Thermal Crack Risk Estimations of Concrete Walls – Temperature and Strain Measurements Correlated to the Equivalent Restraint Method

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ABSTRACT
Self-induced non-elastic deformations in hardening concrete, caused by restrained volume changes due to thermal dilatation and moisture deformations, often leads to cracking. In crack risk analyses, determination of the degree of restraint is vital. One model to estimate the restraint and calculate the thermal crack risk is the Equivalent Restraint Method, ERM. The method has previously been analyzed but needs to be further examined and validated. Recordings of tunnel sections were performed and compared to calculated values by ERM. Satisfying correlation between theoretically estimated and observed temperatures, strains and time of through cracking was achieve which is promising for future implementation and testing of the method.

Key words: Thermal cracking, Early age concrete, Local restraint method, Equivalent restraint method, Modelling, Field measurement.

1. INTRODUCTION

1.1 General

Restrained movements within young concrete during the construction phase, caused by thermal dilation and/or changing moist states, is a major reason for surface and through cracking [1] - [5]. It is concluded that adjoining structure or a restraining entity (rock, subgrade etc.) bonded to the young concrete increases the risk of cracking since the restraint becomes higher, see e.g. [1].

To establish possible measures against cracking, pre-calculations to analyze the risk of cracking during the heating and cooling phases are needed in Sweden for all civil engineering structures. The measures (cooling pipes or heating cables etc.) could be introduced within most calculation models if the strain level is predicted higher than approved [6]. One important action to make the strain estimations more accurate, than using standard input parameters, is to test and evaluate the material properties of the concrete carefully as e.g described in [7].

In [8], the importance to provide reliable restraint predictions is stated, especially regarding the design of a certain measure. This is certainly true when it comes to cooling of repeated construction sections as the restraint usually is difficult to estimate and may thus be an uncertain factor [9]. One way to avoid these difficulties is to establish a complete 3D model with viscoelastic-plastic behavior of the young concrete. A drawback of these kinds of models is that they are cumbersome, time consuming at calculations and suitable software is often costly.

To simplify the restraint estimation for complex structural situations, the so called Equivalent Restraint Method (ERM) [10] may thus be used. Benefits of this method involve a possibility to extract the restraint analyzed by *elastic* 3D calculations and implement them into the so called Compensated Plane Method (2D FEM) for young concrete, e.g. [6] and [11].

The evaluation of how well the ERM corresponds to full scale studies made in [8] was based on the correlation between theoretical and empirical temperatures along with the correlation between theoretical strain ratios and observed crack patterns for some typical cases.

This work provides a refined evaluation of the ERM compared to the evaluation made in [8]. What has been improved is that the model is enhanced with a set of fully tested parameters of the material properties and strain measurements were performed on a chosen typical full-scale case.

2 METHOD

Within this work, a demonstration is performed of the correlation between results from ERM and empirical experiences. Concrete temperatures and strains are recorded in two walls of a real tunnel project and compared to results from a ERM model. The tunnel is cast in 10-meter long monolithic segments, consisting of two walls (denoted as “east” and “west”) and a roof slab.

The process of this work can be described as follows. 1) Laboratory tests regarding material properties of the concrete. 2) Theoretical model developed by ERM to analyze the temperature and strain development of the studied structure. 3) Onsite measurements of temperature and thermal dilation. 4) Import of onsite temperatures (ambient air, adjacent construction and fresh concrete) to the ERM - comparison of recorded theoretical temperature developments. 5) Calculations of concrete stresses and strains and comparisons with measured ones as well as time and location of cracking.

The prerequisite of the fifth step is that the tunnel walls cracks due to thermal dilatation. If they don´t crack spontaneously, heating cables in the base slab can be activated to expand the slab to force cracks in the wall.

3 RESULTS AND CONCLUSIONS

The derived ERM model, used with measured, derived or estimated values of concrete and ambient air temperatures, material parameters, wind speed, filling rate, restraint and heat transfer coefficients, gave a theoretical strain ratio development of the walls examined, see examples in Figure 1.

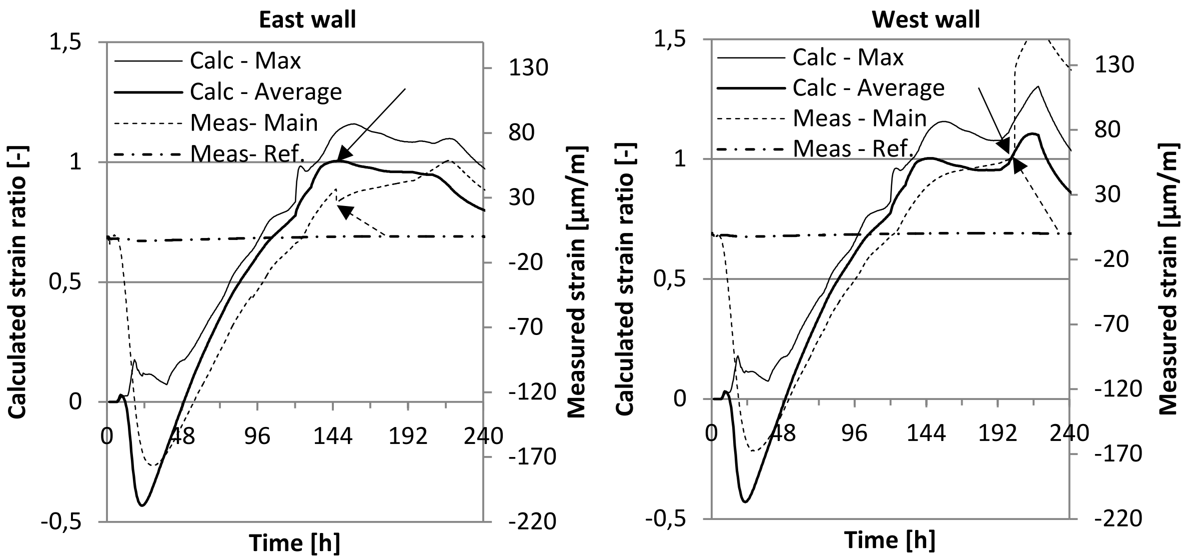

Figure 1 – Theoretical derived strain ratios in the east and west wall. Solid and dashed arrows indicate calculated and recorded time of cracking respectively.

To analyze the risk of cracking, an average was taken over a specific area in the structure where the maximum stress ratio was calculated [12]. In Figure 1 it is seen that the estimated time of cracking for the east wall is 146 h after casting. This is one hour and six minutes prior to the time when the crack occurs at the site. The calculated average strain ratio at point of cracking is 1.01. The estimated time of cracking of the west wall is 203 h after casting, nearly two hours before the observed crack, se Figure 1. Already at 146 h after casting the calculated strain ratio shows a local maximum with magnitude 1.00, but no tensile strength failure was measured.

From the study so far, it is concluded that:

- ERM is suitable for cracking analyses where complicated restraint conditions are present.
- Strain measurements on site provide a good possibility for comparisons to calculation.
- ERM seems to correlated well with real behaviour of a thermal cracking situation.
- Future work involves evaluation of ERM for other typical cases and comparison with other methods.

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