

論文

[2115] A Time-Dependent Uniaxial Constitutive Model of Concrete as Composite Structural Material

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1. INTRODUCTION

It is well known that the seismic load on a structure subjected to an earthquake is extremely complicated because not only the seismic force but also the loading speed changes with time. In finite element method analysis of reinforced concrete structures under such loads with complex histories, it is necessary to have a constitutive model which can give the stress for arbitrary strain-time history. At present there are several models which can be used for cyclic loadings of constant loading speed or monotonic loadings of varied loading speeds separately (1)-(4), but no model suitable to seismic analysis is available. In this paper the time-dependent constitutive relation of concrete is simulated by a so-called "elasto-viscoplastic fracture model" composed of elastic-plastic-viscoplastic bar elements with different elastic, plastic and viscoplastic properties.

2. MODELING PROCEDURES

In this paper the uniaxial constitutive relation of concrete under arbitrary loading histories is proposed to be simulated by the behavior of a structure composed of elasto-viscoplastic bar elements as shown in Fig.1. In order to establish this model the properties of each element has to be known for a given strain-time history.

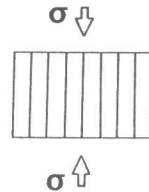


Fig.1 Concrete model

2.1 CONSTITUTIVE RELATION OF ELEMENTS

In the selection of the constitutive relations of individual elements, which use the same forms of equations but different coefficients for each element, it is advisable to use functions which are not only relatively simple but can also represent some basic characteristics of concrete. As shown in Fig.2, each element of the model is composed of three interrelated components, namely, elastic component, plastic component and viscoplastic component in order to account for the corresponding

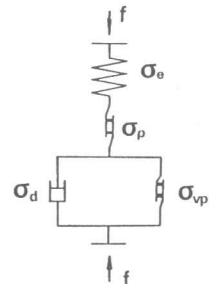


Fig.2 Element model

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strains. The characteristics of each component is explained first. In this paper, the stresses and strains used are normalized by the maximum stress and the corresponding strain respectively with plus for compression.

The elastic component of an element generates the elastic strain of the element only. Assuming the initial elastic modulus of the elastic component being E, the stress of the elastic component is

$$\sigma_e = E \cdot \varepsilon_e \quad (1)$$

As external load increases, plastic strain of concrete will develop even if load speed is very high. The plastic strain depends not only on the stress σ_e applied to this element or the elastic strain according to Eq.(1) but also on viscoplastic strain ε_{vp} because plastic strain is affected by the compact of concrete due to viscoplastic strain. In this model plastic strain is presumed as follows

$$\varepsilon_p / \varepsilon_{e1} = (\text{Exp}(a / (1.0 - \varepsilon_e / \varepsilon_{e1})^b) - \text{Exp}(a) - \varepsilon_{vp} / (\varepsilon_{e1} + C \cdot \varepsilon_{vp}))_{\max} \quad (2)$$

in which a, b and c are material coefficients. The symbol ε_{e1} is the maximum compressive elastic strain that this element can reach. The notation $()_{\max}$ means the maximum value in loading history. For tensile loading it is assumed that time independent plastic deformation does not occur.

In an individual element the time dependent strain is included in a viscoplastic component which consists of a dash pot and a strain hardening slider as shown in Fig.2.

$$d\varepsilon_{vp}/dt = \gamma \cdot \sigma_d / E \quad (3)$$

in which ε_{vp} is viscoplastic strain, γ is supposed to depend on the stress on the dash pot σ_d and a fluid parameter of concrete γ_0 ,

$$\gamma = \gamma_0 (\sigma_d / (E \cdot \varepsilon_{e1}))^d / (1 - (\sigma_d / (E \cdot \varepsilon_{e1}))^e) \quad (4)$$

in which b, e are constants. These formula of the dash pot can also be used for tensile viscoplastic strain ε_{vpt} with the maximum tensile elastic strain ε_{e1t} in place of ε_{e1} . As viscoplastic strain increases the yielding stress of the slider will also become greater due to strain hardening. During the loading process, the yielding stress of compressive strain hardening is given by

$$\sigma_{yc} = E \cdot C_{rp1} \cdot \varepsilon_{e1} \cdot (1 - g / \text{Ln}(\varepsilon_{vp} / \varepsilon_{e1} + \text{Exp}(g))) \quad (5)$$

in which g and C_{rp1} are coefficients, $E \cdot C_{rp1} \cdot \varepsilon_{e1}$ is maximum yielding stress that can be gained through viscoplastic compressive strain hardening of the slider. In the case of tensile viscoplastic strain hardening, the yielding stress σ_{yt} can be obtained by the same strain hardening rule as Eq.5, but with ε_{e1t} replacing ε_{e1} and different values of coefficients. The slider only moves when tensile stress or compressive stress is greater than corresponding yielding stress. The stresses of these components in an element should satisfy equilibrium. Hence, the stress of an element is

$$\sigma_e = E \cdot \varepsilon_e = \sigma_{vp} + \sigma_d \quad (6)$$

in which, σ_{vp} is the stress of viscoplastic hardening slider