DEVELOPMENT OF A RELAXATION TEST-FRAME

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ABSTRACT

This paper describes how relaxation tests on young concrete are performed at the Division of Structural Engineering at Luleå University of Technology. The development of a new test machine is presented and some results from pilot tests are given.

The presented test method can be used to simulate different thermal stress conditions in the casting of massive concrete structures. This means that it may reduce the need for complicated and expensive full scale tests to ensure that no cracking takes place in newly cast concrete structures.

A one meter long concrete beam is poured directly into a form in a steel frame. Temperated air is blown into a hox containing the specimen and is circulated around it. In this way the specimen can be given a temperature development which is representative for a specific concrete structure.

One of the short ends of the specimen is fixed in the steel frame and the other end is free to move in the longitudinal direction. The position of the free end of the specimen is kept within 0.2 μm from the initial position by a servo-hydraulic cylinder. In this way, nearly 100% restraint is obtained. The force acting on the cylinder is directly proportional to the stresses occurring in the concrete specimen.

Key words: Relaxation, thermal stresses, cracking risks, young concrete.

1. BACKGROUND

In newly cast massive concrete structures the temperature rise caused by the hydration process is considerable and extends over a long period of time. Due to restraint conditions imposed in a massive concrete element by adjoining structures or by different parts of the structure itself, the temperature rise will induce compressive and tensile stresses in the element. A question of primary interest is whether the induced tensile stresses will lead to thermal cracking. This question has been discussed by e.g. Emborg (1989) /1/ and Jonasson (1994) /2/.

In order to determine the thermal stresses, elastic and creep properties of the fresh concrete, thermal properties of the concrete and the above mentioned restraint of adjoining structures can be modelled. Models for these properties have been presented by Bazant et. al. (1985), Emborg (1989), Kanstad (1990), Ekerfors et. al. (1993), Emborg et. al. (1993), Rostasy et. al. (1993), Emborg & Bernander (1994), Jonasson (1994), Westman (1994), /1/-/9/

A very important part of the research is to calibrate the theoretical models in laboratory tests for different types of concrete mixes, cement types etc. Thus, a test method has been developed in Luleå where the thermal stresses as well as the time to tensile failure in concrete specimens are recorded. This test method will be presented here.

Laboratory work where thermal stresses and relaxation are studied for young concrete is performed in e.g. Munich, Springenschmid & Breitenbücher (1990), Breitenbücher (1989) and Breitenbücher (1990), /10/-/12/ and Braunschweig, Rostasy et.al. (1990), Laube (1990) /13/. A Rilem working group headed by professor Rupert Springenschmid is investigating the field of thermal cracking. In many other places in the world research on this problem is now being started.

2. TEST METHOD

The frame consists of rectangular hollow steel beams with profile VKR 450x250 mm (steel thickness 16 mm), see Fig 1. The concrete specimen is a 1m long beam, 150 mm in square. In the relaxation tests the concrete is poured directly in the frame. Tensile reinforcement consisting of 8 threaded rods (M6, 100 mm long) at each end transmit tensile forces from the concrete to the frame during the cooling process.

A plastic foil surrounds the specimen protecting it from drying. In the frame the specimen is located in a box made of Plexiglas, see Fig 2. Two heaters blow temperated air into the box in order to give the concrete specimen a temperature development representative to some specific concrete structure.

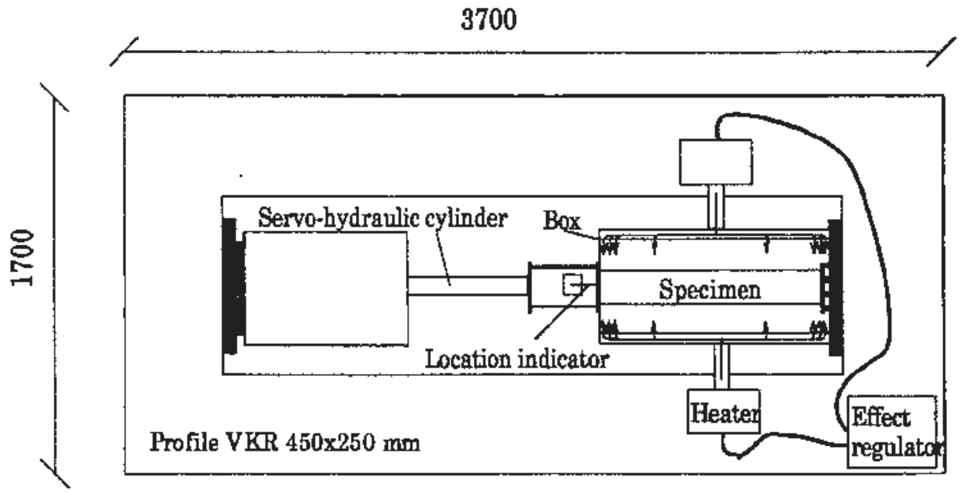

Fig 1. Relaxation test-frame.

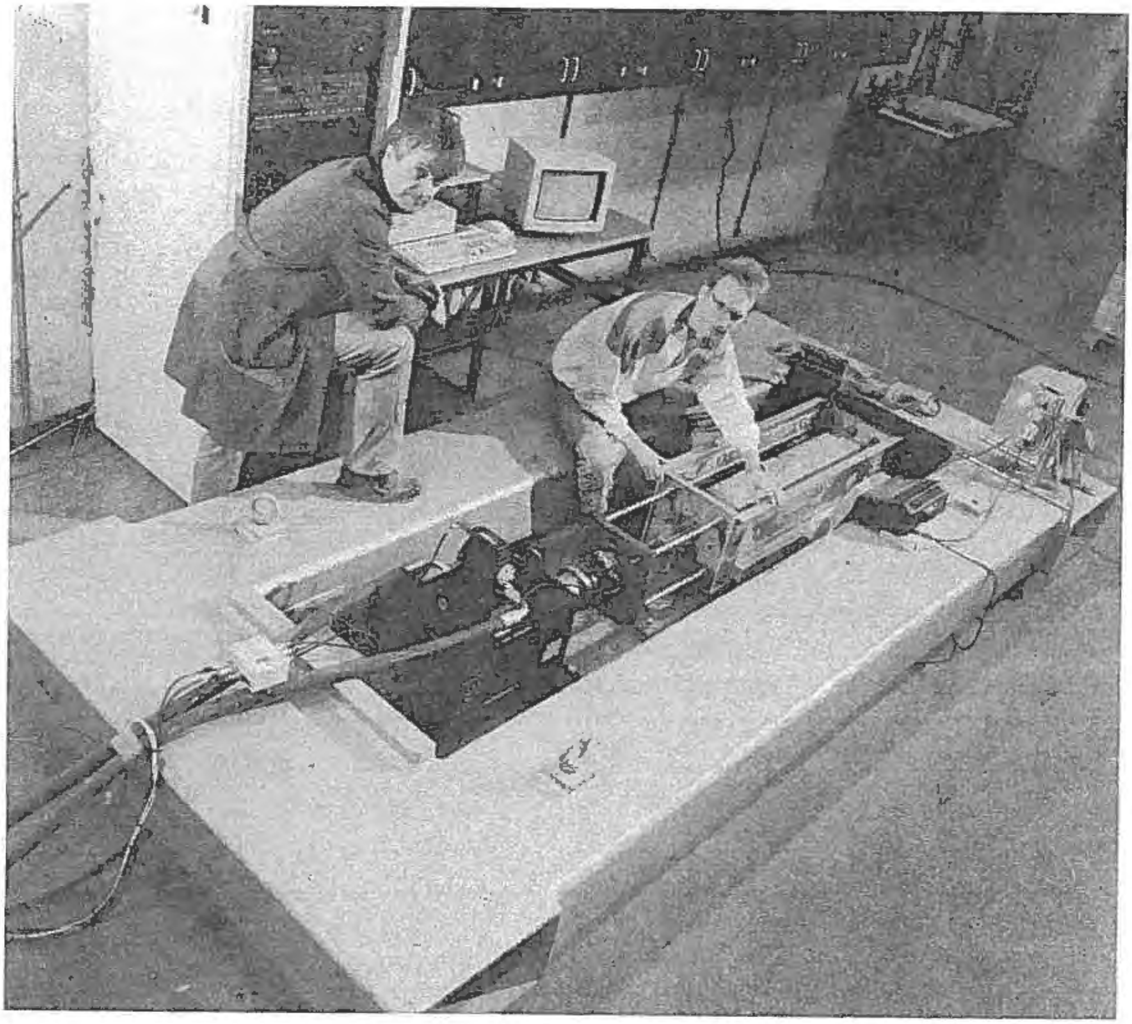

Fig 2. Relaxation test-frame.

One end of the specimen is fixed in the frame, which in turn is fixed to the floor, and the other end is free to move in the longitudinal direction of the specimen. When the temperature rises due to the hydration, the specimen tends to expand. A servo-hydraulic cylinder (capacity ± 750 kN, cylinder stroke 150 mm) will press the free end back into position so that the length of the specimen is held constant. In the same way the servo-hydraulic cylinder will pull the free end back to its initial position when the specimen tends to shrink in the cooling stadium of the test. This is controlled by a displacement indicator measuring the location of the free end related to the floor (i.e. related to the free end). The force excited by the cylinder is directly proportional to the stresses occurring in the concrete specimen.

3. TEMPERATURE REGISTRATION

Every 30:th second the temperature is recorded by seven temperature transmitters cast in the specimen, see Fig 3. If a weighted mean temperature of the transmitters is not equal to the desired value (representative for some specific structure), two heaters starts to blow temperated air into the box containing the specimen.

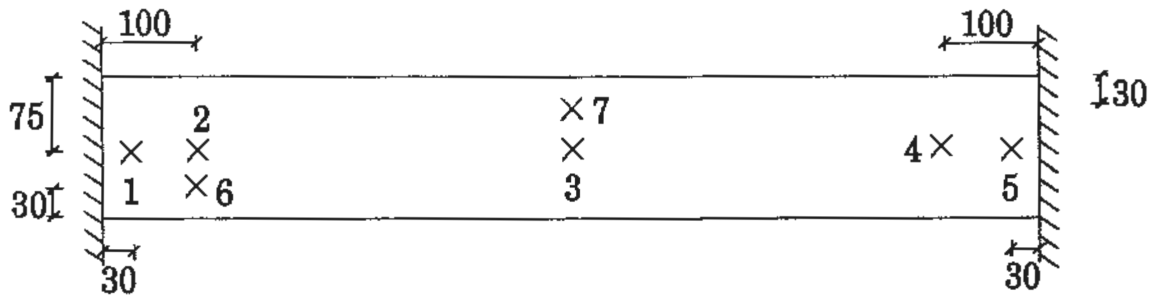

Fig 3. Location of thermal transmitters [mm].

The temperature curve representative for some structure is computed hy the program HETT5 /14/. The modelling with HETT5 is based on data on maturity development and heat of hydration ohtained at laboratory tests on the specific concrete, see e.g. /3/ and /15/.

In the first pilot tests a temperature gradient of approximately 10 °C occurred in the longitudinal direction of the specimen. It was the outer 50 mm of the ends that had a lower temperature than the rest of the specimen. The reason for this was that the ends are in contact with the steel frame, which had room temperature. In order to overcome the problem of end cooling, heating cables have been embedded in the end zone of the specimen. If there is any difference between end temperature and the temperature in the middle of the specimen, the cables are activated. In this way only small temperature gradients (2-3 °C) occur in the longitudinal direction of the specimen, see Fig 4. The temperature gradients in the cross section is even smaller.

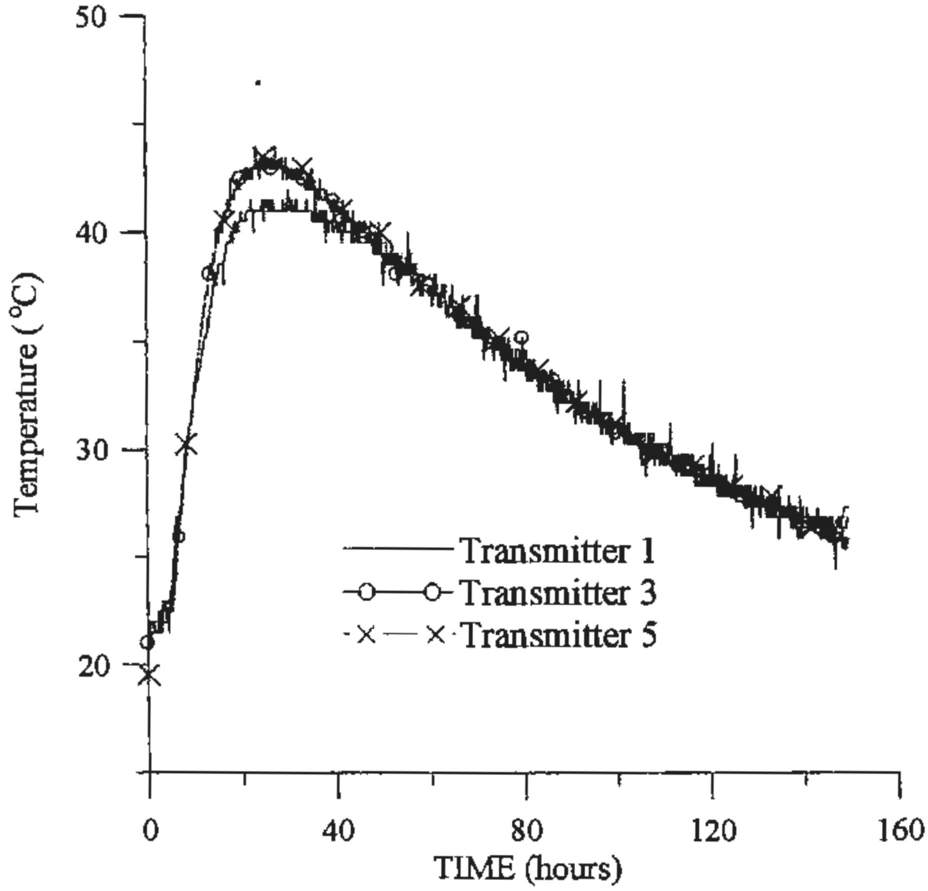

Fig 4. Temperature registrated in the ends and in the centre of the specimen

4. DISPLACEMENT INDICATOR

In order to control the position of the free end of the specimen a displacement indicator is pressed against the free end. The indicator is of type HS/HLS 5B from Welwyn Strain Measurement, see Fig 5. The WSM strain gauge displacement transducer uses a fully active 350 ohm strain gauge bridge to sense spindle displacement. If a displacement larger than 0.2 μm is obtained a compensation is performed by the load cylinder.

Some other technical specifications are:

- Spring force 200 g
- Strain sensitivity 1400 10^{-6}/mm
- Temperature range -10-60 °C
- Resolution infinite
- Range 6.5 mm

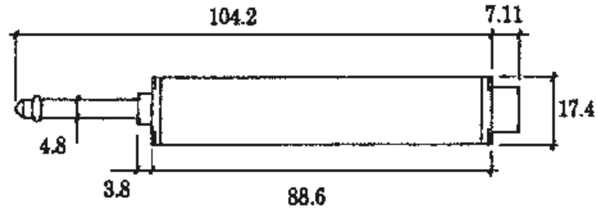

Fig 5. WSM Strain Gauge Displacement Transducer type 5B [mm]

Tbe strain transformer requires only low voltage and current, and can be energised with either DC or AC. Input is 10 V and output 45 mV.

5. REGULATION

The temperature development in the concrete specimen is controlled by a program for a personal computer developed at the Luleå University of Technology. In principal the temperature regulation is performed in seven steps:

1. Read temperature transmitters.
2. Construct weighted mean temperature from selected temperature transmitters.
3. Calculate the temperature difference between the calculated hydration temperature curve and the weighted mean temperature.
4. Calculate the heater output from temperature difference using two serial connected software PID (Proportional Integrating Derivating) regulators.
5. Calculate the temperature difference between end-point transmitters and control point.
6. If the temperature difference exceeds preset value, activate end-point heat cables.
7. Read displacement from indicator and compensate position cylinder for frame stiffness (occurring due to bending of VKR-beam in the short length of the frame).

In the pilot tests all, seven transmitters has been given the same weight, but with the used program it is easy to let the transmitters represent different parts of the specimen by a weighted temperature value. The temperature difference between the two end-points and the control point (in the middle of the specimen) are measured separately. In order to simulate 100% restraint at the stiff end, compensation for the stiffness in the frame are performed if the displacement is larger than 0.2 μm (step 7).

6. THERMAL STRESS COMPUTATION

Data with respect to the mechanical behaviour of the concrete is obtained from laboratory tests on maturity and strength development, creep, heat of hydration and free thermal volume change.

Creep data is then modelled with an extended version of the Triple Power law, see Westman /8/, and transformed to relaxation data by solving the relaxation function R(t,t′) from the compliance function J(t,t′), see e.g. Bazant and Wu /16/. Then a material model consisting of three rheologic elements in series can be used for the analysis of thermal stresses, see Fig 6. The first element describes the fracture behaviour at high tensile stresses. The second is a visco-elastic element describing elasticity and creep and the third element represents thermal displacement.

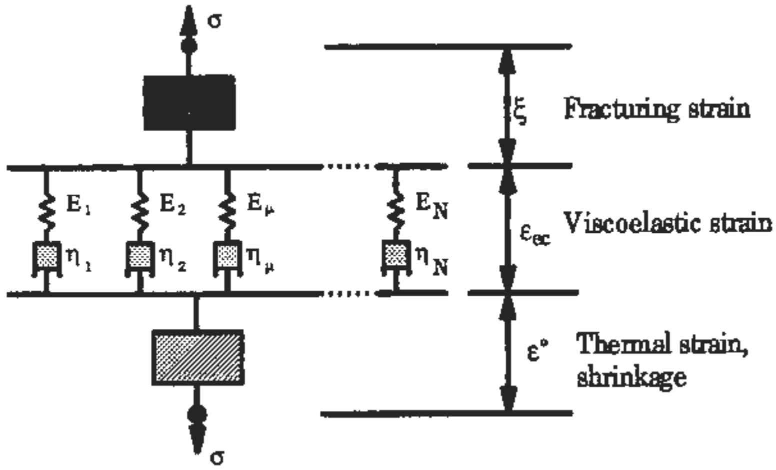

Fig 6. Proposed rheologic model, see e.g. Westman /8/.

In the examples thermal stresses have been calculated using the temperature curve obtained from HETT5. In this case the temperature development in a 0.7 m thick wall with insulated formwork was simulated. Here thermal stresses were calculated disregarding fracturing strain and shrinkage. In Fig 7. calculated stresses and measured stresses from tests on two different concrete mixtures are shown. Input temperatures for the stress analysis were obtained from theoretical computations simulating a concrete structure poured between inflexible supports.

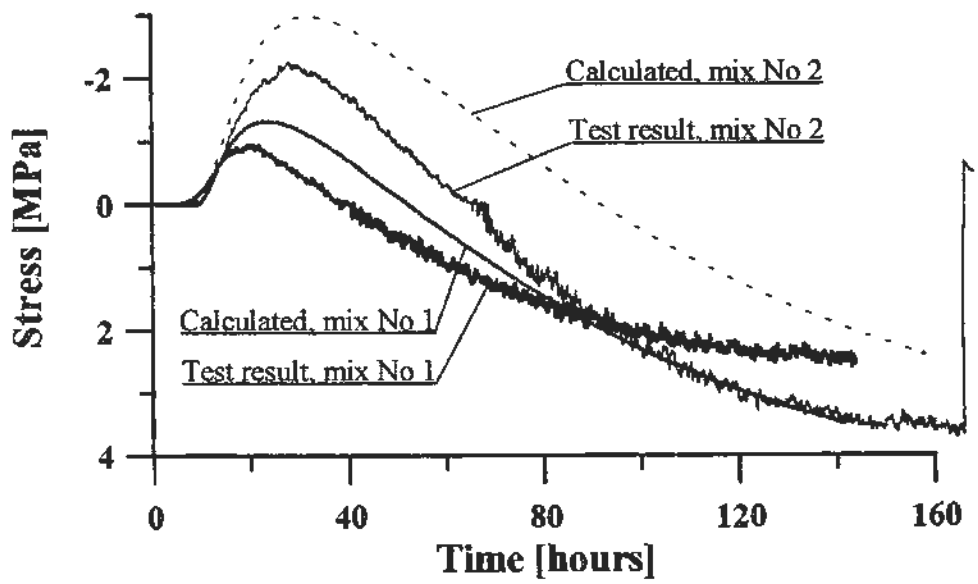

Fig 6. Example of measured and calculated stress development with a linear model disregarding fracturing strain and shrinkage.

As can be seen in the figure there is a certain difference between calculated stresses and the test results, probaly due to the fact that the calculated curves in this case do not consider fracturing strain and shrinkage. The examples demonstrates that, for an accurate thermal stress analysis, a better modelling of the mechanical behaviour is needed, including e.g. fracture mechanics behaviour at early ages, as in the model in Fig 6.

7. CONCLUSIONS

The research with the test-frame and with other versions of such frames has shown that it is of utmost importance for an accurate thermal stress analysis, that correct modelling of the mechanical behaviour is performed. The research has also shown that it is essential to study the overall mechanical behaviour for a concrete subjected to early age temperature increase and decrease. It is not enough to model separate mechanical properties such as creep, strength development etc. as complicated coupling effects occur when the young concrete is heated.

With the test-frame developed at Luleå University of Technology theoretical models for thermal stress analysis can be calibrated, and the behaviour of different concrete mixtures for various casting situations can be checked.

8. ACKNOWLEDGEMENT

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The concept to the method was formed among others by Professor Stig Bernander. Mr Hans-Olof Johansson has performed most of the pilot tests together with the authors. Mr Kjell Havnesköld has developed the control computer program. The work has been supervised by Professor Lennart Elfgren, head of the Division of Structural Engineering at Luleå University of Technology.

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