

Degree of restraint concept in analysis of early-age stresses in concrete walls



Agnieszka Knoppik-Wróbel*, Barbara Klemczak

Department of Structural Engineering, Silesian University of Technology, Akademicka 5, 44100 Gliwice, Poland

ARTICLE INFO

Article history:

Received 6 March 2015

Revised 24 July 2015

Accepted 18 August 2015

Available online 2 September 2015

Keywords:

Degree of restraint

Early-age concrete

Numerical modelling

Restraint stresses

Soil–structure interaction

Wall

ABSTRACT

The degree of restraint is a useful concept for characterisation of early-age thermal–shrinkage stresses occurring in externally-restrained concrete elements such as walls. It can be used not only in manual calculations, but also in numerical analysis to determine the values and distribution of stresses in walls. The issues that must be addressed while defining the degree of restraint of the wall include the stiffness of the restraining body (e.g. foundation), translational and rotational restraints, influence of the construction sequence and support conditions. These issues are discussed in the paper. For the purpose of the study a numerical model is proposed which takes into account sequential casting and interaction between early-age structure and founding soil. The results of the study point out the factors that need be taken into account when modelling structural behaviour of early-age walls for proper determination of the expected stresses.

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1. Introduction

Concrete elements are subjected to early-age volume changes due to temperature and moisture variations which characterise the process of concrete hardening. These volume changes induce stresses in concrete elements. In massive concrete elements, such as foundation slabs or blocks, the stresses are induced mainly by significant temperature differences developing between the interior and the surface of the element (self-induced stresses). In externally-restrained elements, such as walls, thermal–shrinkage stresses result from a coupled action of self-induced (Fig. 1b) and restraint stresses (Fig. 1c). The restraint in these elements is exerted by the bond between the new concrete of the element and the older concrete of the foundation or a previous lift; in a concrete wall tensile stresses result from the restraint of a potential contraction caused by the length changes associated with decreasing temperature of the wall. In typical walls restraint stresses play a predominant role because volumetric strains caused by the temperature and humidity gradients are relatively small in comparison to the linear strains caused by the contraction of the element along the line of the restraint joint [1,2]. Nevertheless, it must be remembered that with the increasing massivity of the wall the share of the self-induced stresses increases. Surface tensile stresses occurring in thick walls (thermal gradients) and formed by early

formwork removal (both thermal and moisture gradients) may lead to surface cracking which can further develop into through cracking.

The magnitude of the restraint stresses depends on a degree of restraint induced against the early-age part of the structure. The degree of restraint can be expressed with the restraint factor, γ_R – a measure which in any point of the element is defined as a ratio between the actual stress generated in the element, σ , to the hypothetical stress at total restraint, σ_{fix} , [4–7]:

$$\gamma_R = \frac{\sigma}{\sigma_{\text{fix}}}, \quad (1)$$

and may take values between 0 at no restraint to 1 at total restraint. It varies throughout the element with the maximum value at the joint between the wall and the restraining body, decreasing towards free edges of the wall.

Fig. 2 presents distribution of stresses in the mid-span cross-section of a base-restrained wall. Stresses generated by the external restraint (σ_{res}) have a major influence on the values and character of the total stresses (σ_{tot}). If there were no temperature and humidity gradients within the element, the stress distribution would be proportional to the degree of restraint as shown in Fig. 2a (there would be no self-induced stresses, $\sigma_{\text{s-ind}}$). Due to the temperature and humidity gradients at the height of the wall, which generate the self-induced stresses, the maximum stress appears above the joint (Fig. 2b) with the maximum value of the stress above the joint. The temperature and humidity gradients at the thickness of the wall also cause self-induced stresses, which

* Corresponding author.

E-mail address: agnieszka.knoppik-wrobel@polsl.pl (A. Knoppik-Wróbel).

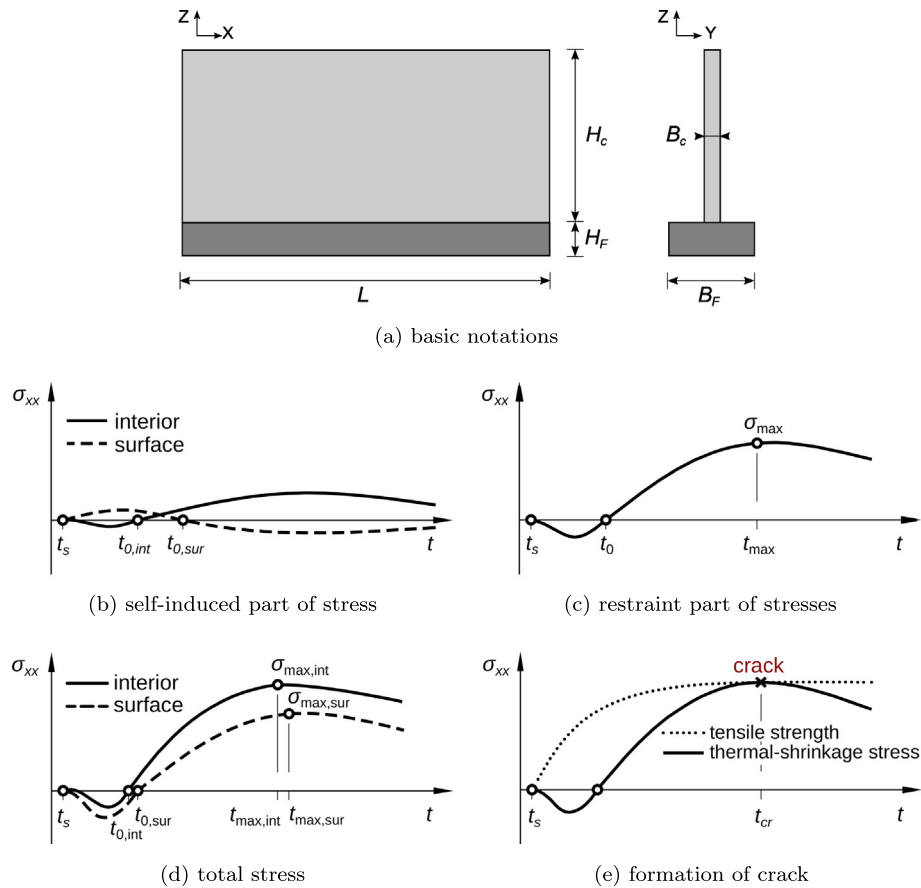


Fig. 1. Development of early-age thermal-shrinkage stresses in time in an externally-restrained element [3].

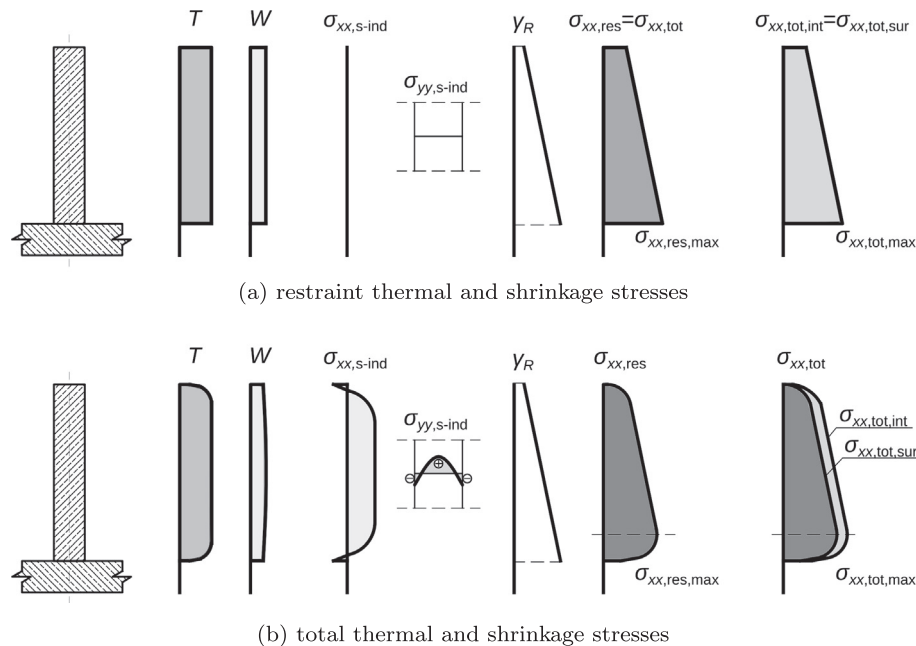


Fig. 2. Distribution of early-age stresses in a cross-section of a wall [3].

are the reason why the values of the total thermal-shrinkage stresses differ in magnitude between the interior and the surface of the wall (Figs. 1d and 2b). If the value of tensile stress in any location of the element exceeds the tensile strength of concrete in that

location, a crack is formed (Fig. 1e). When the stress state in cooling phase looks like in Fig. 2b, which happens if the wall is kept in formwork during the whole process of concrete hardening, development of cracks initiates from the interior of the wall (internal

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