DETERMINATION OF THE COEFFICIENT ψ_2 TO DEFINE LONG-TERM EFFECTS ON CONCRETE ELEMENTS UNDER VARIABLE LOAD

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During the past 12 years, research project regarding time-dependent behavior of concrete elements is ongoing continuously at the Faculty of Civil engineering in Skopje. Experiments were performed on different types of concrete: prestressed, normal and high strength and steel fibre reinforced concrete, with various loading histories. The time-dependent changes in strains, deflections and crack widths were observed in a period of 400 days. This paper presents the effects of variable load on time-dependent behaviour of different types of concrete elements and proposes methodology for determination of coefficient ψ_2.

Keywords: coefficient ψ_2, experiment, long-term variable load

INTRODUCTION

Long-term actions cause significant changes in concrete and reinforcement strain, increase in crack width and deflections, reduction of the tension stiffening and increase in bond-slip[3].

Besides this, degradation of concrete structures is usually medium to long-term process that has great influence on structure's working life. Among specific common causes responsible for structural degradation, action of variable loads is especially important issue for the assessment of long-term effects due to creep and shrinkage in concrete structures.

The effect of long-term actions is usually connected with the permanent load. However, there are certain concrete structures such as: storage areas at warehouses, traffic areas at parking garages and bridges under severe traffic conditions, where the variable loads are acting longer and are with significant magnitude. In these structures, the variable actions could overcome serviceability limit state criteria of concrete structure.

Because of previously stated reasons, in Eurocodes [6] in the serviceability limit design, assessment of effects due to creep and shrinkage of concrete caused by variable load are taken into consideration using quasi-permanent combination of actions (also used for reversible limit states). The level of quasi-permanent load is defined by the quasi-permanent coefficient ψ2 (Eq.1):

$$\sum_{j\geq 1} G_{k,j} + "P" + \psi_{2,1} \cdot Q_{k,1} + \sum_{j\geq 1} \psi_{2,i} \cdot Q_{k,i} \quad (1)$$

The values for the quasi-permanent coefficient ψ2 could be set also by the National Annex. This gives opportunity for research of effects of variable load and its replacement by a quasi-permanent load by the coefficient of participation ψ2.

In EN 1990: Eurocode - Basis of structural design [5], proposed values for the quasi-permanent coefficient for buildings are presented in Tab.1.

The recommended values for ψ2 for road bridges in EN 1990 is 0 [5]. In DIN report 102 "Concrete bridges" based on Eurocodes, for city bridges ψ2 is assumed to 0.2 and in the National application document of Finland for EN 1992-2, ψ2=0.3. The recommended value of ψ2 factor for railway bridges is equal to zero. But if deformation is considered for persistent and transient design situations, ψ2 should be taken equal to 1.00 for rail traffic actions (according to Table A2.3 of EN1990:2002 [5]).

Table 1. Recommended values of coefficient ψ2 for buildings [5]

Action	ψ_2
Imposed loads in buildings, category (see EN1991-1-1)	
Category A: domestic, residential areas	0.3
Category B: office areas	0.3
Category C: congregation areas	0.6
Category D: shopping areas	0.6
Category E: storage areas	0.8
Category F: traffic area, vehicle weight ≤30kN	0.6
Category G: traffic area, 30kN<vehicle weight ≤160kN	0.3
Category H: roofs	0.0

METHODOLOGY FOR DETERMINATION OF THE COEFFICIENT ψ2

This proposal in Eurocode was the basis of the extensive experimental and theoretical research, for determination of the quasi-permanent coefficient ψ2.

Four approaches for determination of the effects of variable long-term actions were considered (Fig.1):

1. from point of zero value of deflection to obtain the value of experimentally determined deflection at the level of action of the permanent load.
2. from point of zero value of deflection to obtain the value of experimentally determined deflection at the level of action of the permanent and variable load.
3. from point of instantaneous value of deflection at permanent load level, (obtained at the first cycle of loading/unloading by variable load) to obtain the value of experimentally determined deflection at action of the permanent load.
4. from point of instantaneous value of deflection at permanent load level, (obtained at the first cycle of loading/unloading by variable load), to obtain the value of experimentally determined deflection at action of the permanent and variable load.

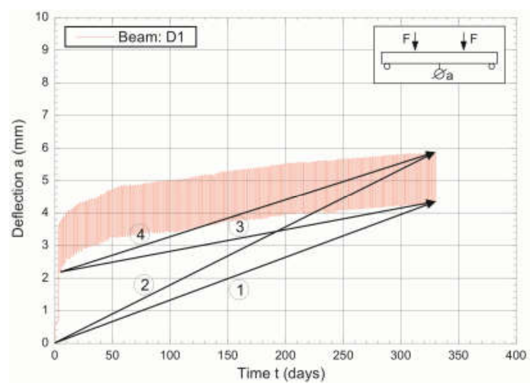


Figure 1. Considered approaches for determination of ψ2

The simplest solution of the problem is taking into consideration the approach 1, because with intensity of the load as sum of permanent and quasi-permanent load, we can obtain initial and time-dependent deflection.

On the basis of experimental research, analytical solution was proposed in which the total deflection from permanent load G and variable load Q obtained from the experiments at,exp(G+Q) is determined as a sum of the initial deflection ao(G+ψ2Q) and long-term deflection at(G+ψ2Q) from permanent load G and variable load represent as quasi permanent load ψ2Q (Eq.2):

$$a_{t,\exp}(G+Q) = a_0(G+\psi_2 Q) + a_t(G+\psi_2 Q) \quad (2)$$

EXPERIMENTAL PROGRAM

The research project consists of 3 experimental programs, denoted as follows:

- Experimental program "PC"(Prestressed concrete) [8];
- Experimental program"HSC"(High strength concrete) [1];
- Experimental program"SFRC"(Steel fiber reinforced concrete) [9] .

The experiments were performed in specially equipped laboratory, located at the Faculty of Civil Engineering – Skopje. The laboratory (Figure 2) enables almost constant temperature, while the relative humidity is controlled with special humidifiers/dehumidifiers to keep it constant.

Figure 2. Part of the laboratory for testing

Each of the experimental programs consists of 24 full scale beams and control specimens for testing of the mechanical and deformation properties of concrete. The beams are with cross section b/d=15/28cm and length of 300cm. The geometry, inbuilt reinforcement and loading scheme for each experimental program is presented in Figure 3.

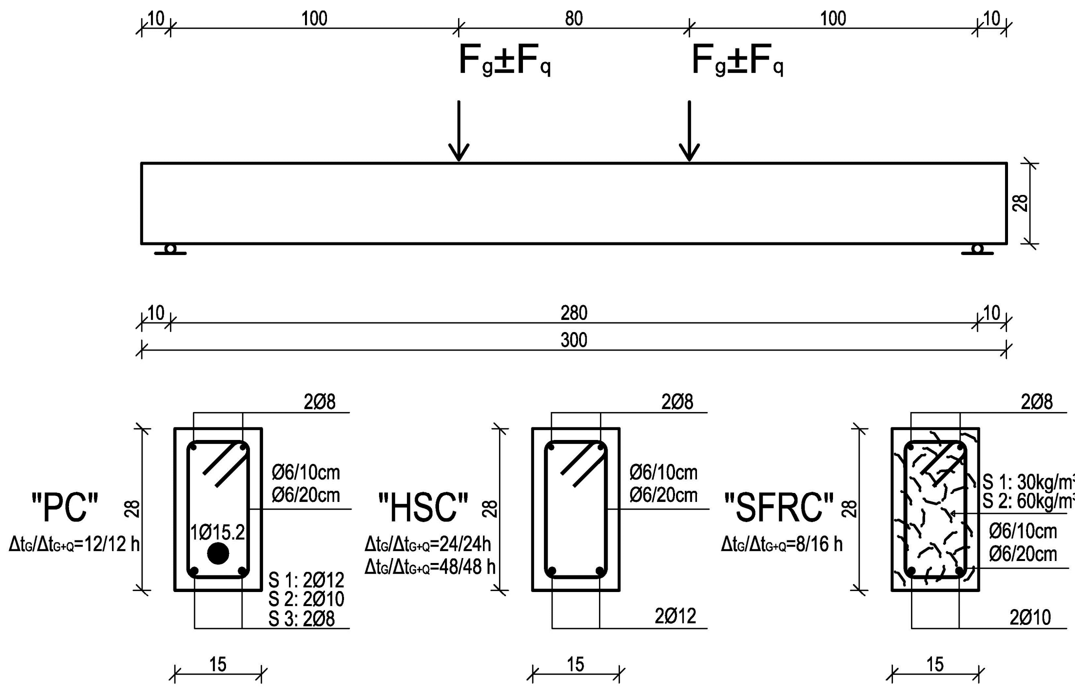


Figure 3. Geometry, reinforcement and loading scheme of the beams

Table 2. Cycles of the loading histories

	Experimental program			
cycles	PC	HSC		SFRC
Δt_G (hours)	12	24	48	8
Δt_{G+Q} (hours)	12	24	48	16

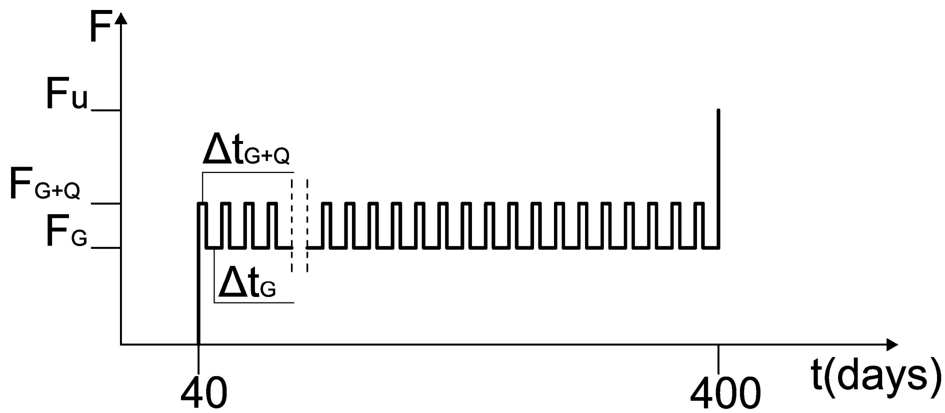


Figure 4. Loading history of the beams

The beams were loaded at the age of 40 days with the specific loading history and at the age of 400 days the beams were loaded to failure. Loading histories were defined by action of constant permanent load and variable load acting in different cycles of loading/unloading, presented in Table 2 and in Fig.4.

RESULTS

For each of the research projects, the following mechanical properties of concrete were tested at the same age as the testing of the full scale beams: Modulus of elasticity, compressive strength, splitting tensile strength and flexural tensile strength. Creep and drying shrinkage, as well as autogenous shrinkage in the case of the high-strength concrete were measured for 400 days continuosly.

The testing of the mechanical and deformation properties is presented in Fig.5. The testing was performed at the age of 40 days and at the age of 400 days.

The experimental results of deformation properties of the research project “HSC“ are presented in Fig.6.

For analytical analysis, evaluation of the autogenous shrinkage, drying shrinkage and creep strains (Fig.7a) was performed by using the B3 Model (Bazant & Baweja 2000) [2]. This analysis provide data to define improved B3 model compliance function J(t,t'), aging coefficient χ(t,t') and relaxation function R(t,t'). All these parameters were used to calculate and to verify long-term deflections by age adjusted effective modulus method (AAEMM method) [4].

In the “SFRC“part of the research project, which analytical analysis are still undergoing, B3 Model [2] and fib Model code 2010 [7] are used to obtain the neccessary data for the AAEMM. This will be done not only for the period of observing the full scale beams of approximately 1 year, but for an age of up to 100 years which is the life design age for certain structures. The analysis of the creep strain after 100 years in logarithmic scale is presented in Fig.7b.

Modulus of elasticity	Compressive strength	Spliting tensile strength	Flexural tens. strength	Creep	Shrinkage

Figure 5. Testing of the mechanical and deformation properties

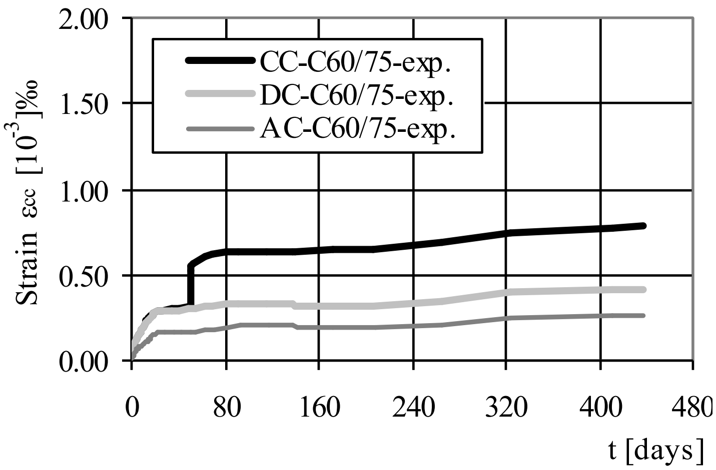
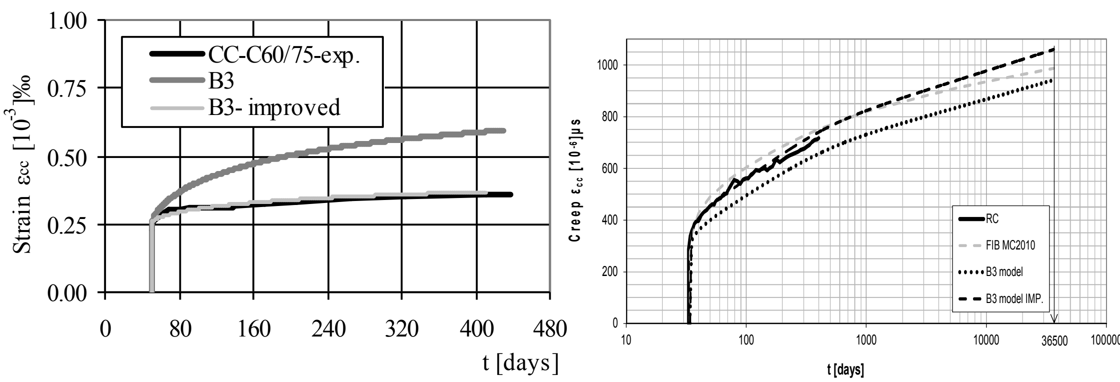


Figure 6. Total strain composed of autogenous shrinkage, drying shrinkage and creep in “HSC“



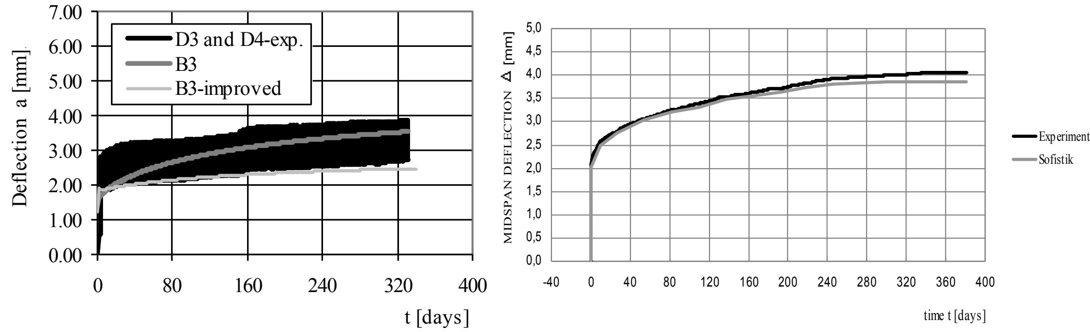
a) b)

Figure 7. a) Analysis of the creep strain by the B3 model in “HSC“ [1]; b) Analysis of the creep strain by B3 Model and fib MC2010 in“SFRC“ [9]

In the “PC“ part of the research project, modeling and analysis of the behaviour of prestressed concrete beams exposed to different history of loading during time were performed with the computer software program SOFISTIK using the finite element method.

To calculate effects from variable action on long-term deflections of concrete elements quasi-permanent load procedure and the principle of superposition were used. The analysis of the long-term deflection for the experimental program “HSC“ is presented in Fig.8a, while for the experimental program “PC“ is presented in Fig.8b.

Obtained quasi-permanent coefficients ψ2 for each experimental program of the research project, for the considered time period of 400 days, are presented in Tab.3.



a) b)

Figure 8. Analysis of the long-term deflection in experimental program: a) “HSC“ [1] b) “PC“ [8]

Table 3. Quasi-permanent coefficient ψ2 for each experimental program for time period of 400 days

	Experimental program			
cycles	PC	HSC		SFRC
Δt_G (hours)	12	24	48	8
Δt_{G+Q} (hours)	12	24	48	16
		ψ_2		
Ordinary concrete	/	0.50	0.65	0.37
PC /HSC /SFRC	0.40	1*	1*	0.20

*Not realistic. Comes out from the low stress level.

A simple linear dependence between factor ψ2 and the variable load duration was found out and is presented in the following Fig.9. From the same figure, almost double decrease of the factor ψ2 can be noticed, when steel fibres are added to the concrete mixture.

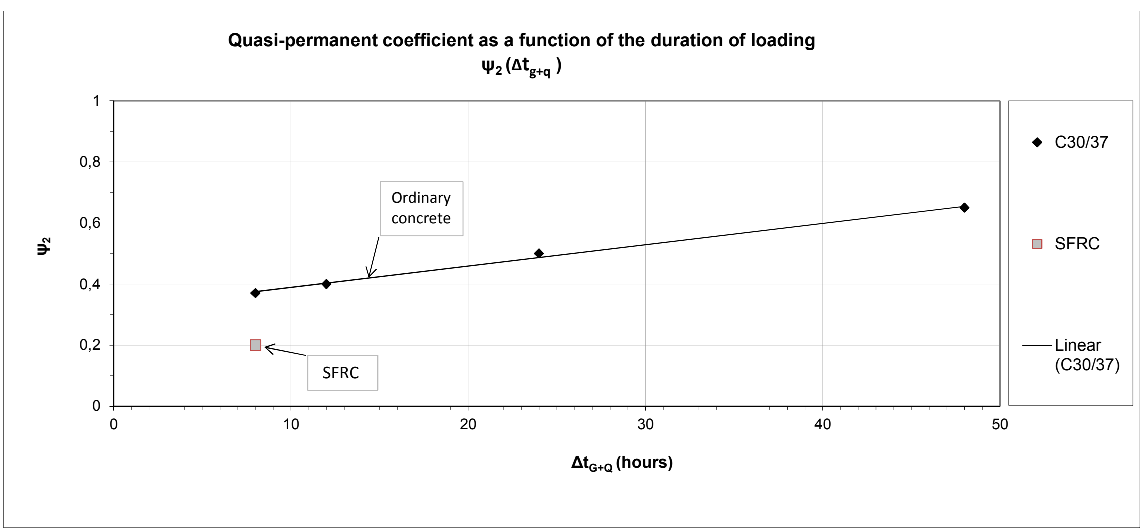


Figure 9. Factor □2 as a function of the variable load duration (Δtg+q)

CONCLUSION

From the experimental and analytical analyses of the long-term behavior of beams made of different types of concrete, subjected to long-term permanent and variable load, the following conclusions can be drawn:

- Actions of long-term permanent and variable load have significant influence on the long-term behavior of concrete beams.
- The quasi-permanent coefficient ψ2 depends on the loading history, i.e. especially on the duration of the cycles when the variable load is acting on the structure (ΔtG+Q).
- For determination of the value of the quasi-permanent coefficient ψ2, the stress and strain states of the cross sections for the different combinations of load cases should be taken into account.

REFERENCES

[1] Arangelovski, T.: Time-dependent behavior of reinforced high-strength concrete elements under action of variable loads, Doctoral dissertation, Skopje: University "Ss. Cyril and Methodius", 2010.

[2] Bazant Z.P. & and Baweja, S.: Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures: Model B3, The Adam Neville Symposium: Creep and Shrinkage-Structural Design Effects, SP-194, American Concrete Institute 2000, Akthem Al-Manaseer (ed.), Farmington Hills: ACI, 2000.

[3] CEB Bulletin d'information No 235.: Serviceability Models-Behaviour and modelling in serviceability limit states including repeated and sustained loads. G. Balazs (eds). Lausanne, 1997.

[4] Jirasek, M. & Z.P.Bazant.: Inelastic Analyses of Structures, London: John Wiley & Sons, 2001.

[5] European Standard EN1990.: Basis of structural design, Standardization Institute of R.Macedonia, Skopje, R.Macedonia, 2002.

[6] European Standard EN1992-1-1.: Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings, Standardization Institute of R.Macedonia, Skopje, R.Macedonia, 2004.

[7] Fib Model Code 2010.: fib Bulletin 65, Final draft, 2012.

[8] Markovski, G.: Influence of variable loads to time-dependant behavior of prestressed concrete elements, Doctoral dissertation, Skopje: University "Ss. Cyril and Methodius", 2003.

[9] Nakov, D.: Time-dependent behaviour of SFRC elements under sustained and repeated variable loads, Doctoral dissertation, Skopje: University "Ss. Cyril and Methodius", 2014.