Discussion of "Thoughts about drying shrinkage: Scale effects and modelling"

by L. Granger, J.-M. Torrenti, P. Acker (*Materials and Structures*, 30 (196) (1997) 96-105).

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The paper by Granger, Torrenti and Acker outlines a theoretical approach to the determination of shrinkage of a concrete member subjected to drying. In that paper, the authors consider that the free drying shrinkage of any element in the concrete is linearly related to the humidity or moisture change of the concrete at that point. The authors continue with analyses of the free shrinkage strains assuming a perfectly elastic, brittle elastic or plastic material. The methodology used by Granger *et al.* is very similar to that presented in a 1993 paper entitled 'Prediction of drying shrinkage of concrete from internal humidities and finite element techniques' [1]. This paper was taken in part from the Ph.D. thesis of McDonald [2].

McDonald used the work of Pihlajavaara [3] to support use of a linear relationship between drying shrinkage and relative humidity of a fine concrete member. McDonald and Roper also discuss that linear and non-linear equations cannot be used for prediction of moisture contents within concrete members and use an empirical relationship to determine the relationship between relative humidity within the concrete member, ambient relative humidity, depth from the drying surface, water-binder ratio and drying period. The resulting equations, relating humidity within the concrete at any time and the linear relationship between humidity and free shrinkage, were used by McDonald and Roper in combination with linear elastic finite element analyses to show close approximation of experimentally measured shrinkage strains for specimens of various sizes. Measured warping strains of concrete specimens during drying were also measured and approximated using the methods presented in that paper. Allowances for creep of the stressed exterior surfaces were further considered by McDonald.

It is disappointing that none of the extensive mathematical equations presented by Granger *et al.* are correlated to experimental data; however, it is pleasing to see that the methods similar to those presented by McDonald in 1990 are subject to continued research.

REFERENCES

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- [3] Pihlajavaara, S. E., 'A review of the main results of a research on the aging phenomena of concrete: Effect of the moisture conditions on strength, shrinkage and creep of mature concrete', *Cement and Concrete Research* 4 (1974) 761-771.

REPLY TO THE DISCUSSION OF D. B. McDONALD

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First of all, we would like to thank Dr. McDonald for his comments on our work and, more generally, on the modelling of drying shrinkage of concrete. However, we would like to take this opportunity to examine these comments from other viewpoints.

• In our paper, we not only consider, as written by McDonald, that the free drying shrinkage of concrete can be linearly related to the humidity and moisture changes in the concrete. We proposed a theoretical approach based on the mechanics of porous media showing that the expression obtained for drying shrinkage

$$\epsilon_{rd} = \text{tr}[\epsilon_{rd}] = \phi^l \frac{3\rho^l R\theta}{M^v(1-\phi)K^s} \ln(h) \quad (\text{see notations in [6]})$$

reveals a double nonlinearity with respect to relative humidity in the form $\phi^l \ln(h)$, where ϕ^l is the part of the porosity occupied by the liquid phase and h is the relative humidity of concrete. From this theoretical expression, and with certain hypotheses explained in [6] (in particular in a certain range of variation of humidity ($h > 50\%$)), we demonstrated that the drying shrinkage can be approximated in two different ways, both classical and yet different [4], first of all as proportional to the change