International Developments in the Field of Civil Engineering Instrumentation for Nuclear Power Plants

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ABSTRACT

This paper reviews recent international developments with regard to the use of instrumentation to monitor the performance of concrete structures to verify the assumptions used in their design and condition monitoring to allow lifetime prediction, confirmation of continued fitness for purpose and identification of maintenance requirements to be carried out.

Internationally, a significant number of nuclear power plants have now been operating for a period in excess of twenty years and some for more than thirty years. As a result, interest in the management of ageing has received a higher priority than was hitherto the case in order to confirm or extend the operational life of nuclear power plants. The issues presented by ageing nuclear installations are therefore of international interest and it is beneficial for experience and information to be exchanged with a view to determining best practice.

The monitoring of concrete structures fulfils an important nuclear safety role on nuclear installations. The majority of the instrumentation used to monitor these civil engineering structures is also found in other industries, but the importance of accurate results and the reliance placed upon these to predict trending and behaviour places higher demands on the systems and equipment used in the nuclear industry. Monitoring has all the characteristics of a safety system (although it is not always classified as such) which has to provide data both for ageing evaluation, and therefore for control of the plant safety margins, and for life management in view of any discussion on plant life extension. In this sense, the continuous feed-back from monitoring to design assumptions and vice versa is a key part of the program and might even lead to in-depth review of operation and maintenance procedures.

Instrumentation may be employed on a temporary basis during commissioning, for whole life monitoring of structures, as a retro-fit to existing structures or on an *ad hoc* basis to investigate a particular aspect of structural behaviour.

The paper considers current and future developments and requirements and the lessons that can be learnt from experience both on nuclear installations and in non-nuclear industries based on the results, conclusions and recommendations of an OECD-NEA international workshop which was held in Brussels in March 2000.

INTRODUCTION

Instrumentation of civil engineering structures fulfils an important, although not widely known, role on nuclear installations. Instrumentation on nuclear power plants is more usually associated with reactor operation and mechanical and electrical plant related to power generation. The majority of instrumentation used to monitor civil engineering structures is also found in other industries, but the importance of accurate results and the reliance placed upon these to predict trending and behaviour places higher demands on the systems and equipment used in the nuclear industry. The changes detected by instrumentation in nuclear power plant civil engineering structures may be grouped into two classes;

- changes occurring in the short to medium term as the result of applied loads, pressures and environmental effects, and;
- changes that occur over an extended period of time which involve ageing effects.

The first class of effects represent the immediate structural response to operational conditions and can be related primarily to design assumptions and analysis. The second class of effects is closely related to the ageing management of the structures and also to design assumptions and analysis relating to ageing effects.

Historically, emphasis has been placed on the use of instrumentation to validate design and analysis assumptions and for initial structural integrity testing and it has been normal for the first structure of a new design or series to be extensively instrumented with subsequent structures receiving less attention. Although instrumentation has been used for long term monitoring this has often been as a result of the continued operation of systems installed for commissioning and structural integrity tests which have then been adopted for long term monitoring purposes. It is now generally accepted that the installation of structural monitoring systems at the time of construction will provide useful information for the lifetime management of nuclear power plant structures and the detection of ageing effects. With regard to the monitoring of civil structures, a distinction may be drawn between this specialised form of surveillance and other types of structural survey. It is therefore useful to define these as follows:

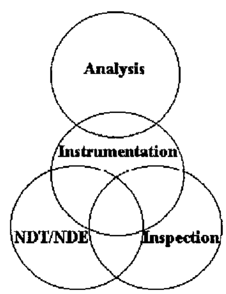
- In-service Monitoring: In-service surveillance and condition monitoring of structures on a continuous or quasi-continuous basis using imbedded or externally applied monitoring devices. This includes automated systems linked to data-logging equipment which may have pre-defined alarm levels.

- In-service Inspection: In-service surveillance of structures by periodic surveys at specified intervals. This may include consideration of information obtained during condition monitoring surveys over the period between inspections.

The information from both of these activities is used to carry out condition assessments although criteria for the interpretation of the data obtained vary greatly. The instrumentation is used at all stages of the life of the plant; from commissioning and structural integrity tests, through operation and maintenance to final decommissioning. The results obtained from monitoring instrumentation are collated and processed to provide information that is of engineering value. This information is then used for

- Confirmation of design assumptions
- Verification of predicted behaviour
- Verification of numerical models
- Identification of trending
- Defect detection
- Lifetime prediction
- Design improvement and development

Monitoring could be considered to be a safety system which has to provide data for ageing evaluation, and therefore for control of the plant safety margins and for life management in view of any discussion on plant life extension. In this sense, the continuous feed-back from monitoring to design assumptions and vice versa is a key part of the programme and might even lead to in-depth review of operation and maintenance procedures. Instrumentation systems and their development and operation have major interfaces with other aspects of nuclear power plant design and ageing management and it can be difficult to to draw a distinction between these different activities. The principal interfaces are shown diagramatically below.



The equipment and techniques used owe much to lessons learned during the monitoring of other large civil engineering structures such as large buildings, dams and bridges. Typical instrumentation that has been used for the monitoring of civil engineering structures on nuclear power plants includes;

Structural Monitoring

- Vibrating Wire Strain gauges
- Foil Resistance Strain Gauges
- Stress Gauges
- Thermocouples
- LVDTs
- Load Cells
- Pendulums
- Extensometers
- Liquid level gauges
- Humidity gauges

Survey

- Total Stations
- Precision level surveys

Corrosion

- Half cells

Seismic Monitoring

- Transducers/Accelerometers

INTERNATIONAL COLLABORATION

Internationally, a significant number of nuclear power plants have now been operating for a period in excess of twenty years and some for more than thirty years. As a result, interest in the management of ageing has received a higher priority than was hitherto the case in order to confirm or extend the operational life of nuclear power plants. The individual national programmes centre on the plant within each country but there are generic ageing effects which are common to all types of plant. The issues presented by ageing nuclear installations are therefore of international interest and it is beneficial for experience and information to be exchanged with a view to determining best practice. The principal organisations currently or recently involved in the examination of ageing effects in nuclear power plant civil structures are the International Atomic Energy Agency (IAEA), Organisation for Economic Co-operation and Development Nuclear Energy Agency (OECD-NEA), Réunion Internationale des Laboratoires d'Essais et de Recherches sur les Matériaux (RILEM) and Commission of the European Communities (CEC) through the EURATOM programme. There is regular liaison between the different international committees and the results of the various programmes examining ageing effects on nuclear power plants have provided valuable support to the national ageing programmes and station operators. The close relationship between structural instrumentation and lifetime and ageing management has led to interest in the development and use of instrumentation systems by the various international organisations involved in developing such programmes.

EURATOM

The work of the international committees is essential to the exchange and dissemination of information and the identification of shortfalls in current knowledge, however they are not in a position to directly finance research and must largely depend on the results of the individual national programmes. In this regard, initiatives such as the EC Fifth Framework programme are very important as a source of true international collaborative research funding. It is important that the results of such work are disseminated widely in order that all parties who have requirement for, or interest in, this work can make use of its findings. The Fifth Framework Programme (FP5) sets out the priorities for the European Union's research, technological development and demonstration activities for the period 1998-2000. FP5 has two distinct parts: the European Community (EC) framework programme covering research, technological development and demonstration activities; and the Euratom framework programme covering research and training activities in the nuclear sector. The latest revised Euratom work programme specifically mentions the ageing of concrete and development of innovative on-line monitoring and inspection techniques as a topic for development under plant life management and similar work is also under development under the EC framework programme.

IAEA

To assist Member States in understanding ageing of systems, structures and components important to safety, in 1989, the IAEA initiated a project on safety aspects of nuclear power plant ageing. The project included a programme of pilot studies on management of ageing of nuclear power plant components that included concrete containment buildings. Phase 1 of the studies assessed the current state of knowledge on age-related degradation, its detection and mitigation. This led to a second phase, the Co-ordinated Research Programme (CRP) on Management of Ageing of Concrete Containment Buildings, which addressed current practices and techniques for assessing fitness-for-service and the inspection, monitoring and mitigation of ageing degradation of concrete containment buildings [1-4]. The original objectives of the CRP, with particular application to concrete containment buildings, were to:

- Produce a summary of current national ageing management practices and experiences for concrete containment structures

- Compile a state-of-the-art report on concrete repair techniques and materials specifically applicable to nuclear containment structures

- Develop crack mapping and acceptance/ repair guidelines applicable to nuclear containment structures

- Develop a set of practical condition indicators and associated guidelines for monitoring concrete containment ageing.

The 1998 IAEA report "Assessment and Management of Ageing of Major Nuclear Components Important to Safety: Concrete Containment Buildings, IAEA-TECDOC-1025" [5] addressed potential ageing mechanisms, age-related degradation and ageing management for concrete, reinforcing steel, prestressing systems, penetrations, liner systems waterstops, seals, gaskets and protective coatings in concrete containment buildings. The document collated practices, experience and advice from IAEA member states but did not address life or life-cycle management of concrete containment buildings as it was written from a safety perspective and life management includes economic planning. The IAEA report contains a section on the detection of ageing in nuclear containments which includes not only instrumentation but also non-destructive testing which is closely related. The construction of nuclear containment buildings involves not only the concrete or prestressed concrete structure but also significant steel components such as the liner. The IAEA report "Assessment and Management of Ageing of Major Nuclear Components Important to Safety: Metal Components of BWR Containment Systems, IAEA-TECDOC-1181" [6] which was published in 2000 similarly dealt with these components but the emphasis was more on non-destructive testing although accoustic emission and on line elecrochemical monitoring were identified as potential methods. A general methodology which relates the data collection phase with the deterioration by ageing and then the residual life evaluation is presented in the Safety Report "Implementation and Review of a Nuclear Power Plant Ageing Mangement Programme" [16] which provides also indications on the typologies of data to be retrieved by monitoring, their frequency and their organisation in appropriate data bases. Another important development in the field of ageing management of concrete NPP structures is the development of an international database and this is currently under active development by the IAEA Division of Nuclear Power.

The IAEA Division of Nuclear Power have extended their activities in the field of the development of the International Database on NPP Life Management. This database is in a multi-modular format covering several modules, each for different key components of NPPs. The database on RPV Materials has already been developed and put into operation, software for the database on NPP Piping has been developed and is currently under test and work on the development of the software for the database on Steam Generators is currently under way. The next module of the database is the International Database on NPP Concrete Structures. Some preliminary work on the proposed content and database structure had already been done previously. This work only got to the very early stages of database development and in the interim a number international and national developments in the subject area have taken place requiring appropriate co-ordination to avoid duplication of effort. The original database was only conceived as a containment database but, following increased interest in the general lifetime management of NPP concrete structures, this has now been extended to cover all NPP nuclear safety related concrete structures. The database will include a section on instrumentation. The IAEA Division of Nuclear Power convened a Consultants meeting on the development of the International Database on NPP Concrete Structures at the IAEA offices at UN HQ in Vienna from 25 to 27 September 2000. A draft specification was developed based on RILEM Report 19, "Considerations for Use in Managing the Aging of Nuclear Power Plant Concrete Structures"[7] and IAEA-TECDOC-1025, "Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Concrete Containment Buildings "[5].

RILEM

In 1994, the RILEM General Council established a committee to examine the methodology for life prediction of concrete structures in nuclear plants (TC160-MLN). The committee was created to review the present state of ageing management procedures for safety related concrete structures on nuclear power plants and to investigate how this work could be developed to allow prediction of the service life of these structures. The committee comprises representatives from thirteen countries and has co-ordinated a five-year programme of activities that included the following.

- Review existing guidelines/procedures for monitoring/evaluating concrete nuclear structures.

- Develop guidelines/standards for performance monitoring and assessment criteria of existing nuclear structures.

- Develop guidelines/standards for performance monitoring of new concrete nuclear structures.

The RILEM Committee TC-160 MLN State-of-the-Art Report [7] presented considerations for use in the managing of ageing of nuclear power plant concrete structures. This included a useful summary paper giving information on the most commonly used instrumentation and potential methods that have been recently developed for the diagnosis of structures, both new and existing. Examples of the application and use of instrumentation in various countries were also given. The committee organised the 8th International Expertcentrum Conference on Life Prediction and Ageing Management of Concrete Structures in Bratislava, Slovakia [8] at which the following main topics were considered:

- Durability & service life
- Assessment, instrumentation, maintenance & repair
- Ageing management
- Reliability, probability & materials
- Case histories & risk informed assessment

A final workshop was held in Cannes, France in October 2000 and the proceedings will be published by RILEM. 36 delegates from 14 countries, and a range of industries and research institutions, attended. One of the major issues highlighted was the use of probabilistic modelling methods to predict service life, and the need to develop these techniques until they are simple and reliable. Possible issues relevant to the nuclear industry include the long-term effects of elevated temperature and irradiation on concrete. Proposals for follow-on TCs may be submitted to RILEM General Council.

Another RILEM technical committee has recently been set up to investigate the closely related subject of Non-Destructive Examination of concrete structures, TC NDE (NDE-3), and although it would have a wider remit than just nuclear power plant structures, the results of this work will be of great interest to the nuclear industry.

OECD-NEA

The Committee on the Safety of Nuclear Installations (CSNI) of the OECD-NEA co-ordinates the NEA activities concerning the technical aspects of design, construction and operation of nuclear installations insofar as they affect the safety of such installations. In 1994, the CSNI approved a proposal to set up a Task Group under its Principal Working Group 3 (recently re-named as the Working Group on Integrity of Components and Structures (IAGE)) to study the need for a programme of international activities in the area of concrete structural integrity and ageing and how such a programme could be organised. The task group reviewed national and international activities in the area of ageing of nuclear power plant concrete structures and the relevant activities of other international agencies. A proposal for a CSNI programme of workshops was developed [9] to address specific technical issues which were prioritised by OECD-NEA task group into three levels of priority:

First Priority

- Loss of prestressing force in tendons of post-tensioned concrete structures
- In-service inspection techniques for reinforced concrete structures having thick sections and areas not directly accessible for inspection

Second Priority

- Viability of development of a performance based database
- Response of degraded structures (including finite element analysis techniques)

Third Priority

- Instrumentation and monitoring
- Repair methods
- Criteria for condition assessment

The CSNI subsequently endorsed the proposal and charged the task group with implementing the programme. The issues which were given first priority were addressed by a workshop on prestress losses in nuclear power plant containments held at Civaux NPP in France in August 1997 [10,11] with participants from 14 countries and by a workshop on development priorities for non-destructive examination of concrete structures held at AEA Technology, Risley in the UK in November 1997 [12,13] with participants from 11 countries. At the Risley NDE workshop, concrete reinforcement corrosion was identified as an issue that required examination and this is currently under consideration for a future workshop. The response of degraded structures (including finite element analysis techniques) was covered by a workshop at Brookhaven National Laboratory, USA in October 1998 [14]. It was considered that development of a performance based database by OECD-NEA was not feasible at present but this is now being progressed by the Division of Nuclear Power within IAEA. CSNI has accepted a proposal to broaden the scope of IAGE Concrete to consider ageing of fuel cycle facilities, fuel storage facilities, and other nuclear structures required to perform a safety function for a very long period of time, eg. decommissioned facilities. A temporary Task Group has been set up based on nationally nominated experts and members of the concrete sub-group with a view to the preparation of an overview report on the relevant issues and priorities for further investigation. Some of the main functions of the CSNI are to exchange information, overcome discrepancies and to reach international consensus on technical issues. IAGE WG and its sub groups participate actively in this effort. The working group has progressively worked through the priority list developed during the preliminary study carried out by the Task Group. Currently almost all of the three levels of priority are effectively complete, although in doing so the committee has identified other specific items worthy of consideration. By working logically through the list of priorities the committee has maintained a clarity of purpose which has been important in maintaining efficiency and achieving its objectives. The performance of the group has been enhanced by the involvement of regulators, operators and technical specialists in both the work of the committee and its technical workshops and by liaison and co-operation with complementary committees of other international organisations. The workshop format that has been adopted (based around presentation of pre-prepared papers or reports followed by open discussion and round-table development of recommendations) has proved to be an efficient mechanism for the identification of best practice, potential shortcomings of current methods and identification of future requirements.

OECD-NEA WORKSHOP ON THE INSTRUMENTATION AND MONITORING OF CONCRETE STRUCTURES

OECD-NEA IAGE held an international workshop on the Instrumentation and Monitoring of Concrete Structures in Brussels, Belgium in March 2000. During the previous workshops, the importance of instrumentation and monitoring was demonstrated as it became clear that these interface with each of the subjects covered. An increased need to address the ageing of concrete structures is now a commonly accepted idea within the nuclear community, primarily because these are the longest lasting structures and also because after decommissioning, inspection programs are likely to be down-scaled putting greater demands on instrumentation. As a consequence, the ageing of instrumentation (including loss of instrumentation and/or retrofitting issues) is an important subject that needs to be addressed. Since the definition of the original priorities by the OECD-NEA Task Group, the importance of instrumentation and monitoring has been more widely recognised (although it should be noted that even at the time that the priorities were determined the representatives from Belgium and Spain recommended that instrumentation and monitoring should have a higher priority; possibly first priority rather than third priority). This was reflected in the participation in the workshop with 64 participants from 19 countries taking part and 20 papers being presented making it the largest workshop run so far. The proceedings were issued in January 2001 and are summarised below [15]. The objective of the workshop was to assess the capability of current instrumentation and monitoring systems to describe the actual state of structures and detect ageing problems. The workshop focused on experience of current instrumentation and monitoring systems with a view to detecting trends for the future. The three sessions of the workshop covered a broad range of activities and issues within the framework of monitoring instrumentation for concrete structures with work from both nuclear and non-nuclear industries being presented.

Eight papers were presented during the first session under the general theme of regulatory considerations and state-of-the-art. These included an overview of the regulatory requirements in the US along with a general description of some possible methods and techniques to inspect concrete structures. It became apparent that inspecting concrete structures non-destructively is a real challenge that needs more development. This was followed by papers describing the current situation and experience in Belgium, the UK, the Ukraine, and Canada which described the types of monitoring equipment used, its performance and the use to which the data obtained can be used. A further paper from France described the MAEVA containment mock-up and specifically presented the concrete behaviour observed by the instrumentation during testing.

Seven papers were presented in the second session under the general theme of detecting ageing in reinforced concrete structures. Papers described the UPUS system for determining the force in a prestressing bar based on ultrasonic measurements (ultrasonic wave propagation time) and SCANPRINT, a global inspection and expert analysis tool for use in ageing management of structures. Using different databases that contain the list of known defects, associated structural pathology, project data, and project inspection records, SCANPRINT can prepare drawings necessary for inspection, record inspection results directly onto the drawings, recall maintenance records, perform analyses, and generate reports. One paper presented a monitoring program used to monitor for cooling towers in Belgium based on results obtained from topographic surveys, inventory of deterioration, and analysis of the structural materials. The process is started with a complete baseline inspection with any defects found being classified. Subsequent monitoring is based on the significance of the defects, with follow-on inspections being either partial inspections between full inspections to monitor a specific defect, or more extensive complete inspections of the structure. All measurements are input into a large database covering some 30 towers in both Belgium and France that have been observed over a period of about ten years.

Case studies and the methodology used in the ageing management and long-term monitoring of concrete structures (primarily prestressed concrete bridges) in Slovakia were presented. Deterioration mechanisms were grouped into either continuous effects tied to operating or environmental conditions and external accidental loading effects. Prediction of service life was made by input of data from long-term observations of strain, deflection, and analysis of carbonation and chloride penetration into relatively simple correlation functions. The importance to the results of temperature and humidity changes, creep and shrinkage of concrete, and changes in modulus of elasticity was noted.

One paper presented an assessment of the strain, force, and temperature data recorded over a 19-year period by monitoring devices contained in the PCRV of the German 300 MW(e) THTR. Evaluation of these in-situ measurements was based on a comparison of measured values and predicted vales from an axisymmetric model of the structure. The long-term behavior of the PCRV during the post-operational state (100 years) was investigated based on several scenarios in order to develop a monitoring strategy.

The third session was devoted to new technologies and non-destructive testing. Two papers dealt with developments in fibre optics. This technology is improving quickly and is now leaving laboratories to be applied to structures in the field (bridges, tunnel linings and retro-fitting of structures). One paper described an acoustic sensor monitoring system for detecting failure of prestressing tendons and concrete cracking. This technology has also made the transition from the laboratory to the field and is now applied to on-site structures such as bridges, parking structures, and tanks. It is worth noting that both fibre optic and acoustic sensor technologies can help earthquake damage estimation. Two papers were presented on Non Destructive Examination (NDE) describing the latest technological improvements such as radiography, ultrasonic testing, impact echo, surface waves, moisture measurements, radar and ultrasonic data used singly or in combination together. Progress with regard to sensors, electronics and computer processing has led to improvements in the accuracy of these techniques although further research is continuing. Two Spanish papers were presented; one describing the state of the art for nondestructive detection of corrosion in steel reinforcement in concrete structures and the other presenting the results of a monitoring project using sensors built into a pilot container of the type used in storage of low and medium level radioactive wastes in Spain. The electrochemical techniques described included polarization resistance (calculation of instantaneous corrosion current and quantification of the corrosion process), half-cell potential measurements (location of corroding reinforcement and indication of the corrosion risk), and electrical resistivity measurements (indication of the risk of corrosion). However, application of these techniques to NPP concrete structures may be difficult because of large section dimensions, high steel reinforcement density, the presence of liners or cladding which create physical barriers to access for inspection, and accessibility constraints due to configuration or hostile environments. The waste container sensors measured temperature, deformation, corrosion potential, corrosion rate, concrete resistivity, and oxygen availability and a GEOLOGGER was used to continuously monitor and record all the parameters. Results to date indicate that all measurement techniques have been working reliably. Discussions could be separated into technology and scientific issues: Instrumentation accuracy and reliability (for both in-situ and retrofitted structural instrumentation) and new technology under development were relevant to the technology category. Bridging the gap between local information given by sensors and global behaviour, understanding degradation with limited available data prior to a decision-making point and linking former and new data obtained from different types and/or generations of instrumentation fell into the second category. A series of conclusions and recommendations were developed from the workshop and have been approved by the IAGE Working Group as given below.

CONCLUSIONS FROM THE OECD-NEA WORKSHOP

There is now a perceived need to address the ageing of concrete structures. To this end, the use and acceptance of instrumentation techniques has increased with time and more reliance is being placed on such techniques.

It is extremely difficult to replace instrumentation which was installed at the time of construction. Cabling can also cause problems but is easier to replace unless imbedded.

Instrumentation provides an indication that something may be happening. Interpretation and diagnosis require detailed studies and assessment and eventually additional inspection.

Numerical modelling assists in interpretation of results obtained from instrumentation. Revised numerical models based on data from instrumentation are useful in predicting future performance. Data from instrumentation during destructive tests of models and monitoring of decommissioned plants can provide useful data for validation of finite-element codes.

The usefulness of installed instrumentation is dependent on the accuracy and reliability of the sensors used. This has also been improved by developments with regard to computer management systems and databases.

To conclude, a) the understanding and use of instrumentation, b) numerical modelling techniques, and c) promising NDE methods are complementary tools for the assessment of ageing of concrete structures.

RECOMMENDATIONS FROM THE OECD-NEA WORKSHOP

While techniques are available to monitor ageing and performance of structures and new systems are available which may be retrofitted, it is recommended that improvements be made in retrofitting instrumentation and in relating it to existing instrumentation.

Although there are some existing NDE methods used as a complement or an alternative to installed instrumentation and for which improvement is needed [11,12], some new promising NDE techniques have been presented. Further development of latter techniques is recommended.

It is recommended that the processing and analysis of results obtained from instrumentation and the relationship between local and global effects be improved. Also, the results should be used to understand degradation mechanisms.

It is recommended that the design of new plants includes instrumentation with a defined objective for the purpose of monitoring structural performance and ageing from the time of construction through to decommissioning.

Where instrumentation is in place, it is very useful for assessment of ageing at all stages of the plant life through to final decommissioning, it is therefore recommended that the longevity/durability of instrumentation and the ease of its maintenance be considered in its selection.

FUTURE DEVELOPMENTS

The use of instrumentation for civil engineering monitoring purposes on nuclear power plants has developed with time, experience and the availability of hardware and software to collect and process the results. The perceived need to address the ageing of concrete structures and ageing phenomena fosters the development of instrumentation technology, monitoring techniques, inspection programs, diagnosis tools and the understanding of damage mechanisms to enable structures to be monitored effectively over time. Monitoring shares many of the characteristics of a safety system which has to provide data for ageing evaluation, and therefore for control of the plant safety margins and for life management in view of any discussion on plant life extension. In this sense, the continuous feed-back from monitoring to design assumptions and vice versa is a key activity which must also include the review of operation and maintenance procedures. The demands made upon the instrumentation with regard to accuracy, reliability and the speed and the extent of processing are continually increasing and may be expected to continue to do so. Developments in instrumentation, data processing and interpretation will enable more structures to be monitored more closely. The boundaries between instrumentation, non-destructive examination and automated inspection overlap and developments in each area are likely to have effects on the others. This will be the case particularly with regard to the analysis of data obtained by these methods and the use to which it is put and displayed to users. However, monitoring alone cannot be regarded as a panacea and the limitations of any system must be borne in mind particularly if heavy reliance is placed upon it to ensure safety. It is therefore important that continued research and development and periodic reviews are carried out in order that methods and procedures may be improved in the light of additional knowledge and technological advances. Initiatives such as the Fifth Framework Euratom research programme are very important as a source of true international collaborative research funding and the consideration being given to setting up an international performance based database on concrete structures by IAEA is to be welcomed. It is important that the results of such work are disseminated widely in order that all parties who have requirement for, or interest in, this work can make use of its findings. New instrumentation systems such as accoustic emission technology which can detect prestressing tendon failures, the onset of concrete cracking and certain aspects of corrosion and on-line corrosion monitoring show great promise and the development of new fibre optic strain gauges which can be monitored continuously will greatly improve structural monitoring techniques. Further work is required with regard to the retro-fitting of instrumentation to existing structures is required but new techniques such as the retro-fitted diverse instrument cluster under development by British Energy show promise. This is against the background of many years of successful operation of instrumentation and monitoring systems which have provided invaluable information to engineers and aided the understanding of the in-service performance of civil engineering structures and constructions. This has been particularly useful for the confirmation of assumptions made, and analyses carried out at the design stage and for in-service condition monitoring.

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