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Modeling of Concrete Response at High Temperature

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Abstract

A rate-type creep law is implemented into the computer code TEMP-STRESS for high temperature concrete analysis. The disposition of temperature, pore pressure and moisture for the particular structure in question is provided as input for the thermo-mechanical code. The loss of moisture from concrete also induces material shrinkage which is accounted for in the analytical model. Examples are given to illustrate the numerical results.

Introduction

Creep is the slow increase of deformation due to a sustained load. Its magnitude depends on age, composition, temperature, humidity, pore pressure, size, etc. Creep may cause extensive stress redistributions in structures, which along with the shrinkage and thermal dilation, may lead to severe cracking. These effects are therefore important and should be included in the structural analysis. In large structures and at low temperature (below 100°C) the effect of shrinkage is insignificant.

Basic Creep Analysis

The type of creep analysis which is applicable to high temperature and humidity is the rate-type approach. Two rheological models, the Kelvin and Maxwell, have been shown to be quite successful in modeling concrete creep [3]. The Maxwell chain model was chosen because the Dirichlet series expansion of the relaxation function yields an easier interpretation of material properties. The Maxwell chain creep model has been incorporated into the thermo-mechanical code TEMP-STRESS.

The effect of creep of a large prestressed reactor containment vessel is illustrated here to show the thermal effects on creep without shrinkage being taken into account. The dimensions and prestressed loads of the cylindrical concrete containment vessel is shown in Fig. 1a and the corresponding discretization of the analytical model is given in Fig. 1b. Prestressing of the containment vessel is performed in 18

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days after casting of the concrete, and the operating temperature of the vessel is increased 75°C from the standard temperature of 25°C on the 730th day after casting.

The creep of the concrete is expressed by the double-power law. An exaggerated vessel deformation for different times is given in Fig. 2a. This shows the effect of prestressing, the increase in temperature and creep on the deformation of the vessel. The deformation of Point A and B on the vessel are shown in Fig. 2b. Notice that the increase of the temperature counteracts the deflection due to creep.

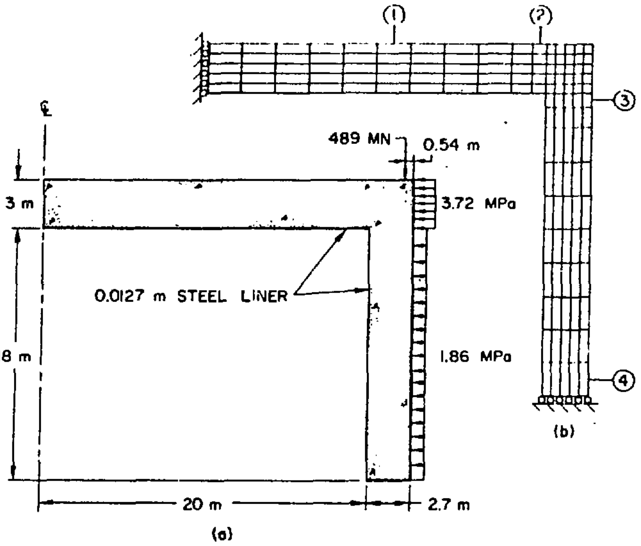

Fig. 1. Vessel Particulars and the Analytical Model.

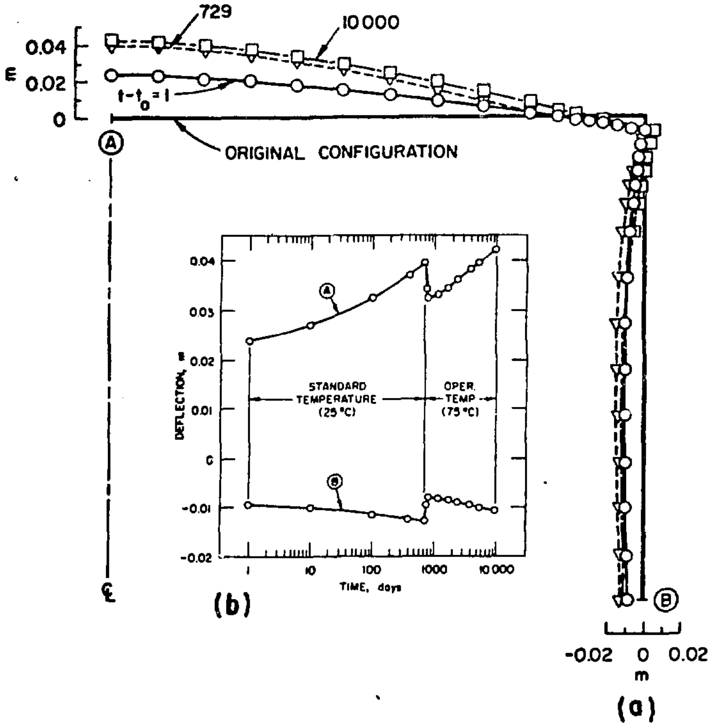

Fig. 2. Vessel Deformations at Various Times.

Effect of Shrinkage

At temperatures beyond 100°C, the modeling of concrete becomes significantly more complex. The complexity comes about because of phase change of water within concrete. With high temperatures, large amounts of moisture are lost from concrete. This loss of water induces several structural changes in concrete behavior, which must be accounted for in the analytical models. One important factor, which must be taken into consideration, is the shrinkage of concrete, which is considered in this section.

In the analytical model shrinkage is assumed to be isotropic and is thus accounted for on a purely volumetric basis. This modeling procedure closely parallels that of thermal material expansion; where the change in temperature is substituted by the loss of moisture. The shrinkage coefficient is assumed to be constant.

The change in moisture of concrete is calculated by a special computer code called TEMPOR2, which provides the time variations of temperature, pore pressure and the moisture disposition. This information is fed into the structural code TEMP-STRESS for stress calculations.

The illustration of the effect of shrinkage due to moisture loss is calculated for an axisymmetric cylinder, the test results of which have been described in Refs. [1] and [4]. These test results pertain to a 75 mm diameter, 150 mm long cylindrical specimen, which is constrained axially at the ends and its external cylindrical surface is being heated by the temperature history given in Fig. 3. The concrete specimen stress-strain data, ranging from room temperature through 770°C, are displayed in Fig. 4.

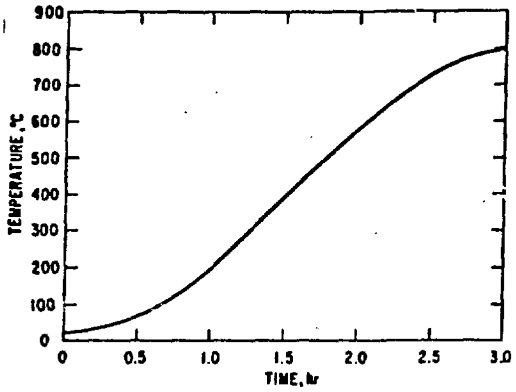

Fig. 3. Temperature History at the Cylinder Surface.

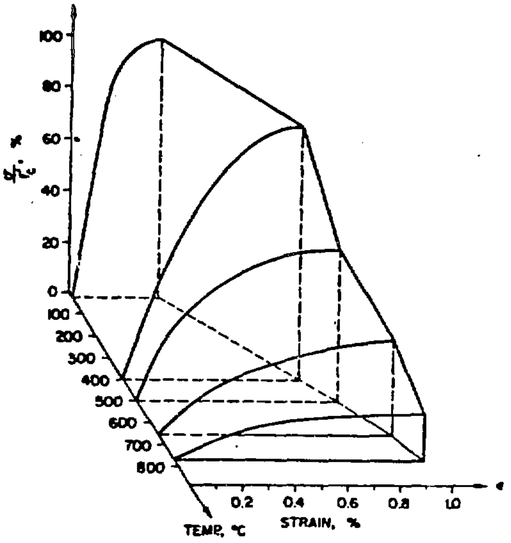

Fig. 4. Stress-Strain Input.

The structural calculations for 6% and 4% moisture losses, with the corresponding test data, are displayed in Figs. 5 and 6. Analytical results are computed for several different values of shrinkage coefficient (k_w), which, according to a recent study [3] should be in the neighborhood of 10^{-5} m^3/kg. The curve designated by $k_w = 0$ corresponds to the case with no shrinkage; only thermal stress is considered.

The major trend of stress increase to a peak value at about 1.5 hr and then gradual decrease primarily reverts to the variation of stress-strain data with temperature. It is observed that shrinkage due to moisture loss has the effect of significantly decreasing the stress peak, which is in general conformity with test data. However, better agreement of analytical results with test data is sought.

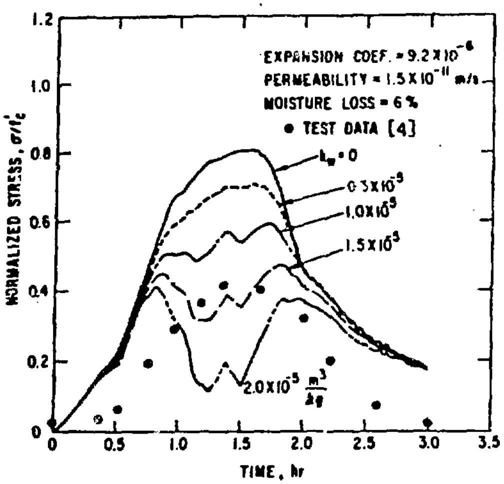

Fig. 5. Average Stress History for Moisture Loss of 6%.

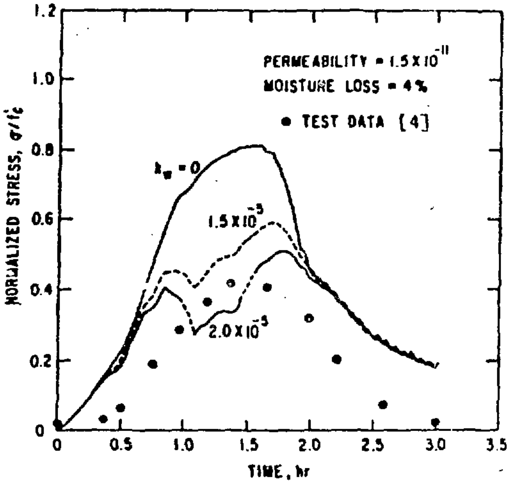

Fig. 6. Average Stress History for Moisture Loss of 4%.

Concluding Remarks

The modeling of linear creep and shrinkage of concrete were described in this paper. There are also other factors in high temperature response of concrete that must be addressed, before a full constitutive model can be implemented. One of these is the compressive and tensile softening in the constitutive relation of concrete. Another is the stress-dependent strain which may be either proportional to temperature or moisture loss. The latter effect still needs more experimental backing before it can be fully accounted for. Nonlinear creep is also an important factor and is being actively pursued at the present time. All these effects have an important bearing on the high temperature response of concrete.

Acknowledgement

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References

[1] Anderberg, Y. and Thelandersson S., "Stress and Deformation Characteristics of Concrete at High Temperatures," Bulletin 54, Lund Institute of Technology, Sweden, 1976.

[2] Bazant, Z. P., "Mathematical Model for Creep and Thermal Shrinkage of Concrete at High Temperature," Nuclear Engineering and Design, Vol. 76, No. 2, Nov. 1983, pp. 183-191.

[3] Bazant, Z. P., "Mathematical Models for Creep and Shrinkage of Concrete," Chapter 7 in Creep and Shrinkage in Concrete Structures, Ed. by Z. P. Bazant and F. H. Wittmann, John Wiley & Sons, Ltd., 1982.

[4] Thelandersson, S., "On the Multiaxial Behavior of Concrete Exposed to High Temperature," Trans. of the 7th Int. Conf. on SMiRT, Vol. H, paper H 3/1, Aug. 1983, pp. 119-126.