Report technical and scientific activities
2003-2006

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isise
Institute for Sustainability and
Innovation in Structural Engineering

Report technical and scientific activities

2003 2006

FCTUC FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE DE COIMBRA

Universidade do Minho
Escola de Engenharia






ISISE – Institute for sustainability and innovation in structural engineering

 Prof. Paulo Lourenço  Prof. Luís Simões da Silva

ISISE is a newly formed Unit involving the Structural Divisions from the Civil Engineering Departments in Universities of Coimbra and Minho. Additional members from Universities of Beira Interior, Polytechnic Institutes in Bragança, Castelo Branco, Coimbra, Guarda, Leiria and Viseu, and University Fernando Pessoa (private) create a truly national network.

The Unit aims at creating a leading cluster in Structural Engineering, with capacity for top quality R&D+I and future attraction of other highly active researchers. The hosting institutions have available recent and complementary laboratory facilities, with a total area of around 3000 m^2 and over 1M€ equipment funding. The Unit is based on two strong leaderships in Universities of Coimbra and Minho, with a common past attitude of proven record towards: internationalization, contracted research, cooperation with industry, top level dissemination in the international arena, PhD students and postdoctoral collaborators. Therefore, outstanding fundamental and applied research is the driving force for ISISE.

The main objective of the Unit is to increase the structural performance of Civil Engineering Works, from a perspective of advanced technology, innovation and a knowledge based economy, with an approach that links Materials to Life Cycle Performance. This includes aspects such as advances in experimental and numerical techniques, product development and technology transfer to the industry, durability and reliability, recycle, reuse, conservation and strengthening, and condition assessment. These aims of ISISE are aligned with international trends, namely with Vision 2030 from the European Construction Technology Platform, focusing in 7 out of the 9 priorities identified, and from the Construction part of the European Steel Technology Platform. In short, ISISE aims at promoting innovation and sustainability, with a link to the construction sector industry.

The Unit is organized in 3 Research Groups, related to Historical and masonry, Steel and mixed, and Concrete construction technologies. The most relevant aims in the fields of Innovation and Sustainability include: (a) characterization of building materials, using carefully, deformation controlled, experiments in concrete, FRP, timber, steel and masonry; (b) constitutive and structural modelling, associated with the development and use of nonlinear constitutive models, and its validation via experimental tests; (c) characterization of structural behaviour, via testing of structures and structural elements and improvement of experimental and assessment techniques; (d) inspection, assessment and monitoring of structures, motivated by new construction processes and materials, and the need to keep existing structures in use; (e) safety evaluation of structures, concerning design of strengthened structures, safety during the building phase, evaluation of behaviour in service and extreme events; (f) development of an integrated life-time structural approach to meet all six Essential Requirements of the CPD (Construction Products Directive). Specific individual Research Group aims include: (a) integrated conservation of Cultural Heritage Buildings; (b) increasing re-use of structural timber and masonry; (c) novel developments in concrete (fibre reinforced, high performance, self compacting, lightweight); (d) increasing use of steel and mixed construction technologies; (e) development of innovative structural systems and strengthening techniques.

ISISE is well equipped, including state-of-the-art non-destructive testing equipment such as radar, sonic testing, drilling resistance measuring system, dynamic identification, resistograph, boroscopic camera, etc., and servo-controlled actuators and modern data acquisition systems, being of particular relevance a loading frame of 500 ton, a biaxial testing machine with 1 m^2 and 200 ton capacity, and a fire laboratory for large scale testing. The laboratories include reaction slabs, reaction walls and several cranes. In addition, advanced software for sophisticated non-linear analysis, both commercial and in-house developed, are available.

After a swift growth, stabilization is in progress: (a) the doctoral studies of the staff members is to be completed in the next triennium; (b) the total number of PhD students reached a constant value of 40; (c) a recent shift from PhD students to Post-Doctoral collaborators is observed. The group is rather internationally oriented, with significant involvement in European projects, journals, committees, joint publications with foreign researchers, and exchange of doctoral students for traineeships. A high record of publications in major international journals has been achieved, together with the regular organization of scientific meetings and seminars.

In the period 2003-2006, publications in international journals with high impact factors include for example Journal of Composites for Construction (ASCE), Journal Structural Engineering (ASCE), Fire Safety Journal, International Journal of Solids and Structures, Computers and Structures, Journal of Constructional Steel Research, ACI Structural Journal, Cement & Concrete Composites, International Journal of Adhesion & Adhesives, Engineering Computations, Building and Environment, Engineering Structures, Earthquake Engineering and Structural Dynamics, among many others, in a total of 90 papers in journals listed in ISI. In the same period, 14 PhD theses have been completed in ISISE.

In addition, three prizes have been recently awarded: Munro Prize from Elsevier for the article "Modeling and vulnerability of historical city centers in seismic areas: a case study in Lisbon", *Engineering Structures*, Ramos, L.F. and Lourenço, P.B. (2004); Thomas Fitch Rowland Award from the American Society of Civil Engineers for the article "Innovative and Contemporary Porto Bridges", *Practice Periodical on Structural Design and Construction*, Cruz, P.J.S. (2004); Young Researcher Award from the Portuguese Association for Theoretical, Applied and Computational Mechanics, Lourenço, P.B. (2003).

Members

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Eduarda Luso
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Luís Ramos
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Paulo Candeias
Pedro Santos
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Rafael Aguilar
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Ricardo Delgado Brites
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Martin Pircher
Senthivel Ramakrishnan

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Projects and Network Actions

CUTINEMO - Carbon fiber laminates applied according to the near surface mounted technique to increase the flexural resistance to negative moments of continuous reinforced concrete structures (PTDC/ECM/73099/2006)

Financing Institution(s): Portuguese Science and Technology Foundation (FCT)

Promoting Institution(s): University of Minho

Coordinator(s): Joaquim Barros

Researchers and collaborators: J. Barros; J. Sena-Cruz; S. Dias; G. Dalfré

Partner Institutions: Not applicable

Period: January 2008 to December 2009

Relevant facilities: FEMIX open source software; Servo close-loop equipments for experimental programs; Universal testing machine.

Objectives:

Develop of a document based on experimental, analytical and numerical research that includes the necessary information to design a strengthening system based on the use of CFRP laminates, applied according to the NSM technique, for the increase of the resistant negative bending moment of continuous RC slabs and beams, taking into account the desired level of moment redistribution capacity, the characteristics of the existent reinforcement arrangement and the properties of the concrete. The formation of two scientists, one in the experimental research domain and the other in the analytical and computational mechanical domains are also important objectives. Technology transfer I&D-industry is also another objective. For this purpose a company will participate in the strengthening procedures of the RC structures to strength. The results obtained from this research will be available for eventual use in the ambit of the guidelines developed by *fib* TG 9.3.

Main achievements:

Near-Surface Mounted (NSM) is one of the most promising strengthening techniques, based on the use of carbon fiber-reinforced polymer (CFRP) laminates. According to NSM, the laminates are fixed with epoxy based adhesive into slits opened into the concrete cover on the tension face of the elements to be strengthened. Due to the characteristics of the application of this strengthening technique, it is specially adjusted to increase the negative bending moments of continuous RC beams and slabs. However, the linear-elastic behaviour of these laminates up to its brittle failure puts some concerning about the moment redistribution capacity these strengthening systems allow, which is intimately related to the level of ductility of the behaviour of the strengthened structure. Furthermore, the carbonation level of the concrete cover of the structure to be strengthened should be also taken into account in the design of the strengthening system, since it would limit the maximum strain that can be applied to the laminates. The spacing between laminates is also another parameter that can influence the strengthening efficacy, due to the detrimental interference between consecutive laminate, which leads to the rupture of the concrete surrounding the laminates. The thickness of the adhesive wall and even its properties are investigated in terms of the strengthening efficacy that NSM can provide, since the bond stresses at laminate-adhesive-concrete zone are also dependent on the adhesive properties.

The possibility of using cement based adhesives of enhanced resistance to fire is also explored in this project, since it can brings significant benefits in terms of protecting the laminates against the effect of high temperatures.

The reinforcement ratio of the existent tensile longitudinal steel bars has also an important role in terms of the efficacy that NSM can provide. The relative position between existent tensile longitudinal steel bars and laminates is another parameter, whose influence in terms of NSM strengthening efficacy is investigated, since the interaction between existent steel bars and laminates can be detrimental. The increment of the resistant negative bending moment that certain CFRP strengthening system can assure might be limited by the shear resistance of the structure. Introducing round cross section CFRP bars in the critical shear failure zones of the slab (see Fig. 1) can avoid this limitation, which is explored in this project.

In the present project the influence of the aforementioned parameters of the efficacy of the NSM for the flexural strengthening of continuous RC beams and slabs to the negative bending moments is assessed. The level of moment redistribution that NSM can assure is also investigated to establish design guidelines that define the maximum moment redistribution index that a given strengthening configuration can provide. To fit this purpose, the project in composed by an experimental program, whose results are used to calibrate the analytical and numerical models to be developed for the design of the strengthening systems and to analyze the behaviour of RC structures strengthened according to the NSM technique.

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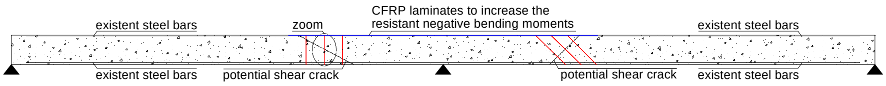
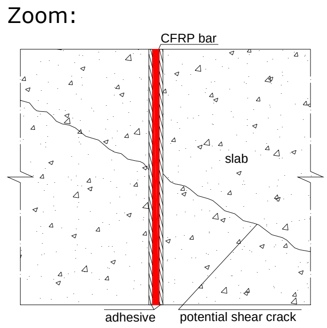
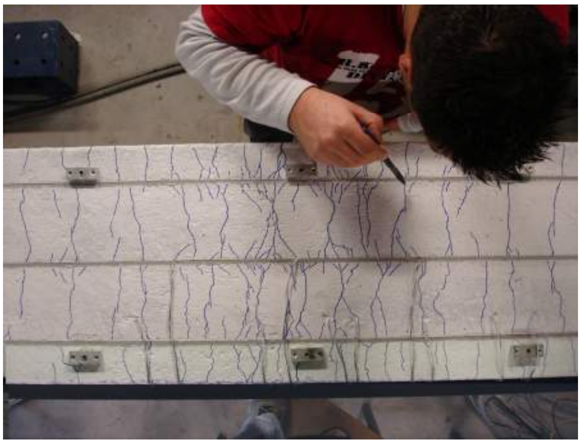


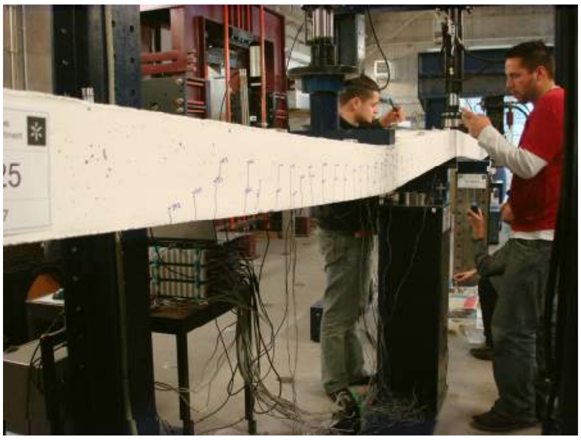


a) b)

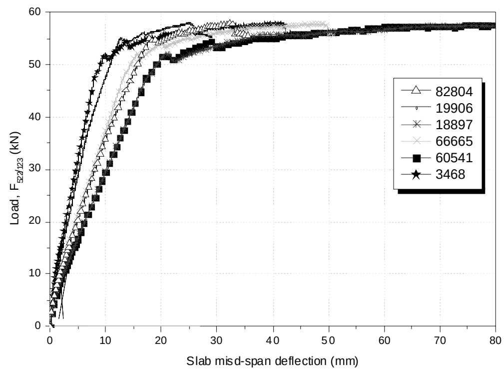
Fig. 1 – a) NSM strengthening technique for two way slab/beam RC elements; b) if necessary, CFRP bars will be used to avoid shear failure.

Preliminary tests:

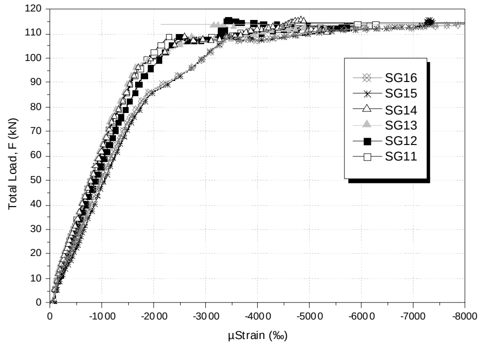




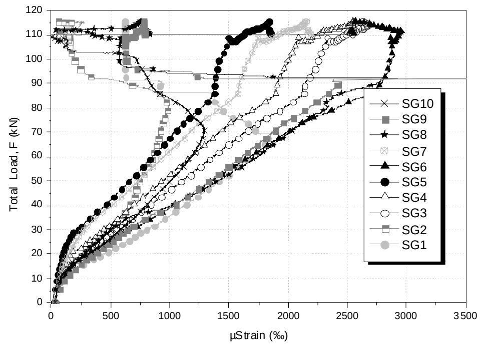
Slab SL15S25



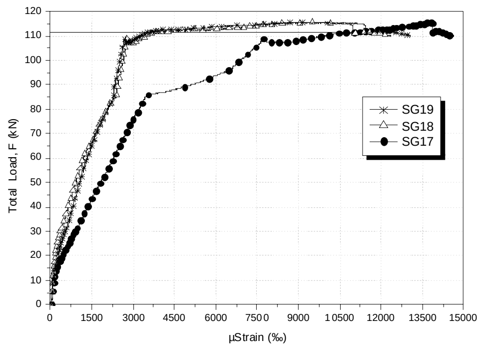
Strains in concrete



Strains in steel reinforcement



Strains in CFRP



SMARTREINFORCEMENT – Carbon fibre laminates for the strengthening and monitoring of reinforced concrete structures
(Project nº 13-05-04-FDR-00031, contract reference ADI/2007/V4.1/0052)

Financing Institution(s): POCI 2010 – IDEIA

Promoting Institution(s): FiberSensing

Coordinator(s): Francisco Araújo (FiberSensing) & Joaquim Barros (UM)

Researchers and collaborators: J. Barros; Sena-Cruz; Alexandre Gomes; Inês Costa; Camilo Basto; Luís Macedo; Vincenzo Bianco; Francisco Araújo; Nuno Costa; Luís Ferreira

Partner Institutions: University of Minho

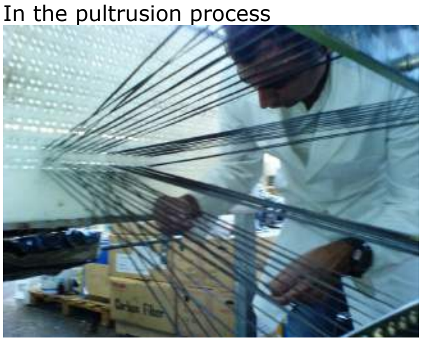
Period: July 2007 to June 2008

Relevant facilities: Pultrusion equipment; Equipment for the production of optical fiber sensors; Equipment to record the signal of optical fiber sensors; Universal testing machine; Servo close-loop equipments; FEMIX open source software.

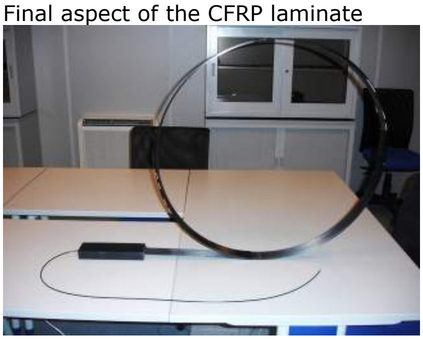
Objectives:
Manufacture carbon fibre laminates that includes optical fiber sensors; characterize the early and long term behaviour of these laminates, under distinct ageing conditions; evaluate the bond conditions of these laminates to the concrete substrate, when applied according to the NSM strengthening technique; assess the performance of these laminates when applied for the flexural and shear strengthening; implement into the FEMIX computer program the necessary routines to simulate the constructive phases of the strengthening process; develop design guidelines for the shear and flexural strengthening of RC structures using this type of laminates.

Main achievements:

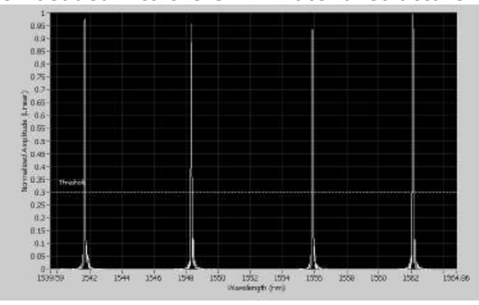
Production of the CFRP laminates including the optical fiber sensors:
In the pultrusion process



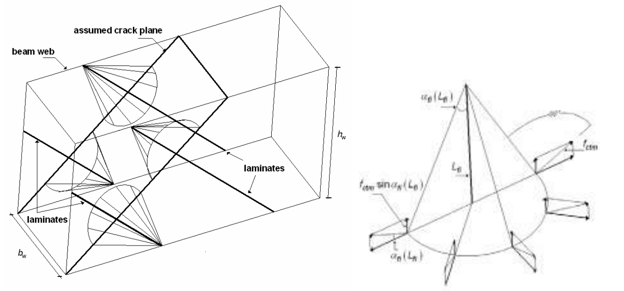
Final aspect of the CFRP laminate



Appraising the signals of the optical fiber sensors embedded into the CFRP material structure:



Analytical Research: A new approach for modeling the NSM shear strengthening contribution in reinforced concrete beams



(a) (b)

Fig. 1 – Main features of the proposed model: (a) crack plane crossed by laminates and their semi-conical fracture surfaces; (b) detail of the semi-conical surface and the distribution of the average tensile strength.

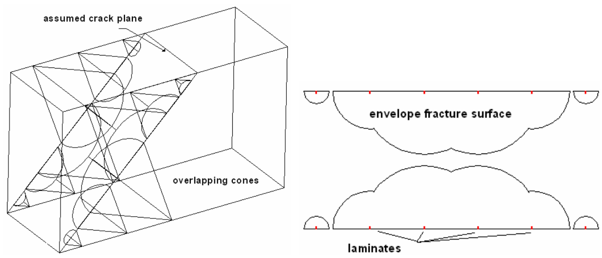


Fig. 2 – Interaction between laminates: (a) semi-conical surfaces overlapping; (b) section parallel to the crack plane.

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Cold Form: construction of industrial portal frames

Financing Institution(s): ADI (Agência de Inovação)

Promoting Institution(s): Vesam Cold-Form

Coordinator(s): Luis Simões da Silva

Researchers and collaborators: Filipe Santos, Hugo Alves

Partner Institutions: Faculty of Science and Technology from University of Coimbra (FCTUC)

Period: September 2004 to August 2006

Relevant facilities: Jack compression 100ton load; Additional data acquisition and control equipment; Lusas Software; Rcad and Robot Software

Objectives:

In a time where the price of the steel is increasing, it is logical to search for alternative solutions. In the context of industrial frames with inclined rafter, the solutions with cold-formed profiles show competitive advantages for spans up to 30 m.

For creating a final solution that can go to the market we develop a project with various phases. Including economical study, business plan, structural analyses, design and detailing of connections.

Main achievements:

The proposed solution presents best ratio weight / resistance; greater ease in the assembly, a scheme anti-corrosive protection more economic and more efficiency in the transport, than conventional metal structures.

Analyzing the technology proposal concluded that can be a substitute for reinforced concrete and metal structure conventional.

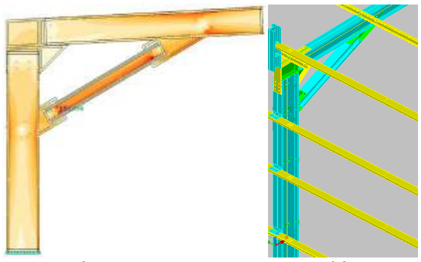
The most important phases of the study are:

- A methodology of comparison of the solutions in cold formed (CF) and hot rolled (HR) was developed in order, to evaluate the advantage of a solution in relation to the other for various spans.;
- Development of a business plan, which was done a external environment, a segment environment, attractiveness of the sector, study market, a prospection market with various visits of companies that develop equivalent products.;
- One of the benefits of cold form is the cross section optimization. Therefore was need to create a software tool to calculate the effective properties of the cross section, as well as the elements resistance according EC3.-,
- The analysis and detail of all connections is very important to describe correctly the behavior of the portal frame. Tests were conducted to calibrate the numerical models.;
-

The solution at this time is in the market with some projects to erect.

Fig 1 - Examples of a portal frame made with cold form.

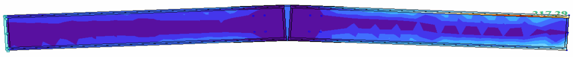
Fig 2 – A compression test with two C profiles gathered by the web in a discontinuous way.



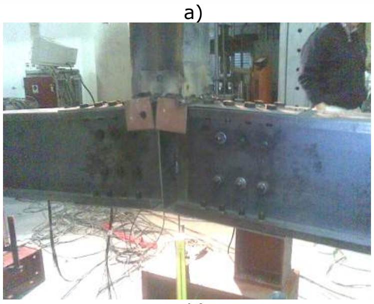
a) b)

c)

Fig 3 – Numerical, detailing and experimental test of the connection column-rafter.



a)



b)

Fig 4 – Numerical and experimental test of the connection rafter-rafter.

Fig 5 – Experimental test of the connection column-foundation.

Fig 6 – New facilities of Vesam Cold-Form.

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Computational strategies for the protection of historical churches (SAPIENS 33935-99)

Financing Institution(s): Supported by the Portuguese Science Foundation

Promoting Institution(s): University of Minho

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Daniel Oliveira; Agustin Orduña

Partner Institutions: Universidade Técnica de Lisboa
Universidade Nova de Lisboa

Period: December 2000 to March 2004

Objectives:

The Umbria-Marche earthquake of September-October 1997, Italy, and the Puebla earthquake of June 1999, Mexico, of relatively small magnitude, provoked the partial collapse of the Basilica of Assisi and several other churches. These losses are not quantifiable in economic terms, as neither lives or cultural heritage can be reinstated by post-earthquake reconstruction plans. In order to prevent such losses in future, the main objectives of the project were:

1. study of seismic vulnerability of Portuguese churches;
2. understanding the compressive failure of masonry under short term and creep loading;
3. development of a limit analysis software for numerical simulations;
4. advanced simulations of case studies.

Main achievements:

The relatively high seismic vulnerability of historical churches can be linked to two main peculiarities of this family of structures: (a) the intrinsic greater structural vulnerability due to open plan, greater height to width ratio and often the presence of thrusting horizontal structures, and (b) the smaller tolerance to cracking if the supported decoration and art work is not to be damaged. This implies a better understanding and enhancement of their inherent earthquake-resistant characteristics, rather than replacement by or addition of separate independent new structural systems inserted within them.

With respect to the seismic vulnerability of Portuguese Churches, three different simplified safety indexes (in-plan area ratio, area to weight ratio and base shear ratio) have been analyzed, taking into account a large sample of fifty-eight Portuguese churches, see Fig. 1. The sample of building has been organized according to the seismic zonation, from high to low seismicity. The results indicate that valuable information can be obtained from simplified methods, with respect to performing a first screening and to prioritizing deeper investigations, see e.g. Fig. 2. A proposal for the usage of simplified methods was made, taking into consideration the in plan area of the building, its height and seismicity, with the simultaneous verification of two indexes, one related to ratio of in plan area and weight, and another related to the maximum base shear force. Ten churches (17%) of the sample require further attention.

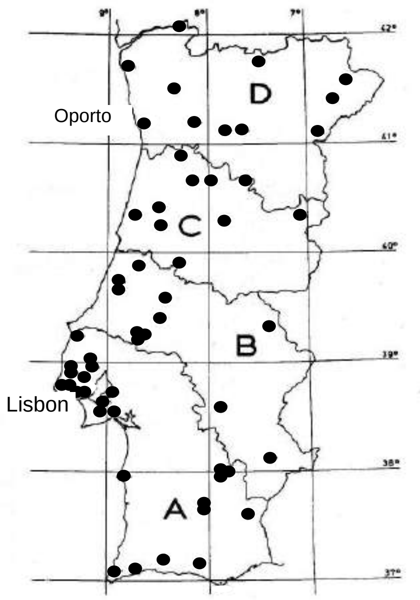


Fig. 1 – Seismic zonation of Portugal and location of the churches (zone A is high seismicity and zone D is low seismicity).

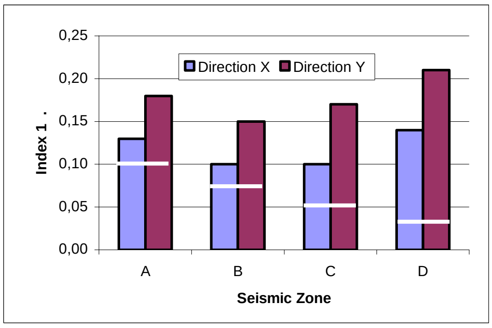
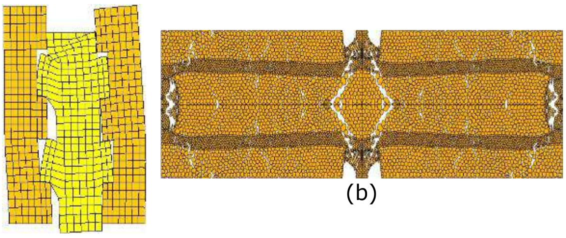


Fig. 2 – Typical example of an average index for the complete sample and thresholds proposed (white line).

The recent collapse of famous historical constructions attributed mainly to the time-dependent behaviour of masonry has driven the attention of the technical community over this issue. Numerical analyses in which parts, units and mortar are individually represented have proven to be of great interest to understand the failure mechanisms. The present project allowed to demonstrate the possibility of discontinuum models and discrete particle models to represent masonry failure, see Fig. 3. In addition, novel experimental results on the creep behaviour of regular ancient masonry including both short-term and long-term creep tests were obtained, see Fig. 4.



(a) (b)

Fig. 3 – FEM simulations of the collapse of masonry: (a) multi-leaf wall; (b) masonry prism.

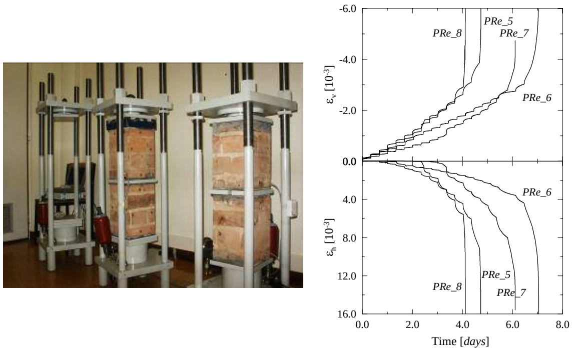
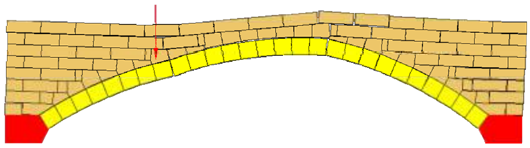


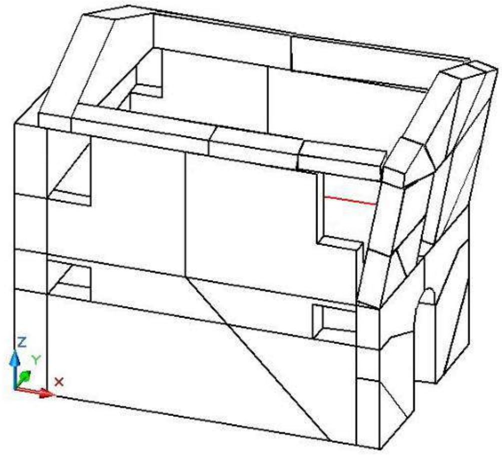
Fig. 4 – Creep tests on specimens recovered from the ruins of the belfry of the Pavia Civic Tower.

The present project allowed to propose formulation of limit analysis for materials with non-associated flow rules, in order to represent the non-dilatant friction failure mode in masonry. Two computer tools were developed for two- and three-dimensional models, respectively. The yield functions proposed are capable to take into account limited compressive stresses. A tie element is added to the formulations in order to model common strengthening techniques. The torsion failure mode on frictional joints appearing in the three-dimensional model had not been extensively studied in the past and theoretical contributions to the subject, including the interactions between torsion strength and the other generalised stresses on rectangular joints are made. The proposal of a novel solution procedure allows the user to follow approximately the structure's behaviour through the loading history until failure. The same procedure is able to obtain better solutions for those cases where previously proposed procedures underestimate the safety factor. The developed computer programmes were used to investigate the behaviour of ancient masonry structures, see Fig. 5.

Finally, the knowledge and numerical tools were applied to emblematic case studies in Portugal, see Fig. 6. This allowed the full demonstration of the possibilities of advanced experimental research and numerical techniques.

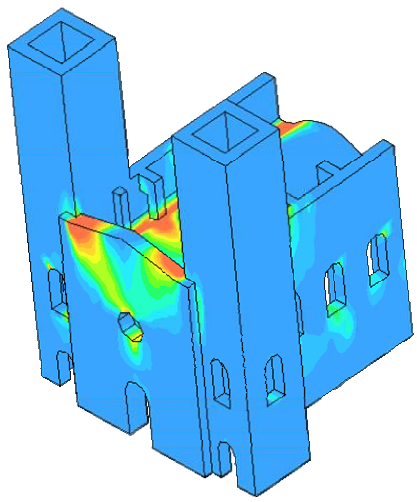


(a)

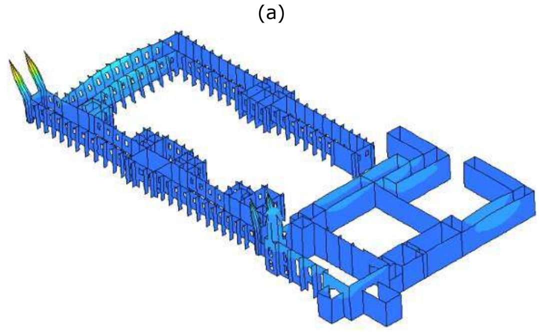


(b)

Fig. 5 – Newly developed software for limit analysis of blocky structures: (a) masonry bridge; (b) full building and macro-blocks.



(a)



(b)

Fig. 6 – Applications to emblematic case studies: (a) S. Torcato church; Monastery of Jerónimos, Lisbon.

Relevant Publications:

Chapters of Books

Lourenço, P.B., Pina-Henriques, J., Chapter 3 – Collapse prediction and creep effects, em: Learning from Failure: Long-term Behaviour of Heavy Masonry Structures, Eds. L. Binda, WIT Press, p. 57-80 (2007).

International Journals

Lourenço, P.B., Pina-Henriques, J.L., Masonry micro-modelling: a continuum approach in compression, Computers & Structures, 84(29-30), 1977-1989 (2006).

Pina-Henriques, J.L., Lourenço, P.B., Masonry compression: a numerical investigation at the meso-level, Engineering Computations, 23(4), p. 382-407 (2006).

Binda, L., Pina-Henriques, J.L., Anzani, A., Fontana, A., Lourenço, P.B., Understanding load-transfer mechanisms in multi-leaf masonry walls, Engineering Structures, 28 (8), p. 1132-1148 (2006).

Lourenço, P.B., Roque, J.A., Simplified indexes for the seismic vulnerability of ancient masonry buildings, Construction and Building Materials, 20(4), p. 200-208 (2006).

Orduña, A., Lourenço, P.B., Three-dimensional limit analysis of rigid blocks assemblages. Part I: Torsion failure on frictional joints and limit analysis formulation, Int. J. Solids and Structures, 42(18-19), p. 5140-5160 (2005).

Orduña, A., Lourenço, P.B., Three-dimensional limit analysis of rigid blocks assemblages. Part II: Load-path following solution procedure and validation, Int. J. Solids and Structures, 42(18-19), p. 5161-5180 (2005).

Orduña, A., Lourenço, P.B., Cap model for limit analysis and strengthening of masonry structures, J. Struct. Engrg., ASCE, 129(10), p. 1367-1375 (2003).

Thesis

Masonry under compression: Failure analysis and long-term effects, José Luís Pina Henriques, PhD Thesis (2005)

Strengthening and rehabilitation of ancient masonry walls, João Carlos Almendra Roque, MSc Thesis (2002).

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PABERPRO - Conception and implementation of a system for the production of lightweight panels of steel fibre reinforced self-compacting concrete

(Project nº 13-05-04-FDR-00007, contract reference ADI/2007/V4.1/0049)

Financing Institution(s): POCI 2010 – IDEIA

Promoting Institution(s): Pregaia, Civitest

Coordinator(s): Joaquim Barros

Researchers and collaborators: Rajendra Varma, João Paulo Dias, Delfina Gonçalves, Ventura Gouveia, Vítor Cunha, Eduardo Pereira, J. Sena-Cruz, Álvaro Azevedo

Partner Institutions: University of Minho

Period: July 2006 to June 2008

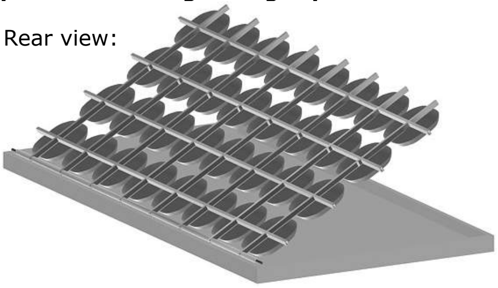
Relevant facilities: Equipment to produce and characterize SFRSCC; FEMIX open source software.

Objectives:
Develop a system for industrialized production of lightweight panels of steel fibre reinforced self-compacting concrete (SFRSCC); characterize the durability properties of the developed SFRSCC; develop a user friend software for the design of SFRSCC panels submitted to the load combinations according to the most recent code recommendations. Develop guidelines for the design of SFRSCC panels for building façades.

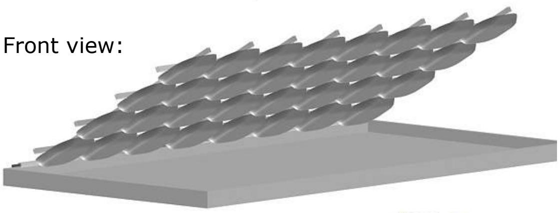
Main achievements:

Design of the system for industrialized production of lightweight panels of SFRSCC:

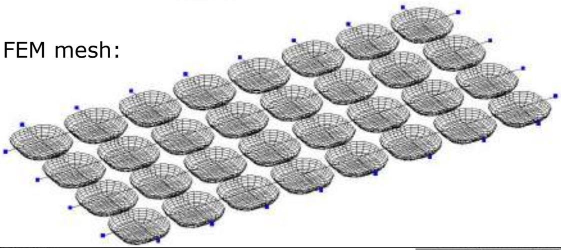
Rear view:



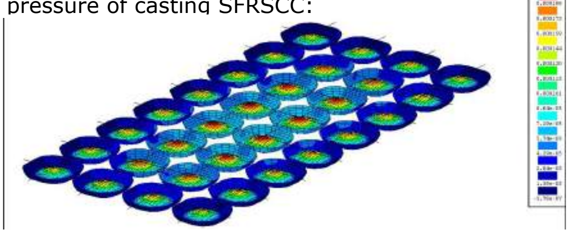
Front view:



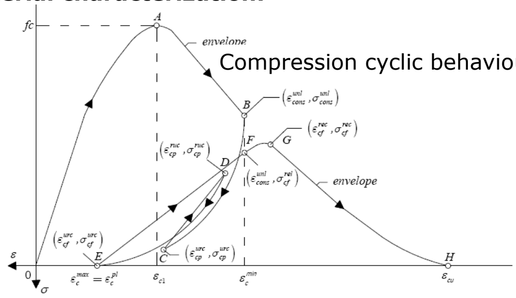
FEM mesh:



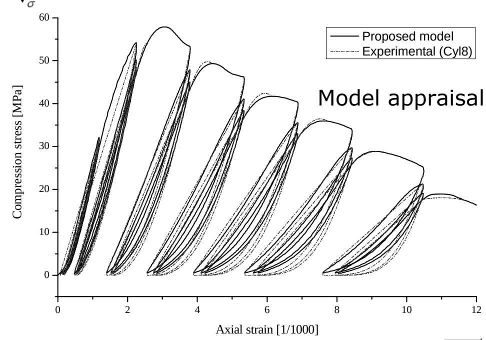
Vertical displacement field due to the pressure of casting SFRSCC:



Material characterization:

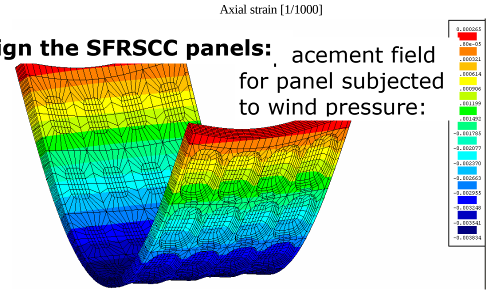


Compression cyclic behaviour:



Model appraisal:

Design the SFRSCC panels: acement field for panel subjected to wind pressure:



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Cost competitive steel fibre reinforced concrete for industrial pavements (POCTI/ECM/34793/2000)

Financing Institution(s): Portuguese Science and Technology Foundation (FCT) - POCTI

Promoting Institution(s): University of Minho

Coordinator(s): Joaquim Barros

Researchers and collaborators: Joaquim Barros; Vítor Cunha, Alberto Ribeiro, Joaquim Antunes, José Amorim, Henrique Fernandes, Ventura Gouveia

Partner Institutions: Pisonort

Period: September 2000 to September 2003

Relevant facilities: FEMIX V3.0 Finite Element package; Servo close-loop equipments for experimental programs.

Objectives:

1. Develop a cost competitive steel fiber reinforced concrete (SFRC) for industrial pavement applications;
2. Characterize the concrete and the bending behavior of SFRC by experimental tests;
3. Cost analysis of traditional and SFRC solutions;
4. Assess the structural behavior by tests in real scale;
5. Develop numerical models to analyze SFRC industrial pavements and setup design guidelines for this application.

Main achievements:

1ST AND 2ND OBJECTIVES

An SFRC was designed abiding by the following conditions: average compressive strength greater than 25 MPa at 28 days; binder content (cement + fly ash) equal to 300 kg/m^3; slump greater than 150 mm; and use of local and untreated aggregates. The strength and the workability requirements were adjusted for an SFRC that could be used in several structural applications, such as partial replacement of conventional reinforcement by steel fibres and slabs on grade. Two types of hooked ends DRAMIX® steel fibres were used: RC 80/60 BN (designated in this work by *F80/60*) with a length (l_f) of 60 mm, a diameter (d_f) of 0.75 mm and an aspect ratio (l_f / d_f) of 80; RC 65/60 BN (designated in this work by *F65/60*) with l_f = 60 mm, d_f = 0.92 mm and l_f / d_f = 65. Both fibres have a yield stress of about 1100 MPa. The compositions are included on Table 1. With the aim of obtaining similar compressive strength and mix workability in all compositions, the water/binding (w/b) ratio was decreased with the increase of fly ash. Table 2 reveals that this purpose was practically attained. The influence of the fly ash was only appreciable in specimens with 7 days. The manufacturing and the curing procedures of the specimens were the ones recommended by RILEM TC 162-TDF.

Table 1 – Compositions.

Component		Content [kg/m^3]		
Cement I 42.5R		300.0	262.5	225.0
Fly Ash *(% of cement)*		0.0 *(0.0)*	37.5 *(12.5)*	75.0 *(25.0)*
Fine sand		173.5	165.5	152.3
Crushed sand		871.0	875.5	869.1
5/15 coarse aggregate		315.7	319.1	319.1
15/25 coarse aggregate		468.2	470.6	467.0
Water		163.8	158.8	153.8
Superplasticizer (Rheobuild® 1000)		7.5		
Steel fibres (% in *volume*)	80/60	0 *(0)*; 10 *(0.12)*; 20 *(0.25)*; 30 *(0.38)*		
	65/60	15 *(0.19)*; 25 *(0.32)*; 35 *(0.45)*; 45 *(0.57)*		

For the second objective, 250 compression tests under displacement control were carried out, as well as, 250 three point bending notched beam tests according to RILEM TC 162-TDF recommendations. The influence of the CCSFRC age, type and content of fibers (C_f), number of effective fibers in the fracture surface (N_f) and the percentage of cement replaced by fly ash were investigated in terms of the flexural and compression behavior, mainly for the post-cracking behavior. The equivalent and the residual flexural parameters determined from the force-deflection relationship of the flexural tests were used to calibrate the analytical formulation for the design of SFRC developed under the framework of the TC 162-TDF.

Table 2 - Compression strength.

Age [days]	Fly-ash [%]	f_{cm} [MPa]
7	0.0	37.0
	12.5	30.1
	25.0	26.5
28	0.0	39.7
	12.5	39.3
	25.0	34.8
90	0.0	47.2
	12.5	46.6
	25.0	45.5

Fiber distribution on the fracture surface

To evaluate the degree of the fiber segregation, the specimen's fracture surface was discretized in four rows and five columns of cells, as it is represented in Figure 1. The average number of fibers counted (visible on the fracture surface) is represented in Figure 2, where an increase of the fiber percentage in the casting direction was observed. This fiber segregation was more pronounced on specimens reinforced with fibers 80/60, and has promoted the development of non-uniform crack opening, as it is shown in Figure 6. Due to the lower percentage of fibers on the top surface in the casting direction, the crack in this surface developed more quickly than on the bottom surface. Therefore, for SFRC of high workability, placed with some vibration, fiber segregation has high probability to occur. In this case, the post cracking behavior of the SFRC specimen is largely dependent on the loading direction, which should simulate the loading of the real application, as much as possible.

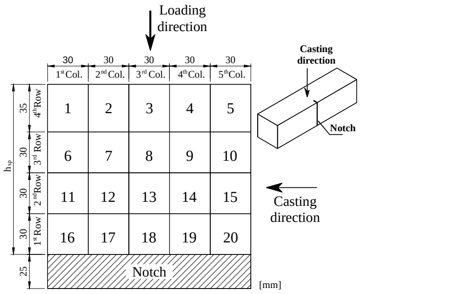


Fig.1 – Discretization in cells of the specimen's fracture surface.

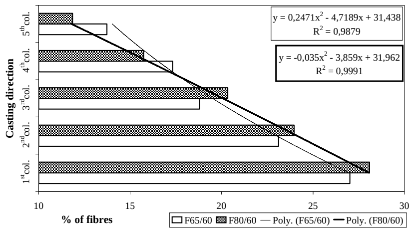


Fig.2 – Average fibre distribution.

Equivalent and residual flexural tensile strength parameters

Fig. 3 shows a linear trend between $f_{eq,2}$ and $f_{eq,3}$, and reveals that $f_{eq,3}$ is slightly lower than $f_{eq,2}$ indicating that, up to a deflection of δ_3, the energy absorption capacity of the designed SFRC was maintained.

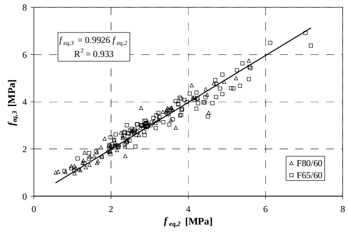


Fig. 3 – Relationship between $f_{eq,2}$ and $f_{eq,3}$.

Influence of the content of fibers

Fig. 4 shows that $f_{eq,2}$ increase with C_f in a linear fashion. A similar tendency was obtained for C_f - $f_{eq,3}$ relationship.

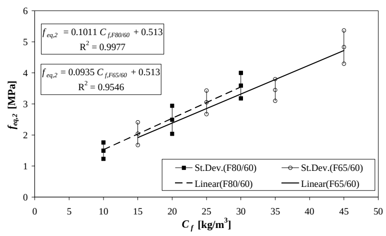


Fig. 4 – Relationship between C_f and $f_{eq,2}$.

Influence of the number of fibers on the fracture surface

Fig. 5 shows that $f_{eq,2}$ increase with N_f in a linear trend, along with a high scatter of values for this relation. Similar trend was observed in the N_f - $f_{eq,3}$ relationship.

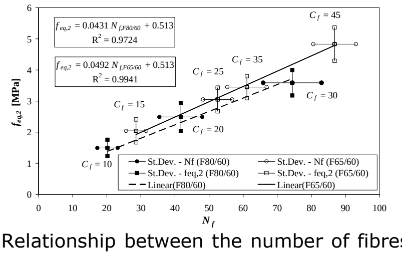


Fig. 5 – Relationship between the number of fibres on the fracture surface, N_f, and $f_{eq,2}$.

Relationship between equivalent and residual flexural tensile strength parameters

The relationships $f_{eq,2}$ - $f_{R,1}$ and $f_{eq,3}$ - $f_{R,4}$ are represented in Fig. 6. A strong correlation between equivalent and residual flexural tensile strength parameters is registered in series reinforced with the utilized types of fibers.

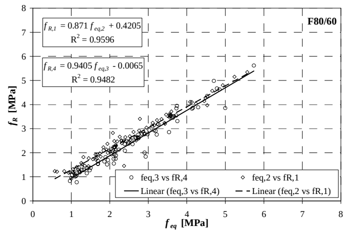


Fig. 6 – Correlation between f_{eq} and f_R in series reinforced with *F80/60* fibers.

3RD Objective

Performing a cost comparison evaluation of current and CCSFRC solutions in industrial pavements domain was the third objective of the program. The planed work was not completely done since it was not enough financial support to assure a research for this task.

4RD Objective

Since the project was only supported in 60% of the required amount, the reaction frame for the tests with real scale panels was not possible to build. Therefore, the fourth objective was not attained in spite of its considerable importance for the calibration of the finite element model developed at the end of the project.

5TH Objective

To accomplish the last objective of the research project, a numerical strategy was developed, involving two numerical models. The first one was designated by Layer model, from which the moment-curvature and the moment-crack opening relationships of a generic cross section can be obtained. This model was used to evaluate the fracture parameters of the conceived CCSFRC using the force-deflection relationship of the flexural tests and performing an inverse analysis with this model (see Figs. 7 and 8).

Using the F-δ relationships obtained from inverse analysis carried out with σ-ε and σ-w methods, a relation between the post cracking strain, ε^{pcr}, and the crack opening displacement, w, was evaluated (see Fig. 9).

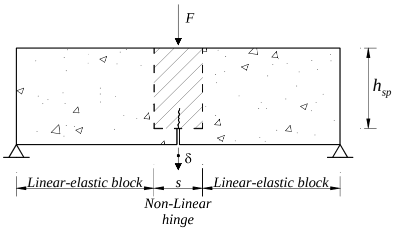


Fig. 7 – Specimen idealization for model use.

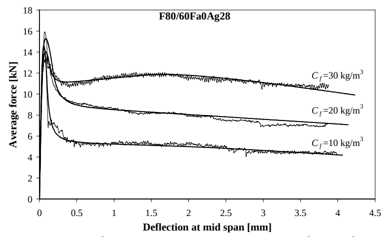


Fig. 8 – Comparison between experimental and numerical F-δ curves when using an inverse analysis based on the σ-w approach.

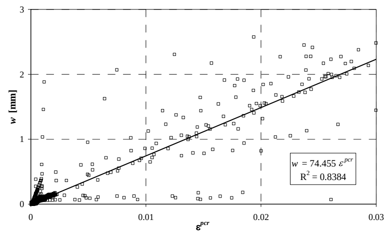
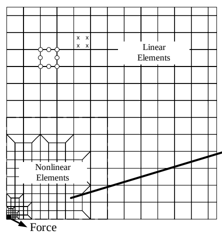


Fig. 9 – Relationship between the post cracking strain, ε^{pcr}, and the crack opening displacement, *w*.

This relationship can be useful in the evaluation of the crack opening when numerical strategies based on the σ-ε approach are used. The length of the fracture process zone, *Lp*, ($\varepsilon^{pcr} = w/Lp$) was in the range between half the specimen cross section height, ($h/2$ = 75 mm), and half the distance between the tip of the notch and the top of the cross section, ($h_{sp}/2$ = 62.5 mm).

The second model is based on the techniques of finite element method (see Figs. 10 and 11).



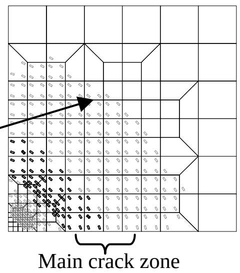


Fig. 10 - Finite element mesh.

Fig. 11 - Crack pattern in the slab top surface.

An interface finite element was implemented into FEMIX computational code in order to simulate the discrete crack initiation and propagation.

Relevant publications:

Books

Dimensionamento de estruturas de betão reforçado com fibras de aço ("Design of steel fiber reinforced concrete structures"), Seminar, Editors. J.A.O. Barros (UM), P. Rossi (LCPC) e B. Massicotte (Montreal), ISBN: 972-8692-09-9, DEC-EEUM, 28/11/2003 (250 issues)

International Journals

Barros, J.A.O., Cunha, V.M.C.F., Ribeiro, A.F., Antunes, J.A.B., "Post-Cracking Behaviour of Steel Fibre Reinforced Concrete", RILEM Materials and Structures Journal, 38(275), p. 47-56, 2005.

Vandewalle, L. et al., "Test and design methods for steel fibre reinforced concrete - σ - ε design method - Final Recommendation", Materials and Structures Journal, 36, p. 560-567, October 2003.

Vandewalle, L. et al., "Test and design methods for steel fibre reinforced concrete - Final Recommendation", Materials and Structures Journal, 35, p. 579-582, November 2002.

Vandewalle, L. et al., "Design of steel fibre reinforced concrete using σ-w method: principles and applications", Materials and Structures Journal, 35, p. 262-278, June 2002.

International Conferences

Barros, J.A.O.; Gouveia, A.V.; Sena-Cruz, J.M.; Azevedo, A.F.M.; Antunes, J.A.B., "Design methods for steel fiber reinforced concrete industrial floors", Third International Conference Construction Materials: Performance, Innovations and Structural Implications, Vancouver, CD, 22-24 August 2005.

Barros, J.A.O., Antunes, J.A.B., "Experimental characterization of the flexural behaviour of steel fibre reinforced concrete according to RILEM TC 162-TDF recommendations", RILEM TC 162 TDF Workshop, pp. 77-89, 20-21 March 2003.

Barros, J.A.O., Antunes, J.A.B., Cunha, V.M.C.F., Ribeiro, A.F., "Post-Cracking Behaviour of Steel Fibre Reinforced Concrete (RILEM Recommendations)", 5th International Colloquium "Industrial Floors", Technique Academy Esslingen, Stuttgart, German, 21-23 January, 2003.

Barros, J.A.O., Sena-Cruz, J.M., "Strengthening a prestressed concrete slab by epoxy-bonded FRP composites and SFRC overlayer", 7th Internacional Conference on Inspection Appraisal Repairs & Maintenance of Buildings & Structures, Nottingham Trent University, UK, 11-13 September 2001.

Organization of Seminars:

Three Seminars of more than 100 attendants per Seminar

Thesis:

Candidate: Alberto Fernandes Ribeiro
Type: Master
Supervisors: Joaquim Barros
Title: Modelos de fenda discreta na simulação do comportamento em flexão de betão reforçado com fibras de aço ("Discrete models for the simulation of the flexural behavior of fiber reinforced concrete")
Conclusion: 03/09/2004

Candidate: Vítor Manuel do Couto Fernandes da Cunha
Type: Master
Supervisors: Joaquim Barros
Title: Análise experimental e numérica do comportamento à tracção de betão reforçado com fibras de aço ("Numerical and experimental analysis of the tensile behavior of steel fiber reinforced concrete")
Status: 073/09/2004

Acknowledgments:

The coordinator of the present work wish to acknowledge the support that was provided by the BEKAERT; Degussa Chemicals Portugal; SECIL – Companhia geral de cal e cimento, SA; Pisonort.

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Development of an industrialized system for structural masonry
(ADI-IDEIA 70/00130 "SINALES")

Financing Institution(s): Supported under the Operational Program for the Science, Technology and Innovation (POCTI) and Incentive Program for Industry Modernization (PRIME)

Promoting Institution(s): Maxit Group, SA
University of Minho

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; João Gouveia; Manuela Almeida; Graça Vasconcelos; Ivone Maciel

Partner Institutions: Not applicable

Period: October 2005 to September 2008

Relevant facilities: DIANA software with user supplied subroutines; Servo close-loop equipments for experimental programs; Reaction wall

Objectives:

The objective of the project is to develop a constructive solution for small and medium size buildings, using a system of confined and reinforced masonry structure, and aiming at more economical solutions, with better performance and more rational building technologies. The Construction Sector represents around 9% of the employment and 7% of the GNP. Residential buildings account for circa 40% of these values and the masonry walls account for around 13 to 17 % of the total cost. The same walls exhibit often damage, being responsible for 25% of the total damage in construction. In this context, the need to rationalize, innovate and to adjust the sector to the actual characteristics of workmanship is not debatable, particularly in light of the globalization of economy and increasing competitiveness. Recent studies demonstrate that a structural solution using masonry is 10 to 15% more economical than the competing reinforced concrete solution. The project includes all the necessary advances for the success of the construction technology, including development of new building products, validation of the new products using experimental testing and numerical analysis, construction of a prototype and preparation of a design manual.

Main achievements:

The expected main achievements include: (a) new blocks; (b) new technologies and building processes; (c) new experimental results; (d) a real scale prototype; (e) design manual and specific design software.

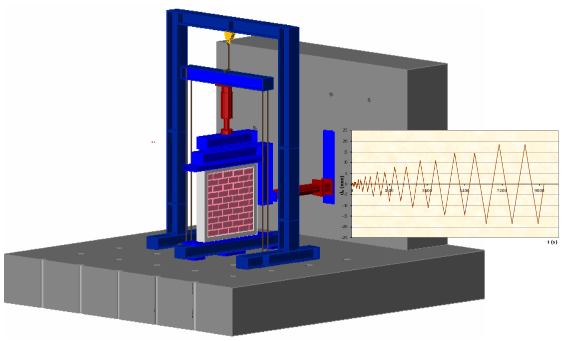
The testing program included 16 walls, scaled 1:2. Two unreinforced walls configurations have been considered, assuming filled and unfilled vertical joint. In the latter, the benefit of using bed joint reinforcement was analyzed. Such configurations have been tested again using confined masonry, always assuming unfilled vertical joints. In wall W6, the horizontal bed joint reinforcement is properly fixed to the reinforced concrete confining elements. Figure 1 presents the different type of masonry specimens.

The results allowed to assess the relevance of vertical joint filling, confining masonry elements and bed joint reinforcement. The difference in terms of strength was very moderate for the different configurations tested. In terms of deformation capacity and energy dissipation, the addition of confining elements and / or bed joint reinforcement represents a significant advantage. These two aspects are much more relevant that the usage of filled / unfilled vertical joints.

Benchmarking of commercial software for masonry design has been carried out, including a description of modelling strategies and an assessment of the results for vertical loading, wind loading and seismic loading. The results indicate too large differences between the programs and design approaches (linear or push-over), see Fig. 2.

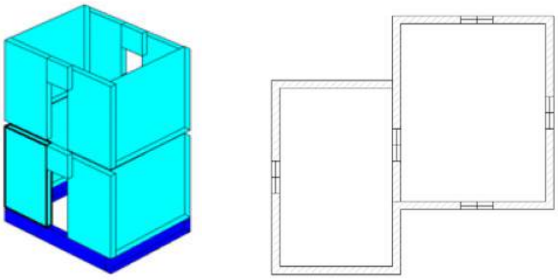
(a)

(b)

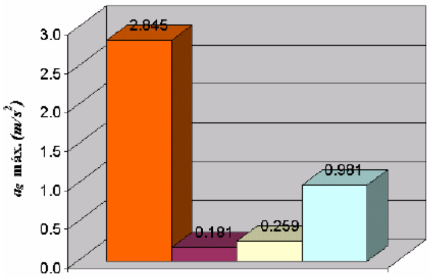


(c)

Fig. 1 – Example of tests carried out.



(a)

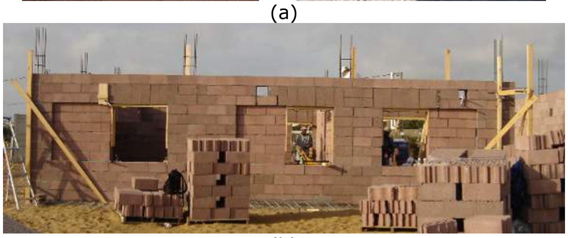


(b)

Fig. 2 – Software benchmarking: (a) Examples of buildings analysed; (b) differences in results for seismic design, using different approaches.

A prototype building using the materials developed in the project has been built for demonstration, see Fig. 3.

(a)



(b)

Fig. 3 – Details of prototype building.

Relevant publications:

Invited Lectures

Vasconcelos, G., Gouveia, J.P., Haach, V.G., Lourenço, P.B., Alvenaria armada: Soluções inovadoras em Portugal, em: Seminário Paredes de Alvenaria – Inovação e Possibilidades Actuais, Eds. Lourenço et al., Universidade do Minho, p. 103-128 (2007).

National Journals

Maciel, I., Lourenço, P.B., Análise de programas de cálculo para estruturas de alvenaria resistente, Construção Magazine, 21, p. 19-24 (2007).

Gouveia, J.P., Lourenço, P.B., O Eurocódigo 6 e o dimensionamento de estruturas de alvenaria, Construção Magazine, 17, p. 34-40 (2006).

International Conferences

Gouveia, J.P., Lourenço, P.B., Masonry shear walls subjected to cyclic loading: Influence of confinement and horizontal reinforcement, Tenth North American Masonry Conference, St. Louis, USA, p. 838-848 (2007).

National Conferences

Gouveia, J.P., Lourenço, P.B, Vasconcelos, G., Soluções construtivas em alvenaria, Congresso Construção 2007, Coimbra (2007).

Gouveia, J.P., Lourenço, P.B., Análise experimental de paredes de alvenaria de blocos de betão leve sob acções cíclicas no plano, Sísmica 2007 – 7º Congresso Nacional de Sismologia e Engenharia Sísmica, Porto, CD-ROM (2007).

Maciel, I. Gouveia, J.P., Lourenço, P.B., Dimensionamento de estruturas de alvenaria sujeita a acções sísmicas, Sísmica 2007 – 7º Congresso Nacional de Sismologia e Engenharia Sísmica, Porto, CD-ROM (2007).

Gouveia, J.P., Lourenço, P.B., Fontes de Melo, A. Alvenaria estrutural: Aplicação a um caso de estudo, 4as Jornadas Portuguesas de Engenharia de Estruturas, Lisboa, CD-ROM (2006).

Gouveia, J.P., Lourenço, P.B., Avaliação do comportamento de paredes de alvenaria com blocos de betão leve, 4as Jornadas Portuguesas de Engenharia de Estruturas, Lisboa, CD-ROM (2006).

Thesis

Desenvolvimento de um sistema industrializado de alvenaria estrutural, João Paulo Martins Gouveia, PhD Thesis, University of Minho, Portugal (expected by February 2008).

Avaliação de software de dimensionamento em alvenaria estrutural, Ivone Alexandra Lima Maciel, MSc Thesis, University of Minho, Portugal (2007).

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Development of innovative systems for reinforced masonry walls
(COOP-CT-2005 CONTRACT N. 018120 - DISWALL)

Financing Institution(s): European Commission

Promoting Institution(s): University of Padua, Italy

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Graça Vasconcelos; Vladimir Haach; Gihad Mohamad

Partner Institutions: University of Minho, Technical University of Munich (Germany), Building Institute RWTH Aachen (Germany), 5 SMEs, 2 Industrial Associations and Bekaert.

Period: January 2006 to January 2008

Relevant facilities: DIANA software with user supplied subroutines; Servo close-loop equipments for experimental programs; Reaction wall; GPR; Thermographic camera

Objectives:

The project aims at developing innovative systems for load and non-load-bearing reinforced masonry walls, based on the advancement of vertical reinforcement and fastening, of mortar and concrete and on their integration with special blocks for the definition of a new constructive system. The adopted approach, from materials through technology and research to case studies, is directed towards product development. The experience of different agents in the process ensures constructability, a key issue in sustainability, rationalisation, quality and cost control in the building industry. The foreseen advantages are: new possibilities for masonry; more economical construction; quality increase for masonry walls; crack-free and earthquake resistant construction. This is of basic importance, since damage in masonry walls represent 25% of the reported damage in buildings and safety in case of earthquake is a major issue. The project follows these steps: assessment of the technical and economical feasibility of the envisaged production and construction technologies by performing parallel experimental and theoretical studies; construction of prototypes as demonstration of the proposed technology and materials; in situ testing to completely validate the system. The main novelties are: development of new products (masonry units, steel reinforcement and fasteners, special mortars and concrete); development of the construction technology, including cost assessment and productivity; experimental and numerical characterization, to obtain a set of values for validation and certification, to define the influence of individual material properties, to perform parametric studies and to provide feedback for further developments; calibration and application of NDT methods for the quality assessment of reinforced masonry buildings; development of guidelines and software for the design of masonry walls according to the new solution and for the updating of codes of practice and standards.

Main achievements:

The project led to typologies of blocks using normal concrete, using two and three cells. The blocks aim at solving the technological and structural problem, meaning that the thermal problem must be solved using an external insulation system or a cavity wall.

The blocks are shown in Figure 1 and, besides fulfilling the required geometrical and structural specifications, they have been designed so that the building process is only marginally changed. The blocks with two cells are similar to existing blocks used for non-structural masonry and the blocks with three cells allow to place the reinforcement inside and to make a better stress transfer in the masonry, see also Figure 2.

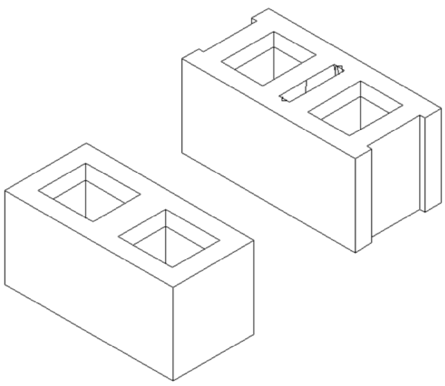


Fig. 1 – Blocks produced for the new system.

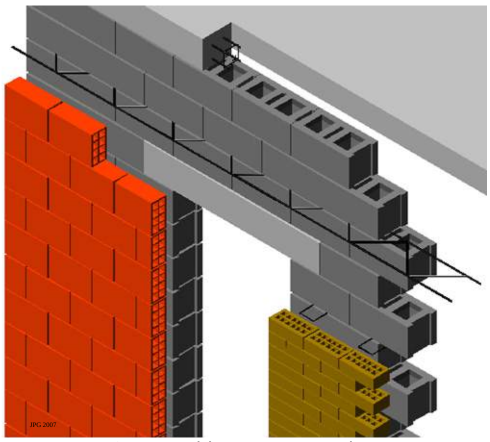


Fig. 2 – Possible execution solutions.

The idea is to built a reinforcement mesh using truss reinforcement and only mortar as a filling / bonding material (i.e. with no use of grout). Certainly, for severe loading it is possible to use also embedded columns, see Figure 3.

The system has been under intense laboratory testing. Figure 4 illustrates a typical failure mode of the walls tested. All walls presented a well distributed cracking pattern, with crushing of masonry in the compressed toes. No significant differences are found between the cracking in walls with reinforcement placed inside the hollow cells or in a continuous vertical joint.

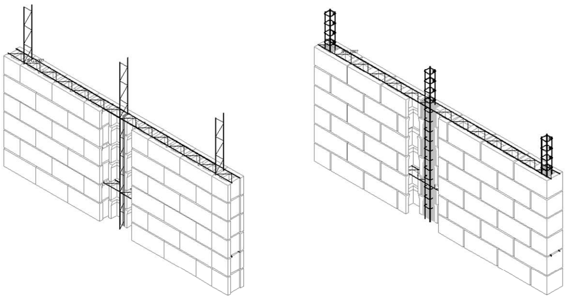


Fig. 3 – Details of the reinforcement placement and alignment of units.

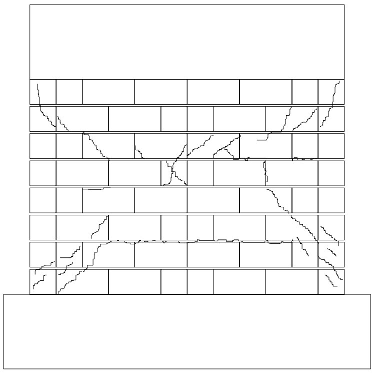
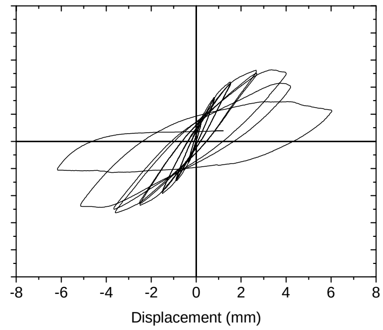


Fig. 4 – Typical failure mode for hollow concrete masonry walls with reinforcement in the vertical joints.

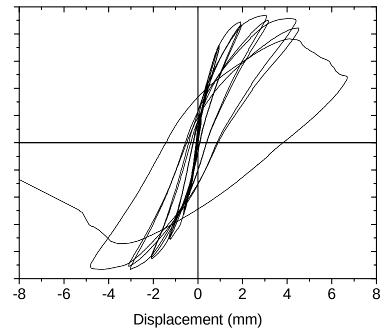
The influence of the amount of vertical load was clear, as higher vertical loads delayed cracking, which appear very close to peak load in this case. Comparing the behavior of the unreinforced masonry with the reinforced walls, it is possible to observe that the reinforcement makes masonry a more homogeneous material. Only the unreinforced masonry walls exhibited localized cracks with considerable opening, which divided the specimen into two parts. After the crack opening, the stress transfer between both parts is achieved almost exclusively at the bottom corners where compressive stresses concentrate.

Figure 5 present the load-displacement diagrams, where it is possible to observe that the reinforcement increases the wall strength and peak displacement. The increase in vertical load leads to a more brittle response. No significant differences in terms of load-displacement diagrams are found between the walls with reinforcement placed inside the hollow cells or in a continuous vertical joint.

Numerical simulations of the experimental programs aim at carrying out parametric studies that allow the definition of design rules appropriate to be included in the codes. For the validation of the modeling strategy adopted different material models included in DIANA® finite element code were considered. Figure 6 illustrates typical results of the numerical analyses, which comparison with experimental results and parametric studies taking into account the aspect ratio of the walls, the level of vertical pre-compression and the amount of reinforcement. A proposal for an adequate design approach is currently being validated.

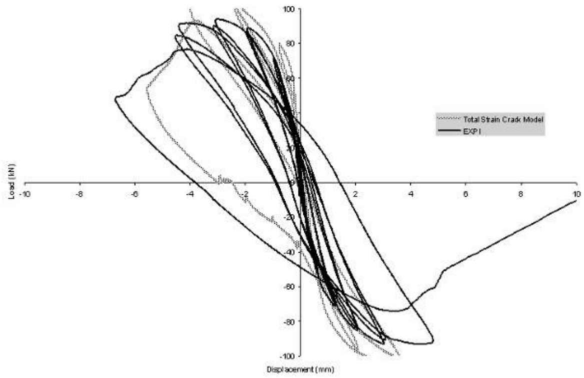


(a)

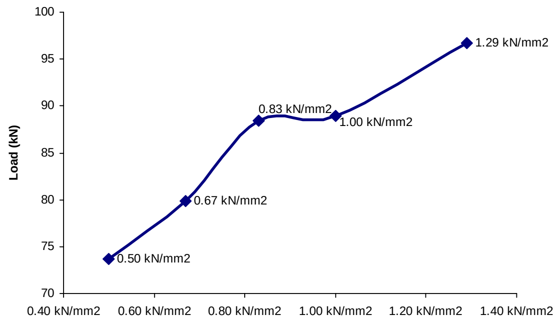


(b)

Fig. 5 – Load-displacement diagrams: (a) reinforced with low vertical load: (b) reinforced with high vertical load.



(a)



(b)

Fig. 5 – Typical results for non-linear analysis: (a) validation of modelling through comparison with experimental results; (b) influence of a given parameter in the results (in this case the vertical pre-compression).

Relevant Publications:

Thesis

Mecanismo de ruptura da alvenaria de blocos à compressão, Gihad Mohamad, PhD Thesis (2007).

International Journals

Mohamad, G., Lourenço, P.B., Roman, H.R., Mechanics of hollow concrete block masonry prisms under compression: Review and prospects, Cement & Concrete Composites, 29, p. 181-192 (2007).

National Journals

Mohamad, G., Lourenço, P.B., Roman, H.R., Ensaios de compressão em prismas de blocos de concreto à compressão – Deformabilidade e modo de rotura, Engenharia: Estudo e pesquisa, 7(2), p. 88-95 (2004).

Invited Lectures

Vasconcelos, G., Gouveia, J.P., Haach, V.G., Lourenço, P.B., Alvenaria armada: Soluções inovadoras em Portugal, em: Seminário Paredes de Alvenaria – Inovação e Possibilidades Actuais, Eds. Lourenço et al., Universidade do Minho, p. 103-128 (2007).

International Conferences

Haach, V.G., Vasconcelos, G., Lourenço, P.B., Mohamad, G., Composition study of a mortar appropriate for masonry cavities and joints, Tenth North American Masonry Conference, St. Louis, USA, p. 530-541 (2007).

Barbosa, C.S., Lourenço, P.B., Mohamad, G., Hanai, J.B., Triaxial compression tests on bedding mortar samples looking at confinement effect analysis, Tenth North American Masonry Conference, St. Louis, USA, p. 992-1002 (2007).

Mosele, F., da Porto, F., Modena, C., di Fusco, A., di Cesare, G., Vasconcelos, G., Haach, V., Lourenço, P.B., Beer, I., Schmidt, U., Brameshuber, W., Scheufler, W., Schermer, D., Zilch, K., Developing innovative systems for reinforced masonry walls, em Proc. 7th International Masonry Conference, London, UK, CD-ROM, 6 pp (2006).

Mohamad, G., Lourenco, P.B., Poisson behaviour of bedding mortar under multiaxial stress state, em Proc. 7th International Masonry Conference, London, UK, CD-ROM, 6 pp (2006).

National Conferences

Haach, V.G., Vasconcelos, G., Lourenço, P.B., Cyclic behaviour of truss type reinforced concrete masonry walls, Sísmica 2007 – 7º Congresso Nacional de Sismologia e Engenharia Sísmica, Porto, CD-ROM (2007).

Mohamad, G., Lourenço, P.B., Roman, H.R., Ensaio de compressão em prismas de bloco de concreto-deformabilidade e modo de ruptura, em XXXII Jornadas Sulamericanas de Engenharia Estrutural, Campinas, Brasil, p. 1557-1567 (2006).

Mohamad, G., Lourenço, P.B., Roman, H.R., Propriedades mecânicas das argamassas sob compressão triaxial-análise e previsão, em XXXII Jornadas Sulamericanas de Engenharia Estrutural, Campinas, Brasil, p. 2954-2963 (2006).

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Efficient structures: From materials to life performance
(REEQ/1092/2001)

Financing Institution(s): Supported under the Operational Program for the Science, Technology and Innovation (POCTI)

Promoting Institution(s): University of Minho

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Paulo J.S. Cruz, Joaquim O. Barros, Daniel V. Oliveira, J. Sena-Cruz, Luis Neves, Graça Vasconcelos; Isabel Valente, Salvador Dias, Jorge Branco, José Luís Ramos; Eduardo Pereira, Said Jalali, J. Barroso Aguiar, Aires Camões Miguel Ferreira; Over 25 PhD students

Partner Institutions: Faculty of Engineering from University of Porto (FEUP)

Period: September 2004 to October 2007

Relevant facilities: New additions include: Laboratory crusher; Automatic pull-off testing machine; ; Muffle with capacity 1100ºC; System for determination of permeability to water of concrete; Laboratory jar mill; Universal hydraulic tension-compression load frame; Certified chamber for performing climatic tests; Equipment for creep tests; Bundle of transducers and actuators; Sawing machine for concrete and stone; Diverse day-to-day laboratory equipment; Additional data acquisition and control equipment.

Objectives:

The tributary regions for University of Minho and FEUP, the top Civil Engineering schools in the North of Portugal, represent 3.2 million people (31.5% of Portugal). This young, industrialized but poor European region attracts limited R&D resources, clearly in opposition with Germany or France, in which R&D is a fundamental component of the development strategy of depressed regions. Therefore, the project aims at creating a Northern cluster in Structural Engineering research, capable of national and international excellence, so that a significant R&D turnover can be attracted. In both institutions, brand new structural laboratories are available, with areas of 1500 m2 and costs of 1 MEuro in total, requiring basic equipment for almost ALL research fields.
The objective of the research program is to increase the knowledge in civil engineering structures, focusing in an innovative perspective: From Materials to Life Performance. Other objectives of the program are the characterization of materials and structures, definition of performance requirements, contribution to safer, economical and added aesthetics constructions, as well as innovation in industrialization, both on product development and construction technologies. Both institutions have intersecting research interests but priority research programs that are, essentially, complementary. Thus, the region and the construction sector will benefit immensely, from the partnership.

Main achievements:

The expected enhanced exploitation of the laboratory facilities available at partner institutions, allowed by the equipment requested within the context of the present program, will contribute directly to: (a) improve the knowledge on materials technology and structural performance, (b) increase the competitiveness of the construction sector aiming at providing economical, eco-efficient, simple, safe and industrialized materials and technologies for constructing high-quality, good-looking and long-lasting structures; (c) conserve and rehabilitate existing constructions aiming at improving the life quality of society in general. These are major contributions is an extremely important sector for global economy.
Significant research contributions of the projects will be made in the fields of Material Innovation and Characterization, and Structural Performance, namely:

- Novel Developments in Concrete (e.g. fiber reinforced, self-compacting and high performance concrete, and controlled permeability formwork);
- Use of Industrial By-products and Waste Materials in concrete and ceramics (e.g. ashes, metakaolin, ceramic by-products, rubber, plastics, wood and cork);
- Product Development in Masonry (e.g. shells, panels, anchors, ties, base isolation and injection materials);
- Characterization of Building Materials (using carefully, deformation controlled, experiments in concrete, FRP, wood, steel and masonry);
- Constitutive and Structural Modeling (associated with the development and use of nonlinear constitutive models, and its validation via experimental tests);
- Characterization of Structural Behavior (via testing of structures and structural elements and improvement of experimental and assessment techniques);
- Inspection, Assessment and Monitoring of Structures (motivated by new construction processes and materials, and the need to keep existing structures in use);
- Safety Evaluation of Structures (concerning design of strengthened structures, safety during the building phase, evaluation of behavior in service and safety of existing constructions).

Examples of outcome of the project are represented in Figs 1 to 5.

Fig.1 – Novel developments in concrete and use of industrial by-products and waste materials in concrete and ceramics.

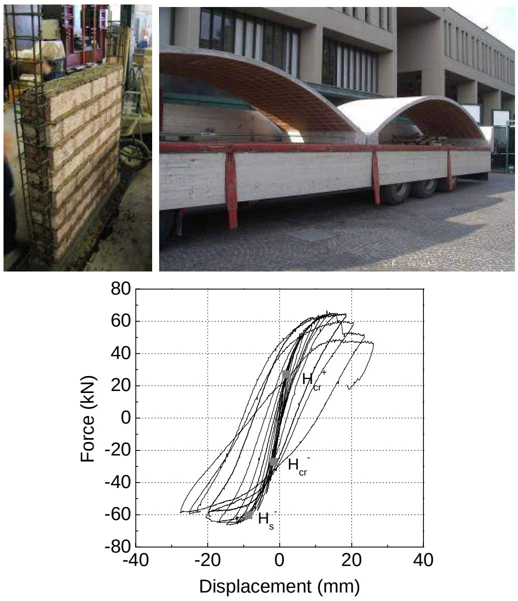

Fig.2 – Product development in masonry and characterization of building materials.

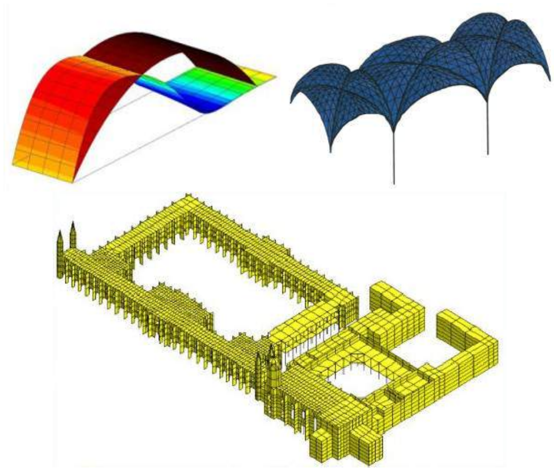

Fig.3 – Constitutive and structural modelling.

Fig. 4 – Characterization of structural behaviour.

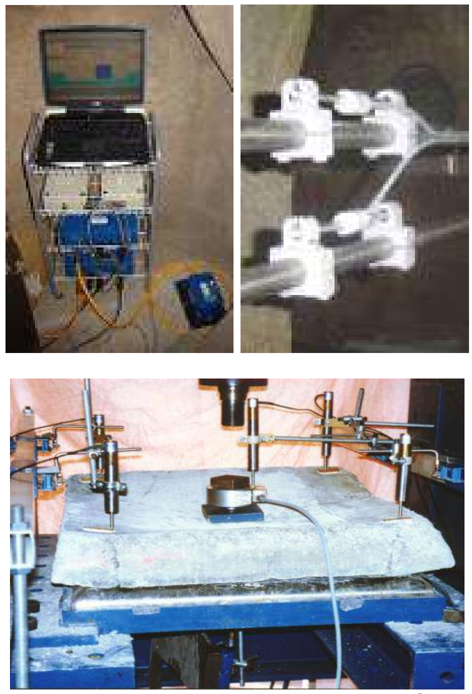

Fig. 5 – Inspection, assessment, monitoring of structures, safety assessment and quality control.

Relevant publications:

All publications of ISISE.

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High performance building products for sustainable construction: Structural masonry design
(ADI-IDEIA "cBLOCO:DE")

Financing Institution(s): Supported under the Operational Program for the Science, Technology and Innovation (POCTI) and Incentive Program for Industry Modernization (PRIME)

Promoting Institution(s): Cerâmica Vale da Gândara, SA
University of Minho

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Graça Vasconcelos; João Gouveia; Pedro Medeiros

Partner Institutions: Not applicable

Period: October 2007 to September 2008

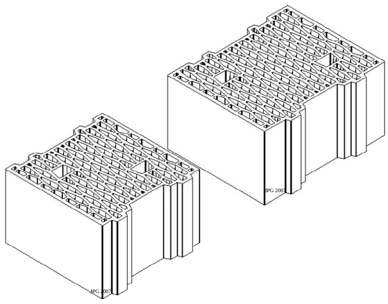
Relevant facilities: DIANA software with user supplied subroutines; Servo close-loop equipments for experimental programs; Reaction wall

Objectives:
This project aims at the development of a clay block that guarantees the thermal requirements of the new Portuguese regulations, together with an adequate mechanical behaviour for its use in unreinforced, confined and reinforced structural masonry.

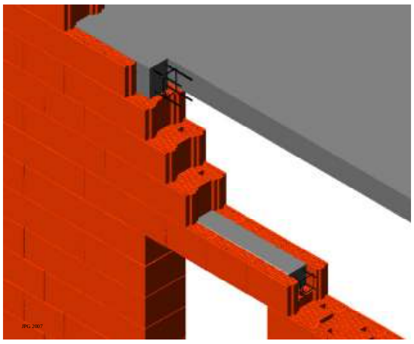
Main achievements:

The development of the adequate clay blocks is still in a preliminary phase, regarding geometrical configuration and ceramic paste, with subsequent mechanical tests. The first results indicate the need of blocks with dimensions 300×200×250, 300×200×300 and 300×200×370, in the form length l × height h × thickness t (in mm), to cover the three climatic zones of the country.

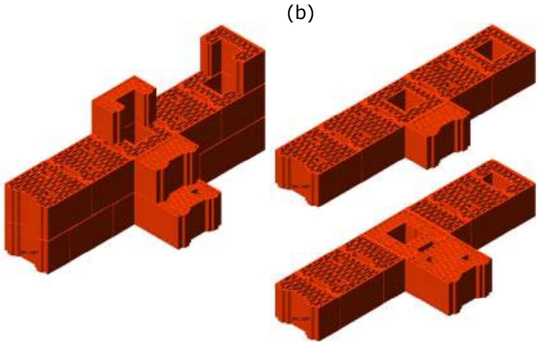
A possible technological solution from the project is shown in Figure 1, where the most relevant characteristic is to use only one masonry leave (and not a cavity wall), without insulation and with filling the vertical joints.



(a)



(b)



(c)

Fig. 1 – Possible solution for clay blocks: (a) block types; (b) execution details; (c) even and odd masonry courses, together with additional blocks for an integral system.

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FICOFIRE - High performance fiber reinforced concrete of enhanced fire resistance
(POCTI/ECM/57518/2004)

Financing Institution(s): Portuguese Science and Technology Foundation (FCT)

Promoting Institution(s): University of Minho

Coordinator(s): Joaquim Barros

Researchers and collaborators: UMinho: Joaquim Barros; Lúcio Lourencço; Simão Santos. FCTUC: João Paulo Rodrigues; Adérito Alves; Paulo Providência

Partner Institutions: Universidade de Coimbra (FCTUC)

Period: March 2005 to March 2007

Relevant facilities: FEMIX V4.0 Finite Element package; furnace; servo close-loop equipments.

Objectives:

Develop a Fibrous Concrete of 50-70 MPa compressive strength, of Enhanced Fire Resistance and high ductility (FRCEFR). Distinct types of fibers will be used. One type has very low degree of polymerization, which in presence of a very high temperature will sublime. Cellulose fibers with fire retardants products which, in presence of very high temperature, will be transformed, by pyrolise, into carbon, shrinking, is an alternative solution. Both types of fibers, under the action of fire will create a network of micro channels for the escape of the water vapor. These types of fibers have also the purpose of decrease the crack propagation during the concrete plastic shrinkage phase. The other type of fiber has the purpose of providing high ductility for the concrete post-cracking behavior. For the alveolar concrete slab application the FRCEFR has also the purpose of being possible the production of slabs of larger span and thickness without the use of steel stirrups.

Main achievements:

Experimental Tests

A mix design program was done with the objective of finding the composition that accomplishes the requirements in terms of fire resistance and concrete ductility, taking into account the economic restrictions for the concrete production and the concrete technological practices indicated by a contractor associated to this project.

Tunnel segments are, in general, reinforced with high percentage of steel bars, in order to attend not only to known load conditions, but also to unpredicted effects. The time consumed deserved by steel reinforcement preparation and installation has significant impact on the final cost of this structural element. Previous research has indicated that steel fibers can totally or partially replace conventional steel bars with technical and economic advantages. To evaluate the possibilities of steel fibers replace partially or totally the reinforcement ratio currently used in this type of application, tunnel segments were manufactured by the developed FRCEFR and submitted to fire tests.

Compression tests at high temperatures and residual properties

Core cylinders of 75 mm diameter and 225 mm height were extracted from a FRCEFR slab, and were submitted to direct compression force in a test equipment that can, simultaneously, apply high temperatures to the specimen (see Figure 1). These specimens were instrumented with thermocouples at pre-established places inside of the specimen, according to the recommendations of RILEM. The specimens, under constant load, were heated up in an electric oven, with a heating rate of 3 K/min until a desired level of temperature was reached. An interval of time was waited for homogenization of the temperature in the specimen, after which the compression test was carried out.

Cylinder specimens (150 mm diameter and 300 mm high) were also set to determine the concrete residual Young's modulus and stress-strain relationship. Beam specimens (600 × 150 × 150 mm^3) were also prepared to assess the residual concrete flexural behavior. One (PP1) and two (PP2) kg per m^3 of concrete of PP fibers (Duro-Fibril, l_f = 6 mm) were used to manufacture the tested specimens. Mechanical tests were performed at 28 days after the concrete exposure to distinct levels of temperature. For each type of concrete and target test temperature, three cylinders and two beam specimens were tested and the average of the corresponding results was used as the final values. The target test temperatures were: 20 ºC (room temperature), 250 ºC, 500 ºC, 750 ºC and 1000 ºC. Concrete specimens were heated, without any applied external load, at a constant rate near to 25 ºC / min until the ambient temperature inside the furnace reaches the target test temperature. Then, the temperature was kept constant for 4 hours. The exposure to the 1000 ºC level of temperature led to the destruction of the concrete specimens.

Fire resistance of concrete tunnel segments

Tunnel segments of distinct volumentric percentage of steel fibres and different steel reinforcement ratio were submitted to fire test and, after have been cooled, their residual flexural resistance was assessed carrying out three point bending tests. The tunnel segments had dimensions of 1.2 x 2.4 x 0.35m^3 and were provided with thermocouples to measure the temperature variation at pre-selected points inside the specimen.

Four tunnel segments were manufactured: a reference specimen of high strength concrete without fibres and with 81 kg/m^3 of conventional reinforcement (Specimen 1). This specimen is similar to the ones used in the construction of tunnels in Portugal; a second one, with 75 kg/m^3 of steel fibres and without steel bars reinforcement (Specimen 2); a third specimen with 45 kg/m^3 of steel fibres and 51 kg/m^3 of steel bars reinforcement (Specimen 3); and finally, a fourth specimen with 60 kg/m^3 of steel fibres and 35 kg/m^3 of steel bars reinforcement (Specimen 4).

The percentage of polypropilene fibres was maintained constant and equal to 2 kg/m^3 in specimens 2, 3 and 4. These specimens, supported in an external structure, were tested in a fire resistance furnace capable of follow the ISO 834 curve. During the fire resistance test, the elements were subjected to a constant load of 174 kN, applied to its mid span and orthogonally to the middle surface of the specimen (see Figure 2). This load was estimating taking into account the load conditions that tunnel segments are submitted in service.

Fig. 1 – Compression tests.

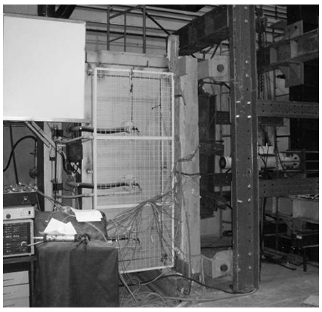

Fig. 2 – Experimental set-up for the fire resistance tests.

Bending tests to assess the residual flexural resistance of tunnel segments

The tunnel segments that did not collapse during fire test were, after cooled in the laboratory environment, tested under a three load configuration in order to evaluate its residual flexural resistance. The elements were tested under displacement control at a displacement rate of 0,001 mm/sec (see Figure 3).

Fig. 3 – Bending tests.

Results

Compression tests at high temperatures and residual properties

On the compression tests, the increase of load level and maximum temperature of exposure conducts to a small resistance. The variation of the residual concrete properties (Young's modulus, compressive and flexural strength) with the variation of the target test temperature is shown in Figures 4 to 6.

Fire resistance of concrete tunnel segments

In general, the tunnel segments behaved well during the fire resistance tests, except for Specimen 2 that only includes fibres. After 10 min of fire exposure a macro-crack occurred at the face turned to the fire, at the loaded cross section. The crack opening has increased up to the flexural collapse of the Specimen that occurred after 110 min the fire test initiation.A postanalyze of the flexural tensile stress introduced by the resultant line load of 174 kN indicated that this load exceeds the load corresponding to crack initiation of the cement based matrix of the FRCEFR used in the fabrication of this Specimen. The other elements resisted completely for more than 240 min without reaching the maximum deflection or speed of deformation indicated in EN 1363-1 for fire resistance tests.

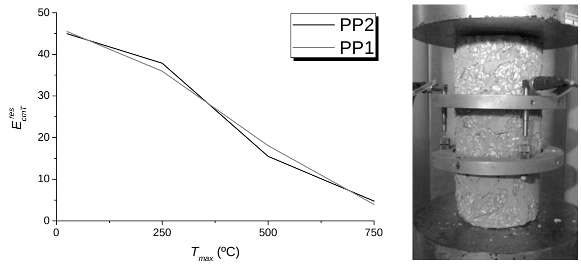

Fig. 4 - Residual Young's modulus for different level of temperature exposure.

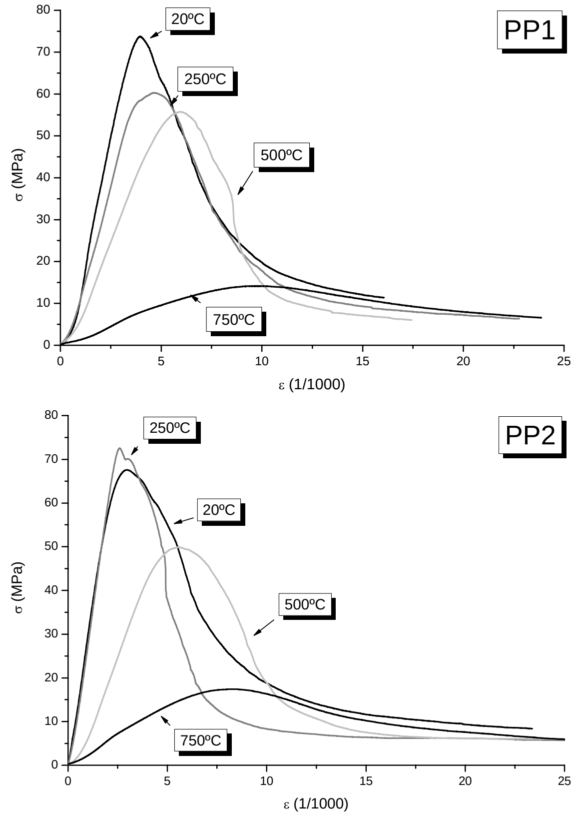

Fig. 5 - Residual compressive behaviour.

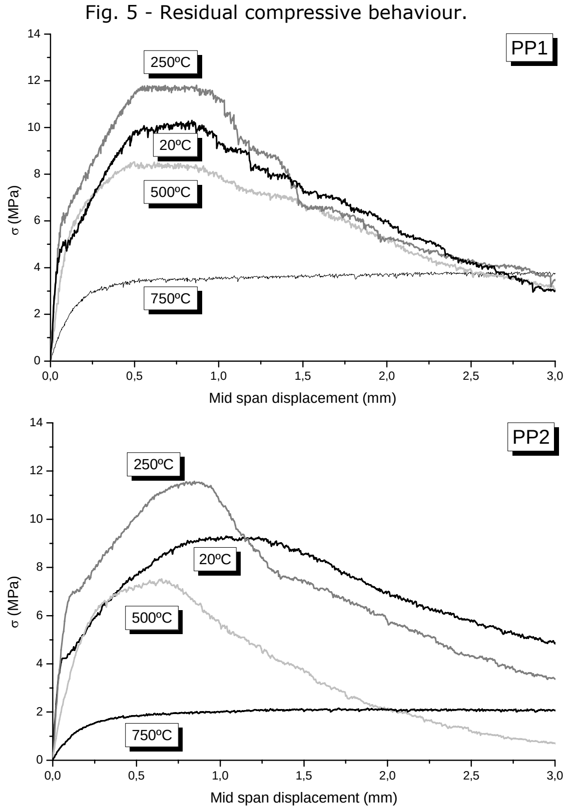

Fig. 6 – Residual flexural behaviour.

Figure 7 presents a synthesis of the results obtained in the fire resistance tests with tunnel segments. Specimen 1 was the first to be tested and, due to deficient functioning of the supports, the test was interrupted at 200min. A significant increase of the deflection rate is observed after 100min of fire exposition, which may be justified by an excessive deformation of the supports. This fact was solved for the subsequent tests. Specimen 3 and 4 presented the smallest deflection rates, which indicates that a reinforcement in terms of steel fibres and bars placed in the contourn of the specimen are good reinforcement solution in terms of retaining the stiffness of the structural element under fire conditions.

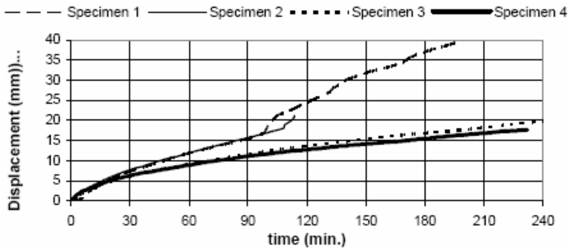

Fig. 7 – Evolution of mid span displacements in the specimens during fire resistance tests.

Bending tests to assess the residual flexural resistance of tunnel segments

The force-deflection curves obtained from the bending tests with the tunnel segments after have been submitted to the fire conditions imposed by the ISO 834 curve are represented in Figure 8. The obtained results shown that Specimen 1 presented the largest residual flexural resistance. The others specimens presented similar load carrying capacity. As already mentioned, Specimen 2 was not tested since it collapsed in the fire resistance test.

Conclusions

The specimens with polypropylene fibres presented less spalling than the specimens without fibres. The existence of these type of fibres in the concrete allowed the creation of channels through which the water steam, generated through the heating of the specimen, can escape.

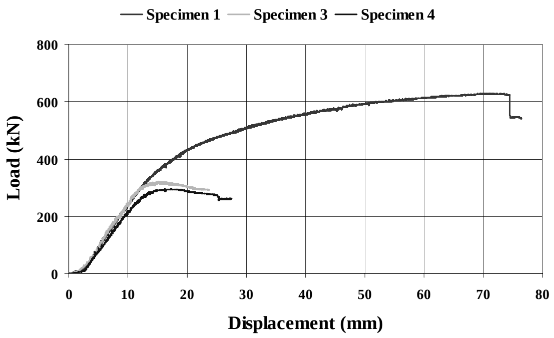

Fig. 8 – Experimental load vs mid span displacement for the tunnel segments after have been exposed to ISO 834 curve.

Partial replacement of conventional reinforcement by steel fibres is a possible solution in terms of fire resistance. However, in terms of residual load carrying capacity after specimens have been submitted to fire conditions imposed by ISO 834 curve, the reinforcement solution based on steel bars (81 kg/m^3) was superior to those based on hybrid reinforcement (45 kg/m^3 of steel fibres and 51 kg/m^3 of steel bars; 60 kg/m^3 of steel fibres and 35 kg/m^3 of steel bars).

Relevant Publications:

International Conferences

Alves, A.; Rodrigues, J.P.; Barros, J.A.O.; Lourenço, L.A.P.; Santos, S.P.F., "Fire behaviour of a fibre reinforced concrete tunnel segments", Fib Workshop, Fire design of concrete structures from materials modeling to structural performance, Universidade de Coimbra, 8 e 9 de Novembro de 2007.

Santos, S.P.F.; Barros, J.A.O.; Lourenço, L.A.P., "Fibrous Reinforcing System to Increase the Shear Resistance of High Strength Concrete", Materiais 2007, FEUP, Porto, 5 pp., 1-4 April 2007.

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National Journals

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Acknowledgments:

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HISTWIN – High strength steel tower for wind turbines
(RFSR-CT-2006-00031)

Financing Institution(s): Research Fund for Coal and Steel – European Union (EU – RFCS)

Promoting Institution(s): TU Lulea, Sweden, Univ. Coimbra, Portugal; Univ. Aachen, Germany; Univ. Thessaloniki, Greece; Repower Portugal, Portugal; Rautarukki, Finland; Germanischer Lloyds, Germany

Coordinator(s): (Univ. Coimbra, Portugal) Luis Simões da Silva; (TU Lullea, Sweden) Milan Veljkovik

Researchers and collaborators: (only Univ. Coimbra, Portugal) Luis Simões da Silva, Carlos A. Silva Rebelo, Rui Duarte Simões, Sandra Jordão, Daniel Dias da Costa

Partner Institutions: TU Lullea, Sweden, Univ. Coimbra, Portugal; Univ. Aachen, Germany; Univ. Thessaloniki, Greece; Repower Portugal, Portugal; Rautarukki, Finland; Germanischer Lloyds, Germany

Period: July 2006 to June 2009

Relevant facilities: (only Univ. Coimbra, Portugal) Acceleration, strain, inclination and temperature transducers; Data acquisition and transmission equipment; Universal test machine; Diverse day-to-day laboratory equipment

Objectives:

The main objective is to improve competitiveness of steel towers used to support multi mega-watt wind turbines. An integrated view on the optimization of the whole steel tower is based on an analysis of the limiting criteria that govern wind tower design. Various cyclic loads during the towers life time enforce the fatigue resistance of the connection to limit the strain level in the shell. This is a restrain for design of a more economical towers and use of higher steel grades. The conclusion leads to a two folded solutions. The first being an investigation for an improvement of the existing flange detail using an available technique from bridge construction to remedy unavoidable imperfections in the joint. The second is proposing a use of the friction type joint to allow higher strains in the shell. A detailed program is conceived to verify these two incremental innovations, experimentally in a laboratory, in a workshop and justify it with in-situ measurements.

Description:

With constantly increasing demand for wind turbines, driven by the need to use renewable energy sources, cost optimization of the steel tower becomes important and commercially justified. The aim of this project is to give an integrated view on the steel tower optimizing the performance of the whole structure rather than critical details separately. Optimization of the tower geometry and innovative solutions for assembly joints are planed to remedy existing limits. The work is being carried-out in five subsequent phases:

1. Improvement of the fatigue performance of the assembling joint will lead to allowance of higher stresses in the shell. Intensive research has been carried-out in the past 15 years focusing on traditional joints. These have their limitations and here new solutions will be developed.
2. The possibility of higher stresses in the shell lead to economical justified utilization of high performance steel, with yield strength up to 460 MPa. In current practice 355MPa is commonly used. This will reduce the steel weight, fabrication cost and the transportation cost, which have an important influence on the total costs.
3. Creating a more slender shell is causing needs to review the stability issues and detailing such as door openings and number and stiffness of stiffening rings. These problems will be studied from:
    a. structural standpoint, optimizing the tower shape and plate thickness,
    b. from the production standpoint by investigating the influence of production tolerances on resistance and production cost
    c. from the assembling standpoint, considering the tolerances during the assembling and transportation costs to determine number of segments .
4. All improvements will be justified by experiments in laboratory and in-situ. Advanced computational methods and state-of-art computers will be used to analyse and model experimental results numerically.
5. Complete and new provisions for the design procedure for wind tower (the various limit state checks and at all possible critical sections) will be given including production and assembling tolerances.

The topics are addressed in the project grouping 27 working tasks in five work packages An overview of the tasks for each working package is given below.

WP1. Design approximation of the wind load on the tower from existing measurements; Shell stability according to the design requirements; Review of different S-N curves for bolted connection according to EC3 and VDI2230; Review of a current design procedure for preloaded anchors; Seismic hazards; Review of the best practice for design of stiffening rings.

WP2 Improvement of the flange joint performance; fatigue "segment" tests; Testing of two bolt types and two treatments of the faying surfaces, grit blasted weathering steel and another with normal steel and zinc silicate paint, for the friction type connection. 15 static segment tests; Fatigue testing of the friction joint 12 tests; creep tests of pretension loss for bolts in slots, 10 tests; Bending tests, 8 static test; Feasibility tests of the friction joint on the segment of the tower; Comparison: flange joint versus friction joints, design and cost analysis.

WP3 Parametric evaluation of the shell thickness with respect to the slenderness of the tower (including soil-structure interaction), the wind load and the seismic hazards; Numerical analysis of effects of different magnitudes of geometrical imperfections (unavoidable in the production) on the resistance of a tower in relation to production costs; Optimization of the tower geometry including detailing; Investigation of the effectiveness of various types of stiffeners around the door opening and optimisation of the cost-benefit ratio.

WP4 Callibration of equipment for in-situ measurements; Long run measurements in-situ on a tower in southern Europe before and after improved joints; A simple short-run in-situ measurements on a tower in northern Europe and evaluation; Evaluation of the tower response from the long-run in-situ measurements; Measurements and evaluation of the achieved pre-tension bolt forces.

WP5 Detailed vs simplified FE model; Influence of the geometrical imperfections and different pretension bolt force, statistical evaluation and equivalent model; Equivalent loading; Optimal safety index in relation to expected failure costs, benchmarking; Guidance on design by FEM and design examples

The overview of the project is shown in Fig. 1 indicating the relationship between work packages. A sequence of the work is shown by the numbers on the arrow showing the relation between work packages.

The success of the project relies on the cooperation between universities, authorities, representatives of industrial users and steel produces. Representatives of all four groups, shown in Figure 2, are involved in the project with different roles.

• The steel producer, founded in Finland, will influence adequate treatment of the base material and to provide data about the materials mechanical and structural parameters. All material necessary for the experiments and feasibility tests will be delivered by the steel producer.
• Universities from four EU countries, Germany, Greece, Portugal and Sweden, will improve the state of knowledge using sophisticated in-situ measurements and laboratory testing methods. They are responsible to carry-out high-quality research and test proposed innovations for better design and maintenance of the wind towers.
• The industrial user, based in Portugal, is responsible to contribute for more cost effective production providing opportunities for measurements in production and in-situ, as well as to carry-out feasibility tests of the friction joint.
• The authority, in this case the insurance company, in charge to assure consistency of new provisions, planed to be achieved in the project, to the generally accepted safety level is based in Germany and has reputation of being the world leader in this area..

Publications:

LTU: Six monthly report for the first reporting period from July to December 2006.

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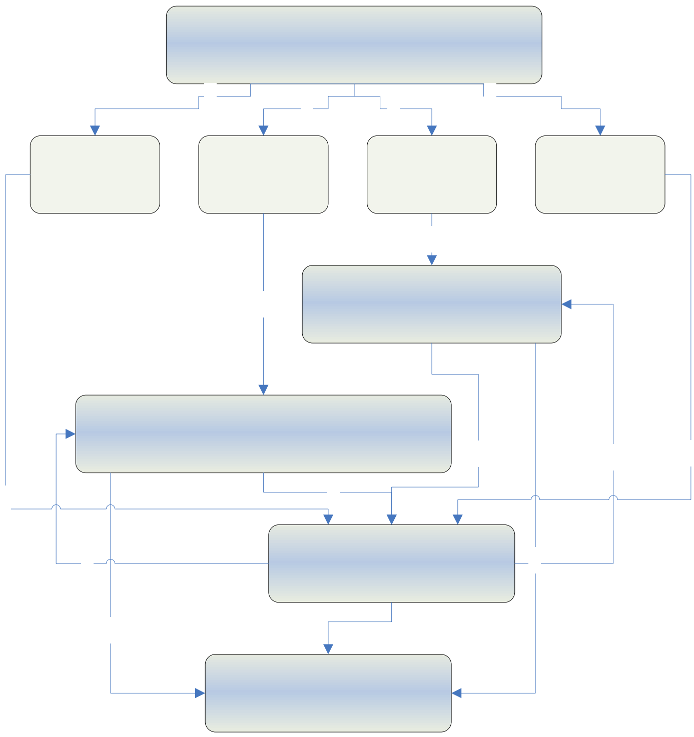

Fig. 1 – Overview of work packages.

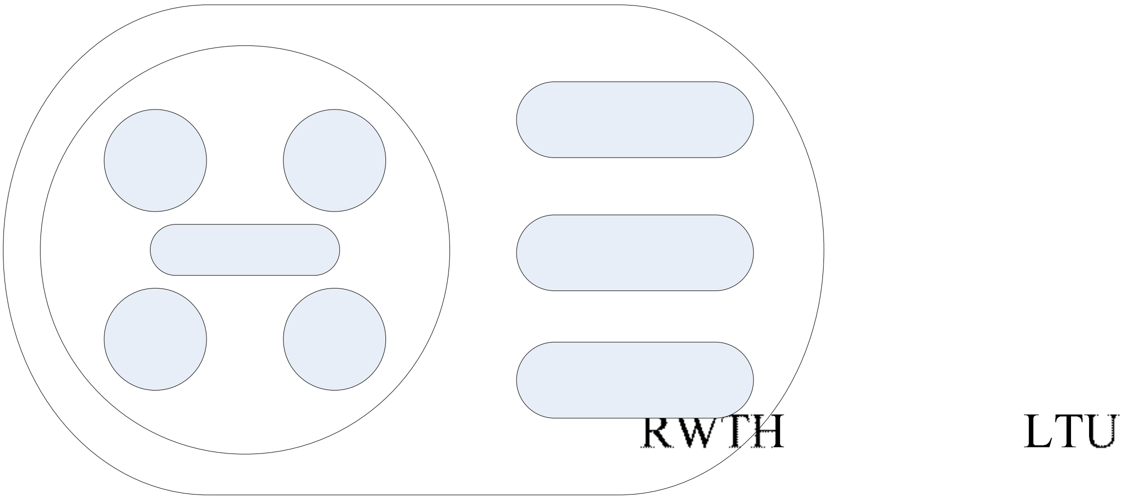

Fig. 2 – Consortium of partners

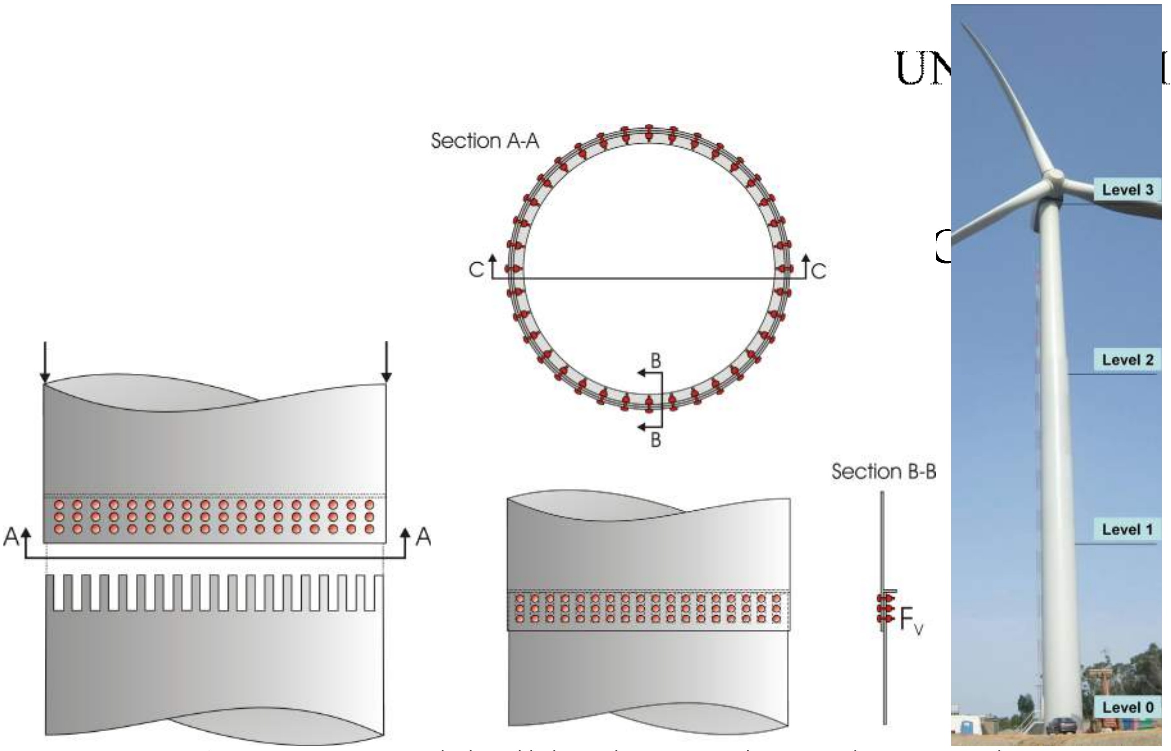

Fig. 3 – Friction type joint with slotted holes and instrumented tower in Algarve, Portugal.

HISTWIN - High strength steel tower for wind turbines
(PTDC/ECM/64217/2006)

Financing Institution(s): Fundação para a Ciência e Tecnologia (FCT)

Promoting Institution(s): Faculdade de Ciências e Tecnologia da Universidade de Coimbra

Coordinator(s): Luis Simões da Silva

Researchers and collaborators: Luis Alberto Proença Simões Silva, Altino de Jesus Roque Loureiro, Carlos Alberto Silva Rebelo Investigador, Sandra Filomena da Silva Jordão Alves, Rui António Duarte Simões, Luís Filipe da Costa Neves, José António Martins Ferreira, Maria Constança Simões Rigueiro, Martin Pircher

Partner Institutions:

Period: January 2008 to December 2010

Relevant facilities: Universal testing machine, Steel frame, Data logger TML TDS 601, Load cells TML several, Deflection gauges TML several, Data logger TML TDS 602, Hydraulic jacks several, Multi-analyzer system Bruel e Kjaer Pulse 3560 D, Pulse software for multi-analyzer system, acelerometers several, NI CompactDAQ hardware National Instruments, lABVIEW full development system.

Objectives:
The main objective of this project is to contribute to the development of the next generation of steel towers used to support wind turbines. This project complements an European Project (RFSR-CT-2006-00031) that is only funded for 60%. The specific objectives are: (i) develop, test and validate novel connection for the assembly of the tower segments with friction joints on slotted holes; (ii) assess the global and local stability of the tower using FEM; (iii) perform in-situ measurements to validate the concept. The aim of this project is to give an integrated view on the steel tower optimizing the performance of the whole structure rather than critical details separately.

Description:

Production of electricity from wind power is an European and Portuguese priority. The steel consumption in steel towers for wind turbines in the period 2007-2009 will reach about 3.5 million tonnes of steel. The steel tower is about 20% of the total costs for the wind turbine. Optimization of the steel tower using improved assembling techniques and higher steel grades has targeted savings of about 10% of the tower costs. Simultaneously, given the increase of the power of the wind turbines, this project will allow the installation of the larger turbines "onshore", an objective that is currently difficult because of transportation problems.

This projects consists of an integrated view on the optimization of the whole steel tower is based on an analysis of the limiting criteria that govern wind tower design. Various cyclic loads during the towers life time enforce the fatigue resistance of the connection to limit the strain level in the shell. This is a restrain for design of a more economical towers and use of higher steel grades. The conclusion leads to a two folded solutions. The first being an investigation for an improvement of the existing flange detail using an available technique from bridge construction to remedy unavoidable imperfections in the joint. The second is proposing a use of the friction type joint to allow higher strains in the shell.

Specifically, the project is organized to give an integrated view on the steel tower optimizing the performance of the whole structure rather than critical details separately. Optimization of the tower geometry and innovative solutions for assembly joints are planed to remedy existing limits. The work will be carried-out in five subsequent phases:

1. Improvement of the fatigue performance of the assembling joint will lead to allowance of higher stresses in the shell. Intensive research has been carried-out in the past 15 years focusing on traditional joints. These have their limitations and here new solutions will be developed.

2. The possibility of higher stresses in the shell lead to economical justified utilization of high performance steel, with yield strength up to 460 MPa. In current practice 355MPa is commonly used. This will reduce the steel weight, fabrication cost and the transportation cost, which have an important influence on the total costs.

3. Creating a more slender shell is causing needs to review the stability issues and detailing such as door openings and number and stiffness of stiffening rings. These problems will be studied from:
   a. structural standpoint, optimizing the tower shape and plate thickness;
   b. from the production standpoint by investigating the influence of production tolerances on resistance and production cost;
   c. from the assembling standpoint, considering the tolerances during the assembling and transportation costs to determine number of segments.

4. All improvements will be justified by experiments in laboratory and in-situ. Advanced computational methods and state-of-art computers will be used to analyse and model experimental results numerically.

5. Complete and new provisions for the design procedure for wind tower (the various limit state checks and at all possible critical sections) will be given including production and assembling tolerances.

This project will be developed in close co-operation with other major international research centres active in this field, in the framework of the European Project HISTWIN. The results of the project will lead to pre-normative information to be presented in technical committees of international organizations (ECCS-TC10-TC8).

Repercussions

A. Technical repercussions
(i) New idea to assemble segments of the tower with friction joints. This has not been done so far and has potential for improving both performance and economy. The proposed innovation belongs to the incremental innovation because it exploits existing technology and focuses on cost and performance improvements. Results of the project will generate new knowledge for friction type joints with the open slotted holes and create base for implementation of this connection type in other applications. This is a contribution for development of faster and cost-effective connection technology.
(ii) Use of high strength steel in steel towers. The use of weathering steel is also in a way innovative as it so far has not been used.
(iii) Development of design procedures for ateel cylindrical shells B. Socio-economical repercussions
(i) Increased competitiveness of Portuguese industry, directly involved in this project, thus contributing for job growth and increase of exports.
(ii) Savings of up to 10% on the cost of a steel tower, corresponding to potential savings in Portugal for the period until 2010 of 10 Mi€ and 100 Mi€ in Europe.
(iii) Positive effect of safety at the construction site reducing situations where incidents may occur.

B. Environmental repercussions
Today, wind power installed in Europe is about 50GW, saving over 50 million tonnes of CO2 per year. Unlike conventional fuels wind energy is available in virtually every nation in the world eliminating long term fuel price risk. This has very positive impact on global economy and sustainable economical growth.

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Fig. 1 – LABVIEW application under developement for long term measurements and data transmission.

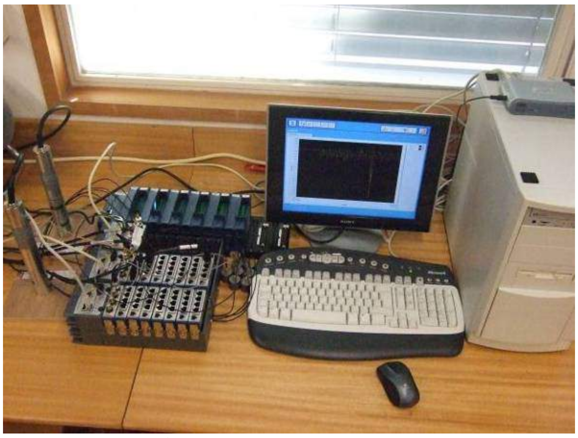


Fig. 2 – Data acquisition equipment.

Fig. 3 – Tower instrumentation in factory.

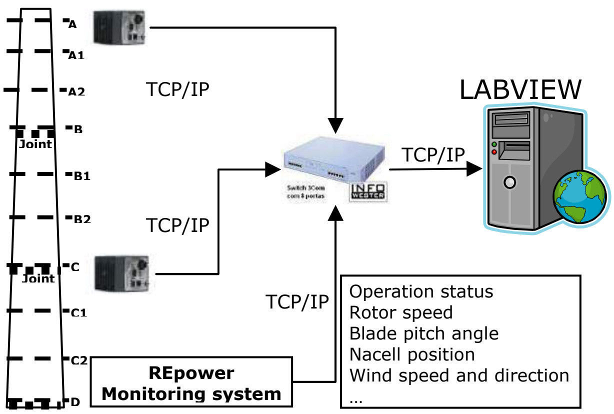


Fig. 4 – Outline of tower instrumentation, data acquisition and remote transmission system.

Improving the seismic resistance of cultural heritage buildings
(ALA/95/23/2003/077-122)

Financing Institution(s): EU-INDIA Economic Cross Cultural Programme (European Union)

Promoting Institution(s): University of Minho

Coordinator(s): Paulo Lourenço

Researchers and collaborators: Pere Roca, Claudio Modena, Shailesh Agrawal, Daniel Oliveira, Giuseppe Gariup, Fillippo Casarin, Ajay Chourasia

Partner Institutions: Technical University of Catalonia (Spain), Central Building Research Institute (India) and University of Padua (Italy)

Period: January 2004 to December 2006

Relevant facilities: DIANA software with user supplied subroutines; GPR; sonic testing; dynamic identification equipment; monitoring systems

Objectives:

The objectives of the project are as follows:
Objective 1: develop an integrated system of assessment which can predict the seismic risk of monuments with respect to performance based criteria, based on definition of local seismicity, geometrical and constructional survey and vulnerability analysis; to create a performance library for monuments, which is open for access and expansion to the entire practicing structural engineering community; to collect, systematically organize and disseminate available knowledge and expertise, in order to create a state-of-the-art in the field of monuments protection;
Objective 2: define guidelines for repair, rehabilitation and prevention procedures on monuments in India, not only in order to upgrade the existing codes but also to define new regulations for the application of innovative techniques to cultural heritage buildings (CHB); the guidelines must be in the form of a widely disseminable document offering guidance on strengthening strategies, not just to professionals, but to conservation bodies and building owners and disseminate the results obtained by the project to an audience wider than the scientific community only. This will be implemented by development of materials on multimedia supports;
Objective 3: carry out problem-focused projects (demonstration projects) and applications of state-of-art non-destructive techniques (pilot applications), in order to quantify the efficiency of alternative existing strengthening strategies and to develop preventive strategies which can enhance the performance of monuments with respect to dynamic loading, while complying with the conservation criteria (integrity, compatibility, reversibility and durability), i.e. respect for the original materials and fabric;
Objective 4: to quantify the socio-economic impact of different structural conservation strategies for the cultural heritage as applied at Indian / European level, in terms of risk analysis and revenue for the tourism industry.
Objective 5: to increase the exchange of expertise between Europe and India, in the field of conservation of cultural heritage buildings, taking into account the best trade-off between the local constraints in a developing country such as India, with an invaluable cultural heritage and own specific building techniques, materials and structural shapes, and the most advanced techniques applicable for building surveying, testing, monitoring, modelling and restoring. The restoration techniques and materials for the Indian case study will be defined, taking into account their compatibility with local and ancient construction techniques and materials.

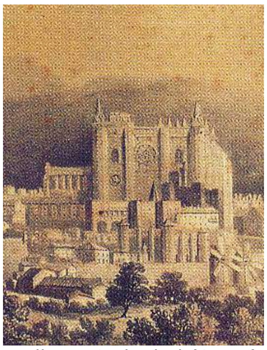
Given that, it can be said that the main objective of the project is the development of a social and economic argument, at Indian-European level, to support an earthquake protection innovative program for cultural heritage masonry buildings at risk. This consider cultural heritage buildings/monuments in earthquake prone areas in Europe and India, identify seismic input scenarios and specific vulnerability features, produce a risk analysis with respect to different return periods, and study advanced upgrading and strengthening techniques. The project is based on a multidisciplinary approach, entailing aspects of risk analysis, in situ survey and monitoring, numerical analyses and the design/application of innovative strengthening strategies. The purpose is to devise strengthening strategies that, based on thorough knowledge of the traditional craft and material, can use modern materials and techniques to prevent vibration borne damage to the structures and to the decorative apparatus.

Main achievements:

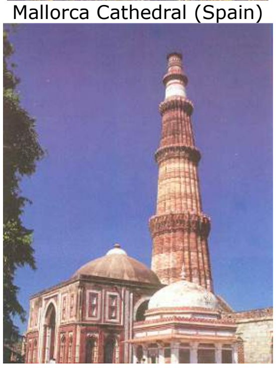
The projects comprises the execution of 8 integrated activities, which combine information exchange, knowledge transfer, applied research and comparative studies, making use of four demonstration case studies in Europe and India, see figure 1. The activities are as follows:
Activity 1: Inventory of monuments at risk
Activity 2: Seismic activity and site effects
Activity 3: Seminar in Padova 2004 (Italy)
Activity 4: In situ tests and monitoring
Activity 5: Evaluation and strengthening
Activity 6: Definition of guidelines
Activity 7: Dissemination
Activity 8: Seminar in New Delhi 2006 (India)

Activity 1 demonstrated that the building typologies and restoration practices in India seem rather different from the ones in Europe, which is a major issue before technology transfer to India. It also enriches European partners' knowledge and future approaches in their own cultural heritage.

Activity 2 allowed to detect different approaches and different safety levels for earthquake action, in the different countries. Again, this is a major issue for information transfer between countries.



Jeronimos Church (Portugal) Mallorca Cathedral (Spain)



Reggio Emilia Cathedral (Italy) Qutb Minar (India)

Figure 1 – Case studies under analysis.

In activity 3, about three-hundred participants joined the Fourth International Seminar on Structural Analysis of Historical Constructions, with an origin in 27 different countries, and one-hundred and fifty papers are included in the conference proceedings. The partners of the project had invited lectures at the Seminar and UNESCO also supported the event, holding a special invited lecture. The European Commission decided to hold a meeting during the event for the creation of a Focus Area in Cultural Heritage, for the 7th Framework.

In activity 4, the geometric survey and historical survey was carried out, together with dynamic and static monitoring system installation. Examples include: in situ testing and investigation included GPR (radar) investigation of all columns of the Jeronimos Church nave, vaults of the nave and North wall, see figure 2; static and dynamic monitoring systems in Reggio Emilia Cathedral, see figure 3

Activity 5 was completed in all case studies, see figure 4. Qutub Minar was further adopted as a benchmark for all partners for this activity, so that it can be further utilized in Activities 6 and 7

Activities 6, 7 and 8 allowed ample dissemination in India and worldwide, including CD-ROM and website, special purpose database for the management of results from the project and video with virtual model for public presentation.

Figure 2 – In-situ testing.

Figure 3 – Static monitoring.

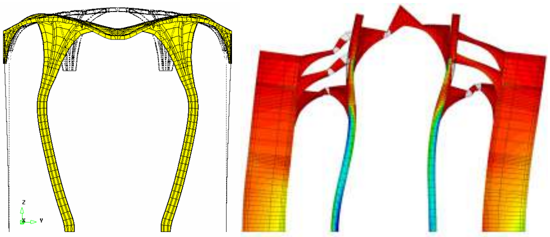


Figure 4 – Numerical modelling and safety evaluation.

Relevant publications:

International Journals

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Lourenço, P.B., Roque, J.A., Simplified indexes for the seismic vulnerability of ancient masonry buildings, Construction and Building Materials, 20(4), pp. 200-208 (2005)

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Ramos, L.F., Lourenço, P.B., Static and dynamic structural monitoring of the Santa Maria of Belém Church, in Lisbon, em II ECCOMAS Thematic Conference on Smart Structures and Materials, Lisbon, Portugal, CD-ROM (2005).

Lourenço, P.B., Oliveira, D.V., Vasconcelos, G., Ramos, L.F., Improving the seismic resistance of cultural heritage buildings, em 1st US-Portugal International Workshop – Grand challenges in earthquake engineering, Lamego, Portugal, p. 19.1-19.13 (2005).

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Agrawal, S., Seismic rehabilitation of heritage buildings in India – problems and prospects, in: Structural analysis of historical constructions 2004: Possibilities of numerical and experimental techniques, p. 3-14 (2004).

Oliveira, D.V., Ramos, L.F., Lourenço, P.B., Roque, J., Structural Monitoring of the Monastery of Jerónimos, International Conference 250th anniversary of the 1755 Lisbon earthquake, Lisbon, Portugal, pp. 466-473 (2005).

Roca. , P., Studies on the origin of deformation and damage in long-span historical structures, in: 11th International Conference on Fracture Mechanics, italy, p. 642 (2005).

Conferences and related Proceedings

Lourenço, P.B., Roca, P., Modena, C., Agrawal, S. (Editors), Structural analysis of historical constructions: Possibilities of numerical and experimental techniques, ISBN 9781403-931559, 9781403-931566, 9781403-931573, McMillan India, New Delhi, 2083 pp (2006).

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Overview of seismic risk for large span buildings heritage.

Modelling of seismic hazard and site conditions for each monument.

Design and validation of systems and devices.

Thesis

Metodologia integrada para avaliação e mitigação da vulnerabilidade sísmica das construções históricas em alvenaria. A igreja dos Jerónimos como caso de estudo, João Roque, PhD Thesis (expected by February 2008).

Damage identification on masonry structures based on vibration signatures, Luís Ramos, PhD Thesis, University of Minho, Portugal (2007).

Análise estrutural de abóbadas poli-nervuradas: Aplicação ao coro alto do Mosteiro dos Jerónimos, Pedro Lança, MSc Thesis, University of Minho, Portugal (2006).

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Krakowiak, K., Lourenço, P.B., Possible strengthening strategies for the Church of Monastery of Jerónimos, Relatório 06-DEC/E-08, Universidade do Minho, 22 pp (2006).

Lança, P.B., Lourenço, P.B., Análise da estabilidade do coro alto da Igreja do Mosteiro dos Jerónimos, Relatório 06-DEC/E-010, Universidade do Minho, 79 pp (2006).

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Industrialised solutions for construction of reinforced brick masonry shell roofs
(CRAF-1999-70420)

Financing Institution(s): Supported by the European Commission under the 5th framework programme

Promoting Institution(s): Suceram (SME)

Coordinator(s): Paulo B. Lourenço, Joaquim O. Barros

Researchers and collaborators: Paulo B. Lourenço; Joaquim O. Barros; Juliana Oliveira; Kesio Palacio; J.C. Almeida

Partner Institutions: 6 industrial companies
Technical University of Catalonia, SPAIN
University of Minho
Universita' degli Studi di Padova, ITALY
University of Berlin, GERMANY

Period: November 2001 to July 2004

Relevant facilities: DIANA software with user supplied subroutines; Servo close-loop equipments for experimental programs; Biaxial rig (specimens up to 1.0 x 1.0 m^2), 2000 kN compression and 500 kN tension

Objectives:

Traditional construction made use of bricks in arches and vaults leading to slender, light and ingenious solutions whose strength was guaranteed by the curved shape. The objective of the current project was to update the old roofing techniques (deeply rooted into the European tradition) to the present situation. Envisaged solutions are short to mid-span thin vaulted roofs made with reinforced brick masonry. Innovations are: industrialization, only light formwork requiring (cheaper and faster construction), broad testing, numerical modeling of the structural behavior (to allow for rationally-based design) and design guidelines. Main advantages sought, when compared to competing techniques: cheaper, eco-efficient, fitting architecture trends, better structural behavior, nice looking and ageing, long-lasting and virtually maintenance-free.

Main achievements:

The main achievements of the project include:

• Proposal of novel industrialised solution for reinforced masonry shells, including partial prefabrication with flexible pre-assembled strips and full prefabrication, see Figs 1 and 2. The former system includes flat strip, with special units, special grips, an adhesive bottom layer to provide joint finishing and an expanded metal sheet top layer as a final assembly set. In the second case, special moulds able to accommodate different joint finishings and large geometrical tolerances have been conceived. In both cases special micro-concrete / mortar mixes have been designed.

Fig. 1 – Novel industrialization techniques: partial prefabrication.

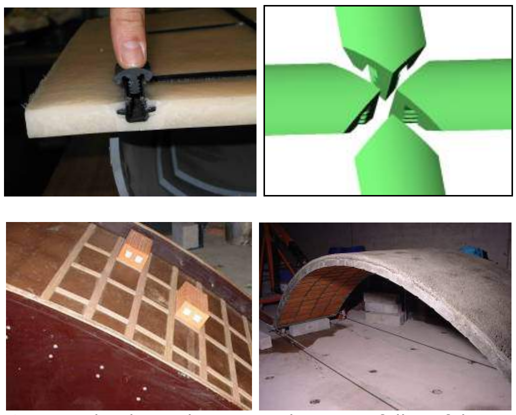
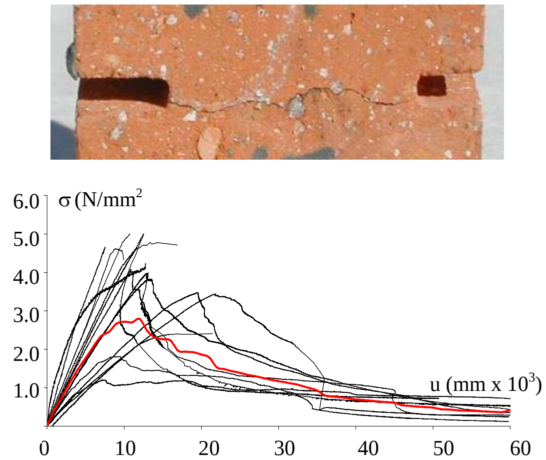


Fig. 2 – Novel industrialization techniques: full prefabrication.

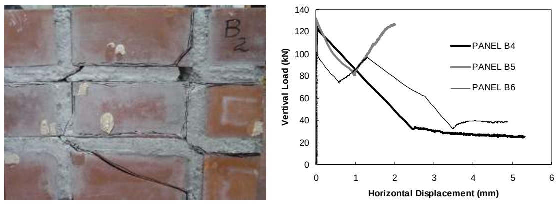
• Construction of prototype buildings using the industrial technologies developed in the project, see Fig 3.

Fig. 3 – Example of prototypes built.

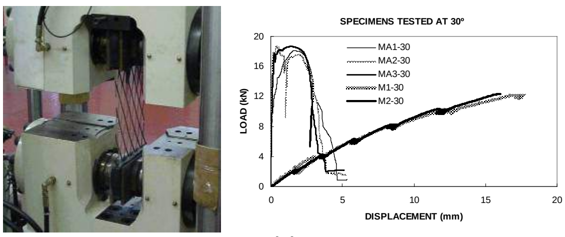
• Comprehensive material characterization, including post-peak behaviour. Of much relevance for the advancement in knowledge and for the novel data gathered for sophisticated non-linear structural analysis are the characterization of brick tensile strength, the assessment of the shear strength of stacked masonry and full characterization of expanded metal sheet., see Fig. 4.



(a)



(b)



(c)

Fig. 4 – Experimental characterization of different materials used in the project: (a) brick; (b) masonry; (c) expanded metal sheet.

Simplified and advanced methods of structural analysis and design, see Figs. 5 and 6. This includes novel developments in non-linear finite elements analysis, tools based on non-linear moment-curvature relations and tools based on limit analysis (kinematic and static approaches). Linear elastic structural analysis was confirmed as a less adequate tool for the design of lightly reinforced masonry arches.

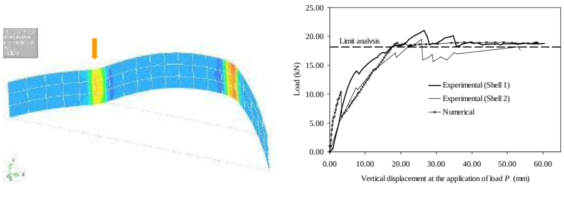


Fig. 5 – Structural tools: analysis software.

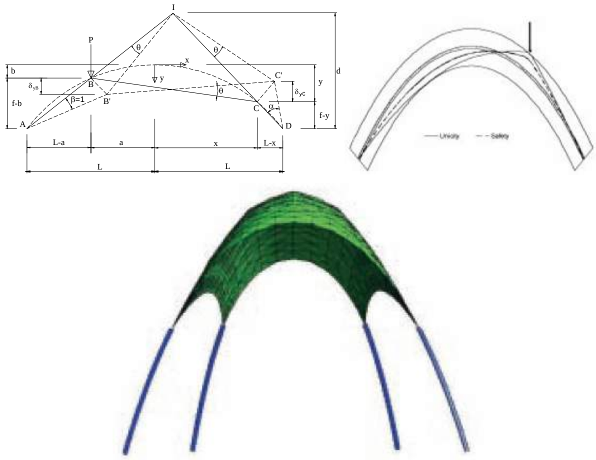


Fig. 6 – Structural tools: design software and design formulas developed.

Relevant Publications:

International Journals

Barros, J.A.O., Lourenço, P.B., Oliveira, J.T., Bonaldo, E., Experimental characterization of a new reinforced brick masonry shell structural system, Structures and Buildings, (accepted for publication) (September, 2007).

Barros, J.A.O., Oliveira, J.T., Bonaldo, E., Lourenço, P.B., Flexural behavior of reinforced masonry panels, ACI Structural Journal, 103(3), p. 418-426 (2006).

Lourenço, P.B., Almeida, J.C., Barros, J.A., Experimental investigation of bricks under uniaxial tensile testing, Masonry International, 18(1), p.11-20 (2005).

Lourenço, P.B., Barros, J.O., Oliveira, J.T., Shear testing of stack bonded masonry, Construction and Building Materials, 18, p.125-132 (2004).

National Journals

Lourenço, P.B., Barros, J.A., Oliveira, J.T., Analysis, testing and building technology for industrialised reinforced masonry shells (in Italian), Costruire en Laterizio, 107, p. 62-63 (2005)

Oliveira, J.T., Bonaldo, E., Barros, J.A.O., Lourenço, P.B., Innovative technologies for the prefabrication of reinforced clay masonry shells (in Portuguese), Engenharia e Vida, 13, p. 62-65 (2005).

Thesis

Advances on the design of thin surface structures in reinforced concrete, Kesio Palácio, PhD Thesis, University of Minho, Portugal (2007).

Experimental investigation about the prefabrication of reinforced clay masonry shells (in Portuguese), Juliana Torres de Oliveira, PhD Thesis (2005).

Characterization of masonry subjected to tension (in Portuguese), José Carlos Costa de Almeida, MSc (2003).

Reports

Palácio, K., Lourenço, P.B., Barros, J.O., Design of RC elements subjected to in-plane loading, Relatório 03-DEC/E-30, Universidade do Minho, 45 pp (2003).

Palácio, K., Lourenço, P.B., Barros, J.O., Numerical Modeling of single shell roofs, Relatório 03-DEC/E-21, Universidade do Minho, 42 pp (2003).

Palácio, K., Lourenço, P.B., Barros, J.O.B., Contribution to Design Criteria for Industrialized Masonry Vaults, Relatório 03-DEC/E-10, Universidade do Minho, 50 pp (2003).

Oliveira, J.T., Barros, J.O., Lourenço, P.B., Bonaldo, E., Flexural behavior of reinforced masonry panels, Relatório 02-DEC/E-10, Universidade do Minho, 70 pp (2003).

Barros, J.O., Lourenço, P.B., Torres, J.O., Bonaldo, E., Task T3.2 – Contribution for a full prefabrication approach of masonry reinforced shells, Relatório 03-DEC/E-05, Universidade do Minho, 15 pp (2003).

Lourenço, P.B., Palácio, K., Prieto, F., Implementation of a constitutive model for masonry shells as a stand-alone subroutine, Relatório 02-DEC/E-13, Universidade do Minho, 50 pp (2002).

Lourenço, P.B., Barros, J.O., Almeida, J.C., Characterization of masonry under uniaxial tension, Relatório 02-DEC/E-12, Universidade do Minho, 24 pp (2002).

Oliveira, J.T., Barros, J.O., Lourenço, P.B., Marques Pinho, A., Uniaxial testing of expanded metal sheet, Relatório 02-DEC/E-11, Universidade do Minho, 31 pp (2002).

Oliveira, J.T., Lourenço, P.B., Barros, J.O., Shear testing of stacked bonded masonry, Relatório 02-DEC/E-10, Universidade do Minho, 33 pp (2002).

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Influence of the joint stiffness in the static and dynamic behaviour of timber structures: consequences of different strengthening techniques

(POCTI/ECM/56552/2004)

Financing Institution: Operational Program for the Science, Technology and Innovation (POCTI)

Promoting Institution(s): University of Minho (UM)

Coordinator(s): Paulo J.S. Cruz (UM)

Researchers and collaborators: Paulo Cruz (UM), Helena Cruz (LNEC), Jorge Branco (UM), Daniel Oliveira (UM), Artur Feio (UM), António Baptista (LNEC), Lukasz (UM), Saporiti Machado (LNEC), António Silva (LNEC) and Ana Santos (UM).

Partner Institutions: National Laboratory of Civil Engineering (LNEC)

Period: February 2005 to June 2008

Objectives:

1. To determine the elastic and post-elastic behaviour of timber joints under monotonic and cyclic loading, especially in what concerns their moment transmission capability;
2. To assess the influence of a number of parameters in the joint behaviour (small geometry variations within the "birdsmouth" shape, materials variability, ageing and weathering, etc);
3. To experimentally assess the efficiency of different joint retrofitting techniques applied to the studied geometry;
4. To study the influence of the joints rotational stiffness (moment transmission capability) in the overall behaviour of truss rafters;
5. To make general recommendations on joints retrofitting having in mind possible overall behaviour modification.

Main achievements:

Structural survey

A preliminary survey aimed to collected data about geometries, typologies, wood species, pathologies, etc. was conducted.

Fig. 1 – Most common trusses typologies of Portuguese traditional timber trusses.

Static and dynamic behaviour of timber trusses

A structural analysis of common trusses traditionally used in roof construction in Portugal was performed. The study includes the results of a two-dimensional linear elastic static and dynamic analysis. The trusses behaviour under symmetric and non-symmetric loads, the king post/tie-beam connection, the stiffness of the joints and the incorrect positioning of the purlins, were some of the structural aspects that have been investigated.

Experimental analysis on original joints

This task includes the design, fabrication, conditioning (and ageing) of full-size timber carpenter knee-joints and their test under monotonic and cyclic loads. Special attention was paid on the birdsmouth joint because of its frequent use in practice. Tests on unreinforced joints were performed in order to acquire information on the primary behavioural characteristics of the joint as well as its sensitivity to some parameters (geometry variations, materials variability, ageing and weathering, etc.).

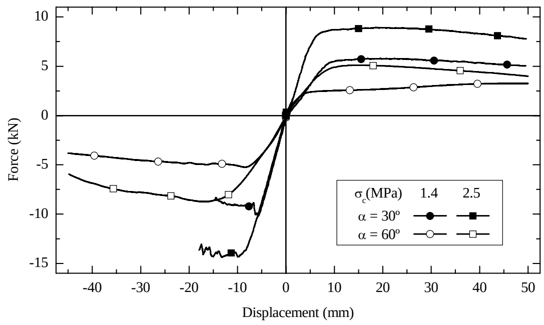


Fig. 2 – Force-displacement curves of unstrengthened connections.

Numerical modelling of traditional timber joints

A fruitful interaction between experimental and numerical analysis enable the team to adequately prepare the former task on the basis of first numerical results, and to simplify this task by eliminating the modelling of non-significant aspects. The numerical analysis used the available orthotropic models developed at University of Minho.

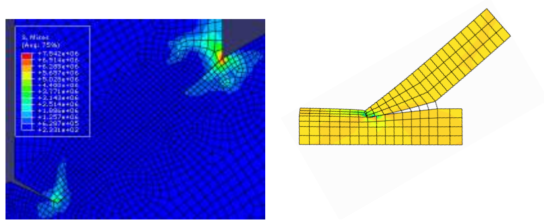
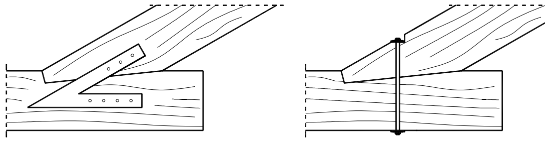


Fig. 2 – FEM model developed for the unreinforced joints.

Experimental and numerical analysis of different joint reinforcement techniques

A comparative study of reinforcement techniques applied to the studied joint geometry was carried out in order to evaluate their effectiveness. These are basic examples of traditionally used typologies and represent modern implementations of traditional strengthening techniques.



(a) Bolt (b) Binding Strip

Fig. 3 - Different types of traditional strengthening techniques evaluated.

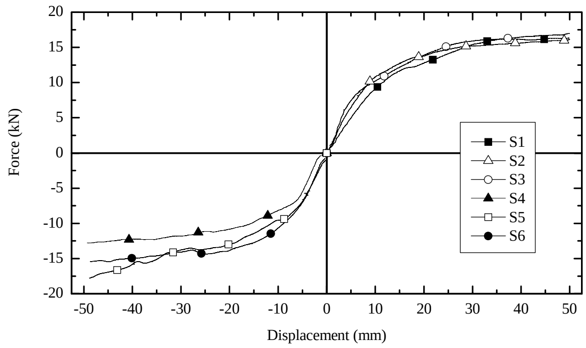


Fig. 4 – Results of a monotonic and cyclic test of a joint strengthened.

Full-scale tests of timber trusses structures

Some timber trusses were experimental and numerical analysed to study the influence of the joint stiffness in the global static and dynamic behaviour. The selected reinforcement techniques are the ones which presented the best results in terms of capacity, stiffness and ductility from the previous tasks. Some of the experimental tests included in this task were carried out in the Structural Testing Laboratory of the University of Trento (Italy).

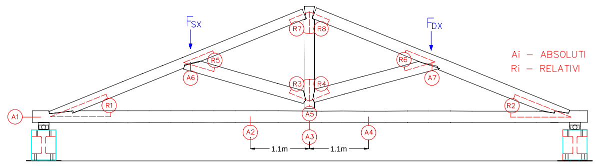


Fig. 5 – Setup of the full-scale tests over two king-post trusses.

Development of design recommendation for Portuguese practitioners

The experimental work and the numerical analysis will be followed by the proposal of practical models. These simple models will be calibrated with the FEM modelling results and experimental results obtained in the static and dynamic analysis of reinforced and unreinforced joints. Based on the previous tasks some design recommendations will be presented.

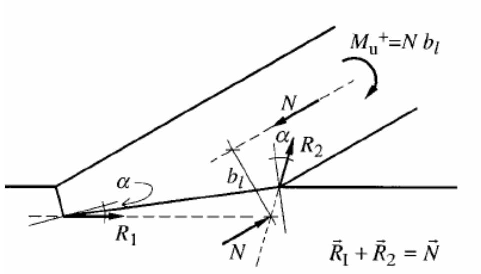


Fig. 6 – Simplified models

Relevant publications:

National Journals

Branco J., Santos A., Cruz P. (2007). Asnas Tradicionais de Madeira: Evolução, Comportamento e Reforço com Materiais Compósitos. Revista Portuguesa de Engenharia de Estruturas (RPEE), Accepted for publication in 12 November 2007.

International Conferences

Branco J., Cruz P., Piazza M., Varum H. (2006). Strengthening Techniques of Portuguese Traditional Timber Connections. Structural Analysis of Historical Constructions. P.B. Lourenço, P. Roca, C. Modena, S. Agrawal (Eds.), New Delhi, 2006, pp. 359-366.

Branco J., Cruz P., Piazza M., Varum H. (2006). Modelling of timber joints in traditional structures. International Workshop on "Earthquake Engineering on Timber Structures". Coimbra, Portugal, November 2006, pp. 1-15.

Branco J., Cruz P., Piazza M., Varum H. (2006). Experimental Analysis of Original and Strengthened Traditional Timber Connections. 9th World Conference on Timber Engineering (WCTE 2006), August 6-10, 2006, Portland, Oregon, USA.)

Branco J., Cruz P., Piazza M., Varum H. (2006). Portuguese Traditional Timber Roof Structures. 9th World Conference on Timber Engineering (WCTE 2006), August 6-10, 2006, Portland, USA.

National Conferences

Cruz H., Palma P. (2006). Ligações em Estruturas de Madeira. Para além dos pregos quadrados; Encontro Nacional Sobre Qualidade e Inovação na Construção (QIC2006); Vol. 2; 733-744; 2006.

Palma P., Cruz H. (2006). Comportamento de ligações tradicionais em estruturas de madeira; 4as Jornadas Portuguesas de Engenharia de Estruturas (JPEE 2006), 2006.

Branco J., Cruz P., Piazza M. (2006). Asnas de madeira. A importância da rigidez das ligações. 4as Jornadas Portuguesas de Engenharia de Estruturas (JPEE 2006), 2006.

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Innovative solutions for non-load bearing masonry infills
(PTDC-ECM-68188-2006)

Financing Institution(s): Portuguese Science and Technology Foundation (FCT)

Promoting Institution(s): Universidade do Minho

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Daniel Oliveira; J. Barroso Aguiar; Aires Camões; Paulo Pereira; Nuno Mendes

Partner Institutions: National Laboratory of Civil Engineering

Period: January 2008 to December 2010

Relevant facilities: DIANA software with user supplied subroutines; Servo close-loop equipments for experimental programs; Reaction wall; 4.0 × 4.0 m^2 shaking table; dynamic identification equipment

Objectives:
The objective is to evaluate the present state of the envelope of the recent built heritage, in order to provide adequate rules and recommendations for the design of new buildings, and define adequate solutions for repair and strengthening. The significant relevance of this project results from: (a) the significant cost of correcting damages usually observed in the envelopes; (b) the recent statement from modern regulations (EC8) that the structural designer is responsible for damages in non-structural walls in the case of an earthquake; (c) the need for adequate prescriptions in non-loadbering walls, in zones of moderate or high seismicity. It is stressed that the walls will be tested simultaneously in in-plane and out-of-plane directions, which is particularly innovative. This type of tests is rather infrequent in buildings, which often do not have masonry walls or, if the walls are present, tests are usually made on in one direction.

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Integrated approach for conservation and valuation of monuments
(POCTI-HEC-60431-2004)

Financing Institution(s): Supported under the Operational Program for the Science, Technology and Innovation (POCTI)

Promoting Institution(s): University of Minho

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Department of Civil Engineering: Paulo B. Lourenço; Graça Vasconcelos; José Luís Ramos; Miguel Amado, Fernando Peña
Department of Earth Sciences: Carlos Alves; Jorge Pamplona
Department of Mechanical Engineering: Fernando Castro; Cândida Vilarinho
Department of Physics: Sérgio Nascimento; José Mendes

Partner Institutions: Graphics Computations Center

Period: March 2005 to October 2007

Objectives:
The main objective of the project is to define and validate a cost-effective approach for assessment, preservation, exploitation and fruition of historical buildings. This objective will be achieved by a information management system based on the internet and a novel graphical interface. The project uses Monastery of Salzedas as a case study, and incorporates the knowledge from a broad range of scientific fields.
The planned tasks include: Onsite Survey and Preliminary Diagnosis; Study of the Traditional Construction and Intervention Techniques; NDT and MDT; Monitoring; Structural Modeling; Promotion and Valuation of Case Studies and Knowledge; Selection of the Intervention and Maintenance Procedures; Guidelines and Recommendations for Intervention and Conservation.

Main achievements:

Conservation and interventions of cultural heritage buildings require an interdisciplinary approach with specialists of different areas of knowledge, for example: non-destructive tests, advanced structural analyses, urban planning, traditional materials (masonry, lime, wood, etc.), mechanisms of deterioration, traditional and innovative techniques of intervention, compatibility, philosophy and ethics of the conservation, etc. However, the mere addition of different experts does not create a team.

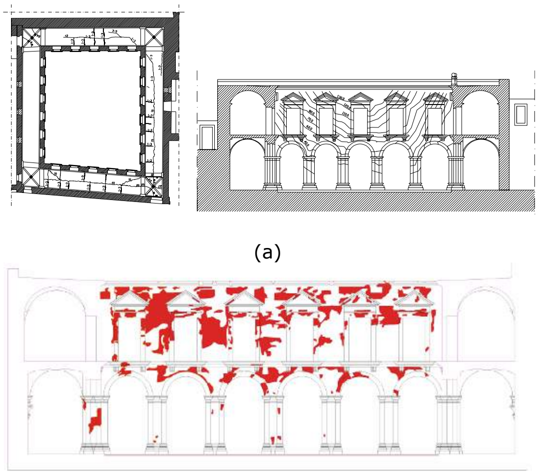
Anyone involved in the conservation of cultural heritage buildings is aware of the enormous amount of information generated by the different specialists, which is generally not handled adequately by owners and/or authorities involved in the process. The consequence is that valuable information is lost in a complex process of reaching a decision that involves many experts and information tends to get forgotten or misplaced in the course of time.

Upon the recognition of this evidence, University of Minho (UMinho) in partnership with Centre of Computer Graphics (CCG) and the former Portuguese Institute of Architectural Heritage (IPPAR) developed an application for the efficient management and visualization of the information related to interventions of cultural heritage buildings. The development was based in a case study with extensive damage and that recently suffered major works in a cloister, namely the Monastery of Santa Maria de Salzedas (Portugal). A database was created for the management of all the information generated during the intervention process of 2005 and the historical information collected which has been produced along the time and has been selected by different areas of study.

The information is accessible via intranet for practioners and on the monastery for visitors, in way that a non-specialist and a team specialist can obtain information with different contents.

Several experts were involved in Monastery of Santa Maria de Salzedas and used the developed information management tool. One examples of work done includes: "Onsite survey and preliminary diagnosis (Fig.)". The survey indicated a poor original condition of the cloister, including significant cracking, tilting of walls and sagging of floors, together with severe deterioration of the bricks and stone. Another part of the complex (East body) is in very bad conditions, particularly the roof. Two roofs are missing and the church has extremely high moisture contents, due to rising humidity.

The information management system includes: a) the design and development of a database for managing the information collected in the intervention project; b) the implementation of a user interface for information access through the internet; c) the implementation of a VR of the monastery; and d) the creation of a "memory" and a "history" of the building for future interventions. The nature of the information presented in the application is mainly technical, even for the general public, aiming at promoting the public awareness of technical aspects related to the conservation of monuments and historical constructions. The application, as well as the database, is structured in three main groups, which define the way in which the information can be accessed, namely spatial units, level of access and thematic areas, see Figs. 2 and 3 for the front-end and the flux diagram of the application. Fig. 4 shows a possible model of the medieval monastery for virtual visit.



(a)

(b)

Fig. 1 – Examples of damage survey in the cloister: (a) cracks and out-of-plane deformation; (b) stone detachment.

Fig. 2 – Examples of management system: Possible monitor window.

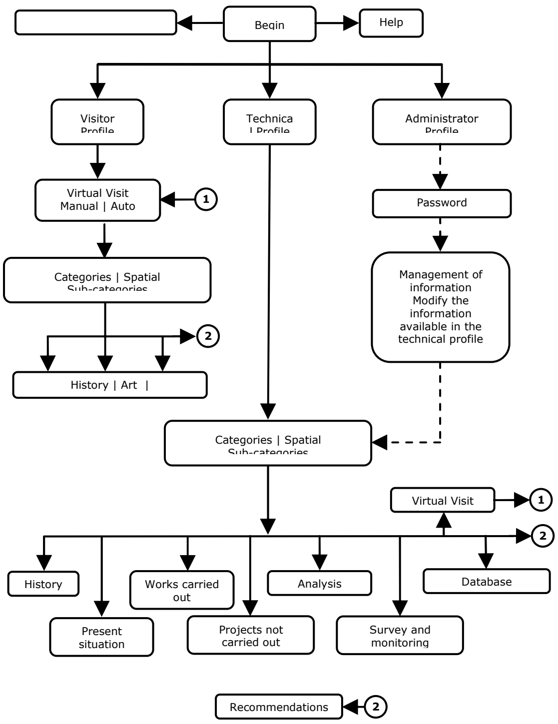


Fig. 3 – Examples of management system: Flux diagram.

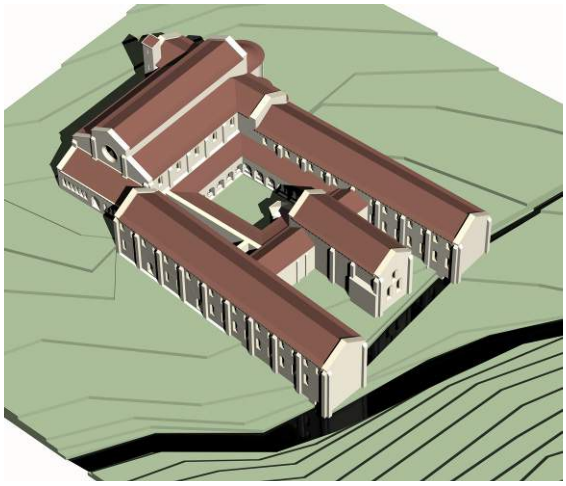


Figure 4 – Hypothetical three-dimensional model of the medieval monastery.

Relevant Publications:

International Journals

Lourenço, P.B., Peña, F., Amado, F., An application for information management in the conservation of cultural heritage buildings. Application to Monastery of Santa Maria de Salzedas (Portugal), International Journal of Architectural Heritage (submitted for possible publication) (August, 2007).

Reports

Amado, M., Lourenço, P.B., Monitorização ambiental da Igreja de Salzedas (temperatura e humidade relativa), Relatório 07-DEC/E-24, Universidade do Minho, 5 pp (2007).

Amado, M., Lourenço, P.B., Peña, F., Modelo tridimensional do Mosteiro de Santa Maria de Salzedas na Idade Média, Relatório 06-DEC/E-15, Universidade do Minho, 36 pp (2006).

Lourenço, P.B., Vasconcelos, G., Ramos, L.F., Ensaios e Sondagens no Claustro do Mosteiro de Salzedas, Relatório 07-DEC/E-01, Universidade do Minho, 19 pp (2006).

Lourenço, P.B., Vasconcelos, G., Análise Estrutural do Claustro do Mosteiro de Salzedas, Relatório 07-DEC/E-02, Universidade do Minho, 19 pp (2006).

Lourenço, P.B., Peña, F., Amado, M., Definição da aplicação para a gestão e visualização da informação relativa ao Mosteiro de Santa Maria de Salzedas, Relatório 06-DEC/E-02, Universidade do Minho, 15 pp (2006).

Lourenço, P.B., Vasconcelos, G., Ramos, L.F., Levantamento e inspecção preliminar do Claustro do Mosteiro de Salzedas, Relatório 06-DEC/E-01, Universidade do Minho, 22 pp (2006).

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GRICES-CAPES – "Investigação em ligações metálicas"

Financing Institution(s): Supported under the International Cooperation Program CAPES (BR) – GRICES (PT)

Promoting Institution(s): University of Coimbra (Portugal), State University of Rio de Janeiro – UERJ (Brasil)

Coordinator(s): Luís Costa Neves (University of Coimbra), Pedro Vellasco (UERJ)

Researchers and collaborators: Luís Simões da Silva, Luís Costa Neves (coordinator), Rui Simões (University of Coimbra), and José Guilherme Santos da Silva, Luciano Rodrigues Ornelas de Lima, Pedro Colmar Gonçalves da Silva Vellasco, Sebastião Arthur Lopes de Andrade, Juliana da Cruz Vianna (UERJ)

Partner Institutions:

Period: 2005-2008

Relevant facilities: All facilities from the partner research groups at the University of Coimbra and the State University of Rio de Janeiro. These include computational facilities and structural laboratory facilities.

Objectives:

The main objectives of the cooperation project between the Steel and Composite Group of the Civil Engineering Department of The University of Coimbra and the PGECIV of the State University of Rio de Janeiro are the training of high level researchers, by co-supervising master and doctoral thesis, the exchange of experiences and research conclusions in the field of steel and composite structures, and in particular in the sub-topic of connections. These results are to be materialized in joint publications, such as international conference papers, international journal papers, and national conferences, both in Portugal and in Brasil. On the other hand, the enhancement of the productivity of both groups is to be expected from the sharing of knowledge and experiences.

Main achievements:

The main orientations of this project involving the "Programa de Pós-Graduação em Engenharia Civil (PGECIV)" and the Steel and Composite Group of the University of Coimbra are the training of high level researchers, the exchange of experiences and research conclusions, and the production of joint publications. To achieve these goals, some steps were taken and are still being taken during the project period.

The PGECIV has four main disciplines in the field of steel and composite structures, were the Portuguese members may give short lectures, during their missions to UERJ. The same may be done in the University of Coimbra by the Brasilian members, both at undergraduate and graduate levels, in particular at the Master in Steel and Composite Structures. This was actually implemented during some of the missions. As examples, Profs José Guilherme and Pedro Vellasco from UERJ were involved at the University of Coimbra in giving lectures on floor vibrations and on composite connections respectively to students that were about to engage in their thesis of the second cycle in the Bologna process. As a result, these elements of the Brasilian team will co-supervise two of those students, together with Luís Costa Neves, from Coimbra.

In the past, prior to this project and during this project, several Msc and Phd thesis were co-supervised by the two teams, but CAPES-GRICES has enhanced a lot the possibilities of this cooperation to be effective.

Besides the enhancement of the productivity of both groups expected from the sharing of knowledge and experiences, a quite substantial number of joint publications were produced, and some examples are listed at the end of this section.

Research activities are divided in three main categories:

1) Steel and composite structures and construction systems.

In this area, the following topics are studied:

- Innovative solutions for residential an commercial decks, exemplified in fig. 1
- Behaviour of steel and composite structures
- Behaviour of steel and composite connections
- Robustness of steel and composite structures and their response to exceptional actions

Fig 1 – Perfobond and T-Perfobond connectors being developed by the Portuguese and Brasilian Teams

These topics are studied in the context of European and Brasilian realities, using the state of the art rules and technologies from both parts, and exchanging the conclusions and trying to extrapolate them to the other part's reality. This is also achieved by contacts between the research teams and construction and industrial companies in the field of the systems being developed.

2) Numerical modelling of steel and composite structures and connections.

Non-linear finite element analysis of these elements were performed by the team, resulting in several conference papers.

An example is the numerical simulation of "T" and "KT" joints in tubular structures, testing and aiming at improving the EC3 design rules (fig. 2).

In this example, a finite element model was developed. To validate the model, material and geometrical properties used in the analysis were the same used in a numerical and experimental study by Lie et al., and both results were compared.

The results of the analysis were used to assess the EN 1993-1-8 performance. In addition, the importance of modelling the weld was assessed.

A parametric analysis was also performed to evaluate the joint global behaviour, using different joint geometries.

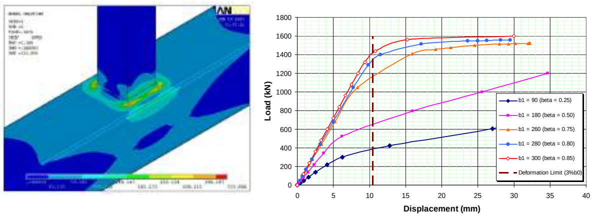

Fig 2 – Numerical simulation of "T" and "KT" joints in tubular structures

3) Dynamical behaviour and modelling of steel and composite structures.
The objectives of this line of research is to evaluate the behaviour of ordinary steel and composite structures when loaded by dynamical actions, such as pedestrian walking in footbridges or other human activities like gymnastics on building floors (fig. 3).

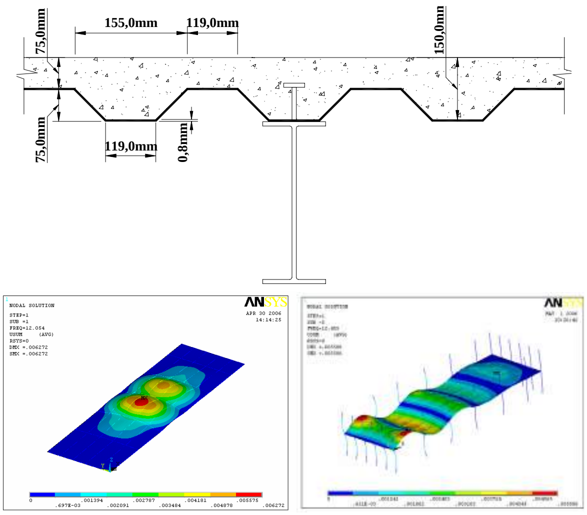

Fig 3 – Numerical simulation the dynamical behaviour of composite floors.

This area of research involves numerical and experimental studies. In December 2007 a real structure will be instrumented in Coimbra, to measure the accelerations and natural frequencies that will be compared to analytical results.

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J. da. C. Vianna, Costa-Neves, L.F., Vellasco, P.C.G.S. and S. A. L. de Andrade, "Structural Behaviour of T-Perfobond Shear Connectors in Composite Girders: an Experimental Approach", Engineering Structures, Elsevier (submitted for publication, 2007)

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Costa-Neves, L.F.; SILVA, Luís Alberto Proença Simões da ; Vellasco, P.C.G.S. . A Model for Predicting the Stiffness of Beam to Concrete Filled Column and Minor Axis Joints under Static Monotonic Loading. Proceedings of Eurosteel 2005, Fourth European Conference on Steel and Composite Structures. Aachen : Druck und Verlagshaus Mainz GmbH Aachen, 2005. v. C. p. 10131-10138.

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PABERFIA – Lightweight sandwich panels of steel fiber reinforced self compacting concrete

Financing Institution(s): Supported under the operational program for the Science, Technology and Innovation (POCTI) and Information Society (POSI), co-participated by FEDER and National Funds of MCT

Promoting Institution(s): Prégaia – Sociedade de Préfabricação, SA

Coordinator(s): Joaquim Barros (UM), Paulo Queirós (Prégaia)

Researchers and collaborators: Joaquim Barros; Eduardo Pereira; Vítor Cunha; Alberto Ribeiro; Simão Santos; Paulo Queirós

Partner Institutions: CiviTest - Pesquisa de Novos Materiais para a Engenharia Civil, Lda. University of Minho

Period: January 2003 to July 2005

Relevant facilities: FEMIX V4.0 Finite Element package; Servo close-loop equipments for experimental programs.

Objectives:

1. Develop a cost competitive steel fiber reinforced self compacting concrete (SFRSCC) for industrial applications (in façade panels);
2. Characterize the compression and the bending behavior of SFRSCC by experimental tests;
3. Cost analysis of traditional and SFRSCC solutions;
4. Assess the structural behavior by tests in real scale;

Main achievements:

Develop a cost competitive steel fiber reinforced self compacting concrete (SFRSCC) for industrial application in façade panels was one of the main purposes of this project. The requirements established for this SFRSCC were the following: average compressive strength at 24 hours greater than 20 MPa; equivalent flexural tensile strength greater than 2 MPa at this age; content of cement not exceeding 400 Kg/m^3; the cement should be the most expensive component of the binder paste. The method developed in the present work for preparing SFRSCC is based on the three following steps: i) the proportions of the constituent materials of the paste are defined; ii) the proportions of each aggregate on the final solid skeleton are determined; iii) the paste and solid skeleton are mixed in different proportions until self-compacting requirements are assured in terms of spread ability, correct flow velocity, filling ability, blockage and segregation resistance, which were assessed performing slump flow (see Fig. 1) and L box (see Fig. 2) tests.

Fig. 1 – Measuring the final diameter of SFRSCC.

Fig. 2.a - End of test.

Fig. 2.b - Measuring h2.

Fig. 2.c - Measuring h1.

In the precasting industry, the ability to demold the elements as soon as possible is an important requirement. To assure safe demolding process, the influence of the concrete age on the flexural (Fig. 3) and compression (Fig. 4) behavior of the SFRSCC should be known. For this purpose, an experimental program was carried out with specimens of 12 hours, 24 hours, 3, 7 and 28 days. Special care was taken to evaluate the post-cracking behavior of the SFRSCC, since the fracture mode I crack constitutive law was derived from the results obtained in these flexural tests, and used in a discrete crack model implemented into a computational code (FEMIX version 4.0) based on the finite element method that is able to simulate the nonlinear behavior of concrete structures (see Fig. 5).

Fig. 3 – Bending Test according to RILEM TC 162-TDF.

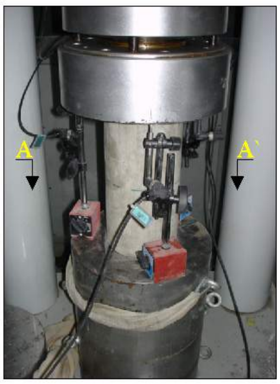

Fig. 4 – Compression Test.

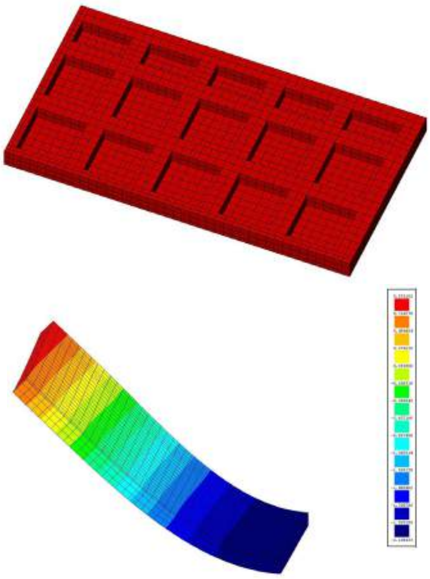

Fig. 5 – Modeling by FEM analysis.

Figs. 6 and 7 show the influence of age on the average compressive strength, f_{cm}, and on the initial average Young's modulus, E_{cm}, respectively.

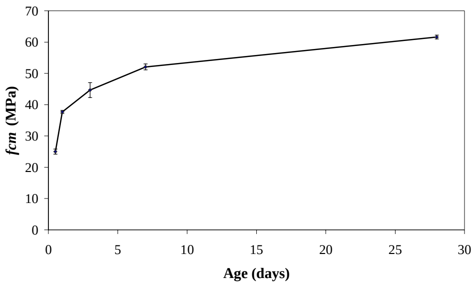

Fig. 6 - Influence of the SFRSCC age on its average compressive strength.

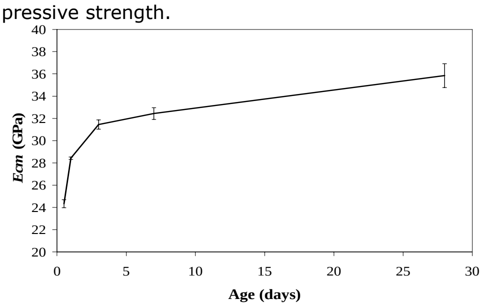

Fig. 7 - Influence of the SFRSCC age on its initial Young's modulus.

From force-deflection curves, F-δ, obtained in the three point notched beam bending tests, the load at the limit of proportionality (F_L), the equivalent ($f_{eq,2}$ and $f_{eq,3}$) and the residual ($f_{R,1}$ and $f_{R,4}$) flexural tensile strength parameters were evaluated at SFRSCC of distinct ages. The influence of the SFRSCC age on the values of these parameters is represented in Fig. 8.

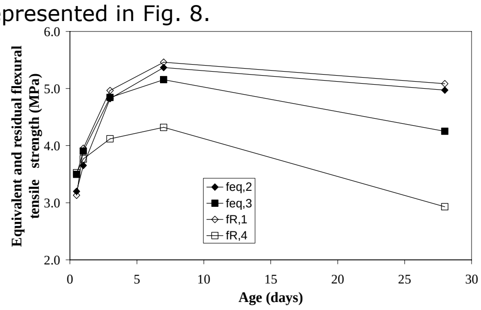

Fig. 8 - Influence of the SFRSCC age on the equivalent and residual tensile strength parameters.

Having been finished the characterization of the compression and bending behavior of the developed SFRSCC, the next step of the research program was to assess the behavior of SFRSCC panel prototypes under load configurations that can simulate the possible failures modes of the real application where the developed SFRSCC is intended to be used: façade panels. Therefore, SFRSCC lightweight panel prototypes were fabricated and tested under load configurations that induce bending (Fig. 9) and punching (Fig. 10) failures modes. Bending failures modes can occur due to wind loads. Since the SFRSCC compression layer is only 30 mm thick in the lightweight parts of the panel, punching can occur if point loads act in this part of the panel.

Fig. 9 - Bending Test in Panel Prototypes.

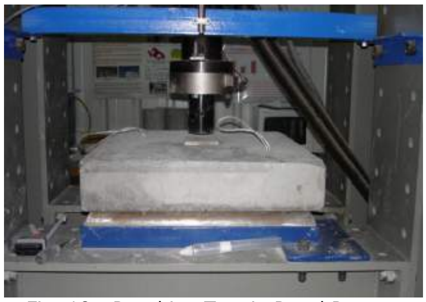

Fig. 10 - Punching Test in Panel Prototypes.

The last phase of the PABERFIA project dealt with the fabrication of a real panel in industrial environment (see Fig. 11). The panel was fabricated in the Prégaia installations, in São Félix da Marinha, Oporto, Portugal. This phase had the aim of verifying if the procedures adopted in the laboratory, in the development of a SFRSCC, can be directly applicable in industrial environment. It had also the purpose of evaluating the behavior of a real panel when submitted to its dead weight and to an increase live load up to its rupture.

Fig. 11 - 4.100×2.200×0.11 m^3 SFRSCC lightweight panel.

The panel supported a uniform distributed load of $8.25/(3.1\times1.5)=1.77$ kN/m^2, plus its dead weight (1.47 kN/m^2), see Fig. 12.

Fig. 12 - Loading test.

The total resisted uniform distributed load (1.77+1.47=3.24 kN/m^2) was higher than the characteristic value to the wind dynamic pressure in building of more than 100 m of height, located in A zone and in zones of type II irregularity (RSA, 1983). It may be concluded that, for the majority of the buildings, where façade panels are intended to be applied, the developed SFRSCC panel provides the necessary structural safety.

Relevant publications:

International Journals

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National Journals

Pereira, E.B.; Barros, J.A.O.; Camões, A.F.F.L., "Betão auto-compactável reforçado com fibras de aço - método de concepção e propriedades mecânicas", Revista da APEB, N. 12, pp.25-31, Maio 2004.

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Pereira, E.B.; Barros, J.A.O.; Camões, F.F.L.A., "Betão autocompactável reforçado com fibras de aço - procura de um método racional de concepção", Relatório 03-DEC/E-23, Departamento de Engenharia Civil, Universidade do Minho, 26 pp., Julho de 2003.

Thesis:

Candidate: Eduardo Borges Pereira
Type: Equivalent to Master
Supervisors: Joaquim Barros and Aires Camões
Title: Self-compacting steel fibre reinforced concrete – from material to mechanical behaviour
Conclusion: To proofs are booked to March 2006

Candidate: Vítor Manuel do Couto Fernandes da Cunha
Type: PhD
Supervisors: Joaquim Barros and Sena Cruz
Title: New methodology for the design, analysis construction and strengthening of industrial pavements using SFRSCC
Status: in course

Acknowledgments:

The coordinator of the present work wish to acknowledge the support that was provided by the BEKAERT; Degussa Chemicals Portugal; COMITAL – Companhia Mineira de Talcos, SA; SECIL – Companhia geral de cal e cimento, SA; DuroEuropa – Produtos Endurecedores, Lda; Marques e Cruz, Lda and FiberSensing.

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Modelling of the performance of timber structures

Financing Institution: European Cooperation in the field of Scientific and Technical Research (COST)

Promoting Institution(s): Swiss Federal Institute of Technology ETH

Coordinator(s): Jochen Köhler (Swiss Federal Institute of Technology ETH)

Member: Jorge M. Branco (Management Committee).

Signatures: Austria, Belgium, Croatia, Denmark, Finland, France, Italy, Ireland, Netherlands, Norway, Portugal, Slovenia, Switzerland and United Kingdom.

Period: December 2006 to December 2010

Objectives:

1. To improve the understanding about typical design and assessment situations as well as the circumstances, including exposure conditions leading to inadequate performance;
2. To provide guidelines on how to assess relevant exposures and to represent these in a format suitable as a basis for the design of high performance timber structures including aspects of moisture-related degradation;
3. To improve the fundamental understanding of timber material and engineered timber products, such as glued laminated timber, as well as the understanding of connections for efficient and reliable use in production and service;
4. To assess robustness and system aspects for timber structures;
5. To develop risk management and control methods for timber structures.

Main achievements:

The safe and sustainable use of materials in construction necessitates that the life-cycle performance of structures can be predicted and reassessed with sufficient accuracy. Recent research achievements in the field of materials science and structural reliability provide a framework for the quantification of safety, serviceability, durability and life-cycle costs of structures. These achievements are so far mainly used in the field of concrete and steel structural engineering. The knowledge about the behaviour of timber materials and structures is still considered as being insufficient for its use in such a framework. The main objective of this Action is to provide the basic framework and knowledge required for the efficient and sustainable use of timber as a structural and building material. This will be achieved by building on three main research activities: the identification and modelling of relevant load and environmental exposure scenarios, the improvement of know-ledge concerning the behaviour of timber structural elements and the development of a generic framework for the assessment of the life-cycle vulnerability and robustness of timber structures. The Action serves as a development platform for the European timber engineering research community to improve the knowledge about the life-cycle performance of timber structures.

Timber is an efficient building material, not least in regard to its mechanical properties but also because it is a highly sustainable material considering all phases of the life cycle of timber structures: production, use and decommissioning. Timber is a widely available natural resource throughout Europe; with proper management, there is a potential for a continuous and sustainable supply of raw timber material in the future. Because of the low energy use and the low level of pollution associated with the manufacturing of timber structures the environmental impact is much smaller than for structures built in other materials. In addition, timber is a rather advantageous building material because of its material properties. Timber is a light material and compared with its weight the strength is high; the strength: weight ratio is even higher than for steel.
However, considering its beneficial properties, timber is still not used to its full potential in the building and construction sector. Many building developers, architects and structural engineers do not consider timber as a competitive building material compared with concrete, steel or masonry. Attributes such as high performance regarding reliability, serviceability and durability are generally not associated with timber as a building material. One of the main reasons for this is that timber is a highly complex material; it actually requires a significant amount of expertise to fully appreciate the potential of timber as a structural building material. There are also a number of issues which need further research before timber materials can achieve the same recognition as a high quality building material such as steel and concrete. These issues are the focal point of this Action.

To ensure the achievement of the objectives, the work within this Action is divided into three working groups (WGs):

WG1: System identification and exposures

WG2: Vulnerability of components

WG3: Robustness of systems

The main tasks of the different working groups are specified as follows:

WG1. System identification and exposures

An important issue of this working group is the collection and the assessment of failures and malfunctions of timber structures on a European scale. Based on these observations possible gaps and shortcomings in current design and maintenance strategies will be identified and reflected in future considerations. Besides the observations and analysis of failures and malfunctions the theoretical aspects underlying different design and assessment situations will also be discussed in WG1.

Specifically the following aspects will be considered in WG1:

• Collecting information about failed or malfunctioning timber structures.

• Analysis of the mechanisms leading to failure and malfunctioning.

• Identification and representation of relevant exposures for the purpose of design and assessment.

• Identification of relevant design and assessment situations, including the identification and mapping of the relevant degradation mechanisms for Europe.

WG2. Vulnerability of components

The consideration of the lifetime performance of a timber structure is based on basic models about the relevant aspects of the structural components and connections. These aspects are:

• Basic strength and stiffness properties of graded timber material, glued laminated timber and related products.

• Dependency of these properties on load and climate scenarios which might occur during the lifetime of the structure, and size dependencies.

• Strength and stiffness properties of connections over service-life.

• Modelling of moisture-related degradation and service-life assessment of timber components and connections.

As found in COST Action E24, the underlying models and procedures used in practice do not consistently account for the uncertainties associated with the used models and the available experimental evidence. The focus of WG2 is to reassess and refine the present practice of modelling, especially for the important situations identified by WG1.

The development of service-life assessment models for moisture-related degradation of timber structures is still in a very early stage as compared with the situation for concrete and steel. To date no quantitative model for the deterioration of wood is implemented in the design codes. Based on the relevant degradation mechanisms identified by WG1, models for the most important of these will be suggested and quantified by WG2.

WG3. Robustness of systems

An important aspect for the assessment of the life cycle performance of timber structures is the interaction of structural components in structural systems. System effects in timber structures are pronounced because of multiscale spatial variability of environmental exposures and material properties. Existing numerical methods used to assess the reliability of timber structures need to be evaluated for their possible application to timber systems, and simplified approaches suitable for day-to-day engineering purposes must be identified. Furthermore, consensus on the general characteristics of timber systems regarding redundancy and robustness has not yet been established. To reach a better understanding of these aspects the following activities are planned within WG3:

• Characterisation of multiscale variability in timber structures.

• Analysis of system effects for several types of timber structures.

• Qualification of robustness as a characteristic of timber structures.

• Establishing a framework for reliability based design and assessment of timber structural systems based on these considerations.

Time schedule:

During the planned duration of the Action, frequent meetings and seminars take place. The so-called Management Committee (MC) meetings have mainly administrative character. Scientific contents are developed and discussed at the so-called Working Group (WG) meetings or seminars.

May 14-15, 2007 - Joint 3rd MC/WG meeting, Graz

October 4-5, 2007 - Joint 4th MC/WG meeting, Eindhoven

March 13-14, 2008 - Joint 5th MC/WG meeting, Helsinki

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INFASO: New market chances for steel structures by innovative fastening solutions

Financing Institution(s): Proposal for financial support from the Research Programme of the Research Fund for Coal and Steel for Research, Pilot and Demonstration projects

Promoting Institution(s): Universität Stuttgart, Germany

Coordinator(s): U. Kuhlmann

Researchers and collaborators:

Partner Institutions: Universität Stuttgart, Germany, Czech Technical University in Prague, GIPAC Ltd., Portugal, Goldbeck West GmbH, Germany, stahl+verbundbau GmbH, Germany

Period: November 2007 to November 2010

Relevant facilities: Laboratory and computational facilities from all partners

Objectives:
"Innovative Fastening Solutions" (InFaSo) promotes and encourages the wider use of steel in building structures where until now only concrete has been used. This is achieved by simple, efficient joints allowing for quick and easy connection of steel beams / columns to concrete structures with large tolerances. These joints also allow easy removal, strengthening and application for renovation by a simplified manufacturing and an enlargement of the design strength and ductility. The results will be prepared in the form of a handbook and electronic construction aids so that also engineers not used to design in steel are able to implement them. Thus "InFaSo" opens the gate for new market chances for steel structures and decisively enhance the competitive position of the European steel construction sector.

Scope:

The various requirements on building structures nowadays lead to a more complex decision than before. When planning buildings the conceptual formulation for future designers and decision makers forms a challenge on different fields. Not only economic efficiency aspects like an easy construction and short construction time have to be taken into account but also additional demands on buildings like the flexibility of use, durability, robustness, sustainability and the possibility for reconstruction of a building. All these aspects are linked up to the optimised application of resources like energy, materials and land. The consumption of these resources has to be considered for erection, operation and also adjustment to changing requirements on buildings. Considering these aspects integrative solutions between different materials, new construction technologies and the dissemination of new design methods are needed. Nowadays in most European countries there is a strong market dominance of concrete as building material though exceptions like office buildings in Great Britain or some prominent high rise structures show that steel structures especially as composite structures are competitive. One decisive reason is that "normal" engineers in practice are often not used to design steel structures especially steel joints. As a second point due to various reasons some structural elements such as foundations or stair cases and fire protection walls have to be made of concrete in any case. So it is the "easiest" solution for architects and designers and of course in the interest of concrete fabricators to realise the whole structure in concrete. However, to have easy to handle fastening solutions is the pre-condition that efficient steel / composite structures are realised. Efficient building structures following the new conceptual design mentioned above use the material according to its structural performance.

Such building structures require efficient connection technologies for joining the steel members to concrete walls or concrete foundations that may be designed not only by university groups but by ordinary designers in practice. The basic requirements for such a connection technology are economical and easy fabrication of the joints, quick and easy erection (which allows also for adjusting large tolerances), applicability also in existing structures, high loading capacity and sufficient ductility and the possibility of an easy design for practical engineers.
Typically problems occur where steel and concrete meet. Due to a gap between fastenings in concrete design and steel design and missing standardised joints that comply with the above mentioned requirements conventional concrete structures are designed as "normal" solutions, where the use of innovative structures – with an intelligent use of the materials according to their performance – would have been the better choice. The key to such innovative solutions is the design of the joints where different elements and different materials are connected. Therefore an integrative solution of steel and concrete design just as intended in this project can help to realise such innovative structures. The new innovative fastening solutions mentioned in this proposal are very quick and easy in assembling. They allow for an easy strengthening, post-installation (in case of renovation) and if necessary removable of the beam. As we are living nowadays in a mostly built surrounding the question how to refurbish and how to adapt existing structures to new requirements is of growing importance. In this project joints with steel profiles are considered that are connected by different kind of fasteners like studs (headed studs) or anchors (high bond or high performance anchors) to the concrete, see Fig. 1. They allow for a very quick and easy erection as for example the beam is just placed on the console, see Fig. 1a.

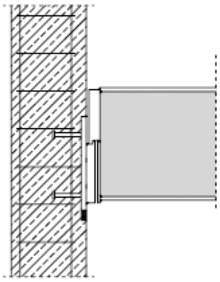

Fig 1 (a) Anchor plate with welded studs and cam as support of steel beams with small nose for horizontal support

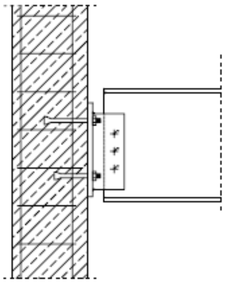

Fig 1 (b) Anchor plate with high performance anchors and welded flag plate as support of steel beam (applicable in renovation)

Furthermore joints of composite beams with walls which also allow a transfer of a small bending moment may easily be realised.
The high strength connections of steel columns by shear studs or anchors enable a very quick and easy erection before but also after finishing the concrete foundations. So the column with end plate and fasteners may be placed in preformed or drilled holes in the foundation which are then injected with high strength mortar (Fig 2b). Tolerances are compensated by choosing adequately large preformed holes. So there are no additional costs for adjustments.

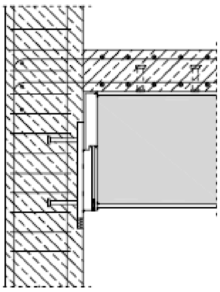

Fig 2 (a) Connection of a composite beam to a wall

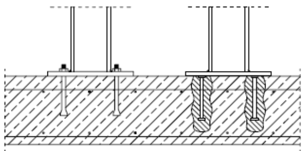

Fig 2 (b) Joints of steel columns to foundation using high performance anchors or high strength mortar and studs

To meet future requirements intelligent joints nowadays also have to provide resistance to fire and earthquake situations. In both cases a large ductility of the connection is required. If properly designed, mixed solutions of steel and concrete are especially appropriate to show increased resistance but also large ductility. This project will profit from the experience of the running project "Robust structures by joint ductility" dealing with steel-to-steel joints where some of the partners are involved. So both increased resistance and sufficiently large ductility are major design criteria for the development of innovative robust fastening solutions between steel and concrete (fig. 3).
Today effectiveness is often limited by isolated views on only one of the materials, steel or concrete and on either the details at the interface or the overall structural system. Therefore the key to innovate structural systems is an integrative modelling of steel joints at the interface of steel and concrete taking into account the requirement on strength, ductility and flexibility for structures often used in practice. These models must be based on harmonised design rules introduced in EC 3 and 2 i.e. accepted by both, the steel and the concrete side.

The solutions must be disseminated in handbooks and construction aids easy to use also for engineers and constructors not used to steel design. Thus the competitiveness of steel structures increases and new market opportunities for steel products are created.

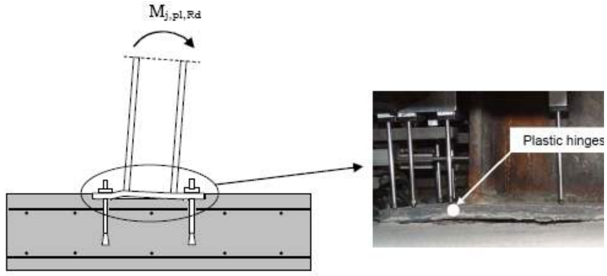

Fig 2 Ductile behaviour of column base joint by post-installing system

Relevant publications:

ACI 318: American Concrete Institute, ACI standard 318, Building Code Requirements for Structural Concrete, 2001, ISBN: 9992130903, 2001.

CEB Design Guide: Design of Fastenings in Concrete, Comite Euro-International du Beton, Thomas Telford, 1997.

ECCS Document No. 109: Design of Composite Joints for Buildings. ECCS Technical Committee 11 – Composite Structures, first edition 1999. Anderson, D. (ed.); Aribert, J.-M.; Bode, H.; Huber, G.; Jaspart, J.-P.; Kronenberger, H.-J.; Tschem-mernegg, F.

EN 1993-1-1: Design of steel structures, Part 1-1: General rules and rules for buildings, 2004.

EN 1994-1-1: Eurocode 4: Design of Composite Steel and Concrete Structures: Part 1.1: General Rules and Rules for Buildings. 2004.

EN 1992-1-1: Eurocode 2. Design of concrete structures – Part 1-1. General rules and rules for buildings. December 2004.

EN 1993-1-1: Eurocode 3. Design of steel structures – Part 1-1: General rules and rules for buildings, July 2005.

EN 1993-1-8: Eurocode 3. Design of steel structures – Part 8: Design of joints. July 2005

Raposo, J.M., Neves, L.F.C., Simões da Silva, L., Experimental Evaluation of the Behaviour of Tensioned Connectors Anchored in Concrete, Proceedings of STESSA 06 – Behaviour of Steel Structures in Seismic Areas, Yokohama, Japan, August 14-17 2006, pp 639-644.

José Maria Raposo, Luís Costa Neves, Luís Simões da Silva, Experimental Evaluation of the Influence of Reinforcement on the Tensile Resistance of Headed Steel Anchors Embedded in Concrete, Proceedings of the 2nd Symposium „Connections between Steel and Concrete", 2007 – University of Stuttgart.

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CUTINSHEAR – Performance assessment of an innovative structural FRP strengthening technique using an integrated system based on optical fibre sensors
(PTDC/ECM/74337/2006) POCTI/ECM/59033/2004

Financing Institution(s): Portuguese Science and Technology Foundation (FCT), POCI program

Promoting Institution(s): University of Minho

Coordinator(s): Joaquim Barros

Researchers and collaborators: UM: Joaquim Barros; Salvador Dias; João Lima; Rajendra Karma; Sena Cruz, INESC: Francisco Araújo, Luís Ferreira, Ireneu Dias, João Ferreira, Filipe Sá, Orlando Frazão

Partner Institutions: Instituto de Engenharia de Sistemas e Computadores do Porto

Period: March 2005 to March 2007

Relevant facilities: FEMIX V3.0 Finite Element package; Servo close-loop equipments for experimental programs

Objectives:
1- Develop a novel shear strengthening technique using laminates of CFRP, which, in comparison to the existent CFRP-based shear strengthening techniques, is simpler and faster to apply and is more efficacy in terms of provide higher increase of beam load carrying capacity and deflection at beam ultimate load;
2- Develop equipment for saw-cutting the slits where the CFRP laminates will be bonded by epoxy adhesive. This equipment should allow cutting slits of regulated width and deepness, and desired longitude;
3- Develop a unit control and acquisition system for measuring the strains in the CFRP laminates using optical fibers. These sensors will introduce marginal interference in the CFRP-concrete bond conditions. This device will be implemented into a servo-loop system to assure stable tests, controlling the test by the signal registered in the optical fiber sensors;
4- Develop design guidelines for this shear strengthening technique.

Main achievements:
In the first part of this project, an equipment for the installation of optical fiber sensors on CFRP laminates was conceived and built (see Fig. 1).

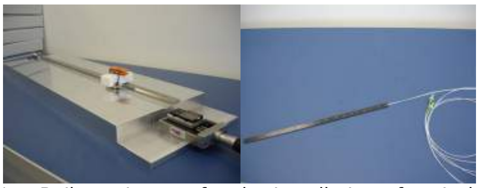


Fig. 1 – Built equipment for the installation of optical fiber sensors on CFRP laminates.

The developed technique is based on fixing, by epoxy adhesive, CFRP laminates or rectangular cross section (10×1.4 mm2), into slits opened on the concrete cover of the lateral beam surfaces. This strengthening technique has the designation of Near Surface Mounted (NSM). The main steps of the NSM technique are shown in Fig. 2.


Opening the slits in the direction and with the desired depth | After the slit has been filled with the adhesive, the laminate is introduced | The adhesive in excess is removed

Fig. 2 – Main steps of the NSM technique for the shear strengthening.

The efficacy of the NSM technique for the shear strengthening of T cross section RC beams was investigated, carrying out three point bending tests. The influence of the percentage and inclination of the CFRP laminates on the increase of the beam shear resistance was analyzed. Fig. 3 presents the T cross section beam prototype used in the experimental program. Fig. 4 shows one of the series of tests of the research program.

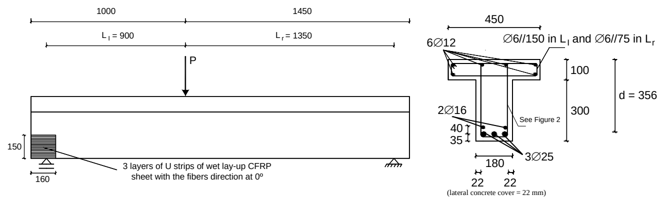


Fig. 3 – Tested beams (dimensions in mm).

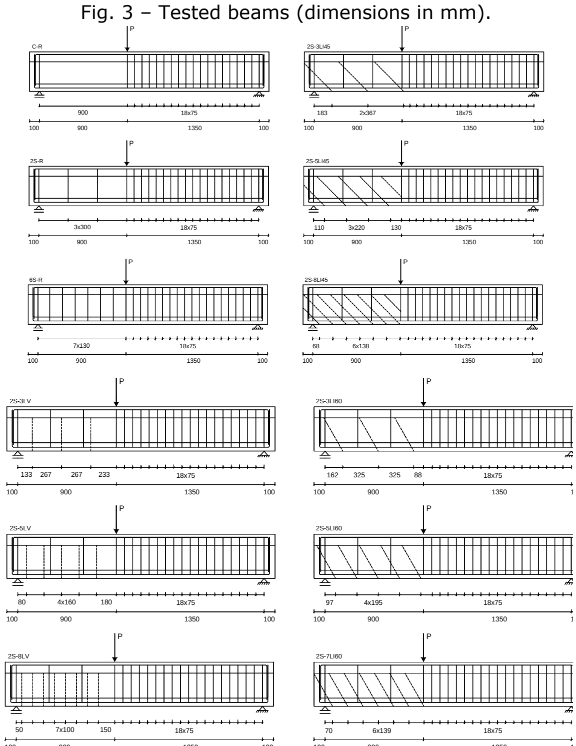


Fig. 4 – Tested beams: localization of the steel stirrups (thick line) and CFRP laminates (dashed line).

The beams were submitted to three point bending tests (see Fig. 5).

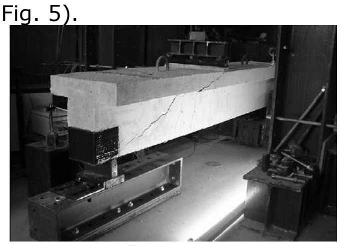


Fig. 5 – Test setup.

The relationship between the applied load and the deflection at the beam loaded section is represented in Figs. 6-9.

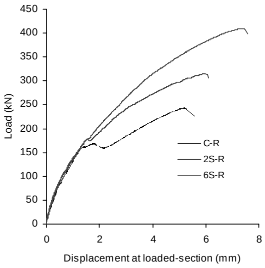


Fig. 6

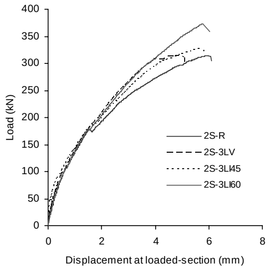


Fig. 7

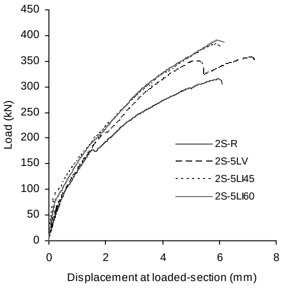
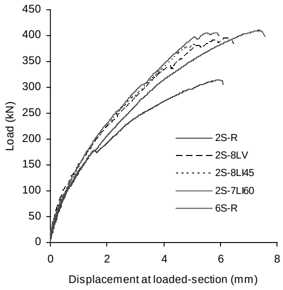
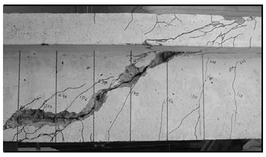


Fig. 8

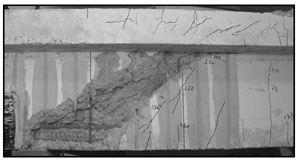


FFig. 9

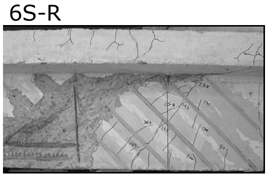
Fig. 10 includes details of the shear failure zones of one of the tested series of beams (the steel stirrups at the smaller beam shear span are indicated by vertical lines).



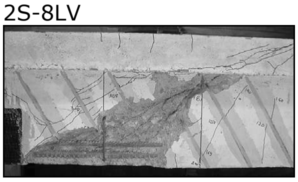
6S-R



2S-8LV



2S-8LI45



2S-7LI60

Fig. 10 – Details of the failure zone of one of the tested series of beams.

Fig. 11 shows, that, for the CFRP percentages analyzed, apart beam with the highest percentage of laminates at 45º (2S-8LI45, ρ_f = 0.16%), in the remaining beams, the shear strengthening efficacy (relative increment of the shear resistance) increased with the increment of shear strengthening percentage, ρ_f. However, it appears that the increase ratio will have a decreasing tendency with the increase of ρ_f.
From the obtained results it was verified that, independently of the CFRP percentage and inclination of the laminates, NSM technique provided a significant contribution for the shear resistance of T section RC beams.

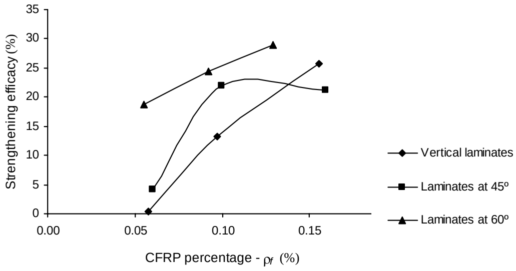


Fig. 11 – Strengthening efficacy vs CFRP percentage.

To assess a relationship between the crack opening and the strain distribution on the laminate crossing the shear crack, indirect tensile tests are being carried out, according to the setup represented in Figure 12. The laminates are monitored by optical fiber sensors, in order to disturb, as minimum as possible the CFRP-concrete bond conditions. The data from these tests will be used to define the effective strain in the CFRP laminates, to be use on the evaluation of the CFRP contribution for the shear resistance of RC beams.

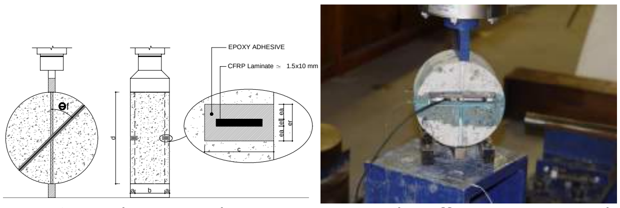


Fig. 12 – Indirect tensile tests to assess the effective strain in the CFRP laminates.

Complementary to these indirect tests, finite element analysis are being carried out with FEMIX-V4.0 computer program to calibrate the material parameters of the constitutive model used to model the material nonlinear behavior of RC beams shear strengthening according to the technique developed in the present research project (see Figs. 13).

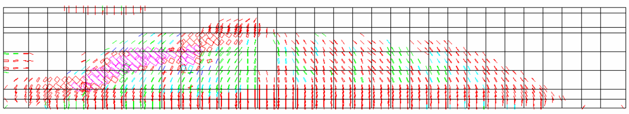


Fig. 13 – Crack pattern on the C-R beam.

Relevant publications:

International Journals

Bianco, V., Barros, J.A.O., Monti, G., "Bond model in the context of NSM-CFRP shear strengthening of RC beams", in appreciation for eventual publication in ASCE Structural Engineering Journal.

Barros, J.A.O., Varma, R.K., Sena-Cruz, J.M., Azevedo, A.F.M., "Near surface mounted CFRP strips for the flexural strengthening of RC columns: experimental and numerical research", in appreciation for eventual publication in Engineering and Structures Journal.

Barros, J.A.O., Bianco, V., Monti, G., "NSM CFRP laminates for shear strengthening of RC beams: tests and mechanical model – Part II", in appreciation for eventual publication in ACI Structural Journal.

Barros, J.A.O., Bianco, V., Monti, G., "NSM CFRP laminates for shear strengthening of RC beams: tests and mechanical model – Part I", in appreciation for eventual publication in ACI Structural Journal.

Dias, S.J.E.; Barros, J.A.O., "Shear strengthening of T cross section reinforced concrete beams by near surface mounted technique", in press, Composites for Construction.

Barros, J.A.O.; Dias, S.J.E.; Lima, J.L.T, "Efficacy of CFRP-based techniques for the flexural and shear strengthening of concrete beams", Journal Cement and Concrete Composites, 29(3), 203-217, March 2007.

Barros, J.A.O.; Dias, S.J.E., "Near surface mounted CFRP laminates for shear strengthening of concrete beams", Journal Cement and Concrete Composites, Vol. 28, N. 3, pp. 276-292, March 2006.

Dias, S.J.E.; Barros, J.A.O., "Experimental research of a new CFRP-based shear strengthening technique for reinforced concrete beams", IBRACON Structural Journal, vol. 1, nº2, December 2005, pp. 103-114.

National Journals

Barros, J.A.O.; Sena-Cruz, J.M.; Dias, S.J.E.; Ferreira, D.R.S.M.; Fortes, A.S., "Nova Abordagem no Reforço de Estruturas com Materiais Compósitos", Revista Ingenium, 84-90, Segunda Série Nº 98, Março/Abril 2007.

Dias, S.J.E.; Barros, J.A.O., "Verificação experimental de uma nova técnica de reforço ao corte com CFRP para vigas de betão armado", Revista IBRACON de Estruturas, vol. 1, nº2, pp. 115-126, Dezembro 2005.

Invited lectures/conferences/Seminars:

"Flexural and shear strengthening of reinforced concrete structures using composite materials.Theory and applications", University of Ferrara, Ferrara, Italy, 27 September 2007.

Website:

www.civil.uminho.pt/composites/Research.htm

PhD Thesis:

Salvador Dias (concluded up to the end of 2007)
Everaldo Bonaldo (concluded up to the end of 2007)
Vincenzo Bianco (concluded up to 10/2008)
Rajendra Varma (in course)

MSc Thesis:

João Lima (Concluded up to the end of 2007)
Monia Perrone (Concluded up to the end of 2007)

PosDoc:

Juliana Oliveira (concluded at July 2007)

Models:

1. Constitutive model to simulate, up to its ultimate load carrying capacity, the material nonlinear behaviour of reinforced concrete beams, strengthened according to the developed strengthening technique;
2. Analytical model and its corresponding computational program to simulate the contribution of NSM CFRP laminates for the shear resistance of RC beams.

Pilot Plant:

For the installation of optical fiber sensors on the CFRP laminates

Prototypes laboratory:

1. Equipment to measure optical fiber sensors;
2. Development of a hardware and software on integrate the Equipment to measure optical fiber sensors into a servo controlled test equipment

Acknowledgments:

The coordinator of the present work wish to acknowledge the support that is being provided by the "Empreiteiros Casais", S&P®, degussa® Portugal, and Secil (Unibetão, Braga).

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Safety evaluation of timber structures through non-destructive methods and stochastic analysis
(PTDC-ECM-66527-2006)

Financing Institution(s): Portuguese Science and Technology Foundation (FCT)

Promoting Institution(s): National Laboratory of Civil Engineering

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Ricardo Brites

Partner Institutions: Universidade do Minho

Period: January 2008 to December 2010

Relevant facilities: Servo close-loop equipments for experimental programs

Objectives:
The objective is to develop and test a methodology for the safety assessment of timber structures, taking into account the stochastic behaviour of strength and stiffness. Timber elements are to be assumed as heterogeneous and presenting significant strength and stiffness variations along its length (a concept already adopted for mechanical timber grading). Timber elements of pine and chestnut will be used, together with three types of cross sections (clean wood, wood with knots and rotten wood). For the different cross sections, minor-destructive and non-destructive methods are to be used for strength and stiffness evaluation. The longitudinal variation profiles of strength and stiffness will also be made, and compared with the original profiles. Likewise non-destructive profiles will be determined and compared with the profile obtained using destructive testing. Finally, non-destructive testing will be used in the safety analysis of an ancient roof, using linear and non-linear finite element analysis.

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Seismic repair and strengthening reinforced concrete beam-column joints with multidirectional CFRP laminates
(PTDC/ECM/74337/2006)

Financing Institution(s): Portuguese Science and Technology Foundation (FCT)

Promoting Institution(s): University of Minho

Coordinator(s): J. Sena-Cruz

Researchers and collaborators: J. Sena-Cruz; J. Barros; A. Azevedo

Partner Institutions: Not applicable

Period: January 2008 to December 2010

Relevant facilities: FEMIX open source software; Servo close-loop equipments for experimental programs; Universal testing machine.

Objectives:

Recently, a second generation of FRP laminates has been developed: It is a multidirectional FRP laminates, i.e. a laminate with fibers in distinct directions. This new type of laminates seems to be a promising material for repairing and strengthening RC joints, since it has multidirectional behavior and can be bolted, improving the anchorage between the laminates and the concrete, as well as and the ductility of the joint. The main objectives of the present project are the: (a) development of a technique to repair and to strength RC beam-column joints with multidirectional CFRP laminates under seismic loading; (b) experimental characterization of bond between multidirectional CFRP laminates and the concrete under monotonic and cyclic loading; (c) experimental characterization of RC beam-column joints strengthened with multidirectional CFRP laminates under cyclic loading; (d) development of numerical models for the simulation of bond multidirectional CFRP laminates and the concrete under monotonic and cyclic loading; (e) development of numerical models for the simulation of RC beam-column joints strengthened with multidirectional CFRP laminates under cyclic loading; (f) development of design recommendations for the application of the repair and strengthening of RC beam-column joints with multidirectional CFRP laminates under seismic loading.

Main achievements:

The main achievements of the project present include:

- *Experimental, numerical and analytical characterization of the bond between concrete and multidirectional CFRP laminates*. For this purpose the test configuration shown in Figure 1 will be adopted.

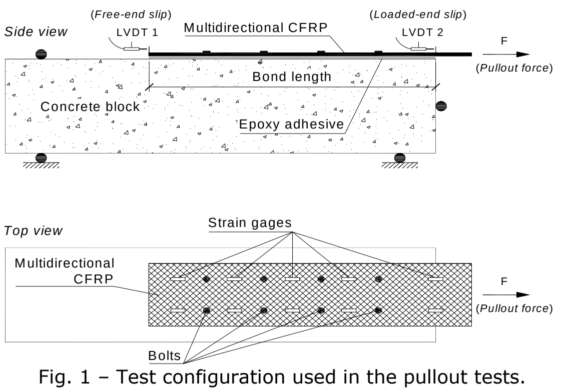

Fig. 1 – Test configuration used in the pullout tests.

The tests will be performed in a servo-hydraulic system with a closed-loop digital controller. The influence of the orientation of the carbon fibers composing the laminate, the bond length, the concrete strength, the bolting configuration and loading history on the bond behavior will be investigated. With this intention, two concrete strength classes, two fiber orientations, five bolt configurations, five bond lengths, and three load configurations will be adopted. For each studied parameter composing each series, three specimens will be used.

- *Experimental investigation of RC beam-column joints strengthened with multidirectional CFRP laminates under monotonic and cyclic loading*. With the aim of providing a fundamental understanding of the behavior of RC beam-column joints strengthened with multidirectional CFRP laminates under monotonic and cyclic loading, an experimental program will be carried out. In this experimental program some fundamental parameters that influence the behavior of RC beam-column joints will be analyzed, namely, the strengthening technique, the column axial force, the joint reinforcement, and the loading configuration. With this purpose, full-scale specimens will be tested according the test configuration shown in Figure 2.

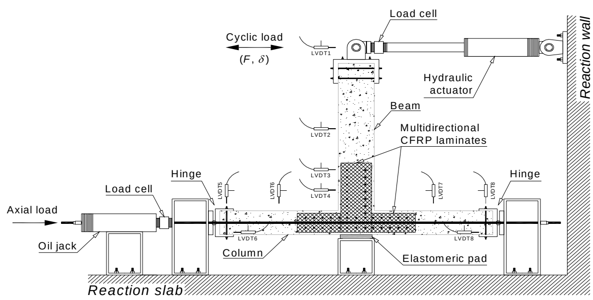

Fig. 2 – Test configuration used in the RC beam-column joints strengthened with multidirectional CFRP laminate tests.

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Seismic vulnerability reduction of old masonry buildings
(POCTI/ECM/61671/2004)

Financing Institution(s): Supported under the operational program for the science, technology and innovation (POCTI 2010)

Promoting Institution(s): National Laboratory for Civil Engineering

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Graça Vasconcelos; Nuno Mendes

Partner Institutions: University of Minho

Period: March 2005 to February 2008

Relevant facilities: DIANA software with user supplied subroutines; Servo close-loop equipments for experimental programs; Reaction wall; 4.0×4.0 m^2 shaking table; dynamic identification equipment

Objectives:

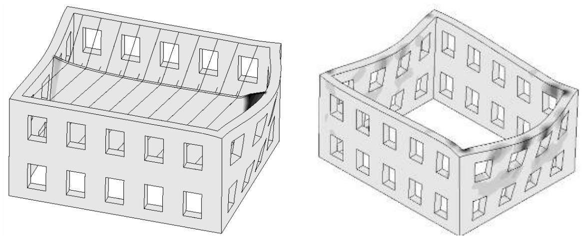
This project aims at the assessment of the seismic vulnerability of a particular type of masonry buildings very common in Portugal through a unique combination of experimental tests on the shaking platform and numerical modeling. The experimental tests will give an insight on the seismic behavior of this typology on a controlled environment while giving at the same time enough data to calibrate the necessary parameters for developing accurate numerical models. Furthermore, 3 different reinforcement solutions will be tested and their influence and effectiveness in the reduction of the seismic vulnerability of this typology will be assessed. In the aftermath of the project, the seismic vulnerability of this typology, either with or without reinforcement, is assessed and the results obtained will allow the definition of vulnerability parameters for simplified analysis. The two main goals are: (1) Study the seismic behaviour of a type of masonry buildings very common in the Portuguese housing stock, namely, 19th century masonry buildings with rubble stone masonry walls and wooden floors, in view of the characterisation of their seismic vulnerability; (2) Assessment of the seismic performance of that building typology, before and after application of 3 different reinforcement solutions, and evaluation of their effectiveness in terms of seismic vulnerability reduction.

Main achievements:

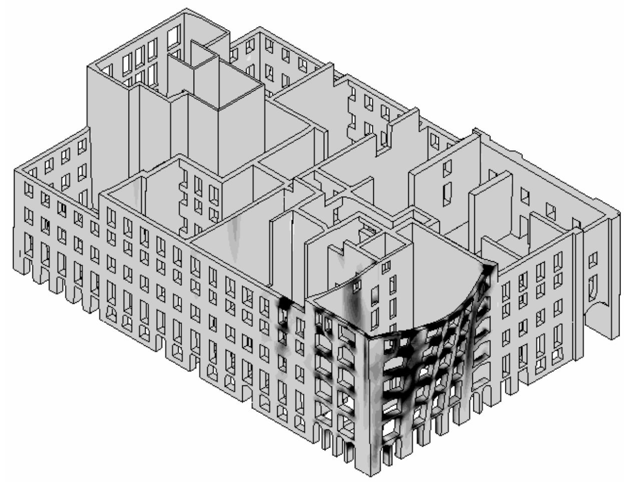
The main achievements so far, from previous related research, include:

- Preliminary tests at the National Laboratory of Civil Engineering (LNEC), see Figure 1. A cohesive material with mechanical properties similar to rubble masonry has been developed. Cyclic tests have been made in shear walls made of this material, for unreinforced and strengthened walls. In addition, tests in 3D scaled models of full buildings have been made at LNEC shaking table.
- Preliminary non-linear analysis at University of Minho, see Figure 2. Seismic vulnerability studies have been started in typical masonry buildings from downtown Lisbon, using small two-storey buildings and a real emblematic block of buildings.

Fig. 1 – Examples of damage survey in the cloister: (a) cracks and out-of-plane deformation; (b) stone detachment, from Candeias, P., Campos Costa, A., Coelho, E., Seismic Strengthening of Old Masonry Buildings with Application of GFRPs, Proc. 1st US-Portugal Int. Workshop on Grand Challenges in Earthquake Engineering 250 Years after the 1755 Lisbon Earthquake.



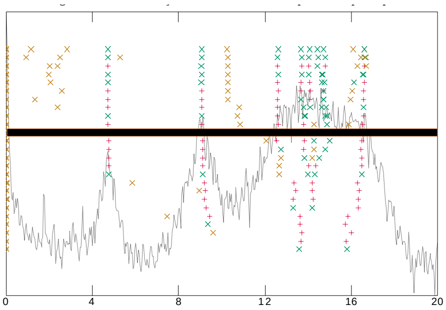
(a)



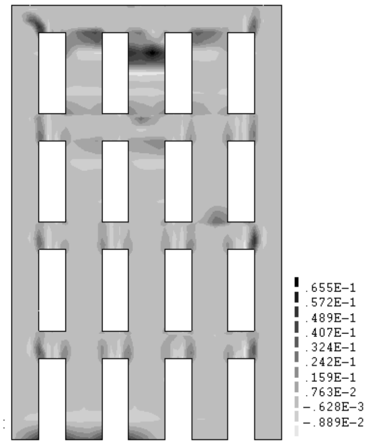
(b)

Fig. 2 – Typical examples of numerical vulnerability studies in old masonry buildings: (a) influence of mid-wall in two-storey building; (b) a emblematic block of buildings in downtown Lisbon.

Figure 3 and 4 illustrate the progress in the project with respect to validation of numerical tools and the novel tests using stone masonry specimens.



(a)



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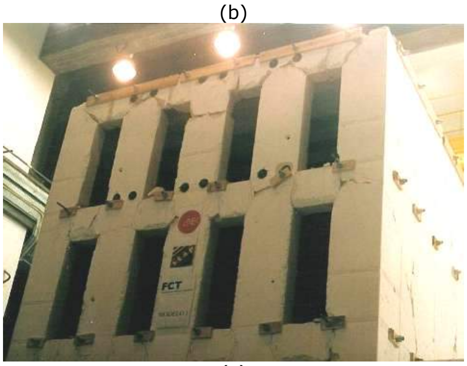

(c)

Fig. 3 – Results of non-linear dynamic analysis: (a) frequency and mode shape identification; (b) simulation; (c) damage in the test.

(a)

(b)

Fig. 3 – Stone masonry specimens under construction at LNEC: (a) walls; (b) two-storey building.

Relevant publications

Invited Lectures

Milani, G., Lourenço, P.B., Modelling masonry with limit analysis finite elements: Review, applications and new directions, em Civil Engineering Computations: Tools and Techniques, Eds. B.H.V. Topping, Saxe-Coburg Publications, p. 217-242 (2007).

Lourenço, P.B., Oliveira, D.V., Improving the seismic resistance of masonry buildings: Concepts for cultural heritage and recent developments in structural analysis, em XII Convegno L'Ingegneria Sísmica en Italia, Pisa, Itália, CD-ROM, 13 pp (2007).

Lourenço, P.B., Improving the seismic resistance of cultural heritage buildings: Concepts and recent developments, em 3er Congreso Nacional de Ingeniéria Sísmica, Girona, Espanha, CD-ROM, 14 pp (2007).

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Strengthening of masonry vaults with composite materials
(POCTI/ECM/38071/2001)

Financing Institution(s): Supported under the Operational Program for the Science, Technology and Innovation (POCTI)

Promoting Institution(s): University of Minho

Coordinator(s): Paulo B. Lourenço

Researchers and collaborators: Paulo B. Lourenço; Daniel V. Oliveira, Ismael Basílio; Claudio Maruccio; J. Poças Martins; K.J. Krakowiak; Ricardo Brites

Partner Institutions: Not applicable

Period: October 2002 to September 2005

Relevant facilities: DIANA software with user supplied subroutines; Servo close-loop equipments for experimental programs; Universal testing machine.

Objectives:

Among the structural elements that constitute masonry constructions, arches and vaults deserve particular attention. Due to the aging effects, movements in the abutments or accidental causes (like earthquakes), these elements are prone to damage that affects the complete structure stability. The need of strengthening techniques to reestablish the performance of these structures, and to prevent its brittle collapse when subjected to ultimate state limits, is a key issue in today's research. For this reason, the present project focus on strengthening of masonry vaults with FRP ("Fibre Reinforced Plastics"). These materials present several advantages, as low specific weight, corrosion immunity and high tensile strength. The simplicity and quickness of application, together with the flexibility of the material, allow a wide range of intervention approaches, linked to strengthening and restoration in different damaging conditions. The objectives of this project are:

(i) to compare the ultimate behavior of masonry canon vaults strengthened by FRP techniques and by locating the strengthening in different positions;

(ii) to develop numerical models able to reproduce the observed experimental behavior.

Main achievements:

The main achievements of the project include:

• Study of bond study on bond between masonry and FRP, see Fig. 1. For this purpose, materials similar to old materials have been used (handmade traditional bricks and weak lime mortars). In order to evaluate the influence of the arch curvature in bond, straight and curved specimens have been used. Different thicknesses and lengths of the FRP composite have been tested. Finally, FRP anchors have been tested in order to evaluate any benefit of their application.

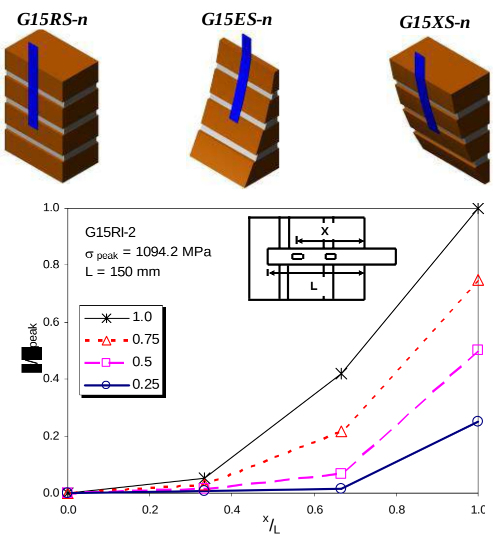

Fig. 1 – Experimental results for bond tests.

• Study of failure mechanisms and performance of FRP composites in the behaviour of single curvature arches subjected to point loads, see Fig. 2. Different amounts of strengthening and different FRP arrangements have been tested, resulting in distinct failure mechanisms. Typically, the collapse load has been increase between +50% and + 200% and the ductility at failure has increased up to 20 times.

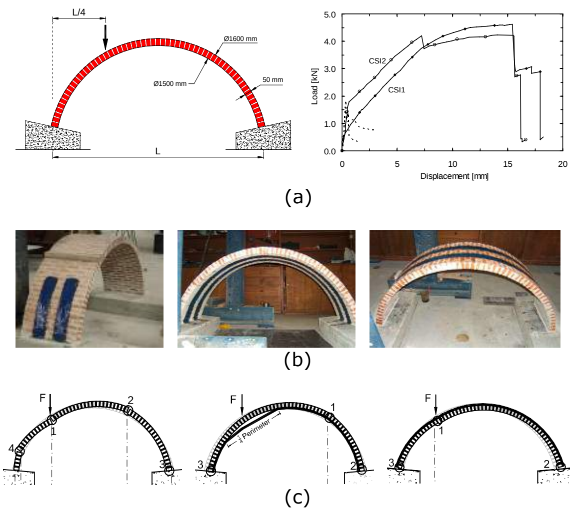

Fig. 2 – Experimental results for the arches: (a) layout and force-displacement diagram; (b) different FRP arrangements; (c) different failure mechanisms.

• Simulations of the bond tests and arch tests with advanced non-linear finite elements, see Fig. 3. The bond tests were adequately reproduced and the available tools can be used for better understating of the results, parametric studies and engineering applications. For the arches, the ultimate load can be adequately reproduced but more insight is needed with respect to FRP slipping and global deformability. The large deformations obtained experimentally in the FRP strengthened arches seem to be hard to reproduce with the existing numerical tools. New developments are currently being incorporated in the models, to better accommodate the observed results.

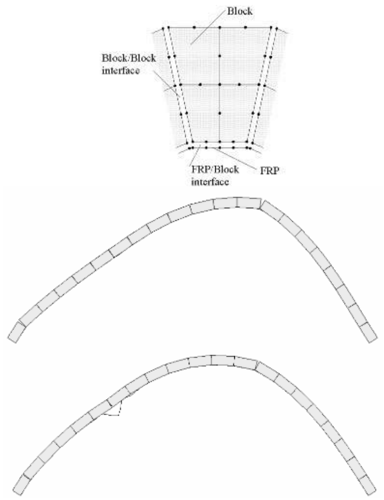

Fig. 3 – Simulation with non-linear FEM.

Relevant publications:

International Journals

Maruccio C., Lourenço P.B., Oliveira D.V., Numerical analysis of the FRP-masonry interfacial behaviour, Journal of Composites for Construction ASCE (submitted for possible publication, July 2007).

International Conferences

Lourenço, P.B., Oliveira, D.V., Basilio, I., Experimental behaviour of FRP-strengthened masonry arches, Tenth North American Masonry Conference, St. Louis, USA, p. 262-273 (2007).

Basilio, I., Oliveira, D.V., Lourenço, P.B., Experimental characterization of FRP-masonry interface behaviour, em 5th International Conference on Analytical Models and New Concepts in Concrete and masonry Structures, Gliwice, Poland, CD-ROM, 8 pp (2005).

Oliveira, D.V., Lourenço, P.B., Repair of stone masonry arch bridges, in Arch Bridges '04, Barcelona, Spain, p. 451-458 (2004).

Lourenço, P.B., Palácio, K., Barros, J.O, Design recommendations for reinforced masonry arches, in Arch Bridges '04, Barcelona, Spain, p. 583-592 (2004).

Basilio, I, Oliveira, D., Lourenço, P.B., Optimal FRP strengthening of masonry arches, em Proc. 13th Int. Brick/Block Masonry Conf., Amsterdam, the Netherlands, p. 361-370 (2004).

Thesis

Strengthening of masonry arches with composite materials, Ismael Basilio Sanchez, PhD Thesis, University of Minho, Portugal (2007).

Advances on the design of thin surface structures in reinforced concrete, Kesio Palácio, PhD Thesis, University of Minho, Portugal (2007).

Simulation of bond and arches in masonry strengthened with FRP, Claudio Maruccio, MSc Thesis, University of Lecce, Italy (2006).

Reports

Lourenço, P.B., Brites, R.D., Report on the stability of the vaults in the Inn's Cloister and ancient morgue of the Christ's Convent, Tomar (in Portuguese), Report 04-DEC/E-23, Universidade do Minho, 20 pp + 3 drawings (2004).

Lourenço, P.B., Krakowiak, K.J., Diagnosis and stability analysis of the skylight in the Cathedral of Porto (in Portuguese), Report 04-DEC/E-21, Universidade do Minho, 27 pp + Annex (2004).

Basilio, I., Oliveira, D.V., Lourenço, P.B., Behaviour of strengthened masonry arches, Relatório 05-DEC/E-21, Universidade do Minho, 39 pp (2005).

Basilio, I., Oliveira, D.V., Lourenço, P.B., Experimental behaviour of masonry strengthened with composite materials under shear loading, Relatório 05-DEC/E-20, Universidade do Minho, 53 pp (2005).

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Strengthening of multi-leaf masonry piers under long term loading
(POCTI/ECM/58987/2004)

Financing Institution(s): Supported under the operational program for the science, technology and innovation (POTCI 2010)

Promoting Institution(s): University of Minho

Coordinator(s): Daniel Oliveira

Researchers and collaborators: Daniel Oliveira; João Roque; Pina Henriques; Paulo Lourenço; Rui Silva

Period: May 2005 to April 2008

Relevant facilities: Servo close-loop equipment for experimental testing; climatic chamber; creep-test frames; DIANA software with user supplied routines

Objectives:

The main objectives of this project are:
i) to assess and develop time-dependent numerical tools for the modelling of creep and stress redistribution on composite masonry piers and walls, strengthened and non-strengthened; the strengthening techniques that will be considered are injection and GFRP anchoring;
ii) to develop simplified rational rules and analytical models for strengthening design, adequate to be included in future codes.

Main achievements:

The first part of the Project deals with the experimental characterization of the structural behaviour of three-leaf masonry walls under compressive loading.
The adopted wall typology as well as materials were defined with basis on the available literature references, aiming at representing typical ancient construction solutions, see figure 1.
In this way, the walls will be built with granite units and using a lime-based mortar. In order to define the most adequate mortar composition, a comprehensive parametric analysis was carried out.

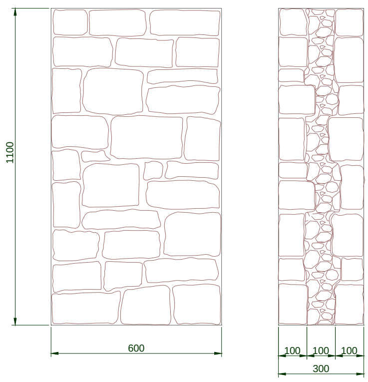


Figure 1 – Geometry of the three-leaf masonry walls.

Unstrengthened three-leaf masonry walls, built at scale 1:2, were built and tested under monotonic compressive loading, see figure 2. In order to reproduce as close as possible the existing stone masonry constructions and considering the important effect of the workmanship, all walls were built by experienced masons.

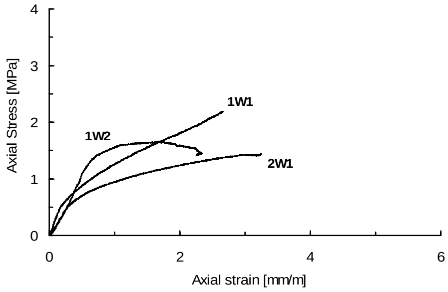
The tests carried out on unstrengthened walls show that the absent of an adequate connection between the external leaves is of critical importance, causing the out-of-plane failure of the walls, see figure 3.

Figure 2 – Construction and testing of the first series of multi-leaf masonry walls.

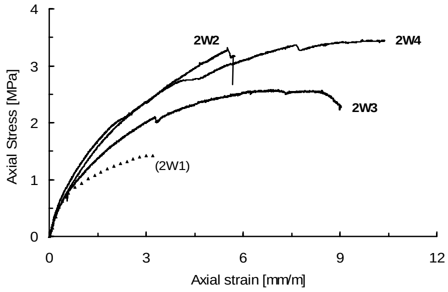
Figure 3 – Observed failure modes (plain walls).

The tests carried out on strengthened walls, by means of grout injections and using GFRP transversal ties, showed that these techniques are effective in the sense that they allowed an increment of the average compressive strength, see figure 4.

Also the typical failure mode of the plain walls was shifted from out-of-plane movement of the external leaves, due to the development of horizontal plastic hinges (global mechanism), to the formation of a dominant vertical cracking pattern, see figure 5.



(a)



(b)

Figure 4 – Axial load-displacement diagram for: (a) plain walls; (b) walls strengthened with GFRP transversal ties.

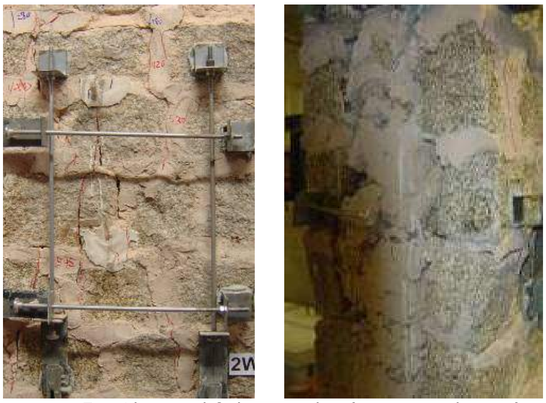


Figure 5 – Observed failure modes (transversal tying).

A second part of the Project concerns the experimental characterization of the creep behaviour of ancient masonry structures. For that purpose, both short term and long term creep tests were carried out (the long term creep tests haven't been concluded yet) on both adobe and clay brick masonry prisms.

All prisms were built and kept inside a climatic chamber in order to assure constant temperature and humidity levels. Both short term and long term creep tests were carried out on creep-test frames, see Figure 6.

The first available results show that creep behaviour is quite important for brick masonry, (see figure 7 and figure 8), but it cannot be adequately described resorting only to short term creep tests. Therefore and within this context, long term creep tests are of primary importance. It is expected that the long term creep results will contribute to better understand the phenomena associated with the long term behaviour of brick masonry structures.


Figure 6 – Creep-test frames.

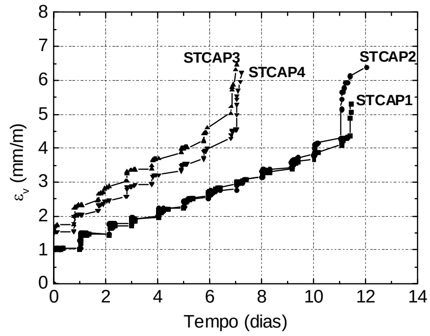


Figure 7 – Short term creep results for adobe prisms.


Figure 8 – Typical crack pattern during testing (adobe prism).

Relevant publications:

International Conferences

Oliveira DV, Silva RA, Lourenço PB - Experimental creep behaviour of masonry, paper to be submitted for publication in the VI Conference of Structural Analysis of Historical Constructions", UK, 2008.

Oliveira DV, Silva RA, Lourenço PB - On the strengthening of three-leaf stone masonry walls, paper to be submitted for publication in the VI Conference of Structural Analysis of Historical Constructions", UK, 2008.

Oliveira DV, Lourenço PB, Garbin E, Valluzzi MR, Modena C., Experimental investigation on the structural behaviour and strengthening of three-leaf stone masonry walls, V International Conference on Structural Analysis of Historical Constructions, New Delhi, pp. 817-826, 2006.

Oliveira DV, Lourenço PB, Experimental behaviour of three-leaf stone masonry walls, International Conference and Brokerage Event on the Construction Aspects of Built Heritage Protection, Dubrovnik, pp. 355-362, 2006.

National Conferences

Oliveira DV, Varum H, Silva R, Pereira H, Lourenço PB, Costa A, Experimental characterization of long term behaviour of adobe structures, 5º ATP – 5º Seminário de Arquitectura de Terra em Portugal, Aveiro, CD-ROM, pp. 10, 2007.

Oliveira DV, Lourenço PB, Silva R, Experimental behaviour of three-leaf masonry walls, JPEE 2006 - 4as Jornadas Portuguesas de Engenharia de Estruturas, LNEC, Lisboa, CD-ROM, pp 13, 2006.

International Journals

Oliveira DV, Silva RA, Lourenço PB – Strengthening of three-leaf stone masonry walls (on-going).

Technical Reports

Oliveira DV, Silva R, Garbin E, Experimental behaviour of three-leaf masonry walls, (to appear soon)Report 06-DEC/E-14, Universidade do Minho, Guimarães, pp. 93, 2006.

Silva R, Oliveira DV, Strengthening techniques applied to three-leaf masonry walls (on-going, to appear soon).

Silva R, Oliveira DV, Experimental creep behaviour of newly brick masonry (on-going, to appear soon).

Mauro A, Lourenço PB, Oliveira DV, Numerical approach to creep behaviour (on-going, to appear soon).

Master Thesis:

Silva R, Experimental characterization of historical masonry with emphasis on its strengthening and long term behaviour, due by March 2008.

Acknowledgements:

The coordinator acknowledges the support provided by the SME's MAPEI and FRADICAL.

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Sustainability of constructions: Integrated approach to life-time structural engineering
(COST Action C25)

Financing Institution(s): European Union

Promoting Institution(s): University of Minho/University of Coimbra

Coordinator(s): Luís Bragança / Luís Simões da Silva

Researchers and collaborators: Over 70 researchers from various European institutions

Partner Institutions: VTT Building and Transport (Finland), Schaur ZTGmbH (Austria), University of Liège (Belgium), Czech Technical University in Prague (Czech Republic), Institute of Architectural Technology (Denmark), University of Stuttgart (Germany), TU Dresden - Institute of Steel and Timber Structures (Germany), Institute of Steel and Light Weight Constructions - RWTH Aachen (Germany), Aristotle University of Thessaloniki (Greece), University of Naples "Federico II" - Faculty of Architecture (Italy), University of Naples "Federico II" - Faculty of Engineering (Italy), Institute of Structural Engineering (Latvia), Institute of Architectural Constructions of Kaunas Technological University (Lithuania), University "Ss. Cyril and Methodius" (FYR Macedonia), TU/e University of Technology Eindhoven - Faculty of Architecture, Building and Planning (The Netherlands), Norwegian Building Research Institute (Norway), Rzeszow University of Technology - Faculty of Civil and Environmental Engineering (Poland), The « Politehnica » University of Technology - Faculty of Civil Engineering and Architecture (Romania), Gradbeni Institut ZRMK, d.o.o. - Building and Civil Engineering Institute ZRMK (Slovenia), University of Gavle - Dep. of Technology and Built Environment (Sweden), Dokuz Eylul University - Faculty of Architecture (Turkey)

Period: October 2006 to October 2010

Objectives:

The main objective of the Action is to promote science-based developments in sustainable construction in Europe through the collection and collaborative analysis of scientific results concerning life-time structural engineering and especially the integration of environmental assessment methods and tools for structural engineering.

The effects of climate change in relation to the long service-life of constructions call for reliable integrated methods. In this way, the transfer of scientific results to applications in methods, product and processes will become faster. Apart from this, recent knowledge gained at the international level will be transferred to the education of new European professionals and developers in the construction sector.

This Action brings together European experts in material and structural engineering to explore technologies and design practices essential for changes in construction. In one way, its roots are deeply in engineering and technology and in another way its purpose is to illuminate the relations between technology, economic growth and the environment. It fosters basic research aiming at producing radical innovations. It boosts product development aimed at high-performance and sustainable constructions. It supports achievements in sustainable engineering for integrated design methods.

This COST Action provides structural engineering with the framework to incorporate sustainability in the design of constructions. This is a novel approach that most structural engineers do not grasp and that is scarcely addressed in the research arena (most research is currently related to the estimation of degradation models with some preliminary attempts to establish global methodologies), but that is essential to meet the requirements resulting from the Kyoto Protocol and EU policy for sustainable development.

Main achievements:

In order to achieve the goals of the Action, three main areas were identified and three working Groups were created to cover those areas (see Figure 1):

WG1 – Criteria for Sustainable Constructions (global methodologies, assessment methods, global models and databases)

WG2 – Eco-efficiency (eco-efficient use of natural resources in construction - materials, products and processes)

WG3 – Life-time structural engineering (design for durability, life-cycle performance, including maintenance and deconstruction).

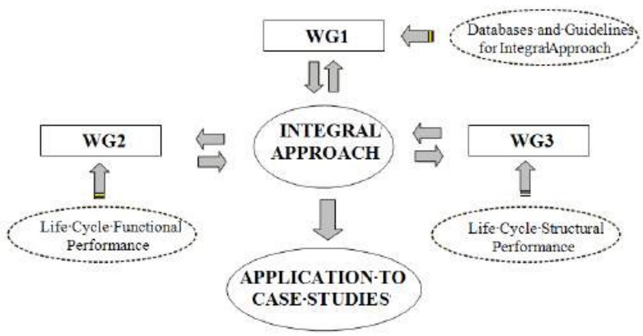

Fig. 1 – Organization of Cost Action C25.

The main achievements of the WG1 will include:

- Report on "State-of-the-art of global methodologies";
- Guidelines for a global approach;
- Report on "State-of-the-art of LCA & LCC";
- Guidelines to perform a LCA according to the implemented methodology;

- Guidelines to perform a LCC according to the implemented methodology;
- Datasheets of current databases for LCI and LCC;
- Links to other selected databases;
- Guidelines for a global database;
- Case-study publication on implementation of methodologies.

The main achievements of the WG2 will include:
- Reports and datasheets on new materials;
- Reports and datasheets on new technologies;
- Guidelines for the creation of an healthy indoor environment;
- Guidelines for improvement of the comfort in buildings;
- Guidelines for energy efficiency;
- Guidelines for the optimisation of water management;
- Guidelines for the use of alternative energies;
- Case-study publication, with recommendations and guidelines.
-

The main achievements of the WG3 will include:
- State-of-the-art report on life-cycle prediction methodologies;
- State-of-the-art report on deterministic and probabilistic degradation models;
- Guidelines for the planning of Maintenance, Repair and Rehabilitation;
- State-of-the-art report on deterministic and probabilistic degradation models;
- Guidelines survey and condition assessment of structures;
- Guidelines for deconstruction;
- Case-study publication (technologies, evaluation methods, recommendations, basics for guidelines).

Relevant publications:

Proceedings of Workshop "Sustainability of Constructions"; L. Bragança, H. Koukkari, R. Blok, H. Gervasio, M. Veljkovic, Z. Plewako, R. Landolfo, V. Ungureanu, L.S. Silva (eds.); Lisbon 13-14-15 September 2007, Portugal,

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Sustainable bridges: assessment for future traffic demands and longer lives

Financing Institution: European Commission within Sixth Framework Programme

Promoting Institution(s): Skanska Teknik AB; in Portugal: Universidade do Minho (UMinho)

Coordinator(s): Jan Olofsson (Skanska Teknik AB); in Portugal: Paulo Cruz (UMinho)

Researchers and collaborators: Paulo Cruz; Abraham Dias de León; Dawid Wisniewski; Isabel Valente; Luís Neves; Lukasz Topczewski; Maciej Maksymowicz; Rolando Salgado.

Partner Institutions: **Czechia**: Cervenka Consulting; **Denmark**: COWI A/S; **Finland** :WSP Consulting KORTES group, Finnish Rail Administration, Finnish Road Administration, University of Oulu; **France**: Laboratoire Central des Ponts et Chausées (LCPC), Societé National de Chemin des Fers (SNCF); **Germany**: Deutsche Bahn AG, Fed Inst f Materials Res. and Testing (BAM), Rheinisch-Westfälische Tech Hochschule, Universität Stuttgart; **Norway**: NORUT Technology; **Poland**: PKP Polish Railway Lines, Wroclaw University of Technology; **Portugal**: Universidade do Minho; **Spain**: Universitat Politècnica de Catalunya; **Sweden**: Banverket, Chalmers University of Technology, Designtech Projektsamverkan AB, Luleå University of Technology, Lund University of Technology, Royal Institute of Technology, Skanska Teknik AB (Coordinator), Sto Scandinavia AB, Swedish Geotechnical Institute, Swedish Road Administration; **Switzerland**: Ecole Polytechnique Federal de Lausanne (EPFL), Swiss Federal Institute for Materials Testing and Research (EMPA); **United Kingdom**: City University, Network Rail, Salford University.

Period: December 2003 to November 2007

Objectives:
1. To increase the transport capacity of existing bridges by allowing axle loads up to 33 tonnes for freight traffic with moderate speeds;
2. To increase the capacity for passenger traffic with low axle loads by increasing the maximum speeds up to 350 km/hour;
3. To increase the residual lifetime of existing bridges up to 25 %;
4. To enhance strengthening and repair systems.

The activities within the project focused on the functional requirements for railway bridges in order to increase the capacities required to meet future demands for heavier axle loads and for high traffic levels.

The project aimed at improving the capacity of delivery without compromising the safety and economy of the working railway.

Main achievements:

The approach was oriented to analyse bridge types and bridge details which are critical for what respects to load carrying capacity, allowable speed and/or residual life. With new innovative modelling a more accurate picture of the actual behaviour of bridges can be achieved. The results obtained were clearly a progress beyond the current state-of-the-art.

The labour was implemented through nine work packages:

- WP 1 – Start up and Classification;
- WP 2 – Guidance and Review;
- WP 3 – Condition Assessment and Inspection;
- WP 4 – Loads, Capacity and Resistance;
- WP 5 – Monitoring;
- WP 6 – Repair and Strengthening;
- WP 7 – Demonstration. Field Testing of Old Bridges;
- WP 8 – Demonstration. Monitoring on New Bridges;
- WP 9 – Training and Dissemination.

UMinho was strongly involved in the WP3, WP4 and WP5 works. In each of those Work Packages UMinho participated in the preparation of the Technical Reports, Guidelines and other publications.

WP 3: Condition Assessment and Inspection

The focus was primarily on concrete bridges, but steel bridges and masonry arch bridges were also considered.

Optimisation of sonic and radar tomographic techniques

UMinho research efforts were mainly orientated towards the optimisation of sonic and radar tomographic techniques for specific problems.

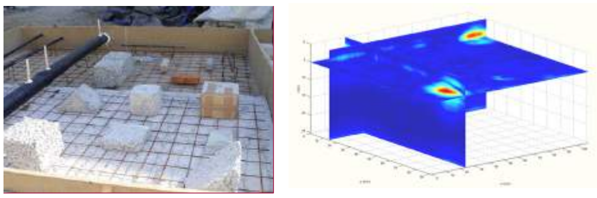

Fig. 1 – General view of a concrete specimen and an example of the results obtained.

A concrete specimen was specially designed and built for simulating a small part of a concrete bridge deck (Fig. 1).

Three tendon ducts in PVC, one with 110 mm and two with 35 mm of diameter, were placed inside the slab. In the larger duct, half the duct was fully grouted and the other half was only partly grouted in order to evaluate the difference between fully filled and partly filled tendon ducts. The other simulated defects included a poorly vibrated or lower density concrete, represented by blocks of concrete with insufficient binder, low density concrete, large voids and blocks with inclined surfaces. Furthermore, one empty glass bottle, one clay brick, wood, mortar prisms and two metallic bars were also inserted in this specimen. The adopted antenna, with a central frequency of 1.6 GHz, exhibited very good resolution and high accuracy for 3D reconstruction and tomography.

GPR inspections were also carried out in three large concrete bridges located in the northern part of Portugal. These applications clearly illustrate the potential to locate the exact position of tendon ducts and reinforcement. In one of those examples, the application of tomographic techniques made possible the assessment of the concrete quality and the comparison with the information obtained with sensors installed inside these elements.

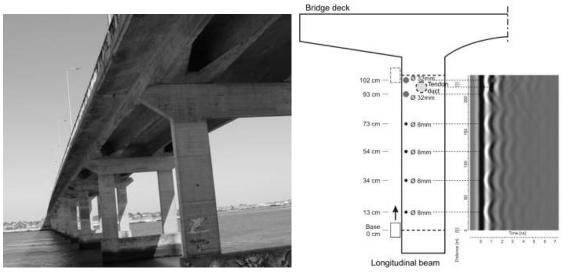

Fig. 2 – Overview of the Barra Bridge and interpretation of a common 2D radargram.

Classification of bridge damages and degradation mechanisms

Until now each country has had its own ways of classification for bridge damages and degradation mechanisms. In order to use a common procedure of structure condition assessment a unified taxonomy was developed.

The proposed classification of bridge defects and degradation mechanisms together with the testing methods described in the Guideline is intended to create a basis for a consistent identification and description of the railway bridge defects as well as for comparable assessment of their condition. Defined relationships between degradation mechanisms and defects should help optimise the maintenance strategies and obtain a reliable foresight of the bridge infrastructure lifetime.

WP 4: Loads, Capacity and Resistance

One of the top priorities for outcomes of the Sustainable Bridges Project was the identification of improved assessment methods. This was accommodated in a "Guideline for Load and Resistance Assessment of Existing European Railway Bridges". UMinho participated actively in the preparation of the Guideline.

Safety and probabilistic modelling

The sub-group endeavoured to explain and summarize the basis of safety assessment using a probabilistic approach, providing not only simplified methods whenever possible, but also examples of application in order to make the documents more readable and understandable.

Steel bridges

The proposed assessment method focuses on fatigue and ultimate load limit states. The approaches utilised were deterministic and probabilistic and used different levels of information.

WP 5: Monitoring

Crack monitoring – Development of a distributed optical fibre crack sensor

A sensor for a reliable detection and monitoring of cracks in concrete and masonry structures was developed. This distributed optical fibre crack sensor does not require prior knowledge of the crack locations, which is a significant advantage over existing crack monitoring techniques. Moreover, several cracks can be detected, located and monitored with a single fibre.

The primary objectives of this research were: 1) To examine the applicability of the sensor to detect and trace the formation of cracks in various locations; 2) To evaluate the capability of the sensor for measuring a range of crack openings related to the sensitivity and control of the sensor response; and 3) To demonstrate the implementation of the sensor when monitoring flexural cracks on RC beams subjected to sustained and repeated loading.

To asses the performance of that sensor, under real situations, several tests were carried out to detect and monitor internal and external flexural cracks on concrete and masonry elements.

In addition to laboratory investigations, the installation of the sensor on a real bridge was performed. Results were reasonably in agreement with direct measurements using crack gauges.

Fig. 3 – Crack detection in the failure test over Övik Bridge.

Relevant publications:

Thesis

Candidate: Abraham Diaz de León Bernard
Type: PhD
Supervisors: Paulo Cruz (UMinho) and Christopher Leung (Univ. of Hong Kong)
Title: An optical fibre sensor for the crack monitoring of reinforced concrete structures
Conclusion: 2007/09/10

Candidate: Łukasz Konrad Topczewski
Type: PhD
Supervisors: Paulo Cruz (UMinho)
Title: Improvement and application of ground penetrating radar non-destructive technique for the concrete bridge inspection
Conclusion: 2007/06/18

Candidate: Dawid Ferdynand Wiśniewski
Type: PhD
Supervisors: Paulo Cruz (UMinho) and António Abel Henriques (FEUP)
Title: Safety formats for the assessment of concrete bridges with special focus on precast concrete
Conclusion: 2007/06/08

Candidate: Luís Armando Canhoto Neves
Supervisors: Dan Frangopol (Univ. do Colorado at Boulder - EUA) and Paulo Cruz (UMinho)
Type: PhD

Title: Life-cycle analysis of bridges considering condition, safety and maintenance cost interaction
Conclusion: 2005/02/11

International Journals

Cruz, P.J.S, Topczewski, L., Trela, C., Fernandes, F.M and Lourenço P.B. (2007), Application of radar techniques to the verification of design plans and the detection of defects in concrete bridges, Structure and Infrastructures Engineering, Taylor & Francis (accepted for publication).

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Cruz, P.J.S., Wiśniewski, D. e Casas, J.R. (2007), Métodos de Avaliação da Segurança de Pontes Existentes, Revista Portuguesa de Engenharia de Estruturas (aceite para publicação).

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Maksymowicz, M., Cruz, P.J.S. and Bień, J. (2006), Concrete railway bridges – Taxonomy of degradation mechanisms and damages identified by NDT methods, Third International Conference on Bridge Maintenance, Safety and Management, July 16-19, Porto, Portugal.

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Neves, L.C., Frangopol, D.M., and Cruz, P.J.S. (2005). Predicting and optimizing lifetime performance of existing steel bridges under preventive and essential maintenance actions, Eurosteel 2005 - 4th European Conference on Steel and Composite Structures, Volume B, 8-10 June, Maastricht, pp. 4.3-83 a 4.3-90.

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Tensile membrane action and robustness of structural steel joints under natural fire
(EC FP5 HPRI – CV5535)

Financing Institution(s): Supported by the European Commission under the 5th framework programme

Promoting Institution(s): BRE - Building Research Establishment, UK

Coordinator(s): Frantisek Wald (Czech Technical University of Praha, Czech Republic)

Researchers and collaborators: Frantisek Wald, Luís Simões da Silva, Aldina Santiago, Luís Borges, David Moore, Tom Lennon, Magdalena Chladná, Martin Beneš.

Partner Institutions: Universidade de Coimbra, Portugal.

University of Bratislava, Slovakia

BRE – Building Research Establishment, UK

Period: October 2002 to January 2003

Relevant facilities: The Cardington Laboratory is a unique worldwide facility for the advancement of the understanding of whole-building performance. This facility is located at Cardington, UK and consists of a former airship hangar with dimensions 48 m x 65 m x 250 m. The BRE's Cardington Laboratory comprises three experimental buildings: a six storey timber structure, a seven storey concrete structure and an eight storey steel structure. The steel test structure was built in 1993. It is a steel framed construction using composite concrete slabs supported by steel decking in composite action with the steel beams. It has eight storeys (33 m) and is five bays wide (5 x 9 m = 45 m) by three bays deep (6 + 9 + 6 = 21 m) in plan. The building simulates a real commercial office in the Bedford area.

Objectives:

Due to the high cost of full-scale fire tests and size limitations of existing furnaces, these studies are based on the observation of real fires and on tests performed on isolated elements subjected to standard fire regimes. However, the failure of the World Trade Centre on 11th September 2001 alerted the engineering profession to the possibility of connection failure under fire conditions. Many aspects of behaviour occur due to the interaction between members and cannot be predicted or observed from isolated tests, such as global or local failure of the structure, stresses and deformations due to the restraint to thermal expansion by the adjacent structure, redistribution of internal forces. Unlike the standard fire curve a natural fire is characterized by three phases: a growing phase, a full developed phase and a decay phase. It is necessary to evaluate not only the effect on the structural resistance during the heating phase, but also the high cooling strains in the joint induced by distortional deformation of the heated elements during the decay phase. In order to address these issues, this experimental programme investigate the global structural behaviour of a compartment on the 8-storey steel-concrete composite frame building at Cardington laboratory during a BRE large-scale fire test on January 16, 2003. The main aim was the examination of the temperature development within the various structural elements, the corresponding (dynamic) distribution of internal forces and the behaviour of the composite slab, beams, columns and connections.

Main achievements:

The main achievements of the project include:

• <u>Fire development and compartment temperature</u>

During the test the predicted local collapse of the structure was not reached; in the compartment with the parametric curve presented in Eurocode 1, Annex A. The quantity of thermal load and the dimensions of the opening on the facade wall were designed to achieve a representative fire in the office building. The maximum recorded compartment temperature was 1107.8 ºC after 54 minutes, while the predicted temperature was 1078 °C in 53 min (Fig. 1).

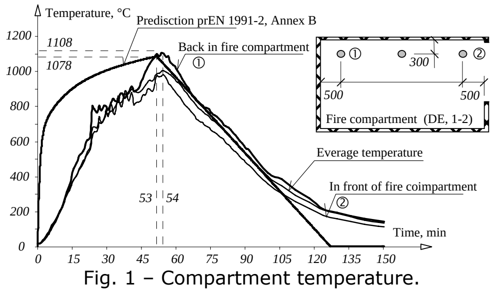

Fig. 1 – Compartment temperature.

• <u>Temperature evolution in the structure</u>

Measurements of the temperature in the mid-span beams were taken on the bottom flange, on the web and on the upper flange. A summary of the temperatures recorded in the beams is presented in Fig.2. The maximum recorded steel temperature of 1087.5ºC occurred after 57 minutes of fire, on the bottom flange of the beam. By calculation and with the help of the time-temperature curve measured on the compartment, a maximum steel temperature of 1067ºC in 54 min was predicted.

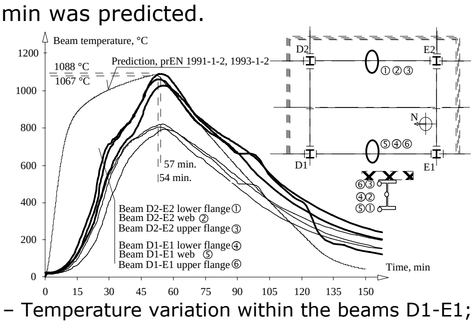

Fig. 2 – Temperature variation within the beams D1-E1; D2-E2.

Measurements of the temperature in the connections were taken on the beam adjacent to the connection, in the plate and in the bolts. A summary of the temperatures recorded in the connections is presented in Fig. 3.

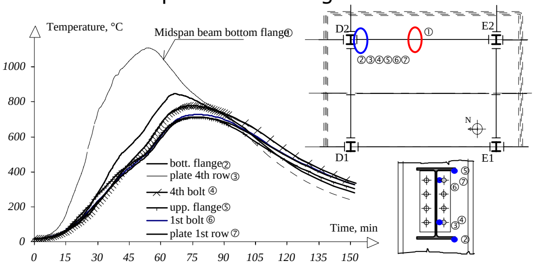

Fig. 3 – Temperature variation within the beam-to-column minor axes end plate connection D2-E2.

In the heating phase, the joint temperature is significantly lower than the remote bottom flange, which is usually the critical element that defines the limiting temperature of the beam. The maximum joint temperature was around 200ºC lower than the maximum temperature of the beam. The first bolt row from the top was significantly cooler than the lower bolts, because of shielding by the adjacent slab and column. The end-plate was hotter than the bolts at the same level due to the ratio of the bolt diameter to the end-plate thickness (20 mm).

• <u>Behaviour of the structural members</u>
During the heating phase, the beam with a lower displacement is the beam near the window, because of lower temperatures, while the beam near the internal wall shows the biggest displacement. In the cooling phase, both these beams partially recovered (Fig. 4).


Fig 4 – Compartment after fire, residual deformation 925 mm, no local collapse of structure

Local buckling of the beam lower flange was one of the main failure mechanisms, see Fig. 5. As temperature and the associated deformations increase, shear buckling of the beam web was observed.


Fig. 5 – Local Buckling.

The formation of a plastic hinge in the beam cross-section next to the protected zone was other of the main mechanisms. This hinge is induced by distortional buckling during the first stage of the heating phase, due to the restraint to thermal elongation provided by the adjacent protected section. Subsequently, during the second stage of the heating phase, the beam rotates around this point due to the large mid-span deflection.
Due to the end-plate loading, bending in the column flange was observed in one of the major axis beam-to-column joints. This behaviour results from the small column flange thickness (t = 21.4 mm) and the small distance between the bolts, the bolted end-plate behaving as a welded joint.

• <u>Composite Slab Behaviour</u>
Fracture in the concrete slab was observed, a large crack propagating from the face of the column flange parallel to the beam (D2-E2), see Fig. 6. This crack developed due to the tension in the concrete slab, along the weak zone in the composite beam - flange extremity. After the concrete cracked, the joint stiffness gradually decreased. Secondary cracks occurred perpendicular to, and continuous across, the connections on both sides of the slab.

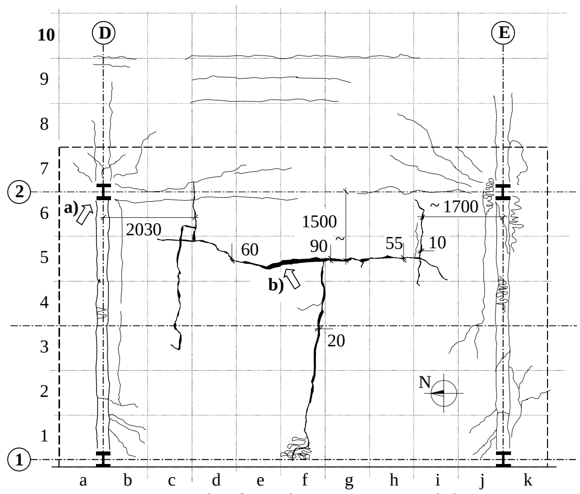

Fig. 6 – Mesh of cracks in concrete slab.

Relevant Publications:

International Journals

Simões da Silva, L., Santiago, A., Moore, D. e Vila Real, P., 'Behaviour of steel joints and fire loading'. *International Journal of Steel and Composite Structures* 5(6), pp. 485-513 (2005).

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Thesis

Behaviour of Steel Joints under a Natural Fire, Aldina Santiago, PhD Thesis (expected in 2008).

Reports

Wald F, Santiago A, Chladná M, Lennon T, Burgess I and Beneš M, Tensile membrane action and robustness of structural steel joints under natural fire, Internal report, Part 1 - Project of Measurements; Part 2 - Prediction; Part 3 – Measured data; Part 4 – Behaviour, BRE, Watford, 2002-2003.

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3D Behaviour of steel Joints between I Beams and SHS Columns with Hollo-bolts: Numerical Models and Experimental Behaviour

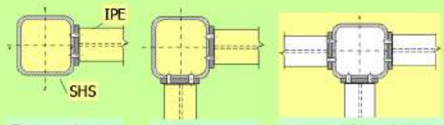
AFONSO C. B. MESQUITA

Supervisor: Luís A. P. Simões da Silva

SCOPE OF THE WORK

The main objective of this research is to determine the initial rotational stiffness, the post-elastic stiffness (membrane stiffness) and the plastic moment of the connections with hollo-bolts in the selected joints, including bolted connection with flush end-plate (Typology A) and bolted connection with extended end-plate (Typology B) under monotonic static load.

JOINT CONFIGURATIONS



External joint | Corner joint | Internal façade joint

Fig.1

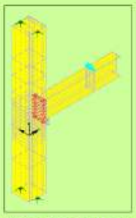
TYPOLOGIES OF CONNECTIONS AND BOLTS

Fig.2 Typology A | Typology B

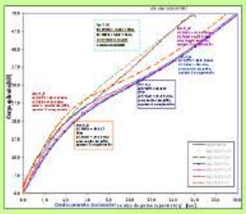
CALIBRATION OF NUMERICAL MODELS

Fig.3

Physical reference model (Neves, 2004)



Numerical model (Mesquita *et al.*, 2006)



Numerical curves *versus* experimental curve

FINITE ELEMENT MODELS DEVELOPED

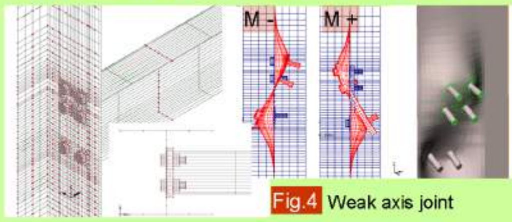


Fig.4 Weak axis joint

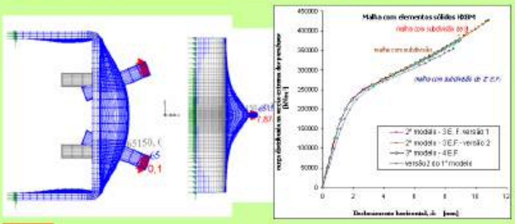
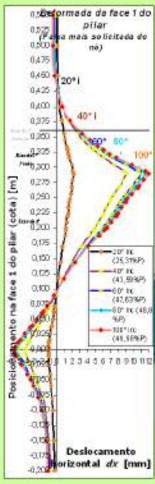
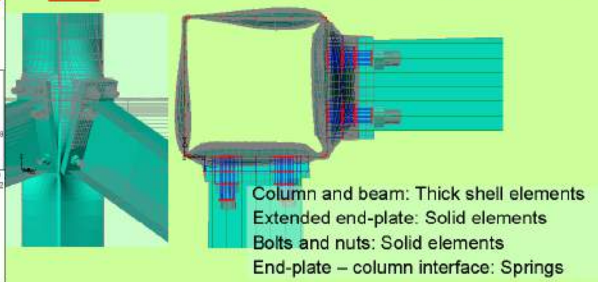


Fig.5 Tubular profile with hollo-bolts in tension (3D elements)

LABORATORY LAYOUT AND PREPARATION OF PROTOTYPES

Fig.7





Column and beam: Thick shell elements
Extended end-plate: Solid elements
Bolts and nuts: Solid elements
End-plate – column interface: Springs

Fig.6 Deformed mesh of a corner joint (*LUSAS* ®)

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HELENA MARIA GERVÁSIO

Supervisor: Luís Simões da Silva

A METHODOLOGY FOR AN INTEGRAL LIFE CYCLE ANALYSIS OF BRIDGES IN VIEW OF SUSTAINABILITY

❑ MODEL FOR AN INTEGRAL LIFE CYCLE APPROACH

- Definition of goals of the study
- Definition of system boundary
- Selection of indicators
- Quantification of indicators → Deterministic quantification (literature models)
- Interpretation of results → MCDA under uncertainties environment

▪ System boundary

Material Production	Construction	Operation	End of life
Raw material acquisition	Transportation of construction equipment	Transportation of equipment	Use of equipment
Transportation to production site	Use of construction equipment	Maintenance operations	Demolition of structure
Production of construction materials	Construction processes	Rehabilitation processes	Transportation of materials/waste to disposal site
Transportation to construction site	Traffic congestion	Traffic congestion	Traffic congestion

▪ Multi-dimensional approach

Sustainable Construction
- Environmental sustainability
  - Eco-system: - Emissions - Pollutants - Land use - Waste
  - Health & well-being: - Toxicity of construction materials - Pollutants
  - Natural Resources: - Optimization of land resources, energy - Recycling
- Economic sustainability: - Maintenance - Life cycle costs
- Social sustainability: - Safety - Noise

▪ Matrix of indicators

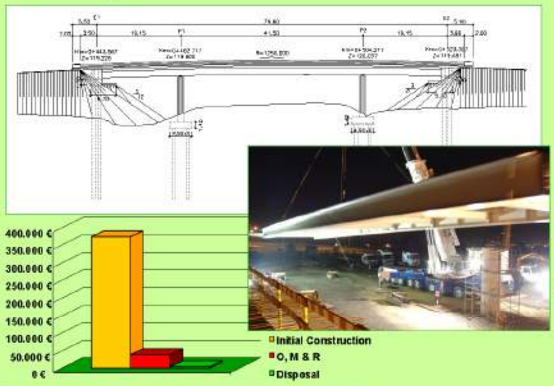
Criteria	Life Cycle Stages: Material production	Construction	Operation	End-of-life
Environmental				
Social				
Economic				

Futher developments in models:
- ➢ Implementation of uncertainties due to life cycle analysis
- ➢ Time and space consideration

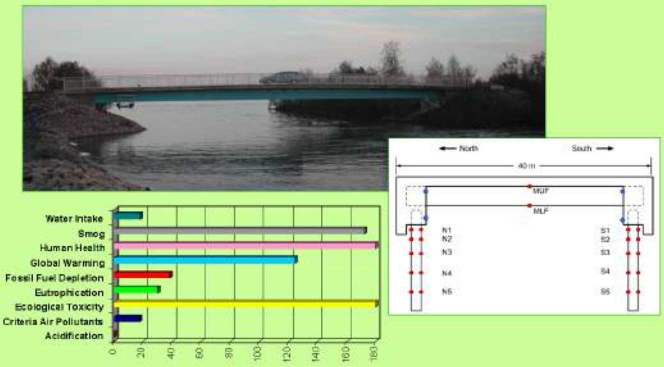
Simulation Analysis
Scenario Analysis
Fuzzy Analysis
Risk Analysis

❑ CASE STUDIES

▪ Composite motorway viaduct (Portugal)



▪ Bridge with integral abutment (Sweden)



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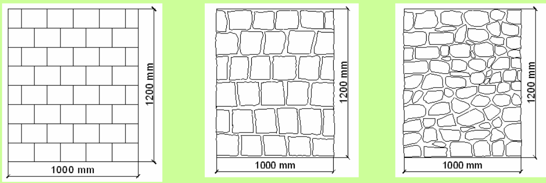
SENTHIVEL RAMAKRISHNAN

Supervisor: Paulo Lourenco

ADVANCED FINITE ELEMENT MODELING OF HISTORICAL MASONRY STRUCTURES

❑ OBJECTIVES

- To evaluate analytically the seismic performance of stone masonry shear walls.
- To compare the seismic response of different type of stone masonry shear walls (Figure 1) found in historical masonry structures.

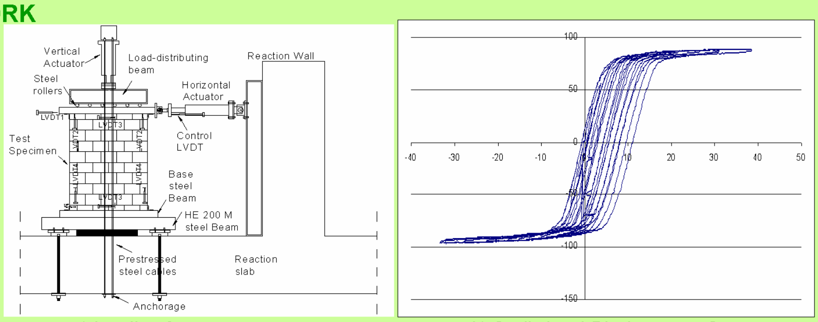


a) Sawn b) Irregular c) Rubble

Figure 1: Type of Historical Masonry Walls

❑ EXPERIMENTAL RESEARCH WORK

- Vasconcelos, G. (2005), "Experimental Investigations on the Mechanics of Stone Masonry: Characterization of Granites and Behavior of Ancient Masonry Shear Walls", PhD Thesis, University of Minho, Portugal.
- Three different axial pre-compression loadings were consider (100, 175 and 250 kN).



a) Loading Arrangement b) Cyclic Load-Displacement Curve

Figure 2: Experimental Set-up and Test Result

❑ FINITE ELEMENT MODELLING

- Nonlinear Finite Element Analysis using DIANA v8.1
- Micro-modeling technique using zero thickness line interface elements for mortar joints.
- Stones and joints are assumed elastic and inelastic respectively.
- Lateral load resistance capacity of wall is directly proportional to axial pre-compression load.
- Analytical failure modes and load-displacement curves are in good agreement with the experimental test results.

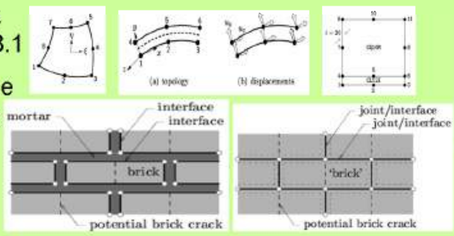


Figure 3: Modeling Techniques for Masonry

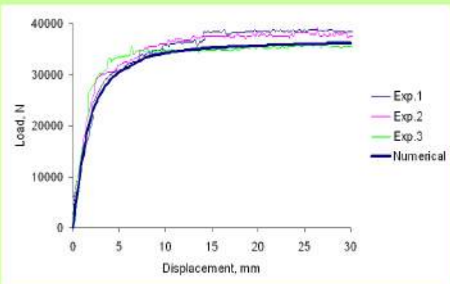


Figure 4: Load-Displacement Curves

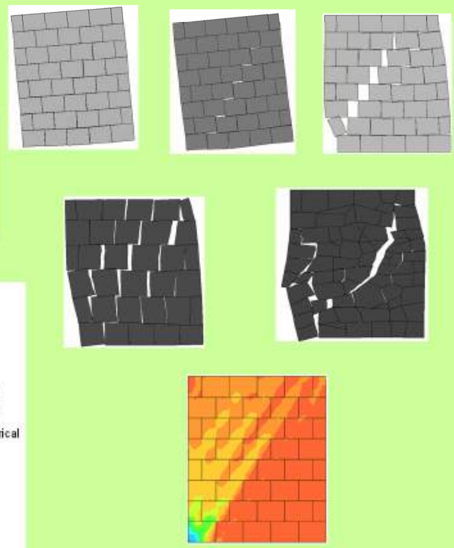


Figure 5: Failure Modes and Stress Contour

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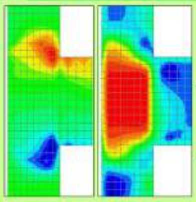
SANDRA JORDÃO

Supervisors: L. Simões da Silva / R. Simões

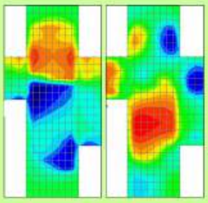
BEHAVIOUR OF INTERNAL NODES WITH BEAMS OF DIFFERENT HEIGHTS WITH HIGHT STRENGHT STEEL S690

❑ THE PROBLEM



External nodes or symmetrical internal nodes

- Three almost uncoupled components.
- Possible to extract the behaviour of the components to use the component method.
- Covered in EC3 Part 1-8

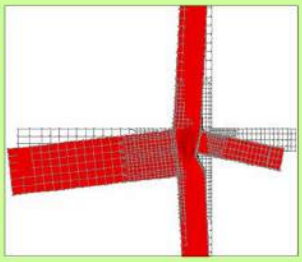


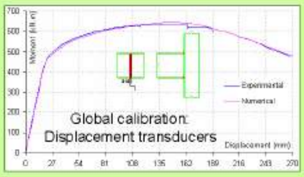
Internal nodes with beams of different heights (INBDH)

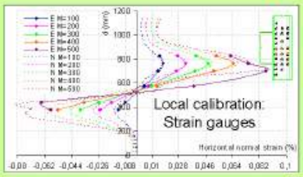
- Complex stress field: coupled components.
- How to assess the behaviour of the components and the whole node ?
- Not covered in EC3

❑ THE PROCEDURE

- Thirteen experimental tests, on 4 different nodes for steel grades S355 and S690.
- Finite element models for all the nodes selected.

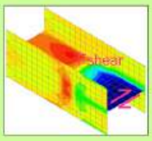


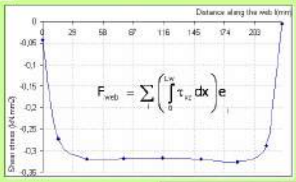


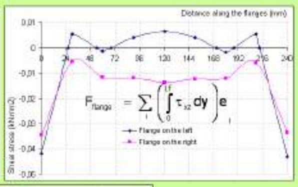


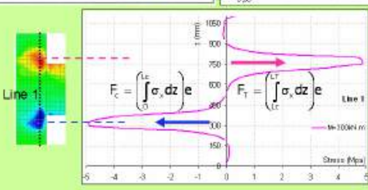
- Calibration of the FE models with the experimental results.

- Use the calibrated FE models to access the behaviour of the components in INBDH.



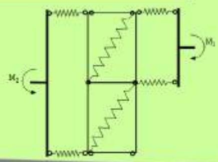






❑ THE OBJECTIVE

- Tailor a mechanical model suited for INBDH, that describes the behaviour of this kind of node in terms of resistance and deformability.



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BEHAVIOUR OF STEEL JOINTS UNDER A NATURAL FIRE

ALDINA SANTIAGO

Supervisors: L. Simões da Silva / P. Vila Real

❑ LARGE-SCALE AND SUB-FRAME FIRE TESTS


Steel building - Cardington


Compartment after fire

- The 7th *large-scale fire test* was performed; the beam-to-column joints were header plate joints. The results showed a thermal gradient along the beam span and within the cross-section. The main failure modes were: local buckling of the beam lower flange and fracture of the header-plate along the welds.
- Six sub-frame test were performed at the University of Coimbra. The beam-to-column joints varied between bolted end-plate, welded and header plate joints. Heating-cooling fire curves were applied to the beam and joints using a *natural fire system* (gas burners).


Initial test configuration

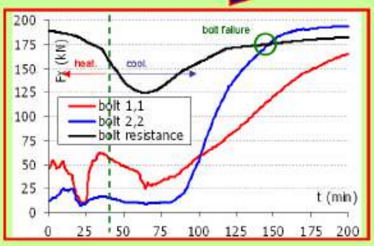

Sub-frame deformation

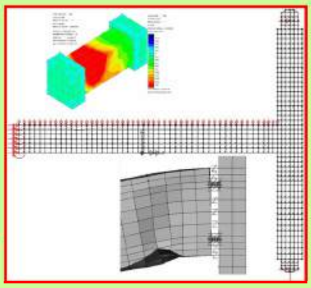

Bolt failure

BOLTS FAIL DURING THE COOLING PHASE!!!

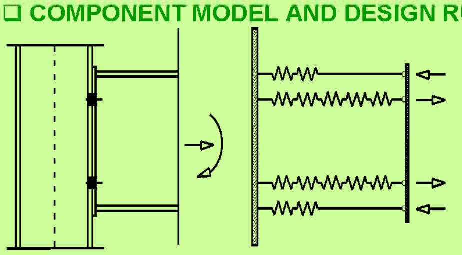
❑ NUMERICAL MODEL AND VALIDATION

- FE analysis, calibrated with the experimental results, allowed the characterization of the mechanical response of each joint component during the fire development.
- The FE program LUSAS was used. The beam, column and end-plate were modelled by shell elements, the bolts were represented by solid elements and the contact by spring elements.





❑ COMPONENT MODEL AND DESIGN RULES



- The proposed model reproduces the response of the components under variable axial force and bending moment curves.
- The tensile and compressive forces do not act in the same line.
- The degradation of the strength and stiffness of the components material with increasing temperature is considered using reduction factors.

THE TENSILE COMPONENTS ON THE LOWER ZONE OF THE CONNECTION SHOULD BE DESIGNED TO AVOID FAILURE FROM THE BOTTOM BOLT ROW!!!

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BOND-SLIP MECHANISMS IN STEEL FIBRE REINFORCED SELF COMPACTING CONCRETE

Institute for Sustainability and Innovation in Structural Engineering

VÍTOR CUNHA

Supervisors: Joaquim Barros / J. Sena-Cruz

INTRODUCTION: In fibre reinforced composites materials, fibre and matrix are bonded together through a weak interface. The study of this interfacial behaviour is important for understanding the mechanical behaviour of such composites. Moreover, with the outcome of new composites materials with improved mechanical properties and advanced cement matrices, such in the case of steel fibre reinforced self-compacting concrete (SFRSCC), the study of the fibre/matrix interface assumes a new interest.

Scope: Assess the pullout behaviour of steel fibres from a SFRSCC medium and ascertain the local bond stress-slip relationship. For these purposes an experimental set-up was defined, which allows the **accurate acquirement of the pullout load versus end-slip relationship**, and an analytical model is implemented to **obtain the local bond law** by a back-analysis procedure. These laws will be used in future work to model the fibre/matrix interface behaviour in structural elements of SFRSCC.

Assessment of the fibre pullout behaviour: The pullout tests were perfomed on a servo-hydraulic Lloyd LR30K machine with a capacity of 30 kN. The test setup is depicted in Fig. 1. The influence of the ***fiber type*** (smooth, hooked), ***embedded length*** (10, 20 and 30 mm) and ***orientation angle*** (0, 30 and 60º) on the pullout behavior of SFRSCC was studied.

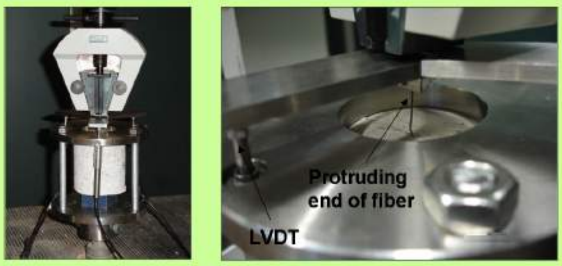

Fig.1 - Test setup.

The local bond phenomena of the fiber-matrix interface was modeled by a ***second order differential equation***. The analytical pullout load-slip relationship was determined using an energy approach. The local bond differential equation was obtained numerically using the ***Runge-Kutta-Nystrom*** method.

The parameters of the local bond stress-slip law that best fitted the experimental pullout load-slip curves of the smooth series were obtained by ***back-analysis***. In Fig. 2(a) is depicted the local bond law used and some parameters obtained in the back-analysis. In Fig. 2(b) are represented some analytical and experimental curves.

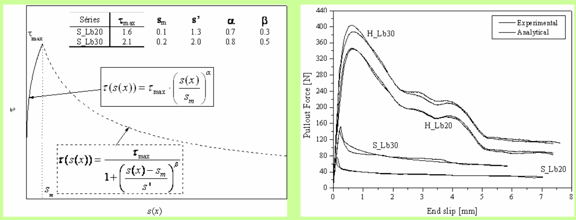

Fig.2 - (a) Local bond law (b) Analytical simulation.

Future work: The response of SFRSCC structural elements will be simulated using a ***mesoscopic model***. For this purpose **particle packing models** will be used on a meso-level to assess the final distribution state of the aggregates and fibres in a certain structural element. In a second step, the location and orientation of the fibres will be inserted in a three dimensional ***finite element mesh*** (see Fig. 3). A multi-fixed smeared crack model will be used to simulate the fracture process of plain concrete, whereas for modelling the fibre contribution will be used the bond-slip laws previously assessed.

Fig.3 - Steps of the meso-level model.

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PEDRO SANTOS

Supervisor: Eduardo Júlio

CONCRETE-TO-CONCRETE INTERFACES: TEXTURE, SHRINKAGE AND MODULUS OF ELASTICITY

OBJECTIVES

- Quantitative characterization of the substrate surface in alternative to the Eurocode 2 proposal
- Assessment of the influence of several parameters on the bond strength of the concrete-to-concrete interface
  - Texture of the substrate surface
  - Differential shrinkage between concrete layers
  - Difference between modulus of elasticity
  - Shear plane angle


Fig. 1a)

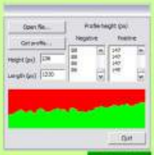
Fig. 1d)

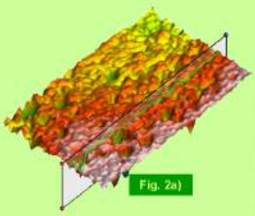
Fig. 2a)


Fig. 1b)


Fig. 1c)

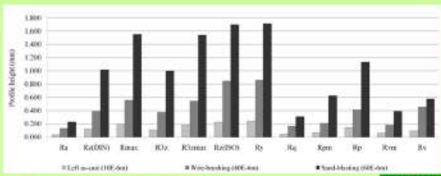
Fig. 2b)

TEXTURE CHARACTERIZATION

- Development of a method based in digital image processing, destructive and very work intensive, for texture characterization, Fig. 1
- Definition of surface profiles and numerical parameters to distinguish surface treatments, Fig. 2
- Development of a laser roughness analyzer, Fig. 3
- Comparison of different methods, including the Sand Patch Method, Fig. 4, and a 3D laser scanner, Fig. 5

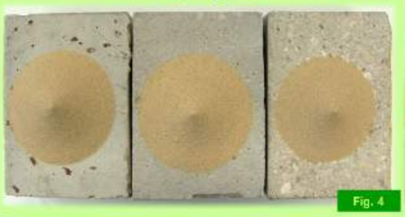
Fig. 4


Fig. 5

EXPERIMENTAL STUDY

- Cast of a large number of specimens, Fig. 6
- 5 surface treatments : left as-cast, wire-brushing, sand-blasting, shot-blasting and hand-scrubbing
- 3 curing conditions: curing room (≈ 20ºC; 90% RH), laboratory (≈20ºC; 75% RH) and exterior
- 3 different ages between layers: 28, 56 and 84 days
- 2 different concretes: 35 and 70MPa
- 3 shear plane angles: 20, 30 and 40 degrees
- 3 bond tests: Slant Shear, Pull-Off and Splitting Test


Fig. 6b)


Fig. 6c)


Fig. 6a)


Fig. 3

CONCLUSIONS

- The bond strength of the interface can be predicted using numerical parameters (roughness and waviness)
- The number of monolithic failures increases when the difference of modulus of elasticity increases
- The bond strength is highly influenced by diary fluctuations of temperature and relative humidity
- Shot-blasting is the most adequate method for surface preparation

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DÉBORA FERREIRA

Supervisor: Joaquim Barros

CONFINEMENT OF CONCRETE COLUMN ELEMENTS OF CIRCULAR CROSS SECTION WITH CFRP SHEETS

ABSTRACT

- Circular cross section concrete elements confined by distinct arrangements of strips of CFRP sheet are submitted to a direct compression load up to the failure point.
- The influence of the width of the strip, distance between strips, number of CFRP layers per strip, CFRP stiffness and concrete strength class on the increase of the load carrying capacity and ductility of concrete columns, is evaluated.
- An analytical model is developed to predict the compressive stress-strain relationship of concrete columns confined by discrete and continuous CFRP arrangements.

CONFINEMENT SYSTEMS

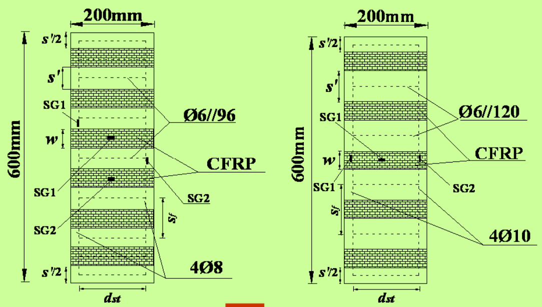


Fig.1

EXPERIMENTAL RESULTS

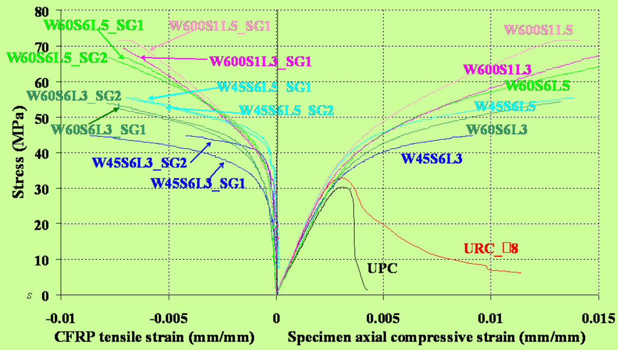
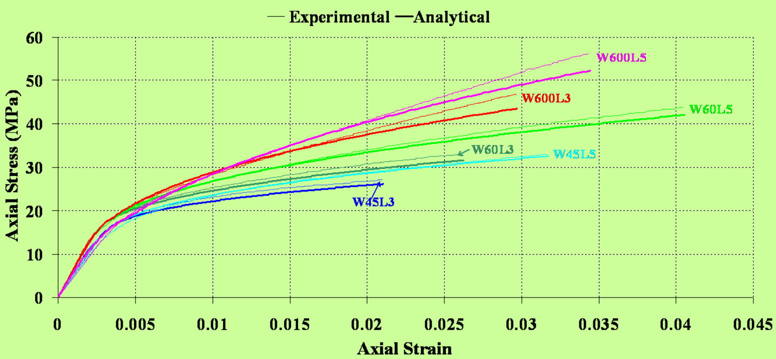


Fig.2

MODELING



$$\sigma_c = f_{co,URC} + k_1 f_l \quad \text{for } \varepsilon_c \geq \varepsilon_{cA}$$

$$\varepsilon_c = \varepsilon_{co,URC}\left[1 + k_2\left(\frac{\sigma_c}{f_{co,URC}} - 1\right)\right] \quad \text{for } \varepsilon_c \geq \varepsilon_{cA}$$

Fig.3

CONCLUSIONS

- The results revealed that above five layers, the increment in terms of load carrying capacity, deformability and energy absorption capacity were all marginal.
- The concrete compressive strength, the CFRP stiffness and the volume of unconfined concrete had a significant influence on the shape of the specimen stress-axial strain response.
- For the specimens of equal ρ_f, the load carrying capacity of partially confined specimens was a little bit lower than the one of the fully confined specimens. However, partial confinement arrangements were easier and faster to apply than full confinement arrangements.
- The developed model accurately predicted the experimental stress-strain response.

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RAFAEL AGUILAR VELEZ

Supervisor: Paulo Lourenço

DAMAGE IDENTIFICATION AND HEALTH MONITORING OF EXISTENT MASONRY STRUCTURES

❑ INTRODUCTION

For the preservation of monuments, health monitoring and damage identification plays an important role. To preserve the constructions, the developments on MEMS technology incorporated with WSN are attractive to monitoring the behavior of structures, particularly, in rather complex masonry structures that require a significant number of sensors to understand the structural behavior. After detection, the next task is to localize the damage and its extension with more detail. Sonic tomography is widely used to detect the presence of voids and flaws, and to find crack and damage patterns.

www.flickr.com

Photo of a Wireless Sensor (Crossbow MPR2400)

Ultrasonic Pulse Velocity System
(www.olsoninstruments.com)

❑ AIM OF THE WORK

- Use non-conventional equipment, such as innovative wireless solutions, for monitoring the behavior of masonry structures.
- Identify the possible presence of damage by modal dynamic identification and sonic investigation.
- Convert the large amount of data available in monuments into risk indices and intervention priorities to assist the owners of the monuments in the heritage preservation.

❑ IMPORTANT TASKS DURING THE PROJECT

Comparison of wireless devices between standard sensors in terms of performance, weight, power consumption, costs, etc.

Installation of wireless systems in some Portuguese Monuments.

Preparation of a novel prototype for sonic tomography to reduce the process time in the signals acquisition and to increase the results quality.

Testing in situ and in the laboratory the prototype developed for sonic tomography.

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LUÍS F. RAMOS

Supervisors: P.B. Lourenço / A. Campos-Costa

DAMAGE IDENTIFICATION ON MASONRY STRUCTURES BASED ON VIBRATION SIGNATURES

❑ OBJECTIVES OF THESIS

- Preservation of the architectural heritage
- Use operational modal analysis to estimate de dynamic properties of historical constructions
- Damage assessment in the masonry structures at early stage

Fatigue collapse of Pavia Tower, 1989, Italy

Fatigue collapse of Noto church, 1996, Italy

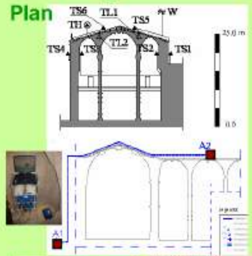
❑ METHODOLOGY

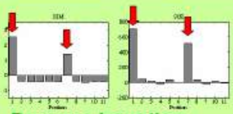
Monitoring the historical Constructions:

1. Global dynamic modal test and a numerical model analysis for static and dynamic calibration
2. Health monitoring plan with a limited number of sensors for damage detection
3. If an alarm is triggered, damage identification methods should be applied to locate damage
4. If a damage is located, a local approach with non-destructive tests should be carried out to locally classify and assess the damage

Dynamic Identification

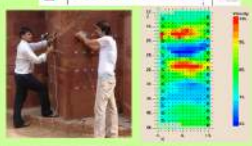
Monitoring Plan





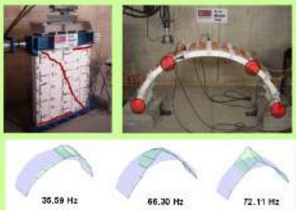
Damage Location

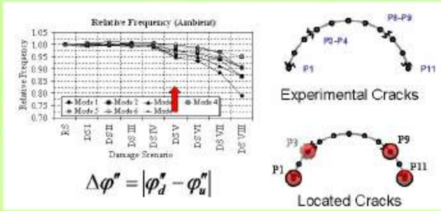
Local ND Tests



❑ LABORATORY SIMULATIONS

- One arch and one wall to replicate masonry constructions were built and damage scenarios were applied by increasing load magnitudes

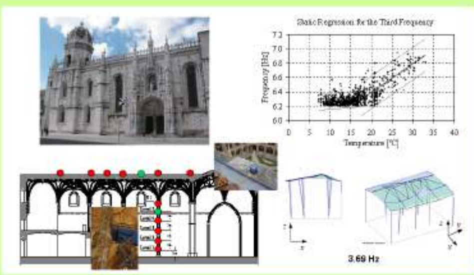




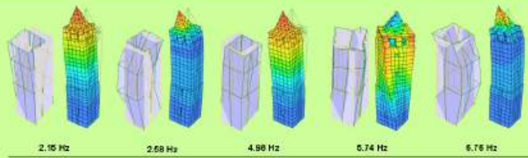
$$\Delta\varphi'' = |\varphi''_d - \varphi''_u|$$

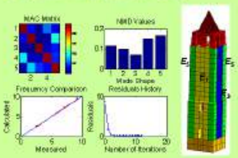
❑ CASE STUDIES

Monastery of Jerónimos, Lisbon



Mogadouro Clock Tower, Portugal





Updating Parameters	Before Rehabilitation [GPa]	After Rehabilitation [GPa]	Difference [GPa]	Relative Values
E_1 [GPa] (South)	0.687	1.974	**+1.287**	**2.87**
E_2 [GPa] (North)	2.210	2.210	–	1.00
E_3 [GPa] (West)	0.302	1.075	**+0.773**	**3.56**
E_4 [GPa] (East)	0.276	0.804	**+0.528**	**2.91**
E_5 [GPa] (Corners)	3.870	3.875	+0.005	1.00

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NUNO MENDES

Supervisor: Paulo Lourenço

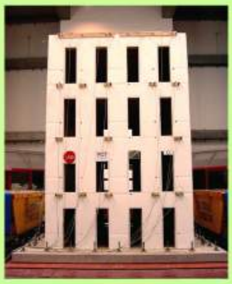
DESIGN AND STRENGTHENING OF MASONRY STRUCTURES

❑ INTRODUCTION

- The first stage of this work is intended to focus on the old buildings, particularly the behavior of "gaioleiros" buildings (1870-1930) under seismic load.
- This building typology is typical of Lisbon and other cities of Portugal, and is characterized by high seismic vulnerability.
- The evaluation of the seismic performance of this buildings was accomplished through an experimental program and numerical analyses.

❑ EXPERIMENTAL PROGRAM

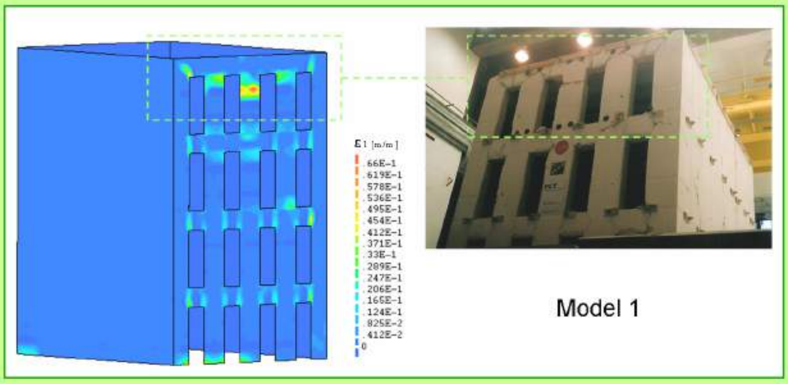
- The tests were performed in the LNEC 3D shaking table on 1:3 reduced scale models.
- The following models were tested:
  - Model 0: without reinforcement;
  - Model 1: reinforcement of the wall-to-floor connections using steel connectors and fiber glass strips glued with epoxy resins.
  - Model 2: connection of opposing walls by means of steel ties at the 3rd and 4th storeys.
  - Model 3: reinforcement of existing piers in the facades by means of fiber glass strips glued with epoxy resins and steel connectors.



Unreinforced model (Model 0)

❑ NUMERICAL ANALYSES

- In the process of calibration of the numerical model, the vibration modes of the structure, the dynamical parameters measured and the crack pattern obtained from experimental program were used.



❑ CONCLUSIONS

- The preliminary results obtained in the tests and in the numerical analyses shows that the models replicate the typical collapse modes of these buildings, in which damage concentration in the last storey is highlighted.

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LILIANA RAQUEL SIMÕES MARQUES

Supervisor: Luís Simões da Silva

DESIGN OF STEEL STRUCTURES USING NON-LINEAR FINITE ELEMENT METHODS

MAIN GOALS

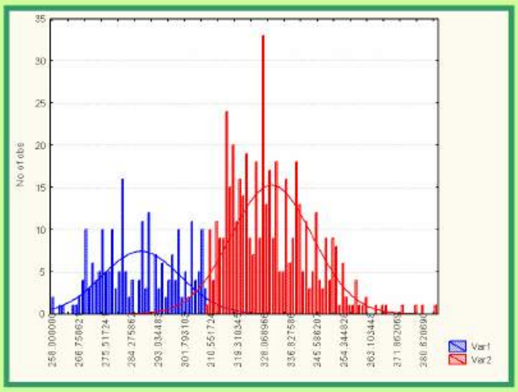
- Developing general methodologies in the scope of nonlinear analysis of structures involving stability problems;
- Development of unified stability checking procedures for any stability phenomena in Eurocode 3;
- Assessment and validation of the general methodology for stability checking of clause 6.3.4 of Eurocode 3 part 1-1;
- Extending stability checking procedures to high strength steels (up to S700);
- A contribution towards the revision of EC3.

RECENT STUDIES - EXAMPLES

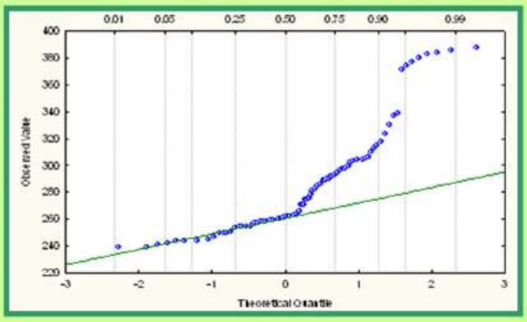
Validation of Eurocode 3 design rules for lateral-torsional buckling of beams

Material Uncertanties

Bi-normal distributions



Regression line adjusted to lower tail



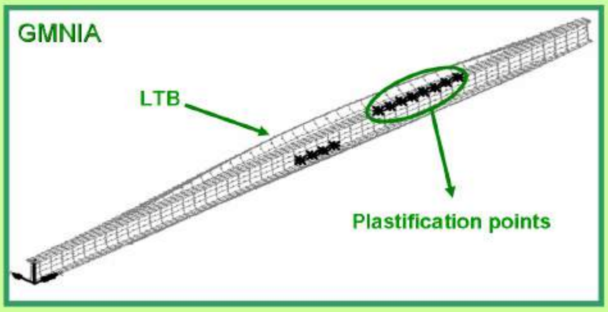
Statistical analysis of test results

Fabrication process	Steel Grade	Source	n	Mean (MPa)	St. Dev (MPa)	CoV	Minimum Value (MPa)	Type of Cross Section
Hot rolled (n=134)	S450	Dibley	5	506.00	48.35	0.10	457.00	UB;UC
	S235 (n=129)	Suzuki	27	281.87	22.93	0.08	195.20	HR
		Fukumoto	65	252.71	9.96	0.04	239.20	
		Wakabaya	3	318.47	17.81	0.06	304.10	
		Udagawa	10	277.24	17.28	0.06	259.00	
		UN	1	-	-	-	290.00	

Non-linear analysis of structures by FEM methods

Load factors

Elasto-plastic behaviour		Elastic Resistance	Plastic Resistance
Geometrical linearity	Mesh no. 2	2.73	3.06
	Mesh no. 3	2.68	3.00
	Mesh no. 4	2.66	2.97
	Theoretical	2.64	2.92
Geometrical non-linearity	No Imp.	2.67	3.00
	Local imp.	0.80	0.83
	Global imp.	0.71	0.72
	L+G imp.	0.64	0.72
	Theoretical	0.59	0.66



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VLADIMIR GUILHERME HAACH

Supervisors: P.B. Lourenço / G. Vasconcelos

DEVELOPING INNOVATIVE SYSTEMS FOR REINFORCED MASONRY WALLS

➢INTRODUCTION

Masonry is one of the most antique structural systems used in the construction. However, it lost prestige with the development of other systems such as reinforced concrete and steel. During decades there was an absence of normalization and design codes for structural masonry. Masonry is today a material relatively unknown for the majority of the civil engineers.

➢ADVANTAGES

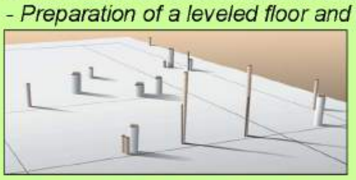
- *Economy in molds*
- *Significant reduction in coverings*
- *Reduction of waste material and workmanship*
- *Flexibility in time rate of the work*

➢BARRIERS

- *Difficult dialog between structural engineering and architecture*
- *Reduced design knowledge by the engineers*
- *Reduced software programs*

➢CONSTRUCTION METHODOLOGY

- *Preparation of a leveled floor and position of walls*



- *Bedding of the first course according to project and positioning of the reinforcement*

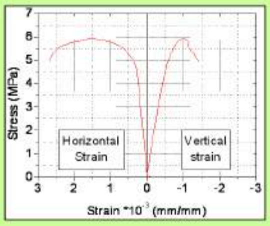
- *Bedding of other courses with horizontal reinforcement*

➢EXPERIMENTAL VALIDATION OF THE SYSTEM

An enlarged experimental program was carried out in order to validate the structural solution, with mechanical characterization of masonry and evaluation of the behavior of masonry walls under horizontal cyclic loads.

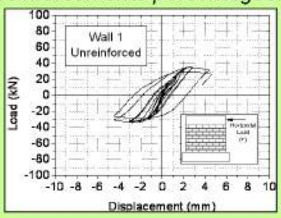
✓ Mechanical characterization of masonry

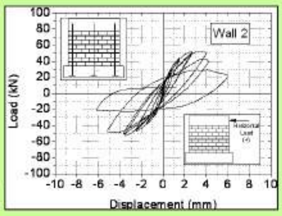
This includes concrete blocks, mortar and unit-mortar interface, and compressive and tensile strength characterization of masonry as a composite.

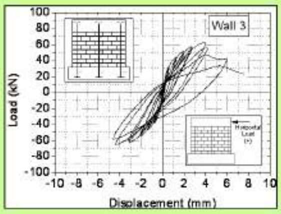


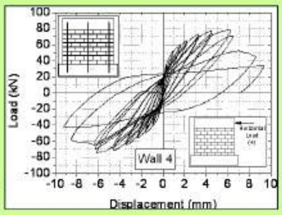
✓ In-plane cyclic tests

The masonry wall tests were carried out on masonry panels with different types of masonry bond, two distinct pre-compression levels and with distinct horizontal reinforcements percentages.









➢CONCLUSIONS

The reinforced masonry systems behave adequately under horizontal cyclic loads. The masonry bond seems not to influence the lateral resistance, lateral deformation and on the energy dissipation. This appear to be a major advantage as the construction technology of reinforced masonry walls can be easily updated from the traditional construction of non-load bearing walls.

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JOÃO P. GOUVEIA

Supervisor: Paulo Lourenço

DEVELOPMENT OF AN INDUSTRIALIZED STRUCTURAL MASONRY SYSTEM

OBJECTIVE

The objective of this work is to develop a constructive solution for small and medium size buildings, using a system of confined and reinforced structural masonry, and aiming at more economical solutions, with better performance and more rational building technologies. The providing innovative solutions for confined structural masonry are to be assessed in terms of strength for seismic loading and of construction costs.

WORKING JUSTIFICATION

i) Masonry walls in residential buildings represent around 12 to 17 % of the total cost. The walls exhibit often damage, being responsible for 25% of the total damage in construction.

ii) Recent studies demonstrate that a structural solution using masonry is 10 to 15% more economical than the competing reinforced concrete solution.

iii) The construction in Portugal presents a singular situation when compared another countries. The structures used a single execution technique: reinforced concrete.

Units for a STRUCTURAL MASONRY SYSTEM

The system is constituted by a block family (masonry unit and special block), steel reinforcement and fasteners, mortars and concrete infill.

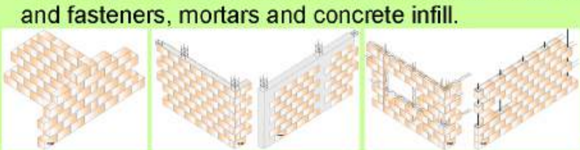

Figure 1 – Scheme of Structures system in study: Simple masonry, confined masonry and reinforced masonry with prefabricated bed joint reinforcement or reinforcing steel bars with concrete infill

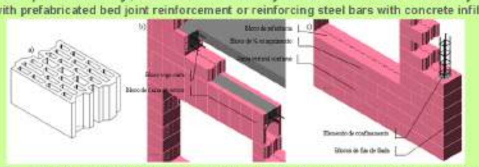

Figure 2 – Light-weight concrete units and scheme of system application.

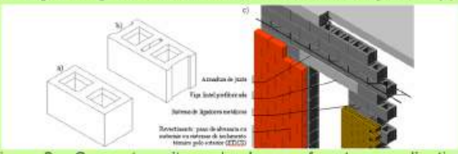

Figure 3 – Concrete units and scheme of system application.

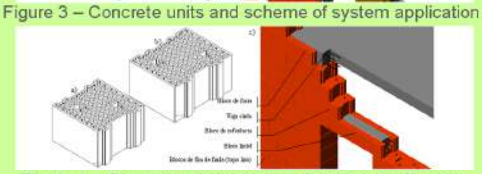

Figure 4 – Clay units and scheme of system application.

EXPERIMENTAL RESEARCH

The new system of masonry has been tested in laboratory. The different tests can be seen in pictures below:

Figure 5 – Evaluation of mechanical properties of materials: masonry units, mortar and concrete infill.

Figure 6 – Evaluation of mechanical properties of masonry: flexural strength, adhesion between units and mortar, compressive strength.

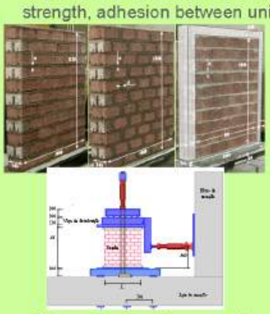

Figure 7 – Specimens and apparatus shear test of masonry

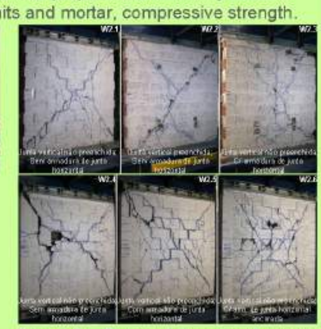

Figure 8 – Typical failure mechanisms

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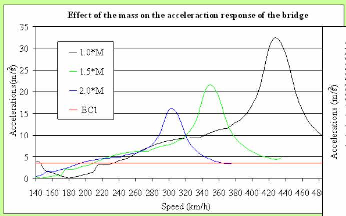
Institute for Sustainability and Innovation in Structural Engineering

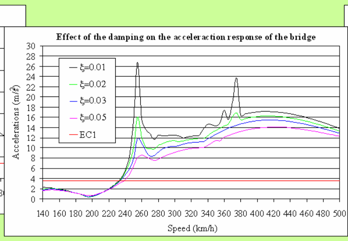
CONSTANÇA RIGUEIRO

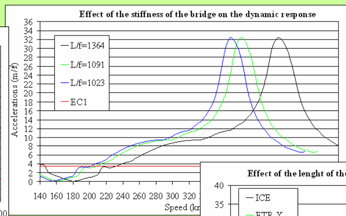
Supervisors: C. Rebelo / L. Simões da Silva

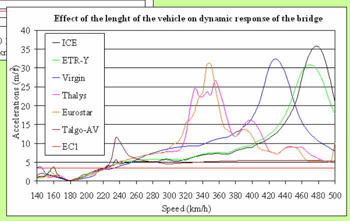
DYNAMIC EFFECTS ON SHORT MEDIUM RAILWAY BRIDGES

❑ THE DYNAMIC BEHAVIOUR OF SHORT TO MEDIUM SPAN BRIDGES









- The dynamic response of simple supported railway bridges with short to medium span are very sensitive to several factors related to the modal characteristics of the structure and the length of the vehicles. Too high vertical accelerations of the decks may affect the stability of the ballast.

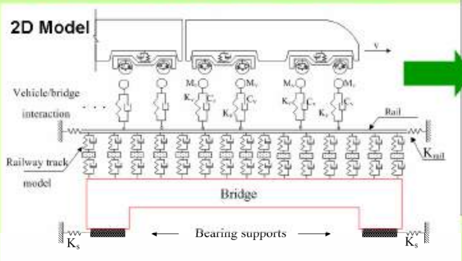
❑ STUDY CASES – Simple supported twin slabs of prestressed concrete

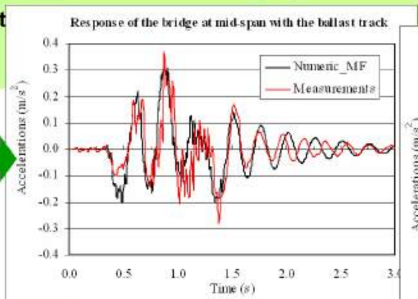
Abutments of a twin slabs viaduct

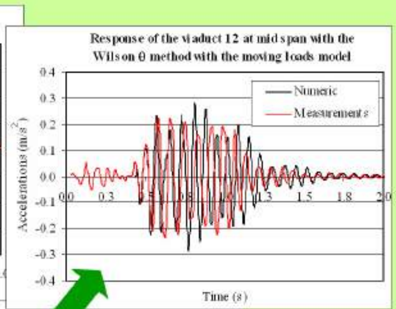
A skew viaduct

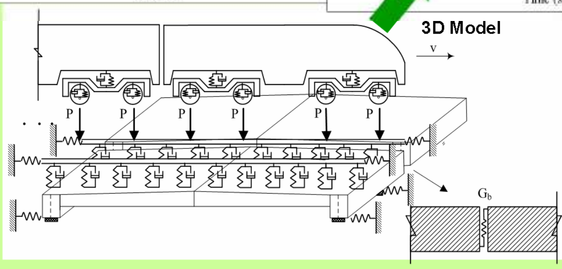
- An experimental program was carried out on several existing short to medium bridges in order to get a better estimation of their dynamic behaviour, which included the modal identification and the measurement of vertical accelerations of the bridges decks during the normal railway operation.

❑ FE MODELS AND VALIDATION









- The ballast effect is similar to low-pass filtering the response acceleration of the non-ballasted deck. This effect is relatively more important when the maximum response of interest is not close to the resonance at critical speeds.

❑ CONCLUSIONS

- The contributions of the railway ballast track, namely of the ballast and the rails are evident on overall dynamic response;
- The first frequency of the bridge is variable during the passage of the trains, due to the variation of the mass and the existence of non linear effects of the ballast and at the supports; The presence of the rails plays an important role.

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EVALUATION OF THE FRICTION COEFFICIENT IN SLIP RESISTANT JOINTS WITH HIGH STRENGTH STEEL

ALEXANDRA FELIZ LIMA CRUZ

Supervisor: Rui Simões

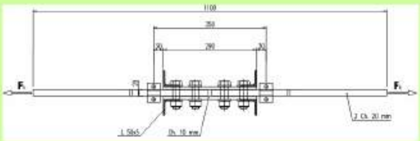
❑ SLIP RESISTANT JOINTS

- Slip resistant joints are quite used in structures submitted to predominantly cyclic loads, as for example, in the steel and composite bridges.
- These joints are built up with cover plates and bolts in shear (see figure) and designed as slip-resistant, both at serviceability limit states or ultimate limit states.
- The global depends greatly of the friction coefficient on the contact surfaces.

Joint

❑ OBJECTIVE

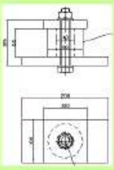
- Evaluation of the friction coefficient with several surface treatments and several steel grades, including **high strength steel** and **cor-ten steel**.



Model

❑ EXPERIMENTAL PROGRAM

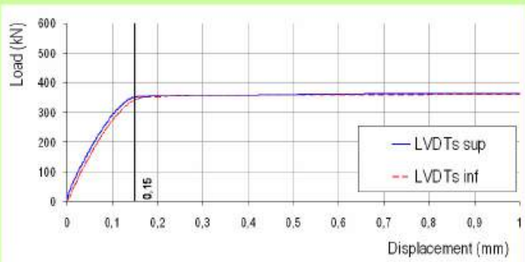
- Developed in the Civil Engineering Department of the University of Coimbra, sponsored by SOCOMETAL (a portuguese company for the manufacture of steel structures).



Force calibration

Experimental tests

❑ RESULTS



Load-displacement curve

Surface tratment

	Surface treatment	Fs, average kN	σ	Friction coeficient $\mu_{average}$	Friction coeficient $\mu_{5\%}$
A	Surface blasted with sand shot (Sa 2[1/2])	389,97	3,43%	0,5862	0,5159
B	Surface blasted with steel shot (Sa 2[1/2])	382,42	3,00%	0,5749	0,5134
C	Surface blasted with steel shot (Sa 3) + Spray metalized with zinc (75 mm)	356,85	1,61%	0,5365	0,5035
D	Chemical cleaning + Hot galvanized (160mm)	357,37	2,80%	0,5375	0,4802
E	Surface blasted with steel shot Sa2[1/2] + Zinc Etil Silicate (70 mm)	313,71	2,42%	0,4716	0,4220
F	Surface blasted with steel shot (Sa2[1/2]) + Zinc Epoxy (70 mm)	259,49	1,15%	0,3901	0,3666

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SOCOMETAL

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ROLANDO SALGADO

Supervisors: Paulo Cruz / Gustavo Ayala

EVALUATION OF VIBRATION BASED DAMAGE DETECTION METHODS APPLIED TO BRIDGES

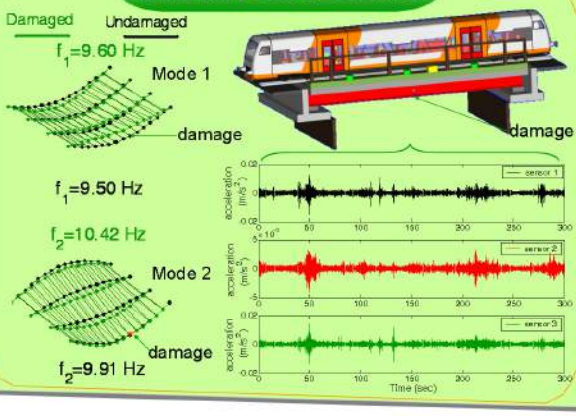
INTRODUCTION

Detecting structural **damage** in bridges is an important issue for **preventing** their **failure** and reducing their maintenance costs. Several methods for detecting damage have been recently proposed. These methods, however have not been so far successfully applied to bridges. For this reason, a comparison of some of these methods is presented.

OBJECTIVES

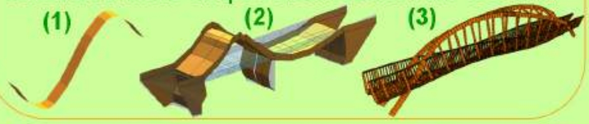
- Develop a numerical model of cracked beam structures and cracked composite bridges to calculated their dynamic response.
- Perform dynamic failure tests on simple specimens.
- Perform dynamic tests on deliberately damaged bridges.
- Perform dynamic tests on undamaged bridges and simulate their dynamic responses with numerical models with updating properties. Use the updated numerical models to simulate the effect of damage.
- Carry out a comparison of several damage detection methods based on wavelet transforms (Discrete Wavelet Transform, **DWT** and Wavelet Packet Signature, **WPS**) and **curvature** of the mode shapes applied to the dynamic properties of the bridges.

DYNAMIC SIMULATIONS



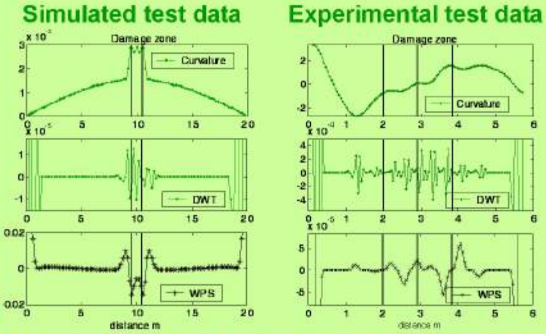
DYNAMIC TESTS

Calculated mode shapes obtained from the test data



RESULTS & DISCUSSION

Simulated test data | **Experimental test data (1)**



Damage detection methods could accurately detect damage from simulate data, however, damage was not clearly detected from experimental test data.

CONCLUSIONS

Evaluated damage detection methods **worked well** with **dynamic simulation** data where noise was not present. When data from **experimental tests** was used, these methods were **very sensitive to noise** in the signals produced during acquisition. Existent damage caused a significant change of modal parameters only in the vicinity of its location. This means that more sensors should be located near and at potential damage zones to increase the chance of detecting damage.

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EDUARDA LUSO

Supervisors: P.B. Lourenço / R.M. Ferreira

EXPERIMENTAL ANALYSIS OF CEMENT AND LIME GROUTS FOR USE IN MASONRY STRUCTURES

❑ PHYSICAL CHARACTERIZATION of COMMERCIALLY AVAILABLE GROUTS

- **A grout to be injected into masonry should comply with a set of requirements, namely rheological, physical, chemical and mechanical.**
- **Some laboratory tests were conducted to determine the properties of commercially available (CA) grouts used to repair masonry: flow time (fig. 1); bleeding; segregation; compressive strength, (fig. 2).**

Fig.1

Fig.2

Fig.3

Fig.4

Fig.5

❑ INJECTABILITY CHARACTERIZATION of CA GROUTS

- **Injection grout is evaluated not only in terms of fluid consistency and homogeneity, but also injectability and penetration.**
- **Using different stones, cylinders have been prepared into plexiglas moulds of 150mm diameter and 300mm height in order to reproduce in laboratory typical Portuguese masonry walls, (fig. 3 and 4).**
- **Four different CA grouts have been used and injected, using a "pressure pot", (fig. 5).**
- **Uniaxial compression tests were performed with displacement control and also indirect tensile test or "Brazilian test", (fig. 6 and 7).**
- **Cylinders injected with each grout were cut vertically so as to inspect the degree of penetration of the grouts, (fig. 8).**

Fig.8

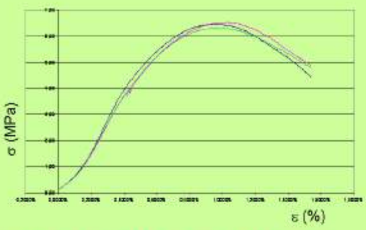

Fig.6

Fig.7

❑ BOND STRENGTH CHARACTERIZATION of CA GROUTS

- **The main property affecting the behaviour of grouted walls is the shear bond strength of the grout-stone interface.**
- **The tensile strength of the interface between grout and the stone, demanded the preparation of composite specimens, made of two stones pieces connected with a 10mm grout layer.**
- **A total of 12 composite specimens were prepared and tensile tests at the age of 90 days are being performed.**

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RUI A. SILVA

Supervisor: Daniel V. Oliveira

EXPERIMENTAL CHARACTERIZATION OF ANCIENT MASONRY WALLS: STRENGTHENING AND LONG-TERM EFFECTS

❑ INTRODUCTION

This work intends to characterize experimentally the behaviour of three-leaf walls under compressive loading and to evaluate the changes due to the application of the most common strengthening techniques on this kind of walls (injection and transversal tying). A second goal deals with the experimental characterization of the creep behaviour of ancient masonry.

❑ EXPERIMENTAL CAMPAIGN

❑ Tests on Materials and Components

Testing of the materials.

Three-leaf wall components: plain inner core, injected core and external leaf.

Monotonic tests for the creep specimens.

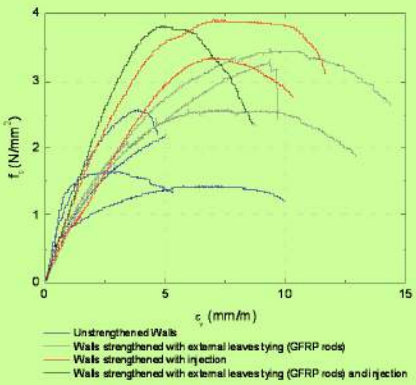
❑ Compressive Tests on Representative Masonry Specimens

Wall Construction

Unstrengthened wall tested under compression

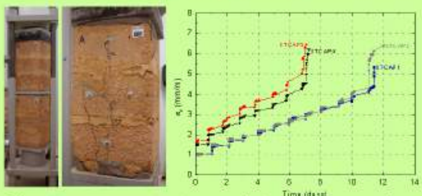
Wall injection

Injected wall tested under compression

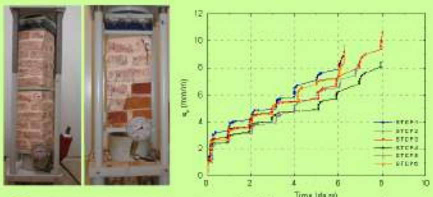


Axial stress–strain curves

❑ Short-Term Creep Tests



Short-term creep tests on adobe masonry prisms



Short-term creep tests on brick masonry prisms

❑ Long-Term Creep Tests

On-going...

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LÚCIO A. P. LOURENÇO

Supervisor: Joaquim Barros

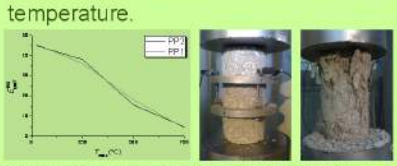
FIRE RESISTANCE OF CONCRETE TUNNEL SEGMENTS

OBJECTIVE

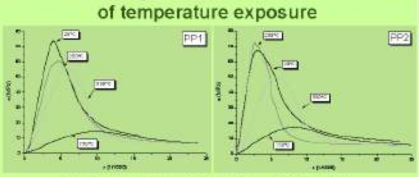
Tunnel segments of different steel reinforcement ratio and percentage of fiber systems were submitted to fire test and the corresponding residual flexural resistance was assessed.

FRCEFR Residual Properties

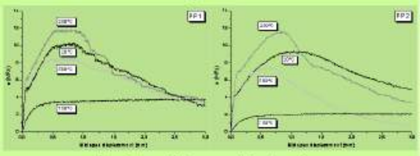
Mechanical tests were executed at 28 days after FRCEFR have been exposed to distinct levels of high temperature.



Residual Young's modulus for different level of temperature exposure



Residual compressive behavior



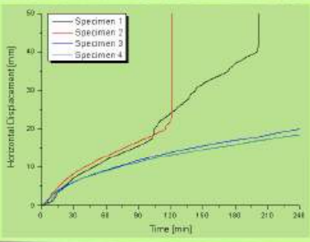
Residual flexural behavior

The presented results can be used for the calibration of numerical models dedicated to the simulation of the material nonlinear behavior of concrete structures that have been submitted to high temperatures.

FIRE TEST – ISO 834

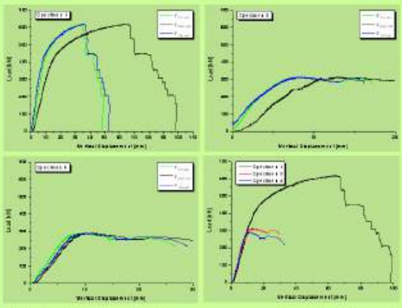
Four tunnel specimen prototypes of 1.2 x 2.4 x 0.35m³ were tested. S1 – No steel fibers and 81 kg/m³ of conventional steel bars. S2 - 75 kg/m³ of steel fibers. S3 - 45 kg/m³ of steel fibers and 51 kg/m³ of conventional steel bars. S4 - 60 kg/m³ of steel fibers and 55 kg/m³ of conventional steel bars. PP fibers content of 2 kg/m³.

These specimens, supported in an external structure, were tested in a fire resistance furnace capable of follow the ISO 834 curve. During the fire resistance test, the elements were subjected to a constant load of 174 kN, applied to its mid span and orthogonally to the middle surface of the specimen. This load configuration aims to simulate the load conditions that tunnel segments are submitted in service.

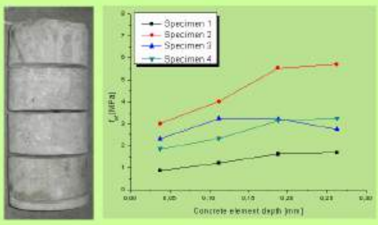


RESIDUAL STRENGTH

The tunnel segments that did not collapse during the fire resistance test were then subjected to bending tests to evaluate its residual resistance.



Variation of the concrete indirect tensile strength test (Brazilian Test) versus concrete depth.



CONCLUSIONS

- Fiber reinforcement is very effective in terms of retaining the tensile strength of tunnel segments submitted to fire.

-Specimens 3 and 4 were less affected by fire exposure.

(results obtained with the cooperation of FCTUC - Coimbra).

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EDUARDO B. PEREIRA

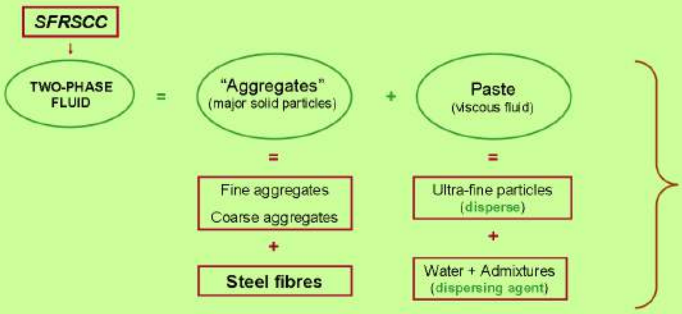
Supervisor: Joaquim Barros

FRESH AND HARDENED BEHAVIOUR OF FIBRE REINFORCED SCC

Steel Fibre Reinforced Self-compacting Concrete

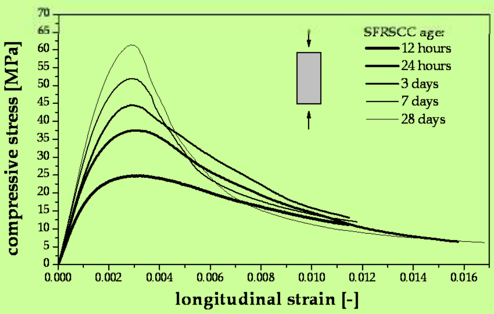
Development of a rational procedure to optimize SCC composition

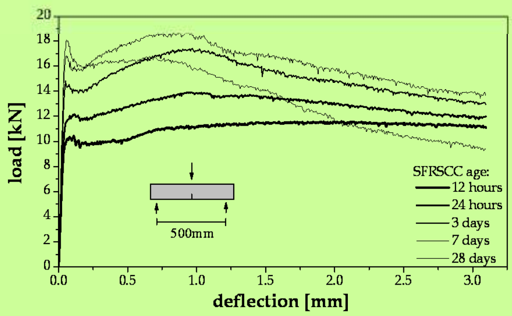
- Combining the implications of concrete constituents on both fresh fluid behaviour and hardened mechanical properties, and considering the hindrance effect of steel fibres in the fresh mix, a rational procedure to optimize SCC was developed.



High Performance Compositions:
- c = 360 kg/m³; w/c = 0.27; SF = 30 kg/m³
- fcm_{28d}=63 MPa;
- good flexural residual strength

- Laboratory tests revealed good overall mechanical performance of hardened SFRSCC designed mixes:





Future Developments

Reach tensile and flexural strain hardening on Fibre Reinforced SCC

- Take the knowledge of ITZ and stiffening mechanisms behaviour during cracking to deeper levels of knowledge, exploring meso- and micro- material scales. Eventually introduce distinct types of fibres, in shape and in nature.
- Enhance Fibre Reinforced SCC ductility and control crack width, in order to enhance its durability and resistance to aggressive agents.

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JOÃO GUERRA

Supervisores: Luís S. Silva / Pedro Vellasco

FORMULATION OF IMPERFECTIONS IN 3D FRAMED STRUCTURES

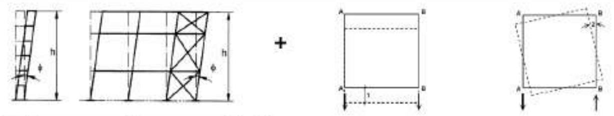
❑ STRUCTURAL IMPERFECTIONS? WHAT ARE THEY?

Imperfections is all that is not intentional include on the structural concept and design.

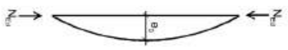
❑ HOW DOES EC3 DEAL WITH IMPERFECTIONS?

Geometrical imperfections + Material imperfections = Equivalent geometrical imperfections

► Global structural level:



► Local structural level:



► Section structural level: in general EC3 refer that no need to be considered (in frame case).

❑ IS IT ENSURED THAT USING EC3) LEADS TO THE WORST IMPERFECTION SITUATION?

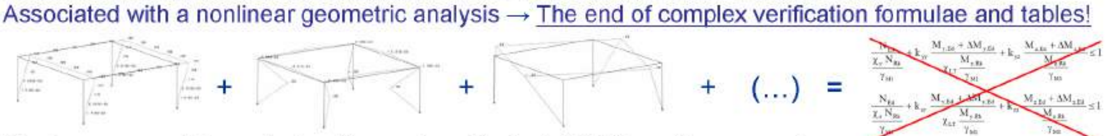
Not necessarily for all cases.

❑ SO, HOW TO FIND THE WORST IMPERFECTION IN A PRACTICAL WAY?

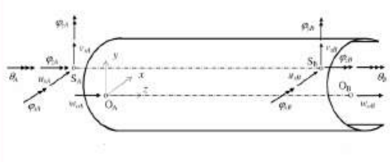
Using the collapse shapes → and relate them to the buckling modes!

In a combination based in buckling modes percentage of importance (ex.: pond rating → $1/\alpha_{Cr}$)

Associated with a nonlinear geometric analysis → The end of complex verification formulae and tables!

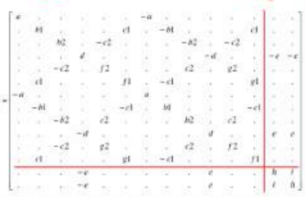


Nonlinear geometric analysis with warping effects, in full 3D matrix approach.



Advantages, features and facilities:

- ► The simplicity and transparence;
- ► Any magnitude criterion depending;
- ► Nonlinear material can be added;
- ► Buckling sectional curve EC3 influence;
- ► Easily adaptable to other Finite Elem/.



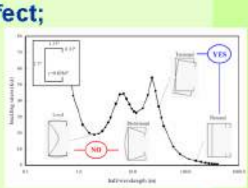
❑ TARGET

→ **Propose a imperfection 3D frame model (global, element and local level);**

→ **Develop a new formulation that can efficiently include all important local effect;**

→ **Define the limits of application and give the recommendations for use.**

❑ MODEL AND VALIDATION



- ► Analytical and numerical model with practical engineering design applications.
- ► Fortran 90 code computer program support, with public release.
- ► Validation of nonlinear formulation with buckling analysis using commercial software .

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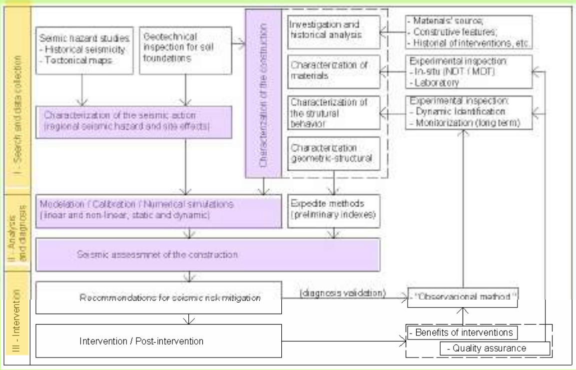
INTEGRATED APPROACH FOR SEISMIC ASSESSMENT OF MONUMENTS: THE CASE STUDY OF BELÉM CHURCH

JOÃO C. A. ROQUE

Supervisors: P.B. Lourenço / D. Oliveira

Approach for seismic assessment of monuments

The seismic safety assessment in historical constructions is a quite complex problem. Usually, this task cannot be done without a dynamic interaction combining historical data with an experimental and analytical investigation.

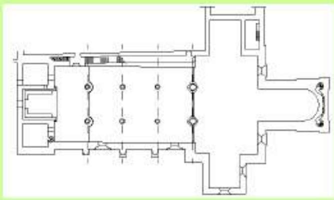


The difficulty of evaluating the real safety level and the possible benefits of interventions may suggest "an observational method" based on monitoring plans. The structural intervention, if really necessary, should be done respecting the cultural and historic significance of the construction, without inducing significant changes to the structure (minimal intervention), with adequate materials (compatible and durable) and techniques, with measures that should not limit further interventions (reversibility) and with a quality assurance works.

Application to a case study

The Monastery of Jerónimos is, probably, the crown asset of Portuguese architectural heritage dating from the 16th century. Its church has considerable dimensions, namely a length of 70 m, a width of 23 m (main nave) and 40 m (transept) and a free height of 24 m.

The main nave is divided by two rows of slender columns, with a free height of about 16.0 m that support a slightly curved vault ceiling. The fan capitals reduce effectively the free span of the vault giving an organic character to the architecture and to the structural perform.



The construction resisted quite well to the earthquake of November 1, 1755. Later, in December 1756, a new earthquake caused the collapse of one column of the nave which cause a partial ruin of the high choir and the vault. In 1888 the bell-tower was modified and elevated.

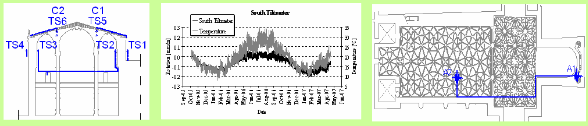
The analysis of previous existing works allows concluding that the geometrical survey of the main nave demonstrates a vertical non-alignment for all the columns and the external walls. The preliminary diagnosis stresses the high slenderness of the columns and the apparent vulnerability of Church in the transversal direction.

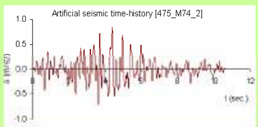
The mechanical characterization of representative masonry prisms under uniaxial compressive loading allowed to obtain an average compressive strength of 10 MPa and an Young's modulus within the range of 20 GPa – 50 GPa.

The main nave (vault and columns) of the church was dynamically identified trough "output only" techniques.

	Vault				Column	
Mode	1	2	3	4	1	2
Frequency [Hz]	3.69	5.12	6.29	7.23	7.12	7.52
Damping [%]	2.34	1.11	1.00	0.77	3.97	5.00

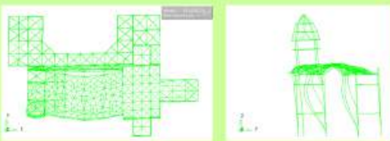
Both a static and dynamic monitoring system were installed in the main nave.
The static monitoring system is composed by six temperature sensors (TS1 to TS6) and two uniaxial tilt meters (C1 and C2). The dynamic monitoring system is composed by two triaxial accelerometers that allows synchronized records.





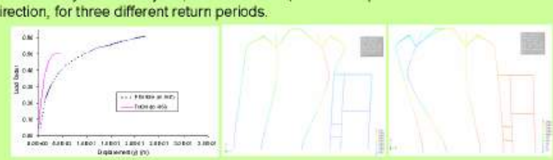
Supported by seismic hazard studies conducted for mainland Portugal, three stochastic hazard scenarios were used with return periods of 475, 975 and 5000 years, respectively. In the absence of available records, three acceleration time-histories were artificially generated for each seismic scenario.

The calibration of the model was performed against the results of the dynamic identification and mechanical tests. Modal analysis found a frequency of 3.8Hz against 3.7Hz achieved experimentally.



A preliminary linear static analysis loads shows, as the preliminary diagnosis, that the transversal direction of the nave controls the behaviour of the church. Subsequent non-linear static analysis show the need for a carefully numerical analysis against earthquakes in the transversal direction.

Non-linear dynamic analyses, in time domain, were then performed for the transversal direction, for three different return periods.



Preliminary results show that 475 yrp earthquakes might cause cracking, but neither local or global collapses are expected. Two more severe seismic scenarios are currently under analysis.

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JOSÉ CARLOS COSTA DE ALMEIDA

Supervisors: P. Cruz / J. de Brito

LIFE-CYCLE ANALYSIS OF ROADWAY BRIDGES

MAIN OBJECTIVES

- Establishment and comparison of the life-cycle costs for the different bridge structural solutions;
- Best economic solutions for the necessary actions aiming at increasing a bridge lifetime.

BRIDGE SELECTION – CASE STUDIES

- Selection of a set of bridges of the Portuguese highway network with the aim of the determination of the most economical structural solution when considering all the costs throughout a bridge lifetime.

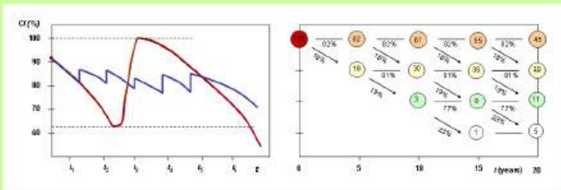
TRAFFIC FLOW

- Historical data
- Traffic counting
- Statistical treatment

- Traffic models
- Forecasting the traffic flow
- Crash analysis

UNCERTAINTY OF THE MAIN PARAMETERS

Establishing a correlation between the damage of a structural element and the deterioration of a bridge is extremely difficult. To overcome this difficulty it is essential to use probabilistic methods such as the Markov Method. The aim of this task is to analyse the uncertainty of some parameters.



COST ANALYSIS

How do we know if a bridge project is worth undertaking?

When should it be carried out?

What is the most cost-effective means of accomplishing it?

What will the effects of the project be on regional economies?

LIFE-CYCLE COST ANALYSIS

$$C = C_0 + C_I + C_M + C_R + C_F - B$$

C – Total costs involved in the construction, operation and replacement of the bridge;

- C_0 – Initial costs;
- C_I – Inspection costs;
- C_M – Maintenance costs;
- C_R – Repair costs;
- C_F – Failure costs;
- B – Benefits.

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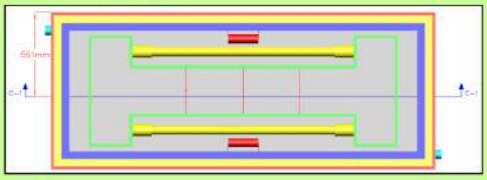
ANTÓNIO VENTURA GOUVEIA

Supervisors: Joaquim Barros / Álvaro Azevedo

MATERIAL NONLINEAR MODEL FOR FIBER REINFORCED CONCRETE SLABS ON SOIL, INCLUDING THERMAL AND SHRINKAGE EFFECTS

Main objectives of this **research**:

1. Develop a **fiber reinforced concrete** (FRC) applicable to slabs on soil to **prevent early-age cracking** due to shrinkage and thermal effects and so **eliminate crack control joints** in concrete pavements of industrial buildings;



2. Develop a **construction joint** for concrete pavements of industrial buildings to **eliminate deterioration** and **loss of load transfer** between adjacent panels;

3. Develop an **interface system** to **reduce the friction** between the **concrete and the soil**;

4. Develop a **material nonlinear model** for **fiber reinforced slabs on soil**:

Yield surface adapted from the **Ottosen yield surface**;

Transform the 2D **elasto-plastic multi-fixed smeared crack** model available in **FEMIX** computer code in a 3D model;

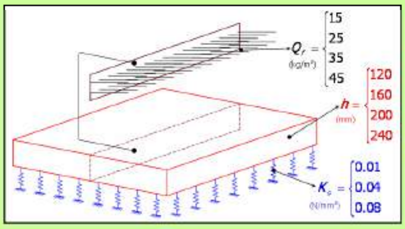
Nonlinear behavior of the **soil** simulated with an **elasto-plastic model**;

Mohr-Coulomb constitutive model for modeling the slab/soil **interface**. **Calibration** with **experimental results**;

Include in the model the different components of **shrinkage** (for example: **plastic and drying**) and **thermal effects** (uniform and differential).

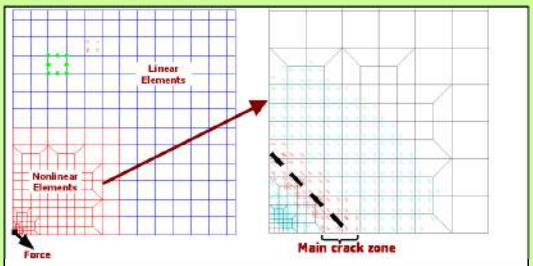
To **appraise** the **model** a **full scale test** in a **industrial FRC floor** will be carried out.

Results of a **parametric study** in a **steel FRC slab on soil**:



Slab: **2D elasto-plastic multi-fixed smeared crack**

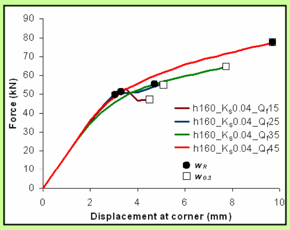
Soil: **unilateral springs** with nonlinear behavior

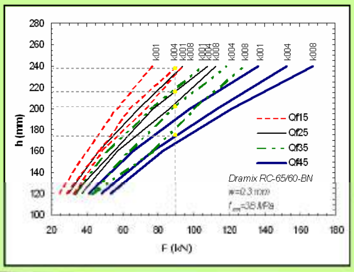


Finite Element mesh

Crack pattern in the slab top surface at a load level corresponding to w=0.3mm (h=160mm, Q_f=25 kg/m³ and K_s=0.01 N/mm³).

Relationship between the **force** and the **deflection** at the **slab corner**





Design chart to **determine** the most **economic solution** of steel FRC slab on soil

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FRANCISCO M. FERNANDES

Supervisor: Paulo Lourenço

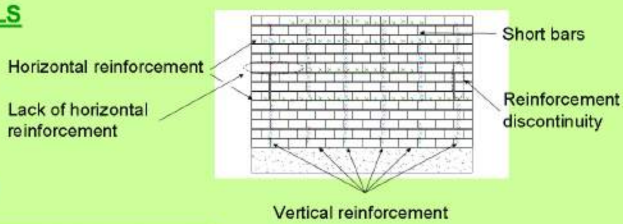
METHODOLOGIES FOR THE DETECTION OF ANOMALIES AND QUALITY ASSESSMENT OF STRUCTURES USING GEORADAR

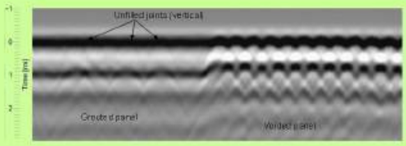
OBJECTIVES OF THE INVESTIGATION

- Develop inspection methodologies for field survey with georadar in civil engineering structures, road pavements, railway embankments, utilities mapping and archaeological survey

INSPECTION OF REINFORCED MASONRY PANELS

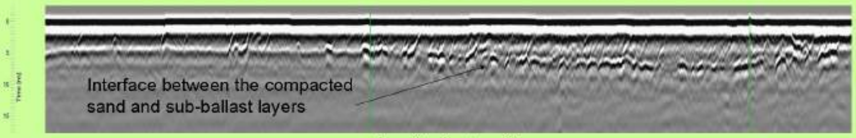
- Assessment of the construction quality and verification of project design
- Detection of reinforcing bars during the construction phase
- GPR correctly identified the location and length of all reinforcing bars
- Grouted and non grouted cells are easily identified



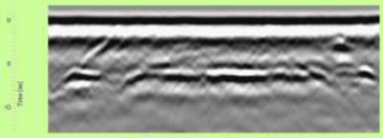


RAILWAY SURVEY

- Detection of the thickness of the sub-ballast layer
- Monitoring the layer's thickness along the track (longitudinally and transversally)



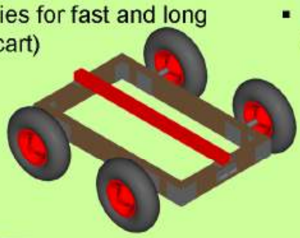
Longitudinal profile



Transversal profile

PAVEMENT SURVEY

- Assessment of the thickness of the bituminous and granular layers of road pavements
- Development of methodologies for fast and long surveys (car with prototype cart)
- Survey acquisitions by foot by adapting small cart for the high frequency antenna



ARCHAEOLOGICAL SURVEY

- Geophysical survey of areas with possible archaeological features
- Survey of industrial pavilions to detect old stone tanks below concrete floor

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CLAUDIO MARUCCIO

Supervisors: D.V. Oliveira / P.B. Lourenço

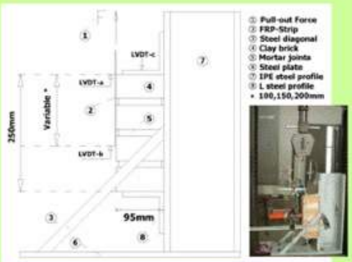
MODELLING OF ANCIENT MASONRY: STRENGTHENING AND LONG-TERM EFFECTS

❑ INTRODUCTION

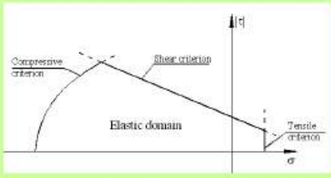
This work concerns advanced numerical modelling of bond strength of FRP to masonry and FRP reinforced masonry arches. The mechanical characterization of the basic materials and of the local interfacial behaviour allowed defining the main parameters and the constitutive law to be adopted.

❑ NUMERICAL MODELLING OF FRP-MASONRY BOND BEHAVIOUR

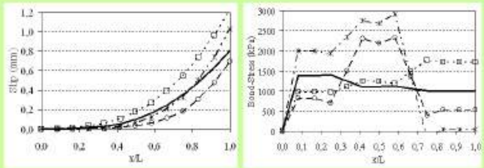
❑ Assessment of the capabilities of existing multi-surface model



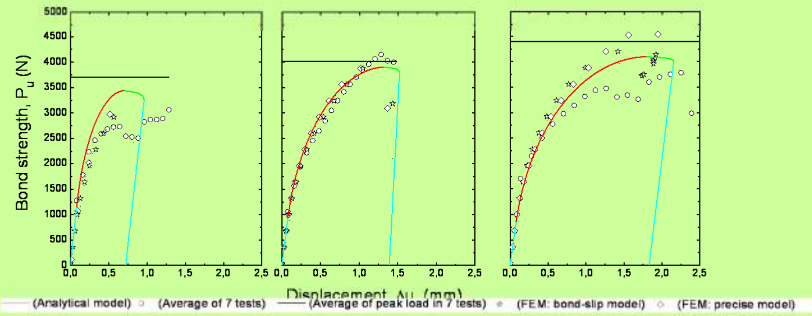
Pull test setup: schematic view and test to be started



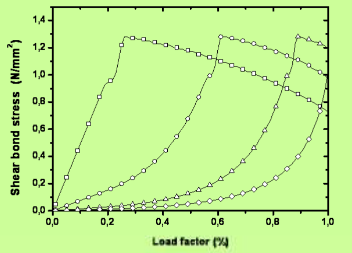
Existing multi-surface interface model (stress space)



Numerical vs. experimental slip and bond stress behaviour



Load displacement diagram : (a) L=100mm; (b) L=150mm (c) L=200mm



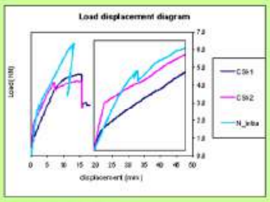
Shear bond stress vs. applied load

❑ Development of a new constitutive model

On going: starting from the existing monotonic model, two new multi-linear hardening laws for tension and shear plasticity are introduced in order to describe the motion of the yielding functions in a more accurate fashion.

❑ Numerical Modelling of FRP-strengthened masonry arches

Numerical vs. experimental results for the extrados FRP strengthened masonry arch



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MODELLING THE CYCLIC BEHAVIOUR OF FRP STRENGTHENED RC STRUCTURES

RAJENDRA KUMAR VARMA

Supervisors: Joaquim Barros / J. Sena-Cruz

❑ OBJECTIVE

The aim of the present project is to develop a fibrous/layered model and constitutive laws to simulate the behaviour of reinforced concrete structures strengthened with Carbon Fibre Reinforced Polymers, submitted to cyclic and monotonic load configurations, taking into account the material nonlinear characteristics. The constitutive laws for concrete, steel reinforcement, epoxy materials, FRP reinforced concrete, as well as the fibrous/layered model are being implemented in FEMIX computer program.

❑ NUMERICAL APPROACH

➢ Fibrous Model

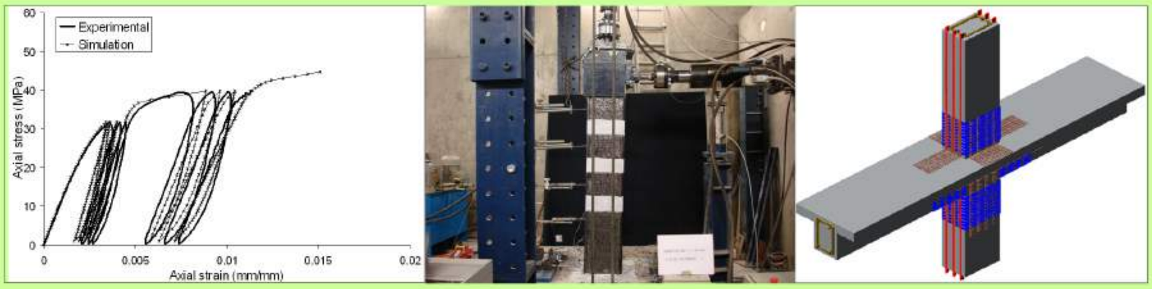
Every structural element is discretized in fibres along its longitudinal direction. The response of each fibre depends on the mechanical characteristics. A constitutive material model is applied to every fibre at material level, according to the material characteristic and, a response is generated from each fibre. The collective response of the fibres in turn produces the response at structural level.

➢ Constitutive Laws

- All cyclic hysteretic curves are enveloped by monotonic loading curve.
- Degradation in stress and strain is of vital importance during every cycle.
- Plastic strain and unloading stiffness decide the shape of hysteretic branches.
- Debonding of materials and crack formation are considered for buckling and pinching effect.

❑ VALIDATION, EXPERIMENT AND FUTURE WORK

The proposed numerical response are compared with experiments carried out at University of Minho. The layered model for shells are being implemented in FEMIX. To validate the proposed models and calibrate the model parameters, experiments focusing on strengthening and retrofit will be performed in future course of action.



(a) Numerical Simulation (b) Column Testing (c) Proposed strengthening strategy

❑ RESEARCH SIGNIFICANCE

The research plays a significant role in seismic design, retrofit and strengthening by FRP materials. It will contribute to the consolidation of the excellence of this group in the field on the use of FRP systems for the strengthening of the built patrimony. This strengthening intervention does not affect the structure appearance, which is an important attribute in terms of Architectural point-of-view.

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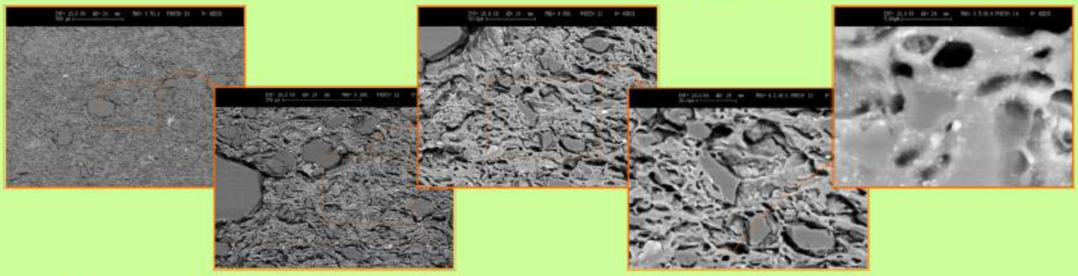
KONRAD J. KRAKOWIAK

Supervisors: Paulo Lourenço / Franz J. Ulm

MULTI-SCALE MODELLING OF QUASI BRITTLE MATERIALS

❑***Multi-scale approach to quasi-brittle materials, predicting the strength and life-time of masonry from the basic scales of its components.***

Microstructural pattern of fired clay brick used in masonry (BSEM).

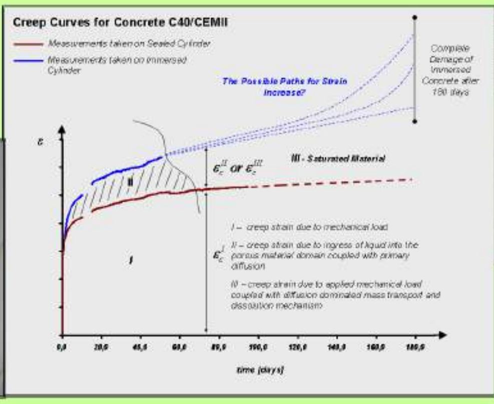


❑ Creep of Concrete Under Severe Conditions

•The main aim of this study is to give clear and proper description of the creep phenomena under combined mechanical and chemical action on the quasi-brittle porous materials like concrete or fired clay brick.

•The creep test was modified to capture the influence of mass transfer on the creep strain. The constant load is transferred to concrete cylinder sealed with aluminium foil (upper), and the specimen inside additionally designed chamber (lower). 6M ammonium nitrate solution was used as calcium leaching agent. The setup and reference cylinders were kept during the test in the control room with constant temperature and humidity. Linear strain gauges were used, three on each specimen in the longitudinal direction.

Experimental setup in the initial phase



Experimental setup in the final phase after 180 days

•The results prove the high impact of leaching phenomena on the creep and damage of material, the sample inside the leaching solution collapsed after 180 days, while the normal sample shows undisturbed creep behaviour characteristic for concrete There is evidence of two physical phenomena taking a place: ingress of fluid into to porous domain of material and dissolution of matrix components combined with diffusion mechanism. Both of them bring additional strain to the specimen. The results shows also the coupling between mechanical and chemical actions on the total deformation, which cannot be ignored.

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JÓNATAS VALENÇA

Supervisors: Eduardo Júlio / Hélder Araújo

MULTI-SPECTRAL ANALYSIS AND LASER SCANNING APPLICATION IN MONUMENTS INSPECTION

❑ SCOPE

- The inspection and geometric survey of structures is essential to program restoration tasks. Traditional topographic techniques are work intensive and time-consuming. Image based techniques, like laser scanning, allow a much faster and more accurate procedure.
- Multi-spectral analysis, if applicable, would allow the detection of material degradation and the automatic mapping of pathologies.


Fig 1a


Fig 1b


Fig 1c

❑ OBJECTIVES

- To develop a new methodology of inspection and geometric survey allowing the generation of three-dimensional models with automatic mapping of predefined material anomalies, with special focus in historic buildings (Fig. 1)
- To develop a new methodology of structural analysis by automatically generating numeric models using finite and discrete elements methods

❑ LASER SCANNING, PHOTOGRAMMETRY AND MULTI SPECTRAL ANALYSIS

Laser scanning and photogrammetry

- The combination of the two techniques results in a powerful and precise tool to acquire a detailed three-dimensional geometric model and to detect and reproduce the material textures (Fig. 2)


Fig 2a

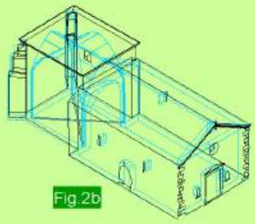
Fig 2b

Multi spectral analysis

- Multi spectral analysis can be used to detect and map material anomalies on structures (Fig. 3a)
- Image regions can be assigned to different material anomalies and the damaged area can be classified and measured (Fig. 3b)


Fig 3a

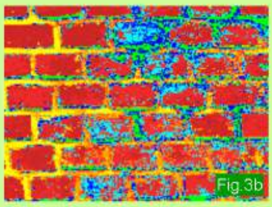
Fig 3b

❑ VALIDATION AND APPLICATION

- The methodology will be calibrated with laboratorial tests, using samples of different materials and with some levels of different induced anomalies
- The methodology will be validated with some case studies, mainly historical masonry structures, churches and bridges, and also relevant RC structures

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GLÁUCIA MARIA DALFRÉ
Supervisor: Joaquim Barros

NSM Strengthening technique to increase the resistant negative bending moments of continuous RC slabs using carbon fiber laminates

INTRODUCTION

Near-Surface Mounted (NSM) is one of the most promising strengthening techniques, based on the use of carbon fiber-reinforced polymer (CFRP) laminates. According to NSM, the laminates are fixed with epoxy based adhesive into slits opened into the concrete cover on the tension face of the elements to be strengthened. This technique has proven to be a promising technique for the flexural and shear strengthening of reinforced concrete (RC) structures, in terms of effectiveness and executability.

The NSM has been investigated and applied, mainly, to increase the positive bending moments of one span RC beams and slabs. However, due to the characteristics of the application of this strengthening technique, it is specially adjusted to increase the negative bending moments of continuous (two or more spans) RC beams and slabs.

In the present work the effectiveness of the NSM for the flexural strengthening of continuous RC beams and slabs to the negative bending moments is assessed. The level of moment redistribution that NSM can assure is also investigated to establish design guidelines that define the maximum moment redistribution index that a given strengthening configuration can provide. To fit this purpose, this work is composed by an experimental program, whose results are used to calibrate the analytical and numerical models to be developed for the design of the strengthening systems and to analyze the behaviour of RC structures strengthened according to the NSM technique.

EXPERIMENTAL AND NUMERICAL PROGRAM

In terms of NSM strengthening effectiveness, the present work has the purpose of assess the influence of:

- concrete carbonation;
- spacing between laminates;
- relative positioning between laminates and existent steel reinforcement;
- damage due to concrete cracking;
- Ratio between the area of CFRP and the area of existing tensile steel reinforcement;

The project has also the aim of develop:

- A shear strengthening strategy to avoid shear failure of NSM flexural strengthened RC continuous slabs;
- Analytical model to design NSM flexural strengthening solutions for continuous RC beams and slabs;
- Numerical model based on the FEM for the simulation of the material nonlinear analysis of NSM strengthened RC continuous structures.

Preliminary tests

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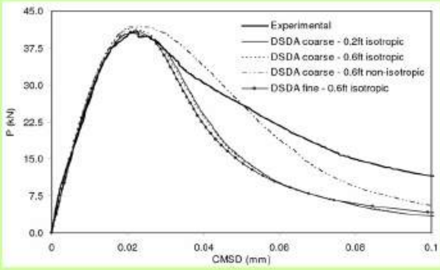
DANIEL DIAS DA COSTA

Supervisors: E. JÚLIO / J. ALFAIATE

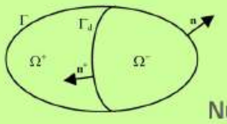
NUMERICAL MODELLING OF THE STRUCTURAL BEHAVIOUR OF REINFORCED CONCRETE INTERFACES

OBJECTIVES

- Study of the structural behaviour of non-monolithic reinforced concrete elements
- The target includes all situations with structural interfaces, mainly:
  - precast concrete structures and strengthening with current and high strength concrete
- Development of numerical tools for the simulation of structural interfaces



STRONG DISCONTINUITY APPROACH



Constitutive laws

- Possibility of applying different constitutive laws for both bulk and discontinuity
- Parametric study of the most relevant material parameters, including:
  - roughness of the substract
  - properties of the added concrete layer
  - the application of resins

Numerical models – development

- Physically located discontinuities
  - Zero-thickness discrete-interfaces
- Bulk and prescribed discontinuities
  - Discrete Strong Discontinuity Approach
  - Generalized Finite Element Method

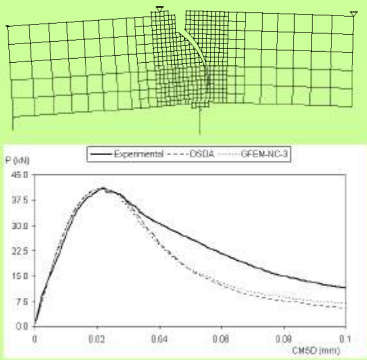
$$\int_{\Omega} \left(\nabla^s \delta\hat{\mathbf{u}}\right) : \boldsymbol{\sigma}\, d\Omega = \int_{\Omega} \delta\hat{\mathbf{u}} \cdot \mathbf{b}\, d\Omega + \int_{\Gamma_t} \delta\hat{\mathbf{u}} \cdot \bar{\mathbf{t}}\, d\Gamma,$$

$$\int_{\Omega^+} \left(\nabla^s \delta\tilde{\mathbf{u}}\right) : \boldsymbol{\sigma}\, d\Omega + \int_{\Gamma_d} \delta[\![\mathbf{u}]\!] \cdot \bar{\mathbf{t}}_d d\Gamma = \int_{\Omega^+} \delta\tilde{\mathbf{u}} \cdot \mathbf{b}\, d\Omega + \int_{\Gamma_t^+} \delta\tilde{\mathbf{u}} \cdot \bar{\mathbf{t}}\, d\Gamma.$$

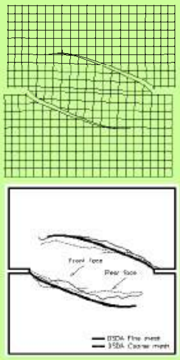
VALIDATION

Benchmarks and several experimental works

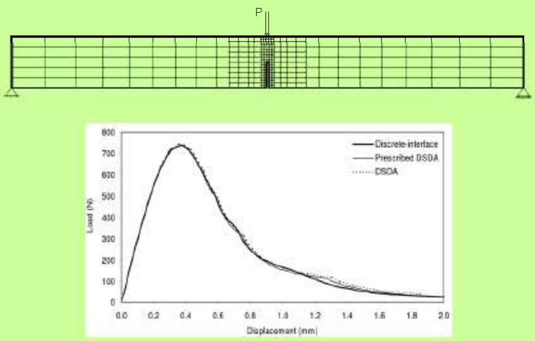
Single Edge Notched Beam



Mixed mode



3 point bending



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JOÃO VELUDO

Supervisors: E. Júlio / P. Pinto

RC FOOTINGS STRENGHTENED WITH MICROPILES - Connection Capacity Between RC Footings and Micropiles

❑ OBJECTIVES

- Assessment of the influence of several parameters on the connections capacity between existing footing and micropiles (Fig. 1)
  - Roughness of the pre-drilled hole surface
  - Pre-drilled hole diameter
  - Micropile surface texture
  - Embedment length of micropile into concrete footing
  - Confinement strengthening of the existing footing

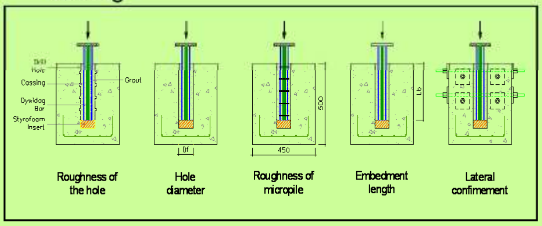

Fig.1

Fig.2

Fig.3

Fig.4

❑ RESULTS OF PHASE I – COMPRESSION TESTS

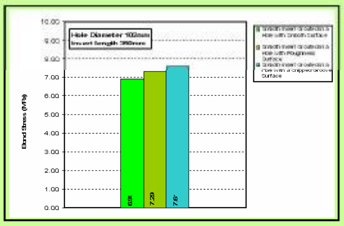

Fig.5

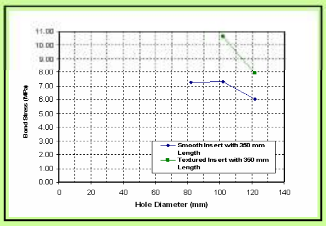

Fig.6

- To characterize the mechanisms of bond strength: adhesion and frictional components
- To define guidelines for the design of the connection micro-piles / existing footing
- To develop, calibrate and validate a numerical model to analyze these connections

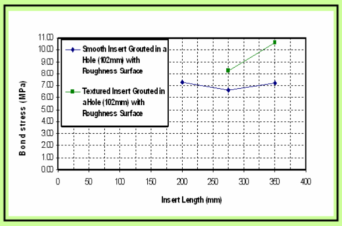

Fig.7

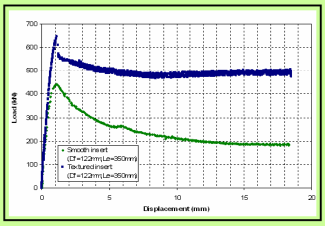

Fig.8

❑ EXPERIMENTAL STUDY

For this research, a number of compression tests (phase I) and tensile tests (phase II) on model micropile-footing connections are under development:

- 3 surface roughness: left as drilled, wire-brushed and chipped grooved
- 3 hole diameter: 92mm, 102mm and 122mm
- 2 types of micropile surface: smooth insert and textured insert with welded rings
- 3 embedment length: 350mm, 275mm and 200mm
- 3 confinement level with Dywidag bars (for textured inserts)

❑ CONCLUSIONS

- For smooth inserts the roughness of the hole has little effect on the bond strength (Fig. 5) since the failure occurs between the grout/micropile interface.
- For textured inserts the failure occurs between the grout/concrete interface.
- The diameter of the hole seems to have a significant influence on the bond strength. The results show an increase capacity for small diameters of the hole (Fig. 6)
- The tests showed that smooth inserts had a brittle failure and textured inserts a plastic response (Fig 8)

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MARTA A. B. AGANTE

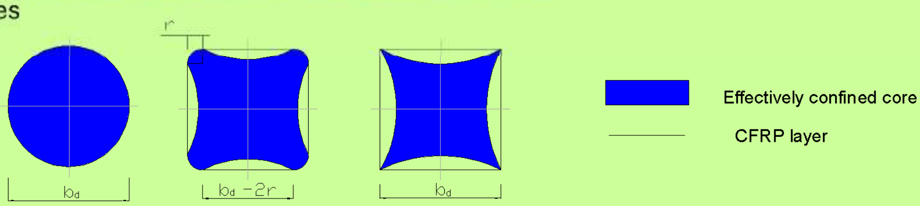
Supervisors: Eduardo Júlio / Joaquim Barros

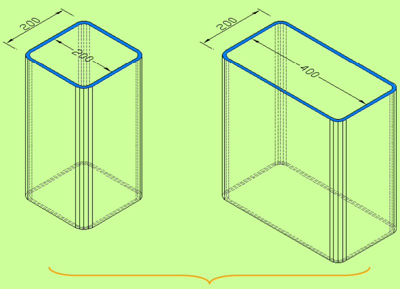
REINFORCED CONCRETE COLUMNS CONFINED WITH POST-TENSIONED CFRP

❑ OBJECTIVES

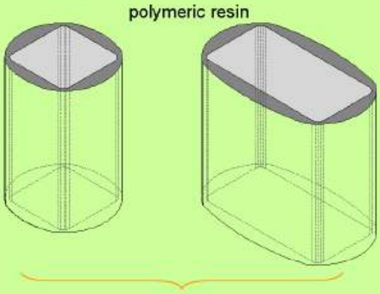
To develop an innovative, simple and effective technique to strengthen square / rectangular concrete columns by confining these with post-tensioned CFRP:

- Develop an expansive mortar / polymer, to apply between the CFRP jacket and de original column to introduce the post-tension
- Determine the appropriate treatment to apply to the surface of the original column and the ideal thickness of mortar / polymer
- Characterization of the effectiveness of this innovative strengthening technique by comparing results with those obtained with other techniques





Post-tensioned CFRP with an expansive polymeric resin



Post-tensioned CFRP with expansive mortar

❑ FIRST EXPERIMENTAL STUDY IN COURSE

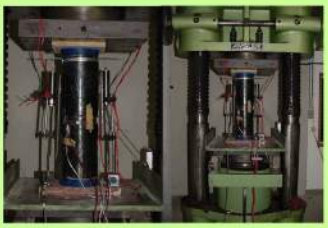
Columns specimens with square and rectangular cross sections confined with different CFRP post-tensioned solutions:

- Expansive mortar
- Injected resin
- New method for CFRP post-tension

These solutions are characterized by measuring:

- Increment of load carrying capacity
- Energy absorption capacity
- Ultimate strains in the CFRP jacket.

Damaged column



Test of a strengthened column

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RICARDO D. BRITES

Supervisors: P. Lourenço / J. Machado

SAFETY EVALUATION OF ANCIENT TIMBER STRUCTURES

❑ GEOMETRIC SURVEY OF ANCIENT TIMBER ROOF STRUCTURES

- Four historical roof structures were surveyed in order to obtain some statistical information about their geometrical properties, as well as roof typologies.

❑ DECAY TESTS IN SMALL CLEAR AND FULL SIZE SPECIMENS

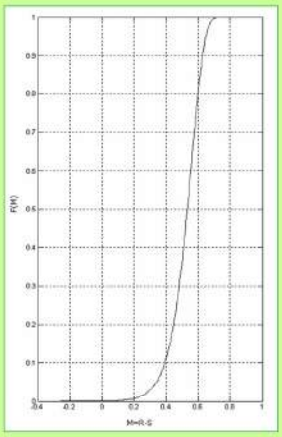
- About 600 *Pinus Pinaster ait.* test specimens are being subjected to several stages of fungal decay and will be tested in tension and compression.
- The "precise" stage of decay will be established by **FTIR analysis**, and also related to the results obtained by the most usual NDT techniques (Pilodyn, Resistograph, Pundit)
- The results will allow to establish statistical relationships among time of exposure, depth of decay, strength and stiffness of timber elements, in addition to weight loss relationships.

Specimen	Standard test procedure	N.º of specimens						
		0% decay	5% decay	10% decay	20% decay	40% decay	60% decay	Total
2x4x12	Compression (according to EN 408)	16	16	16	16	16	16	96
3x9x18		16	16	16	16	16	16	96
8x15x48		16	16	16	16	16	16	96
0.5x5x45	Tension (according to NBR 7190)	16	16	16	16	16	16	96
1.0x5x45		16	16	16	16	16	16	96
2.0x5x45		16	16	16	16	16	16	96

❑ SAFETY EVALUATION OF EXISTING TIMBER STRUCTURES BY MEANS OF RELIABILITY ANALYSIS

- A Monte-Carlo reliability analysis will be performed, using as random variables geometrical and physical characteristics, as well as the applied loads:

Variable	Distribution	Statistical parameters obtained from
Cross-sections	$N(\mu, \sigma)$	Geometrical surveys
Mechanical properties	$N(\mu, \sigma)$, $LN(\mu, \sigma)$	Experimental tests
Self weight	$N(\mu, \sigma)$	Experimental tests
Snow load	$\Gamma(\kappa, \theta)$	Probabilistic model code
Wind Load	$Wb(\kappa, \lambda)$	Probabilistic model code



- The probability of failure P_f and the reliability index β of the timber structure can be found and compared to the target values given in the specialized bibliography.
- The values of P_f and β for several sages of decay will be established, and therefore, the influence of decay in the structural safety of timber structures will be determined.

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PEDRO NUNO GONÇALVES NOGUEIRO

Supervisors: L. Simões da Silva / R. Bento

SEISMIC BEHAVIOUR OF END-PLATE BEAM-TO-COLUMN STEEL CONNECTIONS

Analytical Model

$$M = \frac{(k_{ot} - k_{ht}) \cdot \phi}{\left[1 + \left|\frac{(k_{ot} - k_{ht}) \cdot \phi}{M_{ot}}\right|^{nt}\right]^{1/nt}} + k_{ht} \cdot \phi$$

- The steel structure presented in Fig. 1 was loaded by means of a artificial acelerogram, with PGA equal to 0.45 g.
- The connections were simulated in four different ways.
- Four dynamic analyses were perfomed and two non linear static (pushover) analyses.
- The results can be seen in the following figures.

Studied Structure

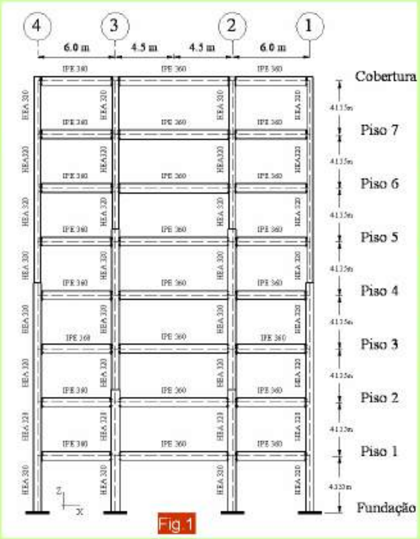
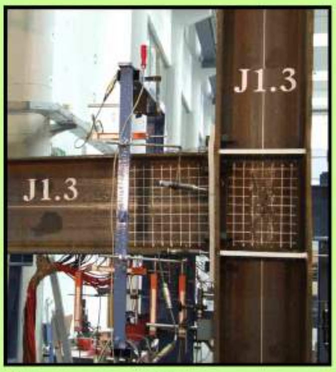
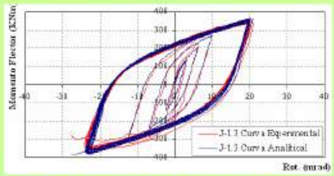


Fig.1

Tested Connection





Experimental and analytical curves (calibration procedure)

Results:

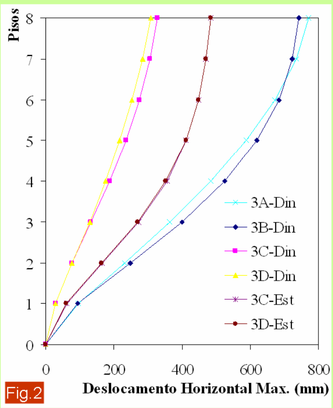


Fig.2

Horizontal storey displacements

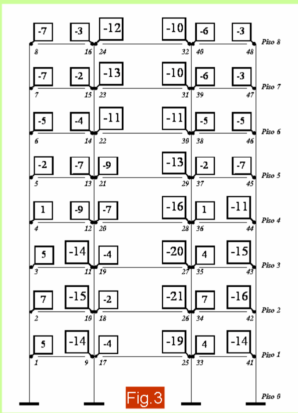


Fig.3

Connection rotations in (mrad), for dynamic analysis and real connections

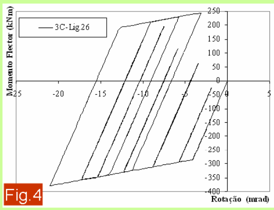


Fig.4

Hysteretic elasto-plástic curve

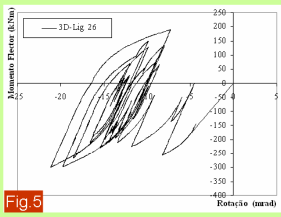


Fig.5

Real hysteretic curve

- This project provides pre-qualified connections for seismic regions

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SEISMIC STRENGTHENING OF RESIDENTIAL BUILDINGS

Risk Analysis and Mitigation

PAULA RAQUEL P. CUNHA LAMEGO

Supervisors: P.B. Lourenço / M.L. Sousa

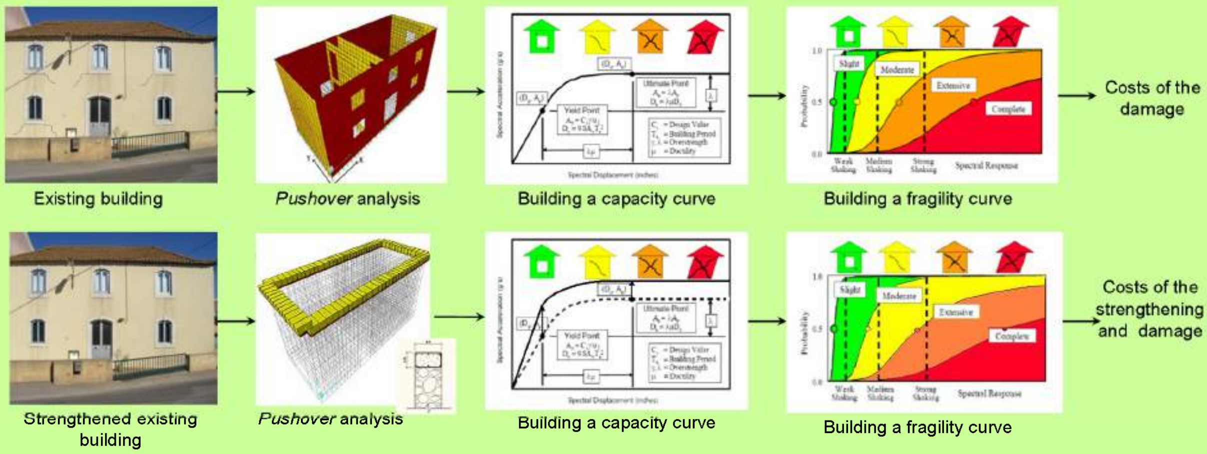
❑ OBJECTIVES

The main objective of this project is the assessment of the costs for the reparation / rehabilitation / reconstruction* of a building, when subjected to seismic loading, and the same costs obtained for the same building with seismic reinforcement.

* The choice between reparation, rehabilitation or reconstruction depends to the level of damages obtained in each analysis.

❑ HOW?

The proceedings are schematically represented below:



- Study of strengthening techniques for seismic rehabilitation
- Study of techniques for seismic risk analysis
- Analysis of the efficiency of the strengthening
- Analysis of the costs

❑ RESULTS

Seismic loss estimates for residential buildings will be obtained before and after interventions.

The feasibility of seismic risk mitigation will be analyzed comparing costs of strengthening with its benefits.

❑ BIBLIOGRAPHY

[1] Lamego, Paula – "Avaliação de técnicas construtivas utilizadas na reabilitação sísmica de edifícios em alvenaria de pedra". MSc Dissertation. Instituto Superior Técnico. Lisbon, March 2007.

[2] Federal Emergency Management Agency – "Multi-hazard Loss Estimation Methodology – HAZUS – MH - MR1 – Advanced Engineering Building Module". Washington, D.C., 2003.

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PAULO XAVIER CANDEIAS

Supervisors: Ema Coelho / Paulo Lourenço

SEISMIC VULNERABILITY ASSESSMENT OF MASONRY BUILDINGS

OBJECTIVES

- Seismic vulnerability assessment of the "Gaioleiro" building typology
- Study of reinforcement techniques effective for their seismic vulnerability mitigation

EXPERIMENTAL MODELS

- Tests were carried out in the LNEC 3D shaking with large sized 1:3 reduced scale models (3.15m wide by 4.15m deep and 0.15m thick walls) representative of a four-storey prototype
- Five models were built to reproduce the most significant features of the "Gaioleiro" buildings under seismic loads, namely the flexible floors, the interconnections between floors and walls, and the façade piers
- Three reinforcement techniques were considered to 1) connect the walls to the floors, 2) connect opposing walls with steel ties and 3) the reinforcement of the piers with glass fibre strips glued with epoxy resins and steel connectors (in conjunction with steel ties)

Model	Walls	Height	Windows	Reinforcement
0	Mortar 1	4.8m	Wood frame	None
00	Mortar 2	5.2m	Wood frame	None
1	Mortar 2	4.8m	No frame	Technique 1
2	Mortar 2	4.8m	No frame	Technique 2
3	Mortar 2	4.8m	No frame	Technique 3

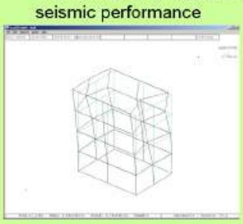
Technique 1

Technique 3

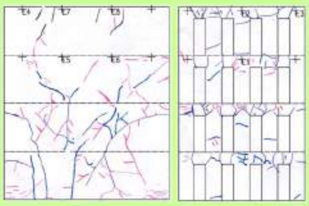
Technique 2

NUMERICAL MODELS

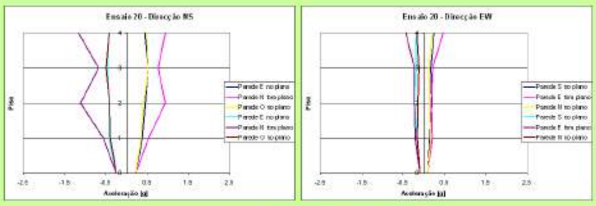
- Work is under way to develop models for design of the seismic reinforcements
- The validation of these models is based on the data available from the experimental tests like modal identification, damage patterns and global seismic performance



First longitudinal vibration mode (Model 2)



East and North walls damage patterns (Model 2)



NS and EW wall vertical acceleration profiles (Model 2)

ACKNOWLEDGEMENTS

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- STAP - Reparação, Consolidação e Modificação de Estruturas, S.A.

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SALVADOR DIAS

Supervisor: Joaquim Barros

SHEAR STRENGTHENING OF REINFORCED CONCRETE BEAMS WITH NSM CFRP LAMINATES

❑ AIM

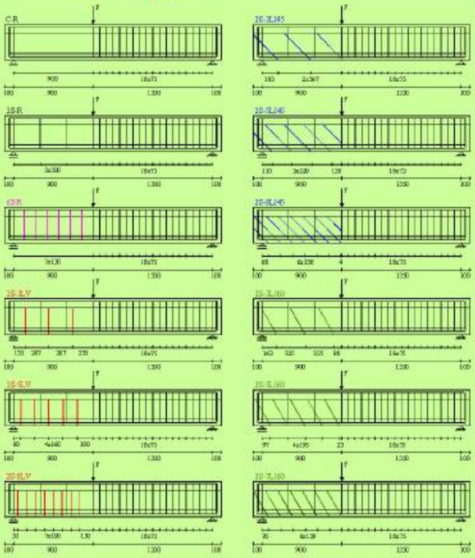
Evaluate the efficacy of the Near Surface Mounted (NSM) technique with CFRP laminates for the shear strengthening of reinforced concrete T beams with a certain percentage of steel stirrups.

SHEAR STRENGTHENING OF RC BEAMS WITH CFRP LAMINATES USING NSM TECHNIQUE

CFRP laminates (1.4x10 mm² cross section) are fixed into pre-cut slits

❑ EXPERIMENTAL PROGRAM

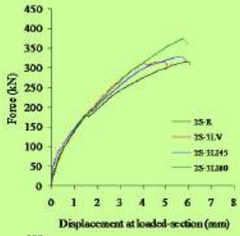
- 1 beam without any shear reinforcement (C-R beam)
- 1 beam with steel stirrups ϕ6@300mm (2S-R beam)
- 1 beam with steel stirrups ϕ6@130mm (6S-R beam)
- 9 beams of ϕ6@300mm with CFRP: 3 distinct percentages of laminates and, for each CFRP percentage, 3 types of inclination for the laminates, 90°, 45° and 60°

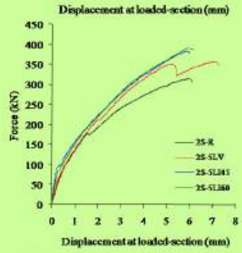


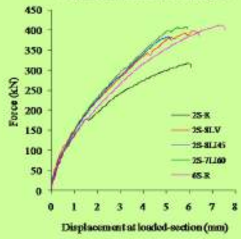
Note: the differences between the tested beams were restricted to the shear reinforcement systems applied in the smaller shear span

Beam	F_{max} (kN)	$\Delta F_{max}/F_{max}^{2S-R}$ (%)[a]	F_{max}/F_{max}^{6S-R}	V_f (kN)[b]	V_f/V_s^{2S-R} (%)
C-R	243	-	0.59	-	-
2S-R	315	0.0	0.77	-	-
6S-R	410	30.2	1.00	-	-
2S-3LV	316	0.3	0.77	0.6	0.3
2S-5LV	357	13.3	0.87	25.2	13.3
2S-8LV	396	25.7	0.97	48.6	25.7
2S-3LI45	328	4.1	0.80	7.8	4.1
2S-5LI45	384	21.9	0.94	41.4	21.9
2S-8LI45	382	21.3	0.93	40.2	21.3
2S-3LI60	374	18.7	0.91	35.4	18.7
2S-5LI60	392	24.4	0.96	46.2	24.4
2S-7LI60	406	28.9	0.99	54.6	28.9

[a] $\Delta F_{max} = F_{max} - F_{max}^{2S-R}$; [b] $V_f = V_r - V_r^{C-R} - V_s^{2S-R}$, $V_r = 0.6 F_{max}$, $V_r^{C-R} = 0.6 F_{max}^{C-R}$, $V_s^{2S-R} = V_r^{2S-R} - V_r^{C-R}$;







Influence of CFRP percentage on failure modes

2S-3LI45

2S-3LI45 - Central laminate

Moment when the laminate debonded: concrete was adhered to the CFRP

2S-5LI45

2S-8LI45

❑ CONCLUSIONS

- For deflection levels higher than the one corresponding to the formation of the shear crack in the 2S-R reference beam (1.56 mm), all the adopted NSM CFRP shear strengthening configurations provided a significant contribution for the beam load capacity.
- Laminates at 60° was the most effective shear strengthening configuration, having provided a maximum increase in the maximum load of 29%. In general the shear strengthening efficacy increased with the increment of CFRP percentage.
- The highest percentage of CFRP was designed to provide a maximum load similar to that of the 6S-R beam, with a reinforcing system composed of six steel stirrups. The test results validated this purpose. The beams with CFRP presented higher stiffness.
- The load carrying capacity of the beams strengthened according to the NSM technique was conditioned by the concrete tensile strength, since the loss of shear strengthening efficacy of the laminates occurred when they debonded, bringing a certain concrete volume at the debond length.
- Below certain spacing between laminates, a group effect occurs due to the interference between consecutive concrete failure surfaces, leading to the detachment of "two lateral walls" from the underlying beam core.

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Project POCTI/ECM/59033/2004

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ISMAEL BASILIO SÁNCHEZ

Supervisors: Paulo Lourenço / Daniel Oliveira

STRENGTHENING OF ARCHED MASONRY STRUCTURES WITH COMPOSITES MATERIALS

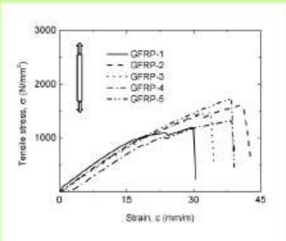
AIMS OF THE RESEARCH:

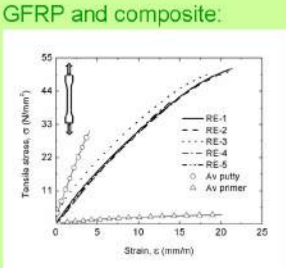
- ❑ Experimental FRP-masonry interface behaviour characterization.
- ❑ Characterization of the structural behaviour of masonry arches strengthened with FRP.

MASONRY STRENGTHENED WITH FRP (1):

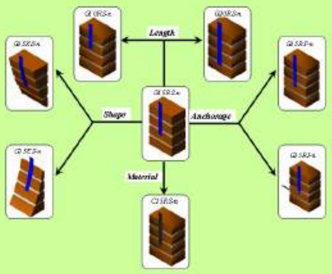
- ❑ Stress distribution along the anchor length and shear stress-relative displacement relationship at the loaded end.

Mechanical behaviour of the GFRP and composite:

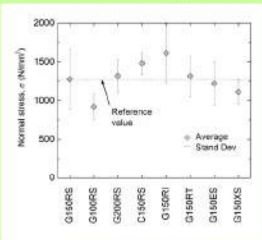


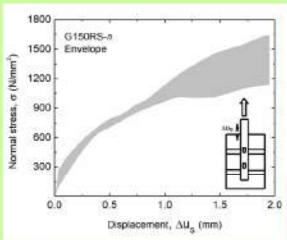


Direct shear tests carried out and test setup:



Peak stress of all masonry specimens under direct shear and envelop of five results:



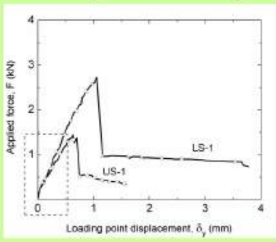


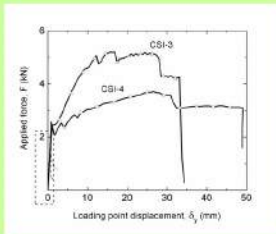
MASONRY ARCHES STRENGTHENED WITH FRP (2):

- ❑ Assessment of the influence of the strengthening on the mechanical behaviour of the arches.

Geometry and test setup:

Load-displacement diagrams:





Maximum load carrying capacity (summary table):

Specimen	GFRP width strip (mm)		Anchored (×)	F_{max} (kN)
	Intrados	Extrados		
US-1	-	-	-	1.43
US-2	-	-	-	1.92
CSE-1	-	90.0	-	2.51
CSE-2	-	106.0	-	3.82
CSE-3	-	166.0	-	3.62
CSE-4	-	150.0	-	3.26
CSI-1	91.0	-	-	4.26
CSI-2	100.0		-	4.63
CSI-3	110.0	-	×	5.41
CSI-4	90.0	-	×	3.81
LS-1	147.5		-	3.18
LS-2	146.5		-	2.73

MAIN CONCLUSIONS:

- ❑ Shear stress distribution along the anchor length was fully characterized.
- ❑ Higher strength values and modified failure mechanisms were obtained by strengthening masonry arches with FRP composites.

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JULIANA C. VIANNA

Supervisors: Sebastião A.L. de Andrade, Pedro C.G. da S. Vellasco, Luis F. da C. Neves

STRUCTURAL BEHAVIOUR OF PERFOBOND AND T-PERFOBOND CONNECTOR IN COMPOSITE GIRDERS

❑ SHEAR CONNECTOR

- Is the component that assures shear transfer between the steel profile and the reinforced concrete slab, enabling the development of the composite action in composite beams.
- This work presents the results from push-out tests made at the Civil Engineering Department of the University of Coimbra, Portugal, on Perfobond and T-Perfobond shear connectors, and an evaluation of the structural behaviour, suitable to transfer shear in composite structures. The experimental programme was configured according to the Eurocode 4.

❑ TYPICAL TESTED CONNECTORS GEOMETRICS

- The main difference between the studied Perfobond and T-Perfobond connectors is the presence of a flange, providing a further anchorage to the system.

PERFOBOND CONNECTOR

T-PERFOBOND CONNECTOR

❑ MODELS FOR THE STRENGTH PREDICTION OF CONNECTORS

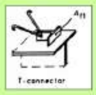
- Shear resistance of **Perfobond connectors** was derived by Oguejiofor & Hosain:

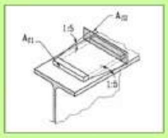
$$q_u = 4{,}5.h.t.f_c^{'} + 0{,}91.A_{tr}.f_y + 3{,}31.n.d^2.\sqrt{f_c^{'}}$$

Contributions for the overall resistance:
- the bearing concrete resistance at the connector face,
- the steel reinforcement bars in the concrete slab,
- and the concrete cylinders in shear that are formed through the connector's holes

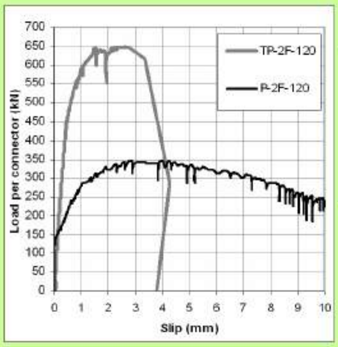
- For **T-Perfobond connectors** the first estimation is based proposal for the calculation of the resistance of a T-connector (block type) used in the 1992 Eurocode 4:

$$q_u = \eta.A_{f1}.f_{ck}/\gamma c \qquad \sqrt{A_{f2}/A_{f1}}$$



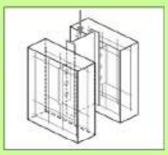


❑ CONCLUSIONS FROM PUSH-OUT TESTS:



- **T-Perfobond** connectors have a larger resistance and a higher stiffness than **Perfobond** connectors for similar longitudinal plate geometries. The advantage of using that type of connector may also be dictated by the fact that it is produced with ordinary laminated I or H sections, saving material and workmanship.
- The slip observed in the tests of T-Perfobond was smaller than the minimum required slip capacity of 6mm, thus not coping to Eurocode 4 requirements for a plastic distribution of shear force in the connectors along the structural element. It can also be observed that this fact may not be significant if an elastic distribution is to be adopted.

PUSH-OUT TEST



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HUGO COSTA
Supervisor: Eduardo Júlio

TIME BEHAVIOUR OF REINFORCED CONCRETE ELEMENTS STRENGTHENED WITH LIGHTWEIGHT AGGREGATE CONCRETE

❑ SCOPE

- The development of concrete constituents, combined with the production of lightweight aggregates with higher compressive strength, turned possible to achieve high performance lightweight aggregate concretes - LWAC (fig.1).
- Several impressive structures have been made using LWAC (fig.2), taking advantage of its reduced self weight, high resistance, low shrinkage and high durability due to a improved internal curing.
- The correct knowledge about predicting the LWAC properties and structural behaviour is essential to accomplish a efficient design.


Fig.1


Fig.2a


Fig.2b

❑ OBJECTIVES

- Development of a mix design methodology for LWAC and prediction of its mechanical properties: compressive and tension strength, interface shear strength, elasticity modulus, shrinkage and creep.
- Experimental testing of failure and time-dependent behaviour of reinforced concrete elements, beams and plates, strengthened with LWAC.
- Development, calibration and validation of numerical models based on experimental results. Proposal of expressions to analyse and design structural elements strengthened with LWAC.

❑ CHARACTERIZATION OF LWAC MECHANICAL PROPERTIES


Fig.3a


Fig.4


Fig.5a


Fig.5b

- Compressive strength (fig.3)
- Tension strength (fig.4)
- Elasticity modulus (fig.5)
- Shrinkage (fig.6)
- Creep (fig.7)


Fig.7a

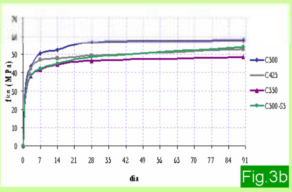
Fig.3b

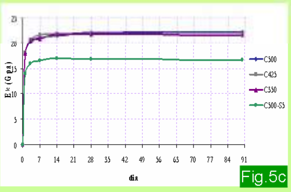
Fig.5c

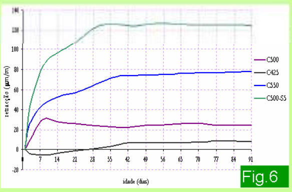
Fig.6

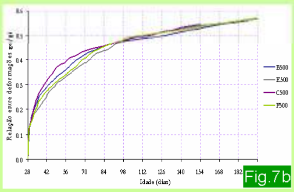
Fig.7b

❑ CONCLUSIONS

- The mix design methodology allowed a reliable prediction of LWAC properties, with good correlation between these and the lightweight aggregates characteristics.
- Shrinkage deformation is reduced when compared to codes prediction.
- Evolution of creep deformation is similar for the produced LWAC, even with different densities and strengths.

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JORGE M. BRANCO

Supervisors: PAULO J. CRUZ / MAURIZIO PIAZZA

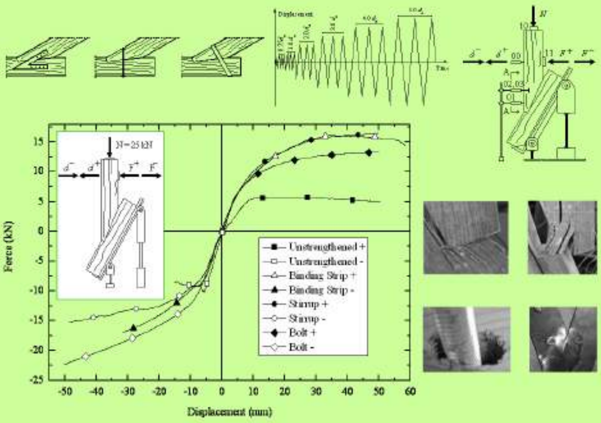
TRADITIONAL TIMBER TRUSSES AND CONNECTIONS. STRUCTURAL BEHAVIOUR AND STRENGTHENING

❑ OBJECTIVES

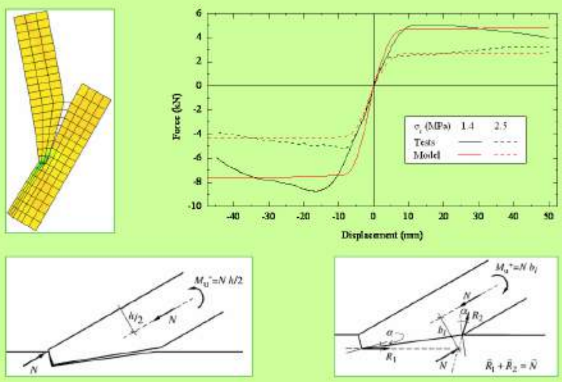
- Structural survey
- Numeric analysis of the static and dynamic behaviour of traditional timber trusses
- Experimental and numeric analysis of original and strengthened connections
- Semi-rigid modelling of the connections behaviour
- Laboratory and field tests on full-scale timber trusses
- Semi-rigid modelling of timber trusses

❑ Survey

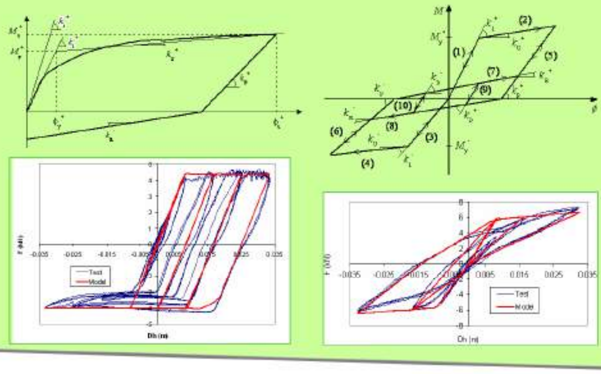
❑ Exp. analysis of full-scale timber connections



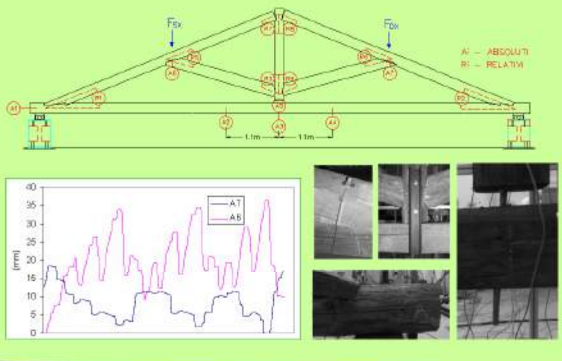
❑ Numeric analysis of full-scale timber connections



❑ Semi-rigid modelling of connections



❑ Full-scale tests on timber trusses



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USE OF TIMBER, GLASS AND TIMBER-GLASS COMPOSITE ELEMENTS IN BUILDING STRUCTURES

JOSÉ MANUEL PEQUENO
Supervisor: PAULO J. S. CRUZ

The structural utilization of timber glass composite solutions is a daring constructive system. It is still in a very early stage, but already presents an important potential of applicability in architecture.

- **Objectives of the system:**
  - **Structure -** glass compression capacity; timber tension resistance;
  - **Architecture –** design and natural lighting; expressive and aesthetic effects;
  - **Sustainability –** integrated passive solar systems;
  - **Applicability –** safety; user-friendly prefabricated system.

▪ Experimental Studies

▪ **Structural Adhesive Bonding** - *Joints & Adhesives*

▪ **Composite Beams** - *Architectural Design & Lighting / Strength, Stability & Safety*

▪ **Composite Structural Panels** - *Glass in Façades/ Laminates & Composite Architectural Design/ Integrated Solar Systems*

▪ Architectural Applications

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