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Amount of Prestressing Based on Serviceability Requirements

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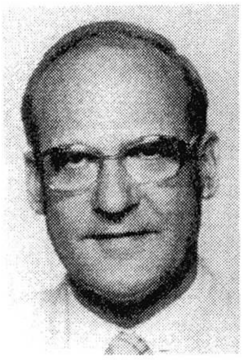

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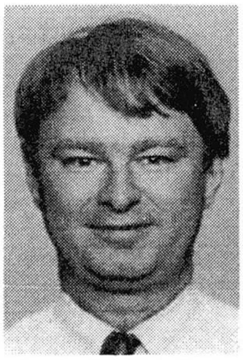


Summary
The paper proposes design criteria for the choice of the amount of prestressing. Based on an extension of the well known load balancing method, the proposed criteria permit a simple and effective design of the amount of prestressing at serviceability. The paper also discusses the favorable effect of compressive stresses induced by prestressing on cracking and water-tightness of PC structures. In situ measurements as well as numerous test results demonstrate that the proposed criteria lead to structures that are more durable and less prone to an increase in deflections and cracking over time.

Keywords: bridges, prestressed concrete, serviceability, cracking, design criteria, cyclic loading, in situ measurements, residual crack opening, water-tightness

Abstract

Behavior in service is extremely important for all structures, and serviceability requirements should be central in the choice of the amount of prestressing. They are unfortunately often omitted in the initial design, only to be checked in subsequent verifications. This is unfortunate, considering the fact that structures spend most of their useful life at the serviceability limit state. Owners and users alike are more concerned with the actual behavior of structures during their service life than by their possible behavior at the ultimate limit state.

In spite of intense research in the field of cracking and deformations, there is a lack of clear and easily applicable design procedures for the serviceability limit state,. This article proposes such criteria, based on the concept of compensation of deformations, which is essentially a generalization of the load balancing method. These criteria are essentially based on the behavior under permanent loads. The paper, however, includes some considerations about irreversible effects due to cracking under variable loads.

In the **compensation of deformations** approach, instead of *balancing loads* as in the load balancing method, the designer *compensates deformations*. Although it increases the computing effort, this approach has the great advantage of taking into account the effect of anchorage forces and the effect of non-rectilinear gravity axes (fig. 1). The degree of compensation of deformations β is defined as :

$$\beta = \frac{w_c\,(P_m)}{w_c\,(g)} \quad with \quad P_m = \frac{P_{t=0} + P_{t=\infty}}{2}$$

where

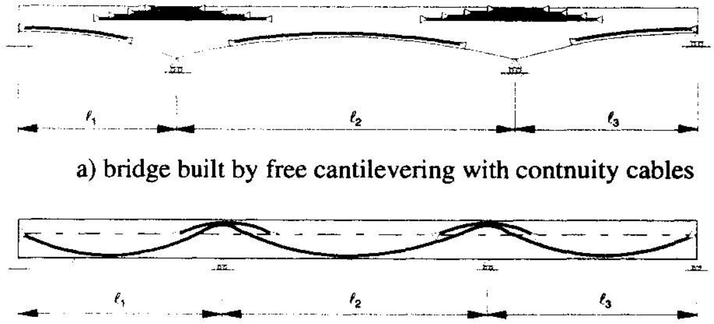
w_c : elastic deflection at mid-span (creep is not taken into account as it would appear in the numerator as well as in the denominator of eq. 1)

P_m : average prestressing force over the lifetime of the structure , $P_m = (P_o + P_\infty) / 2$

β : degree of compensation of defections

g : permanent and occasionally semi-permanent loads

Because moments induced by the prestressing cables only approximate the moment diagram induced by permanent loads, the value of β defined above varies slightly from point to point along the axis of the structure. For simplicity's sake, β is normally taken at mid-span



a) bridge built by free cantilevering with contnuity cables

b) bridge with overlapping cables

Figure 1: *Situations for which the application of the load balancing method is impractical*

Table 1: *Recommended β-values for various types of structures*

Type of structure	Increased requirements	Normal requirements
Road bridge	0.9	0.8
Rail bridge	1.1	1.0
Building slab	0.6	0.5
Heavily loaded slab	> 0.6	> 0.5

The concept of compensation of deformations permits a **choice of the amount of prestressing** based on a single global and rational criterion. Table 1 gives values of β as a function of the structural type and requirements. These values are indicative, in that they are to be used for the initial choice of the amount of prestressing, and that they are not intended to replace the usual code checks. As a rule, the amount of prestressing obtained by applying this table is slightly larger than the minimum amount required by most current codes. The values given for slabs are smaller than for beams, because of the favorable effect of the tensile strength of concrete. Observed behavior both short- and long-term demonstrate that the proposed values lead to an excellent performance in service. At the same time, it has been observed that bridges with β-values significantly lower than indicated in table 1 often exhibit an unsatisfactory behavior at service state.

Table 2: *Residual crack opening after an exceptional loading*

σ_{perm} [MPa]	≈ 0	-0.5	-1	-2	≤ -5
w_{res} [mm]	0.2	0.1	0.075	0.05	0.025

A good behavior in service implies that cracks that may occasionally open under exceptional service loads have a sufficiently **small residual crack opening** under permanent loads. Passive reinforcement ratio, bar diameter and concrete properties have a strong influence on residual crack opening, but the two most important factors are the stress level under permanent loads and the magnitude of the maximal tensile stress under the exceptional load. Table 2 summarizes the results of a parametric study for typical stress ranges. It indicates the compressive stress required to effectively limit the residual crack opening under permanent loads w_{res}. Its validity is limited to the case when no yielding of the reinforcement occurs under the exceptional load.

Conclusions

Starting from a perspective of good behavior at the serviceability limit state, the article proposes **very general criteria** for the choice of the amount of prestressing. These criteria are focusing on the behavior under permanent loads for both cracking and deflections. The influence of variable actions (movable loads and temperature) is taken into account through their irreversible contribution to the behavior under permanent loads.