




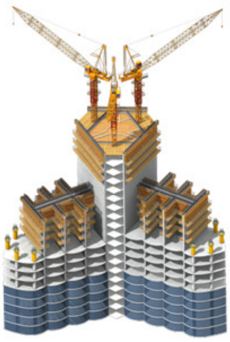

Advanced Course

Advanced Professional Training

CREEP AND SHRINKAGE EFFECTS IN CONCRETE STRUCTURES

Coordinators:

Prof. Mario A. Chiorino

Politecnico di Torino, Turin, Italy

Prof. Domingo J. Carreira

Illinois Institute of Technology, Chicago, USA

with the patronage of

American Concrete Institute

Advancing concrete knowledge

CISM International Centre for Mechanical Sciences

Udine, Italy

May 23 - 27, 2011




CISM • International Centre for Mechanical Sciences

Palazzo del Torso • Piazza Garibaldi, 18 • 33100 Udine • Italy

Telephone: +39 0432 248511 • Fax: +39 0432 248550 • E-mail: cism@cism.it

Creep and Shrinkage Effects in Concrete Structures

Coordinators:
- **Mario A. Chiorino** (Politecnico di Torino, Torino, Italy, mario.chiorino@polito.it)
- **Domingo J. Carreira** (Illinois Institute of Technology, Chicago, IL, USA)

with the patronage of ACI American Concrete Institute

Modern concrete structures are becoming more and more complex as a result of elaborate conceptual design and intricate construction techniques combining cast-in-place and prefabricated elements, structural steel components, prestressing and segmental erection, tensioning of stays and ties, jacking, and so on. Typical examples are large span cantilever and cable-stayed bridges, cast-on-form or cantilever built arches prestressed by jacking, composite steel-concrete structures, concrete or steel-concrete high-rise and supertall buildings. Some of these examples represent extreme recent applications of structural concrete. In general, we may speak of structures characterized by sequential applications of external actions (loads and imposed deformations) and by progressive variation in the restraint conditions during construction and early life. For these reasons, these structures are very sensitive, from the construction stage until the end of their service life, to time-dependent effects caused by delayed deformations of concrete (creep and shrinkage). If proper attention is not devoted to these effects, structural reliability in terms of serviceability and, in some instances, of ultimate safety may be adversely affected.
An appropriate evaluation of such effects for designing durable and safe structures requires the establishment of reliable methods for predicting creep and shrinkage strains (a material properties problem), and for determining the consequent time-dependent structural response with an adequate degree of accuracy (a structural analysis problem).
The first part of the course briefly addresses the problem of selecting realistic prediction models, focusing on factors affecting rheology of hardened concrete, criteria for construction of a comprehensive database of creep and shrinkage tests and validation/calibration of prediction models with respect to it, comparison and statistical evaluation of different models, with a discussion on adequate statistical indicators.
The second and main part of course deals with analysis of structural effects. Fundaments of the theory of aging linear viscoelasticity are reviewed and basic theorems and general solutions illustrated for the cases of effective homogeneous structures with rigid or elastic (steel) restraints and of heterogeneous structures and sections. Numerical methods for the solution of hereditary integral equations in terms of incremental forms based on a sum or on conversion to rate-type laws with internal variables are illustrated, as well as algebraic simplifications like the age-adjusted-effective-modulus method. Guidelines are indicated for selecting the appropriate computational approaches, with attention to design stage and sensitivity of the structure.
Advanced problem like hygrothermal effects and cracking, interaction of creep with shear-lag and with flexible shear-connections in composite beams, effects of creep and shrinkage in complex structures such as tied arches, cable-stayed bridges and high-rise buildings are discussed in the last part of the course, together with techniques for long-term structural monitoring and interpretation of results.

The course is modeled after the harmonized formats of the following technical guidance documents: the CEB Manual on the same subject (1984), the corresponding sections of *CEB-FIP Model Code 1990* and of *fib Textbook on Structural Concrete* (2010), and, especially, the recent advanced ACI Guide *"Analysis of Creep and Shrinkage Effects in Concrete Structures"* (2010, under final approval) and the proposed new section on the same subject for the *fib* New Model Code 2010 under final editing. The whole set of these documents was edited by the first coordinator with the cooperation of other experts and in particular, for the last two, of the second coordinator and most of other lecturers. Emphasis will be given within the course to this favorable scenario of internationally harmonized, although progressively evolving, fundaments and basic rules of application for codes and technical guidance documents on a subject of significant relevance for the long-term reliability assessment of modern concrete structures, highlighting areas of well established consensus and open problems.

The course is addressed to doctoral and postdoctoral researchers, teaching and research assistants in structural mechanics, civil and structural engineering, specialists and practicing engineers in the field of advanced structural analysis and design.

Keywords: Concrete, Creep, Shrinkage, Prediction Models, Creep Analysis, Aging Viscoelasticity, Time-dependent Structural Response, Long-term Reliability, Structural Monitoring

Invited Lecturers

Domingo J. Carreira (Illinois Institute of Technology, Chicago, IL, USA)
5 lectures on: Advanced problems. Hygrothermal effects and cracking. Interaction of creep with shear lag effects in box girders and in wide flanged concrete or steel-concrete composite beams and additional influence of flexible shear connections. Effects of creep and shrinkage in high-rise concrete or steel-concrete buildings.

Mario Alberto Chiorino (Politecnico di Torino, Torino, Italy)
7 lectures on: Fundaments of aging linear viscoelasticity. Effective homogeneous concrete structures with rigid or plastic yielding restraints. Basic theorems: imposed loads and deformations; single and multiple changes of structural system. Effective homogeneous concrete structures with elastic restraints. Heterogeneous structures. Computational methods for the numerical solution of hereditary integral equations. Algebraic simplifications: AAEM method. Guidelines for time dependent analysis of structures.

Mamdouh M. El-Badry (University of Calgary, Calgary, Alberta, Canada)
7 lectures on: Cross section analysis. Prestress losses in members with one layer of prestressing steel. Time dependent analysis of prestressed concrete members with multiple layers of prestressing and reinforcing steel using creep-transformed section method. Time dependent analysis of composite members: influence of different thickness of concrete; steel-concrete composite members. Members subjected to sustained temperature gradient.

Ian N. Robertson (University of Hawaii, Honolulu, HI, USA)
4 lectures on: Monitoring of time dependent effects in large structures. Design of instrumentation system for long-term structural monitoring. Instrument installation and monitoring challenges. Short-term loading and thermal effects. Long-term shrinkage and creep effects. Comparison with shrinkage and creep prediction models.

Mario Sassone (Politecnico di Torino, Torino, Italy)
8 lectures on: General numerical incremental solutions for heterogeneous and sequential structures in the aging linear viscoelastic domain. Solutions by AAEM method. Solutions for effective homogeneous concrete structures with elastic restraints. Discussion of case studies: segmental concrete bridges and constructions, tied concrete arches, cable-stayed bridges, high-rise concrete or steel concrete buildings. Analysis of beams and framed structures with account for cross section heterogeneities.

Carlos C. Videla (Pontificia Universidad Católica de Chile, Santiago, Chile)
4 lectures on: Creep and shrinkage prediction models and related uncertainty aspects. Factors affecting creep and shrinkage of hardened concrete. Comprehensive database on creep and shrinkage. Guide for modeling and calculating shrinkage and creep in hardened concrete. Statistical evaluation of available prediction models. Discussion of statistical indicators. Influence on the reliability assessment of structures: random scatter, uncertainty of prediction and confidence limits.

References

BOOKS:

Mathematical fundaments of theoretical rheology and aging linear viscoelasticity

Gross, B., 1953, "Mathematical Structure of the Theories of Viscoelasticity ", Hermann.

Lovitt. W. V., 1950, "Linear Integral Equations", Dover.

Persoz, B., 1969, "La Rhéologie", Masson, Paris.

Salençon, J., 2009, "Viscoélasticité pour le Calcul des Structures", Les Éditions de l'École Polytechnique.

Smirnov, V., 1975, "Cours de Mathématiques Supérieures" Tome IV, Première partie, MIR, Moscow.

Volterra V., 1909, "Sulle equazioni integro-differenziali della teoria della elasticità" (On the Integro-differential Equations of the Theory of Elasticityt, in Italian), Accademia dei Lincei, Vol.XVIII.

Volterra V., 1909, "Equazioni integro-differenziali della elasticità nel caso della isotropia" (Integro-diffferential Equations of Elasticity in the Case of Isotropy, in Italian), Accademia dei Lincei, Vol.XVIII.

Volterra, V., 1913, "Leçons sur les Fonctions des Lignes", Gauthiers-Villars, Paris.

Time dependent properties of concrete

Neville, A.M., Dilger, W.H. and Brooks, J.J., 1983, "Creep of Plain and Structural Concrete," Construction Press.

Time dependent analysis of concrete structures

Ghali, A., Favre, R., and Elbadry, M., 2002, "Concrete Structures – Stresses and Deformations", Spon Press.

Jirásek, M., and Bažant, Z.P., 2002, "Inelastic Analysis of Structures", Wiley and Sons.

GUIDES, MANUALS AND PRE-STANDARD DOCUMENTS:

Prediction models for creep and shrinkage

ACI 209.1R-05 "Report on Factors Affecting Shrinkage and Creep of Hardened Concrete", ACI, 2005. *See also enclosed extended list of references.*

ACI 209.2R-08 "Guide for Modeling and Calculation of Shrinkage and Creep in Hardened Concrete", ACI, 2008. *See also enclosed extended list of references.*

FIB, "Structural Concrete. Textbook on Behaviour, Design and Performance. Updated Knowledge of the CEB/FIP Model Code 1990,", Volume 1, fib Bulletin 1, fib, Fédération Internationale du Béton, Lausanne, Switzerland, July 1999, pp. 37-61; new ed. 2010, fib Bulletin 51, pp. 53-78.

Time dependent analysis of concrete structures

ACI 209.3R-XX "Analysis of Creep and Shrinkage Effects in Concrete Structures", Reported by ACI Committee 209, M. A. Chiorino (Ed), ACI 2010, final draft may be obtained from the Editor, expected publication 2011. *See also enclosed extended list of references.*

CEB, 1984, "CEB Design Manual on Structural Effects of Time-dependent Behaviour of Concrete", Chiorino M.A. (Chairm. of Edit. Team), CEB Bull. 142 Georgi Publ.

CEB, 1993, "CEB-FIP Model Code 1990", Section 5.8 *Structural Effects of Time-dependent Properties of Concrete*, CEB Bull. 213/214, Comité Euro-International du Béton.

CEB, 1993, "Revision of the Design Aids of the CEB Design Manual Structural Effects of Time- dependent Behaviour of Concrete in Accordance with CEB-FIP Model Code 1990", prepared by M. A. Chiorino and G. Lacidogna, CEB Bull. 215.

Chiorino M.A. and Sassone M., "Further considerations and updates on time dependent analysis of concrete structures", in Structural Concrete, Textbook on behaviour, design and performance, 2nd edition , fib Bulletin 52, International Federation for Structural Concrete, Lausanne 2010, pp. 43-69.

PAPERS:

Testing methods for creep and shrinkage

Carreira, D. J., and Burg, R. G., "Testing for Concrete Creep and Shrinkage," in: A. Al-Manaseer ed., "The A. Neville Symposium: Creep and Shrinkage - Structural Design Effects", ACI SP-194, 2000, pp. 381-422.

Prediction models for creep and shrinkage

Bažant, Z. P. and Baweja S., "Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures - Model B3", in: A. Al-Manaseer ed., "The A. Neville Symposium: Creep and Shrinkage - Structural Design Effects", ACI SP-194, 2000, pp. 1-83.

Gardner, J. and Lockman, M. J., "Design Provisions for Drying Shrinkage and Creep of Normal-Strength Concrete", ACI Materials Journal, 2001, pp. 159-67.

Videla, C. et al., "Updating Concrete Drying Shrinkage Prediction Models For Local Materials," ACI Materials Journal, V. 101, No. 3, 2004, pp. 187-198.

Time dependent analysis and monitoring of concrete structures

Bažant Z.P., "Numerical Determination of Long-range Stress History from Strain History in Concrete", Material and Structures, Vol. 5, 1972, pp. 135-141.

Bažant, Z.P.,, "Prediction of Concrete Creep Effects Using Age-adjusted Effective Modulus Method", Journal of the American Concrete Institute, V. 69, 1972, pp. 212-217.

Bažant, Z. P., "Theory of Creep and Shrinkage in Concrete Structures: a Précis of Recent Developments", Mechanics Today, Vol.2, Pergamon Press, 1975, 1-93.

Bažant, Z.P., "Creep of concrete", in "Encyclopedia of Materials: Science and Technology", K.H.J. Buschow et al., eds. Elsevier, Amsterdam, Vol. 2C, 2001, pp. 1797-1800.

Carreira, D. J. and Poulos T. D., "Designing for Effects of Creep and Shrinkage in High-Rise Concrete Buildings", in. in J. Gardner and M. A. Chiorino eds., "Structural Implications of Creep and Shrinkage of Concrete", ACI SP-246, 2007, pp. 107-131.

Chiorino, M.A., Creazza, G., Mola, F., and Napoli, P., "Analysis of Aging Viscoelastic Structures with n-Redundant Elastic Restraints", Fourth RILEM International Symposium on Creep and Shrinkage of Concrete: Mathematical Modelling, Z.P. Bažant ed., Northwestern University, Evanston, 1986, pp. 623-644.

Chiorino, M. A., "A Rational Approach to the Analysis of Creep Structural Effects", in J. Gardner and J. Weiss eds., "Shrinkage and Creep of Concrete", ACI SP-227, 2005, pp. 107-141.

Chiorino, M.A., "Effetti statici dei fenomeni differiti del calcestruzzo: radici storiche e nuovi orientamenti (Structural effects of time-dependendent behavior of concrete: historical notes and new trends)", in Italian, in "Moderni orientamenti di ingegneria strutturale e geotecnica", M. A Chiorino editor, FrancoAngeli, Milano, 2006, pp. 81-152. *See also the enclosed extended list of references.*

Chiorino, M.A., "An Internationally Harmonized Format for Time Dependent Analysis of Concrete Structures", M. A. Hirt et al. Eds., Proceedings of Joint IABSE-fib Conference on Codes in Structural Engineering, Developments and Needs for International Practice, Dubrovnik, 2010, Volume 1, pp. 473-480.

Casalegno, C., Sassone, M., Chiorino, M.A., "Time dependent effects in cable-stayed bridges built by segmental construction", The Third International fib Congress, 2010, May 29 - June 2, Washington D.C.

Dilger, W.H., Creep Analysis Using Creep-transformed Section Properties, Journal of the Prestressed Concrete institute, V. 27, No.1, 1982, pp. 98-117.

Giussani, F., Minoretti, A., Mola, F., Savoldi, C., "Improvements in Long-term Structural Analysis of Cable–Stayed Bridges", 29th Conf. on Our World in Concrete & Structures, Singapore, 2004, pp. 265-272.

Mola, F., "The Reduced Relaxation Function Method: an Innovative Approach to the Analysis of Non-homogeneous Structures", Proceedings of the International Conference on Concrete and Structures, Hong-Kong, C.I. Premier Pte-Ltd Ed., Singapore, 1993.

Mola, F., and Gatti, M. C., "General and Approximate Approach for the Analysis of Composite Steel-Concrete Members with Deformable Connectors", Studi e Ricerche, Vol. 17, Politecnico di Milano, Italy, 1996, pp. 69-98.

Robertson, I. N., and Li, X., "Shrinkage and Creep Predictions Evaluated using 10-year Monitoring of the North Halawa Valley Viaduct", in N.J. Gardner and J. Weiss eds. "Shrinkage and Creep of Concrete", ACI SP-227, 2005, pp. 143-162.

Robertson, I. N., "Prediction of vertical deflections for a long-span prestressed concrete bridge structure", Engineering Structures, Vol. 27, 2005, pp. 1820-1827.

Sassone, M., and Chiorino, M. A., "Design Aids for the Evaluation of Creep Induced Structural Effects", in N. J. Gardner and J. Weiss eds., "Shrinkage and Creep of Concrete", ACI SP-227, 2005, pp. 239-259.

Robertson, I. N., "Correlation of Creep and Shrinkage Models with Field Observations", in A. Al-Manaseer, "The Adam Neville Symposium: Creep and Shrinkage – Structural Design Effects", ACI SP-194, 2000, pp. 261-282.

Sassone, M., Bigaran D., and Casalegno C., "Numerical Approach to Viscoelastic Analysis of Concrete Structures in the Frame of Equilibrium Method" in N. J. Gardner and M. A. Chiorino eds., "Structural Implications of Shrinkage and Creep of Concrete", ACI SP-246, 2007, pp. 21-35.

WEB SITES

Creep Analysis Research Group: www.polito.it/creepanalysis

Papers by Prof. Bažant may be downloaded from:
www.civil.northwestern.edu/people/bazant.html

CISM • International Centre for Mechanical Sciences
Palazzo del Torso • Piazza Garibaldi, 18 • 33100 Udine • Italy
Telephone: +39 0432 248511 • Fax: +39 0432 248550 • E-mail: cism@cism.it