Structural Safety 62 (2016) 47–56

Contents lists available at ScienceDirect

Structural Safety

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

Reliability assessment of vertically loaded masonry walls

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ARTICLE INFO

Article history:
Received 4 November 2015
Received in revised form 2 June 2016
Accepted 3 June 2016
Available online 10 June 2016

Keywords:
Partial safety method
Full probabilistic method
Limit state function
First order reliability method
Estimating the coefficient of variation ECOV
Monte Carlo simulation MCS
Bivariate normal distribution
Latin hypercube sampling method LHS
Hasofer–Lind transformation

ABSTRACT

For the safety assessment of vertically loaded masonry walls, the Eurocode 6 considers a linear limit state function with only one basic parameter for the compressive strength of masonry. This assumption disregards the contribution of the uncertainty in other material parameters, like the elastic modulus, which is more important than the compressive strength in slender masonry walls. Furthermore, Eurocode 0 gives no clear advice on how to deal with the partial safety factors for non-linear problems in general.

A reliability assessment has been carried out for the vertically loaded masonry walls, in order to clearly understand the contribution of the uncertainty of different material parameters on the evaluation of safety. The limit state function of the problem has been calculated using the transfer-matrix method. The full probabilistic approach has been applied using Monte Carlo simulations which helped to propose a new approach for the use of the partial safety factors in the non-linear analysis.

1. Introduction

In recent decades, a great progress has been achieved in computational techniques and engineering software, which made the non-linear structural analysis possible for the practising engineer.

Many codes of practise today are based on the partial safety factors which can be used for problems defined by linear limit state function. However, the code provisions give no advice about how to deal with the partial safety factors in the non-linear analysis. The provisions given in EN 1990 are rather general and leave the decision to the practising engineer. In some codes, a new safety format on the basis of the global safety factors was introduced, e.g. DIN 1045-1 and EN 1992-2.

In EN 1996-1-1, the limit state function defining the problem of vertically loaded masonry walls has been considered linear with one basic material parameter for the compressive strength of masonry. One partial safety factor γ_M has been defined for the material which takes into account the uncertainty in the compressive strength. However, for slender masonry walls, where stability failure occurs due to the second order effect, the vertical load bearing capacity becomes dependent from the elastic modulus but not from the compressive strength. This nonlinear behaviour leads to the question of the basic approach of the partial safety factors and the related material properties in numerical analysis of masonry structures.

In the following sections, the available safety formats are going to be reviewed and the resistance of the wall will be modelled in both global and partial safety formats.

2. Safety formats

Several proposals for the appropriate safety format for non-linear analysis of concrete structure were proposed (see e.g. Schlune et al. [1,2], Cervenka [3], fib model code 2010 [4], and Allaix [5]). But the current safety formats doesn't properly account for modelling the uncertainty in non-linear analysis. In the following, the safety formats based on partial factors, global factors, and probabilistic analysis are going to be discussed.

2.1. Partial factor format

The European standards use reliability verification approach on the basis of partial factor method. It is an appropriate format for linear limit state functions. This format describes the uncertainties in the variables by means of the design values assigned to each variable. The design values of the variables are usually introduced in terms of their representative values or characteristic values. The design resistance can be obtained as following:

$$R_d = \frac{R(f_d)}{\gamma_{Rd}} \tag{1}$$

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http://dx.doi.org/10.1016/j.strusafe.2016.06.004

where γ_{Rd} is the safety factor considering the uncertainty in structural resistance, f_d is the design value of material strength and is given by:

$$f_d = \eta \cdot \frac{f_k}{\gamma_m} \tag{2}$$

where f_k is the characteristic strength of the material, η is a conversion factor to correct the resistance for durability effect, γ_m is a partial safety factor considers the uncertainty in material properties. The following simplification of expression (1) can be made:

$$R_d = R\left(\eta \cdot \frac{f_k}{\gamma_M}\right) \tag{3}$$

where

$$\gamma_M = \gamma_m \cdot \gamma_{Rd} \tag{4}$$

The design value for single action can be obtained as following:

$$S_d = S(\gamma_F \cdot F_{\text{rep}}) \tag{5}$$

where γ_F is the partial safety factor of action. F_{rep} is the representative value of action.

Considering a normal distribution for the strength of masonry with mean value μ_f and standard deviation σ_f, the characteristic strength can be obtained by the following equation (Fig. 1):

$$f_k = \mu_f \cdot (1 - k_n \cdot V_f) \tag{6}$$

$k_n = 1.645$ when the number of tests goes to infinity. If the number of tests is known, k_n can be determined from table D1 in EN 1990.

The partial safety factor for the material strength γ_f can be obtained as a ratio of the characteristic value to the design value and given by:

$$\gamma_f = \frac{f_k}{f_d} = \frac{1 - k_n \cdot V_f}{1 - \beta \cdot \alpha_f \cdot V_f} \tag{7}$$

By taking the coefficient of variation of material strength $V_f = 0.125$ with a target reliability index on nnual basis $\beta = 4.7$ (EN 1990 [6] for reliability class RC2 and 1 year reference period) and sensitivity factor $\alpha_f = 0.8$, gives $\gamma_f = 1.5$.

If the distribution of the material strength is lognormal, the characteristic values can be given as following:

$$f_k = \frac{\mu_f}{\sqrt{V_f^2 + 1}} \cdot e^{-k_n \cdot \sqrt{\ln(V_f^2+1)}} \tag{8}$$

The above equation can be reduced to the following simple expression:

$$f_k = \mu_f \cdot e^{-k_n \cdot V_f} \tag{9}$$

The partial safety factor can be determined for lognormal distribution as following:

$$\gamma_f = e^{(-k_n + \beta \cdot \alpha_f) \cdot V_f} \tag{10}$$

By taking the coefficient of variation of material strength $V_f = 0.194$ with target reliability index on annual basis $\beta = 4.7$ and sensitivity factor $\alpha_f = 0.8$, gives $\gamma_f = \gamma_M = 1.5$.

2.2. Global resistance factor format

The global resistance format introduced to consider the non-linearity of the limit state function which cannot be considered in the partial safety format [4]. The calculation of design resistance based on the mean value takes the following form:

$$R_d = \frac{\mu_R}{\tilde{\gamma}_R \cdot \gamma_{Rd}} \tag{11}$$

γ_{Rd} is the model uncertainty factor and takes into account the quality of the resistance model. CEB-FIB code [4] recommends $\gamma_{Rd} = 1.0$ for no uncertainties, $\gamma_{Rd} = 1.06$ for low uncertainties, and $\gamma_{Rd} = 1.1$ for high uncertainties.

$\tilde{\gamma}_R$ global resistance factor related to the mean value and can be estimated from full probabilistic analysis. However, for special cases when the distribution of the resistance is known, the global resistance safety factor can be calculated by the method of estimating the coefficient of variation ECOV. In ECOV, the coefficient of variation can be estimated from two non-linear analysis at the mean and the characteristic values of the material strength.

If the resistance is normally distributed, the coefficient of variation V_R can be calculated as following:

$$V_R = \frac{1}{1.65}\left(1 - \frac{R_k}{\mu_R}\right) \tag{12}$$

The global central resistance factor can be calculated as follows

$$\tilde{\gamma}_R = \frac{1}{1 - \beta \cdot \alpha_R \cdot V_R} \tag{13}$$

If the resistance is log-normally distributed, the coefficient of variation V_R can be calculated as following:

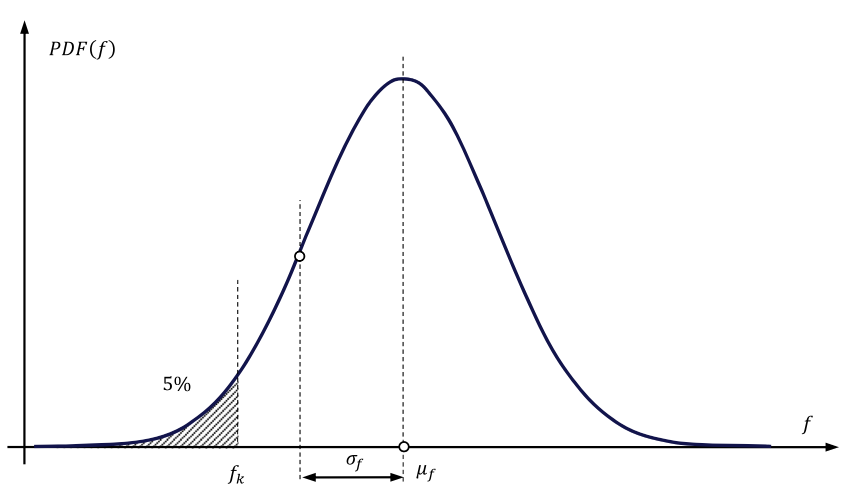

Fig. 1. Determination of the characteristic value of the material parameter in case of normal distribution.