Partial Prestressing, From Theory to Practice

Volume II. Prepared Discussion

edited by

M.Z. Cohn

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Waterloo, Ontario
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PREFACE

These volumes contain the edited documents presented at the NATO-Sponsored Advanced Research Workshop (ARW) on *Partial Prestressing, from Theory to Practice*, held at the CEBTP Research Centre of Saint-Rémy-lès-Chevreuse, France, June 18-22, 1984. The workshop was a direct extension of the International Symposium on *Nonlinearity and Continuity in Prestressed Concrete*, organized by the editor at the University of Waterloo, Waterloo, Canada, July 4-6, 1983.

The organization of the NATO-ARW on Partial Prestressing was prompted by the need to explain and reduce the wide differences of expert opinion on the subject, which make more difficult the acceptance of partial prestressing by the profession at large. Specifically, the workshop attempted to:

- produce a more unified picture of partial presetressing, by confronting and, where possible, reconciling some conflicting American and European views on this subject;

- bring theoretical advances on partial prestressing within the grasp of engineering practice;

- provide the required background for developing some guidelines on the use of partial prestressing, in agreement with existing structural concrete standards.

The five themes selected for the workshop agenda were:

(1) Problems of Partially Prestressed Concrete (PPC).

(2) Partially Prestressed Concrete Members: Static Loading.

(3) PPC Members: Repeated and Dynamic Loadings.

(4) Continuity in Partially Prestressed Concrete.

(5) Practice of Partial Prestressing.

In order to best reach the above-mentioned workshop goals, the adopted format for debating the five themes involved:

- identification of main problems and points of divergence in an introductory report;

- presentation of objective facts and arguments on each theme, from the American and European viewpoints, through theme survey reports;

- prepared discussion on aspects of detail for each theme;

- spontaneous comments and discussion of prepared contributions;

- summaries and tentative recommendations.

Each of the five workshop themes was debated during a full working day; mornings were dedicated to the presentation of the survey reports and afternoons were reserved for the prepared and spontaneous discussions.

Regrettably, these Proceedings volumes do not include a few presentations listed in the programme (one survey and some prepared discussions) for which no printable versions had been available. Manuscripts (and illustrations) in French were translated in English, all texts were edited and occasionally were abbreviated to better fit the scope of the publications.

Volume 1 contains the Introductory Report (Chapter 1), Survey Reports for the five themes (Chapters 2 to 12), a PPC Bibliography and Author Index (Chapter 13). All general references in Volume 1 (bracketed numerals) are keyed on the bibliography compiled in Chapter 13. Particular references at the end of each chapter are identified in the text by the prefix r (i.e. [r1]).

Volume 2 contains the prepared discussions (Chapters 1 to 32) and is divided into five parts, each corresponding to one theme in the workshop programme.

The *Guidelines for the Use of Partial Prestressing,* expected to emerge from the NATO-ARW, are under the consideration of an Ad-hoc Committee organized during the workshop. It is hoped that following these Proceedings, the *Guidelines* draft will be finalized and prepared for publication in the not too distant future.

My friend and NATO-ARW co-director, Dr. E. Absi of CEBTP, Paris, France, deserves much credit for his efficient cooperation during the arduous months of workshop preparation, the kind hospitality extended to our workshop guests, and his untiring contribution to the practical arrangements for the meetings. The technical programme was established with the valuable assistance of an advisory committee; including Messrs. M. Chaussin, C. Freyermuth, D. Jenny, J. Muller, Professors F. Levi, R. Lacroix, A. Naaman and A. H. Nilson. Professor V. V. Bertero and Mr. J. Mathivat joined the members of the advisory committee in chairing various workshop sessions and ensuring the high efficiency and technical standards of the debates.

It is a pleasure to acknowledge the contribution of the Direction, Secretariat and Staff of the C.E.B.T.P., Paris, France, the Research Laboratories at St.-Rémy-lès-Chevreuse, in providing a pleasant working environment for the meetings. Related technical and social functions were enhanced by the participation of such distinguished personalities as Mr. J. Chapon, President, Guiding Council for Research in Civil Engineering, Paris, France, and Mr. J. J. O. Gravel, Scientific Counsellor, Canadian Embassy, Paris, France.

Special appreciation is due to the NATO Division of Scientific Affairs, whose financial support was instrumental in the organization of the Advanced Research Workshop. This has also benefited from the varied support of its sponsors: ACI (American Concrete Institute), AFB (Association Française du Béton), CSCE (Canadian Society for Civil Engineering), N.S.F. (U.S. National Science Foundation), PCI (Prestressed Concrete Institute) and PTI (Post-Tensioning Institute).

Last, but not least, the financial support of CSCE, PCI, PTI and RCRC-ASCE (Reinforced Concrete Council of American Society of Civil Engineering) is gratefully acknowledged: without their support the publication of these Proceedings would have been impossible.

The combined efforts of all contributors to the successful conduct of the NATO-ARW on *Partial Prestressing, from Theory to Practice*, enabled most of its initially stated objectives to be reached. It is hoped that the publication of these Proceedings will help in consolidating the achievements of the Paris workshop and securing to partial prestressing its proper place in the modern practice of structural engineering.

Waterloo, November 1985. M. Z. Cohn

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PART I

PROBLEMS OF PARTIAL PRESTRESSING

Chapter 1

ON THE PROBLEMS OF PARTIAL PRESTRESSING

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The definition of full versus partial prestressing should be related to the behaviour under service load, (crack formation, reopening of cracks, or tensile stress limits), and it seems logical to define a corresponding degree of prestressing suitable for distinguishing between fully and partially prestressed sections.

The adoption of an optimum prestrain, favoured by some authors, is superfluous as long as the serviceability and ultimate limit state conditions are satisfied, and it may result in uneconomical structures.

The use of partially prestressed concrete is acceptable even where fatigue phenomena may be present. The stress limits ensuring safety against fatigue may be satisfied even where there are cracks, provided these are of moderate width.

The use of partially prestressed concrete is acceptable even in moderately corrosive environment. The durability requirements may be satisfied for moderate ambient conditions and limited crack widths. Cracks parallel to the tendons are the most dangerous and usually are not eliminated by prestressing.

The principal advantages of partial prestressing are the possibilities of controlling deformation, economy, optimum use of both reinforcement types, and (usually) greater robustness than for fully prestressed structures. This is demonstrated by a spectacular example.

1. INTRODUCTION

Professor Cohn is to be complimented for organizing the excellent symposium on "Nonlinearity and Continuity in Prestressed Concrete" at the University of Waterloo, Canada, in July 1983, and now, less than one year later, this Advanced Research Workshop covering the same subject.

Our subject is: "Partial Prestressing: From Theory to Practice".

I am afraid that there are too many researchers and too few practicing engineers gathered here. We probably ought to make up for this by adjusting our subject more towards: "The researcher's contributions to solving the practicing engineer's problems".

Professor Cohn has made excellent contributions to our understanding of the behaviour of partially prestressed structures in various stages from the serviceability limit state to the ultimate limit state [1].

However, we must inform the designers whether a combined ultimate limit state and serviceability limit state design is sufficient or, if it is not, when supplementary investigations are required.

Professor Cohn has made an admirable effort not only in organizing this workshop, but also, through his introductory survey [3] preparing us for this week's discussions, partly by a review and partly, in an untraditional way, by letting various experts speak for themselves through a large number of quotes.

2. PARTIAL PRESTRESSING DEFINITION

The basic purpose of prestressed concrete structures is to avoid concrete tensile stresses under service load or to keep them below a specified limit. The definition of this limit is a popular topic of discussion.

In the ultimate limit state, the effect of prestressing is negligible.

The definitions of full and partial prestressing must thus logically be tied up with the controversial limit of concrete tensile stresses (or crack formation) under service load. The stresses are almost independent on the non-prestressed reinforcement. Consequently, I cannot agree with Professor Cohn's tentative "description" (in the first paragraph of [3]) of a "Partial prestressed concrete member is one which derives its strength from a combination of prestressed reinforcement (A_p) and non-prestressed reinforcement (A_s)". This would be the case, admittedly to a minor degree, for almost all prestressed structures, including those designed by Freyssinet.

According to [3], p.14, both the Canadian Code and Naaman accept the same criterion, and Lin and Burns go even further: "non-prestressed reinforcements are employed in the member....".

These criteria divert attention from the essential by referring, not to the purpose: to limit certain concrete stresses at the serviceability limit state, but to the behaviour at the ultimate limit state, or even just to the question of providing additional non-prestressed reinforcement.

The same applies to Cohn's proposals [3], p.14:

(a) reinforced concrete and prestressing reinforcement stressed at or below the maximum permissible limit, or

(b) concrete prestressing reinforcement below the maximum permissible limit.

Economic aspects seem likely to exclude the types of structure covered by these definitions from the group of competitive solutions of interest to the practicing engineer.

The definition of partially versus fully prestressed concrete must refer to a given cross section of a structure, because some sections may be partially and others fully prestressed.

The definition of full versus partial prestressing should be connected with the behaviour under service load, either crack formation, reopening of cracks, or tensile stress limits. As the corresponding calculation involves considerable inaccuracies, the exact criterion is of little importance.

If defining a cross section as fully prestressed when no cracks occur in the concrete under service load and as partially prestressed when such cracks do occur, the distinction coincides with the stress analysis (cracked or uncracked section), which is a practical advantage.

3. DEGREE OF PRESTRESS

Cohn states in [3], p.20:

> "For reasons altogether not too clear, the CEB-FIP Model Code MC-78 [401] has given up the various classes of Prestressed Concrete in earlier editions and no reference of Partially Prestressed Concrete or corresponding degrees of prestressing are to be found. This can be interpreted only as an implicit vote against the need for identifying Partially Prestressed Concrete as such and qualifying its extent by a specific 'degree of prestressing'."

CEB's reason for abandoning the "classes" was the fear that designers or clients might confuse "classes" with classes of quality, with Class 1 as the best. For example, if the main concern were to avoid a detrimental upward deflection due to the combination of prestress and creep, then a lower class would be the best solution.

A comparison between Bachmann's Degree of Prestressing and Cohn and Bartlett's Partial Prestressing Index in eqs. (5) and (7) on p.15 of [3] might give the impression that they are identical. However, according to [1], p.9, the M in eq. (7) is a value corresponding to an arbitrary value of ϕ according to the $M-\phi$ relationship and thus not the service load value as in eq. (5).

In conformity with the above comments on definition, it seems logical to define a degree of prestressing suitable for distinguishing between fully and partially prestressed sections. This condition is satisfied by Bachmann's definition and by the definition of χ according to eq. (4) of Cohn's paper [3].

The use of the quantity χ implies a practical advantage, because the neutral axis depth βd for rectangular cross sections depends on χ and $\Sigma\alpha\rho$ according to eq. (1):

$$\beta^2(3-\beta)\chi+4(1-\beta)\Sigma\alpha\rho-2\beta^2=0 \tag{1}$$

where α denotes the modular ratios and ρ the geometric ratios ("percentages") of prestressed and non-prestressed reinforcements.

χ is about unity for fully prestressed sections and is equal to zero for non-prestressed sections, so it is a suitable parameter, indicating the place of a given section in the spectrum of fully prestressed, partially prestressed, and non-prestressed sections.

4. OPTIMUM PRESTRAIN

On the question of the optimum prestrain in the tendons [3], various authors agree on the principle (p.33, last paragraph):

> '...'*Theoretically the most suitable case is that for which the onset of plasticity is reached simultaneously by both types of reinforcement,...*''.

This restriction appears to be superfluous as long as the serviceability and ultimate limit state conditions are satisfied. The restriction may result in a limitation of the prestrain and an uneconomical structure.

5. FATIGUE

According to [3] (p.36, last paragraph), Cestelli-Guidi has pointed out that partially prestressed concrete is not to be used where fatigue phenemona may be present. This requirement appears too conservative. The stress limits ensuring safety against fatigue may be satisfied even if moderate crack widths are present.

The fatigue strength of the anchorages and joints in the tendons is considerably lower than that of the tendons. The fatigue strength of a structure can thus be improved by placing anchorages and joints in zones with small stress variations, provided an efficient bond between tendons and concrete is ensured. Bonded tendons may consequently result in a higher fatigue strength than unbonded tendons. This fact has been experimentally verified at the Department of Structural Engineering, Technical University of Denmark.

6. CORROSION

According to [3] (p.36, last paragraph), Cestelli-Guidi has pointed out that partially prestressed concrete is not to be used in corrosive environments. This seems too restrictive. The durability requirements may be satisfied for moderate ambient conditions of exposure and limited crack widths.

In this connection it should also be realized that cracks parallel to the tendons are more dangerous than cracks perpendicular to the tendons, and that the former type is usually not eliminated by prestressing.

7. ADVANTAGES AND DISADVANTAGES OF PARTIAL PRESTRESSING

According to [3], p.35, partially prestressed structures have smaller concrete stresses than fully prestressed structures, and thus have smaller prestress losses due to elastic shortening.

This contribution to the prestress loss has no practical consequences because it is reversible and thus disappears in the decisive phase, viz. when the concrete stress approaches zero.

In [3], p.36, the "losses of prestress in concrete due to the presence of rebars, with a corresponding reduction of the decompression load; hence, larger overload deflections;" is listed as a disadvantage of partial prestressing. As in the previous case, the elastic (reversible) effect of the reinforcing bars has no such consequences. On the contrary,