

NONLINEAR METHODS OF STRUCTURAL ANALYSIS

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The physical and mathematical implications of different types of material non-linearity are discussed. Requirements for the mathematical description of material characteristics are stated; this leads to some considerations on how experiments on material behaviour should be conducted to yield results (non-linear stress-strain relations, failure criteria) which can be used as a basis for the analytical treatment. Examples compare calculated and experimental results for structures with non-linear and time-dependent behaviour. Also, it is illustrated how finite element and fracture mechanics concepts may be combined for the determination of crack behaviour in complex structures.

New results are presented for the analysis of geometrically non-linear structures. Stability and large-deflexion analysis of thin shells is treated and illustrated by examples.

Some results are given concerning the suitability and economics of different numerical solution techniques for non-linear problems. Attention is drawn to the development of associated software.

DISCUSSION

G. L. ENGLAND, U. K.

Q Referring to the creep analysis of the thick walled concrete vessel in Dr. Willam's presentation I would like to make firstly an observation and then couple this with a question. The observation concerns the methods of analysis used to predict the time variation of the stresses in the vessel wall. For the example given the rate of creep analysis forms a lower bound estimate for the stresses at the inside face because this method overestimates changes of stress, while the effective modulus theory gives an upper bound solution. Both theories predict identical solutions when the creep capacity of the concrete is sufficiently high to enable the long-term steady state solution to be achieved. Superposition methods, depending upon this particular form give solutions which lie between the two methods mentioned previously and may or may not provide more acceptable solutions than the rate of creep analysis. This will depend upon the nature of the creep strains and recovery strains which are introduced into the analysis at times after initial stressing and heating. My question therefore is: does the superposition analysis of paper M 2/2 take into account the temperature-dependent irrecoverable creep strains and the essentially temperature-independent recovery strains or does it allow for creep and recovery strains of equal magnitude when an element of the material is subject to an incremental change of stress which may be either positive or negative ? Also, do those changes of strain correspond to the creep strains obtained in control experiments for a specimen first heated and loaded at the time of stress alteration ?

K. WILLAM, Germany

A Let me thank first Prof. England for his interesting remark regarding the upper and lower bound properties of the effective modulus and rate of creep method. The superposition method as employed for the determination of creep of the thick-walled cylinder does not consider differences for creep and creep recovery. The creep law available to us was derived at the IKI Bochum, from the creep data accumulated at Taylor Woodrow. To my knowledge these creep specimens were subjected to a heat cycle before loading in order to simulate the effects of heat of hydration in mass concrete.

Y. R. RASHID, U. S. A.

C The use of time-temperature shift hypothesis can be used to generalize isothermal creep formula to transient temperature fields. The method is published in the JAM.

K. WILLAM, Germany

A Dr. Rashid, I like to thank you for your comment indicating the usage of "temperature-compensated" time to account for non-isothermal creep of metals. The well-known time-temperature shift principle forms the basis for constitutive relations of thermorheo-

logically simple materials exhibiting memory. Normally creep of metals is described by equations of state, where temperature effects are incorporated directly in the creep law.