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# LONG-TERM BEHAVIOR OF PRECAST CONCRETE GIRDER WITH CAST IN PLACE DECK AND DIAPHRAGM

**Abstract:** Composite precast-cast in place bridge girders made continuous for live load are very popular solution for bridges of small to medium spans. In domain of service state of stresses, material nonlinearity of concrete structures, manifested through creep, shrinkage and cracking, plays an important role in structural behavior. As for the design for long-term effects restrained bending moment that would develop over intermediate supports is most critical feature. In order to predict time-dependant effects in concrete structures, engineers need reliable data for creep and shrinkage properties of concrete and analytical procedures to account for these effects. There are several recommendations for time-dependant concrete properties, and developments in computational techniques make it possible to use any type of model. This study was undertaken as an attempt to evaluate the influence of various creep and shrinkage model recomendations on the continuity behavior of composite concrete girders made continuous, after an extended period of time.In this paper numerical simulation is obtained using nonlinear FEM model of DIANA application.

**Key words:** Time-dependence; Concrete; Creep; Shrinkage; Nonlinear structural analyze

# PONAŠANJE PREFABRIKOVANIH NAKNADNO KONTINUIRANIH BETONKIH NOSAČA TOKOM VREMENA

**Rezime:** Spregnuti betonski montažno-monolitni mostovi, sa kontinuitetom nad srednjim osloncima za saobraćajno opterećenje, predstavljaju veoma zastupljeno rešenje za mostove manjih do srednjih raspona. U domenu eksploatacionih napona, betonske konstrukcije pokazuju nelinearno ponašanje koje se ogleda kroz tečenje, skupljanje i pojavu prslina. Nad srednjim osloncima, gde se ostvaruje kontinuitet, razvija se tokom vremena moment savijanja, nezavisno od opterećenja. Ova pojava je posledica tečenja i skupljanja betona, i da bi se ponašanje ovakvih konstrukcija tokom vremena, moglo predvideti, projektantima na raspolaganju stoje nekoliko modela vremenskog ponašanja betona i čitav niz kompjuterskih aplikacija za nelinearnu analizu konstrukcija. U ovom radu analizirana je posmatrana pojava uz upotrebu programske aplikacije za nelinearnu analizu konstrukcija metodom konačnih elemenata DIANA. Izvršena je komparativna analiza na numeričkom primeru prefabrikovanog armiranobetonskog i prethodno napregnutog nosača uz korišćenje različitih predloga za skupljanje i tečenje betona.

**Ključne reči:** Dugotrajni efekti; Beton; Tečenje; Skupljanje; Nelinearna analiza konstrukcija

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# 1. INTRODUCTION

Since second quarter of twenty century, corresponding with mass usage of concrete as a building material, concrete bridges are built using the methods previously used for steel bridges. Most often building technique for beam bridges of small to middle spans (20 - 40m separate spans) is the erection of prefabricated girders of the whole span. Bridge construction consisted of pre-fabricated longitudinal beam elements of whole span and cast in place deck slab. Link between adjacent spans was provided with expansion join, with all functional difficulties that more joins involves (discontinuity in deck – riding discomfort, mentence problems). "Series of simple span" bridges were constructed with composed concrete section consisted of precast elements and cast in place slab. The idea of creating continuous structure was imposed so as to improve riding surface and reduce mentence costs. Several solutions for creating continuity were used. Continuity is nowadays mainly achieved with mild reinforcement, which is posed in deck slab, cast together with diaphragm in support regions.

Design of ''continuous for live load" bridges demands a detailed analysis of the material properties and time-dependent effects. The subject of this paper is time-dependant effects in a statically indeterminate concrete structure, made in phases. The construction is generally done in two steps. In the first step the beams are simply supported and carry their own weight plus the load from the formwork and the wet cast concrete of the slab. In the second step, after hardening of the in-situ concrete, the structure becomes continuous, but only for the additional dead load and the variable loading. Furthermore, the sections of these continuous girders are composed of precast concrete elements and cast in place slab. For this type of structure and building process the redistribution of internal forces within the structure will progressively change during the subsequent life of the structure, even if load remains constant.

Concern of viscous concrete properties, requires a nonlinear structural analysis that includes time-dependent effects of creep and shrinkage. In this paper numerical simulation of the some experimental long-term investigations of composite concrete beam made continuous, using nonlinear FEM model of DIANA application is presented. Various proposed material properties are used in analyze to present sensibility of the results.

# 2. TIME-DEPENDANT STRUCTURAL ANALYSIS

## 2.1 Practical methods for structural problems

Stress strain relations for concrete through time are described with the special type of equations known as Volteras integral equations, (1).

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

Kern of integral equation is two parametric function known as creep function, expressed by relation (2).

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

Mathematical equations, proposed in various Codes or recommendation, are trying to be exact as much as can be, considering many parameters (concrete strength, relative humidity, temperature, size effects), but are not suitable for the solution of equation (1) in closed form. There are several metods for structural analysis, concerning stress-strain relation (1). In table 1, types of structures parallel with appropriated practical methods are presented.

*Table 1 – Review of Methods and structures types*

<table>
<tr><th colspan="2">Method</th><th>Structure type</th></tr>
<tr><td colspan="2">Step – by – step method</td><td>All type of structures</td></tr>
<tr><td rowspan="2">Simplified methods</td><td>Algebraic (EM,MS,AAEM)</td><td rowspan="2">Homogenous or quays homogeneous structures, with parts that may be approximated as homogenous and with rigid restrains or linearly elastic restrains and with relatively low stresses variations (up to 30%)</td></tr>
<tr><td>Rate of creep methods<br>(Dishinger's method)</td></tr>
<tr><td colspan="2">Application of the four basic theorems of the theory of linear viscoelasticity</td><td>Homogenous structures with rigide restrains</td></tr>
</table>

Quite a large number of concrete structures can be approximated as homogenous or quasi homogeneous (homogeneous along separate elements), so in design process second and third groups of methods can be used. Structural type, which is the subject of this paper, can hardly be approximated as homogeneous, so is indicated for usage of general numerical step-by-step method.

General method, known as step – by – step method is based on numerical integration of equation (1), so that is sutable not only for every structural kind bat for any kind of creep function, as well. As step-by –step method required the memory of all previous steps it is not sutable for hand calculations and it often involves usage of special software, for nonlinear structural analyses. Creep function, that is usually used in such applications, is already approximation of concrete behavior (varioius Codes or recommendations. For the needs of numerical procedures, applications approximates that function once again with suitable mathematical series. For the various combinations of material variables in input data; one can obtain quite different results, which questions the estimated results. For that reason, it is more appropriate to use methods that do not pretend to high accuracy, but leads into the right direction of structural behavior. That will be demonstrated in numerical examples.

## 2.2 Simplified methods

Very popular method for estimating effects of creep and differential shrinkage, especially in USA, is so called PCA method published by the Portland Cement Association (PCA) in August 1969 [5-7]. Based on the rate of creep, PCA method is indicated for homogeneous structures, assuming constant sectional properties along the beam element. This assumption is, more or less, correct in case of prestress precast girders. When precast girder is reinforced further simplification must be made. Considering the presence of cracking some kind of effective stiffness must be established.

For two spans PCA – method proposes the equation for estimating restrain moment:

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

With:

$$Ms = \varepsilon_{s,d} E_s A_s (y_{com,2} + \frac{d_p}{2}) \tag{4}$$

Sign "+" represents positive moment, $\varphi$ is creep coefficient, $\varphi_0$ is the creep from the time of prestressing to the time continuity is established, Mp and Mg are moments caused by prestress and self weight in continuous monolithic structure, while Ms is moment introduced by differential shrinkage, described with (4). Index ''s'' represents properties of slab, while the member in parentheses is distance from the centoid of the slab to the centoid of the composite section. Differential shrinkage is the difference between slab and remnant girder shrinkage.

### 2.3 Non linear finite element structural analyze

A usually numerical procedure for structural analyze concerning time dependent effects consists in step-by-step solution of integral type creep low. As in any FE analyses, structure is already discretized in space (finite elements), but to enable numerical solution of nonlinear problems a time discretization is performed as well (steps – increments). Another kind of material nonlinearity is the presence of cracks in concrete structures. So in nonlinear structural analyze steps presents not only discretization of time, but discretization of loads in steps to track cracking. To achieve equilibrium of the external loads and internal forces at the end of the time and load increment, an iterative solution algorithm is used, since the equations are not linear. This procedure is called incremental-iterative solution procedure.Commercial software, DIANA Finite Element System, is used to obtain such an analyze [3]. This software is capable to solve various kinds of structural problems, here is in brieft present feature of the program that are used in this particular analyze

Strait, two-node, two-dimensional elements, based on the Bernoulli theory, were used for nonlinear analyze. All elements were integrated with three points Gauss scheme along the beam axes and cross section was integrated with eleven points Simpson scheme. In analyze brittle cracking model was adopted. Constant stress cut-off was applied for precast and cast in place concrete. Brittle behavior is characterized by the full reduction of the strength after the strength criterion has been violated. Constant stress cut-off indicates that a crack arises if the major principal tensile stress exceeds $f_{ctm}$. For solving this nonlinear problem DIANA Phased Structural Analyses is performed.

## 3. Effects of concrete viscouse properties on behaviour of composite for live load bridges

### 3.1 Effects of creep under dead load and prestressing

Under long lasting load, that is dead load and the prestressing force the precast concrete girder creeps. Self weight of the girder cause the downward deflection and corresponding end slope. When the girder end is locked by continuity of the composite superstructure, a negative restrain moment is develops.

Prestressing initiate opposite deflection and end slope then the self weight, producing a positive restrain moment at the continuity join over time.

Mutual action of self weight and prestress inducts restrain moment that can be either positive or negative. That depends on intensity of prestressing force and tendon layout. It is usual that restrained moment resulting from self weight and prestress is positive.

When the precast girder is reinforced, there is no prestressing force, so, restrained moment resulting from self weight is negative.

### 3.2 Effects of differential shrinkage

Since the girders are precast, the deck concrete will be of a younger age than the girders. Certain amount of shrinkage of precast girder would occur before the deck slab is cast. Differential shrinkage would appear, since the slab concrete has yet to shrink, exceeding the remaining shrinkage in the girder concrete.

The composite girder-slab structure deflects downward, analogous to the effect of the self weight, negative restrain moment at the intermediate supports develops. Differential restrained shrinkage presents imposed deformation. In case of imposed deformation creep of concrete reduce the value of this negative restrain moment.

## 4. EXAMPLES AND COMPARISONS

In order to demonstrate differences in structural behavior of subjected type of structures concerning long term behavior, two type of precast girders those are prestresses (case A )and reinforced (case B ) are analyzed. Two methods are used: PCA method and DIANA Phased Structural Nonlinear Analyses. Three recommendations for concrete creep and shrinkage are used: ACI209 [1], MC90 [2] and EC2 [4].

Sections for bridge structures of single spans of 20m that were used in these exampes are shown on figure 1. For the simplicity, precast girder has the rectangle section.

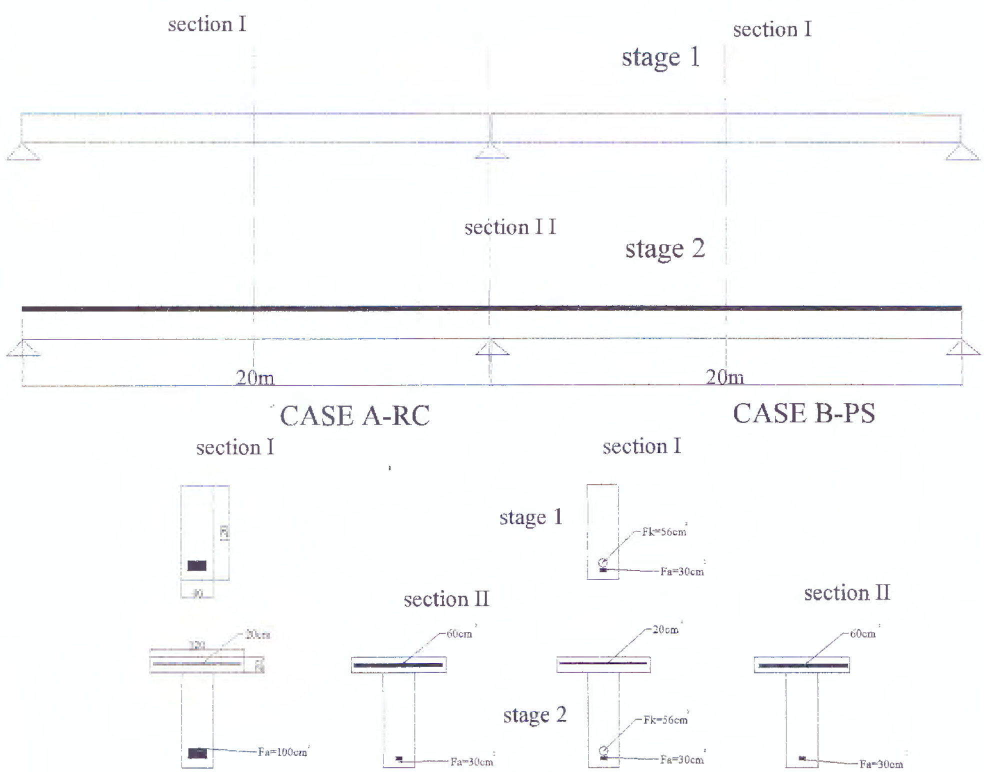


*Figure 1Girder used in presented numerical example*

The girder section was choused so as to satisfied both cases, but the amount of reinforcement in reinforcement precast section is extremely high (2%) to satisfied commonly used simplified calculation. The simplified calculation was provided with the assumption that the precast girders carry its weight and weight of the slab as the sample span, while the live load is carried by continuous composite structure. The amount of the live load is assumed to be equal to the self weight (which is quite real). The amount of the positive reinforcement in mid span was determined under assumption that the self weight of girder and slab is carried by girder as simple span, while live load is carried by composed section of continuous structure. This simplified treatment is ordinary for subjected structural type. The cable layout is assumed to be straight as is in case of pre-tensed precast girder. The girder was loaded at the age of 28 days; while the slab was cast at the age of 42days (14 day after the girders were posed).

Restrained moment are presented on the figures below. Effects are graphed over the percentage of redistribution that is ratio of the restrained moment to continuity moment obtained from linear elastic analyses. Linear elastic value is obtained for continues monolith structure loaded with self weight and prestress. Since in monolith structure (non composed sections) no differental shrinkage would appeare, on the graphs are presented results obtained using DIANA when no shrinkage would occure. In case of prestressed precast girder results are more sensitive on neglecton of differntial shrinkage even changing the sign of restarined moment.

Brocken lines are result obtained using PCA method. PCA method is indicated for prestressed precast girders (with no cracked). Reiforced precast girder cracked under the self weight, so that properties of the cracked girder section were used for obtaining results on figure3.

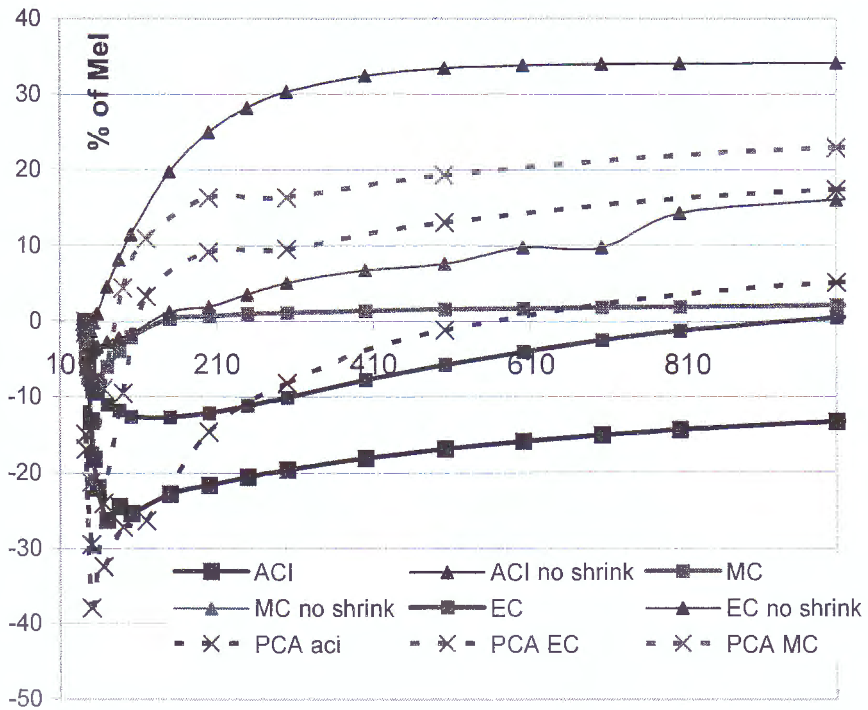


*Figure 2 Restrained moment in % of elsatic value for prestressed precast girder*

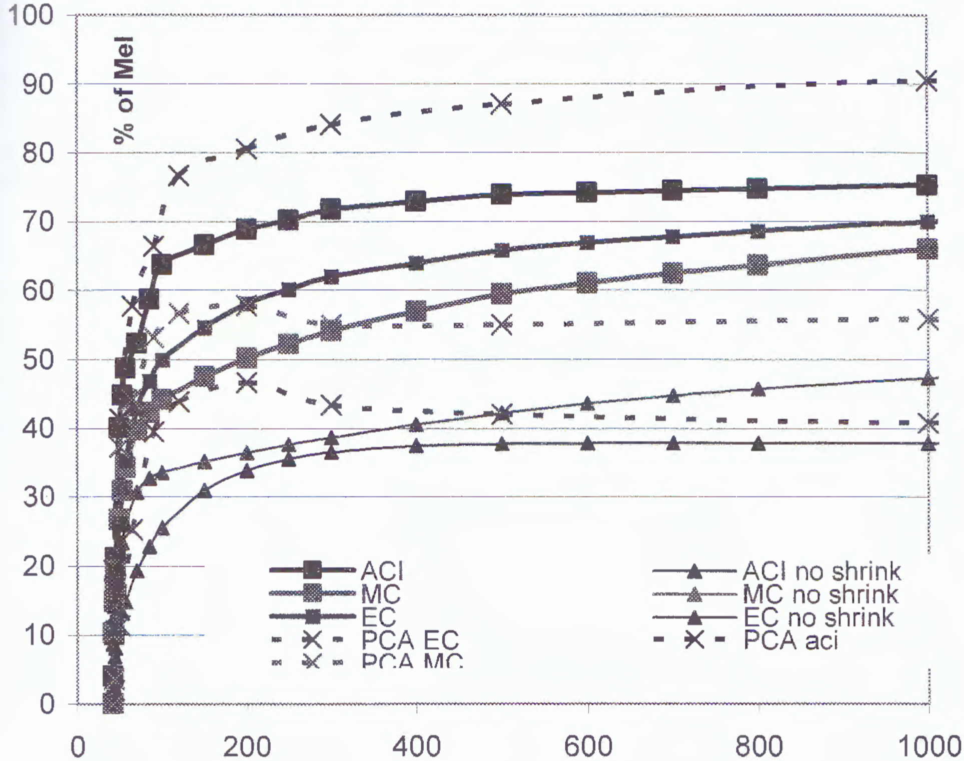


*Figure 3Restrained moment in % of elastic value for reinforced precast girder*

Analyzing the results presented on figure 2 it can be concluded that prediction of concrete material properties, that is used in computation, concerning creep and shrinkage, are of most influence. Restrained moment is negative at initial period due to intensive increase of differential shrinkage. Final sign of restarined moment is mainly positive reaching approximately 30% of linear elastic value for continues monolith structure loaded with self weight and prestress. Usage of PCA method distribute the results in range of 15-30% of elastic solution.

Results on figure 3, for cracked precast girder are more comparable, since the sign of restarined moment is always negative. Once again, the effects of differential shrinkage are noticeable. In this case, final restrained moment, concerning both creep and shrinkage, is almost the same for all model of concrete properties ( nearly 75% of elastic value). Negation of differential disperse results to 40-50%. In this case, PCA method distribute the results in range of 40-95% of elastic solution.

## 5. Conclusions

Based on the results from the numerical example presented above it can be concluded that material properties used in design and analyses are of most importance concerning long term behavior. There are large differences between the available recomendations for predicting creep and shrinkage concrete properties and the inability of any accurate model to all the test data. Concerning that it is advisable to use various material models in design to obtain upper and lower limits for stresses and deformation. In view of that statement it is felt that the simple method with no pretence to great accuracy is to be preferred, to predict long term behavior of precast concrete girder with cast in place deck and diaphragm.

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