ДГКМ
ДРУШТВО НА ГРАДЕЖНИТЕ КОНСТРУКТОРИ НА МАКЕДОНИЈА

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ОДНЕСУВАЊЕ ПРИ ДОЛГОТРАЈНО ДЕЈСТВО НА ТОВАРИ НА КОМПОЗИТНИ БЕТОНСКИ ГРЕДИ КОИ СЕ КОНТИНУИРААТ

РЕЗИМЕ

Временските ефекти се значајни за димензионирање на бетонски конструкции. Меѓутоа, за да може да се смета на овие ефекти, потребни се аналитички процедури и веродостојни податоци за течењето и собирањето на бетонот. Со цел поедноставно да се решаваат овие проблеми, развиени се голем број на софтвери. Во овој труд презентирана е нумеричка симулација на експериментално долготрајно однесување на бетонски греди, кои од префабрикувани прости греди се направени континуирани. Нелинеарната анализа со помош на софтверот DIANA и поедноставениот метод за предвидување на отпорниот момент се споредени со експерименталните резултати. Беа употребени материјални модели ACI 209, MC 90, LRFD и EC2. Материјалните модели се исто така споредени во поглед на усогласеноста на пресметаните со измерените моменти.

Клучни зборови: композитни греди, бетон, методи за изградба, течење, собирање,нелинеарна анализа

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LONG-TERM BEHAVIOR OF COMPOSITE CONCRETE GIRDERS MADE CONTINUOUS

SUMMARY

Time-dependent effects are significant for the design of range of concrete structures. Reliable data for creep and shrinkage properties of concrete and analytical procedures are needed to account for these effects. A number of software applications have been developed to deal with time-dependent properties of concrete. In this paper numerical simulation of experimental long-term behavior of composite concrete beams made continuous is presented. DIANA software nonlinear FEM analysis and a simplified method for prediction of the continuity restraint moment are compared with the experimental results. ACI 209, MC 90, LRFD and EC2 material models have been applied. Material models were also compared with respect to compliance of calculated and measured moments.

Key words: composite beams, concrete, construction methods, creep, shrinkage, nonlinear analysis

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1. INTRODUCTION

The erection of whole span prefabricated girders is frequently used building technique for beam bridges of small to medium spans (20 – 40 m). Bridge structure is composed of prefabricated longitudinal beam elements of one span and cast in situ deck slab. In case that there is no continuity above inner supports, adjacent spans are connected with expansion joints. Joints are followed with driving discomfort and maintenance problems. A continuous structure has reduced number of joints followed with improved deck surface and reduced maintenance costs. Continuity is nowadays mainly achieved by the mild reinforcement embedded in a deck slab that is cast together with the continuity diaphragm at the support area.

The construction is generally performed in two phases. During the first phase precast beams are simply supported carrying their own weight, load from the formwork and cast in-situ concrete of the slab. In the second phase, after hardening of the in-situ concrete, structure becomes continuous, but only for additional dead load and live load. The cross sections of these continuous girders are composed of precast concrete elements and a cast in-situ slab. For this type of the structure, redistribution of the internal forces will take place in course of time. The subject of this paper is development of the restraint moment in continuity joint in course of time, under sustained load. The continuity moment caused by superimposed dead load and live load is not considered in the study.

2. REDISTRIBUTION OF INTERNAL FORCES IN COMPOSITE CONCRETE BRIDGES MADE CONTINUOUS

The restraint continuity moment develops over time, when a continuous bridge structure is created from a series of simple spans by casting continuity joints. There are two main causes: the creep under a load that was applied on simple spans and the differential shrinkage between parts of a composite cross section.

2.1. Effects of creep under dead load and prestressing

The creep of concrete causes an increase of deflection and corresponding end slope due to self weight of the girder. When the girder end rotations are restrained by continuity, a negative restraint moment develops, Fig. 1a. Prestressing initiates an opposite deflection (camber) and end slope than the self weight, producing a positive restraint moment at the continuity joint over time, Fig.1b.

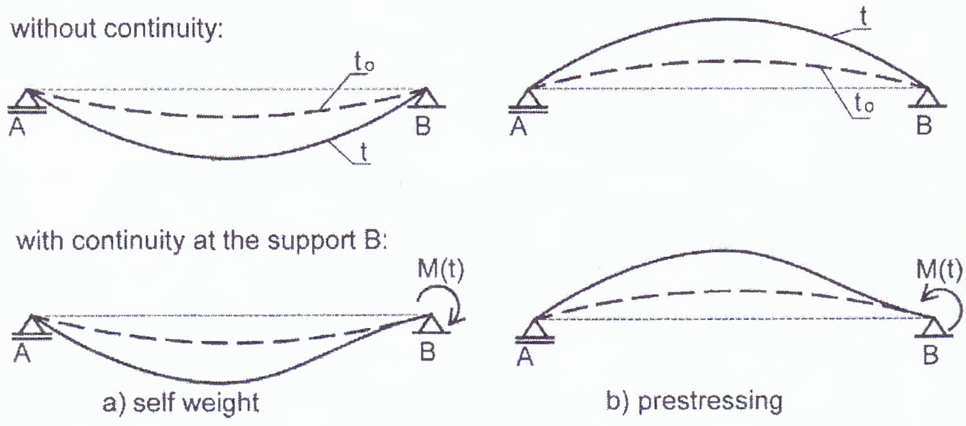

Fig. 1. Development of the restraint moment due to self weight (a) and prestressing (b)

The interaction of self weight and prestress induces a restraint moment that can be either positive or negative. Usually, the restraint moment resulting from self weight and prestress is positive.

2.2. Effects of differential shrinkage

The deck concrete is of a different age than the precast girders concrete. Part of the shrinkage of the precast girders occurs before casting of the deck slab. The shrinkage of slab concrete exceeds the remaining part of the girder's shrinkage, so that differential shrinkage appears.

The composite girder-slab structure deflects downward due to the differential shrinkage, and, similar to the effect of the self weight, a negative restraint moment develops at the continuity joint, Fig. 2.

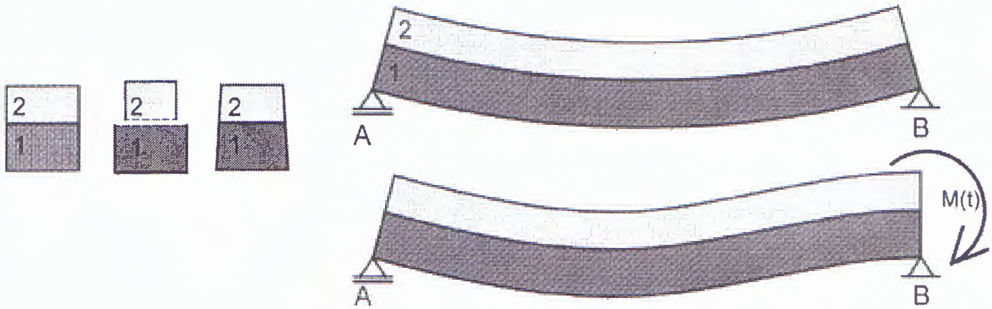

Fig. 2. Effect of differential shrinkage

The creep under dead load and prestressing and the differential shrinkage may together produce either negative or positive restraint moment. The sign and the value of restraint moment depend on several parameters: construction schedule, material properties, prestressing force, tendon layout and ratio of slab to girder stiffness. Usually, a net positive restraining moment would develop. This moment tends to reduce continuity.

3. TIME-DEPENDENT STRUCTURAL ANALYSIS

In course of time, stress-strain relations for concrete are described with a special type of equations known as Volterra's integral equation:

$$\varepsilon_{\sigma}(t)=\int_{0}^{t} J(t,\tau)d\sigma(\tau) \tag{1}$$

The kern of the integral equation is two-parametric creep function:

$$J_{c}(t,\tau)=\left[\frac{1}{Ec(\tau)}+\frac{\varphi^{ceb}(t,\tau)}{Ec(28)}\right] \quad or \quad \left[\frac{1}{Ec(\tau)}+\frac{\varphi^{ACI}(t,\tau)}{Ec(\tau)}\right] \tag{2}$$

The creep coefficient function is a subject of the whole field in concrete rheology. Mathematical equations, proposed in various Codes or recommendations, involve many parameters (concrete strength, relative humidity, temperature, size effects), but are not suitable for the solution of Eq. (1) in closed form. Methods for structural analysis, which account for the time-dependent properties of concrete, develop together with calculation techniques. Simplified methods require approximations concerning homogeneity of the structure and modification of the creep function in a more convenient shape.

3.1. Simplified methods

These methods do not require use of the special software for nonlinear structural analyses.

A very popular method for estimating the effects of creep and differential shrinkage, especially in the USA, is the so-called PCA method, published by the Portland Cement Association (PCA, 1969.). This method is based on the rate of creep, and is very effective for hand calculation. The PCA method is appropriate for homogeneous structures, assuming constant sectional properties along the beam element. This assumption is valid for prestressed precast girders.

For two spans, PCA method proposes following equations to estimate the restraint moment:

$$M(t) = (Mp - Mg)(1 - e^{-(\varphi - \varphi_0)}) - \frac{3}{2} Ms \frac{1 - e^{-\varphi}}{\varphi} \quad (3)$$

$$Ms = \varepsilon_{s,diff} E_b A_b (y_{com,2} + \frac{d_b}{2}) \quad (4)$$

Sign "+" represents positive moment. φ is the creep coefficient. φ_0 is the creep coefficient from the time of prestressing to the time when continuity is established. *Mp* and *Mg* are bending moments due to prestressing and self weight in a continuous monolithic structure, while *Ms* is the moment introduced by differential shrinkage, Eq. (4). Index "*b*" represents properties of the slab. The expression in brackets is a distance from the centroid of the slab to the centroid of the composite section. Difference between shrinkage of the slab and remaining girder shrinkage is differential shrinkage $\varepsilon_{s,diff}$.

3.2. Non-linear structural analysis

Common numerical procedure for structural analysis involving time dependent effects performs step-by-step solution of the integral type creep low, expressed by Eq. (1). Modification of the creep function to the form of a Dirichlet series is also used in most of computer applications. The creep functions from codes, usually used in such applications, are already approximations of concrete behavior. One must have in mind that applications approximate creep function once again, with suitable mathematical series, for the purpose of numerical procedures.
In any FE analysis, the structure discretised to finite elements. To enable numerical solution of nonlinear problems a time discretization is also performed. Since the equations are not linear, an iterative solution algorithm is used to achieve equilibrium of external loads and internal forces at the end of time increment. This is so-called incremental-iterative solution procedure. In this paper, DIANA Finite Element System[5] was used to evaluate impact of predicted material properties of concrete on the results.

4. COMPARISON OF EXPERIMENTAL AND ANALITYCAL RESULTS

Pilot tests of continuous girders were performed in PCA laboratories in the period 1960-1961. Girders were a true copy of the prototype (AASHTO type III girder) with a scale factor of 2:1. Detailed description of models is presented in references 6 and 7. Models were formed from two simple span precast prestressed girders of 10.06 m span, spacing 7.62 cm on the intermediate support. Girders were made continuous by casting a continuity joint together with the slab. Long-term monitoring was running through 2 years, including survey of the intermediate support reaction. Change of the support reaction indicated development of the continuity moment. Results of this research were published in a series of Bulletins[6,7], establishing reference values for verification of design procedures for prediction of the restraint moment in a continuity joint.

In this paper, results obtained by two methods (PCA analytical method and DIANA step-by-step FEM numerical procedure) are compared with PCA experimental data. Four material models for concrete creep and shrinkage (LRFD[1], ACI 209[2], MC90[3], and EC2[4]) were used. Concrete grade, constant relative humidity and cement type were input parameters.

Comparison of the results is presented in Fig. 3. Continues lines show results of nonlinear phase analysis (DIANA). The PCA method results are presented in dashed lines. Experimental data ("Mathoc measured") indicated development of the positive final continuity moment.

It appears that various models for the concrete creep and shrinkage result in similar behavior regarding the continuity moment. Negative restraint moment develops immediately after the continuity is established. In approximately one month, this moment starts to decrease, Fig. 3.

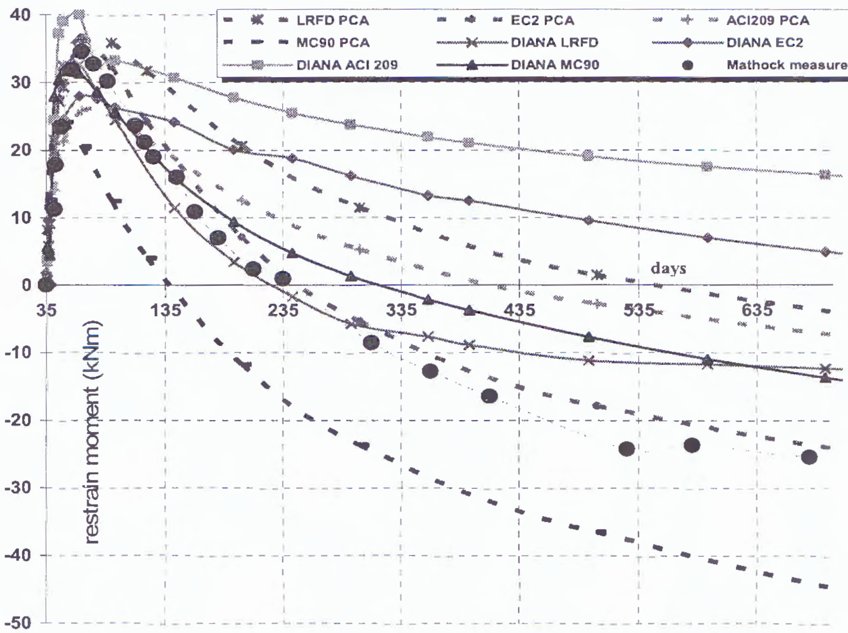

Fig. 3- Measured and calculated values of restraint moment

Negative value of the calculated final restraint moment is obtained only at DIANA nonlinear phase analysis with ACI209 material model. All other material models and methods finally lead to a positive value and may be compared with the test results. The final positive values of the restraint moment for various creep and shrinkage recommendations scatter over the wide range. Results for the maximum negative value of moment are more consistent, but it is a transient phase in the initial period.

Presented results show that material properties used in design are of the most importance for analysis of the long-term behavior. There are large differences between the available recommendations for predicting creep and shrinkage properties of concrete. In the design phase, material properties of real concrete are not known. None of the recommendations provides accurate model to all the test data. In the example presented in the paper, best compliance with experimental data is obtained with EC2 material model for creep and shrinkage.

As for method applied, both DIANA step-by-step FEM nonlinear analysis and PCA analytical method gave similar accuracy in comparison with experimental data for the restraint continuity moment.

5. CONCLUSIONS

Based on the results from presented example it can be concluded that material properties used in design are of the most importance for analysis of the long-term behavior. Best compliance with the experimental data is obtained with EC2 material model for creep and shrinkage.

Both analyzed methods for estimating restraint moment (non-linear analysis, PCA method) are accurate to a similar level in comparison with the measured values. The simple PCA method with no pretence to great accuracy is to be preferred to predict long term behavior of composite concrete girders made continuous.

In view of the uncertainty of material properties, it is advisable to use various material models combined with simplified methods in design to obtain upper and lower limits for stresses and deformations.

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