CREEP AND AGING EFFECTS IN SEISMIC ANALYSIS OF SHALLOW ARCH BRIDGES

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SUMMARY

The paper presents an analysis of the creep and aging effects on dynamic response of concrete shallow arch bridges. Comparative analyses, using a range of different creep and shrinkage parameters and functions are conducted to estimate their respective influence on dynamic structural characteristics.

INTRODUCTION

Loading histories experienced by the reinforced concrete structure prior to some dynamic excitation do affect the structural response (Ref.6). This is equally true for the loading histories cousing imediate inelasticity as for the effects of creep and shrinkage causing inelastic strains. These long-term effects are usually disregarded in dynamic analysis, but their consideration may be relevant for creep sensitive slender structures like shallow shells, long span prestressed beams and shallow arch bridges.

Although there is no doubt that these effects do exist for shallow arch bridges it is extremely hard to estimate their influence on the dynamic bridge response. This is mainly due to the fact that appropiate creep and shrinkage data are usually not available (or are available in same inadequate form) but it also depends on the fact htat, after bridge completion, the bridge geometry may be corrected several times prior to the final crown hinge closure. Therefore the structure has varying geometry at the period when most of the primary creep and shrinkage takes place.

The scope of the paper covers in fact a parameter study of a dynamic response of shallow arch concrete bridge, where a whole range of comparative analyses, employing various parameters for the creep functions, are conducted in order to asses their respective importance.

STRUCTURAL DISCRETIZATION AND ADOPTED MATERIAL MODEL

The analysis procedure adopted here employs spatial discretization via finite element method. Two dimensional bridge idealization includes beam elements, where the nonlinear effects within a crossection are traced through the series of one dimensional layers (Ref. 1).

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The behaviour of concrete is represented by nonlinear inelastic stress/strain law (fig. 1).

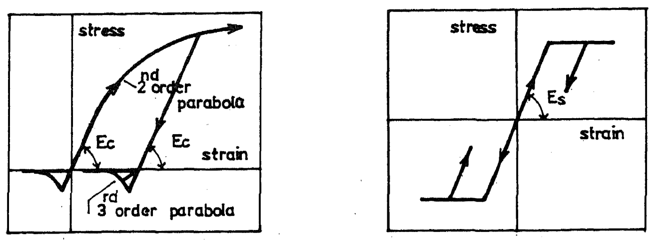

fig. 1

In compression the interpolation between the equally spaced points is made using the second order parabola. In the case of unloading initial elasticity modulus is employed. On the tension side, stress/strain law is linear until tensile strength of concrete is reached. Third order parabola definies the descending branch between the tensile strength and the ultimate tensile strain. After tensile cracking, compressive stresses can be activated only after crack closure (Ref.5).

The behaviour of steel is assumed to ideally elasto/plastic (fig.1), both in compression and tension.

As the purpose of this study is estimate the effects of mainly creep on dynamic response, the adopted creep model will be descused in more detail.

Here, the dependance of strains and stresses on the water content and temperature histories is disregarded, so the concrete can be viewed as a linear aging material and the creep law is assumed to be linear, i.e. stresses (or strains) are considered to be a function of the previous strain (or stress) history only (Ref.4).

In the integral type formulation, the uniaxial creep law can be formulated in either of the following two equivalent forms (Ref. 2)

$$e(t) - e^{o}(t) = \int_{o}^{t} J(t,t')\, dS(t') \qquad (1)$$

$$S(t) = \int_{o}^{t} E_R\,(t,t')\,(de(t') - de^{o}(t')) \qquad (2)$$

where

t time from casting of concrete

S stress

e strain

e^{o} stress independent inelastic strain

$J(t,t')$ creep function - strain at the time t caused by constant unit stress acting since time t'

$E_R(t,t')$ relaxation function - stress at time t caused by unit strain introduced at time t'

$1/J(t,t) = E_R(t,t) = E(t)$ - instantaneous E modulus

As the integral type formulation requires storing of complete stress history, the rate-type formulation is prefered where only the stresses from previous time step are needed.
The rate type formulation based on Maxwell chain model employs the following stress/strain relations (Ref. 2)

$$S = \sum_i S_i \qquad \dot{e} - \dot{e}^o = \frac{\dot{S}_i}{E_i} + \frac{S_i}{V_i} \; (i=1,2..n) \tag{3}$$

where S_i are hidden stresses (partial stresses) in the individual Maxwell units.
The relationship between V_i (t') (viscosities) and E_i(t') (spring moduli) is assumed to be constant, i.e.

$$T_i = \frac{V_i}{E_i} = \text{cost} \tag{4}$$

where T_i is relaxation time.
If e = 1.0 for t.GE.t' and e = 0.0 for t.LT.t' together with the initial condition $S_i(t') = E_i(t')$ from Eq.(3) it follows

$$S_i(t) = E_i(t') \exp^{-(t - t')/T_i} \tag{5}$$

From Eq.(2) and with $S = \sum_i S_i$ the relaxation function isthen determined as

$$E_R(t,t') = \sum_{i=1}^{m} E_i(t') \exp^{-(t - t')/T_i} + E_n(t') \tag{6}$$

where m = n-1 and $E_n(t')$ is equlibrium spring modulus for infinite viscosity and infinite relaxation time.
For every t', $E_i(t')$ is determined using the least square method from the known relaxation curves which can be found by the corversion of test creep curves.
Alternatively, for every t',$E_i(t')$ can also be determined using the least square method, from the known relaxation curves. Furthermore,to smooth E_i-s with respect to t' an approximation is adopted

$$E_i(t') = E_{oi} + E_{1i}t'^{1/8} + E_{2i}t'^{1/4} + E_{3i}t'^{1/2} + E_{4i}t'^{3/4} \tag{7}$$

where constants $E_{oi} - E_{4i}$ can again be obtained using least square method. Specific values for $E_{oi} - E_{4i}$ have been published (Ref.2) for few concrete qualities, and simple method to give a good fit for most creep tests, by using at least one known relaxation set of data for a certain concrete is presented recently (Ref.5).
As the rate type creep law can not be effectively used with standard step by step integration schemes (Euler or Runge - Kutta), the special algorithm solving differential equation withim every time step is employed.
With this algorithm inelastic creep deformation can be calculated for every time step Δt_r if the load history only for the previous time step Δt_{r-1} is known.
The model predicts results (Ref.5) which are in good agreement with experimental evidence.

The shrinkage of concrete is modelled using the expression (Ref.3)

$$e_{sh}(\bar{t},t_o) = e_{sh}\ k_h\ F_s(\bar{t}) \qquad (8)$$

where

t_o curing time - age of concrete in days at the beginning of drying
$\bar{t}=t-t_o$ duration of drying in days, t current age of concrete
F_s shape of the shrinkage curve as a function of $\bar{t}$
k_h^s humidity coefficient

All shrinkage parameters adopted here are assumed to be the same as the ones determinad earlier (Ref. 3) and the numerical prediction studies reported recently (Ref. 5) indicated very good agreement with different experimental data.

The dynamic equilibrium equations are solved using implicit direct integration scheme (Newmark $\gamma = 0.25$), employing the equlibrium and energy balance check (Ref. 7,8).
The geometric nonlinearity is included trough convected coordinates formulation (Ref. 1).

COMPARATIVE ANALYSIS AND PARAMETER STUDY

In numerical analysis real shallow arch concrete bridge has been concerned (fig.2). The arch was modelled with 7 beam elements, each of them subdivided into 10 segments, each segment composed of 16 layers

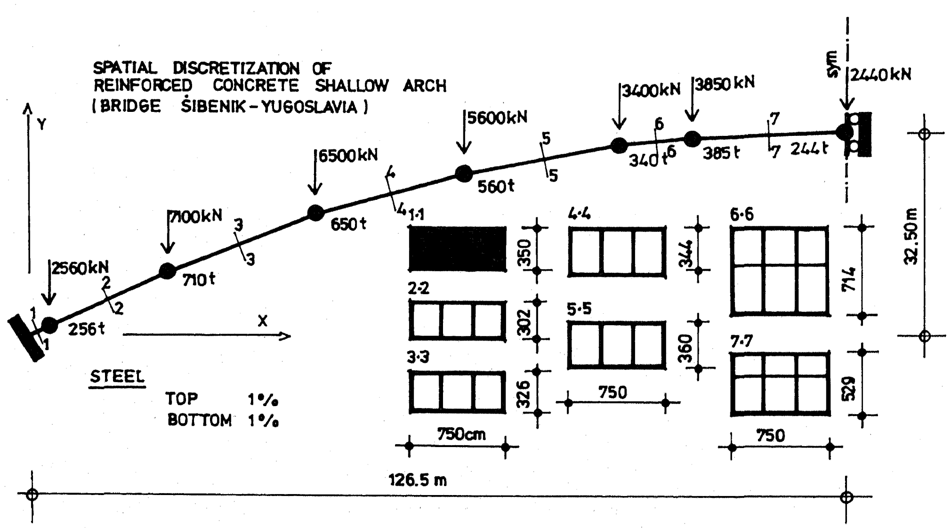

fig. 2

Two different parameter studies are made (A and B) (fig. 5,6). In both of them stress/strain laws for concrete and steel, as well as shrinkage parameters for concrete, are as shown on fig. 3.
In case A five analysis has been made. In first three (A1, A2 and A3), own weight of the bridge was taken as static load applied at age of 28 days, followed by dynamic excitation at age of 15 years (constant vertical acceleration a_y = 1.0 g)

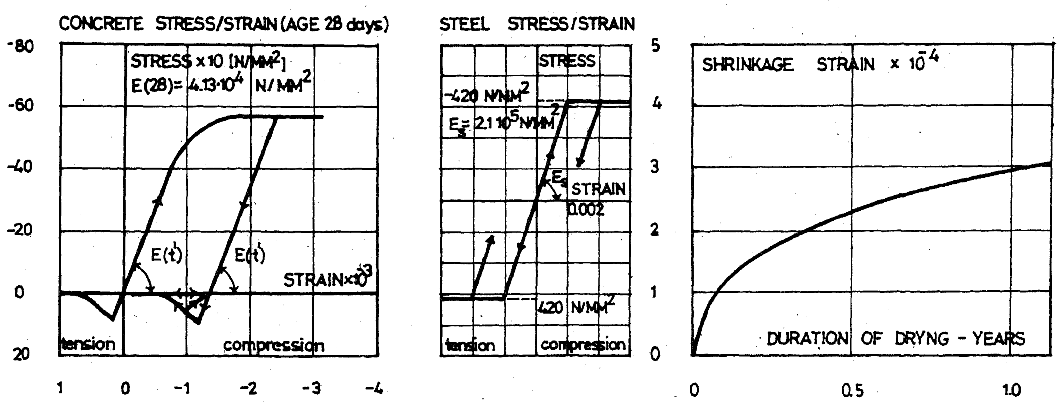

fig. 3

In analysis A1,A2 and A3,three different creep data (1,2 and 3-fig.4) were employed. In case A4 and A5 creep data were the same like in analysis A1 and A3 respectively, and also with the same static load history, followed by higher level of dynamic excitation (coustant vertical acceleration a_y=2.0g). Comparision between analysis A1, A2 and A3 (fig.5) indicate that the dynamic properties of the concrete arch were not changed significantly in spite of complete stress redistribution (due to the inelastic concrete deformation), specialy in analysis A3 were creep of concrete is very high.

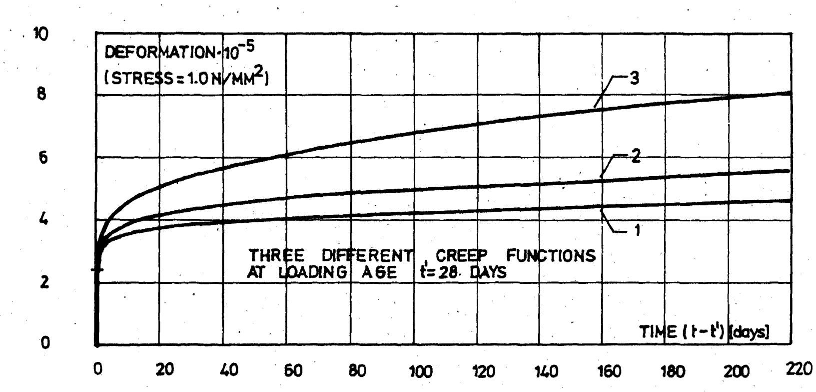

fig. 4

Comparison between analysis A4 and A5 (fig. 5) (higher level of dynamic excitation) showhs higher amplitudes of vibrations in analysis A5, due to the high creep effect, which produced more segnificant demage in the arch

In study B (fig.6) three different analysis has been made. In all of them the same relaxations data were used (curve 3, fig.4) but with three different load histories (B1, B2, B3). The magnitude of static loads, applied at age of 28 days, and dynamic excitation (a_y = 1.0g) was like in the case

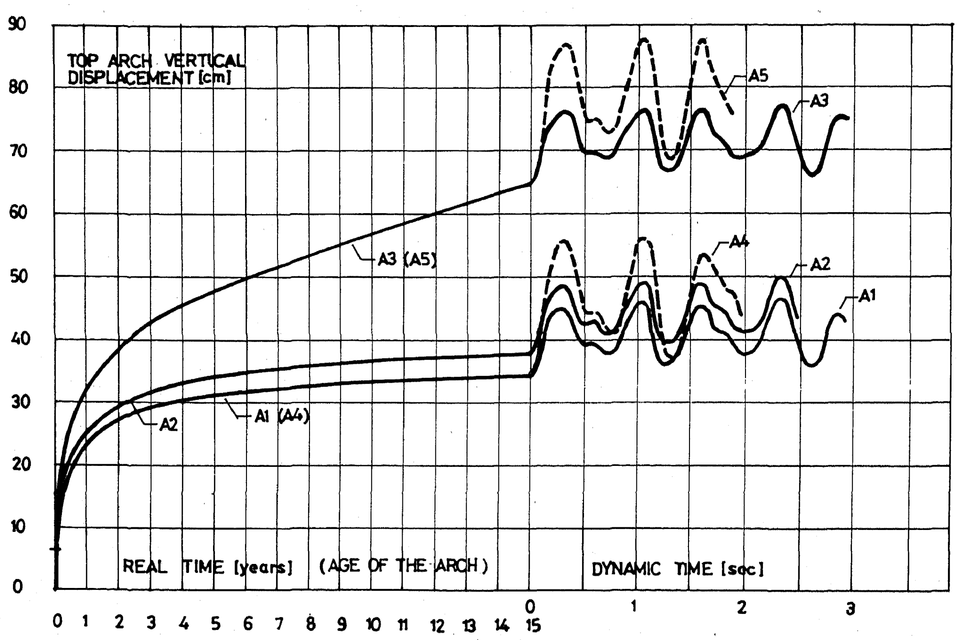

fig. 5

A, but at different ages of the structure.
In analysis B1 dynamic excitation followed at the age of 40 days, in analysis B2 at the age of one year and in analysis B3 at the age of 15 years. Case study B (fig.6) shows that the aging of concrete has significant influance on dynamic properties of reinforced concrete arch.
For young concrete structure (B1) the fundamental period of vibrations was approx. 15% larger than in the old concrete bridge (B3), and max. amplitude approx. 20% higher.

CONCLUSION

The influance of concrete ageing, creep and shrinkage on dynamic

properties of the reinforced concrete shallow arch has been considerated. The analysis indicated significant influence of concrete ageing.
Th influance of creep and shrinkage of concrete (stress redistribution) were not of very high influence, but this influence is higher at the higher level of dynamic excitation, where the accumulated demage (due to the stress redistribution) becomes more important.
Analysis indicated that it is not possible apriori to say that the influance of creep and shrinkage on dynamic properties of any reinforced concrete shallow arch is small or large.
This influance strongly depend on arch geometry, load history and material properties of the structure.

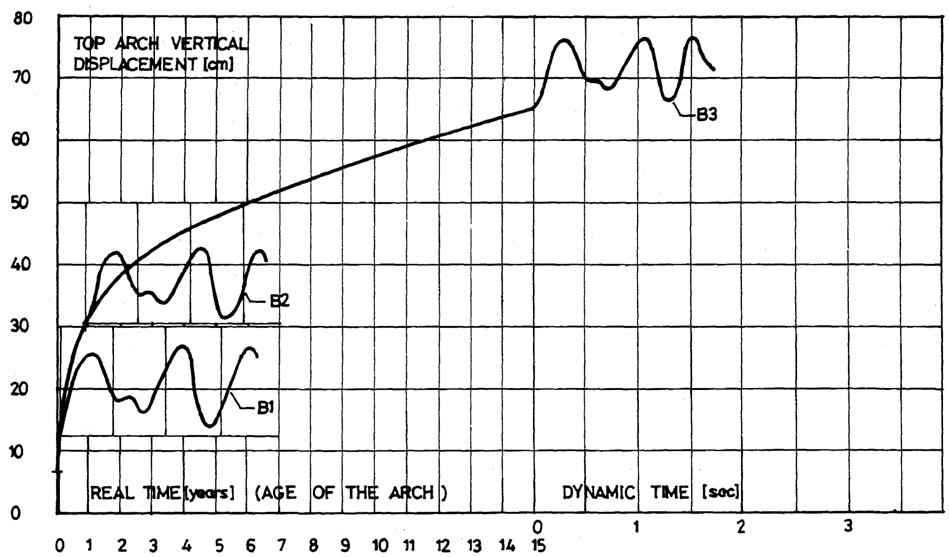

fig. 6

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