CREEP AND AGING EFFECTS IN SEISMIC ANALYSIS
OF SHALLOW ARCH BRIDGES

J. Ožbolt (I)
N. Bičanić (II)
Presenting Author: J. Ožbolt

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 causing immediate 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 appropriate creep and shrinkage data are usually not available (or are available in some inadequate form) but it also depends on the fact that, 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 assess 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 crosssection are traced through the series of one dimensional layers (Ref. 1).

(I) Research Assistant, Civil Engineering Faculty, Zagreb, Yugoslavia

(II) Docent, Civil Engineering Faculty, Zagreb, Yugoslavia

183
The behaviour of concrete is represented by nonlinear inelastic stress/strain law (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 defines 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)

\[
e(t) - e^0(t) = \int_0^t J(t,t')ds(t')
\]

(1)

\[
S(t) = \int_0^t E_R(t,t') \left(\Delta e(t') - \Delta e^0(t')\right)
\]

(2)

where

- \(t\) : time from casting of concrete
- \(S\) : stress
- \(e\) : strain
- \(e^0\) : 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 preferred 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)

\[ S = \sum_{i=1}^{n} S_i \]
\[ \dot{e} - \dot{\varepsilon}^0 = \frac{S_i}{E_i} + \frac{S_i}{V_i} (i=1,2..n) \] (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.

\[ T_i = \frac{V_i}{E_i} = \text{cost} \] (4)

where \( T_i \) is relaxation time.

If \( \dot{e} = \dot{\varepsilon}^0 \) for t.GE.t' and \( \dot{e} = 0.0 \) for t.LT.t' together with the initial condition \( S_i(t') = E_i(t') \) from Eq.(3) it follows

\[ S_i(t) = E_i(t') \exp\left(-\frac{(t - t')}{T_i}\right) \] (5)

From Eq.(2) and with \( S = \sum_{i=1}^{n} S_i \) the relaxation function is then determined as

\[ E_i(t,t') = \sum_{i=1}^{m} E_i(t') \exp\left(-\frac{(t - t')}{T_i}\right) + E_n(t') \] (6)

where \( m = n-1 \) and \( E_n(t') \) is equilibrium 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 conversion 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

\[ E_i(t') = E_{0i} + E_{1i} t'^{1/8} + E_{2i} t'^{1/4} + E_{3i} t'^{1/2} + E_{4i} t'^{3/4} \] (7)

where constants \( E_{0i} - E_{4i} \) can again be obtained using least square method.

Specific values for \( E_{0i} - E_{4i} \) 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 (Buler or Runge - Kutta), the special algorithm solving differential equation within every time step is employed.

With this algorithm inelastic creep deformation can be calculated for every time step \( \Delta t_r \) if the load history only for the previous time step \( \Delta t_{r-1} \) 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)

\[ e_{sh}(\overline{t}, t_0) = e_{sh} k_h F_s(\overline{t}) \]  \hspace{1cm} (8)

where

- \( t_0 \) curing time – age of concrete in days at the beginning of drying
- \( \overline{t} = t - t_0 \) duration of drying in days, \( t \) current age of concrete
- \( F_s \) shape of the shrinkage curve as a function of \( \overline{t} \)
- \( k_h \) humidity coefficient

All shrinkage parameters adopted here are assumed to be the same as the ones determined 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 \( \beta = 0.25 \)), employing the equilibrium and energy balance check (Ref. 7,8). The geometric nonlinearity is included through 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 $a_y = 1.0 \text{ g}$)

![Concrete Stress/Strain (Age 28 days)](image1)

![Steel Stress/Strain](image2)

![Shrinkage Strain $\times 10^{-4}$](image3)

**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 (constant vertical acceleration $a_y = 2.0 \text{ g}$). Comparison 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), specially in analysis A3 were creep of concrete is very high.

![Creep Functions](image4)

**fig. 4**
Comparison between analysis A4 and A5 (fig. 5) (higher level of dynamic excitation) shows higher amplitudes of vibrations in analysis A5, due to the high creep effect, which produced more significant damage in the arch.

In study B (fig. 6) three different analyses have 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 A, but at different stages 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 influence 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 influence of concrete ageing, creep and shrinkage on dynamic
properties of the reinforced concrete shallow arch has been considered. The analysis indicated significant influence of concrete ageing. The influence 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 damage (due to the stress redistribution) becomes more important.

Analysis indicated that it is not possible a priori to say that the influence of creep and shrinkage on dynamic properties of any reinforced concrete shallow arch is small or large. This influence strongly depend on arch geometry, load history and material properties of the structure.

![Diagram](image)

fig. 6

REFERENCES

(1) Blaauwendraad, J. (1972) Realistic analysis of reinforced framed structures Heron, Delft, IBBC - TNO


