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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(99)11
Unclassified

NPP CONTAINMENT PRESTRESS LOSS

SUMMARY STATEMENT

English text only

81405

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter; Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consist of all OECD Member countries, except New Zealand and Poland. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of the NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

- *encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
- *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
- *developing exchanges of scientific and technical information particularly through participation in common services;*
- *setting up international research and development programmes and joint undertakings.*

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries.

CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its programme of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus in different projects and International Standard Problems, and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups and organisation of conferences and specialist meeting.

The greater part of CSNI's current programme of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment and severe accidents. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programmes and operates an international mechanism for exchanging reports on nuclear power plant incidents.

In implementing its programme, CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

Foreword

Principal Working Group 3 of the CSNI deals with the integrity of structures and components, and has three sub-groups, dealing with the integrity of metal structures and components, ageing of concrete structures, and the seismic behaviour of structures.

A status report on the ageing of concrete structures was prepared during 1995 by a task group to initiate activities in this field under PWG3. This recommended that workshops be held on the following topics:

- First priority
  - Loss of pre-stressing force in tendons of post-tensioned concrete structures (workshop held at Civaux, August 1997)
  - In-Service Inspection techniques for reinforced concrete structures having thick sections and areas not directly accessible for inspection (workshop held at Risley, UK, November 1997)
- Second priority
  - Response of degraded structures, including Finite Element analysis techniques (workshop held in Long Island, USA, November 1998)
  - Viability of development of performance-based database (it has been decided not to pursue this)
- Third priority
  - Instrumentation and monitoring (workshop will be held in Brussels in March 2000)
  - Repair methods (to be addressed later)
  - Criteria for condition assessment (to be addressed later).

Tendon prestress loss was the first topic addressed by the group, as seen from the above list, with a workshop organised jointly by IPSN and EDF, and sponsored jointly by WANO and OECD-NEA. RILEM, FIB and IASMiRT also co-sponsored the workshop. The proceedings were issued without any conclusions or recommendations as NEA/CSNI/R(97)9, as the objective was to concentrate on utility experience. PWG3 has since reflected on this topic in the light of the workshop, and the summary here is the opinion of the group.

The complete list of CSNI reports, and the text of reports from 1993 on, is available on http://www.nea.fr/html/nsd/docs/

Conclusions

1. Present experience suggests that the current methods for the prediction of the loss of tendon prestress are generally satisfactory.

2. The nuclear industry has adopted regulatory and codified methods for predicting the loss of prestress in nuclear power plant (NPP) prestressed concrete containments from international and national standards that are not necessarily specific to nuclear design. The application of the different methods to a specific case is likely to lead to significant differences in the predicted losses.

3. Theoretical and experimental research have established the importance of understanding how chemical, hygral, mechanical and thermal factors influence the short term and long term behaviour of prestressed concrete. In particular, they have differentiated between creep, drying shrinkage and relaxation of prestressing steel and identified the interdependency of these phenomena. However, research has, as yet, failed to formulate a universal and reliable model for predicting both short and long term loss of prestress in actual prestressed concrete structures. Current and proposed activities aimed at improving the prediction of loss of prestress include: the creep behaviour of concrete in a biaxial or multiaxial stress field, standardisation of creep experiments to provide reliable data; experiments on the effects of temperature on prestressing steels. and the development of approximate formulae and both empirical and semi-empirical models to improve the prediction of shrinkage and creep in concrete, and relaxation of steel.

4. Improved and simplified simulations of creep and shrinkage phenomena that can account for the environment and loading history of prestressed concrete containments and pressure vessels will assist: the development of design regulations/standards; the choice of concrete mix; the development of relevant monitoring programmes, and ageing management including plant life extension.

5. Prestressed concrete containments and pressure vessels use both grouted (bonded) tendons and ungrouted (unbonded) tendons. The workshop considered the relative merits of both systems.

- Grouted Tendons. The cementitious grout: surrounds the tendon in an alkaline environment that will inhibit corrosion of the steel, and prevents the ingress and circulation of corrosive fluids. In case of break of a tendon, due to the bond with the grout, part of the prestress remains transmitted to the concrete. Therefore grouted tendons are less vulnerable than ungrouted tendons to local damage. They reduce the risk of the containment being by-passed via tendon ducts, particularly important where the containment is unlined. However, grouted tendons can not be visually inspected, mechanically tested or re-tensioned in the event of greater than expected loss of prestress.

- Ungrouted Tendons. Prestressing force is transmitted to the concrete, primarily, at the location of the anchorages. Corrosion is prevented by organic petroleum based greases or corrosion inhibiting compounds. These are either applied to the surface of the tendon prior to installation or injected into the tendon duct following completion of the stressing sequence. Some countries use a combination of both coating and injection. Tendons can be removed for visual inspection/replacement; mechanically tested in-situ; and retensioned to maintain prestress. Ungrouted tendons are more vulnerable than grouted tendons to local failure and corrosive fluids can circulate along the ducts. Ducts may provide a route for containment by-pass in unlined containments, although the practice of keeping ducts filled with corrosion protection medium reduces the likelihood of by-pass.

6. Experience presented at the workshop indicates that comprehensive and regular monitoring of the behaviour of containments and pressure vessels at operational plant assist our understanding of the cause of loss of prestress. Containments around the world include instruments to measure: anchorage loads; concrete strain; structural geometry; concrete temperature; and surface cracking. Data collected from more

than 150 structures aged between 3 and 40 years indicate that, for the majority, loss of prestress has been less than predicted. However, for some containments, losses have exceeded predictions. Measured losses vary from containment design to containment design but significant differences have also been observed between containments in the same design series. The variation in measured losses has been attributed to a number of factors including: concrete composition; aggregate type; the presence of a liner; high relaxation of steel tendons; concrete temperatures; loading history and the environment. Regulatory and codified prediction techniques do not necessarily account for such factors.

7. Many plant include direct measurement of tendon loads at the anchorage. A number of papers reported problems with the reliability and accuracy of tendon load measurement. The use of tendon load to interpret loss of prestress requires careful consideration of the method used to measure the load and the design of the prestressing system.

8. Nuclear containments and pressure vessels are designed with large margins on structural integrity. Therefore, a higher than expected loss of prestress does not necessarily jeopardise the integrity of the structure. However, under accident conditions the margin on precompression of the concrete is reduced and therefore there is an increased risk of cracking. This may result in a corresponding increase in the leak rate of unlined containments. Periodic testing of the containment is used to evaluate its leaktightness.

9. The workshop discussed the corrosion protection media used for containments and pressure vessels having ungrouted tendons. For systems where the tendon duct is filled with protection media, greases have been developed that optimise: viscosity, resistance to penetrating concrete; water displacement; alkalinity and electrical conductivity. For systems using coated tendons, with time the grease loses its lighter oil component but the residue is still capable of providing corrosion protection to the tendons.

Recommendations

1. Information on direct load measurements (in particular their accuracy and reliability) should be considered at the future PWG3 concrete group instrumentation workshop.

2. Current research activities and operational experience should be followed to ascertain whether present uncertainties in predicting losses can be reduced.