Long-term strains of compression elements in tall buildings

Long-Term Strains of Compression Elements in Tall Buildings

Contraintes à long terme apparaissant dans les éléments comprimés des bâtiments élevés

Langzeitverformungen gedrückter Elemente in Hochhäusern

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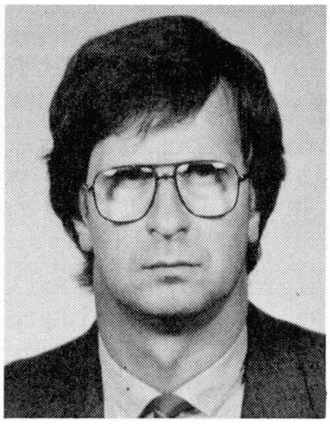

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SUMMARY

This paper presents a theoretical solution for the determination of strains due to creep and shrinkage of concrete, in compression elements of tall buildings. The analysis of the creep and shrinkage effects takes into account the variability in percentages of cross-section reinforcement as well as the actual variation of the increasing normal forces. On the site of the Press Centre in Bratislava, selected compression elements were measured over a two year period. At the same time, measurements were made of unloaded specimens. The author presents an analysis of the measured strain values.

RÉSUMÉ

La solution théorique concernant la détermination des contraintes dues au fluage et au retrait est présentée, dans le cas des éléments comprimés de bâtiments élevés. Cette analyse tient compte des différents pourcentages d'armature dans les sections comprimées, ainsi que de l'augmentation de l'effort normal dans le temps. Pendant plus de deux ans, des mesures ont été effectuées sur des éléments comprimés sélectionnés du centre de presse de Bratislava. D'autres tests étaient menés conjointement sur des éléments non-chargés. Une analyse des résultats obtenus est présentée.

ZUSAMMENFASSUNG

Der Beitrag behandelt die theoretische Ermittlung von Betonverformungen infolge Kriechens und Schwindens in gedrückten Elementen von Hochhäusern. Bei der Analyse der Kriech- und Schwindauswirkungen werden verschiedene Bewehrungsgrade der gedrückten Elemente sowie verschiedene Annahmen über die zeitliche Belastungserhöhung untersucht. Beim Bau des Pressezentrums in Bratislava wurden im Zeitraum von 2 Jahren Langzeitverformungen ausgewählter gedrückter Elemente gemessen. Zum Vergleich wurden im gleichen Zeitraum Verformungen an unbelasteten Elementen ermittelt. Der Autor behandelt die Analyse der gemessenen Verformungen.

1. INTRODUCTION

Within the last years a large number of tall buildings exceeding 30 stories have been built. Such buildings of great height are very sensitive to cumulative differential length changes of their vertical elements. One of the influences affecting these changes in reinforced concrete structures are long-term strains due to volume changes, namely to creep and shrinkage of concrete which depend on a considerable number of influances. The overall contraction of the vertical load-carrying elements is the sum of a number of partial changes. The determination of elastic strains due to load does not present any difficulties. Therefore, in the paper we shall concentrate on the analysis and possibilities of determination of long-term strains which, under certain conditions, may exceed elastic strains several times. The extent of the creep and shrinkage of concrete is influenced by a variety of factors such as environmental effects, age of concrete during the exposure of the member to the load, concrete grade, reinforcement percentage, etc.

Prof. Bruggeling [1] presents the basic introduction of time-dependent effects. We would like to support his note that it is very important to understand when and why time-dependent effects are of importance for the behaviour and on the durability of a structure.

Traditionally, the effect of creep, shrinkage and temperature is considered in horizontal structures, such as long span bridges. These effects are usually neglected in multistory concrete buildings since, in the past, such structures seldom exceeded 20 stories. A number of recent ultra high rise buildings built without consideration of creep, shrinkage, and temperature effect in the vertical elements have developed partition distress, as well as structural overstress in horizontal elements. It is necessary for the structural engineer to consider the various differential movements and to develop acceptable structural, as well as architectural details, for the satisfactory performance of the building. We shall try to solve the specific problem of deformations which will complete the part 4.1 of the paper [2] .

2. ANALYSIS OF CONCRETE CREEP

In view of the calculation of effects of concrete creep on volume changes, the vertical elements in tall buildings can be characterized by several main factors:
- variability of reinforcement of the cross-sections of vertical elements,
- curve of the increase of load over time, depending on the progress in the construction of the building,
- stress due primarily to compressive forces.

Besides considering the effects of volume changes on length changes (shortening of the vertical elements in tall buildings), it is also necessary to account for these changes with respect to the distribution of the stresses over the cross-section of the member. The higher percentage of reinforcement reduces the increment of compressive stress acting on the reinforcement and increases the increment of tensile stress acting on concrete, adversely affecting the load-carrying capacity of the materials used.

This effect in combination with varying curves of possible load increases demonstrates Fig.1. In view of the extent of strain due to concrete creep it may be noted that increased percentage of reinforcement reduces the extent of deformation due to the creep of concrete (Fig.2).

The real course of load increasing over time can, in essence, be assumed for each element of the tall building already at the design stage. In general, this course can be modelled as shown in Fig.3. In the calculation of the effects of concrete creep, this course must be replaced by an appropriate function. The simplest solution is the one assuming a constant load increase, immediately from the onset of loading. However, such calculation is very unrealistic and can only provide very distorted date.

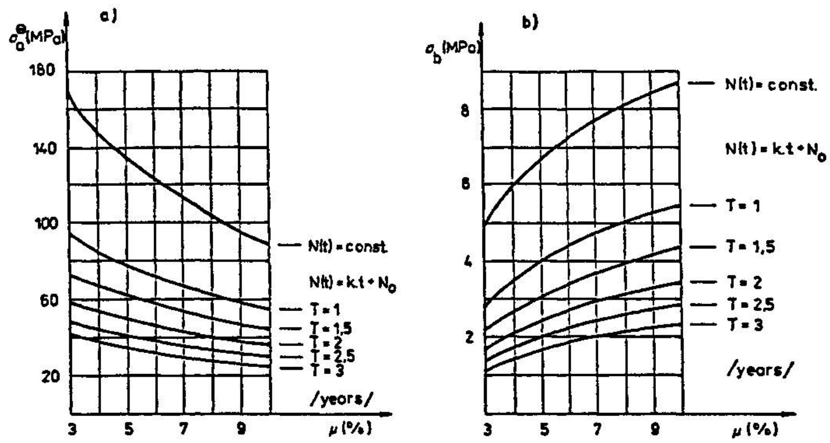

Fig. 1 Stress in the reinforcement (a) and stress in the concrete (b) due to concrete creep at varying percentages of cross-section reinforcement, accounting for the differences in the duration of building construction time

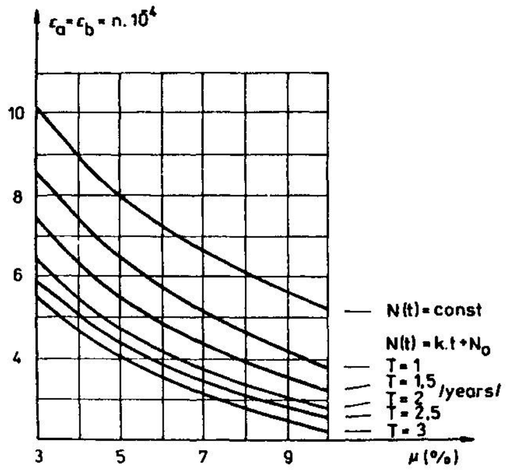

Fig. 2 Dependence of the extent of deformations due to creep on the percentage of cross-section reinforcement, accounting for the differences in the duration of building construction time

The most suitable is the possibility of substituting a bilinear relationships for the course of load increase on the member where, in the first part, the course of loading is a linear function of time and, in the second part, it is constant. This is a relatively most accurate expression of the real course of the load. The decisive factor is the time of construction T which it is relatively easy to determine in practice. The following conclusions can be drawn from the solutions of concrete creep effect at varying substitutions for the course of loading (Fig.1):

- the longer is the construction time T, the lower are the increments of compressive stress from creep on the reinforcement, and the increments of tensile stress from creep on the concrete. A similar dependence also applies to the strain generated by the creep of concrete.

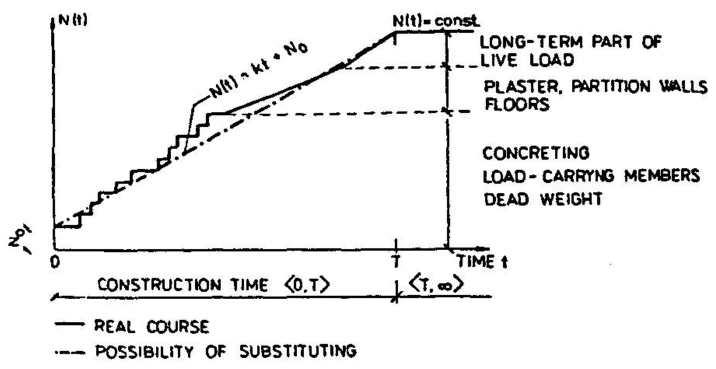

Fig. 3 The curve of normal force increase in the column of tall building

3. ANALYSIS OF SHRINKAGE EFFECTS

In relation to the effects of shrinkage, a higher percentage of reinforcement results in reducing the increment of compressive stress from shrinkage acting on the reinforcement and in increasing the increment of tensile stress acting on the concrete (Fig.4). Because the shrinkage is independent on the stress, it is also independent on the course of load increase. With respect to the strain, a higher percentage of reinforcement reduces the extent of strain from the shrinkage.

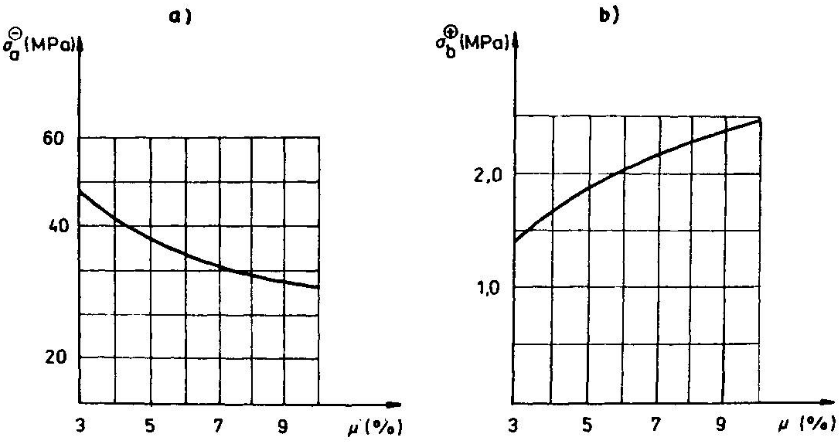

Fig. 4 Dependence of the stress in the reinforcement (a) and in the concrete (b) due to concrete shrinkage on the percentage of cross-section reinforcement

4. TALL BUILDING AND MEASUREMENT POINTS

The measurements of long-term strains of compression elements in the Press Centre tall building, Bratislava, may be listed, with regard to the investigated results, in the group of measurements whose conclusions offer a picture about the course of creep and shrinkage of concrete in a specific structure type. Due to this fact our attention was given to two structurally and statically important compression elements of the structure, i. e. load-carrying columns with a high percentage of reinforcement and gable walls with a low percentage of reinforcement.

The tall building has a height of 104 m. The measurements were conducted on the following floors (Fig.5): 4th floor, the measurement points being S1 to S4 columns and Š1 and Š2 walls, 11th floor, the measurement points being S5 and S6 columns and Š3 wall. S1 to S4 column dimensions were 1 400 x 700 mm (with welded I - section) and reinforcement 16 No 25 mm bars, having an overall reinforcement of 7,44 %. S5 and S6 column dimensions were 1 200 x 600 mm, the overall reinforcement 8,32 %. Wall thickness was 500 mm and the wall was reinforced with steel angles and reinforcing bars, the overall reinforcement being 1,15%. The selected structure points allowed only for overall strain measurements. These strains include a number of partial strains, i. e. strains due to tempe-

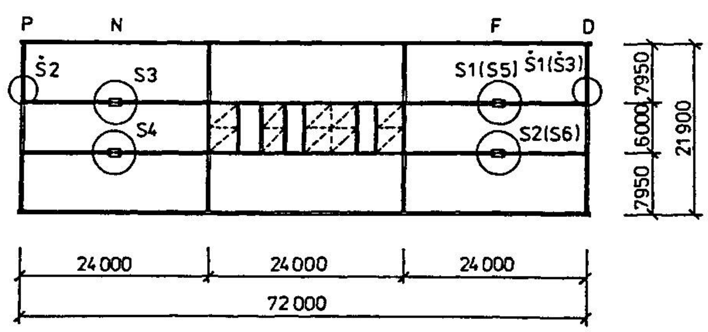

Fig. 5 Scheme of plan layout of tall building of Press Centre

rature changes, shrinkage namely due to changes in humidity, elastic strains due to load on a measured element, and strains due to creep of concrete.

5. THEORETICAL VALUES OF DEFORMATION

The growth of load of particular elements of the measured points in time was calculated according to the actual construction work sequence. Elastic strains were calculated from the assumption of central load of cross-sections of the measurement points. Modulus of elasticity of concrete in particular time was determined on the basic of laboratory results. Theoretical calculations of strains due to creep of concrete was conducted according to the e. g. Dishinger's theory of ageing. Differential equation of the 1st order with the right side will have the following form:

$$\frac{dN_{b\varphi}}{d\varphi} + \alpha N_{b\varphi} = (1-\alpha)\frac{dN(t)}{d\varphi} \qquad \text{where: } \alpha = \frac{A_a}{A_i} = \frac{A_a}{A_a + A_b/n} \tag{1}$$

The solution assumes the variability of the modulus of elasticity of concrete over time [3] :

$$E_{bN} = \frac{E_{b0}}{1 + \varphi_t \psi_N} \qquad n_0 = \frac{E_a}{E_{b0}} \qquad n_N = \frac{E_a}{E_{bN}} \qquad \frac{n_N}{n_0} = 1 + \psi_N \varphi_t \tag{2}$$

where: E_{b0} - initial modulus of elasticity of concrete

E_{bN} - modulus of elasticity of concrete in time at axial force load

ψ_N - subsidiary creep coefficient

The differential equation (1) is solved in two intervals. In $\langle 0, T \rangle$ interval on the assumption that $N(t) = k \cdot t + N_0$ (Fig.3). After substitution

$$\frac{dN_{b\varphi}}{d\varphi} + \alpha N_{b\varphi} = (1-\alpha)\frac{0{,}625\,k}{\varphi_\infty - \varphi} \qquad I = \int_0^{\varphi} \frac{e^{\alpha\varphi}}{\varphi_\infty - \varphi}\, d\varphi \tag{3}$$

$$N_{b\varphi} = (1-\alpha)\, e^{-\alpha\varphi} N_0 + e^{-\alpha\varphi}(1-\alpha)\, 0{,}625\, k\, I \tag{4}$$

Subsidiary creep coefficient ψ_N^1 valid for interval $\langle 0, T \rangle$ is

$$\psi_N^1 = \frac{k\,t + N_0}{\varphi\alpha\, e^{-\alpha\varphi}(N_0 + 0{,}625\,k\,I)} - \frac{1}{\alpha\varphi} \tag{5}$$

k - coefficient of erection race, N_0 - initial value of normal force,
φ - creep coefficient in time t ,
ψ_N^2 shall be valid for the interval $\langle T, \infty \rangle$.

$$\psi_N^2 = \left[\frac{N}{(1-\alpha)e^{-\alpha\varphi_\infty}(N_0 + 0{,}625\,k\,I)} - 1\right]\frac{A_b}{A_a\varphi_\infty \cdot n_N^1} - \frac{1}{\varphi_\infty} \tag{6}$$

N - maximum value of normal force, φ_∞ - creep coefficient in time = ∞. The following is valid for the resultant value of the elasticity modulus ratios

$$n_{N\infty} = n_N^1 (1 + \psi_N^2 \varphi_\infty) \tag{7}$$

The calculation of strains due to creep is

$$\sigma_{b\infty} = \frac{1}{n_{N\infty}} \frac{N}{A_{i\infty}} \qquad \sigma_{a\infty} = \frac{N}{A_{i\infty}} \qquad A_{i\infty} = A_a + A_b / n_{N\infty} \tag{8}$$

$$\sigma_b^{creep} = \sigma_{b\infty} - \sigma_{b0} \qquad \sigma_a^{creep} = \sigma_{a\infty} - \sigma_{a0} \tag{9}$$

The calculation of strains due to shrinkage (restrained shrinkage) at uniaxial state of stress was conducted according to the following relation

$$\varepsilon_{t\tau_1} = \frac{\varepsilon_{st\tau_1}}{\mu \, n_{\tau_1} \varphi_{t\tau_1}} \left(1 - e^{-\alpha \tau_1 \varphi_{t\tau_1}} \right) \tag{10}$$

$\varepsilon_{st\tau_1}$ - relative deformation of concrete at free shrinkage at time t which started to appear at time τ_1 , n_{τ_1} - modular ration of reinforcement for the age of concrete at time τ_1 , $\varphi_{t\tau_1}$ - creep coefficient at time t for the load which started to act at time τ_1.

6. TEST AND MEASUREMENT RESULTS

Concrete compressive strenght and elasticity modulus tests in time were conducted to obtain material characteristics of concrete. Cubes and prisms were fabricated from identical concrete mixture and treated under conditions identical to those of the tall building. Temperature and humidity were measured by thermohydrographs located in the shed at the control non-loaded cubes and at the hole in the wall. The measured deformations at the non-loaded plain concrete reference blocks include the effects of free shrinkage of concrete and temperature changes. Deformations due to temperature changes were calculated from the measured temperature values. Fig.6 shows plots of mean strains measured at two basic measurement points. A relatively good agreement can be stated when comparing the calculated values of deformations due to creep and shrinkage of concrete and elastic strains. The chosen method of calculation of the theoretical strain values due to creep and shrinkage of concrete for the given type of elements of the structure has been found as suitable and recommentable for use.

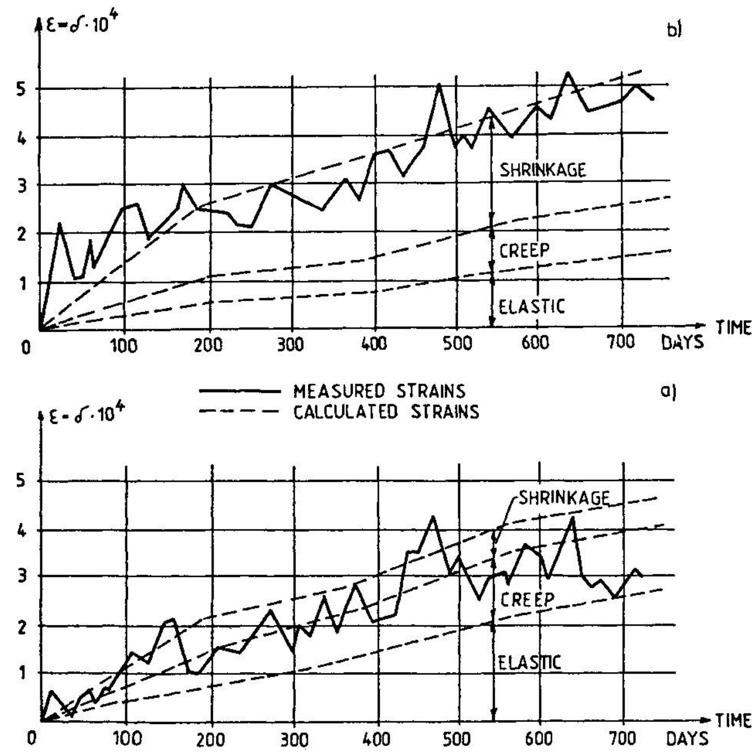

Fig. 6 Plots of measured mean strains at measurement points a/S1,S2,S3,S4 b/Š1,Š2

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