Project No. TST5-CT-2006-031522

HP FUTURE-Bridge

High Performance (Cost Competitive, long-life and Low Maintenance) Composite Bridges for Rapid Infrastructure Renewal

STREP Project

PRIORITY 1.6.2 Sustainable Surface Transport

HP FUTURE-BRIDGE FINAL REPORT

Publishable Final Activity Report

Period covered: from October, 1st 2006 to September, 30th 2009

Date of preparation: October 2009

Start date of the project: October, 1st 2006

Duration: 36 months

Project coordinator name: Juan Manuel Mieres Royo

Coordinator organisation name: Acciona Infraestructuras

Revision: Final

TABLE OF CONTENTS

1. Project Execution

1.1 Introduction

The present document sets out a general vision of the works carried out by the consortium members during last the three years within the framework of the HP FutureBridge project co-financed by the European Commission under 6th Framework Programme. Hereby we summarize the project objectives, partners involved, as well as the works that have been carried out on the 3-year project as well as the main publishable results.

1.2 The HP FUTURE-Bridge Project: Concept and Objectives

HP FUTURE-Bridge

http://www.gestionidi.com/futurebridge

In the last 50 years EU's transport networks infrastructure expenditure related to its GDP has declined by almost 50 percent. The result is an aged infrastructure much of which has been built with the technologies and systems developed in late 19th or early 20th century. The consequences are clearly visible: traffic delays, congestion, deficient bridges and structures, deteriorating roads and motorways. When ten new Member States (NMS) joined the European Union on 1 May 2004, the land surface of the EU increased by a quarter to over 6.4 million square kilometres[1]. This increase means that a huge increase in transport networks that take care of the communication between different locations within this land surface has taken place. Therefore, it can be expected that mentioned transport networks need an important upgrade to be able to 'support' the new service loads growing from European Transport Policy.

NMS are therefore facing a strong challenge in the coming years in transport infrastructure renewal that permit quick and effective goods exchange and citizens mobilisation. For that purpose all NMS have prepared and will update Transport Infrastructure Plans regarding networks of roads, rail and waterborne infrastructure

To achieve economical, environmental and social objectives means that renewal must be done in rapid, cost effective, high quality and sustainable way by reducing production lead-time, manufacturing and maintenance cost while reducing the environmental impact by reducing energy consumption, waste production and recyclability and by enhancing new business models and specialized jobs.

Important elements in these networks are the bridges in strategic and logistic terms as well as in economical terms. In economical terms it represents currently about 20% of the total infrastructure costs in roads and 15% in rail transport. To avoid that these bridges will be a bottleneck in the upgrading of these infrastructures, **cost-effective and quick and sustainable construction concepts for these bridges are needed**.

[1] www.cordis.lu

Renewal will require repair of existing bridges but also both **new bridges** that will substitute the existing ones in those cases that this option is cheaper, quicker and sustainable while preserving social and cultural aspects and new bridges as a consequence of the infrastructure plans. **The HP FUTURE-Bridge project addresses these needs**.

The overall objective of the project is the development of a new high performance and cost effective construction concept for bridges (HP FUTURE-Bridge) based on the application of fibre-reinforced polymers (FRP) for rapid renewal and long life service infrastructures in the NMS.

Essential technical elements of the new concept are:

- Deck and beams of hybrid FRP (Carbon - Glass / thermoset - thermoplastic) composites. Pillars of hybrid FRP - concrete. The Deck concept by itself will be a solution for renovation of existing deteriorated infrastructures.
- Multiobjective material optimization for design optimization. Multivariable optimization criteria that essentially attempts to compromise design objectives.
- Performance based simultaneous engineering and manufacturing
- On-site industrialisation
- Flexible design and manufacturing from one-off, small series and mass customisation
- Development of mobile manufacturing lines
- New hybrid materials combination for improved fire and high temperature resistance and recyclability.

The FUTURE-BRIDGE overall work has been divided into 9 strongly linked Workpackages. Each scientific WP is led by a different core group partner; being each one of them excellent in the specific tasks involved in the WP they lead. In FUTURE-BRIDGE most partners are involved in 2 or 3 scientific WPs. Each WP has specific objectives, and has been structured and distributed in time so that output from earliest ones can be used as the necessary input for the following ones.

First of all, and in order to be competitive, it has to be done a Life Cycle Cost Model that will evaluate the sustainability of Fibre Reinforced Polymer bridge decks. This study, however, will seek to create an even more inclusive analysis by expanding the definition of costs to include social costs, particularly those that are usually ignored in cost analysis studies.

The requirements for NMS countries (and others), with their specific cultural, social and environmental idiosyncrasy, will be taken into account to guarantee the viability of the technical solution. In order to achieve this purpose, aspects such us sustainability and life cycle costs will be managed.

The new concept, FUTURE-Bridge, has to be developed, dealing with the overall aspects (components and innovation necessities) of this concept in composite bridges. In order to compare new concept solution versus traditional one (concrete and steel), some critical and independent parameters will be used to tackle this problem and find the best solution by using Multi-Criteria Decision Making (MCDM) tools. FUTURE-Bridge concept goes together with the development of a performance based design, which deals with design methodology, modelling, dynamic behaviours and design versus manufacturing interactions and a performance based manufacturing, defining a new manufacturing methodology, in order to be effective in reducing manufacturing costs and production lead times

As well as design and manufacturing, advanced materials have to developed and optimized seeking a cost-competitive design. We will also research to provide suitable solutions to the fire problem through suitable fire coatings.

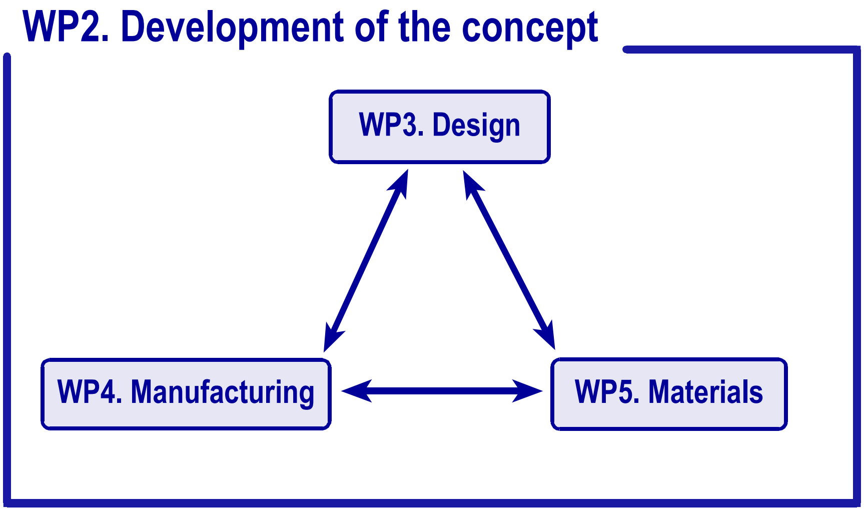


Figure 1. The HP FUTURE-Bridge concept

Figure 1 summarized the development of the HP FUTURE-Bridge. Once the framework is established, the work is performed under the three basic pillars that make the HP FUTURE-Bridge concept: design, materials and manufacturing.

This extensive research programme will finally be assessed through the construction of pilot bridge solutions which will demonstrate FUTURE-Bridge to be a high-performance and cost-competitive solution for infrastructure renewal and new bridge constructions and thus, will allow us to expand the concept and create a real business opportunity for FUTURE-Bridge through a competitive concept that will face the challenges of the future.

1.3 The HP FUTURE-Bridge Consortium

The contact details of the project coordinator and the participants of the project is provided in the next paragraph.

HP FUTURE-Bridge project coordinator

ACCIONA Infraestructuras (project coordinator)
R&D Division
Juan Manuel Mieres and Javier Bonilla
Tel.: +34 91 791 20 20
jmieres@acciona.es, jbonilla@acciona.es

HP FUTURE-Bridge participants

1	Acciona, coordinator	6	OCV
2	Fundación Labein	7	Joint Research Centre
3	Mostostal	8	University of Ljubljana
4	Municipality of Kamnik	9	Huntsman Advanced materials
5	Van Wees	10	Mikrosam

1.4 Development of the HP FUTURE-Bridge concept

According to the secuential structure in which the FutureBridge Project is divided, the first works that needed to be adressed were the were related to set the requirements that will have to accomplish the HP FUTURE-Bridge concept, and the definition of the HP FUTURE-Bridge concept.

In view of that, it was done a revision and definition of the requirements that the HP FUTURE-Bridge must tackled: normative review, analysis of the infrastructure plans in three different European countries, the requirements from the point of view of the owner and operator of the infrastructure and the socio-economical and cultural requirements.

The revision of the requirements, and especially of the Infrastructure plans of three different countries, Slovenia, Poland and Spain, provided a valuable output for the definition of the HP FUTURE-Bridge project, referring to the most common length of the European bridges in our transport network. In addition to this, also the existing normative, the requirements of the owner, both public and private, and the socio-economical and cultural requirements have been analysed and defined.

Thus, the definition of the HP FUTURE-Bridge for a bridge length between 25 and 30 metres would allow us to cover at least 60% of the existing and under construction bridges. Moreover, if we manage to define this concept for a length up to 60 metres, we are covering almost 80% of the existing bridges, and with a length up to 80 metres, we are on a situation over the 80%.

We can see that in a beam bridge (or box-beam bridge), the usual spans vary from 5 to 40m (up to 60m); in the case of an arch bridge, the usual spans are varying from 40 to 300m.

Therefore, and taking into account these considerations, we have considered the following typologies to be further researched under the HP FUTURE-Bridge project:

- a box-beam bridge;
- an arch bridge.

Therefore, the research that has been developed on the latter works has been directed on the two directions that have been pre-defined as the HP FUTURE-Bridge project, being one of them the development of an FRP arch bridge superstructure and the second the development of a cost-effective girder bridge solution.

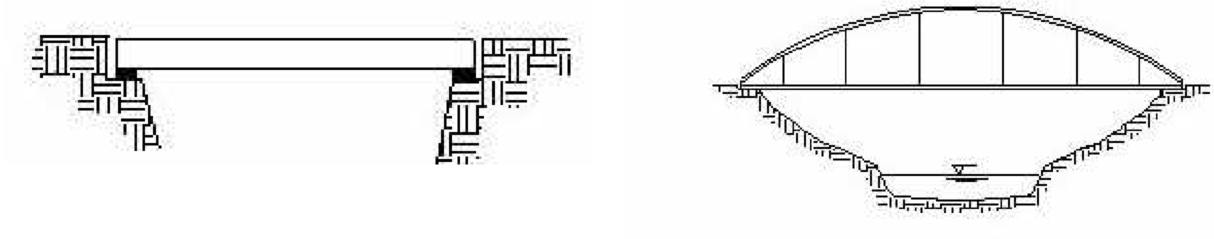


Figure 2. The two HP FUTURE.Bridge typologies. Simple scheme.

1.4.1 Arch bridge development

By using an arch to partially support the loads taken by the box beam deck, the stiffness of the box-beam elements could be considerably relaxed, thus providing a means of substantially reducing the material costs of the beam element. Conversely, an arch bridge would still require a deck, in which case a more flexible version of the original box-beam design could be used to carry the local (as opposed to primary bending loads) deck loads. Using carbon fibre cable stays, thus incorporating the concept of cable-stayed bridges into the overall bridge design, would then transmit the loads from the deck to the arch.

Therefore, the activities during the last three years were focused on design and optimization of the arch bridge in terms of geometry, support conditions and deck systems considering, at the same time, the the most suitable manufacturing process.

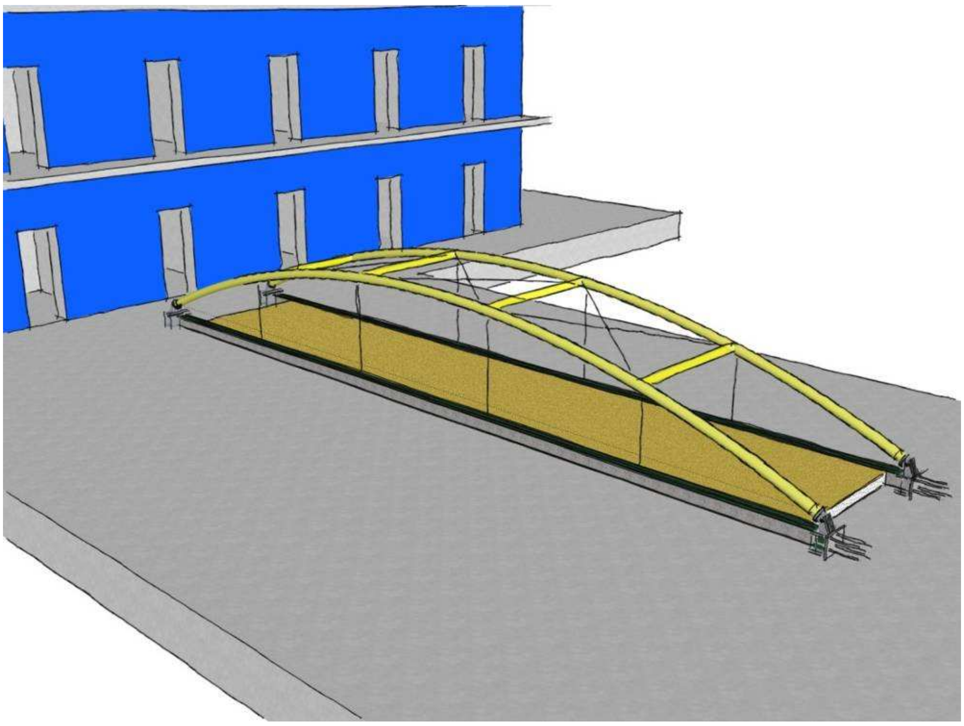


Figure 3. Arch bridge prototype

Fiber-angle lay-up and lamination strategies were defined in close collaboration of the partners involved, as well as the definition of fibre and resin material specifications. A deck system was also designed based on the use of H-section pultrusions. One of the key issues is the development of the joint sections and special erection system for which a patent has been filed.

Regarding the manufacturing processes, works have been oriented to the development of technologies for optimizing the manufacturing processes and reducing manual works. In the case of the arch bridge, the elements were manufactured using the filament winding method through the development of a new fibre delivery systems that was specially designed and developed to improve the rovings' unwounding. This new machinery allowed manufacturing the tubes of the arch minimizing the problems.

Due to the compression stresses on the arch tubes, usual joint systems were not valid to achieve the desired joint strength. Therefore, an special resin was developed ad-hoc for this purpose. Two resin thermoset and thermoplastic systems were developed having to fulfil fire and high temperature conditions apart from attack parametres like temperature, humidity, solar irradiation, accelerated degradation and alkaline immersion. Also the compatibility between thermoset and thermoplastic resins was assured.

Some tests were accomplished in order to analyze the durability of polymeric materials and optimize the composition of the materials. Several glass fibre production campaigns were launched to assess the statistical consistency and reproducibility of this sizing as well as to obtain additional long term data in both tensile strength and in-plane shear strength with various types of laminates, before this sizing can be officially launched on the market. At this point, it can be concluded that this new glass fibre development represents a significant step towards the use of glass fibre reinforced epoxy composites in bridge applications.

1.4.2 Girder bridge development

The develpopment of the HP FUTURE-Bridge girder bridge followed the same sequential methodology as for the case of the arch bridge. First of all, and according to the project requirements, a design methodology was defined based on the concept definition. The first step in the design process is to consider the actions acting on the structure. Starting from an initial geometry, the goal of the sectional design approach procedure is to determine the optimal thicknesses as well as the sequence of lamination. Three optimization processes have been followed along the project lifetime to achieve the optimum cross-section from technical performance and cost-effectiveness.

Once the beam was designed through the sectional approach, a finite element model of the same beam was implemented in a commercial software in order to optimize the model. In this tipology of bridge (girder-beam bridge) it was also maintained a close relation between the design and manufacture phases. This collaboration allowed a more efficient process of manufacturing.

Taking into account the requirements of the project, the manufacture of the beams of this typology of bridge invoved the development of a new type machinery. In this case, it has been designed and developed a new cross-ply machine and a new type of creel. The first system (cross-ply machine) consists on the development of the UD machine to make Glass/Polypropylene, Glass/ Polyphenylene and Carbon/Polyphenylene thermo-plastic laminates.

During the last year of the proyect, the efforts were focused on the development of a new type of creel. This system is a new mobile trolley with a unique design for unwinding glass roving from packages with a weight of up to 25 kilograms. The system avoid the twist introduced into the the roving hampering when UD laminates are being manufactured.

Figure 4. Glass fibre creel designed

Beyond the design process, a real scale test was performed in order to assess the technical performance and feasibility of the concept designed. Beams were manufactured at ACCIONA facilities and tested at the JRC facilities. Load bearing capacity and fulfilment of the normative requirements (e.g. max displacement) as well as evaluation of the dynamic performance were tested on the laboratory. The next figure shows the beam ready to be subjected to the load test.

Figure 5. Manufactured beam over test device

The same two resin thermoset and thermoplastic systems developed for the arch-beam bridge were used in this case for the manufacture of the beams. These systems had to fulfil fire and high temperature conditions as well as the rest of the parameters fixed in the terms of the project.

1.5 The HP FUTURE-Bridge concept assessment

During the third year of the project, two pilot girder bridges have been designed, manufactured, tested and monitored in order to assess their technical performance and feasibility with respect to the fulfilment of the project objectives. The two pilot bridges were built up in Spain. Each bridge consists of three simply supported spans whose lengths are 10 m, 14 m and 10 m, respectively.

Figure 6. . Beams on their supports

Each span of the girder deck is made up of four simply supported hybrid glass/carbon fibre composite beams transversely connected through a reinforced concrete deck. The design is consistent with the beam tested under the RTD activities and tested on real scale at the laboratory. The weigh of each bridge is 4 times lighter than the structural equivalent steel bridge and 20 times lighter than a Reinforced Concrete beam. Thus, it was possible to lift them to their precise position through the use of a simple truck-crane.

Figure 7. Beam placement

According to current legislation of all the European countries, in general terms, all bridges must be subjected to a charge-test before putting in a good condition. The aim of this test is controlling the suitable conception and the good execution of the work by means of the examination of its behaviour under the operation loads. The load test consists of carrying out, at least, one load cycle which involved placing trucks in certain positions. This tests were accomplished succesfully and the two bridges are in use at this moment.

Besides the technological developments performend under the RTD activities, and the Demonstration of these activities, it has also been developed a Life Cycle cost model to compare the HP FUTURE-Bridge solution against the classical ones. FutureBridge LCC analyzes the advantages and disadvantages of three different bridge solutions from the point of view of costs, which also includes the associated environmental costs. Once the LCC of the bridge designed (concrete, steel and FRP) has been calculated and considered, it give us information about bridge global performance costs.

As a matter of this, it has been proved the technical feasibility of the HP FUTURE-Bridge concept and it has been approached in a cost-competitive manner. However, it has been detected that whereas the design and materials areas are well covered, further research is necessary on manufacturing as the lack of industrialisation in the manufacturing processes at a cost-competitive cost results in decreasing the benefits achieved by the use of FRP against conventional materials. Increasign industrialisation will due to increase competitiveness, which in turn will result in a more competitive direct cost of the raw material due to higher demand, and by then, in an even far beyond cost-competitive concept.

1.6 Conclusions

I has been proved the technical feasibility of the HP FUTURE-Bridge concept and it has been approached in a cost-competitive manner. However, the consortium has detected that whereas the design and materials areas are well covered, further research is necessary on manufacturing as the lack of industrialisation in the manufacturing processes at a cost-competitive cost results in decreasing the benefits achieved by the use of FRP against conventional materials

The HP Future-Bridge project supposes an impulse to the development of the composite materials in the frame of civil engineering. As far as all the requirements raised by the project have been enterely fulfilled it can be affirmed that project has been developed succesfully.

Besides the competitive advantages providing by composite materials compared to traditional materials in economic and environmental terms make them a discipline whose future is increasingly bright.

2. Dissemination and use

A patent has been submitted to the European Patent Office as a result of the technological developments within the project. Besides new opportunities have been opened for FRP bridges in Spain and Poland (based country of the two construction companies involved in the project). Also, new business relations are being established between the partners dealing with materials development and supply (OCV and Huntsman), manufacturing processes experts and machinery manufacturers (Mikrosam and VanWees) and contractors (Acciona and Mostostal).

The website for the HP FUTURE-Bridge project was created, with public access to it and it is obviously a publishable result for the project. The website address changed during the second year of the project and it is currently: http://www.gestionidi.com/futurebridge. The website has been maintained updated.

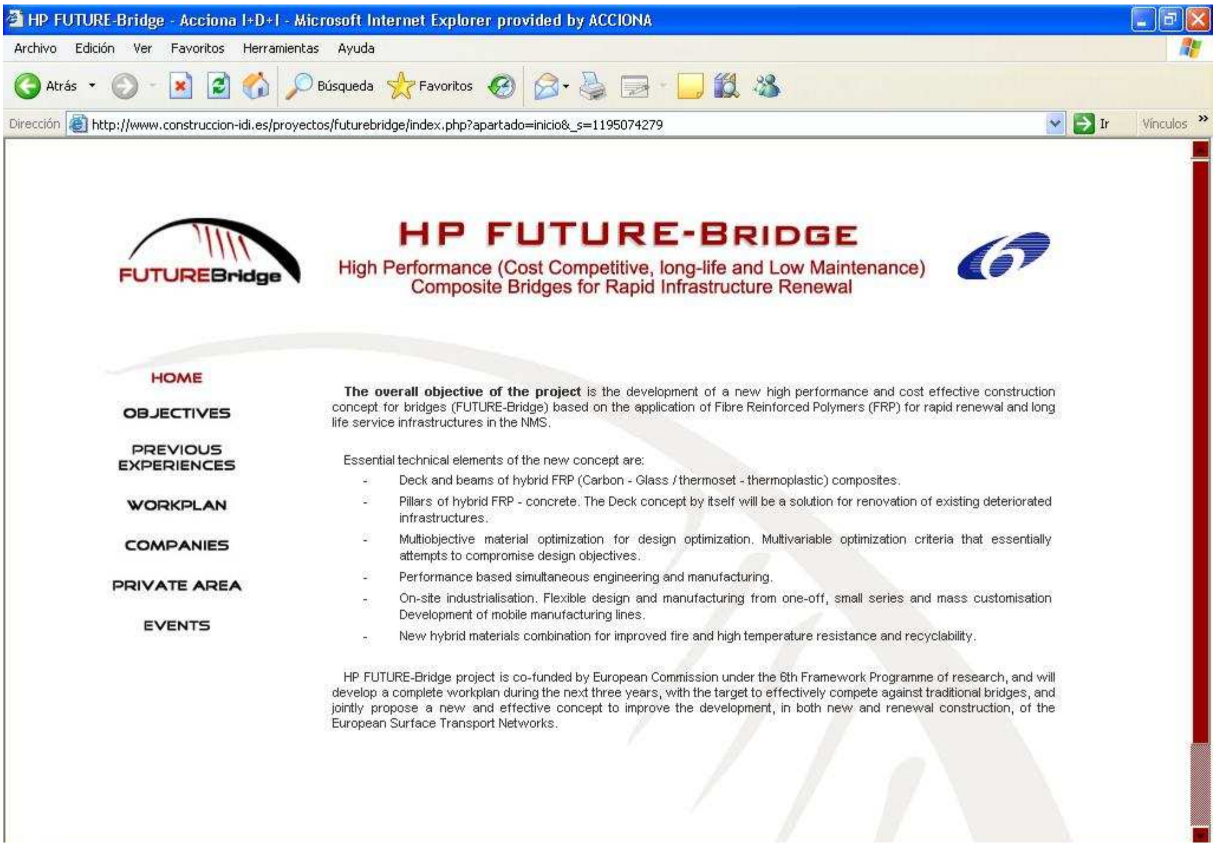
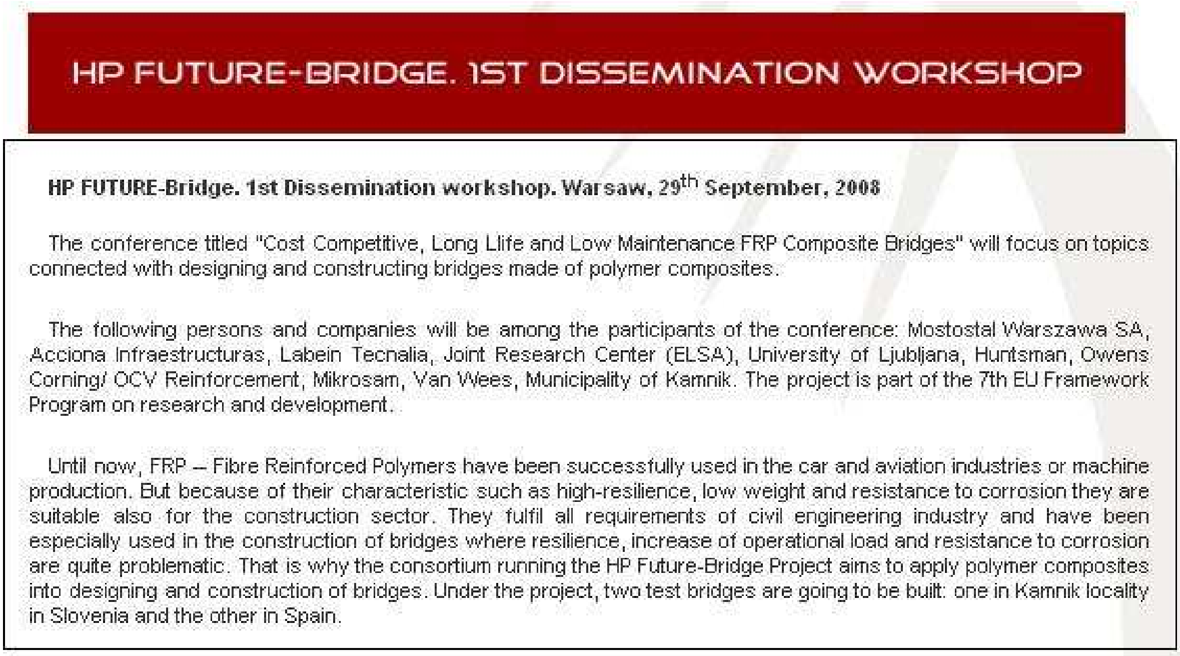


Figure 8. HP FUTURE-Bridge website

The website is divided into the following sections:

- Objectives.
- Previous experiences.
- Work plan.
- Companies.
- Private area.
- Events.

Main events are announced on the website; for example, the 1st dissemination workshop which was held in Warsaw in September 2008.



HP FUTURE-BRIDGE. 1ST DISSEMINATION WORKSHOP

HP FUTURE-Bridge. 1st Dissemination workshop. Warsaw, 29th September, 2008

The conference titled "Cost Competitive, Long Llife and Low Maintenance FRP Composite Bridges" will focus on topics connected with designing and constructing bridges made of polymer composites.

The following persons and companies will be among the participants of the conference: Mostostal Warszawa SA, Acciona Infraestructuras, Labein Tecnalia, Joint Research Center (ELSA), University of Ljubljana, Huntsman, Owens Corning/ OCV Reinforcement, Mikrosam, Van Wees, Municipality of Kamnik. The project is part of the 7th EU Framework Program on research and development.

Until now, FRP – Fibre Reinforced Polymers have been successfully used in the car and aviation industries or machine production. But because of their characteristic such as high-resilience, low weight and resistance to corrosion they are suitable also for the construction sector. They fulfil all requirements of civil engineering industry and have been especially used in the construction of bridges where resilience, increase of operational load and resistance to corrosion are quite problematic. That is why the consortium running the HP Future-Bridge Project aims to apply polymer composites into designing and construction of bridges. Under the project, two test bridges are going to be built: one in Kamnik locality in Slovenia and the other in Spain.

Figure 9. Futurebridge workshop on the website

With respect to dissemination, many actions have been undertaken within the project lifetime and beyond. The first of them took place even before the project had officially started, when the project was "unofficially" presented at the TRA2006 conference that was held in June 2006. This action, performed by Acciona, was done at Acciona's own cost, which shows that the coordinator, and the project consortium as a whole, are fully aware and committed to the dissemination of the project. Since then, different congresses and related events have been attended by the project partners in order to raise awareness of the project development, such as FRPRCS-9 congress, one of the best-known and recognized FRP symposiums in the world, attracting a large audience covering different stakeholders (academy, industry, scientific community, etc). The publication of the full paper attracted a number of enquiries with respect to the futurebridge project and results.

The Municipality of Kamnik did its best to actively promote the HP FUTURE-Bridge project locally and regionally as well as on national level. The Mayor of The Municipality of Kamnik mr. Smolnikar, held a few press conferences where among other things the HP FUTURE-Bridge project was presented. Furthermore the Municipality made a lot of efforts to publish a dozen of articles mentioning the project in different newspapers and other written publications, also on the internet. Articles were published in national newspapers Delo (around 60.000 editions) and Dnevnik (around 50.000 editions) as well as on the local level in the official publication of Municipality of Kamnik called »Kamniške novice« (Kamnik's News) with around 27.500 editions. The project was also mentioned on the municipality's website.

Other important dissemination action has been the celebration of the 1st HP FUTURE-Bridge dissemination workshop which was held in Warsaw in September 2008 organised by Mostostal. 56 people external to the consortium attended the workshop including representatives from the industry, administration, research and educational community and also students

Figure 10. HP FUTURE-Bridge workshop announcement

LIST OF FIGURES