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ONGOING AND FUTURE RESEARCH IN SUPPORT OF EUROCODE 8

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ABSTRACT

Since 1993, several European research institutions have been working together in earthquake engineering research. In particular, a pioneering research project of prenormative research in support of Eurocode 8 (PREC8), funded by the European Commission and the National Authorities, involved 19 European laboratories with complementary expertise and research facilities. A summary of the project is included in this paper. Moreover, ICONS, a new research project extending the scope of PREC8 into less conventional concepts and subjects, is introduced. Aspects such as displacement based design, strengthening and repair and composite structures will be investigated within the different ICONS working groups.

KEYWORDS

Earthquake research, Eurocode 8, Training and Mobility of Researchers, Seismic action, Innovative design concepts, Strengthening and repair, Composite structures, Shear walls

INTRODUCTION

In spite of the important advances of Earthquake Engineering, the recent seismic events in the USA, Japan and Europe have shown how vulnerable developed societies still are to the effects of earthquakes, both in human and economic terms. Research in order to decrease such vulnerability, which to a very large extent depends on the better or worse seismic response of structures, is clearly a need.

Expertise in research and seismic design of structures has long been available in Europe, as have been specialised facilities for earthquake testing of structures, in particular shaking tables. With the setting-up in 1989, at the initiative of the Joint Research Centre (JRC), of the European Association of Structural Mechanics Laboratories and the subsequent opening in 1992 of the ELSA reaction-wall facilities in Ispra, a new dimension was given to earthquake engineering research in Europe.

The European Commission (EC), strongly interested in the development of an advanced European standard for earthquake resistance of structures (Eurocode N. 8, in the series of Structural eurocodes), is funding several research networks in seismic hazard and vulnerability. Furthermore, launching the Human Capital Mobility (HCM) programme in 1991, the EC stimulated a series of cooperative actions between various laboratories and universities with complementary expertise. Under the HCM, specialised facilities for earthquake research have been funded and to the researchers was facilitated the access to those facilities.

Furthermore, the European Commission, in collaboration with other international organizations (e.g. EFTA), is promoting and partially supporting several pan-European research projects, taking the form of pre-competitive or basic research or activities of public utility, and extending the participation of third countries in Community programmes. The COST-C1 project - Semi-rigid joint behaviour - set-up in 1989, is a typical example. A seismic working group has been setting up to investigate seismic performance of these structures (Pinto, 1994). The extension of both the COST projects and the HCM programme to the New European Countries is worth mentioning.

These developments are resulting in a new integrated European approach towards protecting communities vulnerable to the effects of earthquakes and the outcome is already visible by the number and quality of the research work presented in the last European Conference of Earthquake Engineering (10thECEE, 1994) in Vienna and the recent Fifth SECED Conference (5thSECED, 1995) held in Chester, United Kingdom. Furthermore, Europe has emerged as a major player on the international scene: cooperative research projects with Japan and USA are being discussed and European researchers are throughout requested to impart this cooperative research experience and the corresponding results (e.g. (Calvi *et al.*, 1995; Pinto, 1995)).

Under the above mentioned Human Capital and Mobility programme of the EC, a network of 19 European Laboratories is working since 1993 on the PREC8 project of prenormative research in support of Eurocode 8 (EC8), the provisional European standards for the design of structures in seismic regions. The results of PREC8 reaching now its final stage, in the areas of reinforced concrete structures, infilled frames, bridges and foundations are expected to contribute significantly to the revision of EC8 upon its conversion into European standards. A pioneering collaboration was established between this research network and the experimental earthquake research facilities, namely: the European Consortium of Earthquake Shaking Tables (ECOEST) (Severn, 1995) and the ELSA reaction-wall facility of the JRC at Ispra (Donea *et al.*, 1995).

In view of the success of the HCM programme and giving continuity to its research/development and training policies, the European Commission launched in 1995 the new Training and Mobility of Researches (TMR) programme with similar characteristics to the HCM one. Therefore, the institutions involved in PREC8 have prepared a new research project extending the scope of PREC8 into less conventional concepts and subjects which should be developed further to convert EC8 into a truly state-of-the-art standard for the safe, yet economic design of earthquake resistant new structures and for the seismic upgrading of existing ones.

This new TMR network proposal on Innovative Seismic Design Concepts for New and Existing Structures, the acronym adopted being ICONS, involves 12 European laboratories and again will take advantage from the support and cooperation of the experimental earthquake research facilities.

The scope of this paper is to present the ICONS research project, namely: the objectives, main tasks and research approach. Being the project the continuation of the PREC8 working methods extending its scope to new subjects, a brief review of this research project is included.

PRE-NORMATIVE RESEARCH FOR EC8 (PREC8)

The Eurocodes -the European provisional standards for constructions- are being prepared by the European Committee for Standardization (CEN, Technical Committee No 250) under mandate of the European Commission. The Eurocodes are being released by the CEC as provisional norms (ENV). After a period of three years, during which comments are expected, the Eurocodes will be accepted as European norms (EV). The process of approval of each Eurocode has reached different stages. For the case of Eurocode 8 (EC8) (Eurocode 8, 1994/95), the code relevant to the design of structures in seismic areas, priority needs for supporting research have been identified.

A scientific network has been set up to accomplish a Pre-normative Research Programme in support of EuroCode 8 (PREC8), under the Human Capital and Mobility programme of the European Commission. The network groups 18 research organisations in the European Union. The identified priority topics are:

- *Reinforced concrete frames and walls*: The objective is to clarify the interrelation between a number of design parameters used in EC8 which, in a combined form, influence the nonlinear behaviour of structures subjected to earthquake ground motion. The parameters under study include regularity classification, values of the behaviour factor, methods of analysis and effects of capacity design procedures. The project also addresses the clarification of the requirements specified in EC8 for reinforcing steel, in light of the new steel production technologies in Europe, and accounting for the ductility demands resulting from the design prescriptions included in EC8.
- *Infilled frames*: The main objective consists of contributing to the revision of all EC8 clauses which relate to the effect of infills on the seismic design and response of reinforced concrete frames and dual systems.
- *Bridges*: The main objectives for bridges are essentially related to regularity and behaviour factor procedures. Secondary objectives are related to capacity design procedures, second-order effects, asynchronous motion of piers and isolation/dissipation devices. Reference is made to EC8, Part 2 - Bridges.
- *Foundations and retaining walls*: Of concern here are the seismic response and safety verification of direct foundations, deep foundations and retaining walls.

Experimental/Numerical Work and Achievements

Experimental and numerical work was carried out within the research groups. The experimental work includes the following:

- A full-scale infilled R/C frame building tested in the ELSA laboratory. Two infilled configurations were tested, namely: uniformly infilled and open first storey (soft-storey frame);
- Several large-scale R/C bridges tested in the ELSA laboratory using the pseudo-dynamic testing method with substructuring;
- Shaking table testing of a scaled bridge model at ISMES, Bergamo, using simultaneously three shaking tables in order to simulate asynchronous input motion;
- Shaking table testing of infilled frames carried out at the Earthquake Engineering Research Centre, University of Bristol and at the National Laboratory for Civil Engineering, in Lisbon;
- Shaking table testing of scaled R/C frames designed for different ductility, at the Technical University of Athens;
- Shaking table testing of small scale models, in order to investigate the effects of different reinforcement ratios of columns and the relative eccentricity in two horizontal axes, at the Technical University of Darmstadt;
- Assessment of the influence of the mechanical characteristics of the reinforced steel produced in Europe, on the ductility of reinforced concrete elements.

The numerical work includes:

- Non-linear analyses of R/C building structures designed according to EC8 for different ductility classes, for different seismic zones (medium and high design accelerations) and for different uses (relative importance of vertical versus horizontal loads, which may affect the outcome of the capacity design provisions);
- Non-linear analyses of the tested bridges using different models (refined and global models), definition of regularity classes for bridges and formulation of a "regularity index" to classify a priori a given bridge in those classes;
- Calibration of global models for infilled frames from the experimental results and from refined models and numerical non-linear analyses of infilled frames with different number of storeys.

Detailed description of the research programme, performed work and achievements can be found in the technical papers presented at the 11th WCEE - Special Session on Pre-normative Research in Support of Eurocode 8.

INNOVATIVE SEISMIC DESIGN CONCEPTS
FOR NEW AND EXISTING STRUCTURES (ICONS)

The ICONS research network setup under the new European programme Training and Mobility of Researchers (TMR) extends the scope of PREC8 into less conventional concepts and subjects which should be developed further to convert EC8 into a truly state-of-the-art standard for the safe, yet economic design of earthquake resistant new structures and for the seismic upgrading of existing ones. ICONS will extend across the three main pillars of seismic design, namely: 1) seismic action, 2) design concepts and methods and 3) construction and strengthening techniques. As shown in Table 1, the project is divided into five tasks.

Table 1. Time-Scheduling and main tasks for ICONS

TASKS	SUB-TASKS	1996				1997				1998			
		J-M	A-J	J-S	O-D	J-M	A-J	J-S	O-D	J-M	A-J	J-S	O-D
1 Seismic Action	Analysis of significant strong-motion (SGM) data	x	x	x									
	Simulations with SDOF/MDOF models		x	x	x	x	x	x	x				
	Development of damage controlled spectra									x	x	x	x
	Application to bridge structures					x	x	x	x	x	x	x	x
	Deliverables: *Analysis of SGM completed; First non-linear simulations; Results from non-linear simulations; Results from first applications to bridges; Damage controlled spectra for different structural types and systems*												
2 Assessment Strengthening/ Repair	Theoretical framework of assessment operations	x	x	x	x	x	x	x	x				
	Rapid screening methods for seismic assessment		x	x	x	x	x	x	x	x	x		
	Selective intervention techniques for seismic S&R		x	x	x	x	x	x	x	x	x		
	Experimental verification (materials and techniques)			x	x	x	x	x	x	x	x		
	Code provisions for SA and upgrading									>	>	x	x
	Deliverables: *Screening methods for seismic assessment; Analytical models for repaired strengthened elements; Dimensioning procedures for connecting devices or systems and S/R elements; Code provisions related to SA and Upgrading of Structures*												
3 Innovative Design Concepts	Base Isolation / Bridges			x	x	x	x	x	x	x	x		
	Base Isolation / Buildings	x	x	x	x	x	x	x	x	x	x	x	x
	Uplifting/Rocking as Base Isolation	x	x	x	x	x	x	x	x				
	Displacement Based Design		x	x	x	x	x	x	x	x			
	Deliverables: *Development of concept fundamentals; Elaboration of Innovative design concepts*												
4 Composite Structures	Design formulas	x	x	x			x	x	x	x	x	x	x
	Numerical modelling	x	x	x	x	x	x	x	x	x	x	x	x
	Classes of sections	x	x	x				x	x			x	x
	Tests		x	x	x	x	x	x	x	x			
	Deliverables: *Testing programme and tentative design formulas; Formulas in a 'designer's guide' form; Proposal of design rules and q factors*												
5 Shear-Wall Structures	Model development and validation	x	x	x	x	x	x	x	x	x	x	x	x
	Numerical assessment of EC8 design rules	x	x	x	x	x			x	x	x	x	x
	Improvement of EC8 clauses for SW design			x	x	x	x	x	x	x	x		
	Deliverables: *Evaluation of current design rules; New RC models; Proposal for updating of EC8*												

Research objectives and work plan

Task 1: Seismic Action. Addressed are special, yet common cases of seismic actions, such as impulsive-type ground motion in near-source (epicentral) areas and long-duration long-period motions in the far-field over soft soils. To cover such special cases of seismic action, the conventional seismic design based on a design acceleration spectrum will be revisited, to include in the representation of the design seismic action one or more measures of structural damage which will account better than the sole displacement ductility factor for the peak acceleration and displacement demands of near source impulsive type of motions and for the energy dissipation demands of long duration far-field motions. For this purpose, use will be made of the wealth of recent strong motion records along with the observed damage, as well as nonlinear response analyses with appropriate models for the hysteresis and for the quantification of structural damage, as a function of both maximum deformations and energy dissipation.

Task 2: Assessment of seismic vulnerability and development of strengthening/repair techniques. This task will focus on the development of general and of construction-type-specific methodologies for the assessment of the seismic vulnerability of existing buildings and bridges of the most common construction types, i.e., reinforced concrete, masonry and steel construction.

Repair and strengthening intervention techniques for the above types of construction will be addressed through a combination of experimental and analytical work. The emphasis will be placed on the development and validation of appropriate techniques, with a special attention paid to the application of new fibre-reinforced composites with good mechanical and durability characteristics.

A major rehabilitation effort of the aging European building stock and infrastructure networks is expected to start around the year 2000. It is natural that in earthquake-prone areas seismic upgrading of buildings and bridges will accompany their general rehabilitation against aging and to meet the needs of tomorrow. This effort will not only assist in the future improvement of the pioneering part 1.4 of EC8 on repair and strengthening, but will also provide the basis for the development of the currently non-existing Eurocode on assessment and redesign of structures against "normal" (i.e., non-seismic) actions.

Task 3: Innovative design concepts. This task will address, both for new and for existing structures, the development of some seismic design concepts which have either a rather long history but still lack in maturity and application, such as the concepts of base isolation and energy dissipation, or are just emerging on the European and the international scene, such as the concept of displacement-based design (in necessary association with capacity design).

The concepts of base isolation and energy dissipation will be tackled with emphasis on the development of methods for the rational selection of the characteristics and the design of the isolation and dissipation devices, and on the application to bridges. The new findings of Task 1, regarding the representation of impulsive-type or long duration seismic actions, will be taken into account in the present study of base isolation and energy dissipation.

Displacement Based Design is a novel concept aiming at designing structures and proportioning their members directly on the basis of displacement and deformation demands, rather than on the basis of internal forces derived from an elastic response spectrum modified through a global behaviour factor to account for local and global energy dissipation. This latter conventional design procedure does not recognize adequately the fact that structures fail during earthquakes not due to imposed forces that they cannot resist, but due to imposed deformations they cannot accommodate. Direct displacement based design seems to be a more rational design concept, holding the promise of producing structures that will be at the same time safer and more economic. It will be developed both for the design of new buildings and bridges (especially of bridge piers), as well as a tool to be used, in combination with Capacity Design, for the assessment of existing buildings. Regarding the latter, the changes required to Capacity Design rules for their application to assessment of existing buildings will be identified and proposed.

Task 4: Steel/concrete composite structures. Prenormative research in composite construction has become essential to improve present seismic design procedures for frame construction. The gaps of knowledge and the inadequacy of the state-of-the-art on this particular topic was recognised by the 18-nation committee of national representatives, SC8, which voted in 1994 to transfer the corresponding part of Eurocode 8 from part of the normative document into an "Informative Annex", due to the incompleteness of the code. In particular, there is need for further research on the topic of proportioning and detailing of composite members and sub-assemblages for satisfactory energy dissipation. This question will be pursued through a combination of analytical/numerical and experimental work aiming at a correct assessment of the behaviour of composite steel concrete structures.

The problem of the definition of a hierarchy in the strength of the components will be addressed through the development of plastic resistance formulas for the beam column intersection zones of frame structures and for composite shear links, taking into account the various possible structural detailing of these zones. These relations will be developed with the help of extensive numerical modelling of the critical regions. A test programme adequate for the calibration of the analytical/numerical approaches will be defined and its results analysed. The geometrical limits for effective composite structures will be defined in terms of proportions of the steel sections and of proportions of concrete relatively to steel. These results will then be written in the form of a proposal for EC 8 code provisions and requirements.

Task 5: Shear-wall structures. In addition to composite construction, the proposed project will address open problems regarding the most common material for earthquake resistant construction in Europe: reinforced concrete. Important questions regarding the application of Capacity Design principles to shear wall design, the proportioning of shear walls in cyclic bending with high shear, the proportioning and detailing of single walls of non-rectangular (L- or U-shaped) cross-section and of coupled walls, etc., which have been identified so far through the trial application of Eurocode 8 as badly in need of further research, will be addressed by a combination of analytical/numerical and experimental work. In addition, the important case of very stiff lightly reinforced walls, which respond in a global rocking mode with partial uplift, will also be taken up within this part of the work, from the point of view of proportioning and detailing, taking into account the reduction of the response due to the uplift. The development of improved models for reinforced concrete, taking into account both bending and shear behaviour, is also judged essential for accurately representing the seismic response of shear walls. These models should be capable of predicting all sources of dissipation, and cover the whole range of structures classified as shear walls, including very low shear span ratios, and for any steel ratio and detailing.

Research teams in the network and training content

The ICONS TMR-Network groups 12 partners from 8 European countries, namely: ELSA laboratory of the JRC, European Commission; Politecnico di Milano, Italy; Imperial College of London, UK; LNEC, Portugal; University of Rome 'La Sapienza', Italy; University of Patras, Greece; University of Pavia, Italy; Geomateriaux, Environment and Ouvrages (GEO), France; Politechnical University of Madrid, Spain; University of Liege, Belgium; Technical University of Darmstadt, Germany; Geodynamique et Structures, France. Fig. 1 illustrates the organization designed for the ICONS network as well as the participating partners in each working group. The partners of ICONS have a long experience in collaborative research projects. Most of them participate in the technical working groups of CEB and EC8. As members of the European Association of Structural Mechanics Laboratories (EASML), they participated in joint research projects on reinforced concrete, masonry and composite structures.

The technical/scientific staff involved in the proposed research activities includes highly qualified European experts in the various disciplines of Earthquake Engineering. Senior researchers deeply engaged in numerical modelling at different refinement levels (local, semi-global and global), holders of the European large scale testing facilities and code-makers have agreed to work together in order to prepare and develop an advanced research programme having in view the drastic revision of EC8 foreseen by the year 2000. Fully sharing the spirit of TMR, the partners of ICONS are looking forward to host young European scientists, in particular at post-doctoral level. Through their participation in the research programme, they will improve their knowledge in the various disciplines of earthquake engineering and consequently contribute to set up a high level European scientific/technical community in this important field.

Several aspects related to training of young researchers within the proposed network should be highlighted. The first is linked to the recognized scientific/technical expertise of the research teams involved in the project. A second attractive aspect is the proposed approach to the research activity that combines, in many tasks, analytical and experimental work. The researchers will be given the possibility of developing analytical models and tools in advanced computer environments (e.g. object oriented type codes) and of participating in large scale tests using new testing techniques (e.g. the pseudo-dynamic test method). Furthermore, as the ICONS partners include several researchers participating in technical committees for establishing design codes and

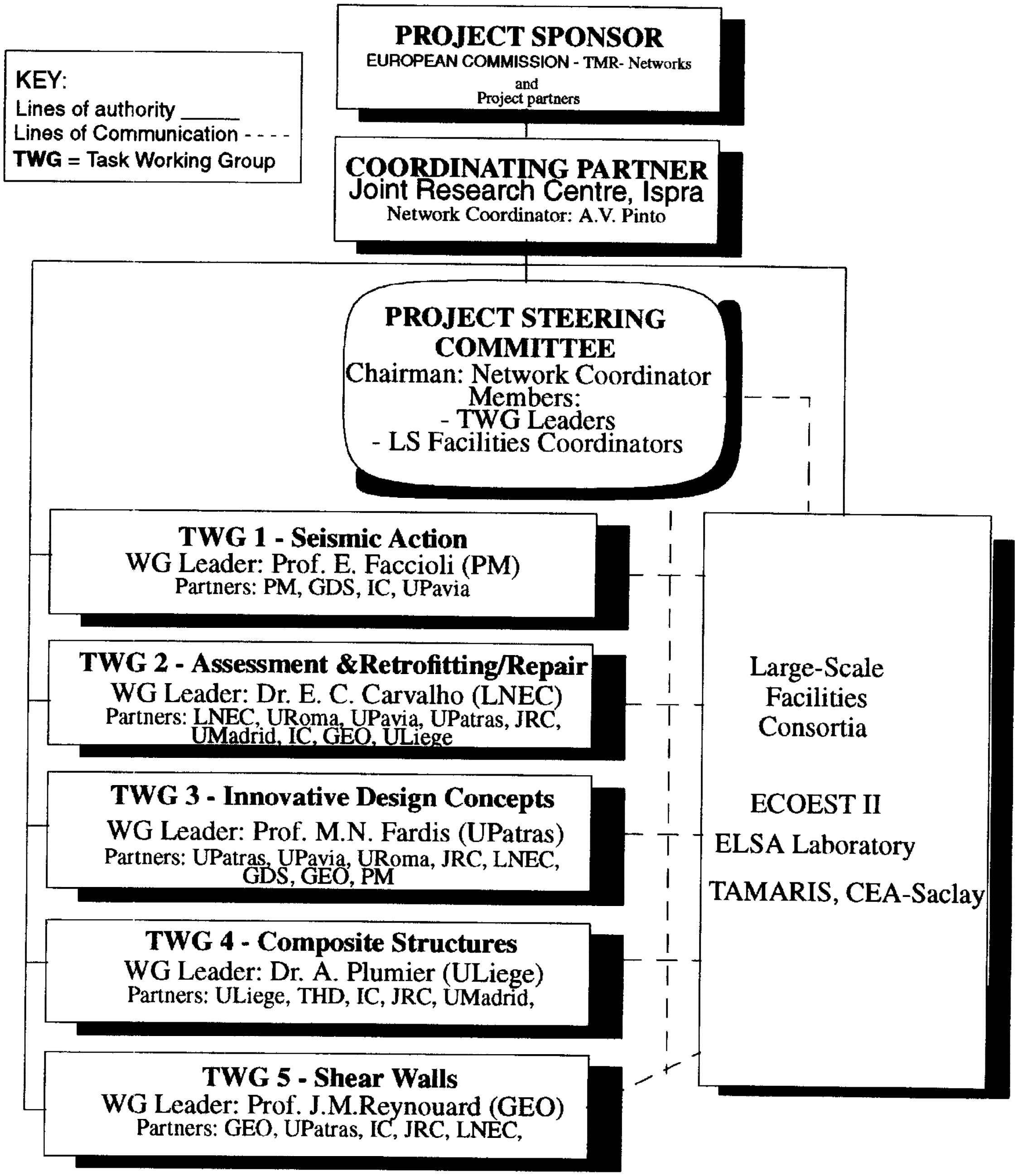

Fig. 1. ICONS management structure, Working Groups and partners

standards (Eurocodes and CEB), the young researchers will be involved in another interesting phase of the project connected with design codes and standards. This part includes the identification of the research achievements relevant to the up-dating of the design codes. This is for them a significant step forward, compared to the work they use to do in academic environments.

Involvement of industry

The research programme of the present network is mainly directed to the validation and improvement of the various parts of Eurocode N. 8 (EC8), the European seismic design code which has been recently published as European pre-Standard ENV 1998 and may subsequently be adopted by the CEN countries for trial application. It is furthermore envisaged that around the year 2000 these pre-Standards will be revised, taking into account the results of the trial applications as ENV and the new findings of the European earthquake engineering research community. Thus, the findings of the research to be performed by the network are expected to contribute to the conversion of EC8 into a European standard and subsequently provide the needed basis for its further revision foreseen for beyond the year 2000.

In addition to this indirect contribution to the European construction industry and to the realization of the European open market, provided by the research in support of EC8, the network is also dealing with three very important subjects relevant to industry and civil protection authorities, namely: the assessment of seismic vulnerability of existing structures, the development of retrofitting and repair techniques and the use of Isolation/Dissipation devices in civil engineering structures. In fact, as clearly evidenced during the last major earthquakes (Northridge, USA and Kobe, Japan), the assessment of seismic vulnerability of existing structures and the subsequent development of retrofitting techniques represent key issues in order to mitigate the effects of future earthquakes and avoid both human casualties and economic losses.

Several industrial firms have expressed their interest in the above research areas and are available to provide support for the design and construction of test specimens needed within the Technical Working Groups of ICONS. In particular, manufacturers of base isolation devices, suppliers of fibre-reinforced polymeric materials and steel producers represent a first group of industries fully supporting the project from the beginning. Other industries (e.g. cement and epoxy resin producers) have more recently accepted to support the proposed research. Furthermore, it is envisaged to associate civil protection authorities with the aspects of the project relevant to the public safety.

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