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Research Paper

Influences of Concrete Elasticity Modulus and Long – Term Observation of Structures

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ABSTRACT: *The paper will propose a very simple procedure for the calculation of stresses and strains during long - term observation of concrete structures, when a procedure has already been formed in which E (t) = E_0.The application the modulus of elasticity of concrete is, until now, a problem, that it seems, has not been sufficiently solved in the practice and theory of RC, PC and Composite structures. A new stress-strain relation is presented, which simply complements previously published relations, which have been successfully applied in the design and construction of structures for over 60 years. An answer will be given when the creep measure (specific viscous strain) may be erroneous or insufficiently accurate through the examples of several well-known authors.The paper contains the second part of the material published in this journal (see:[17]).*
KEYWORDS*: *Concrete, modulus of elasticity, rheological data, creep (vi scosity), experiment

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I. INTRODUCTION

In the current practice of calculating the application of the modulus of elasticity under long-term loads, there are a large number of expressions, which have an empirical or semi-empirical character. A form of expression corresponding to experimental results and the form of other characteristics in rheological models can now be applied, which is described more widely in the works of the author [11] [13].

In addition, in the application of terms for the measure of concrete creep, a completely clear separation of elastic from viscous parts of stress and deformation of concrete structures is proposed (see [11]).

This approach is also useful when considering the measurement results of these quantities on concrete samples, because the analysis of the obtained measurement results should be significantly improved.

Measurements of imposed deformations on concrete samples should measure and eliminate possible errors, ie correctly evaluate the results and reduce (or increase) the results by comparing the measurement values with the mean value of the trend of the required values.

The imposed deformations originate from the changing temperature, then the shrinkage of the concrete and the humidity of the appropriate environment in which the structures or only the concrete samples will be. The dimensions of the concrete elements can also affect the specified values [2] [6] [14] [16].

II. REDUCTION FACTOR FOR MODULUS E (t)> E0

If we observe the experimental values of specific strain of concrete samples due to the action of unit stress, we obtain by measuring viscous strains (idealized) curve of viscous strains denoted by (1) in Figure 1.

This a well-known curve in many publications in this field, but also in many books that consider concrete as a viscoelastic material in the working conditions of structures when the working stresses of concrete are lower than the strength of concrete, ie in accordance with the following expression $\sigma c<0.5$ fc'.
In the author's earlier works, an overview of these relations was formed, if the equality E (t) = E0 is considered to be valid.

[2]RC - Reinforced Concrete , [3]PC – Prestressed Concrete

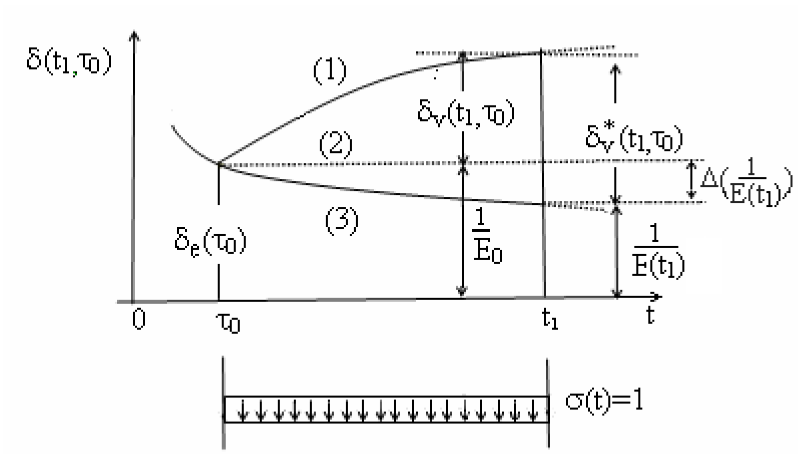

Fig.1 Curves of unit strains of concrete samples as a function of observation time

Therefore, earlier presentations will not be repeated. Now our subject will be the stresses and strains of concrete on the samples and their coincidence with the results of long-term observations of RC, PC and Composite structures.

The horizontal line (2) defines the area of strains δe below it, which is determined by the initial reciprocal value 1 / E0, for the load $\sigma(\tau_0)=1$, in the time interval $\tau_0 < \tau <= t_1$. This area can be called *the initial elastic area.* Above this straight line is *a unit viscous (creep) area* of $\delta_v\ (t_1,\tau\ )$.The sum of the ordinates of these two areas gives *the total unit strain* of the samples:

$$\delta(t_1,\tau_0) = \delta_e(\tau_0) + \delta_v(t_1,\tau_0)$$

Total measure Elastic measure Creep measure (1)

It can be seen in more detail in the work of the author [16][17].

In addition to the described curve (1) and line (2), Fig. 1 also shows curve (3) which determines the mode of change of the unit elastic strain 1 / E (t) depending of the observation time (t). This function is decreasing because it characterizes the area between curve (2) and curve (3) as elastic, ie $\delta_e\ (\ t\ ) = 1/E(t)$.

Most researchers define a unit viscous strain $\delta_v(t_1,\tau)$ as an ordinate.between curve (1) and line (2) according to expression (1) . However, some of them consider it more correct to use viscous strain $\delta_v^*(\ t_1,\tau\ )$ takes between line (1) and (3) .Evidence of this statement is given by equation (2a):

$$\frac{1}{E_0} + \delta_v\ (t_1,\tau_0) = \frac{1}{E(t_1)} + \delta_v^*\ (t_1,\tau_0) \qquad (2a)$$

The equation is only seemingly true according to Fig.1. However, the expression(2a) seems to be correct only consequently of the way the right side of the equation is marked, because it contains a part of elastic strains between line (2) and courve(3), which is equal to $\Delta(1/E(t))$, although it was considered viscous. The drop elastic strains, due to the increase in the value of the modulus of elasticity E (t) at time t, between line (2) and curve (3) in Fig.1 is:

$$\Delta(1/E(t)) = 1/E_0 - 1/E(t) \qquad (2b)$$

We can now conclude that in Fig. 1, the value denoted with $\delta_v^*(t_1,\tau)$ by Aleksandrovskij does not represent a viscous strain, because it also contains a part of the reduced value of the elastic strain..

For a clearer and easer presentation of this paper, one of the more successful practice proposals in our opinion, the formula for E (t) from [16] is repeated:

$$E(t)= E_n\,(1- e^{-\alpha t}) \quad \text{- Theory of aging} \qquad (3a)$$

Where is: $E_n = k_n Eo$ - Final value
$k_n = 1.16$ - Coefficient of increase of modulus of elasticity when is $t=t_n$
$\alpha = 0.073$ - Coefficient in expression (3a) determined by the experiment for the mean flow of the curve E (t) and for the selected series of concrete samples.

The initial time (τ_0) can be chosen as desired, although it is often assumed that τ_0 = 28 days . The index n suggests that the formula is correct only for the theory of aging.
The initial age of concrete during loading can be between the selected value (τ_0) and 90 days for the conditions environments of the local region (eg: region of Serbia).Observation time should be t1 <365 days (or 270),which is valid also locally.

For the second theory of concrete, which is equally important, the initial loading time should be τ_0 > 365 days (exceptionally already 270 days). Then the following expression holds:

$$E(t)= E_\infty \quad \text{- Heritage theory} \qquad (3b)$$

The observation time should be t_1> 365 days. Similar conditions apply to the nature of the environment as stated for the theory of aging.
If the observation time is between 90 and 365 days, partial coefficients should be found according to the author's work [15], and then apply the above two limit theories of concrete.

Experimental coefficient of concrete creep, according to the theory of aging, is defined by the expression:

$$\varphi(t_i)_{exp} = \frac{\varepsilon_v(t_i)}{\varepsilon_e} \qquad (4a)$$

It can applies only for τ_0 = const. Therefore, it is considered that the only correct thing is that it should be determined experimentally in relation to the initial time τ_0, and it follows that is $E_0 = E(\tau_0)$=const.
Accordingly, the function of curve (3) is decreasing and therefore stresses and strains should be reduced by means of a *reduction factor*:

$$k_{red}(t_1) = \frac{E_0}{E(t_1)} \qquad (4b)$$

If expression (3a) is used for E (t) the following curve for stress reduction is easily obtained.

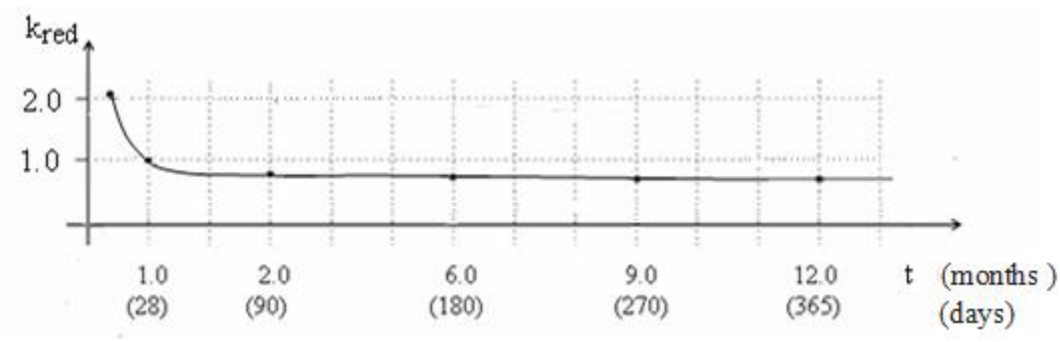

Fig2. Change of reduction factor k_{red} depending on the observation time t

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In order to facilitate the taking of data for k_{red} , they are also given with the help of Table.1, at the time of observation t = 7. 28, 90, 180 and 365 days. The table also lists the factors for increasing the modulus of elasticity k_{inc} (increase), for which there may be interest in parallel.

Table 1. Increase factors k_{inc} and Reduction faktors k_{red} as a function of observation time (t)

t(days)	3	7	28	90	180	365
$k_{inc}(t)$	0.23	0.47	1.00	1.113	1.127	1.158
$k_{red}(t)$	4.35	2.13	1.00	0.887	0.873	0,863

Values for increase factor k_{inc} (t) are entered based on the results for E (t) in the paper[16]. Between the displayed points for the selected t_i, the corresponding value of the increase and reduction factor can be found by interpolation. Another possibility is to use the expression for E (t) directly, and then find the factor $E_0/E(t)$.

It should be noted that the following relation applies: $k_{inc}(t)=1/\ k_{red}(t)$. Initial time ($\tau_0$) was adopted 28 days in the above consideration. In special cases of practice (for example: when works need to be accelerated etc.) there is a need to (τ_0) be greater or less than 28 days, at that time it should be experimentally or approximately, having in mind Fig.2 and data of paper[16] and[14], to estimate the coefficients k_n and α in the expresssion (3a) .

III. EXPRESSIONS FOR THE KERNEL OF INTEGRAL EQUATIONS AND CREEP MEASURES

Almost all stress-strain relations for concrete start from only two forms of integral equations.
The first form is known as the Boltzmann relation:

$$\varepsilon(t) = \sigma(\tau_0)\,\delta(t,\tau_0) + \int_{\tau_0}^{t} \frac{d\sigma(\tau)}{d\tau}\,\delta(t,\tau)\,d\tau + \varepsilon_{s1} \qquad (5)$$

, and the other as Voltaire 's integral equation

$$\varepsilon(t) = \frac{\sigma(t)}{E(t)} + \frac{1}{E(t)}\int_{\tau_0}^{t} \sigma(\tau)\,K(t,\tau)\,d\tau + \varepsilon_{st} \qquad (6)$$

In the second equation, the kernel of the integral equation can be obtained using the expression for the total unit measure of concrete strains: δ (t, τ) :

$$K(t,\tau) = E(t)\frac{\partial}{\partial\tau}[-\delta(t,\tau)] \qquad (7)$$

Most authors use expression (5) to solve the problem of determining stresses and deformations of concrete structures, and only a rare expression (6). All use, as far as this authors know, the total unit measure δ (t, τ).

Only a few proposals for the total unit measure of concrete strain, that have adopted, the variable modulus of elasticity E (t)> E0, will be now presented:

1.Arutjunjan (see: [5])
He adopted in his book for the kernel of the integral equation expression (6) as a function of the total creep measure δ (t, τ) according to the following expression:

$$\delta(t,\tau) = \frac{1}{E(\tau)} + \left(C_0 + \frac{A_1}{\tau}\right)\left[1 - e^{-\gamma(t-\tau)}\right] \qquad (8)$$

Many books cite this relations as a valuable contribution to concrete theory. The relation is important for a more successful understanding of boundary theories of concrete: theories of aging and heritage. It is used for the calculation of stresses and strains of concrete structures. The obtained analytical solutions are quite complex, therefore, according to this opinion, it is less often used in practice. [5] [6] [13].

2.Alexandrovskiy [14]
His proposal has already been analyzed in the part under point 2 (expression (2a)). It is now given again, because the creep measure formulated in this way is present in many works, of which Rzanicin's book is cited in the references [5].
Total unit strains is given in the form:

$$\delta(t,\tau) = \frac{1}{E(\tau)} + \delta_v^*(t,\tau) \quad (9)$$

Expression (9) has two parts, although the exact viscous measure of creep is only the second part up to curve (2) in Fig. 1. The second part of expression (9) is "unit quasi-viscous dilatation". The modulus of elasticity in this expression is a function of the initial loading time.

The creep function $\delta_v*(t,\tau)$ is not justified, because the time interval (τ_0,t_1) and only the initial value of the module E_0 are always used to determine the creep coefficient function(see:[17]).

3.Jordaan [10]
His expression, which is quite presented in the references, is as follows:

$$\delta(t,\tau) = \frac{1}{E(\tau)} + [\gamma(t) - \gamma(\tau) + c_2[\gamma(t) - \gamma(\tau)] \cdot [1-e^{-\lambda c_1(\gamma(t) - \gamma(\tau))}] \quad (10)$$

In this form, the total unit measure depends of the initial time τ and the observation time t. In his papers, suggestions and proposals are given on how to enable new research on the behavior of concrete samples during long - term monotonic actions, in order to solve formulated six current structural problems.

4. Mihailovic ([17])
The proposal differs significantly from the previously presented variants. The elastic is completely separated from the viscous part of the strains because the viscous measure $\delta_v(t,\tau)$ is used in expression (6) instead of the total uniit measure $\delta(t,\tau)$. The terms for strains and stresses of concrete structures become much simpler. Now, for a more complete presentation, only the results based on the paper will be given [16]:
a) Young concretes (According to the theory of aging)

$\delta_v(t, \tau) = [\varphi(t) - \varphi(\tau)]/E_0$; $\delta_e(\tau_0) = 1/E_0$ (10a)
where is: $\varphi(t) = (1- e^{-\beta n t})$; $\varphi_n = \varphi_{tot}$
applies to: $3 <= \tau_0 <= 90$ days;

b) Old concretes (According to the theory of heritage)

$\delta_v(t - \tau_0) = \varphi_\infty (1- e^{-\beta\infty (t - \tau_0)})/E_0$; $\varphi_\infty = \varphi_{tot}$: $\delta_e(t-\tau_0) = 1/E_\infty$ (10b)
applies to: $t-\tau_0 >= 365$ days

The formation of this proposals was mostly influenced by the cited works in the References:
Ulickij [6], Aleksandrovski [14], Courbon [12], Rush (see: [2]), Trost [8] .
In this way, the expressions for strains and stresses become simpler, which will be illustrated in the following text and attached numeral examples.

IV. NEW RELATIONS STRESS-STRAIN OF CONCRETE FOR E (t)> E_0

When the elastic component is separated from the viscous component of the total unit measure, the expression for the kernel of the integral equation has the following form:

$$K_v(t,\tau) = E_0 \frac{\partial}{\partial \tau}[-\delta(t,\tau)] \quad (11)$$

Here expression (11) has only viscous part of the integral equation kernel , which does not contain the elastic part of the total unit deformation of concrete.
The kernel according to (11) can be replaced in (6), and the following expression is obtained:

$$\varepsilon(t) = \frac{\sigma(t)}{E(t)} + \frac{1}{E_0}\int_{\tau_0}^{t} \sigma(\tau) K_v(t,\tau)\, d\tau + \varepsilon_{st} \quad (12a)$$

Expression (12a) is more favorable than expression (6) due to the introduction of a new viscous kernel and represents, as far as we know, a new form of the integral equation.This shape can also use direct values for E (t).
If we include in expression (12a) expression (4b) for the reduction factor (k_{red}), it can easily be reduced to the following form:

$$\varepsilon(t) = \frac{\sigma(t)}{E_0} k_{red} + \int_{\tau_0}^{t} \sigma(\tau) K_v(t,\tau) d\tau + \varepsilon_{st} \qquad (12b)$$

It is expected that new shape of the relation(12a) and (12b) will facilitate the calculation of stresses and deformation of RC, PC and Composite structures.
The first part of these equations defines the elastic component of strains of concrete (ε_e), the second the viscous strains of concrete (ε_v), and the third some external imposed strains. Relation (12b) allows the use data of Table 1 or expression (4b) which facilitates the calculation of the reduction factor.

For practice, it should be specified that there are two pre-planned cases of application of the elasticity modulus:

I. E (t) = E0 (k_{red} = 1)
The influence of changes in the values of the modulus of elasticity is neglected in the long-term observation of concrete creep. Sometimes in practice module use increases of up to 10% are entered for E(t).. In the tasks of stresses and deformations calculation, elastic components with viscous components are added. Moments of inertia and other characteristics are taken as an idealized (transformed state) of cross section (see: Example 2).

II. E(t) > E_0 (k_{red}<= 1)
The effect of increasing the modulus of elasticity is taken as the state at the time of observation t only for elastic components of stresses and deplacments.Viscous components of stresses are the same as in previous case.
Two types of analysis are used:

a) Computational analysis of stress decrease on concrete samples in the interval (τ_0, t_1) using reduction factors according to formula (4b) or according to Table 1.
b) Computational analysis of stresses in concrete and steel in concrete structures, in long-term loadings, is performed by summing the elastic and viscous components of the stresses in points of cross section at time t = t1. The cross-sectional area of concrete at time t= 0 is Ac_0, and at time t_1 it is assumed to be enlarged, namely as Ac (transf) = Ac_0 $Ec(t_1)$ / Ec_0 , due to the increase in the value of the elasticity modulus at point t_1.

Example 1
Elastic strains of concrete samples depending of τ_0 and of long-term observation (t1):

Data: E_0 = 3150 kN / cm2 ; σ_0 = 1 kN/cm^2
τ_0 = 28 days (see Fig.2)
t1 = 180 days

Find: E (t1) =? ; k_{inc} (t) =? ; k_{red} (t) =?
$\delta_e(\tau_0)$=? ; $\delta_e(t_1)$=?

Results: From Table 1 follows k_{inc} (t_1) = 1.127 and $k_{red}(t_1)$= 0.873
$E(t_1) = k_{inc}(t_1) E_0$= 1.127x3150 = 3550kN/cm^2
$\delta_e(\tau_0)$= 1/ E_0=1/3150= 0.317 [%o 1/kN/cm^2]
$\delta_e(t_1)$= 1/ $E(t_1)$=1/3550=0.228[%o 1/kN/cm^2]

In this example, the elastic strains of concrete were reduced by 11% compared to the values in time t= 0.
The results can be used for easier selection of the force P_0 on concrete samples, when measuring strains for each value of t1.

Example 2
Stresses and strains of composite cross section steel-concrete
The example was processed by colleague Ljiljana Tadic at the 1997 exercises in the lessons of composite structres at the Faculty of Civil Engineering in Subotica.

I .Stresses and deformations of structures in case E (t) = E_0 (Calculated by computer)
a). Moments of inertia and other characteristics
Elements of cross section, and their centroids are given in Fig.3.

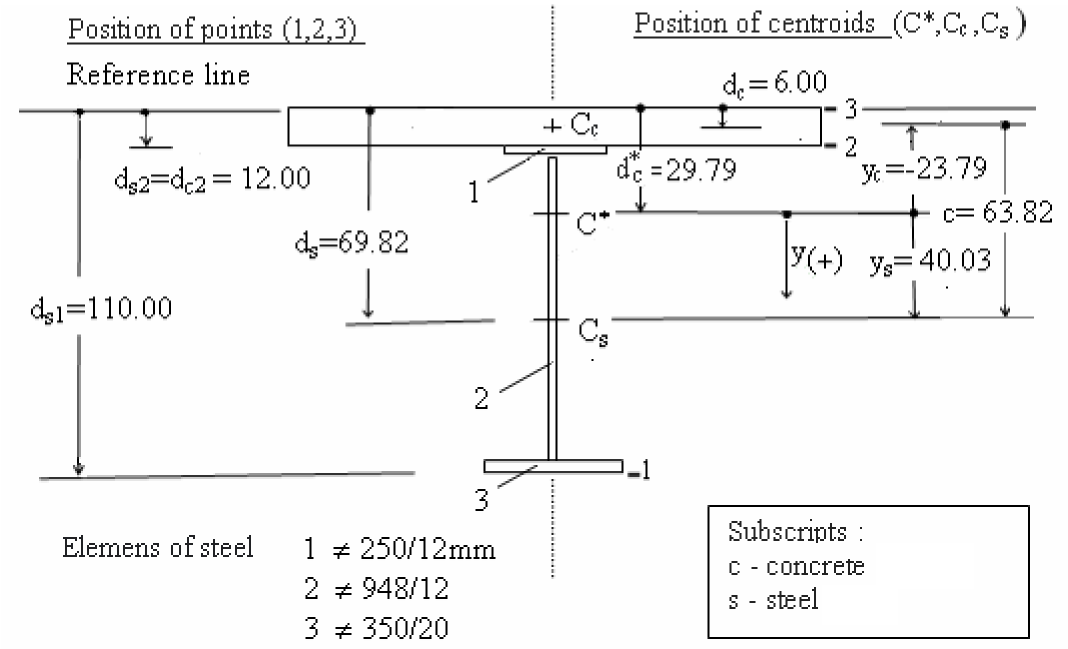


Fig.3 Cross section of girder and positions of the center of gravity of steel and concrete

b).Table2- Moments of inertia and other characteristics

MOMENTS of INERTIA (Iy) _ General section

Data

Eso (kN/cm^2)	Aso (cm^2)	Iso (cm^4)	dso (cm)	nso (-)
21000,00	214	302025	69,82	1
Ec (kN/cm^2)	**Ac (cm^2)**	**Ic (cm^4)**	**dc (cm)**	**nc (-)**
3150,00	2400,00	28800	6	0,15

Results

Âs (cm^2)	Îs (cm^4)	ys (cm)	Âb (cm^2)	Îb (cm^4)	yb (cm)
214,00	302025	40,03	360,00	4320,00	- 23,79
E* (kN/cm^2)	**A* (cm^2)**	**I* (cm^4)**	**dc* (cm)**	**Is* (cm^4)**	**Ib* (cm^4)**
21000,00	574,00	853006	29,79	644879	208127

c) Stresses and strains of cross section (Calculated by computer)

The internall forces of phase IV for load Δg are:

N=0 ; M=508.24 kNm

φ_n=2.8 ; The observation time is: t1 = 180 days

Stresses by section height will be shown in tables and graphs for stresses at time t = 0 and for t = t1

STRESSES of COMPOSITE SECTION (due to Load) _ General section

Data for internal forces and control point section

No (kN)	Mo (kNm)		
0.00	508.24		
ds1 (cm)	ds2 (cm)	db2 (cm)	db3 (cm)
110.00	12.00	12.00	0.00

Results

Stresses in time t=0 (kN/cm2):

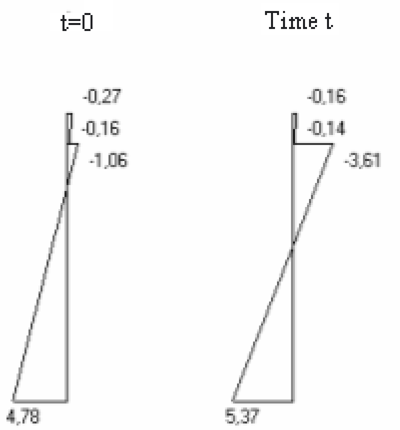
Õs1	Õs2	Õb2	Õb3
4.78	-1.06	-0.16	-0.27

Stresses in time t (kN/cm2):

Õs1	Õs2	Õb2	Õb3
5.37	-3.61	-0.14	-0.16

Viscous forces

Nv (kN)	Mv (kNm)	Db(yb) (kN)	Ds(ys) (kN)
-1134.65	273.31	148.57	-148.57



Time t t=0

If viscous stresses in concrete are required using the results shown, can be calculated: stresses for points 2 and 3:

$$\sigma_{cv,2} = \sigma_{c,2}(t_1) - \sigma_{ce,2}(t_1) = -0.14-(-0.16) = 0.02 \text{ kN/cm}^2$$
$$\sigma_{cv,3} = \sigma_{c,3}(t_1) - \sigma_{ce,3}(t_1) = -0.16-(-0.27) = 0.11 \text{ kN/cm}^2.$$

II. **Stresses and strains using the Reduction factor in case E (t)> E0**

The data for internal forces are the same as under I . (Note: Results for strains are not shown.)

a) Determination of the Reduction factor for $t = t_1$

Using expression (4b) or Table 1 for t1 = 180 days, we find:

$k_{red} = 0.873$

$k_{inc} = 1.127$: Next: $E(t_1) = 1.127 \cdot 3150 = 3550$ kN/cm^2

b). Moments of inertia and other characteristics

MOMENTS of INERTIA (Iy) _ General section

Data

Eso (kN/cm²)	Aso (cm²)	Iso (cm⁴)	dso (cm)	nso (-)
21000,00	214	302025	69,82	1
Ec (kN/cm²)	Ac (cm²)	Ic (cm⁴)	dc (cm)	nc (-)
3550,00	2400,00	28800	6	0,169

Results

Âs (cm²)	Îs (cm⁴)	ys (cm)	Âc (cm²)	Îc (cm⁴)	yc (cm)
214,00	302025	41,78	405,71	4868,57	- 22,04
E* (kN/cm²)	A* (cm²)	I* (cm4)	dc* (cm)	Is* (cm⁴)	Ic* (cm⁴)
21000,00	619,71	877526	28,04	675606	201919

c) Stresses of composite section (Elastic component)

The stress distribution by section height will be shown only for elastic stresses in time t1, because the viscous stresses are the same as in the case under I. (see: expression (12a))

STRESSES of COMPOSITE SECTION (due to Load) _ General section : Girder F

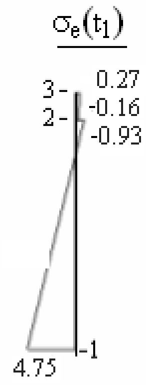
Data for internal forces and control points:

No (kN)	Mo (kNm)		
0.00	508.24		
ds1 (cm)	ds2 (cm)	d_c2 (cm)	d_c3 (cm)
110.00	12.00	12.00	0.00
E* (kN/cm^2)	FI (-)	εsn (‰)	
21000.00	2.8	-0.3	

Results

Stresses in time $t=t_1$ (kN/cm^2):

$\sigma s1$	$\sigma s2$	$\sigma_c 2$	$\sigma_c 3$
4.75	-0.93	-0.16	-0.27



If we compare the obtained values under I. and under II. for elastic stress components it differ the most for

point 2s: 1.06 /0.93 (14%)., and for point 1s: 4.78 / 4.75 (0.63%).

The small values of the differences for the concrete points are the result of the redistribution of the increase in the value of E (t1) much more to the steel than to the concrete part . At time t1 new moments of inertia of in some parts of cross section are formed. As the ratios of the moment of inertia of concrete and the total moment of inertia are equal to approximately $I_c^*/I= 0.24$, and for steel the same ratio is $I_s^*/I= 0.76$, this shows that there are many more steel then concrete , and that its position have more affects on the total moment of inertia. In concrete points 2c and 3cb, a difference is less than 1%.of stesses is obtained.

V. CONCLUSIONS

The following conclusions can be drawn:

1. In the new stress-strain relation proposal the second member contains a viscous kernel (K_v), which is different from the kernel (K). The second member represents only the viscous strain of the concrete.
2. Variable modulus of elasticity for concrete under long-term loading has effects only on elastic deformations of concrete (see: Example 2);
3. Total deformation of concrete structures has elastic and viscous deformations, according to the new proposal at expressions (12a) and (12b). The effect of temperature, shrinkage etc need to calculate independently;
4. The value of the modulus of elasticity as a function of the observation time can be found using the formula for E (t) or via Table1 for = 28 days. If the time is $\tau_0 \neq 28$ days it should be repeated previous calculation procedure introducing and new experimental value for k_n and α ussing expression (3a) [16] .
5. Viscous deformations of concrete structures depend on the initial time of the loads, their shape of load and from the selected observation time.
6. Analytical and numerical solutions of problems, on input of viscosity properties for PC and Composite structures, are much more complex if the form of integal equation (5) is used in relation to the other (Voltaire's) integral equation(6).

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