crack openings at locations directly related to the stability of the vaults;
- available pre-disaster information:
  - a first study on the stability of the vaults of the eastern aisle of the Park Abbey is performed (1998);
  - the opening of the main cracks is monitored for a period of 1 year (1998-1999);
  - recently, the monitoring campaign was picked up again. Besides the initial seasonal effect, a clear trend in increase of the cracks was monitored (06/2007);
  - a stability study is performed and urgent temporary interventions are planned (07/2007);
  - execution of these interventions is planned (10/2007);
- mid-long-term (planned) actions:
  - a stability study including required consolidation and strengthening of the masonry walls of the eastern aisle is planned in the near future.

Discussion

Emergency interventions versus restoration

In the preservation process the following steps are generally present and often referred to (Krakow Charter, 2000, Venice Charter, 1964):
- anamnesis: collecting information, describing, documenting the building, its context building history. It includes plans and cross-sections or 3D-data, information related to past interventions, changes in structural layout, used materials, witnesses of malfunctioning etc.;
- analysis: analysis of conservation state, performing structural analysis, checking the load-bearing capacity based on on-site NDT-testing or others, on laboratory data and on structural monitoring;
- diagnosis: judging the building’s safety;
- therapy: design, execution and control of consolidation and strengthening measures.

In case of an emergency intervention (=therapy), the steps are identical. Only the time frame is more limited since limited time is available for the diagnosis and therapy. This puts additional pressure on the preceding steps.

Causes of collapse – unpredictability

Both the tower of St-Donatus and the Maagdentoren tower in Zichem were in a state of neglect for a long period. Several inspection reports made by Monument Watch Flanders already urged for better preventive maintenance and interventions. Despite the overall awareness of the state of decay of these
structures, their partial collapse occurred rather sudden, without immediate cause and its timing could be considered to be unpredictable.

For the bell-tower of the church of Meldert however, the crack pattern and state of decay were only discovered shortly before collapse. Monitoring of the crack pattern demonstrated the imminent danger. The collapse took place when emergency interventions were started, fortunately during lunch break so that nobody got injured.

In all cases mentioned above, people involved in the subsequent emergency interventions have not been able to organize this within their agenda beforehand. Communication channels in between the parties involved often have to be established. In the case of the reinforced barrel vault shell structure, the impact of fork-lift on the evening before Christmas, it took 7 days before urgent shoring could be provided.

In case of urgent interventions, speeding up the process, while maintaining quality of interventions, can only be achieved when the first step in the intervention process (anamnesis) can be skipped and the second one (analysis) focused on the requirements posed by the emergency interventions.

**Timing and funding:**

From the given examples it is clear that timing is different depending on the type and ownership of the building. When no people are endangered directly (eg. City wall/ Romanesque tower), the awareness of the endangered monument is more limited. It takes several years to provide the required funding to ensure the conservation of the structure. In case of private ownership and/or people being endangered directly, the awareness is much more intensive, resulting in a more efficient interaction in the intervention process.

**Anamnesis - availability of information:**

In several cases, the information related to the monument is limited or non-existent. This puts additional pressure on the intervention measures. The shoring of Saint-Jacob’s church in 1971 is partly based on misleading assumptions, lacking correct information.

As such this is a plea towards preventive collection of information related to historic structures within a strict archiving framework suitable for monuments or historic structures. Optimal information, related to geometry, load-bearing behavior, reports of regular inspections performed, reports on materials testing clearly results in a more efficient understanding of the building, which is indisputably in favor of all eventual (urgent) interventions. The documentation file should be attached to the monument comparable to a medical file attached to a patient (SPRECOMAH, 2007; WTA-NI-VI, 2007).

Inspectors should be given continuous further training, especially in recognizing signs of imminent danger to the physical safety of building users and of imminent danger to the structural integrity of the building.

In most of the above examples, even very experienced engineers were caught by the events: in particular the collapse of masonry remains an unpredictable event. The authors are convinced that their collection of data on collapses and on near-collapses should be continuously updated, and presented and explained to building owners and inspectors, to improve their sensitivity for damage and danger.

**Analysis and diagnosis - correct judgment of structural stability**

This item very much relates with the availability of information and thus also with timing. From the examples it is clear that correct and complete information related to intelligent monitoring of well chosen parameters indicating the structural behavior in an unbiased manner, are required for a correct judgment of the structural integrity and safety. Lacking required information because of non-availability or limited disposal of time, affects the judgment made, since the latter is influenced by the responsibility to be taken by the expert engineer in charge. The judgment is to be performed by an expert engineer relying on her/his expertise in this complex field. In all examples given, covering the majority of recent (imminent) collapses of historic structures, the consultancy was relocated and finally performed by a specialized engineering office, often in close collaboration with a specialized research institute.
Therapy – structural emergency interventions

The choice of structural interventions and their adequacy largely depend on the available data from various sources: monitoring, documentation, thorough investigation, and others. When urgent interventions are required, besides reversibility, the step towards definitive consolidation or strengthening has to be kept in mind:

- in the case of Saint-Jacob’s – although never executed in this way - the temporary shoring also served as a step towards the strengthening of the foundation and replacement of the pillars;
- in the case of the Romanesque city wall of Leuven the added temporary shoring is part of the process towards permanent strengthening of the foundation.
- due to time pressure and the lack of information, optimal and reversible emergency interventions are not always achievable. However, there is a clear tendency that the emergency interventions are to be in line with the preservation charters as far as possible and thus have to be kept in mind at all stages;

The interventions (temporary and permanent) are to be documented well. Both the planning and execution of the interventions are to be part of this documentation. It allows a better planning of future intervention:

- the removal of the flying buttresses of Saint-Jacob’s church is well documented. Photographs are provided of each of the flying buttresses before removal, visualizing the numbering of the stones painted on the stones. CAD plans further complete this information allowing their possible future reconstruction.

Conclusions

Although the examples given are all of different nature, a common denominator is looked for. In all cases a thorough understanding of the structural behavior of often complex historical buildings is required for an appropriate judgment of (urgent) interventions. The judgment of the load-bearing capacity is based on the structural understanding that is validated by means of structural modeling in combination with the monitoring of crucial parameters of the actual built heritage at risk and largely depends on the available information. Therefore, an overall archiving framework is to be set up in which all information related to the building can be put at the disposal of the responsible engineer, being the medical file of the monument.

The series of (imminent) collapses in the last years significantly increased the public awareness of endangered buildings within Belgium. The subjective feeling and belief in the structural safety of buildings, based on their age of several centuries, is now perceived differently: age is no guarantee of safety. New and appropriate safety assessment tools need to be developed.
References


SPRECOMAH, Guidelines and Conclusions from the first seminar held at Leuven, june 2007, Seminars on PREventive COnservation and Monitoring of the Architectural Heritage), funded by the European Commission, FP6, 2006.