Engineering Structures 33 (2011) 210–217

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Modelling and analysis of time-dependent behaviour of historical masonry under high stress levels

E. Verstrynge [a,*], L. Schueremans [a], D. Van Gemert [a], M.A.N. Hendriks [b]

[a] K.U.Leuven, Department of Civil Engineering, Kasteelpark Arenberg 40, 3001 Heverlee, Belgium
[b] T.U.Delft, Faculty of Civil Engineering and Geosciences, Stevinweg 1, 2628 Delft, The Netherlands

ARTICLE INFO

Article history:
Received 25 June 2010
Received in revised form
22 September 2010
Accepted 7 October 2010
Available online 10 November 2010

Keywords:
Masonry
Finite element modelling
Creep
3-leaf masonry
Time-dependent behaviour
3D rheological model

ABSTRACT

Masonry which is subjected to high, sustained stress levels can suffer from long-term damage accumulations. This type of stress-induced damage interacts with other long-term phenomena, such as deterioration and fatigue. In this work, the time-dependent damage which is caused by elevated stress levels is analysed and modelled. A one-dimensional rheological model, which was calibrated on the results of an extensive experimental test campaign, is extended to a three-dimensional version. The time-dependent constitutive relations are implemented in a finite element code. The issues of triaxial stresses and mesh-dependency are addressed. In a first application, the model is used to simulate the long-term behaviour of a masonry tower. Secondly, the effects of time-dependent stress redistributions on the long-term stability of three-leaf masonry are investigated.

1. Introduction

Assessing the stability of historical masonry structures is a complex task, which demands a reliable evaluation of the current damage state and possible damage accumulation. Historical structures have never been built according to a target lifetime and it could falsely appear that their past performance and long lifetime are a guarantee for future safety. History has proven that this is a dangerous assumption. Long-term damage accumulation can cause historical masonry structures to collapse, without any change in loading conditions, such as the occurrence of a fire, an earthquake or foundation settlements to name a few.

Creep damage generally occurs in tall constructions, such as bell towers or medieval city towers, as rather high stress levels are present at the base of these constructions due to the self-weight. Another example are structural components which are subjected to high load levels, such as slender pillars of large churches. Damage accumulations which occur during creep deformation are usually within limits, but at high stress levels, they can result in partial or total failure of the structure. It was found in former research that the stress limit for creep damage initiation ranges from 40%–50% of the compressive strength for low-strength masonry to 60%–70% for higher strength masonry [1].

Examples of documented failures, attributed to long-term damage accumulation under sustained stresses, are the collapse of the tower of Chichester Cathedral in the United Kingdom, 1861, the San Marco bell tower at Venice in Italy, 1902, the Civic Tower at Pavia in Italy, 1989 [2], the St. Martinus Church at Kerksken in Belgium, 1990, the St. Magdalena Church at Goch in Germany, 1992 and the Cathedral of Noto in Italy, 1996, although for this last one, damage was increased by an earthquake [3]. Also in Belgium, two recent collapses of historical monuments were attributed to long-term damage accumulation under high stress levels: the collapse of the bell tower of the St. Willibrordus Church at Meldert (Fig. 1(a) and (b)) and the partial collapse of the Medieval Maagden tower at Zichem (Fig. 1(c) and (d)). Both collapses occurred in 2006 [4].

Stability of historical masonry under creep deformations has been addressed extensively by Binda [5], Anzani [6], Modena [7] and by Pina-Henriques [8]. A numerical model to calculate the time-dependent deformations of brittle materials, such as concrete and masonry, under monotonic and sustained stresses was proposed by Papa and Taliercio [9]. It is based on rheological models with the inclusion of damage parameters.

During past research, an adapted version of this model has been calibrated and validated with the results of an extensive experimental research program, involving different types of creep tests on masonry specimens with lime mortar [10].

In the next section, the background of the creep model will be outlined briefly. Thereafter, the model is extended to a

* Corresponding author.
E-mail addresses: els.verstrynge@bwk.kuleuven.be (E. Verstrynge), luc.schueremans@bwk.kuleuven.be (L. Schueremans), dionys.vangemert@bwk.kuleuven.be (D. Van Gemert), M.A.N.Hendriks@tudelft.nl (M.A.N. Hendriks).

0141-0296/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2010.10.010