well delay corrosion, but not prevent it. An interesting area of research is highlighted on the use of mixtures of silica fume, cement, fine sand, polymers and inhibitors for coating rebars to protect them before and during use. It would have been timely for some mention of paint-on anode systems and cathodic protection and the section dealing with surface protection of concrete could have been usefully expanded.

There are a few minor typographical errors in the text and the photographic quality is not good. However, it is always worthwhile for somebody of lengthy experience, such as the author, who has spent her working life in industry (Wimpey Laboratories), to divest themselves of a lifetime's involvement with concrete in this way. We should all take note.

P. C. HEWLETT
(Peter Hewlett is Managing Director of Cementation Research Ltd and a visiting Industrial Professor in the Department of Civil Engineering at the University of Dundee.)

Nordic concrete research. Publication No. 5

Edited by The Nordic Concrete Federation

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This book is the latest annual volume presenting a compilation of papers on research projects within the field of technology and structural design of concrete, carried out or concluded during 1986 in the five Nordic countries. The 17 papers were selected by the Research Committee of the Nordic Concrete Federation and, as may be expected, cover a wide range of topics. Briefly, these include: roller-compacted concrete; high-strength beams; chloride binding in cement paste; joints in precast hollow core panels; calculation methods for combined thermal and mechanical loading; limitation of crack widths; joints and details in a prefabricated column–slab system; Danish approach to concrete durability problems; testing compactibility of no-slump concrete; compatibility of binder and superplasticizer in high-strength concrete; shear capacity of prestressed beams in regions of plastic hinges; analysis and design of r.c. shell structures; durability of cement-bound composites; non-linear 3-D analysis of r.c. structures; non-linear analysis of r.c. structures using quadrilateral membrane elements; bond between reinforcement and concrete in vacuum-treated zones; service design life with regard to frost resistance.

The presentation is functional but adequate and all the papers are in English. The previous four annual volumes are still available from the Nordic Concrete Federation each priced at NOK 150,- and a leaflet is available which lists the papers and authors in the books.

J. N. CLARKE

Partial prestressing, from theory to practice

Editor: M. Z. Cohn

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This important contribution to the literature of prestressed concrete is the outcome of a week of seminars and informal discussions by an international gathering of research workers and practitioners at a NATO-sponsored Advanced Research Workshop on partial prestressing held in Paris in June 1984. The need for the meeting had become evident a year previously at the international symposium on Non-linearity and Continuity in Prestressed concrete at Waterloo University, and a debt of gratitude is owed to Professor M. Z. Cohn, not only for his initiative but also for a great amount of detailed work which has born fruit in the present publication.

The stated objective of the Workshop was a move towards the unification of the subject, particularly by the reconciliation of conflicting American and European views. A second aim was to bring theoretical advances on partial prestressing within the grasp of engineering practice, and it was thirdly intended to provide the background for the development of guidelines on the use of partial prestressing in conformity with existing structural concrete standards.

The first of the two volumes consists mainly of pre-published survey reports, two for each of five themes as separate American and European statements on each theme. This volume is introduced by a brief historical sketch, a statement of the objectives of the Workshop and a collection of topical questions and controversial points. The second volume comprises the prepared discussion on each theme, after revision following discussion at the Workshop.

The first theme, *Problems of partial prestressing*, is reported by Cohn and Levi. Cohn gives a very extensive survey of the development and basic behaviour of partially prestressed concrete (PPC) from which there emerge some theoretical and potentially controversial problems such as the adequacy of a single parameter to represent the degree to which a member is prestressed. Even the definition of partially prestressed concrete is not a matter of unanimity. Later, in discussing disadvantages of PPC construction, a concise list of practical problems is given.

Levi in his survey report, refers to the 1978 CEB–FIP Model Code as fairly representative of present European opinion and, in considering the principles of ultimate and serviceability limit state analysis, identifies a number of current problems. Prominent among these is the effect of very high strength passive reinforcement on the tolerable reduction of prestress, the application of the CEB–FIP RC crack formulae to PPC, and the need for a more complete understanding of the minimum reinforcement percentage requirement.

The prepared discussion on Theme 1 comprises six short papers. Brøndum-Nielsen makes a telling contribution to the debate on the definition of partial prestressing and degree of prestress; he also points out the important advantage of the improved robustness of partially prestressed structures. Mathieu draws attention to the deterioration of serviceability under repeated loading and reports an analytical study showing that, with unbonded or defectively bonded post-tensioned tendons and a relatively small percentage of non-prestressed reinforcement, the deflection of a PPC structure may be very sensitive to loads slightly above the service load. Bruggeling offers some general comments on the advantages of PPC and makes a plea for the integration of design methods for the two types of construction, RC and PPC, into a unified procedure for structural concrete. Trost reviews the advantages of PPC with the aid of some worked examples and diagrams while Lambotte *et al.* present the results of 3-year tests on unloaded and axially loaded prisms to show the effect of non-prestressed reinforcement. Values calculated by the integral type creep law and by the CEB 1978 Model Code method agree well with experimental deformations and show the methods to be applicable to calculation of loss of prestress. An experimental study is also described by Chaussin and Trinh who give the results of tests on thin-webbed beams subject to shear. The risk of failure is seen to be greater with reduced prestress but the margins of safety appear adequate.

Theme 2, *Partially prestressed members under static loading*, is reported by Naaman and Lacroix. Naaman's survey has been developed from an earlier paper at the 1983 International Symposium at Waterloo and also refers to provisions of the 1983 ACI Code, where relevant to PPC. There is a thorough general review of the main areas of analysis and design, an incursion into one or two controversial topics and some original experimental data on deflection and crack width under constant amplitude cyclic loading. The European perspective is represented in the shorter paper of Lacroix who concentrates his discussion largely on one or two topical questions. He considers specification of the degree of prestressing to be of no practical value and unnecessary if the ultimate limit state criteria are satisfied. With regard to serviceability, the arbitrary nature of crack width limits is emphasized, as also is the fact that well-compacted good quality concrete is of at least equal importance in protecting reinforcement against corrosion. An additional criterion is the stress range in the reinforcement which has to be limited to avoid fatigue.

In the prepared discussion on Theme 2, Branson and Shaikh present work on the application of the ACI method of calculating deflection (based on the effective second moment of area I_e) to partially prestressed members. Two alternatives are offered, according to whether the deflection is related to the zero deflection point or to the deflection under prestress and dead load. Experimental data are compared with calculated values of I_e and the neutral axis depth ratio and the paper includes examples of practical calculations. Lambotte and Van Nieuwenburg describe the results of long-term (2 year) tests of PPC beams at the Magnel laboratory, forming part of a collective programme by six Belgian university laboratories. Calculations by the CEB–FIP 1978 Model Code gave satisfactory values provided that loss and redistribution of stress were correctly taken into account, and a partial prestressing ratio of 65–75% appeared to be necessary to limit the long-term crack width to 0.1 mm. Wastiels gives stresses and strains in beams or one-way slabs with unbonded tendons, calculated assuming linear elastic behaviour, and also presents a simplified approach suitable for calculating the decompression and cracking loads. Nawy applies a mathematical model, relating maximum weighted crack width to the increase of reinforcement stress to test results covering a range of simply-supported beams with pre-tensioned and post-tensioned tendons and four 2-span continuous beams. Crack equations are given, suitable for the serviceability control of partially prestressed beams at service load and overload conditions. Crack control is also the subject of the paper by Suzuki and Ohno who consider about 190 test beams in proposing equations relating crack

width to crack spacing and average strain change in the reinforcement.

Theme 3 is *Partially prestressed members under repeated loading*. The first of the two survey reports, by Bennett, begins with a historical review of fatigue results reported in Europe since the early days of prestressing and the accepted behaviour of cracked prestressed members is summarized. An account is given of analytical methods for predicting response and strength under repeated loading, and also some practical observations concerning design. The other report by Bertero deals with the use of partially prestressed members for earthquake-resistant design and construction. Beginning with an updated state-of-the-art for seismic-resistant building design there follows a section on present practice in the seismic-resistant design of concrete structures leading to a review and evaluation of available data on seismic behaviour of PPC members and their sub-assemblages. The present consensus is that PPC members will tend to have a greater seismic response than RC owing to their lower energy dissipation, but that this may be offset by increased curvature before cracking and/or reduced mass of the members. Experimental data published by Park (New Zealand), Muguruma (Japan) and their associates are summarized.

In the prepared discussion of Theme 3 new tests are reported by Foo and Warner and by Lambotte. The former describe six tests terminating in progressive fracture of the main reinforcement and pre-tensioned tendons at a life not significantly different from that obtained from tests in air; however, they point out the need for a precise stress analysis to determine the stress cycles at the critical sections. Lambotte describes five groups of tests in which 4×10^6 cycles up to the service load were followed by a programme of steps of increasing load every 10^6 cycles until failure. Inomata presents an analytical method to calculate moment–curvature relationships of PPC sections subjected to reversed cyclic overloading which gives reasonably good predictions of the results of eight tests and shows that partial prestressing may significantly improve the energy dissipation capacity. Trinh and Hashing report an experimental study of fatigue-corrosion of non-prestressed reinforcing bars, fatigue-tested in concrete beams in a marine environment, providing some useful preliminary data on the possible limitations of PPC under these conditions. Cordes and Trost present some experimental results of the fatigue strength of curved prestressing tendons, showing a reduction of fatigue strength of 35% for strands and 60% for quenched tempered steels and hard-drawn wires due to simultaneous lateral pressure and slip. Lenschow discusses some of the uncertain factors which have caused hesitation in the use of PPC for structures exposed to long-term dynamic loading (e.g. offshore construction and tall buildings). These include the combination of dynamic and stochastic loading, corrosion of reinforcement at cracks, dynamic creep of concrete, fatigue and shear capacity under dynamic loading. Muguruma outlines the seismic design procedure for PPC introduced in the new Japanese (AIJ) Building Code and reviews research work on seismic problems in five different areas, namely shear behaviour, flexural ductility under cyclic high overload, beam–column joints and frame excitation. Giannini *et al.* present an analytical investigation of a model consisting of a cantilever, with or without external axial force, using cyclic non-linear stress–strain curves for concrete and steel and artificial accelerograms of given frequency content, with seismic intensity given in terms of peak ground acceleration. This enables the effect of partial prestressing on the response to be considered and discussed in comparison with reinforced concrete and fully prestressed concrete.

Theme 4, *Continuity in partially prestressed concrete*, is introduced by the survey reports of Cohn and Arenas. Cohn gives a typically thorough chronological review of the increasing understanding of the subject, beginning with a useful section defining terms and explaining concepts. There is a good objective summary of the bygone controversy on the validity of complete redistribution of moments (i.e. plastic theory) at ultimate load, and the more recent debate on the nature and treatment of secondary prestressing effects under conditions of non-linear deformation. The final part of the report, concerning design, reviews alternative non-linear design methods together with the provisions of some of the codes and standards. The report by Arenas represents the European perspective and also describes the main available methods of non-linear analysis, illustrated by some results from the author's own research. There are also useful sections on the selection of prestressing degree and tendon layout in partially prestressed continuous beams and on stresses induced by thermal gradient and support settlement, complementing the more general review of Cohn.

The contribution of Giuriani to the prepared discussion of Theme 4 deals with the effect of cracking, both at the time of prestressing and, particularly relevant in PPC, at service load. Treating the prestress as analogous to a "tension stiffening" effect, the mathematical procedure is presented together with some analytical results for continuous beams under uniform load. Three of the papers present the results of analyses of continuous beams. Cauvin treats the prestress as an initial state of stress represented by the axial force and moment and shows the progressive changes in these two parameters in four examples, two of which are of indeterminate structures. Warner and Yeo report an analytical study carried out to check the ductility requirements for moment redistribution in the Australian Code. Campbell *et al.* compare the values obtained from a non-linear mathematical model with the results of four tests of continuous

beams of two spans; it is shown that the mathematical prediction is adequate and also that the response may be more simply predicted by the linear elastic stiffness line in the early stages and the plastic stiffness line in the latter part of each test. Appleton contributes to the debate on the treatment of secondary moments, with particular reference to the Portuguese Code, while Thielen and Jungwirth offer some observations on hyperstatic effects and moment redistribution in three-dimensional elements (e.g. slabs).

Theme 5, on the final day of the Workshop, was devoted to the *Practice of partial prestressing*. Menn, in an introductory report, shows from the point of view of the practitioner how secondary effects, due both to prestress and to temperature and shrinkage, can be calculated and accommodated by relatively simple procedures. Freyermuth traces the development of post-tensioning techniques in the USA, and their use for partial prestressing, with particular reference to unbonded tendons. Jenny gives a historical review of partial prestressing in American practice, reflected in successive technical committee reports and codes of practice. An extremely interesting feature of this paper is the summary of the results of a survey on the extent and reasons for the use of partial prestressing based on a questionnaire completed by 65 pretensioning plants in the USA and Canada.

The seven papers on Theme 5 cover a wide range of practical topics. Birkenmaier gives an account of a prestressed bridge of four continuous spans built in 1958, in which the severe conditions imposed by the site could not be satisfied within the current code and resulted in a partially prestressed solution based on the principles now adopted in the Swiss Code. Libby gives the views of a practising engineer on a number of the issues which have tended to recur throughout the Workshop. Trinh describes a six-month durability test of reinforced and partially prestressed concrete elements subject to cyclic loading under marine (splash zone) conditions. Crack healing and irreversible deflections are noted, but "no abnormal or unacceptable feature in the behaviour of the PCC structures". Macchi proposes a tentative set of more liberal code clauses for statically indeterminate PPC structures, and Aparicio compares the results of commonly used elastic or plastic methods of design with the results of a more sophisticated analysis for several actual structures. The two final papers deal with optimization; Almeida and Appleton describe an automatic technique for calculating the minimum prestressing force and corresponding tendon profile in continuous PPC beams, while Saouma and Sikiotis present an optimization procedure for partially prestressed beams and outline techniques for solution including an innovative interactive graphics method.

The two volumes are clearly printed and, having regard to the amount of material, there are comparatively few errors or diagrams which have been too severely reduced for the writing to be read easily. A major asset of the work is the bibliography of 801 publications covering the period from 1937 to June 1984, although the reader should note that in one or two papers the bibliography reference numbers may be confused with those of the author's own list of references.

One of the few disappointments for those of us who attended the Workshop was that the practitioners among us were heavily outnumbered by the academics and researchers. Inevitably this imbalance is reflected in the published proceedings which, some may feel, do not therefore do full justice to the title. Nevertheless, we have here what is likely to become a major reference work for all concerned with partially prestressed concrete, and its value should perhaps be judged in the future by the way in which the still incomplete transition "From Theory to Practice" is finally accomplished.

E. W. BENNETT
(Ernest Bennett is Honorary Lecturer at the Department of Civil Engineering, University of Leeds.)

Seismic design of concrete structures

Comité Euro-International du Béton (CEB)

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The last half-dozen years or so have seen the publication of a number of important new seismic codes of practice. These include the draft of the seismic Eurocode EC8, major draft revisions to the seismic provisions of the United States Uniform Building Code (UBC: 1988) and to the New Zealand loading code NZS 4203, and the publication of another American document, the Building Seismic Safety Council (BSSC) Recommended Provisions, formerly ATC-3.06. Specifically for concrete structures, there have also been major advances in the issue of Appendix A to the American Concrete Institute's ACI 318-83, and