New Materials and Systems for Prestressed Concrete Structures

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Project details

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Objective

A. BACKGROUND

Prestressed concrete structures form an important part of Europe’s physical infrastructure for transportation, energy production, nuclear power plants, water and waste-water treatment and buildings. Especially for the transportation infrastructure, most major large span bridges (roads and railways) are post-tensioned structures. This method of construction as well as prestressing (high strength steels directly embedded in the concrete) has now been in use for almost 50 years. As revealed by several national and international reports, these structures actually are in sufficiently good condition. The increasing age, the environmental impact and increasing traffic load may change this situation as documented by a small, but significant number of failures and collapses in the UK, Belgium, Italy and Germany. These collapses, premature demolitions, unforeseen extensive maintenance work all over Europe and the temporary ban of post-tensioning construction technology in UK created great concern about the durability and safety of these structures.

Structural engineers (IABSE, IBMAS) and owners responsible for public safety of prestressed concrete structures are concerned, especially because the knowledge acquired in research on normal reinforced structures (e.g. in the action COST 521, Brite/Euram project DuraCrete) is not sufficient to address the problems of prestressed structures. This is due to the fact that both the theoretical basis, materials characteristics, inspection methods and the technologies involved are completely different from those involved in the design, construction and maintenance of traditional reinforced concrete (RC) structures. In a recent International Federation of Buildings (FIB) workshop held in November 2001 the different aspects of durability problems have been reviewed and the available solutions and strategies for improvement have been discussed. A clear distinction in the approach between the huge existing stock of “old” structures and the new ones has to be made.

I. New prestressed structures

To achieve the required durable safety, new prestressed structures must be designed and executed with new innovated materials and construction methods and modern views on service life and protection in mind, including planning of monitoring, inspection and future maintenance. New materials that are being introduced into the field are glass- or carbon fibre composites and new high-alloyed high strength steels. These new materials offer improved durability but long-term experience exists only for glass-fibre cables and the design codes might have to be adapted for the different materials properties. New technologies are based on a complete encapsulation of the sensitive high strength materials into a polymeric plastic duct and/or on the improvement of grout and grouting techniques as well as on electrically isolated tendons that allow a simple non-destructive monitoring of the cables. New construction methods include external prestressing with both bonded and unbonded post-tensioning systems with an appropriate detailing in the design process. The “design for durability” according to the current philosophy is based on a multi-layer protection approach, including concrete cover, sealing and membranes, duct, grout in the duct and special corrosion protection of the steel in the grouted duct.

II. Existing structures

Regarding the existing stock of prestressed and post-tensioned structures, the main concern and source of failures with the prestressed cables is external chloride penetrating to the steel, from sources such as de-icing salts or seawater mainly at...
"week points" of a structure) such as bearings or expansion joints. In addition, insufficient grouting of the ducts causes serious problems. Owners and maintenance authorities responsible for safety and adequate technical and economic management are increasingly concerned about the durability and safety of the structures. Several important points have to be addressed with increasing need: assessment and monitoring of highway structures (see action COST 345 where a database on procedures was established). New non-destructive assessment methods will provide new possibilities as has been pointed but by COST 345 under "future research work needed". Intense research is ongoing on new NDT techniques such as Pulse-echo methods, impact-echo, ground penetrating radar, magnetic methods and reflectometric methods known from high-energy and telecom cables.

Definition of the serviceability and stability of a structure at the in service-stages requires new risk and safety considerations. When structures require maintenance and repair, new innovative techniques (as e.g. electrochemical chloride removal, cathodic protection) and strengthening with external carbon-fibre sheets or external post-tensioning have to be developed especially for prestressed structures.

Finally, a unified approach to evaluating economic aspects of durability design, assessment, monitoring and intervention strategies over the service life is needed to compare various options and to identify optimal solutions.

Despite the fact that a lot of knowledge on durability and safety of normal reinforced concrete structures has been acquired in the last years (COST 509, COST 521, DuraCrete etc.), this knowledge and expertise does not help to solve the problems outlined above:

- the high-strength steels used are not only susceptible to (chloride) induced corrosion as is the normal reinforcing steel but the combined action of high stress and corrosion can lead to a sudden failure and rupture of the steel;
- the actual state of the high-strength steel can not be assessed by non-destructive methods (as e.g. potential mapping) because the metallic ducts act as a shield;
- repair techniques developed for normal reinforced concrete can not be applied to prestressed structures because full prestressing does not allow concrete removal

III. Use of the COST framework

In various countries the awareness of the problems in durability and safety of prestressed concrete structures mentioned above has resulted in national research projects and many more will follow. It is felt that both individual projects and national programmes will benefit from European co-ordination through a COST Action. Due to historic differences, the expertise in various fields is divided over many countries. Approaches already developed in one country could, with proper attention for local differences, be applied in another country and thereby increase the effective output of the research effort over Europe. COST is seen here - due to its open structure - as the most appropriate body for dealing with this topic.

B. OBJECTIVES AND BENEFITS

Main objective

The main objective of the Action is to increase the knowledge on the durability of existing and newly built prestressed concrete structures in order to prolong their service life (80 instead of 50 years), to minimise repair and monitoring costs and to improve their long-term safety.

Secondary objectives

This project will provide additional more specific results important for owners and maintenance authorities, construction industry, engineers and researchers:

- improved guidelines for durable corrosion protection of new prestressed structures and elements - system approach, multi-layer protection
- new prestressing materials with improved durability - non ferrous materials, new steel types
- new prestressing systems with improved durability - new duct materials, grouting, electrical isolation, long term monitoring
- new methods for assessment of the corrosion condition of existing prestressed concrete structures
- development of non-destructive inspection methods and monitoring strategies for prestressing and post-tensioned structures
- more economic and less disruptive intervention techniques for prestressed structures and elements
- degradation models specifically developed for prestressed concrete
- understanding of the long term economic effects of various design, assessment and intervention options

Benefits

The potential economic benefits of the Action are substantial: the development and application of successful inspection, assessment and maintenance procedures would ensure - only for the highway network - the continued high performance of the transportation network and save billions of Euro in construction, maintenance and traffic delay costs. For nuclear power plants a more reliable information on the safety of the structure also would save considerable amount of money due to the delay or omittance of repair work. The development and acceptance, throughout Europe, of procedures and standards would also give rise to tangible and intangible benefits to users, maintaining authorities, construction companies and owners.

A European-wide Action would allow an exchange of information between different countries and promote sound engineering practice. The identification of those academic, public and private sector organisations which are in the position to maximise the benefits arising from the work of the Action will form a critical part of the dissemination process.

C. SCIENTIFIC PROGRAMME
The Action will address the following topics in materials research important for durability and safety of new and existing prestressed concrete structures. In order to reach a durable system, the combination of several factors has to be considered.

- **New materials for prestressed concrete** (carbon fibre, glass fibre, composites, high alloyed high-strength steels, corrosion protected steel)
- **New systems for prestressed concrete** (polymer ducts, electrical isolation, external prestressing, unbonded tendons, new grouting materials and techniques)
- **New methods for the assessment and monitoring of existing prestressed structures** including serviceability and safety of a structure in the service stage
- **New maintenance and repair methods developed for prestressed concrete** with a better cost / benefit ratio than the existing ones
- **New service life approach** - design for durability and safety for prestressed concrete structures including improved guidelines for durable corrosion protection

In the following, the topics are described in more detail:

### New materials for prestressed concrete

In order to assure the durability and safety of prestressed structures, the materials used have to guarantee the required mechanical properties and resistance against environmental degradation.

The subtopics include:

- **New metallic materials**: High strength steel with improved yield strength and high alloyed CrNi steels with high strength are currently being developed for prestressed concrete. Their corrosion resistance to pitting- and stress corrosion as well as to hydrogen embrittlement has to be studied experimentally and expressed in terms of modelling.
- **New non metallic materials**: Carbon fibre, glass fibre and polymeric composite materials are in use or currently improved and developed for prestressed concrete. These materials might be used for new structures or for external strengthening of old ones.
- **New grout materials**: Cementitious grouts with improved flow and corrosion protection properties are being increasingly used in order to prevent voids in post-tensioning ducts. The influence of the admixtures on the corrosion of metallic high strength materials (ev. also corrosion inhibitors) and on polymeric materials (duct) will be proposed to study.
- **New duct materials**: Polymer ducts or sheathings are increasingly used for internal and external post-tensioning. The long-term stability and durability of these materials (HDPE, PP) in the alkaline environment concrete and / or at the atmosphere (UV radiation, ozone) are not yet well known. Another problem is the influence of high temperatures and the fire resistance.

### New systems for prestressed concrete

Problems faced in the past to reach the required long-term durability and safety of prestressed concrete lead to two different approaches: one of external post-tensioning, where the cables are more easily accessible for inspection and the high strength steel can be replaced (unbonded tendons). The other one is to use tight polymer ducts (with optional electrical isolation of the high strength steel from the rebar network) to completely protect the steel from water and chloride. The subtopics are:

- **Full encapsulation of high strength steel**: corrugated polymer ducts for a complete protection of the sensitive steel, combined with the possibility of electrical isolation, shall be studied. In this context several questions / research needs arise: behaviour of the electrical isolated steels with respect to AC and DC stray currents (railway bridges), accumulation of liquid phases of the grout due to hindered evaporation, fatigue behaviour.
- **Electrically isolated tendons**: Electrical isolation of the high strength steel in the duct from the rebars allows to measure the degree of protection of the polymer duct. The monitoring technique, based on the electrical resistance method, its instrumentation and data acquisition / interpretation has to be further improved and established.

### New methods for the assessment and monitoring of existing prestressed structures

The existing non-destructive techniques routinely used for normal concrete structures cannot be applied on prestressed or post-tensioned structures. Thus for the existing structures new NDT techniques have to be found and developed. The related assessment procedure cannot simply be transferred to prestressed structures due to the lack of significant information (input parameters).

- **New non-destructive inspection methods**: radar, ultrasonic, X-ray, magnetic or other radiation techniques as well as impact echo and acoustic emission shall be tested together with traditional ones. Clear information on the benefits and limits shall be worked out.
- **Design of new warning systems**: When suitable sensor systems can be embedded in existing or repaired structures, the progress of damage can be assessed more easily. Sensors can include stress and deformation (optical fibres, gating systems) but also humidity, chloride, carbonation, potential, etc.
- **Interpretation of data in terms of safety and durability**: A framework to combine information from sensors and NDT techniques within existing assessment procedures shall be worked out and developed for the special case of safety and durability of prestressed structures (risk of brittle, sudden failure).

### New maintenance and repair methods developed for prestressed concrete

Applying the existing repair options for normal concrete to prestressed concrete often leads to very costly and in the same time poorly effective solutions. New options shall be developed:
- New improvements in electrochemical protection methods: permanent protection such as cathodic protection with impressed current or with sacrificial anodes, current flow "on demand" according to environmental conditions. Repair methods such as electrochemical chloride removal to be applied safely to prestressed concrete. Clear information on the benefits and limits shall be worked out.
- New strengthening and non-intrusive protection methods: external strengthening with reinforced polymer sheets, load limits, fire resistance, new fibre and matrix materials.

New service life approach - design for durability and safety

Prestressed and post-tensioned concrete structures require different models for the design for durability and safety, also the service life approach is different.

- Design for durability: design models for the new materials and systems as outlined above have to be developed. The incorporation of a permanent monitoring system and / or the possibility to activate a protection (integrated corrosion protection) have to be included in the design process.
- Service life: Methods to determine the most cost-effective point in the life of a structure for preventative measures or for repair actions and the evaluation of cost effectiveness of protection strategies (life cycle costing) have to be developed for prestressed concrete.

In this topic improved guidelines for durable corrosion protection will be elaborated in collaboration with and as input for international bodies such as FIB or RILEM.

D. ORGANISATION

The programme of the work will be coordinated by the Chairman of the Management Committee with the support of at least one Vice-Chairman. The work of the Action will be organised in Working Groups, following the research topics outlined in C (Scientific programme). In a matrix organisation, three of the working groups are thematic

- New materials for prestressed concrete
- New system for prestressed concrete
- New maintenance and repair options for prestressed concrete

Two other working groups are transversal, thus considering the actions and results of all of the other three groups:

- New methods for the assessment and monitoring of prestressed structures
- New service life approach for prestressed structures

The members of the working group will provide an appropriate mix of technical expertise and research capabilities for the task of the group. A working group leader will coordinate the research work of the group. The coordination of the work will be done in regular meetings of the individual working groups. Exchange of information is promoted also by the Web site of the Action (reserved section). Short time scientific missions will facilitate the collaboration.

An annual workshop of all the working groups will summarise the findings of the different working groups, disseminate information within all the participating projects. The first workshop will be mainly "internal". In the following years also other experts, representatives of organisations and authorities will be invited in order to improve the dissemination.

The interaction with other related COST Actions (e.g. COST 345), with bridge engineers (International Association for Bridge Management and Safety, IBMAS), with the International Association of Bridge and Structural Engineers (IABSE), FIB, is planned to be established by inclusion and exchange of experts, joint workshops and seminars and the exchange of information.

The contacts with these international associations will help to dissipate the results of the European COST Action on an international level, it may result in the participation of research groups from USA, Canada etc. A website for the Action will be established after approval of the Action. The site will contain a public part (general information, objectives, public reports) and a reserved part (exchange of results and documents between participants).

E. TIMETABLE

The duration of the Action will be five years. It is expected that the Action will have, on one hand, no "departure problems" due to the fact that at least part of the experts were involved in the COST 521 action and a body of the MC - including several new experts - already exists. On the other hand this action is targeted on long term phenomena (corrosion is a slow process) and also the tests involved take a long time: in order to study new materials (completely new solutions are emerging), new systems (new reinforcement systems), monitoring, diagnostics, prognostics (new sensors and applications of IT) and new maintenance and repair options (new in-situ methods) as outlined in C (Scientific programme). Thus in order to meet the main objective of this Action “to prolong the service life of prestressed concrete structures” the five years are needed.

Year 1 - Management committee discussion of the scientific program and the multi-disciplinary matrix approach, publication of Call for Proposals
- Opening Seminar: research ideas and project market
- Management Committee deciding on Working group structure and responsibilities

Year 2 - Working group meetings: start-up and development of collaboration
- Workshop: first results
- Management Committee assessing organisation of the Action and start defining End Products for dissemination of results
Year 3: - Working group meetings: start defining End Products
- Workshop: progress made
- Management Committee assessing progress and deciding on structure of End Products and further dissemination actions to end users

Year 4: - Working group meetings: discussion of research results and work on End Products
- Workshop: further progress and draft End Products
- Management Committee assessing progress, deciding on End Products, Final Workshop and further dissemination actions

Year 5: - Working group meetings: Final research reports and End Products
- Final Workshop: presentation of End Products to End Users
- Management Committee assessing the results of the Action and End Products
- Evaluation by experts

F. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest:

Austria
Denmark
France
Finland
Germany
Italy
Ireland
Netherlands
Norway
Slovenia
Spain
Switzerland
United Kingdom.

On the basis of the national estimates provided by the representatives of these countries, the economic dimension of the activities to be carried out under the Action has been estimated, in 2002 prices, at roughly -Euro 12 Million.

This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

G. DISSEMINATION PLAN

Overview

The objective of this dissemination plan is to define the possible end-users of the results of the Action, describe how the results will be communicated to them and how the results could affect European construction industry and owners of structures.

Wider dissemination

The results of this Action will also be disseminated to a wider audience as follows:

- Internet: an Internet Homepage for the Action will be established through CORDIS - The European Commission Research and Development Information System. This will be linked to other relevant home pages.

- If deemed appropriate, a special Homepage will be established to provide a more detailed account of the activities of the action and to promote information exchange.

- E-mail network: It is intended to establish an e-mail network to ensure that the key people within Europe (and increasingly also world-wide) can contribute readily to the Action.

- Publications and Reports: the results of the action will be disseminated through reports to the targeted recipients. It is intended to make the interim and final reports available on the Internet and to allow such reports to be downloaded.

- Events: At this stage, the only specific events where the findings of this Action will be published and presented are the annual EUROCORR conferences, where a special COST section is planned. All participants from the various COST countries may present results of the Action in national or international events, seminars or conferences referring to this COST Action. At half time and at the end of the Action an International Workshop is planned where the results are presented to a wider audience of civil engineers, authorities and construction companies.

- Links with other projects: this Action is embedded in a wider context of civil engineering, maintenance of highway structures (specifically COST 345). Links to other research bodies and associations as the International Association for Bridge Management and Safety (IBMAS), International Association for Bridge and Structural Engineers (IABSE) and RILEM have been established.