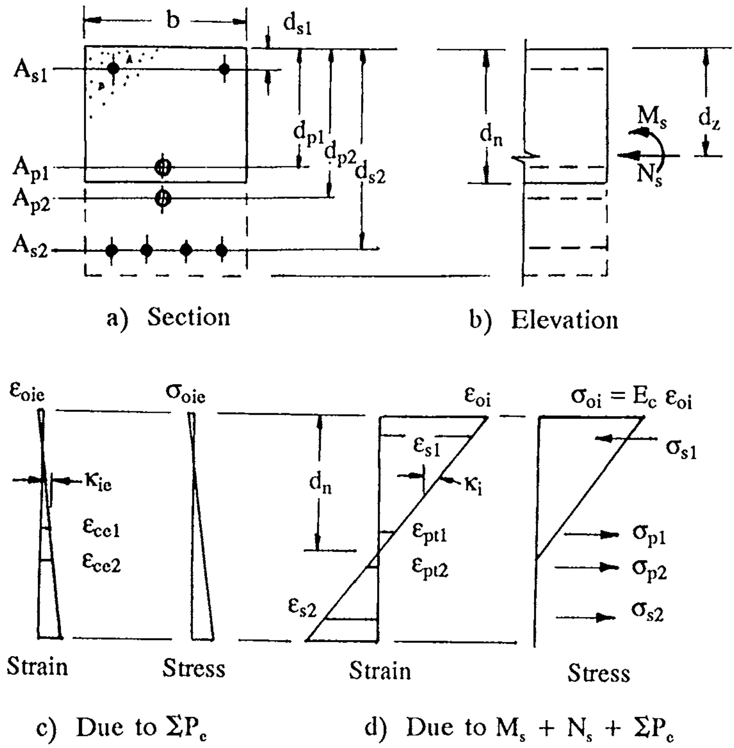


Fig. 3--Cracked section -- short-term behavior

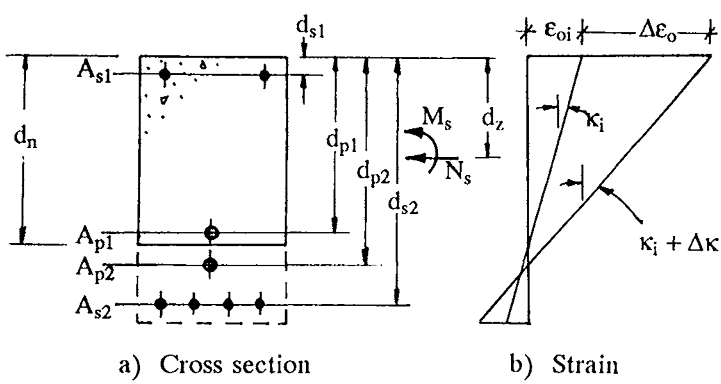


Fig. 4--Cracked section -- time analysis

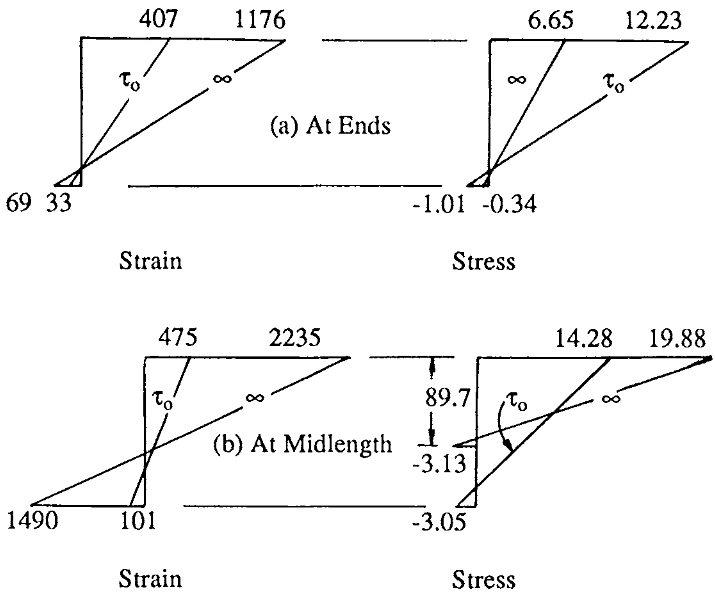


Fig. 5--Calculated stress and strain in column tested by Kordina [8]

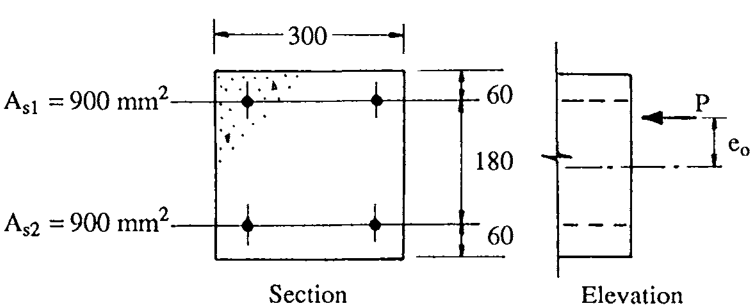


Fig. 6--Column cross section used in analytical investigation

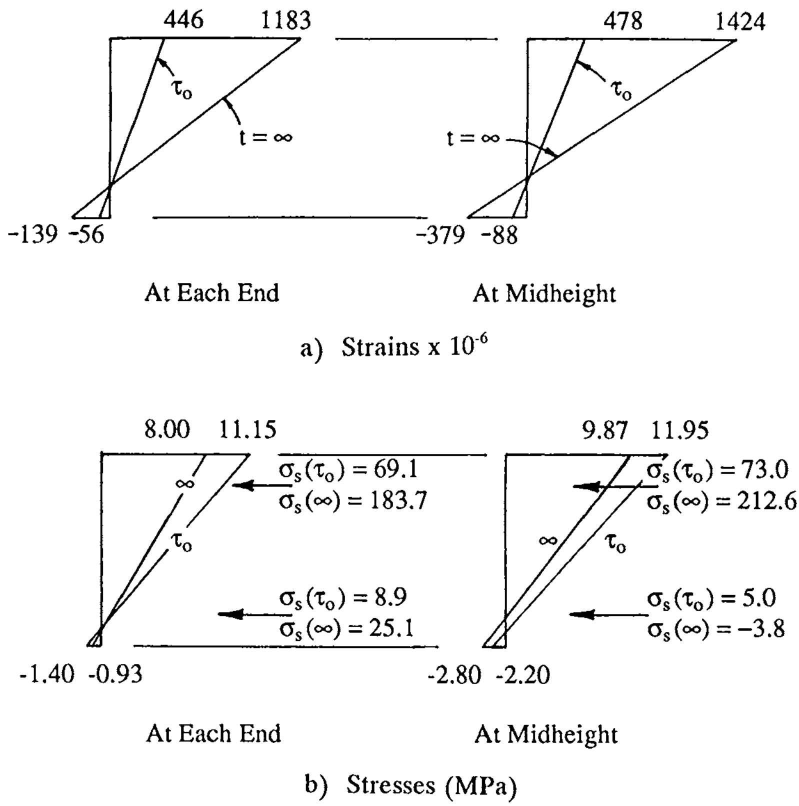


Fig. 7--Stresses and strains on critical cross sections -- Case A

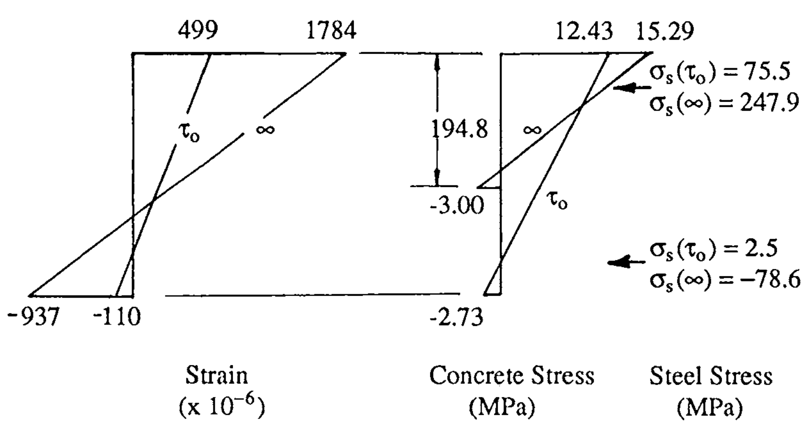
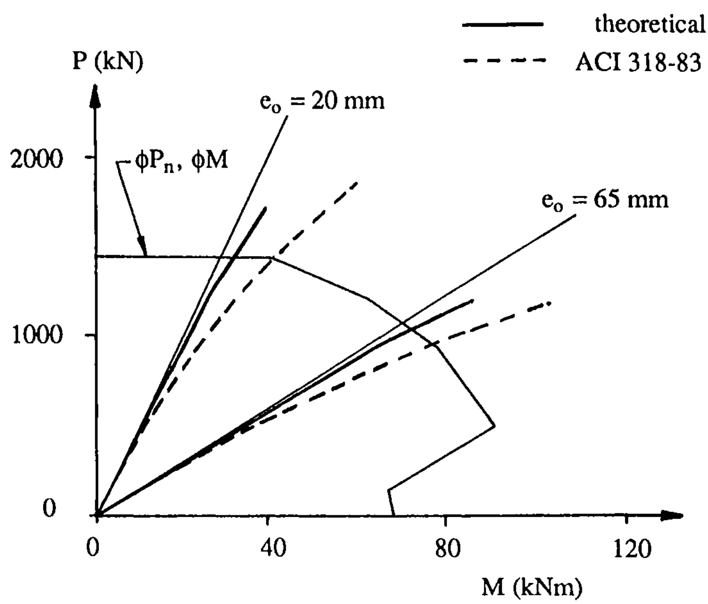
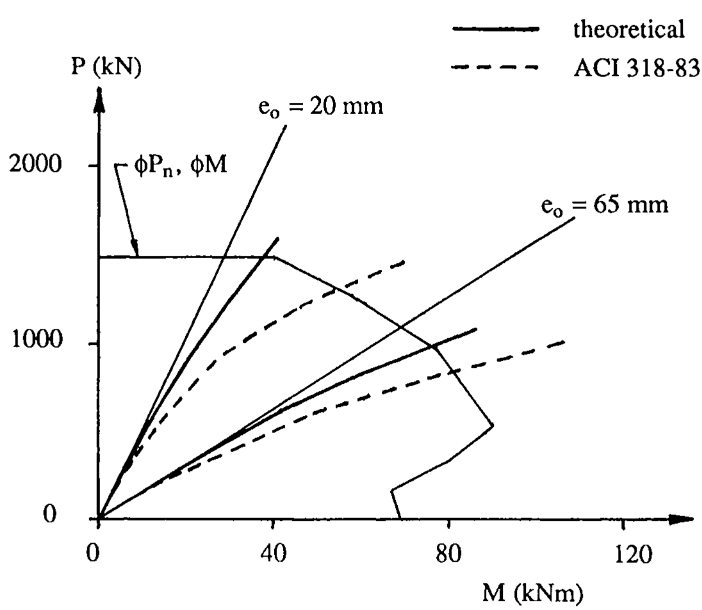


Fig. 8--Stress and strain at midheight -- Case B

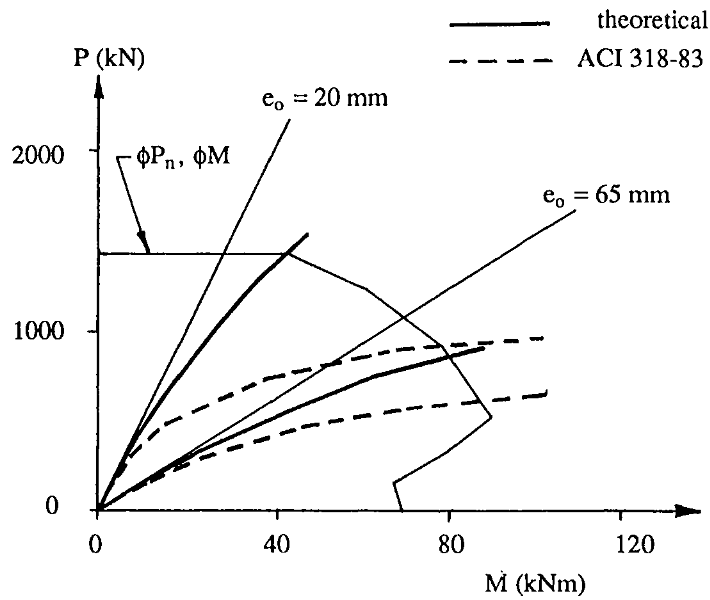


a) Initial loading

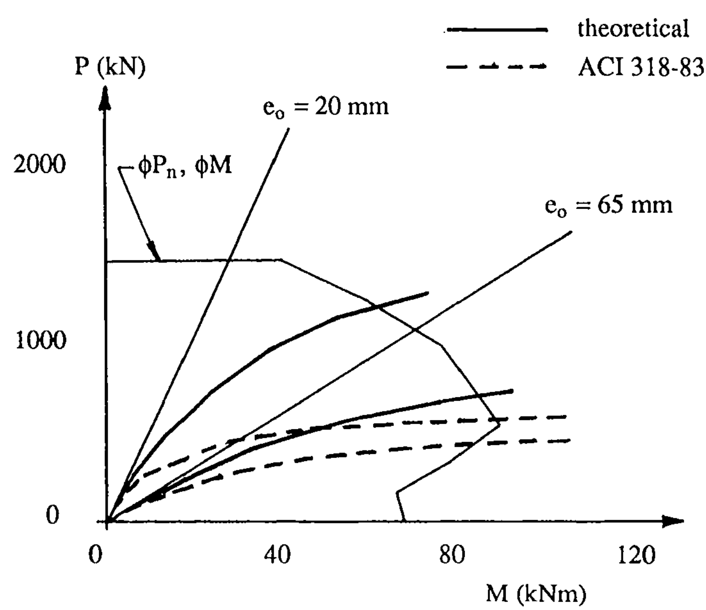


b) Long-term loading

Fig. 9--Axial force versus bending moment -- L = 3000 mm

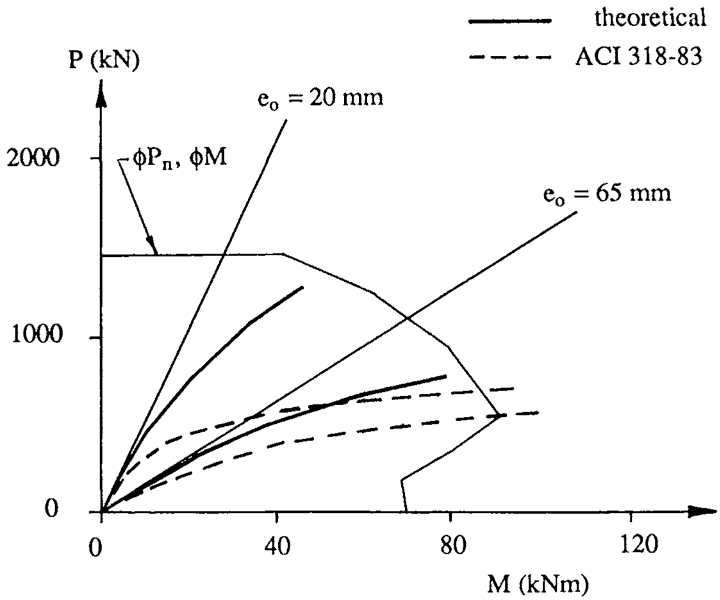


a) Initial loading

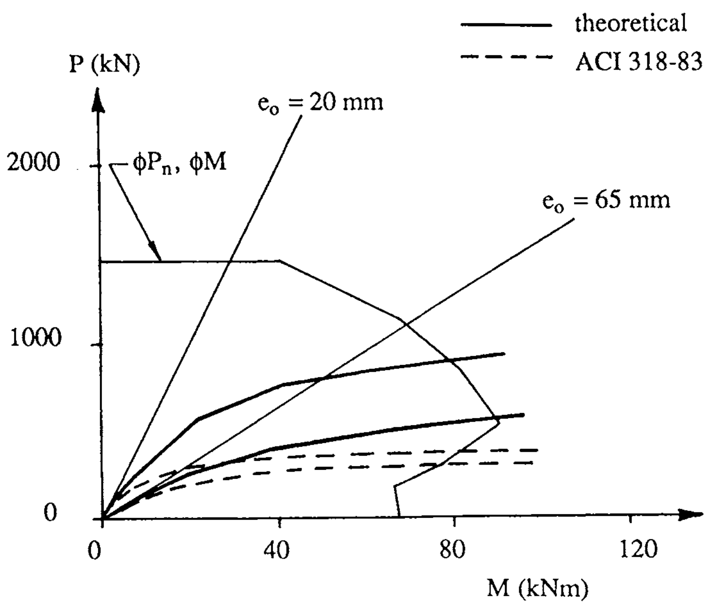


b) Long-term loading

Fig. 10--Axial force versus bending moment -- L = 6000 mm



a) Initial loading



b) Long-term loading

Fig. 11--Axial force versus bending moment -- L = 7500 mm

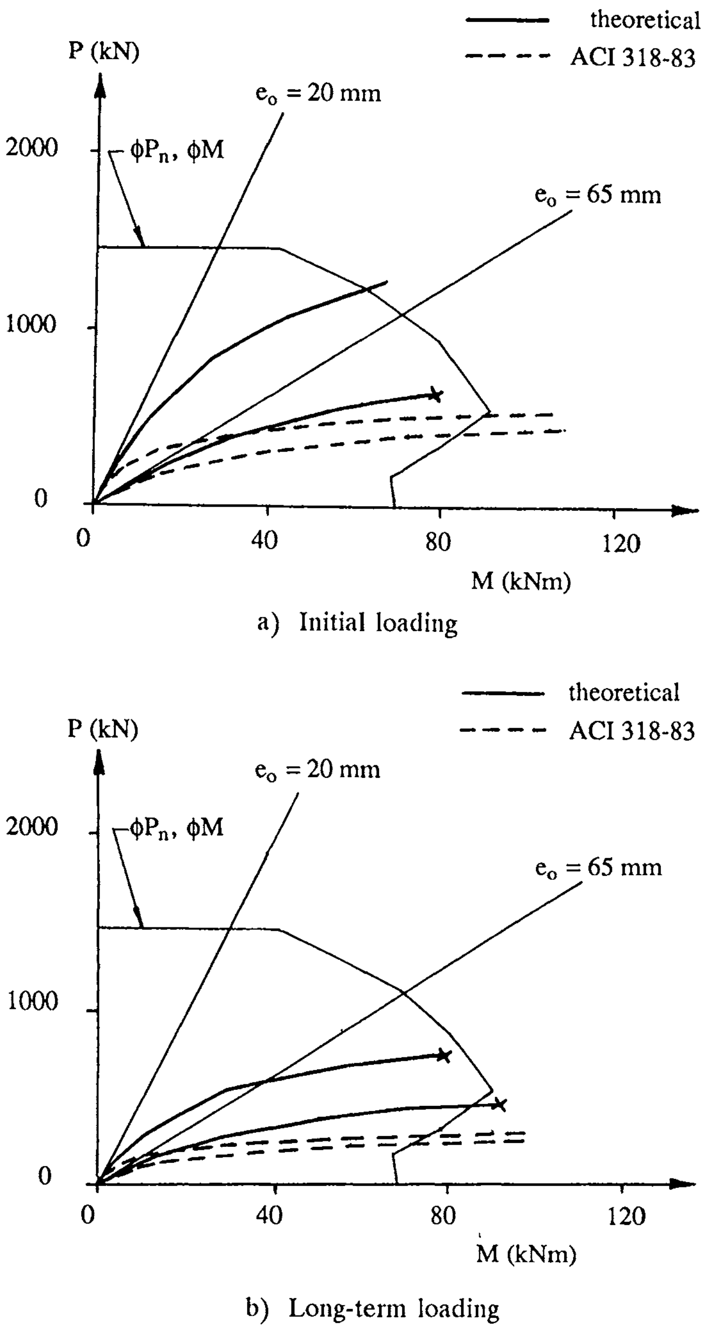


Fig. 12--Axial force versus bending moment -- L = 9000 mm

SP 129-6

Time-Dependent Deflections of Prestressed Members: Rational and Approximate Methods

by A. Aswad

Synopsis: The long-term camber prediction under sustained loads is an important part of the design of pretensioned flexural members. Critical members are non-composite roofs and bridge members which have medium or large span/depth ratios or elements made of light weight concrete. Currently the most common approximate design method is one that relies on empirical multipliers applied to initial cambers and deflections. When compared to a rational approach, substantial differences in prediction of long-term camber or deflection are noticed. The approximate method appears to overestimate the permanent sag or underestimate the camber. It also does not consider certain creep, shrinkage and relaxation properties. It is concluded that such methods may be unreliable for critical members and that the rational method is preferred. For preliminary design of longer spans, revised multipliers are suggested for use with the approximate method.

Keywords: Camber; creep properties; deflection; prestress loss; prestressed concrete; pretensioning; shrinkage; viscoelasticity.

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INTRODUCTION

Current Analysis Methods

The prediction of camber at erection time and the long-term camber (or deflection) is particularly important in the design of modern pretensioned flexural members. Currently the most widely used method of statically determinate elements is based on a paper published in 1977 (1), and has been adopted by the PCI Design Handbook (2). This approximate method predicts the camber at erection, Y_e, and the final camber, Y_f, for a composite member as follows:

$$Y_e = -1.80\ y_1 + 1.85\ y_2 \qquad [1]$$

$$Y_f = -2.20\ y_1 + 2.40\ y_2 + 2.30\ y_3 + 3.00\ y_4 \qquad [2]$$

where y_1 to y_4 are instantaneous, elastic deflection components due to prestress, self weight, topping and superimposed dead loads, respectively. If the member is without composite topping then the approximate equations become:

$$Y_e = -1.80\ y_1 + 1.85\ y_2 \qquad [3]$$

$$Y_f = -2.45\ y_1 + 2.70\ y_2 + 3.00\ y_4 \qquad [4]$$

Since this method was proposed no systematic study to confirm its accuracy was reported in the technical literature. The author, however, is aware of many cases over the last seven years where predictions based on this approach deviated significantly from observed cambers or deflections. This prompted the present study with the hope of coming up with explanations and recommendations.

Changed Factors

Several material and geometry factors changed in the last decade since (1) was published. Some of these are:

- Longer span/depth ratios in bridges and buildings are becoming more common today. They exceed the average values of the mid 1970's.

- Sections are getting slimmer.
- Low-relaxation strand, which was almost non-existent at the time, came into wider use to the point where it is the dominant variety today. Such strand has significantly less long-term relaxation loss. Therefore, for the same release force, a member should exhibit more final camber today than a decade ago.
- Today's concrete mixes are using a lot more additives such as high-range water reducers, etc. These have substantially reduced creep and shrinkage for steam-cured concretes. The approximate method relies on release cambers and instantaneous deflections but cannot account for the more favorable long-term volumetric changes.
- The approximate method calculates the initial camber assuming a constant prestress force throughout the member. It is well known that some heavily prestressed members exhibit as much as 10 ksi stress difference in strand stress between the midspan and the ends.

Paper Objective

Whenever large span/depth ratios or light weight concrete are used, the approximate method underestimates the long-term camber significantly. In the past several years, the author concern prompted him to develop rational analyses and programs which offer flexibility in material and geometric variables (3,4). The adequacy of the rational approach was also confirmed by actual measurements (3).

The purpose of the present paper is to briefly describe a more rational approach for deflection prediction, compare its results with (2) and offer appropriate recommendations.

AVAILABLE INFORMATION ON VOLUME CHANGES

Information on systematic creep and shrinkage tests of steam-cured concrete, the type commonly used in pretensioned members, is not widely available. Many producers started using high-range water reducers since the late seventies with significant reduction in the water/cement ratio. Recent test results on specimens containing superplasticisers which were steam-cured for about 14 hours have been reported (5). Excerpts from the latter tests are shown in Figures (1) and (2). It is clear that superplasticised concretes exhibit somewhat less creep than the recommendations in standard ACI 209.

Strand relaxation data for various jacking ratios and information on stress-strain-time relationships are available (6,7,8). With the low-relaxation strand coming into wider use, the amount of loss attributed to relaxation is much smaller than in the case of non-stabilized strands, often by a factor of 4.