Construction and Building Materials 155 (2017) 88–102

Contents lists available at ScienceDirect

Construction and Building Materials

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

An investigation into the time dependency of shear strength of clay brick walls; an approximate approach

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HIGHLIGHTS

- The reduction of wall shear strength during the time is discussed.
- Time dependent structural degradation models for shear strength of clay brick walls are proposed.
- Aging factors and safety life period for shear brick walls are derived.

ARTICLE INFO

Article history:
Received 30 April 2017
Received in revised form 9 August 2017
Accepted 10 August 2017

Keywords:
Brick wall
Shear strength
Time dependent model
Degradation
Service life

ABSTRACT

Time dependent structural degradation has an adverse effect on the long term performance and safety of structures. The present study mainly investigates time dependency of in-plane shear strength of clay brick walls and tries to enhance individual models for the resistance degradation. It also develops a framework for numerical aging analysis based on multivariable field test data. The results, obtained from the numerical analyses done on the collected data in accordance with ASTM C1531, are then applied to derive suitable resistance degradation functions and predict the uncertain long term shear resistivity of clay brick walls.

1. Introduction and background

The long term performance of structures depends on a multiplicity of influences [1]. Age is one of the main influential factors. Civil structures are as a rule exposed to unfavorable environmental effects and various time variant actions, which result in time dependent structural degradation (TDSD) [2]. Degradation evolution affects the materials strength and thus, the structural limit states. This process has a significant adverse effect on long term safety life of a structure [3]. That's why TDSD prediction is crucial in design and maintenance planning [4]. Structural design methods are nowadays well established for time independent models. However, time dependent analysis is by far less mature due to many inherent uncertainties. As a result, simulation of TDSD is increasingly gaining importance [5].

Generally, the process of TDSD tends to be uncertain due to variability inherent in the operating environment, load conditions and aging process. Many researchers have attempted to investigate the subject in different structural types and study the parameters, which further TDSD. Some notable works are due to Madsen et al. [6], Chin-Diew Lai et al. [7], Stewart et al. [8], Ceravolo et al. [9], Akiyama et al. [10], Sanchez-Silva et al. [11] and Bu et al. [12] all highlighting the importance of considering time dependency aspects in the design process. Although notable researches have been progressing, such studies in the masonry area are less numerable.

Masonry construction is very common in many parts of the world [13]. Moreover, a considerable amount of existing structures in many counties are of this kind [14]. A common type in this practice is unreinforced masonry (URM) built with clay brick walls. In brick URM buildings, the walls generally sustain earthquake induced lateral loads. They resist most of lateral loads by in-plane shear action. Therefore, the expected safety life of a brick masonry structure subjected to seismic loads highly depends upon wall shear strength. Similar to other resistances, shear strength of brick walls may decrease during the time.

Despite widespread application of brick masonry, incommensurate amount of investigations is done on its time dependent load

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http://dx.doi.org/10.1016/j.conbuildmat.2017.08.055
0950-0618/

Nomenclature

A_b	Contact surface area
a, *b* and *c*	Function parameters
CY	Construction year
g(t)	Resistance degradation function (Aging factor)
R	Resistance capacity
R_0	Initial resistance
R_t	Resistance at time *t*
Q	Earthquake induced lateral load
s	Shear strength of brick wall
t	Age in year
v	Ultimate jack load
σ_c	Normal stress due to gravity
μ	Friction coefficient

carrying capacity and design procedure. Among the works which can be cited, as an early work, Maes et al. [18] in a paper on the reliability based assessment of existing masonry structures, highlighted time dependency aspects and compiled some possible degradation functions in this type of construction. In addition, a few probabilistic models of masonry degradation as a transition process from a given performance state to a lower state are discussed in Bekker [19]. John Nichols [20] investigated about the progressive degradation of masonry shear walls mostly under harmonic loading. Furthermore, the deterioration test procedure applied on the full scale masonry models built in aggressive environment is described in Garavaglia et al. [21]. They proposed two different stochastic approaches, modeling the decay process of masonry over time. Additionally, aging tests on masonry samples are described in Cultrone et al. [22]. Anzani et al. [23] worked on probabilistic modeling of masonry structures. Their model proposes estimation of the residual life of masonry structures based on horizontal and vertical parameters of the secondary creep strain rates. Verstrynge et al. [24] in 2011 issued a study about time dependent behavior of lime mortar masonry. They also published separately an investigation on the modeling and analysis of time dependent behavior of historical masonry under high stress levels [25]. Krzan et al. [26] completed a case study on influence of aging and degradation of load bearing capacity of historical masonry buildings. Ageing in-situ tests on Kolizej Palace built in 1847, Krzan et al. [26] found that aging had significant effects on mechanical properties of masonry and its constituents. It was concluded that reduction of compressive and tensile masonry strength caused by decay process may be up to 30% and 36% respectively. In a recent study, Micic and Asenov [27] worked on the probabilistic finite element analysis of aging masonry wall. Some other noteworthy studies are due to Schueremans et al. [28], Maheri & Sherafati [29] and Ghiassi et al. [30], which all highlight the significance of considering temporal changes in URM design. As far as the authors are aware, little work about time effects on shear strength of brick walls is currently available. They could not find any time dependency model, specifically developed for in-plane shear strength of clay brick walls. Considering the importance of the resistance parameter and the current trend towards the use of time dependent design, more studies on this subject are needed.

The objective of the present work is to give an insight into the TDSD of in-plane shear strength of clay brick walls. Besides, the study tries to develop an approximate rational approach in modeling TDSD based on multivariable field test data by using statistical methods, which has not been common in such investigations. For this purpose, results of thousands in-situ tests in accordance with ASTM C1531 [31] on clay brick walls with different ages are collected and analyzed. ASTM C1531 is a regular established test method to measure wall shear strength in place. The data is then analyzed to derive long term TDSD models by using trustworthy methods such as least squares curve fitting technique. The derived relationships would try to simulate time dependency in shear brick walls. To report the study, in the initial parts of the paper, several relevant aspects such the seismic role of wall shear strength, the test description and material properties are described. These are followed by the analysis procedure and chosen strategies to overcome the study limits. The proposed time dependency models are then applied to derive related aging factors. These relationships are used to predict the expected service life. Finally, some strategies are discussed for safe endurance of brick URM structures. The concluding remarks provide several recommendations for possible future research work.

2. Theory and methodology

2.1. The importance of time dependency of shear strength of brick walls

In low-rise construction, brick URM is commonly used [13]. It is a widespread application in many parts of the world, leading to economical and efficient structural solutions. In URM buildings, walls are the first line of defense against earthquake induced lateral loads. They mainly hold the seismic load in in-plane shear action as well as in in-plane compression [29]. Therefore, their in-plane shear capacity is a premier factor, when a URM structure is supposed to resist lateral loads [32]. Since the seismic response of such buildings greatly depends on the in-plane shear capacity of walls, it is vital that an adequate amount of brick shear walls be provided in both perpendicular directions of the structure. This minimum required wall amount is determined in design specifications as wall density. Wall density has a critical role in safety of URM structures [33]. The values recommended for wall density in related codes are generally derived depending on the seismicity of a particular area and by considering a constant amount for wall shear strength [13]. Accordingly, one of the governing limit state functions for the lateral resistance of URM buildings could be as:

$$g(R,Q) = R - Q \tag{1}$$

In which, *R* is the capacity, i.e. the total sideward resistance of brick shear walls. It could be the product of total wall section areas in one direction in the wall shear sliding strength amount. *Q* is the demand in the form of lateral loads resulting from earthquake or wind effects in that direction. Hence, the boundary condition between desired and undesired performances is when $g = 0$. As continuous random variables, *R*, *Q* and the resulting quantity of $(R - Q)$ are shown by their probability density functions (PDF) in Fig. 1. The shaded area in the figure represents the probability of failure (P_f).

A common ignorance during the design process is that resistance is not actually a continual constant amount. Indeed, the structural capacity may be decreasing during the time. Similar to other structural resistances, wall shear strength may gradually reduce due to damage accumulation caused by various fatigue mechanisms. Public safety requires that seismic evaluation of masonry structures provides quantitative evidence of sufficient capacity for future demands. Apparently, the impact of time