

ICIST

Instituto de Engenharia de Estruturas, Território e Construção

Scientific and Technological Projects



March 2012



INSTITUTO SUPERIOR TÉCNICO 1911-2011



Prof. Jorge de Brito

Instituto de Engenharia de Estruturas, Território e Construção (ICIST) is a research unit within Instituto Superior Técnico (IST), funded by Fundação para a Ciência e a Tecnologia (FCT), the Portuguese governmental research agency. With its current (2012) 101 PhD and 83 non-PhD members, it is the largest university-based research centre in the fields of Civil Engineering in Portugal.

ICIST has the purpose of developing scientific and technological research, promoting innovation and development, scientific dissemination and consultancy in the areas of its Research Groups:

- *Earthquake Engineering and Seismology* (group 1);
- *Mechanics, Modelling and Analysis of Structures* (group 2);
- *Studies in Construction* (group 3);
- *Structural Design and Geotechnics* (group 4);
- *Information and Design Support Systems* (group 5); and
- *Architecture* (group 6).

The main objective of ICIST researchers is to carry out the research needed for the advancement of the areas of their expertise. The centre supports activities such as the publication in scientific journals, the supervision of PhD and MSc theses, the participation in technical committees, the promotion of joint publications with foreign researchers, the participation and organisation of technical and scientific meetings, and the participation and coordination of European and national scientific and technological projects.

In 2007 the multiple activities of ICIST members have earned the centre the rating of *Very Good*. Since then, the centre has grown in members, and most particularly in scientific productivity indicators. A total of 212 papers published in international leading peer-review journals (189 ISI and 23 Scopus), 53 completed PhD theses (and 94 on-going as of 2011), more than 3 M€ in funding for scientific projects and more than 2 M€ in consultancy testify the R&D work developed at ICIST in the 2007-2010 period only.

ICIST members have a significant involvement in national and international scientific and technological projects. This document lists the twenty projects with competitive funding which have been developed during 2011 and been coordinated by ICIST members (projects with the participation of ICIST members but coordinated by others were not included).

I am sure the list reflects the diversity of the R&D work currently developed at the Institute and the commitment of its members with the scientific and technological activity.

Jorge de Brito
President of ICIST

SCIENTIFIC AND TECHNOLOGICAL PROJECTS (Competitive Funding)

Contents

City Induction: a model for formulating, evaluating, and generating urban designs	5
Damage and Fracture Models for Concrete Structures Analysis	9
Development of a Pre-eruptive Alert Table for Fogo Volcano, Cape Verde	12
Dual analysis of finite element solution errors	13
Dynamic soil behaviour. Soil-structure interaction. Application to anchored flexible earth retaining structures.....	14
EWV - Exchanging worlds visions: modern architecture in Africa “Lusófona” (1943-1974) looking through Brazilian experience established since the 1930s	15
Experimental study of the seismic risk in the Lisbon region	17
FIRE-FRP - Fire Protection Systems for GFRP Pultruded Profiles.....	18
Generalized Beam Theory (GBT) – Development, Application and Dissemination	20
IN_LEARNING – Designing Active Learning Environments	23
Instrumental Study of Active Faults of Lower Tagus Valley	25
Large Diameter Piles Under Axial Loading.....	26
Learning Environments in Portugal. 2nd and 3rd grade elementary and secondary school buildings.....	29
LT-PORTUGAL - Architecture and Urban Planning	32
Mechanical and durability performance of concretes made with fine recycled aggregates from construction and demolition waste from Portuguese recycling plants.....	33
Modelling and Analysis of Nanostructures: Carbon Nanotubes and Nanocomposite Materials	36
Mozambique African Rift Tomography	39
Nonlinear Static Methods for Assessment/Design of 3D Irregular Structures.....	41
Performance-based Seismic Design Procedures	44
REABEPA - Structural rehabilitation of masonry walls in old buildings.....	45
RETURN - Rare Earthquake and Tsunami Recurrence.....	47
RIVERSAR - Exploiting SAR imagery to improve floodplain inundation models in the Tagus River	49
SAFE_PC - Safety of Precast Structures: General Design, Connections and Seismic Behaviour	51
E-mail: jcamara@civil.ist.utl.pt.....	52
SANDWICHE - Rehabilitation of Building Floors with Lightweight High Performance GFRP Sandwich Panels.....	53
SCENE - Site Condition Evaluation for National Seismic Hazard Estimation	55
Seismic vulnerability analysis of old masonry buildings.....	57
Strong Site Effects in São Sebastião Volcanic Crater	59
SUBSIn - InSAR detection and characterization of subsidence and landslides in the Lisbon region.....	61
Urban System under Earthquake Threat: An Integrated Global Approach. Application to the Azores (USuET)	63
Virtual Reality Technology applied as a support tool to the planning of construction maintenance.....	64

City Induction: a model for formulating, evaluating, and generating urban designs

PTDC/AUR/64384/2006

KEY WORDS: Urban model, Ontology, Space syntax, Shape grammars

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): -

PERIOD: 01-06-2007 to 30-09-2011

FINANCING (€): 166.431 **IST/ICIST (€):** 166.431

COORDINATOR(S): José Pinto Duarte. **RESEARCHERS AND COLLABORATORS:** Jorge Alberto Gil; José Nuno Beirão; Nuno Filipe Montenegro.

SUMMARY

Urban planning has a considerable impact on the economic performance of cities and regions and on the quality of life of the population. Efficiency at this level largely depends on the capacity to identify community needs and to recognize the potential of the territory to satisfy them, and then to plan the built space to maximize the satisfaction of such needs using the least resources. However, such capacity is currently hampered by the lack of integrated instruments for formulating, evaluating, and generating urban plans. The goal of this project is to create a model that constitutes the foundation for the development of such instruments using new technologies. The project departs from existing partial theories, namely Alexander's pattern language, Hillier's space syntax, and Stiny's shape grammars, among others, and attempts at completing, linking, and merging them to create the desired model. It foresees the development of three studies, each leading to a PhD dissertation.

The first study is concerned with the formulation of urban problems—the formulation model. It will depart from Alexander's pattern language and existing urban design guidelines to create a system for generating the specifications or the ingredients of a plan given a site and a community. It will take into account both the physical features of the site and the social and economic characteristics of the population.

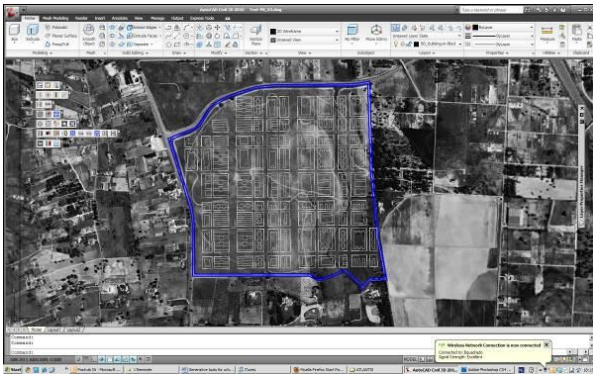
The second study will be targeted at the development of an urban design evaluation system—the evaluation model. It will depart from Hillier's space syntax theory and extend it to incorporate features currently not covered by this theory, which focuses on geometric space configurations. The new features will address

social, environmental and infrastructural aspects. The goal is to provide the basis for comparing, rating, and ordering alternative design solutions.

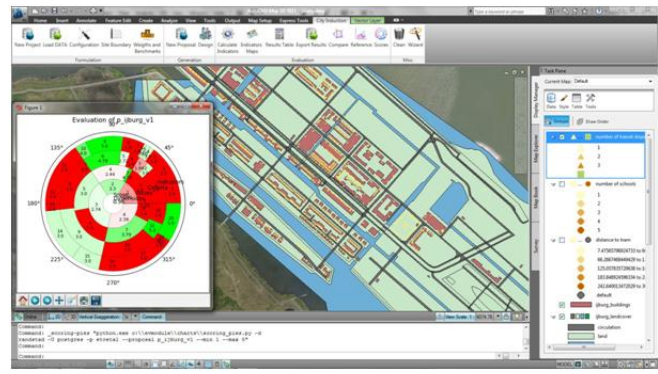
The third study aims at creating a system for generating alternative design solutions within a given urban design language—the generation model. It will look into Stiny's shape and description grammars formalisms to codify the rules of syntax of the plan so that it generates solutions that match specifications set a priori and are appropriate for the given design context.

The three studies will encompass the development of a common, urban space ontology to guarantee the syntactic and semantic interoperability and integration among the partial models. This ontology will be used to structure and codify information into a Geographic Information System (GIS), which will be the kernel for the computer implementation of the larger model. A CAD system will be used to construct 3-dimensional digital models from the information stored in the GIS. The project will aim at sketching the prototype of an interactive computer system for exploring urban design solutions, which will facilitate the dialogue between the various participants in the urban design and implementation processes, such as community members, town halls, financing institutions, designers, promoters and developers. The project will be targeted at the site planning scale.

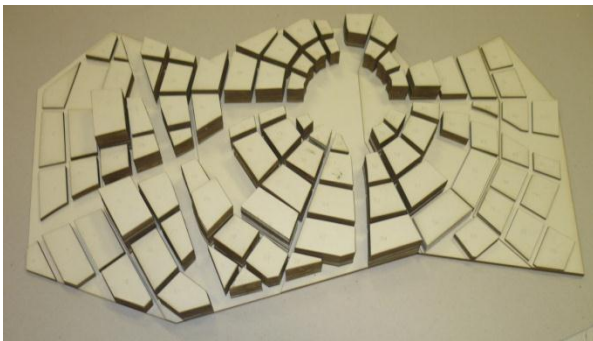
In short, following Stiny and March's design machines concept, the project will (1) define the structure for building urban design machines, and (2) sketch a specific machine for a design context used as a case study. This machine should be able to produce flexible and adaptable site plans for evolving design contexts.



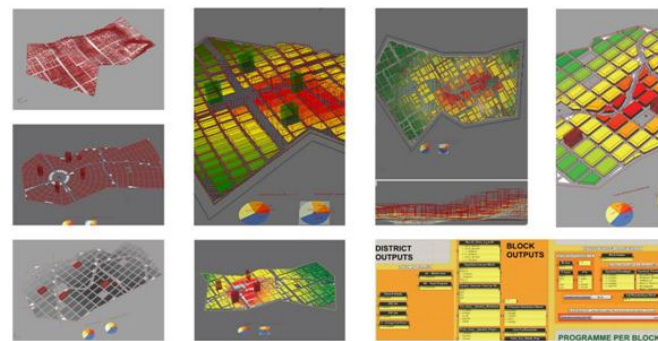
Interface to generate and view solutions using the local characteristics and an urban pattern vocabulary.



Display of a solution with multi-level pie chart and thematic maps.



Physical model produced by a rapid prototyping process of laser cut from the digital 3D model generated by City Induction.



Prototype of the model to generate urban solutions developed in Rhine and Grasshopper, allowing the exploration of alternatives via parametric variations and the production of urban indices.

DELIVERABLES

Book chapters

Stouffs, R., Beirão, J. N., & Duarte, J. P. (2011). Sortal Grammars for Urban Design. In S. Müller Arisona, P. Wonka, G. Aschwanden, & J. Halatsch (Eds.), *Digital Urban Modeling and Simulation. Communications in Computer and Information Science (CCIS)* (Vol. 242). Springer Berlin Heidelberg. In print.

Duarte, J. P., Beirão, J. N., Montenegro, N., & Gil, J. (2011). City Induction: formulating, generating, and evaluating urban plans. In S. Müller Arisona, P. Wonka, G. Aschwanden, & J. Halatsch (Eds.), *Digital Urban Modeling and Simulation. Communications in Computer and Information Science (CCIS)* (Vol. 242). Springer Berlin Heidelberg. In print.

Beirão, J. N., & Duarte, J. P. (2009). Urban Design with Patterns and Shape Rules. In E. Stolk, & M. Brömmelstroet (Eds.), *Model Town - Using Urban Simulation in New Town Planning* (ch. 9, pp. 148-165). Almere, The Netherlands: New Town Institute.

Papers in international journals

Beirão, J. N., Kunze, A., Tunçer, B., Stouffs, R., & Duarte, J. P. (n.d.). Urban patterns for decision making in participatory urban design, in *Urban Studies*. Submitted on July 31 2011.

Montenegro, N., Beirão, J. N., & Duarte, J. P. (n.d.). Public space patterns: modelling the language of urban space, in *International Journal of Design Sciences and Technology*. Europia Productions, Paris. Accepted on October 18 2011, forthcoming.

Beirão, J. N., Duarte, J. P., Stouffs, R., & Bekkering, H. (n.d.). Designing with Urban Induction Patterns: a Methodological approach, in *Environment and Planning B: Planning and Design*. Accepted on October 14 2011, forthcoming.

Montenegro, N., Gomes, J., Urbano, P., & Duarte, J. P. (n.d.). An OWL2 Land Use Ontology: LBCS in *Lecture Notes in Computer Science (LNCS)*, in *Future Internet, special issue on "NeoGeography and WikiPlanning"*, Murgante, B; Borruso, G.; Gibin, M (eds). Accepted on July 18 2011, forthcoming.

Gil, J., Beirão, J. N., Montenegro, N., & Duarte, J. P. (n.d.). On the discovery of urban typologies: Data mining the multi-dimensional morphology of urban areas, in *Urban Morphology*. Accepted on March 17 2011, forthcoming.

Beirão, J. N., Duarte, J. P., & Stouffs, R. (2010). Creating generic grammars from specific grammars: towards

flexible urban design. *Nexus Network Journal*, vol. 13, no. 1, April 2011, pp. 73-111.

Duarte, J. P., & Beirão, J. N. (2012). Towards a methodology for flexible urban design: designing with urban patterns and shape grammars, in *Environment and Planning B: planning and design*, vol. 38 (5) 2012, pp. 879-902.

Beirão, J., Duarte, J., Montenegro, N., & Gil, J. (2010, May). Monitoring urban design through generative design support tools: a generative grammar for praia, in M. Matalasov (Ed.) *AMIT - Architecture and Modern Information Technologies*, vol, 2 (11), May 2010.

Proceedings in international conferences

Beirão, J. N., Nourian, P., & Walderveen, B. (2011). Parametric 'Route Structure' Generation and Analysis: An interactive design system application for urban design. *Proceedings of IASDR 2011, Diversity and Unity*. Delft, The Netherlands.

Montenegro, N., Gomes, J., Urbano, P., & Duarte, J. P. (2011). 4CitySemantics: GIS-Semantic Tool for Urban Intervention Areas. *Proceedings of the 7th Virtual Cities and Territories Conference - 7VCT*, (pp. 549-554).

Beirão, J. N., Nourian, P., & Mashoodi, B. (2011). Parametric urban design: An interactive sketching system for shaping neighbourhoods. *Proceedings of the 29th Conference on Education in Computer Aided Architectural Design in Europe – eCAADe 2011*, (pp. 225-234). Ljubljana, Slovenia.

Montenegro, N., Beirão, J. N., & Duarte, J. P. (2011). Public Space Patterns: towards a CIM standard for urban public space. *Proceedings of the 29th Conference on Education in Computer Aided Architectural Design in Europe – eCAADe 2011*, (pp. 79-86). Ljubljana, Slovenia.

Gil, J., Almeida, J., & Duarte, J. P. (2011). The backbone of a City Information Model (CIM): Implementing a spatial data model for urban design. *Proceedings of the 29th Conference on Education in Computer Aided Architectural Design in Europe – eCAADe 2011*, (pp. 143-151). Ljubljana, Slovenia.

Celani, G., Duarte, J. P., Beirão, J. N., & Vaz, C. (2011). Optimizing the "characteristic structure": Combining shape grammars and genetic algorithms to generate urban patterns. *Proceedings of the 29th Conference on Education in Computer Aided Architectural Design in Europe – eCAADe 2011*, (pp. 491-500). Ljubljana, Slovenia.

Montenegro, N., Beirão, J. N., & Duarte, J. P. (2011). Public Space Patterns: Modeling the language of urban space. In G. Carrara, A. Fioravanti, & A. Trento (Ed.), *Proceedings of the 13th International Conference on Advances in Design Sciences and Technology*, on

Connecting Brains Shaping the World. Part V – Ontology, BIM and IFC Representations. Rome, Italy.

Montenegro, N., Gomes, J., Urbano, P., & Duarte, J. P. (2011). An OWL2 Land Use Ontology: LBCS in Lecture Notes in Computer Science (LNCS). *Proceedings of the 11th International Conference on Computational Science and Its Applications - ICCSA 2011* (pp. 185-197). University of Cantabria, Santander, Spain: Springer.

Gil, J., Beirão, J. N., Montenegro, N., & Duarte, J. P. (2010). Assessing Computational Tools for Urban Design: Towards a "city information model". *Proceedings of the 28th eCAADe Conference Proceedings – eCAADe 2010*, (pp. 361-369). ETH Zurich, Switzerland.

Beirão, J., Mendes, G., Duarte, J. P., & Stouffs, R. (2010). Implementing a Generative Urban Design Model: Grammar-based design patterns for urban design. *Proceedings of the 28th eCAADe Conference Proceedings*, (pp. 265-274). ETH Zurich, Switzerland.

Gil, J., & Duarte, J. P. (2010). A review of urban design sustainability evaluation tools. *Proceedings of the 10th International Conference on Design & Decision Support Systems in Architecture and Urban Planning*. Eindhoven, The Netherlands.

Beirão, J. N., Duarte, J. P., & Stouffs, R. (2010). Creating specific grammars from generic grammars: towards flexible urban design. In K. Williams (Ed.), *Nexus 2010 conference*. University of Porto, Portugal.

Gil, J., Montenegro, N., Beirão, J. N., & Duarte, J. P. (2010). On the Discovery of Urban Typologies. In Pinho, P. and Oliveira, V (Eds.), *Bringing City Form Back Into Planning, Proceedings of the CITTA 3rd Annual Conference on Planning Research*, (pp. 163-176). Faculdade de Engenharia da Universidade do Porto, Porto, Portugal.

Beirão, J. N., Montenegro, N., Gil, J., Duarte, J. P., & Stouffs, R. (2009). The city as a street system: A street description for a city ontology. *SIGraDi 2009 - Proceedings of the 13th Congress of the Iberoamerican Society of Digital Graphics*, (pp. 132-134). Sao Paulo, Brazil.

Montenegro, N., & Duarte, J. P. (2009). Computational Ontology of Urban Design. In B. Colakoglu, & G. Cagdas (Ed.), *Proceedings of the 27th Conference on Education in Computer Aided Architectural Design in Europe - eCAADe 2009*, (pp. 253-260). Istanbul, Turkey.

Beirão, J. N., Duarte, J. P., & Stouffs, R. (2009). An urban grammar for Praia: towards generic shape grammars for urban designs. In B. Colakoglu, & G. Cagdas (Ed.), *Proceedings of the 27th Conference on*

Education in Computer Aided Architectural Design in Europe - eCAADe 2009, (pp. 574-584). Istanbul, Turkey.

Gil, J., Montenegro, N., Beirão, J. N., & Duarte, J. P. (2009). On the Discovery of Urban Typologies: Data Mining the Multi-dimensional Character of Neighbourhoods. In B. Colakoglu, & G. Cagdas (Ed.), *Proceedings of the 27th Conference on Education in Computer Aided Architectural Design in Europe - eCAADe 2009*, (pp. 269-278). Istanbul, Turkey.

Beirão, J. N., Duarte, J. P., Gil, J., & Montenegro, N. (2009). Monitoring urban design through generative design support tools: a generative grammar for Praia. *The 2nd Portuguese-Speaking Regional Science Conference, 1st Cape Verde Congress of Regional Development, 15th Congress of the Portuguese Association for Regional Development and the 3rd Congress of Nature Management and Conservation*. Cidade da Praia, Cabo Verde.

Beirão, J. N., Duarte, J. P., & Stouffs, R. (2009). Grammars of designs and grammars for designing. *CAAD Futures 2009*, (pp. 1-15). University of Montreal, Canada.

Montenegro, N.; Duarte, J. P. (2008). Towards a Computational Description of Urban Patterns: an urban formulation ontology. In M. Muylle, & E. De Vos (Ed.), *Proceedings of the 26th Conference on Education in Computer Aided Architectural Design in Europe - eCAADe 2008*, (pp. 239-248). Antwerpen, Belgium.

Beirão, J. N., Duarte, J. P., & Stouffs, R. (2008). Structuring a Generative Model for Urban Design: Linking GIS to Shape Grammars. In M. Muylle, & E. De Vos (Ed.), *Proceedings of the 26th Conference on*

Education in Computer Aided Architectural Design in Europe - eCAADe 2008, (pp. 929-938). Antwerpen, Belgium.

Gil, J., & Duarte, J. P. (2008). Towards an Urban Design Evaluation Framework: integrating spatial analysis techniques in the parametric urban design process. In M. Muylle, & E. De Vos (Ed.), *Proceedings of the 26th Conference on Education in Computer Aided Architectural Design in Europe - eCAADe 2008*, (pp. 257-264). Antwerpen, Belgium.

Beirão, J. N., & Duarte, J. N. (2009). Urban Design with Patterns and Shape Rules. In E. Stolk, & M. Brömmelstroet (Eds.), *Model Town - Using Urban Simulation in New Town Planning* (ch. 9, pp. 148-165). Almere, The Netherlands: New Town Institute.

Beirão, J. N., Duarte, J. P., & Stouffs, R. (2008). Proceedings of Workshop 1 on Generative Urban Design. *3rd International Conference on Design Computing and Cognition*. Georgia Tech, Atlanta, GA, U.S.A.

Completed Theses

Beirão, J. N. (Completed, expected defense date: 2012). *CityMaker: Designing Grammars for Urban Design*. PhD Dissertation. Delft, The Netherlands: Faculty of Architecture, Delft University of Technology.

Montenegro, N. (2010). *Building a Pre-Design Ontology: Towards a model for urban programs*. Msc Dissertation. Lisbon, Portugal: Faculty of Architecture, Technical University of Lisbon.

CONTACTS:

Prof. José Pinto Duarte

Tel.: +351 213 615 839

E-mail: jduarte07@gmail.com

Damage and Fracture Models for Concrete Structures Analysis

PTDC/ECM/71519/2006

KEY WORDS: Damage Continuum Mechanics, Fracture Mechanics, Concrete Structures, Hybrid and Mixed Finite Elements

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-01-2008 to 31-12-2011

FINANCING (€): 136.000 **IST/ICIST (€):** 136.000

COORDINATOR(S): Luís Castro. **RESEARCHERS AND COLLABORATORS:** Carlos Tavares Fernandes , Eduardo Pereira, João Teixeira de Freitas, Vítor Leitão

SUMMARY

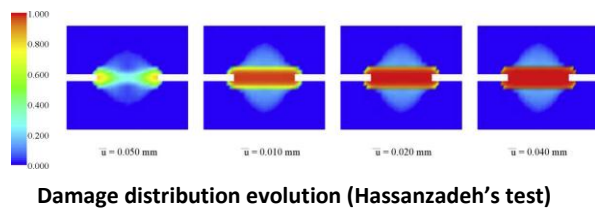
The development of robust and computational competitive numerical techniques for the physically non-linear analysis of concrete structures is the main objective of this research project. To support the numerical computations, hybrid and mixed finite element models will be used. The performance of meshless methods will also be assessed. Since the decade of 90 the research team has been involved in the development of effective alternative hybrid and mixed finite element formulations. An extensive validation program and performance evaluation allowed the identification of the most relevant properties of these formulations. It made also possible the recognition of the models that possess the characteristics that allow them to overcome some of the limitations associated with the use of the classical finite element formulations. In this context, one of the most powerful tools is the hybrid-mixed stress model, due to the flexibility in the selection of the approximation functions and to the accuracy that can be achieved in the computation of the stress field. More recent it is the involvement of the group in the development of meshless methods; very encouraging results have already been obtained with the use of the Moving Least Squares technique.

After establishing the properties of these alternative formulations, the following challenge consisted in extending their application into the analysis of problems closer to Engineering practice. In a first step, elastoplastic models for the analysis of plane structures have been developed. After that, continuum damage models for the physically non-linear analysis of concrete structures have been studied and implemented. The research group has acquired some experience in the development and use of this type of models. The research in this area evolved in the framework of a research project already

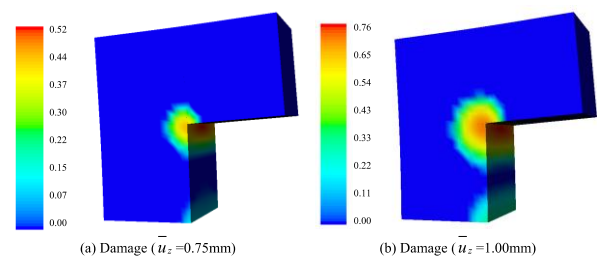
concluded (POCTI/ECM/33066/2001) and the main results have been presented in a PhD thesis. The physically non linear analysis of concrete structures is still a challenge and corresponds to an application field where the high performance alternative formulations can be conveniently explored. The fracture processes associated to the propagation of defects strongly influence the structural behaviour of concrete structures and may be modelled using continuous or discrete approaches. The constitutive models able to reproduce diffuse micro-cracking in a continuum without creating a real discontinuity in the material lie in the first category. The Continuum Damage Mechanics is the most popular continuum approach. One strong drawback associated to the application of pure continuous models lies in the fact that fragile rupture is frequently governed by the growth of a dominant crack. The second approach is suited for these cases. A discrete approach corresponds then to introduce in the model a displacement discontinuity with a cohesive constitutive behaviour. Although both approaches continue to deserve the scientific community attention, the current trend is clearly to combine the two methodologies. In such a way, the analysis is initiated with the application of a continuum damage model. From a given damage value or from a critical size of the strain localization bandwidth, a displacement discontinuity is introduced in the model and the evolution of the process is modelled with a cohesive crack law.

The project is organized in two tasks. Task 1 is centred in the extension and the generalization of the damage models developed in the framework of the PhD thesis and the research project mentioned above. In a first stage, coupled plasticity and damage models will be implemented and assessed. Then, the models will be generalized in order to make possible the

consideration of dynamic loadings. Finally, the first steps towards the generalization of the existing models to 3D analysis will be undertaken. The objective of Task 2 is the study and implementation of cohesive fracture models for concrete analysis. In this context it is important to explore the features of the hybrid and mixed finite element models in the accurate representation of singularities and discontinuities. The first goal of this task corresponds to the development of numerical tools to simulate the formation and the evolution of the discrete cracking. In a second stage adequate transition techniques to



move from a pure continuous analysis based on damage mechanics models to a discrete analysis based on the consideration of cohesive crack models will be studied, implemented and validated. For the development of each one of the research tasks, the launching of a doctoral program is planned. For the development, calibration, validation and performance evaluation of the new models it is important to ensure the support of foreign external consultants, with the purpose of complementing the experience and expertise of the research team, and to strengthen the cooperation links with the respective institutions.



DELIVERABLES

Papers in international journals

LAM Mendes and LMSS Castro, "Hybrid-mixed stress finite element models in elastoplastic analysis", *Finite Elements in Analysis and Design*, Vol 45, Issue 12, pp. 863-875, doi:10.1016/j.finel.2009.06.021, 2009;

CM Silva and LMSS Castro, "Continuum damage models with non-conventional finite element formulations", *International Journal of Non-Linear Mechanics*, Vol 45, Issue 2, pp. 83-99, doi:10.1016/j.ijnonlinmec.2009.09.005, 2010;

LMSS Castro, "Polynomial wavelets in hybrid-mixed stress finite element models", *Communications in Numerical Methods in Engineering*, Vol 26, Issue 10, pp. 1293-1312, doi:10.1002/cnm.1215, 2010;

CM Silva, LMSS Castro, "Damage analysis of concrete structures using polynomial wavelets", submitted for publication, *Computers & Structures*, 2010;

MRT Arruda, LMSS Castro, "Structural dynamic analysis using hybrid and mixed finite element models", submitted for publication, *Finite Elements in Analysis and Design*, 2011;

MRT Arruda, LMSS Castro, "A new hybrid-mixed stress model for the analysis of concrete structures using damage mechanics", submitted for publication, *Computers & Structures*, 2011;

CM Silva, LMSS Castro, "Continuum damage mechanics with hybrid-mixed stress formulations",

submitted for publication, *International Journal for Numerical Methods in Engineering*, 2011;

MRT Arruda, LMSS Castro, "Application of a new hybrid mixed finite element in static and dynamic non-linear analysis of concrete structures", to be submitted for publication, *International Journal of Non-Linear Mechanics*, 2011.

Papers in national journals

MRT Arruda and LMSS Castro, Modelos híbridos-mistos de tensão para a análise dinâmica no domínio do tempo, *Revista Portuguesa de Engenharia de Estruturas*, 5, pp. 13-19, 2009;

Communications in conferences

MRT Arruda, LMSS Castro, "Implementação de modelos híbridos-mistos de tensão para a análise dinâmica no domínio do tempo", *Congresso de Métodos Numéricos em Engenharia 2009*, Barcelona, June 2009;

MRT Arruda, LMSS Castro, "Modelos híbridos-mistos de tensão para a análise dinâmica fisicamente não-linear de pórticos de betão armado", *Congresso de Métodos Numéricos em Engenharia 2009*, Barcelona, June 2009;

CSR Garrido, LMSS Castro, "Hybrid-mixed stress finite element models for the physically non-linear analysis of concrete three-dimensional structures", *CST 2010 The Tenth International Conference on Computational Structures Technology*, Paper 306, Valencia, September, doi:10.4203/ccp.93.306, 2010;

JMA Martins, LMSS Castro, "Hybrid displacement finite element models for the physically nonlinear analysis of three-dimensional concrete structures", CST 2010 The Tenth International Conference on Computational Structures Technology, Paper 305, Valencia, September, doi:10.4203/ccp.93.305, 2010;

MRT Arruda, LMSS Castro, "Hybrid-mixed stress finite element models for the dynamic analysis of reinforced concrete frame structures", CST 2010 The Tenth International Conference on Computational Structures Technology, Paper 300, Valencia, September, doi:10.4203/ccp.93.300, 2010;

MRT Arruda, LMSS Castro, "Time integration procedures with hybrid-mixed stress finite elements", CST 2010 The Tenth International Conference on Computational Structures Technology, Paper 303, Valencia, September, doi:10.4203/ccp.93.303, 2010;

CM Silva, LMSS Castro, "Damage analysis of concrete structures using polynomial wavelets", CST 2010 The Tenth International Conference on Computational Structures Technology, Paper 58, Valencia, September, doi:10.4203/ccp.93.58, 2010;

MRT Arruda, LMSS Castro, "Modelos de dano contínuo com elementos finitos híbridos-mistos de tensão", CMNE 2011 – Congresso de Métodos Numéricos em Engenharia, Art. 230, Coimbra, June, 2011;

MRT Arruda, LMSS Castro, "Continuum damage models using hybrid mixed stress formulations", coRAN 2011 – International Conference on Recent Advances in NonLinear Models; Structural Concrete Applications, Coimbra, November, 2011;

Internal reports

JAT Freitas and LMSSC, Hybrid stress elements for continuum damage analysis, DECivil, 2008;

Completed Theses

MRT Arruda, Modelos de dano para análise de estruturas de betão, PhD thesis submitted June 2011;

CSR Garrido, Modelos híbridos-mistos de tensão para a análise fisicamente não-linear de estruturas tridimensionais de betão, MSc dissertation, 2009;

JMA Martins, Modelos híbridos de deslocamento para a análise fisicamente não-linear de estruturas tridimensionais de betão, MSc dissertation, 2009.

CONTACTS:

Prof. Luís Castro

Tel.: +351 218 418 253

E-mail: luis@civil.ist.utl.pt

Development of a Pre-eruptive Alert Table for Fogo Volcano, Cape Verde

POCTI/CTA/32730/2000

KEY WORDS: Volcano; Alert; Eruption; Monitoring

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 26-09-2000 to 25-09-2003

FINANCING (€): 74.820 **IST/ICIST (€):**74.820

COORDINATOR(S): João Fonseca. **RESEARCHERS AND COLLABORATORS:** Arlindo do Rosário; Bruno Vicente Eberl de Faria; Inocêncio José Miguel de Barros; João Luís Gustavo de Matos; Nicolas d'Oreye de Lantremange; Sandra Isabel das Neves Heleno da Silva

SUMMARY

Fogo Island, in the N Atlantic, is a conic ocean island stratovolcano with 30Km diameter, rising nearly 6000 metres above the surrounding seabottom. It erupted twice during the 20th century, in 1951 and 1995. During the historical period (1500 onwards) the eruptions of Fogo Volcano succeeded at average intervals of 20 years. The population of Fogo (30000 inhabitants) are therefore subjected to significant levels of volcanic hazard.

Between 1997 and 1999, IST, LECV and ECGS collaborated in the design and instalation of a telemetred geophysical monitoring system in Fogo Volcano (Project VIGIL). This monitoring system, which is now in routine operation, allows the daily inspection of short-period and broadband seismic data from 7 stations around the Volcano, and tilt data from 2 sites. These data are supplemented by gps campaigns carried out at regular intervals of 6 months (Project GPS-FOGO).

The main aim of these cooperation activities is the reduction of the volcanic hazard affecting the population of Fogo Island. The adopted approach for the present proposal, which follows the onset of

routine monitoring operation in October 1999, consists of:

- moniting the secondary volcanic activity during inter-eruptive periods;
- establishing normal levels of fluctuation of activity parameters such as frequency of occurrence of tectonic and volcanic earthquakes, frequency of occurrence and amplitude of harmonic tremor and tilt.
- determining thresholds of abnormal parameter variation for selected parameters identified as potential eruption precursors.
- assigning pre-eruption alert levels to selected combinations of abnormal parameter values.

Although the adopted criteria will reflect the volcanic monitoring experience accumulated elsewhere, it is widely recognized that volcanic behaviour varies strongly from case to case, depending on factors such as the silica content of the magma, presence of underground or surface water, etc... Therefore, the first step towards being in a position to adopt an alert-level table for a particular volcano is the characterization of its specific inter-eruptive secondary activity. This is the main goal of this project.

CONTACTS

Prof. João Fonseca

Tel.: +351 218 417 535

E-mail: jfonseca@ist.utl.pt

Dual analysis of finite element solution errors

POCI/ECM/56999/2004

KEY WORDS: Finite element method; Error analysis and adaptivity; Dual analysis; Equilibrium formulations

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-01-2005 to 31-12-2007

FINANCING (€): 60.000

IST/ICIST (€): 60.000

COORDINATOR(S): José Paulo Moitinho de Almeida. **RESEARCHERS AND COLLABORATORS:** Orlando Pereira

SUMMARY

In numerical simulations of physical problems two types of error are generally present: the modeling error, ie the difference between the real problem and the mathematical model, and the discretization error, ie the difference between the numerical solution and the exact solution of the mathematical model. The modeling error is often much larger than the discretization error, in which case numerical data can be directly compared with physical data to assess the validity of a model, but this is correct only when it is certain that the discretization error is small. The relevance of error analysis stems from this fact and is not restricted to specialized problems; it should be used in daily engineering practice. Extreme situations, such as the Sleipner platform collapse, support this conviction. Dual analysis provides not only information about the magnitude of the error, but certified error bounds.

Two drawbacks are normally associated with this approach: the bad behaviour of equilibrium models and the exaggerated values of the error estimated by this approach. The development of new equilibrium formulations and particularly the generalization of the use of appropriate macro-elements has considerably diminished the relevance of the first point. Regarding the other point recent developments on the calculation of bounds for the error in local variables halved the error bound and nearly halved the interval containing the exact value, but it is expected that it will always exist, when the error measure is a bound of the error of two solutions. This project will develop

techniques to improve the use of duality based techniques to bound global and local errors of the approximations provided by the finite element method.

For elastostatic problems this will consist in testing the existing formulations for different problems and in developing techniques to extract improved error estimates, which are not necessarily bounds, from adaptive refinement sequences.

For steady state dynamical problems the research will be centred on the extension of the existing error bounds. The procedures developed will enable the determination of curves that bound, from above and from below, a response of the model as a function of the applied frequency.

For transient problems the focus will be on the development of formulations that generalize the concepts being developed for steady state problems. When this goal is achieved it will be possible to obtain, for a given load history, an interval containing a response at a given time and an envelope of the response within a given time interval. The development and identification of finite element formulations with dual properties for geometrically non-linear problems will also be considered. The long term objective is to achieve a characterization of the response similar to that being developed for the other problems. It is expected that, in the future, these tools to determine bounds of the local error may become an everyday practice, improving the quality of the analysis upon which design decisions are taken

CONTACTS:

Prof. José Paulo Moitinho de Almeida

Tel.: +351 218 418 235 E-mail: moitinho@civil.ist.utl.pt

Dynamic soil behaviour. Soil-structure interaction. Application to anchored flexible earth retaining structures

PTDC/ECM/77372/2006

KEY WORDS: Earthquake, Anchored flexible earth retaining structure, Soil-structure interaction, Soil dynamics model

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Faculdade de Engenharia da Universidade do Porto (FE/UP)

PERIOD: 01-01-2007 to 30-12-2010

FINANCING (€): 179.941 **IST/ICIST (€):** 92.211

COORDINATOR(S): Carlos Santos Pereira. **RESEARCHERS AND COLLABORATORS:** Ana Teresa de Carvalho, Emanuel Maranha das Neves, João Paulo Serra

SUMMARY

In Geotechnical Earthquake Engineering some fundamental topics are still open to research. Among those, one can mention the soil-structure dynamic interaction, which is a key phenomenon in the seismic behaviour of retaining structures. The structural behaviour of those geotechnical structures is strongly determined by its stiffness. Most of the published research on this subject deals with gravity retaining structures. Not surprisingly, current design approaches rely on pseudo-static equilibrium considerations,

which are strictly applicable to that kind of structures. Flexible retaining structures of several types, of which the anchored flexible walls deserve a special mention, are progressively being used. Given the growing complexity and risk of retaining earth works, the use of advanced modelling tools and the recent publication of geotechnical codes, such as the Structural Eurocodes, there is a renewed need for new design rules validated by detailed research work.

DELIVERABLES

CONTACTS:

Prof. Carlos Santos Pereira

EWV - Exchanging worlds visions: modern architecture in Africa “Lusófona” (1943-1974) looking through Brazilian experience established since the 1930s

PTDC/AUR-AQI/103229/2008

KEY WORDS: Modern Movement Architecture; Portuguese Speaking Africa; Heritage; Building technology

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Instituto Camões (IC); Instituto da Habitação e da Reabilitação Urbana (IHRU); Instituto de Investigação Científica e Tropical (IICT/MCTES); Universidade do Minho (UM)

PERIOD: 01-03-2010 to 28-02-2013

FINANCING (€): 188.502

IST/ICIST (€): 105.552

COORDINATOR(S): Ana Tostões. **RESEARCHERS AND COLLABORATORS:** Ana Isabel Magalhães; Elisiário Miranda; João Caldas; Manuel Correia Guedes; Maria João Grilo; Maria Manuel Oliveira; Maria Manuela Portugal; Maria Teresa Fernandes; Vincenzo Riso

SUMMARY

EWV aims to study the architecture built in Africa “Lusófona”, mostly in Angola and Mozambique, during the modern movement period in his possible continuity more or less explicit with the reference constituted by the Brazilian production. The reception and nowadays the reinterpretation of the modern movement architecture imply the preservation of the physical, conceptual and cultural identity. The paradox lies on the fact that modern movement architecture deals and stresses a special moment of political affirmation, freedom expression and democratic values. The question is: how could this modern expression be the vehicle of colonisation?

The few academic works dealing specifically with the former overseas provinces and colonies only amount to a fragmented outline, composed by single patches investigating partial geographic and time zones; leaving out vast sectors to be studied and totally lacking of a global perspective of the phenomenon. Partner institutions decided to collaborate in EWV on the base of their previous experience from which it is to refer the widespread recognition and prestige of the team leader research on modern architecture while the other team members have developed various direct studies as well about modern architecture.

The chronological limits consider 1943 as the start of research and 1974 as the end, corresponding the fall of the colonial regime. In fact, in 1943 rose from Brazil the wave which spread modern architecture ideas in the global world. In this framework, young Portuguese

architects went overseas (and Brazil) looking for a freedom expression denied in Portugal. These pioneers of Modern movement in Africa demonstrated how modern project could be local interpreted improving and enriching the whole experience. In fact, they had to face very different conditions, physical and social, and therefore experiment daring solutions in terms of a specific response. Their experience remains valuable and interesting still today. For the first time, questions nowadays known as sustainability began to be considered as a key design concept. Modern buildings were inspired to provide a pleasant and comfortable environment. They looked for an economic and flexible design, responsive to situation changes and using the technologies available at the time mixed with the local building tradition. This research could find an important contribution in the knowledge as it concentrates on both the survey of the existing building types and the development of a technological Know-How. The methodology will establish a set of criteria for the selection and description of buildings and urban spaces. Then research will integrate different information sources (bibliography, archives and direct observation), through the elaboration of new drawings of the selected works, describing them from the site description up to the technological detail. Those drawings will be then used for the construction of all the possible specific interpretative essays.



Fábrica de Cerâmica *Monteiro & Giro*, Quelimane, Moçambique, Arménio Losa e Cassiano Barbosa.

DELIVERABLES

Proceedings in international conferences

A. Tostões, A. Magalhães, “EWW – Exchanging World’s Visions: modern architecture in the Portuguese Colonies in Africa (1943-1974) looking through Brazilian experience since the 30’s” in “African Modernity, Modern Movement Architecture in Sub-Saharan Africa”, 11th International DOCOMOMO Conference, Mexico City, 2010.

A. Magalhães, “Modern Architecture in Africa: Open-air Movie Theatres”, 11th International DOCOMOMO Conference, Mexico City, 2010.

E. Miranda, “Infrastructural Buildings in Angola and Mozambique from the Third Quarter of the Twentieth Century”, 11th International DOCOMOMO Conference, Mexico City, 2010.

A. Tostões, M.M. Oliveira, “Transcontinental Modernism. M & G as an *Unité d’habitation* and a factory complex in Mozambique”, DOCOMOMO International Journal 43 – 2010/2 *Brasília 1960-2010*, Winter 2010, pp. 70-73.

A. Tostões, “O arquitecto Pancho Guedes”, in *As áfricas de Pancho Guedes*, Lisboa, Sextante, pp. 66-69.

A. Magalhães, “Património Moderno na Cidade Pós-Colonial - Arquitectura em Angola: De Luanda ao Lobito”, International Conference “África – Arquitectura e Urbanismo de Matriz Portuguesa”, Lisboa, Univ. Autónoma de Lisboa, Jan. 2011.

E. Miranda, “De Maputo à Beira, uma «selecção moderna»”, Conferência Internacional: África – Arquitectura e Urbanismo de Matriz Portuguesa, Lisboa, Univ. Autónoma de Lisboa, Jan. 2011.

A. Tostões, “Modernidade Transcontinental”, Barcelona, Escola Tècnica d’Arquitectura de Barcelona, May 2011.

A. Tostões, “Looking both sides”, 9º Seminário DOCOMOMO Brasil, Brasília, Junho de 2011.

A. Tostões, M.M. Oliveira, “Moderno Transcontinental: O complexo Monteiro & Giro em Quelimane, Moçambique”, Anais do 9º Seminário DOCOMOMO Brasil, Brasília, June 2011.

J.V. Caldas, “Design with Climate in Africa. The World of Galleries, *Brise-Soleil* and *Beta Windows*”, DOCOMOMO International Journal 44 – 2011/1 *Modern and Sustainable*, Summer 2011, pp. 16-23.

A. Tostões, “Recuperación y rehabilitación del patrimonio moderno”, Jornada internacional *La Modernidad ignorada. Arquitectura moderna en Luanda, Angola*, ETS Arquitectura y Geodesia, Universidad Alcalá, 9 Nov. 2011.

A. Tostões, A. Magalhães, “Modernidade ignorada. A boa vida moderna: lazer, comunidade e cidade”, in Martí, Núñez Paz; Goycoolea, Roberto, *La Modernidad ignorada. Arquitectura moderna en Luanda, Angola*, ETS Arquitectura y Geodesia, Universidad Alcalá.

A. Tostões, “Entre Cáncer y Capricornio: un laboratorio de Arquitectura. Vivienda en la África Subsahariana, los casos de Angola y Mozambique”, *Visions* n.10, Barcelona, Edicions ETSAB, Escola Tècnica d’Arquitectura de Barcelona, 2011.

CONTACTS:

Prof. Ana Tostões Tel.: +351 218 418 332 E-mail: tostoes@civil.ist.utl.pt

Experimental study of the seismic risk in the Lisbon region

POCTI/CTA/194/2001

KEY WORDS: Seismicity; Risk; Hazard mapping; Monitoring

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-10-2001 to 31-02-2003

FINANCING (€): 89.775 **IST/ICIST (€):** 88.656

COORDINATOR(S): João Fonseca. **RESEARCHERS AND COLLABORATORS:** Carlos Alberto de Sousa Oliveira; Sandra Heleno Silva

SUMMARY

Project RE.SIS.TE - Instrumental Study of the Seismic Risk in the Lisbon Area - was presented to the FCT for funding in 1994, and approved in 1999, with reference PRAXIS/CTA/194/94. Among the main objectives of the proposal was the installation and operation of a broadband seismographic telemetric network dedicated to the study of the microseismicity of the Lower Tagus Valley, with a view to characterising the seismogenic processes of this seismically active zone. Due to budget cuts, this objective was adopted as the sole goal of the project.

Due to delays in the licensing of the radio-frequencies by the regulatory agency, necessary for the final assembly and delivery of the equipment, the

seismographic stations are not yet delivered. However, the contract for its supply is signed (March 2001) and the radio-frequencies assigned (June 2001).

The tasks that will be conducted during the second phase of the project are:

- reception and test of the seismographic equipment
- installation of the seismic stations and characterisation of the station's seismic noise.

Long term scientific objectives that depend on the slow gathering of the data will be the object of a companion project funded by FCT - TAGUSNET/32720/99.

CONTACTS

Prof. João Fonseca
Tel.: +351 218 417 535
E-mail: jfonseca@ist.utl.pt

FIRE-FRP - Fire Protection Systems for GFRP Pultruded Profiles

PTDC/ECM/100779/2008

KEY WORDS: GFRP pultruded profiles; Fire protection systems; Experimental study, Numerical simulation

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Instituto de Engenharia Mecânica e Gestão Industrial (INEGI/UP); Unidade de Mecânica Experimental e Novos Materiais (MENM/INEGI/UP)

PERIOD: 01-10-2009 to 30-09-2011

FINANCING (€): 199.693 **IST/ICIST (€):** 164.713

COORDINATOR(S): Fernando Branco. **RESEARCHERS AND COLLABORATORS:** António Diogo; António Marques; Carlos Tavares Fernandes; Celeste Pereira; Francisco Silva Lemos; João Alcino Rodrigues; João Teixeira de Freitas; João Correia; Jorge Proença

SUMMARY

This project addresses the study of the fire behaviour of glass fibre reinforced polymer (GFRP) pultruded profiles with the purpose of developing fire protection solutions that enable their structural use in buildings. The study focus on the thermophysical and thermomechanical properties of the material, the fire reaction and the fire resistance behaviour of GFRP beams and columns, and on the effects of different fire protection systems on those properties.

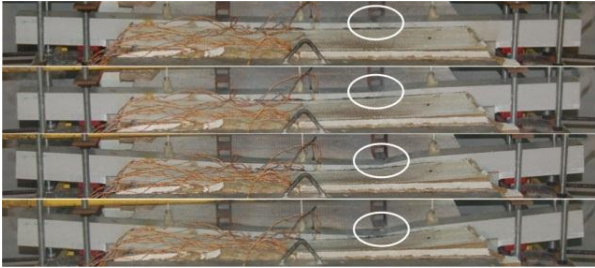
GFRP profiles offer several advantages when compared to traditional materials, namely in what concerns strength, self-weight, insulation properties, maintenance and durability. Although they also offer competitive life-cycle costs, there are well-founded concerns with their fire behaviour. This issue is yet to be addressed in a comprehensive manner and has hampered the widespread use of GFRP profiles in buildings, where construction elements must have adequate fire reaction behaviour and sufficient fire resistance. Although flame retardants and phenolic resins induce significant improvements on the fire reaction properties, the few studies that have addressed this subject suggest that adequate fire protection systems need to be developed to allow the structural use of GFRP profiles in buildings. Moreover, the analysis of the literature shows that the effort of adapting the available FE codes to model the fire response of GFRP profiles may justify the development of special-purpose tools to overcome difficulties reported on the implementation of conventional FEs, namely in what concerns the sensitivity of the solutions to the variation in time and in space of the properties of the fibre-resin mixture.

The effectiveness of different passive (gypsum and calcium silicate boards, intumescent coatings, cementitious mortars) and active (water cooling) fire protection systems will be evaluated to assess the

structural use of GFRP profiles in buildings. Such solutions, already well-established for metallic structures, still need to be developed for GFRP profiles and this is one of the main goals of this project. A comprehensive experimental study of the GFRP profiles and the fire protection systems will be performed including (i) dynamic mechanical analyses and thermogravimetric and differential scanning calorimetry tests, to evaluate the thermophysical and thermomechanical properties of the materials; (ii) mechanical tests (tension, compression, shear) on GFRP laminates at varying temperature, to determine the material stiffness and strength as a function of temperature; (iii) fire reaction tests on GFRP profiles; (iv) full-scale fire resistance tests on loaded GFRP beams and columns. The numerical modelling methodology, designed to support the applications that relate directly with the experimental programme and the gradual incorporation of the modelling difficulties inherent to each application, comprises three main stages of development: (i) an improved FE model simulating the nonlinear thermochemical problem, based on the independent approximation of the temperature and material volume ratio fields; (ii) a FE thermomechanical model of the physically and kinematically nonlinear response of GFRP profiles, based on the independent approximation of the deformation and (generalized) stress-resultant fields; (iii) a coupled thermochemical and thermomechanical model of the structural response under fire conditions, exploiting the conceptual consistency built into the design of each model.

The careful assessment of the performance of innovative fire protection systems for GFRP profiles is the main target of this project. Such systems should enhance the structural use of GFRP profiles in buildings, namely in construction rehabilitation,

exploiting the advantages they offer over traditional materials.



Fire resistance tests on GFRP beams protected with intumescent paint: failure sequence (time interval, approximately 1 s.)

Practical relevance of the results to be obtained implies the fulfilment of two requirements: the availability of proven application recommendations and reliable modeling tools. The numerical models to be developed will allow the simulation of the fire behavior of GFRP profiles with arbitrary cross-section and different fire protection systems, and provide thus additional means to support their structural design. A user's manual will be prepared, allowing the fire protection design of GFRP profiles for building construction and recommending construction procedures and technical specifications for the developed solutions.

DELIVERABLES

Papers in international journals

J.R. Correia, F.A. Branco, J.G. Ferreira, Y. Bai, T. Keller, "Fire protection systems for floors of buildings made of GFRP pultruded profiles. Part 1: Experimental investigations", *Composites Part B: Engineering*, Vol. 41, No. 8, 617-629, 2010.

Y. Bai, T. Keller, J.R. Correia, F.A. Branco, J.G. Ferreira, "Fire protection systems for floors of buildings made of GFRP pultruded profiles. Part 2: Numerical investigations", *Composites Part B: Engineering*, Vol. 41, No. 8, 630-636, 2010.

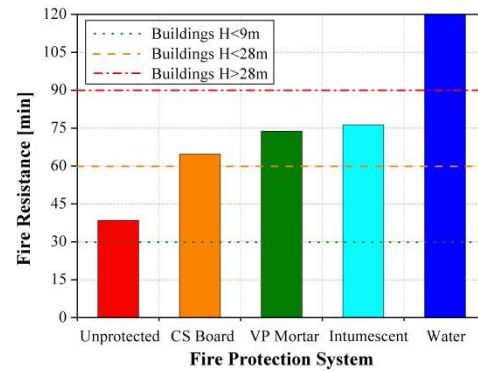
J.P. Firmo, J.R. Correia, P. França, "Fire behaviour of reinforced concrete beams strengthened with CFRP laminates: protection systems with insulation of the anchorage zones", *Composites Part B: Engineering* (in press).

Proceedings in International conferences

J.P. Firmo, J.R. Correia, P. França, "Fire protection systems for reinforced concrete beams strengthened with CFRP laminates: experimental tests and numerical simulation of thermal response", *16th International Conference on Composites for Construction (ICCS16)*, Porto, July 2011.

CONTACTS:

Prof. Fernando Branco Tel.: +351 218 418 230 E-mail: fbranco@civil.ist.utl.pt



Fire resistance (min.) of distinct fire protection systems



Fire resistance tests on GFRP beams protected with calcium silicate: failure sequence (time interval, approximately 1 s.)

International Conference on Composites for Construction (ICCS16), Porto, July 2011.

M.M. Gomes, J.R. Correia, F.A. Branco, "Tensile and compressive behaviour of GFRP pultruded profiles at elevated temperature", *16th International Conference on Composites for Construction (ICCS16)*, Porto, July 2011.

Completed Theses

Comportamento ao fogo de vigas de betão armado reforçadas à flexão com laminados de fibras de carbono (CFRP). Desenvolvimento de sistemas de protecção, Dissertação de Mestrado, Instituto Superior Técnico, Universidade Técnica de Lisboa, Dezembro de 2010.

Internal Reports

M.M. Gomes, J.R. Correia, F.A. Branco, *Comportamento mecânico em tracção a temperaturas elevadas de perfis pultrudidos de GFRP*, Relatório IST-3-1, Tarefa 3 do projecto PTDC/ECM/100779/2008, Fevereiro de 2011.

Generalized Beam Theory (GBT) – Development, Application and Dissemination

PTDC/ECM/108146/2008

KEY WORDS: Numerical modelling Thin-walled metal and composite (FRP) structures; Thin-walled metal and composite (FRP) structures; Vibration and dynamic analysis

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-01-2010 to 31-12-2012

FINANCING (€): 159.482

IST/ICIST (€): 159.482

COORDINATOR(S): Dinar Camotim. **RESEARCHERS AND COLLABORATORS:** Dinar Camotim; Cilmar Basaglia; Nuno Freitas Silva; Nuno Silvestre; Pedro Borges Dinis; Rodrigo Gonçalves; Rui Silva Bebiano

SUMMARY

In order to ensure quality in the design of structures formed by thin-walled components (profiles and/or plates) one must perform a rigorous evaluation of the behaviour of its members and joints and possess efficient design methodologies. The very high slenderness of most steel and composite (FRP) profiles commonly employed in practical applications makes them highly susceptible to the occurrence of local, distortional and global buckling phenomena, as well as to the interaction between them. On the other hand, the cross-section dimensions typical of very slender structural elements imply that their connections exhibit very specific configurations and physical characteristics, which must be taken into account when determining their structural behaviour.

Until recently, the rigorous analysis of the behaviour of thin-walled members and structures was only possible by adopting complex shell finite element models (or finite strip models, in the restrictive context of isolated simply supported prismatic members) and using sophisticated and powerful computer programs. However, this approach involves quite high computational costs, besides the difficulties associated with handling a large volume of data and results, and often requires an in-depth knowledge about non-linear structural analysis - at present, these facts/limitations still make the above approach prohibitive for routine applications.

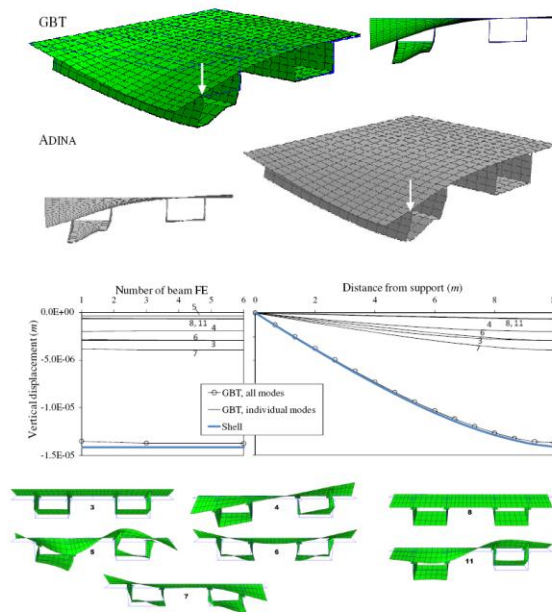
An alternative and very promising (high computational efficiency, elegance and “structural clarity”) approach consists of employing formulations and computational implementations (beam finite elements) of the “Generalised Beam Theory (GBT)”, originally proposed by Schardt and which was the object of significant developments in the last few years: novel

formulations and numerical implementations, as well as extension of its domain of application to cover several types of analyses, constitutive laws and structural configurations. In this context, it is worth noting that the research team involved in this project has been responsible for a major share of the most important aforementioned GBT developments, and is recognised as the world leader in this field. Due to the accumulation of knowledge and experience concerning the use of GBT to analyse the structural behaviour (first-order, buckling, post-buckling, vibration and dynamics) of thin-walled members and structures, made both of metals and composite (FRP) materials, this research team is in a particularly privileged position to not only (i) continue and extend the range of validity of tasks previously initiated or concluded, namely through the development, numerical implementation and application of novel GBT formulations applicable to types of analyses and/or structures not yet addressed, but also (ii) promote the dissemination and widespread use of GBT amongst the scientific and technical communities working with steel and composite structures.

Regarding the derivation, numerical implementation and application of novel GBT formulations, it is intended to develop formulations to analyse the (i) vibration behaviour of steel and composite members with arbitrary cross-sections, (ii) buckling behaviour of steel frames with tubular cross-sections, (iii) post-buckling behaviour of steel members and simple frames with open and tubular cross-sections, (iv) post-buckling behaviour of composite elements with arbitrary cross-section, (v) buckling behaviour of steel arches and curved members, (vi) elastic-plastic behaviour of steel members and simple frames.

Moreover, it is also planned to (i) develop a new methodology to perform the cross-section analysis, which will be applicable to cross-section with an arbitrary geometry and will lead to an added “structural clarity” in the analysis of cross-sections with closed cells, and (ii) applications of available formulations to problems involving the first-order, buckling, vibration and dynamic behaviour of steel and composite steel-concrete bridges. Concerning the dissemination of GBT amongst the scientific and technical communities, it is intended (i) to publish text books making it easy to acquire fundamental concepts and (ii) to develop and make available to structural designers easy-to-use computer programs. As for the

first aspect, it is planned that several members of the research team will collaborate in the elaboration of two or three books devoted to the (i) buckling behaviour of steel members and simple frames, (ii) buckling behaviour of composite members and (iii) vibration behaviour of steel and composite members. Regarding the second aspect, the first step will be to develop a computer program to be freely available and able to perform buckling and vibration analyses of thin-walled members with arbitrary cross-sections and various material behaviours. Next, it is intended to develop computer programs able to carry out (i) buckling and vibration analyses of simple steel frames and (ii) post-buckling analyses of steel members.



GBT and ADINA analyses of a box-girder bridge with diaphragms located at the piers subjected to a mid-span eccentric point load: deformed configurations ($\times 10^5$) of half bridge, vertical displacement of the point of load application vs. number of GBT beam finite elements, variation of the vertical displacement along the longitudinal line containing the load point of application and configurations of the most relevant cross-section deformation modes.

DELIVERABLES

Paper in international Journals

Camotim D, Basaglia C, Silva NF, Silvestre N, “Numerical Analysis of Thin-Walled Structures Using Generalised Beam Theory (GBT): Recent and Future Developments”, Computational Technology Reviews, Volume 1, B. Topping et al. (Eds.), Saxe-Coburg Publications, 315-354, 2010.

Basaglia C, Camotim D, Silvestre N, “GBT-Based Buckling Analysis of Thin-Walled Steel Frames with Arbitrary Loading and Support Conditions”, Int. J. Structural Stability and Dynamics, vol. 10, nº 3, 263-85, 2010.

Gonçalves R, Camotim D, “Steel-Concrete Composite Bridge Analysis Using Generalised Beam Theory”, Steel & Composite Structures, vol. 10, nº 3, 223-243, 2010.

Gonçalves R, Ritto-Corrêa M, Camotim D, “A New Approach to the Calculation of Cross-Section Deformation Modes in the Framework of Generalized Beam Theory”, Computational Mechanics, vol. 46, nº 5, 759-781, 2010.

Silva NF, Degenhardt R, Camotim D, Silvestre N, “On the Use of Generalised Beam Theory to Assess the Buckling and Post-Buckling Behaviour of Laminated CFRP Cylindrical Stiffened Panels”, Int. J. Structural Stability and Dynamics, vol. 10, nº 4, 737-760, 2010.

Camotim D, Basaglia C, Silvestre N, "GBT Buckling Analysis of Thin-Walled Steel Frames: A State-of-the-Art Report", *Thin-Walled Structures*, vol. 48, nº 10-11, 726-743, 2010.

Dinis PB, Camotim D, Silvestre N, "On the Local and Global Buckling Behaviour of Angle, T-Section and Cruciform Thin-Walled Members", *Thin-Walled Structures*, vol. 48, nº 10-11, 786-797, 2010.

Silva NF, Silvestre N, Camotim D, "GBT Formulation to Analyse the Buckling Behaviour of FRP Composite Open-Section Thin-Walled Columns", *Composite Structures*, vol. 93, nº 1, 79-92, 2010.

Silva NF, Camotim D, Silvestre N, Correia JR, Branco FA, "First-Order, Buckling and Post-Buckling Behaviour of GFRP Pultruded Beams - Part 2: Numerical Simulation", *Computers & Structures*, 10/2010.

Proceedings in international conferences

Basaglia C, Camotim D, Silvestre N, "Non-Linear GBT for Thin-Walled Steel Frames: Formulation, Implementation and Application", *Proceedings of SSRIC Annual Stability Conference, Orlando*, 461-480, 11-15/5, 2010.

Basaglia C, Camotim D, "Buckling, Post-Buckling, Collapse and Design of Two-Span Cold-Formed Steel Beams", *Proceedings of International Colloquium on Stability and Ductility of Steel Structures*, E. Batista et al (Eds.), Rio de Janeiro, 913-920, 8-10/9, 2010.

Camotim D, Basaglia C, Bebiano R, Gonçalves R, Silvestre N, "Latest Developments in the GBT Analysis of Thin-Walled Steel Structures", *Proceedings of International Colloquium on Stability and Ductility of Steel Structures*, E. Batista et al (Eds.), Rio de Janeiro, 33-58, 8-10/9, 2010.

Silva NF, Camotim D, Silvestre N, Correia JR, "Comportamento Linear e Estabilidade Local e Lateral por Flexão-Torção de Vigas Pultrudidas de GFRP", *Actas em CD-ROM do Encontro Nacional de Materiais e Estruturas Compósitas*, AJ Ferreira (Ed.), Porto, 8-10/9, 2010.

Basaglia C, Camotim D, Silvestre N, "Local, Distortional and Global Post-Buckling Behaviour of Thin-Walled Steel Frames Using Generalised Beam Theory", *CD-ROM Proceedings of Tenth International Conference on Computational Structures Technology*, B. Topping et al (Eds.), Valência, 14-17/9, 2010.

Bebiano R, Silvestre N, Camotim D, "Generalised Beam Theory Dynamics of a Two-Track High-Speed Railway

Bridge Deck", *CD-ROM Proceedings of Tenth International Conference on Computational Structures Technology*, B. Topping et al (Eds.), Valência, 14-17/9, 2010.

Basaglia C, Camotim D, "On the Direct Strength Design of Continuous Cold-Formed Steel Beams", *Proceedings of 20th International Specialty Conference on Recent Research and Developments in Cold-Formed Steel Design and Construction*, R. LaBoube, W.-W. Yu (Eds.), St. Louis, 185-204, 3-4/11, 2010.

Basaglia C, Camotim D, "Buckling Analysis of Cold-Formed RHS Frames Using Generalised Beam Theory", *Tubular Structures XIII*, B. Young (Ed.), Hong Kong, 187-195, 15-17/12, 2010.

Submitted

Silvestre N, Camotim D, Silva NF, "Generalised Beam Theory Revisited: from the Kinematical Assumptions to the Deformation Mode Determination", *Int. J. Structural Stability and Dynamics*, 12/2010.

Basaglia C, Camotim D, Silvestre N, "Non-Linear GBT Formulation for Open-Section Thin-Walled Members with Arbitrary Support Conditions", *Computers & Structures*, 2/2011.

Basaglia C, Camotim D, "On the Incorporation of Load Application Effects in the GBT Buckling Analysis of Thin-Walled Steel Beams and Frames", *Structural Stability Research Council Annual Stability Conference*, Pittsburgh, 10-14/5, 2011. (1/2011)

Gonçalves R, Freitas I, Camotim D, "Aplicação da Teoria Generalizada de Vigas a Barras com Materiais Elastoplásticos", *Congresso de Métodos Numéricos em Engenharia*, Coimbra, 14-17/6, 2011. (3/2011)

Natário P, Silvestre N, Camotim D, "Utilização da Teoria Generalizada de Vigas para Analisar a Instabilidade Localizada da Alma em Vigas de Aço Enformadas a Frio", *Congresso de Métodos Numéricos em Engenharia*, Coimbra, 14-17/6, 2011. (3/2011)

Completed Theses

Engº Rui Alexandre Silva Bebiano - "Stability and Dynamics of Thin-Walled Members – Application of Generalised Beam Theory", *Engenharia Civil*, IST, Universidade Técnica de Lisboa, 2010. (Orientador e Co-Orientador Científicos: Dinar Camotim e Nuno Silvestre)

CONTACTS:

Prof. Dinar Camotim

Tel.: +351 218 418 402

E-mail: dcamotim@civil.ist.utl.pt

IN_LEARNING – Designing Active Learning Environments

PTDC/AUR-AQI/105410/2008

KEY WORDS: Active Learning Environments, Space use analysis, Design criteria, Space-pedagogy matrix

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa (FCT/UNL); INESC Inovação, Instituto de Novas Tecnologias (INOV/INESC/IST/UTL); Unidade de Investigação em Educação e Desenvolvimento (UIED/FCT/UNL)

PERIOD: 01-01-2010 to 01-01-2013

FINANCING (€): 166.726 € **IST/ICIST (€):** 100.683 €

COORDINATOR(S): Teresa Heitor. **RESEARCHERS AND COLLABORATORS:** Ana Tomé; Gabriel Pestana; Helena Barranha; João Fernandes; Maria Alegre; Mário Nunes; Rogério Rilhas; Vítor Teodoro

SUMMARY

IN_LEARNING focuses on active learning environments (ALE) in the framework of secondary and higher education. ALE corresponds to high performance learning settings, i.e. spaces designed to suit new approaches to learning and teaching beyond those typical of structured classes of standardized duration with breaks in between, in a way to facilitate student-centered and collaborative learning, to promote and foster informal contacts and continuous learning experiences to their students.

IN_LEARNING aims at:

- identifying which settings best support student-centered learning methods;
- analysing the impact of the design of learning facilities on student centered learning methods;
- exploring what has been achieved, by assessing how the physical space supports formal and informal learning activities;
- identifying what developments will be required in the near future. The project rationale derives from the fact that the architecture of educational facilities has a crucial contribution to enhance student learning. The way in which learning occurs and the developments in collaborative research and teaching opportunities have created pressure upon existing educational facilities built for a 'one size fits all' model of teaching and learning. Today there are a certain number of key questions that must be considered when addressing architectural quality in educational facilities.

The impact of student-centred learning methods, such as problem-based learning, evidence-based learning, reflective study and group work, implies learning activities that are more socially responsible and reflexive, where learners and teachers collaborate on

a problem in a specific, localized context (e.g. studios, laboratories). The increasing rate of computer use for learning and teaching implies an integrated learning environment combining learning space and service delivery around the integrated digital environment.

Learners and teachers spend a large amount of their time outside classes. The time spent in socially peer-to-peer oriented settings discussing academic work or other related topics as well as in "learning events" is part of the learning process. It happens through flexible and informal processes in casual community settings, (e.g. learning hubs, alcoves, lobbies, common rooms) which allow a greater tolerance of noise and activity.

Learning is now understood as a decentralized process that takes place anytime, anywhere. ALE should be able to motivate learners and promote learning as an activity, support collaborative as well as formal practice, provide a personalized and inclusive environment, and be flexible in the face of changing needs. This resulted in a growing need for:

- flexible learning spaces that promote an interactive exchange of knowledge;
 - informal learning precincts and student socializing areas where people go for collaboration and share information in a social and casual two-way process;
- The main research question is on how the configurative properties of learning settings influence the users experience of space, generate interaction and facilitate their capacity to acquire and share knowledge. It is argued that the spatial configurations have the potential to position learners and teachers and regulate the ways in which knowledge is shared and learning takes place. The type of rules imposed on

users by space constitutes the key condition in how the socio-informational function may arise. The answer to this question requires the development of a space-use analysis model capable of a systematic, objective and non-arbitrary description.

IN_LEARNING concentrates on:

- the formulation of a theoretical framework between the relations of the design of learning facilities and the way people learn in formal and informal modes;
- the survey and assessment of ALE, concerning formal and informal modes of learning;
- the development of a specific space-use analysis tool (SUA), based on the exploration of video technology for images in motion. Video data is crossover with “Space Syntax” models. Emerging spatial patterns of space-use and knowledge-sharing are identified by combining spatial description with the motion graphics and post processing analysis.



DECivil. Atrium North. Test image.

DELIVERABLES

Proceedings in international conferences

T. Heitor, R.M. Pinto (2012) Thinking critically towards excellence in school buildings, Space Syntax Symposium 8 (SSS8), Santiago de Chile, Jan. 2012

A. Tomé, T. Heitor (2012) Computer Vision of Mobility in Informal Learning Spaces Space Syntax Symposium 8 (SSS8), Santiago de Chile, Jan. 2012

A. Nogueira, T. Heitor, M. Carreira, G. Rodrigues, A. Pedroso (2011) Visual analysis methodologies based on Virtual Reality (V.R.) technology: Rio de Janeiro's Botanical Garden, Brazil and Cerco's Garden, Portugal, 2do. Congreso Iberoamericano y X Jornada: "Técnicas de Restauración y Conservación del Patrimonio", Sept. 2011 La Plata, Argentina

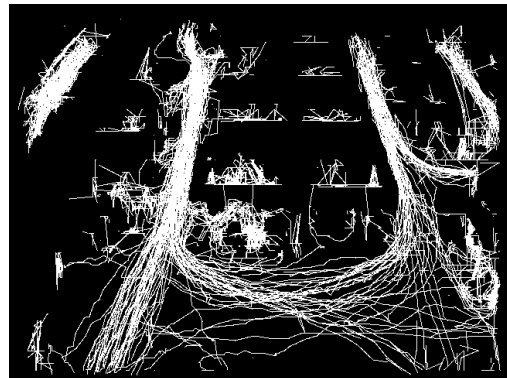
M. Bacharel Carreira, T. Heitor (2011) Active learning environments in university context. Between formality and informality, WTA Conference, Brno

CONTACTS:

Prof. Teresa Heitor

Tel.: +351 218 418 320 E-mail:teresa@civil.ist.utl.pt

IN_LEARNING considers 5 tasks: 1: Project management; 2: Formulating a theoretical framework between the relations of the design of learning facilities and the way people learn in formal and informal modes; 3: Survey of formal and informal types of ALE; 4: SUA development: specification and validation, implementation and testing; 5: Data gathering and systematization. The comprehensive study of ALE, based on the analysis of spatial layouts and equipment design together with the space-use analysis, will provide a broad understanding of the performance of learning settings. This in turn will allow recognizing whether these settings are meeting the needs of contemporary curricula, identify well-designed spaces and major failures and help to spread good architectural design practice.



Movement pattern. Observation interval > 60 minutes (8 am).

T. Heitor, A. Nogueira, M. Bacharel Carreira, G. Rodrigues, A. L. Pedroso (2011) Virtual Heritage: Simulations and Visualization Tools, CAA 2011

A. Nogueira, T. Heitor, M. Carreira, G. Rodrigues, A. Pedroso (2010) Visual analysis methodologies based on Virtual Reality (V.R.) technology: Rio de Janeiro's Botanical Garden, Brazil and Cerco's Garden, Portugal, CITTA3 Conference, Porto

Papers in international Journals

A. Tomé, T. Heitor (2011) Para um método de análise espaço-uso – uma abordagem sintáctica. PARC Journal - Issue 7, Vol. 2, Oct. 2011

OECD (2011) “Designing for Education: Compendium of Exemplary Educational Facilities 2011”, Sept. 2011

S. Pereira (2011) Tornar Visível a Forma Como Somos Tocados Pelo Mundo Recensão Crítica de “The Eyes of the Skin” de Juhani Pallasmaa. PhD in Architecture, IST

Instrumental Study of Active Faults of Lower Tagus Valley

POCTI/CTA/32720/2000

KEY WORDS: Active Fault; Microseismicity; Seismic Hazard; Seismotectonics

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-11-2000 to 31-10-2003

FINANCING (€): 184.555 **IST/ICIST (€):**184.555

COORDINATOR(S): João Fonseca. **RESEARCHERS AND COLLABORATORS:** Carlos Sousa Oliveira; Sandra Isabel das Neves Heleno da Silva; Susana Pires Vilanova

SUMMARY

The Lower Tagus Valley Region (LTV) is characterized by moderate seismic activity with historical destructive earthquakes of $ML > 6.5$, such as the events of 1909, 1858 and 1531. These events occur at distances less than 50 km from the city of Lisbon, affecting areas that are now densely populated and have intense industrial activity. Hence, the detailed mapping of the seismogenic structures is indispensable for an adequate quantification of the seismic risk.

The LTV is the SE border of an aborted rift of Triassic age. This accounts for the fragility of the lithosphere and reactivation of inherited structures under the present compressive stress due to the convergence between Africa and Eurasia. The LTV is covered by Cainozoic sediments, which reduce the likelihood of surface rupture associated with the historical events, a common situation at any rate in intraplate scenarios.

The scarcity of instrumental seismological data for the area, due to the high detection threshold of the National Network, associated with the lack of direct geological evidence for Active Tectonics, makes it difficult to develop seismotectonic models. The only instrumental study of the microseismicity that was carried out so far took place in 1987/88, had the duration of 11 months (Fonseca, 1989; Fonseca and Long, 1991), and showed the existence of seismic activity with magnitudes between $ML = 1$ and $ML = 3$ which is not detected by the present network. As an example of the importance of the study of this type of

seismicity, we quote the investigation of the New Madrid Seismic Zone (USA) between 1974 and the present through the deployment and operation of microearthquake networks, and the resulting seismotectonic model and associated hazard studies (Stauder et al., 1976; Chiu et al., 1997, etc...).

The objective of the present proposal is the instrumental study of the microseismicity of the LTV, namely hypocentral location and determination of joint focal mechanisms for events above $ML = 1$, and the tomographic study of the lithosphere underneath the LTV.

This proposal is companion to a previous proposal, approved and in progress - Project RE.SIS.TE. - under which the acquisition of 4 seismographic stations is currently taking place. The specific objectives of this proposal are: 1) to reach the minimum configuration that allows the adequate processing and analysis of the data (7 stations); and 2) to provide the adequate staff for the first 3 years of operation.

The present proposal is also complementary to the Palaeoseismological study of the LTV currently being conducted by the proponent research team, under funding from the FCT and the ECGS.

The proposed approach stems from the recognition that in an intraplate area with soft sediment cover the analysis of the seismicity, combined with the search of indirect geological evidence of faulting, is a requirement for the identification of seismogenic structures.

CONTACTS

Prof. João Fonseca

Tel.: +351 218 417 535

E-mail: jfonseca@ist.utl.pt

Large Diameter Piles Under Axial Loading

PTDC/ECM/70505/2006

KEY WORDS: Piles, Axial loading, Pile load test, Cyclic elastoplastic model

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Faculdade de Engenharia da Universidade do Porto (FE/UP)

PERIOD: 01-07-2007 to 30-09-2011

FINANCING (€): 135.840 **IST/ICIST (€):** 108.720

COORDINATOR(S): Jaime Santos. **RESEARCHERS AND COLLABORATORS:** António Viana da Fonseca; Arézou Modaressi; Luís Santos Castro; Ricardo Leal Duarte; Sérgio Cançado Paraíso; Sofia Costa d'Aguiar

SUMMARY

This project aims to contribute to the advance in the knowledge on the behaviour of piles under axial loading, with particular emphasis on large diameter piles (800mm or higher). The design of pile foundations is still controlled by estimation of axial capacity, but in many applications, such as in large diameter piles the critical issue is more likely to be the magnitude of displacements under operating conditions. This project provides an opportunity to reflect on the recent advances that have been made over the last two decades in the design of piles under axial loading, and to identify those aspects that should be improved using sound conceptual models and analyses. It will also provide the opportunity to analyse the data collected recently in 2 well-characterized experimental sites in Portugal (supervised by the leader of this project). The scope of work for the proposed project has 2 main parts:

1) This project is justified by the needs to support a strong research team on geotechnics and numerical modelling providing the opportunity to developed an integrated study, which includes numerical modelling using either simplified 1-D or sophisticated 3-D models and also high quality experimental data to validate the analyses. This project will make use of the results obtained in two experimental sites: ISC'2-FEUP and the New Tagus River Cross experimental sites. In the ISC'2-FEUP experimental site an extensive in situ and laboratory geotechnical testing program was carried out; besides, fully instrumented static and dynamic load tests were performed in 3 different kinds of piles. In the New Tagus River Cross to optimize the foundation design several load tests were performed: i) 3 fully instrumented static load tests on experimental piles with 800mm of diameter; ii) several high strain dynamic load tests on experimental piles

with 800mm of diameter; iii) high strain dynamic load test on experimental pile with 1500mm of diameter; iv) several high strain dynamic load tests on 2200mm diameter foundation piles of the main bridge.

2) The experimental sites and the research work developed in ISTUTL (Instituto Superior Técnico da Universidade Técnica de Lisboa since 2000 (POCTI/ECM/36057/2000) has contributed largely to disseminate the use of dynamic load test (DLT). Nevertheless, the developed research work is still limited and the DLT have not been fully implemented in Portugal.

The research on dynamic pile load test aims to conduct a comprehensive evaluation of the wave equation methods and to propose dynamic analyses based on improved 1-D soil-pile interaction models calibrated with 3-D analyses and case studies. It will provide the elaboration of a database with comparative studies of accomplished dynamic load tests with static load tests performed on driven and cast in place piles, using available data in Portugal (a few recent cases) and in Brazil (20 years of experience). The proposed research project will provide the opportunity for the development of several theses. The analyses and comparison studies will provide much more confidence for the use of DLT in Portuguese practice on foundation design and construction. Particular emphasis will be given to analyze the mobilization of the base resistance, focusing on long and large diameter bored piles, which are widely used in bridge foundations in Portugal. This project will enhance the collaboration of our groups with other invited researchers outside Portugal (Bengt Fellenius from Canada, Arezou Modaressi from École Centrale de Paris and Sérgio Paraíso from Brazil).



Foundation piles of a bridge



Dynamic load test on experimental pile (800 mm) with a 20 ton hammer

DELIVERABLES

Concluded Theses

PhD thesis of Sofia D'Aguiar. Numerical Modeling of Axial Soil-Pile Load Transfer Mechanisms. Ecole Centrale de Paris & Instituto Superior Técnico, Technical University of Lisbon (double degree), 2008.

MSc. thesis of Rui Diogo Gomes da Silva. The design of pile-raft foundations. MSc. in Civil Engineering. Instituto Superior Técnico, Technical University of Lisbon, 2009. (in portuguese)

MSc. thesis of Ricardo José Leal Duarte. Application of dynamic load test to evaluate pile capacity in residual soil from granite. MSc. in Structural Engineering. Instituto Superior Técnico, Technical University of Lisbon, 2009. (in portuguese)

MSc. thesis of Tiago Miguel Baleia da Silva Pereira. Analysis of the axial load capacity of a pile considering the effects of residual load. MSc. in Civil Engineering. Instituto Superior Técnico, Technical University of Lisbon, 2008. (in portuguese)

MSc. thesis of David Jorge da Rocha Pereira Fernandes: "Definição de curvas de transferência de carga vertical de estacas moldadas em Solo Residual de Granito. Caso de Estudo do Campo Experimental da FEUP. Master Degree in Civil Eng. University of Porto. July 2010. (in portuguese)

Books

Santos, J.A. (2008). Proc. 8th International Conference on the Application of Stress Wave Theory to Piles, Millpress, Rotterdam. ISBN 978-1-53603-909-7.

Viana da Fonseca, A.; Santos, J.A. (2008). International Prediction Event - Behaviour of CFA, Driven and Bored Piles in Residual Soil. ISC'2 Experimental Site, FEUP and IST. ISBN: 978-972-752-104-3 and ISBN: 978-989-95625-1-6.

Papers in International Journals

D'Aguiar, S.C.; Modaressi, A., Santos, J.A. & Lopez-Caballero, F. Piles under cyclic axial loading: study of the friction fatigue and its importance in piles behavior. Canadian Geotechnical Journal (accepted, March 2011).

D'Aguiar, S.C.; Modaressi, A.; Santos, J.A. & Lopez-Caballero, F. Elasto-plastic constitutive modelling of soil-structure interfaces under monotonic and cyclic loading. Computers and Geotechnics (accepted, Feb 2011, on-line version already available).

Albuquerque, P.J.R.; Massad, F.; Viana da Fonseca, A.; Carvalho, D.; Santos, J.A.; Costa Esteves, E. (2011). Effects of the construction method on pile performance: evaluation by instrumentation - part 1: experimental site at the University of Campinas. Soils and Rocks (in press, April 2011).

Albuquerque, P.J.R.; Viana da Fonseca, A.; Santos, J.A.; Costa Esteves, E.; Massad, F.; Carvalho, D. (2011). Effects of the construction method on pile performance: evaluation by instrumentation - part 2: experimental site at the Faculty of Engineering of the University of Porto. Soils and Rocks (in press, April 2011).

Papers in National Journals

Gouveia Pereira, J.J.; Santos, J.A.; Gomes Correia, A.; Simões, T.N. (2009). Dynamic load test – A case study on bored piles. Geotecnia - journal of the Portuguese Geotechnical Society, Brazilian Society for Soil Mechanics and Geotechnical Engineering and Brazilian Society for Engineering and Environmental Geology, 115:21-43. (in portuguese)

Proceedings in international Conferences

D'Aguiar, S.C.; Lopez-Caballero, F.; Modaressi, A.; Santos, J.A. (2009). Piles under cyclic loading: study of the friction fatigue and its importance in piles behavior. 17th International Conference on Soil

Mechanics and Geotechnical Engineering, Egypt, Alexandria, vol. 2, 1313-1316.

Santos, J.A.; Matos Fernandes, M.; Costa, M.P.; Correia, A.; Oliveira, P. (2009). A Case Study of Non-Displacement Piles in Pliocene Sands. 17th International Conference on Soil Mechanics and Geotechnical Engineering, Egypt, Alexandria, vol. 2, 1232-1235.

Costa D'Aguiar, S.; Santos, J.A.; Lopez-Caballero, F.; Modaressi, A. (2008). Comparison of static and dynamic pile load tests using an elastoplastic soil model. 8th International Conference on the Application of Stress Wave Theory to Piles, editor Santos, J.A., Millpress, Rotterdam, 643-651, IST, Lisbon.

Gouveia Pereira, J.J.; Santos, J.A.; Gomes Correia, A.; Simões, T.N (2008). Static and dynamic load tests comparison considering load-energy level and soil non-linearity. 8th International Conference on the Application of Stress Wave Theory to Piles, editor Santos, J.A., Millpress, Rotterdam, 585-589, IST, Lisbon.

Cruz, N., Pinto, P., Viana da Fonseca, A., & Andrade, R. (2008). Pile bearing capacity of the new bridge over Zambezi River (Mozambique): Predictions and performance of static load test results. ISSMGE 11th Baltic Sea Geotechnical Conference, 15-18 Sept. Geotechnics in Maritime Engineering, vol.1, pp. 35-41. Edit. Mlynarek, Zikora & Dembicki. U.Techn. Gansk.

Topa Gomes, A., Viana da Fonseca, A. & Fahey, M. (2008). Deformation properties of granite residual soil – defining design parameter. Deformation Characteristics of Geomaterials. Proc. of the 4th International Symposium (IS-Atlanta 2008), vol. 1, pp. 221-228. Ed. S. Burns, P. Mayne & C. Santamarina. IOS, Millpress.

Cruz, N., Viana da Fonseca, A., Pinto, P. e Andrade, R. (2008). Capacidade de carga de estacas da fundação da nova ponte sobre o Rio Zambeze. Previsões e verificação através de ensaios de carga pelo método de Osterberg". 5º Congresso Luso-Moçambicano de Engenharia, Maputo, 2 a 4 de Setembro de 2008. (Artº

Refª 28A003 -Proceedings do Congresso em CD-ROM). (in portuguese)

Massad, F. & Viana da Fonseca, A. (2008). Atribuição de sentido geotécnico a parâmetros de Cambeftort de interacção solo-estaca, em compressão axial. SEFE VI – Seminário de Engenharia de Fundações Especiais e Geotecnia. S. Paulo, 3-5 Nov. Vol. 1, pp105-115 (artigo: PAP0057-01, Tema “Resp. em Fundações e Geotecnia”. ABEF/ABMS. S. Paulo, Brasil. (in portuguese)

Viana da Fonseca, A. & Santos, J. (2009). Insight Learning from the Results of ISC2 Pile Prediction Event in Residual Soil. ASCE-GSP 186: Contemporary Topics in In Situ Testing, Analysis, and Reliability of Foundations, pp. 18-24. International Foundation Congress & Equipment Expo IFCEE'09, Orlando, USA.

Proceedings in National Conferences

Duarte, R.J.L.; Santos, J.A.; Castro, L.M.S.S. (2010). Dynamic load test numerical modelling considering the non-linear behaviour of soil and pile – part 1. 12th National Congress on Geotechnics, University of Minho, in CD-Rom. (in portuguese)

Duarte, R.J.L.; Santos, J.A.; Castro, L.M.S.S. (2010). Dynamic load test numerical modelling considering the non-linear behaviour of soil and pile – part 2. 12th National Congress on Geotechnics, University of Minho, in CD-Rom. (in portuguese)

Costa Esteves, E., Viana da Fonseca, Laranjo, M. (2010). Previsão da capacidade de carga de três estacas de tipologia diferente através de formulações teóricas baseadas nas propriedades do solo. 12th National Congress on Geotechnics, University of Minho, in CD-Rom, pp. 623-632. (in portuguese)

Costa Esteves, E., Viana da Fonseca, A., Esteves, C. (2008). Modelação numérica em diferenças finitas do comportamento de uma estaca em solo residual do granito ensaiada em compressão. 11th National Congress on Geotechnics, Universidade de Coimbra, vol.2, pp. 233-240. (in portuguese)

CONTACTS:

Prof. Jaime Santos

Tel.: +351 218 418 418

E-mail: jaime@civil.ist.utl.pt

Learning Environments in Portugal. 2nd and 3rd grade elementary and secondary school buildings

POCI/AUR/56515/2004

KEY WORDS: School Buildings; School Design Criteria; Space Use Analysis; School Building Performance

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): -

PERIOD: 01-07-2005 to 31-10-2007

FINANCING (€): 65.477

IST/ICIST (€): 65.477

COORDINATOR(S): Teresa Heitor. **RESEARCHERS AND COLLABORATORS:** Ana Cristina Santos Tostões; Manuel Arriaga Brito Correia Guedes; Maria Alexandra de Lacerda Nave Alegre

SUMMARY

The project aims to study public school facilities – 2nd and 3rd grade elementary and secondary schools (E(2,3)+S) - built in Portugal during the 20th century. The project rationale derives from the fact that school buildings have a crucial contribution to make to improve educational achievement. A good educational planning policy can only produce results if an educational building policy is developed at the same time, both to rationally organize educational construction and to propose that space be planned to take account of the leading educational innovations of the day. Today there are a certain number of key questions that must be considered when addressing architectural quality in educational facilities. School buildings must be inspiring and need to provide a pleasant and comfortable environment for learning. They need to be of sustainable and flexible design, inclusive and responsive to curriculum changes and to the most recent developments in ICT technologies. They must be open to wider use, thereby binding schools into their local communities. They should optimize investments and must be operated and maintained efficiently according to high performance building concepts. Innovative research seeks architectural answers on how to design high performance school buildings that make efficient use of the resources invested in building, renovating and running educational facilities. To secure the best possible architectural design input to deliver schools that meet users' needs and expectations over time and offer a positive environment that supports learning and teaching is a major challenge. The main project

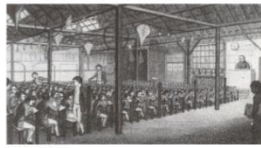
purpose is to analyze the different attempts to create learning environments in Portugal i.e., to identify the educational concepts and architectural models that influenced the production of E(2,3)+S along the 20th century; to give an idea of what has been achieved, by assessing how the physical environment supports effective learning; and to examine what developments will be required in the near future. The main questions, which the project will address, are the following: What major current trends in school design can be identified in Portugal? What major changes affect learning environments? How does school building design concretely respond to those changes? Which school buildings/projects best support effective learning and serve the community? What potential developments in education might be delivered through building schools in the future? The project concentrates on both the survey of the existing E(2,3)+S building types and the development of a school specific space-use analysis tool (SUA). The comprehensive study of school physical environment, based on the analysis of spatial layouts, building technologies and equipment design; space, comfort and safety norms; and surveillance and security strategies together with the space-use diagnosis, will provide a broad understanding of the E(2,3)+S built environment. This in turn will allow recognizing whether buildings are meeting the needs of school users, identify well-designed projects and major failures and help to spread good architectural design practice.

Modos de organização pedagógica e métodos de ensino

Modo de organização pedagógica - forma de organizar o ensino numa escola



ensino individual



ensino mútuo

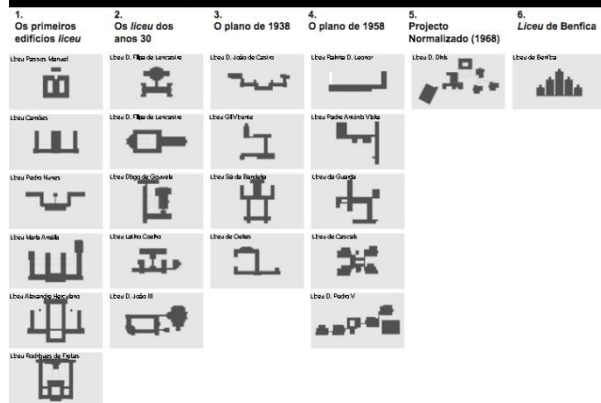


ensino simultâneo. Classe.



sala de aula

Caracterização tipológica do edifício liceu em Portugal



DELIVERABLES

Tomé, A.; Heitor, T. (2006) “Condição De Adaptabilidade Dos Espaços Culturais. Um Caso De Estudo. Solar Dos Zagallos” In Seminário Internacional Nutau 2006 – Inovações Tecnológicas e Sustentabilidade, Universidade de São Paulo (Brasil), Outubro de 2006.

Heitor, T.; Tomé, A.; Dimas, P.; Silva, J.P. (2007) “Synchronizing Spatial Information In Complex Environments: A Crossover Of Space Syntax And Spatial Information Visualization” in Proceedings of 6th Space Syntax International Symposium, Istanbul Technical University’s Architecture Faculty, Istanbul, de 12 a 15 de Junho de 2007.

Heitor, T.; Tomé, A.; Dimas, P.; Silva, J.P. (2007) “Measurability, Representation And Interpretation Of Spatial Usage In Knowledge-Sharing Environments – A Descriptive Model Based On Wifi Technologies” in Technical Report 42, Workshop on Behavior Monitoring and Interpretation, BMI 07, in conjunction with 30th German Conference on Artificial Intelligence, Osnabruck, 10 de Setembro de 2007.

Heitor, T. (2009) O Locus Da Aprendizagem in António Sena da Silva, Fundação Calouste Gulbenkian, Lisboa, pp 23-27

Heitor, T. (2009) School Modernization In Portugal, Towards A Sustainable Model Of Intervention, International Conference Sustainable School Buildings: From Concept To Reality Ljubljana, Slovenia, 1-2 October, Ministry of education and Sport of the Republic of Slovenia and the OECD Centre for Effective Learning Environments (CELE)

Heitor, T. 2009 Secondary Schools Modernisation Programme: The Portuguese Experience in Knapp, E. , Macmillan, S. and Noschis, K. (ed) Architectural Quality in Planning and Design of Schools” Part 4 Projects experiences, Compartments, Lausanne

Heitor, T. (2005) Potential Problems And Challenges In Defining International Design Principles For Schools ‘Ad’hoc experts’ group meeting on evaluating quality in educational facilities Programme for Educational Buildings (PEB/OCDE), Caparide, Junho

Alegre, Alexandra (no prelo); *Arquitetura Escolar. O Edifício Liceu em Portugal (1882-1978)*, investigação desenvolvida no âmbito da dissertação de Doutoramento a publicar na colecção Textos Universitário de Ciências Sociais e Humana, Fundação Calouste Gulbenkian, Lisboa.

Alegre, Alexandra (2010) *Liceus, Escolas Técnicas e Secundárias*, Edição Parque Escolar E.P.E., Lisboa.

Alegre, Alexandra (2010); *O Projecto de Miguel Ventura Terra para o Edifício do Liceu Pedro Nunes (1909-1911) e Cronologia Liceu Pedro Nunes* – coordenação do caderno realizado para a inauguração das obras de reabilitação da Escola Secundária de Pedro Nunes, Parque Escolar E.P.E.,

Alegre, Alexandra (2010); *Reforma de Passos Manuel de 1836 – O Plano dos Liceus Nacionais e Os Projectos para o Liceu Passos Manuel (1882-1911)* in *Liceu Passos Manuel – coordenação do caderno realizado para a inauguração das obras de reabilitação da Escola Secundária de Passos Manuel*, Parque Escolar E.P.E..

Alegre, Alexandra (2010); *Saúde, higiene e arquitectura Escolar. Os liceus da I Republica*, in *Catálogo da Exposição Corpo – Estado, Medicina e Sociedade no tempo da I República*, Programa das Comemorações do Centenário da República, Lisboa, p. 97-109.

Alegre, Alexandra (2009); *Arquitetura para o edifício secundário em Portugal: Princípios e evolução ao longo do século XX* in *Escolas Secundárias – Reabilitação*, Colecção Arquitecturas, Edição Caleidoscópio, Casal de Cambra, p. 5 –15.

Alegre, Alexandra (2008); O Estudo Normalizado dos Liceus Tipo in *Renovar. Escola Secundária de D. Dinis*, 002, Coordenação Teresa Heitor, Edição Ministério da Educação, Lisboa, p. 16-18.

Alegre, Alexandra, Heitor, Teresa (2006); Reflexos do desenvolvimento tecnológico da construção na arquitectura escolar portuguesa da década de 60, Seminário NUTAU'2006, Faculdade de Arquitectura e Urbanismo da Universidade de São Paulo, Brasil. 9-13 de Outubro.

CONTACTS:

Prof. Teresa Heitor

Tel.: +351 218 418 320

E-mail:teresa@civil.ist.utl.pt

LT-PORTUGAL - Architecture and Urban Planning

POCI/AUR/57428/2004

KEY WORDS: Building Refurbishment; Environmental Design; Energy Consumption; Project Method

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): -

PERIOD: 01-09-2005 to 30-06-2007

FINANCING (€): 36.222

IST/ICIST (€): 36.222

COORDINATOR(S): Manuel Correia Guedes. **RESEARCHERS AND COLLABORATORS:** Manuel Guilherme Caras Altas Duarte Pinheiro; Pedro Manuel Gameiro Henriques; Teresa Frederica Tojal Valsassina Heitor

SUMMARY

The mechanism of energy use in buildings is complex, involving three main factors: the physical building itself; the efficiency of the energy-using equipment such as cooling plant and lighting; and the way in which the occupants control the building and systems. Different combinations of these factors lead to a wide variance in energy use. For example, poor fabric insulation, and inefficient cooling system, and occupants controlling excess heat by opening windows, may all contribute to high energy use. Refurbishment provides the opportunity to directly improve the building fabric and systems, and these improvements may promote better occupant satisfaction and performance. For example, the fitting of room thermostats would remove the need for occupants to open windows to control overheating in winter. In developing a strategy, it is useful to be able to rank the impact of various refurbishment measures. Savings are not simply additive – for example the value of cooling energy saved by applying a shading system is dependent on the efficiency of the air conditioning system. In Portugal, there is a critical need for architects to incorporate energy-conscious

strategies on the process of refurbishment design, particularly in the case of office buildings, which is a building sector associated to higher ratings of energy consumption. Passive design technology is still widely unknown or misused by Architects, to a large extent because information on these issues is scarce, mostly referring to foreign climatic and building contexts. There is also a great need for user-friendly tools, like the LT method, particularly for demonstrating and validating its use in the Portuguese context.

The project will exploit existing tools and techniques for the environmental analysis of office building refurbishment strategies, in particular the LT Method (Lighting and Thermal energy), which is an energy design tool that can quickly assess the energy use (lighting, cooling, ventilation and heating) and thermal comfort implications of design options – both in existing projects and also to inform design decisions. Despite the complexity of the analysis, the LT Method is easy to use and to apply to a range of situations. It is thus an ideal to assess refurbishment strategies, to which it has been applied before, and to make comparisons between various refurbishment options.

CONTACTS:

Prof. Manuel Correia Guedes

Tel.: +351 218 418 267

E-mail: mcguedes@civil.ist.utl.pt

Mechanical and durability performance of concretes made with fine recycled aggregates from construction and demolition waste from Portuguese recycling plants

PTDC/ECM/108682/2008

KEY WORDS: Fine recycled aggregates; Concrete; Sustainability in construction, Construction and Demolition Waste

PROMOTING INSTITUTION(S):

IST-ICIST

PARTNER INSTITUTION(S): Centro de Recursos Naturais e Ambiente (CERENA/IST/UTL)

PERIOD: 01-04-2010 to 31-03-2013

FINANCING (€): 150.953

IST/ICIST (€): 150.953

COORDINATOR(S): Jorge de Brito. **RESEARCHERS AND COLLABORATORS:** António Costa; Luís Evangelista; Teresa Carvalho; Miguel Santos; Paulo França; Rui Isidoro

SUMMARY

According to UNFPA, in 2008 more than half of the world's population lives in cities, setting a new record in the history of Mankind, and in 2030 that number will reach about 5 billion people. Human migration to urbanized areas helps world development but the increasing pressure on the cities' urbanized areas leads to an increase in buildings, with an increase in the construction and demolition waste produced, with obvious negative environmental impacts. It is estimated that between 3 and 6 million tons of CDW are produced in Portugal every year, with a tendency to increase, since Portugal is starting to renew its housing park, contrasting with the traditional trend of creating new buildings.

Among the different measures available to process CDW, its recycling is one of the most interesting because it leads to a reduction of natural raw materials extracted, reducing the consequent environmental impacts associated, and it significantly reduces the amount of CDW taken to landfill.

In concrete production, it is widely accepted that part of the coarse natural aggregates (CNA) can be replaced by coarse recycled aggregates (CRA), without drastically reducing its properties. However, the same does not apply to fine recycled aggregates (FRA) use, in replacement of fine natural aggregates (FNA), since it is claimed that the environmental advantages achieved by using FRA do not compensate the significant reduction of performance of these concretes. The main cause that is presented for such detrimental effect lies on the fact that FRA have far greater porosity and water absorption, therefore

inducing worse behavior to the concretes made with them.

On the other hand, some recent investigations have proven differently, suggesting that fine recycled aggregates concrete (FRAC) is a viable product, both in terms of mechanical and durability behavior. The extraction of FNA has considerable environmental costs, either by dredging river or sea beds or by crushing natural stone. Dredging FNA at river or sea beds causes changes in the river's water flow, leading to erosion on the downstream shores. Dias (2005) studied the impact of river bed dredging activity on the main Portuguese rivers, having concluded that the activity should immediately cease, with the exception of the dredge required for naval transports. The Sandpit project (EVK3-CT-2001-00056) developed to estimate the impacts of massive North Sea's sea bed sand extraction on the local and regional ecosystems, alerted to the fact that this activity could affect tide and current wave on the areas exploited. As an alternative to sand extraction, there is the possibility of crushing rocks to create sand artificially. This process also has significant negative environmental impacts, because it uses natural stone, a limited abiotic resource, which could have been used for "nobler" purposes, and it uses natural resources and produces emissions during the crushing process.

Considering these factors, the possibility of using FRA on concrete production has two clear advantages: (a) it allows reducing natural resource consumption, as well as the associated environmental impacts inherent to the extraction or production activity; this happens

because FRA are automatically generated with crushing of CDW, being a by-product of the process; (b) it allows reducing the quantities of dumped materials, generating an increase of capacity of deposit of non recyclable or hazardous materials.

Taking all these factors into account, the main purpose of this research project, totally innovative in Portugal, is to evaluate, as thoroughly as possible, the properties of concretes made with FRA created from CDW gathered at Portuguese recycling plants. In order to do this, it will be required that a state-of-the-art research is conducted, followed by a field survey of the FRA produced from CDW at Portuguese recycling plants, which will allow classifying and characterizing the different types of FRA produced. Using samples from these FRA, an extended campaign is to be made, in which several families of FRAC, considering different type of FRA and different replacement ratio of FNA for

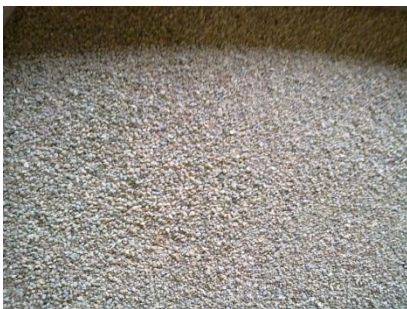
FRA, will be tested. These concretes will be analyzed in terms of mechanical, rheological and durability properties and comparisons between their behavior and that of reference concretes, made solely of natural aggregates, will be conducted.

Finally, based on the conclusions previously drawn, it is expected that a proposal of a new guide for the use of FRA on concrete production is published, considering the type of FRA used, the nature of concrete to be produced and its environmental exposure.

The large experience of the research team, and of the principal researcher in particular, in the field of the use of CRA and FRA in the production of structural concrete, demonstrated by a significant number of international publications, guarantees the efficacy of the methodology proposed.



Various stages of the aggregates' recycling process.



Post-treated recycled aggregates.

DELIVERABLES

Completed Theses

F. Rodrigues, "Caracterização de agregados finos reciclados provenientes de centrais de reciclagem portuguesas", Dissertação de Mestrado Integrado em Engenharia Civil, Instituto Superior Técnico, Lisboa, Outubro de 2011, 192 p.

Proceedings in International Conferences

F. Rodrigues, T. Carvalho, M. Pereira, L. Evangelista, J. de Brito, "Physical and chemical-mineralogical characterization of fine recycled aggregates from construction and demolition waste", Fray International Symposium, Cancun, Novembro / Dezembro de 2011.

Proceedings in National Conferences

F. Rodrigues, T. Carvalho, L. Evangelista, J. de Brito, "Caracterização de agregados finos reciclados provenientes de centrais de reciclagem portuguesas", 2º Congresso "Inovação na Construção Sustentável (Cincos 10)", Centro Habitat, Curia, Novembro de 2010, pp. 85-95.

Internal Reports

F. Rodrigues, M. Bravo, L. Evangelista, J. de Brito, "Desempenho mecânico e de durabilidade de betões produzidos com AFR obtidos a partir de RCD de centrais de reciclagem portuguesas - Estado da Arte",

Relatório ICIST, Relatório da Tarefa 1 do Projecto FCT PTDC/ECM/108682/2008, Março de 2011.

F. Rodrigues, L. Evangelista, J. de Brito, "Desenvolvimento de uma nova metodologia para a determinação da densidade e absorção de água de AFR", Relatório ICIST, Relatório da Tarefa 2 do Projecto FCT PTDC/ECM/108682/2008, Fevereiro de 2011.

F. Rodrigues, T. Carvalho, L. Evangelista, J. de Brito, "Levantamento das Quantidades de RCD Processadas em Portugal e Descrição das Centrais de Reciclagem" Relatório ICIST, Relatório da Tarefa 3 do Projecto FCT PTDC/ECM/108682/2008, Maio de 2011.

CONTACTS:

Prof. Jorge de Brito
Tel.: +351 218 419 709
E-mail: jb@civil.ist.utl.pt

Papers in International Journals

N. Fonseca, J. de Brito, L. Evangelista, The influence of curing conditions on the mechanical performance of concrete made with recycled concrete waste, *Cement and Concrete Composites*, Volume 33, Issue 6, July 2011, Pages 637-643

P. Pereira, L. Evangelista, J de Brito, The effect of superplasticisers on the workability and compressive strength of concrete made with fine recycled concrete aggregates, *Construction & Building Materials* (accepted for publication)

Modelling and Analysis of Nanostructures: Carbon Nanotubes and Nanocomposite Materials

PTDC/ECM/103490/2008

KEY WORDS: Computational Modelling, Structural analysis, Carbon nanotubes, Nanocomposite materials

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Centro de Química Estrutural (CQE/IST/UTL)

PERIOD: 01-01-2010 to 28-02-2013

FINANCING (€): 78.034

IST/ICIST (€): 78.034

COORDINATOR(S): Nuno Silvestre. **RESEARCHERS AND COLLABORATORS:** José N. Canongia Lopes, Bruno Faria, Dinar Camotim, Pedro B. Dinis

SUMMARY

Carbon nanotubes (NTs) are macromolecules of carbon in a periodic hexagonal arrangement with a cylindrical shape. NTs behave as structural systems formed by a large amount of carbon atoms that stay in equilibrium due to inter-atomic forces. NTs have one (single-walled NT) or several (multi-walled NT) layers of carbon graphite sheets. Since their discovery in 1991, numerous studies have shown that they possess exceptional mechanical properties, the theoretical elastic modulus and strength of single walled NTs being around 1 TPa and 200 GPa, respectively. However, if some force or displacement is imposed to a NT, its honeycomb (hexagonal) inter-atomic structure tends to deform and moves into another equilibrium state, thus affecting its macro-scale properties. The use of atomic force microscopes and transmission electron microscopes has revealed instability phenomena in NTs, both elastic buckling and post-buckling with large deformation.

In order to model and analyse the NT structural behaviour, two approaches have been mainly adopted: (i) the atomistic approach, based on molecular dynamics (MD) and (ii) the mechanical approach, based on continuum mechanics (CM). Due to its ability to reproduce the realistic NT structures, MD simulation is a very useful tool to estimate the mechanical properties of NTs. However, due to their huge computational effort and time consuming, practical applications of MD simulations are limited to systems containing a limited number of atoms. Conversely, CM simulations are computationally much more efficient but they must be rigorously calibrated in order to achieve a correct estimation of the NT (strength and stiffness) behaviour. Concerning CM simulations, there are two main types of NT models: (i) shell model and (ii) frame model. There have been

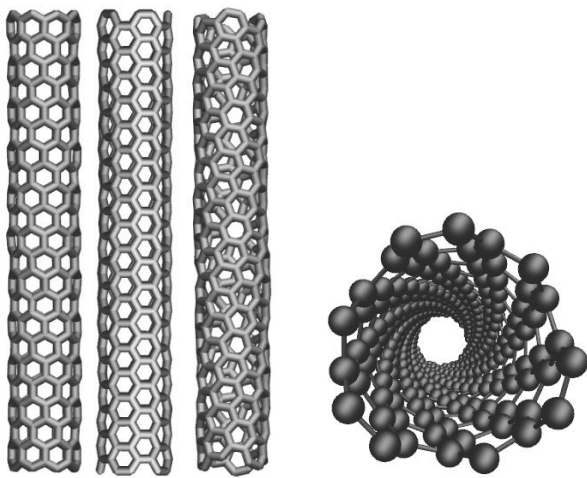
some controversial opinions about the best model to analyse the structural behaviour of NTs. The shell model is the simplest one since only five input data are necessary to describe the NT structure: length L , radius r , thickness t , Young modulus E and Poisson ratio. However, this model is not sensible to either the type of periodic hexagonal arrangement of carbon atoms (armchair, zig-zag or chiral) or the helicity of the NT.

The frame model takes these aspects into account since the bars simulate the covalent bonds between carbon atoms. Recently, some investigations have shown that CM analyses, based on either shell or frame model, are very useful but may lead to erroneous estimates of the NT behaviour due to misunderstanding of input data. The present project proposal is strictly related to the computational modelling and structural analysis of NTs and is aimed to propose more simple but realistic and rigorous models to analyse NTs. The combination of the NTs outstanding mechanical properties with their high aspect ratio (length/diameter) and low density, makes them ideally suited to use as reinforcement and to develop superior nanocomposite materials (NMs).

Some investigations have shown that the addition of small amounts of NTs can considerably improve the mechanical properties of polymeric and metal composites. However, the mechanical properties of NMs largely depend on some issues, namely (i) the stiffness and strength properties of the matrix, (ii) the behaviour of individual NTs and, most of all, (iii) the dispersion and volume fraction of individual NTs in the matrix. If item (i) is currently fairly well understood by the scientific community, the same evidence does not apply for items (ii)-(iii). In this context, the present project proposal aims at providing in-depth studies on

the (strength and stiffness) behaviour of NTs either individually or in combination with a matrix (NMs). Therefore, this project has two main objectives: 1) to develop continuum methods to simulate the behaviour of structures at nanoscale and 2) to provide in-depth information concerning the stiffness and strength of NTs and NMs. The research group is focused in the stability and non-linear behaviour of thin-walled structures and is the world leader in developing the “Generalised Beam Theory - GBT”. The group has recently started a new research topic regarding the analysis and behaviour of structures at the nano-scale. In particular, CM (shell models) was

used to perform an in-depth study on the influence of the NT length on their critical strain under compression, curvature under bending and twisting angle under torsion. Additionally, the team has excellent skills from the chemical point of view, which are crucial for the performance of molecular dynamics simulations. Due to the past research experience of the team in the specific areas of expertise of this project (i.e., computational modeling of continuum and molecular systems), the research group is very well prepared to achieve the proposed objectives with great success.



(a)

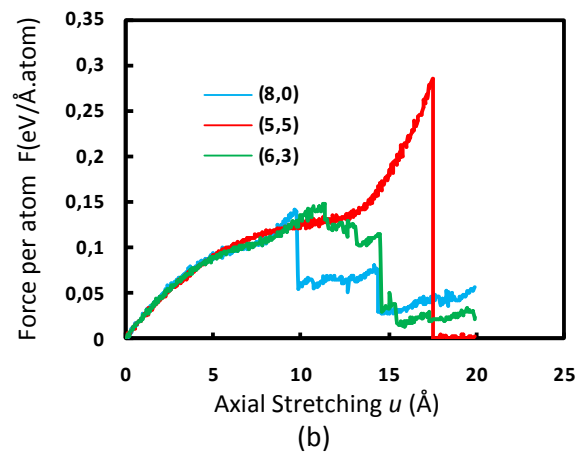


Figure 1 – (a) CNTs (8,0), (5,5), (6,3) and (b) variation of force F with stretching u

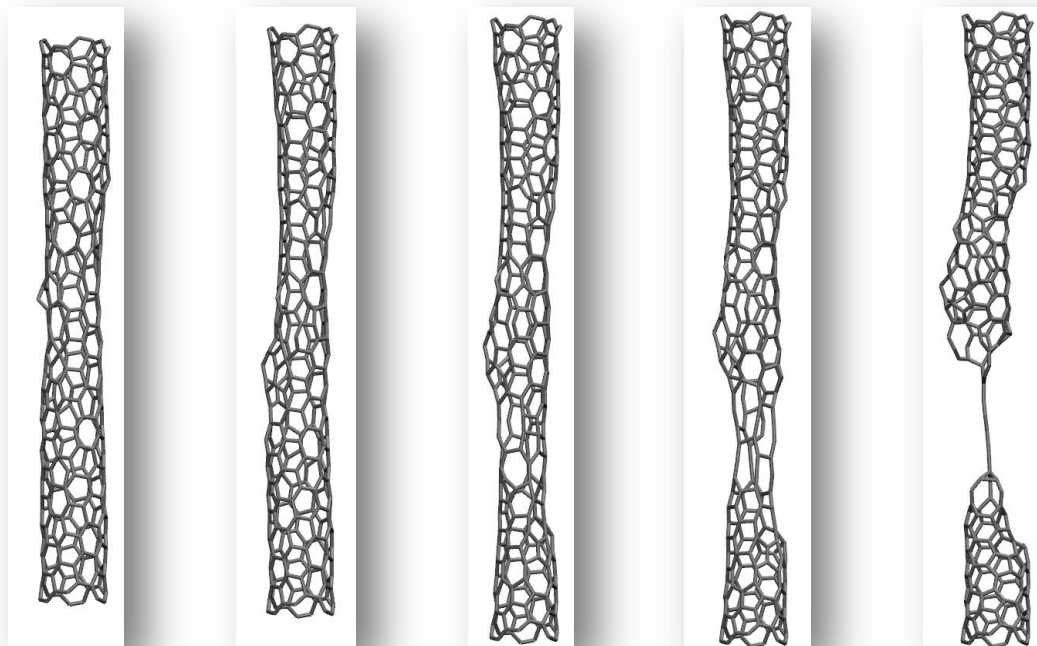


Figure 2 – Snapshots of C-C bond break and collapse of CNT (6,3) under tension

DELIVERABLES

Papers in international Journals

Faria B., Silvestre N., Canongia Lopes J.N. (2011) "Interaction diagrams for carbon nanotubes under combined shortening-twisting", *Composites Science and Technology*, Vol. 71, nº 16, pp. 1811-1818.

Silvestre N., Wang C.M., Zhang Y.Y., Xiang Y. (2011). "Sanders shell model for buckling of single-walled carbon nanotubes with small aspect ratio", *Composite Structures*, Vol. 93, nº 7, pp. 1683-1691.

Wang C.M., Tay Z.Y., Chowdhury A.N.R., Duan W.H., Zhang Y.Y., Silvestre N. (2011). "Examination of cylindrical shell theories for buckling of carbon nanotubes", *International Journal of Structural Stability and Dynamics*, Vol. 11, nº 6, pp. 1035-1058.

Silvestre N. (2011) "On the accuracy of shell models for torsional buckling of carbon nanotubes", *European Journal of Mechanics A/Solids*, accepted for publication, 2011.

<http://dx.doi.org/10.1016/j.euromechsol.2011.09.005>

Silvestre N., Faria B., Canongia Lopes J.N. (2011) "A molecular dynamics study on the thickness and post-critical strength of carbon nanotubes", *Composite Structures*, accepted for publication.

Papers in International Conferences

Silvestre N., Faria B., Canongia Lopes J.N. – "Carbon Nanotubes: Are They Thin-Walled?", *Proceedings of the 6th International Conference on Thin-Walled Structures (ICTWS 2011) – Recent Research Advances and Trends*, Timisoara, Romania, 5-7 September 2011, Volume 2, pp. 991-998.

Faria B., Silvestre N., Canongia Lopes J.N. – "Strength and Stiffness of Carbon Nanotubes under Combined Shortening and Twisting via Molecular Dynamics

Simulations", *Proceedings of the 16th International Conference on Composite Structures (ICCS 16)*, Porto, Portugal, 28-30 June 2011, Abstract nº 95 (CD-ROM).

Faria B., Silvestre N., Canongia Lopes J.N. – "A molecular dynamics study on the strength and collapse of tensioned and twisted carbon nanotubes", Accepted for presentation at the 1st ECCOMAS Young Investigators Conference (YIC2012), Aveiro, Portugal, 24-27 April, 2012.

Silvestre N., Faria B., Canongia Lopes J.N. – "Molecular dynamics simulations on the strength and stiffness of Carbon Nanotubes surrounded by polymeric molecules", Accepted for presentation at the 1st International Conference on Mechanics of Nano, Micro and Macro Composite Structures, Torino, Italy, 18-20 June, 2012.

Thematic Session in International Conferences

Multi-scale Modeling of Graphene- and Carbon Nanotube-Reinforced Composites, Thematic Session Organizers: Nuno Silvestre and Konstantinos Tserpes, 1st International Conference on Mechanics of Nano, Micro and Macro Composite Structures, Torino, Italy, from 18 to 20 June 2012. The topics are:

Modelling and analysis of graphene and CNTs (Micromechanics, mesomechanics and nanomechanics; Molecular dynamics simulations and continuum mechanics models; Non local theories and scale effects)

Characterization of the behaviour of graphene and CNTs, including vibration and buckling

Modelling and analysis of nano-composite materials (Prediction of strength and fracture; Damage mechanics and fatigue; Multi-scale methods and modeling; Experimental testing)

CONTACTS:

Prof. Nuno Silvestre
Tel.: +351 218 418 410
E-mail: nunos@civil.ist.utl.pt

Mozambique African Rift Tomography

PTDC/CTE-GIX/103249/2008

KEY WORDS: Lithosphere; East African Rift; Plate Tectonics, Seismotectonics

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Department of Earth Sciences, University of Bristol (DESUB); Department of Geology, University of Leicester (DGUL); Direcção Nacional de Geologia de Moçambique (DNGM)

PERIOD: 01-03-2010 to 28-02-2013

FINANCING (€): 199.968 **IST/ICIST (€):** 199.968

COORDINATOR(S): João Fonseca. **RESEARCHERS AND COLLABORATORS:** Ana Margarida Ferreira; Mohamed Salah; Paulino Cristóvão Feitio; George Helffrich; Stewart Fishwick

SUMMARY

40 years after the birth of Plate Tectonics, recent developments in space geodesy continue to provide evidence for the existence of new plates. In Mozambique, 3 new microplates were recently proposed, the Victoria, Rovuma and Lwandle Plates, thus solving the long lasting mystery of the connection of the East African Rift (EAR) to the South West Indian Ridge (SWIR) in the Indian Ocean. That these late additions to the plate mosaic are in Africa is little surprise, as the African continent lags behind most regions in the planet in what concerns geodetic and seismological observations. Further north, from the Afar triple junction in Ethiopia to the East African Plateau of Uganda and west Tanzania, it has been known to geologists that the African continent is undergoing a split, with the Nubian and Somalian plates diverging along an east-west direction at a rate of about 8mm/year in the North and about 3mm/year in the South. This is the modern archetype of continental rifting, the process whereby continental land masses are torn to give to accommodate the oceans of the geological future: nearly 300 million years ago, West Iberia was rifted from Newfoundland in a similar fashion, and the North Atlantic formed in between. East Africa is one of the few places on Earth where the early stages of continental rifting can be investigated without the geological overprint of further tectonic processes.

However, while the plate tectonic significance of the EAR was understood since the 70's, a difficulty subsisted until recently: the track of the Nubia-Somalia border was lost near the northern border of Mozambique, after surrounding the East African Plateau with two arms (the eastern branch and the western branch of the EAR), and this fuelled a scientific debate over the nature of the continuation of the EAR towards the SWIR and the location of the

triple junction. This debate had fast developments in the last 5 years. Only in the last two years significant progress was made, through the analysis of larger space geodetic data, leading to the identification of the Victoria, Rovuma and Lwandle microplates and taking the extension of the EAR in a nearly North-South to join the SWIR at latitude 49 S. In February 2006, the Mw7.0 Mozambique Earthquake added a late clue to the location of the border faults of the continental rift. From the Red Sea to southern Tanzania, the structure of the lithosphere has been thoroughly investigated during the last 20 years with geophysical techniques - mainly gravity and seismic methods - to learn about the 3D structure of an active rift in different stages of evolution: young sea floor spreading in the Red Sea, continental breakup in Ethiopia, Kenya and Tanzania. Further South, however, the political instability of the last decades prevented geophysical investigations. While space based geodesy finally gathered enough data to advance a more robust model for the plate boundary running in a North-South direction through Mozambique, it is fundamental and timely to start amassing ground-based data to validate and refine the new model.

Recent work in the Gulf of California or in Etyopia are examples of the power of seismic deployments to address these issues. Mozambique is a unique place where the transition from stable craton to rifted continental crust - an unsolved geologic problem - can be investigated. The development of two microplates - Victoria and Rovuma plates - straddling the extrapolated rift axis, as suggested by the space geodetic data, is an exciting new observation, which may bear important clues to this transitional process, and assist in the interpretation of structures that are associated with old rifts.

The proposed study will complement the EAGLE project further north, where the rifting process is in a more advanced stage, and the KAAPVAAL project to the east and south, which is inside the Nubia craton and does not cover the Mesoproterozoic structures of the Mozambique Belt or the currently active structures.

As a first step towards the characterization of the 3D structure of the Mozambican sector of the plate boundary, project MOZART will deploy and operate during 24 months a network of 30 broadband stations, loaned from the SEIS-UK equipment pool. This network will provide essential data to: - the study of

the distribution of local seismicity in the region; - the mapping of crustal thickness (Moho depth) through receiver function analysis; - the study of seismic anisotropy (shear wave splitting) in the region, and causative inherited mesoproterozoic structures; - the computation of a tomographic velocity model for the crust and upper mantle in the region. The integrated analysis of these results will shed unprecedented light in the geodynamic processes that are taking place in one of the least studied - and, in view of the very latest results, one of the most interesting - portions of the Earth's lithosphere.



Seismographic station.



Old military tower converted to a seismographic station.

CONTACTS:

Prof. João Fonseca

Tel.: +351 21843212

E-mail: jfonseca@ist.utl.pt

Nonlinear Static Methods for Assessment/Design of 3D Irregular Structures

PTDC/ECM/100299/2008

KEY WORDS: Seismic assessment, Seismic Design, Nonlinear static procedures, 3D irregular structures

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-07-2009 to 30-06-2012

FINANCING (€): 199.569

IST/ICIST (€): 199.569

COORDINATOR(S): Rita Bento. **RESEARCHERS AND COLLABORATORS:** Beatriz Claudino; Carlos Bhatt; Luís Guerreiro; Mário Lopes; Rita Peres

SUMMARY

The project aims to study and evaluate the performance of a set of novel performance-based seismic design and assessment procedures to 3D irregular structures. It will also focus on the development of next-generation related procedures and guidelines. This project builds upon the previous FCT research project POCI/ECM/59306/2004 which ended up with the organization of an International Workshop on Nonlinear Static Methods for Design/Assessment of 3D structures (<http://www.3dpushover.org/>). One of the main objectives of proposal is to improve the results obtained and to develop the recommendations proposed in the abovementioned Workshop. Twelve famous researchers on the topic from different countries were invited. Names like Anil Chopra, Peter Fajfar, Helmut Krawinkler, Rakesh Goel, Stavros Anagnostopoulos, Andreas Kappos, amongst others, contributed to the high quality of the presented papers, to the lively and fruitful discussions that followed and to the substantial and objectives recommendations produced.

The project aims to verify and improve the recommendations outlined in that meeting taking a further step on the 3D Pushover problem. The positive outcome from recent research seems to indicate that it is certainly worthy to continue to pursue the further development and/or verification of NSP, with the objective of arriving at an eventual introduction in seismic design codes and regulations of such procedures, which are, in general, lacking. Nonlinear Static Procedures (NSPs) can be integrated in a Performance Based Seismic Design philosophy. It is generally recognized that structures designed within these deformation-based criteria, using Performance-Based Design Procedures, are most likely to behave

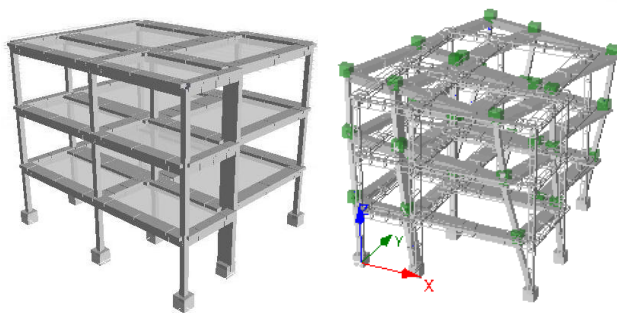
sensibly in seismic scenarios. It is also widely accepted that performance criteria can be better controlled by evaluating the deformations in the structure, both at global and component levels. The Nonlinear Static Procedures (NSP) raised in this context are a powerful tool for performance evaluation. Seismic design codes, like the FEMA-273, FEMA-356, FEMA-440 and the ATC-40, have recommended the use of this type of procedures.

More recently, the Eurocode8 (EC8-CEN, 2004) also incorporated the procedure as an evaluation technique. However, some issues still need to be clarified regarding the format with which the pushover analysis has to be performed, thus requiring further research and development. The employment of NSP in the seismic assessment or design of structures has gained considerable popularity in recent years, backed by a large number of extensive verification studies that have demonstrated its relatively good accuracy in estimating the seismic response of regular structures. However, the extension of such use to the case of 3D irregular structures has been the object of only restricted scrutiny, which effectively ends up by limiting significantly the employment of NSP to assess actual existing structures, the majority of which do tend to be non-regular. In addition, such few studies have typically concentrated on the application and verification of a single NSP approach, thus not providing useful elements of comparison between the different available methodologies. The existence of a national research group to work in this topic, closely following and influencing the latest and most relevant improvements in the subject, seems of obvious importance. Moreover, it must also be able to cooperate and contribute at an international level in the framework of this research domain.

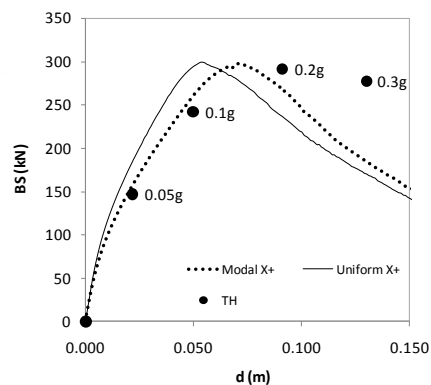
Adequate international cooperation has been ensured, for Anil Chopra (University of California, Berkeley), Rakesh Goel (California Polytechnic State University, San Luis Obispo), Peter Fajfar (University of Ljubljana, Slovenia) and Rui Pinho (University of Pavia, Italy) have been invited and accepted to become consultants for this research project. One of the aims of the project is to assess the performance of the ACSM (Adaptive Capacity Spectrum Method) in 3D irregular buildings. Suggestions will be made to overcome the specificities of this kind of structures. This method will be compared with other proposed NSP and it is expected to better estimate the seismic response of irregular 3D

structures. Recent studies on the well known SPEAR building developed by Pinho et al. seem to grant some validity in employing pushover analysis in the context of performance-based seismic assessment of 3D irregular buildings, in particular the ACSM. They also seem to be in-line with similar studies carried out by Rui Pinho and his team for plane frames (Pinho et al., 2008b) and bridges.

Nonetheless, given the preliminary nature of these studies, it is obviously advocated that additional work considering different 3D buildings must be carried out before any definitive conclusions and recommendations might be made.



3D model of a three storey building



Capacity curve of a three storey building

DELIVERABLES

Papers in international journals

Bento R., Bhatt C. 2010: "Using Nonlinear Static Procedures for Seismic Assessment of the 3D Irregular SPEAR Building", *Earthquake and Structures (EAS)*, An International Journal, Techno-Press, Editors-in-Chief: Stavros Anagnostopoulos (European ed.), Izuru Takewaki (Asia-Pacific ed.), Jerome P. Lynch (American ed.), Vol 1, Nº 2, 177-195.

Bhatt C., Bento R. 2011: "Extension of the CSM-FEMA440 to Plan-Asymmetric Real Building Structures", *Journal of Earthquake Engineering and Structural Dynamics*, John Wiley & Sons., Vol. 40, Issue 7. Publicado online em Wiley Online Library (DOI: 10.1002/eqe.1087).

Bhatt C., Bento R. 2011: "Assessing the Torsional Response of Existing RC Building using the Extended N2 Method", *Bulletin of Earthquake Engineering*, A. Ansal editor, Springer The Netherlands Publisher. Publicado online em Springer Science+Business Media B.V. (DOI: 10.1007/s10518-011-9252-8).

Papers in international conferences

Bhatt C., Bento R. e Pinho R. 2010: "Verification of Nonlinear Static Procedures for a 3D Plan-Irregular Building in Turkey", *Proceedings of the 14th European*

Conference on Earthquake Engineering (14ECEE), Ohrid, República da Macedónia.

Massena B., Bento R. e Degée H. 2010: "Consequences of Design Choices in Direct Displacement Based Design of Reinforced Concrete Frames", *Proceedings of the 14th European Conference on Earthquake Engineering (14ECEE)*, Ohrid, República da Macedónia.

Bhatt C., Bento R. e Pinho R. 2010: "Assessing a real 3D Turkish RC Building using Nonlinear Static Procedures", *Proceedings of the 9th National and 10th Canadian Conference on Earthquake Engineering*, Toronto, Canadá.

Bhatt C., Bento R. 2011: "Nonlinear Static Procedures on the Seismic Assessment of Existing Plan Asymmetric Buildings", *Proceedings of the 2011 World Congress on Advances in Structural Engineering and Mechanics (ASEM11plus)*, South Korea.

Bhatt C., Bento R. 2011: "Estimating Torsional Demands in Plan Irregular Buildings Using Pushover Procedures Coupled with Linear Dynamic Response Spectrum Analysis", *Proceedings of the 6th European Workshop on the Seismic Behaviour of Irregular and Complex Structures (6EWICS)*, Haifa, Israel.

Papers in national conferences

Bento R., Bhatt C. 2010: "Análise Estática Não Linear de um Edifício na Turquia - Regulamentos Americanos vs. Eurocódigo 8", Sísmica 2010, 8º Congresso Nacional de Sismologia e Engenharia Sísmica, Aveiro, Portugal.

Bento R., Bhatt C. 2010: "Avaliação Sísmica de um edifício Irregular em Planta - Extensão N2 vs. N2

Original", Sísmica 2010, 8º Congresso Nacional de Sismologia e Engenharia Sísmica, Aveiro, Portugal.

Massena B., Bento R., Degée H. 2010: "Implications of different Design Assumptions in Direct Based Design of RC Frames", Sísmica 2010, 8º Congresso Nacional de Sismologia e Engenharia Sísmica, Aveiro, Portugal.

CONTACTS:

Prof. Rita Bento

Tel.: +351 218 418 210

E-mail: rbento@civil.ist.utl.pt

Performance-based Seismic Design Procedures

POCI/ECM/59306/2004

KEY WORDS: Performance Based Seismic Design; Non linear Static Analyses; Displacement Based Design; Pushover Analyses

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-01-2007 to 31-12-2008

FINANCING (€): 90.000

IST/ICIST (€): 90.000

COORDINATOR(S): Rita Bento. **RESEARCHERS AND COLLABORATORS:** André Ramos Barbosa; Filipe Manuel Mendes Rodrigues; Jorge Miguel Silveira Filipe Mascarenhas Proença; Mário Manuel Paisana dos Santos Lopes

SUMMARY

The project aims to study a set of novel performance-based seismic design and assessment procedures and to help in the development of next-generation related procedures and guidelines. In recent years it has been generally conceived that structures designed conforming to a particular deformation-based criteria, using Performance-Based Design Procedures, are most likely to behave sensibly in seismic scenarios. It is also widely accepted that performance objectives, set using these design procedures, can be best achieved by controlling the deformations in the structure, both at global and component levels.

In this context, the Non-Linear Static Analysis, in the form of Pushover Analysis, has emerged as a strong contender for performance evaluation. It is sometimes used to design new buildings despite of not being really intended for that purpose. Modern design codes, like the FEMA-273 (1997), FEMA-356 (2000) and the ATC-40 (1996), have recommended the use of this procedure as a tool for design and performance evaluation. Recently, the Eurocode 8 (EC8-CEN 2003) also incorporated the procedure as an evaluation technique. However, consensus still needs to be reached regarding the format with which the pushover analysis has to be used. Moreover, there are some unresolved issues that need to be addressed, thus requiring further research and development.

Besides the non-linear static analysis - and still based on Performance-Based Design concepts -, a technique used to initiate the design process by imposing an initial damage state, called the Displacement-Based

Design (DBD), was also developed. The DBD procedure can be considered as a step-by-step technique, in which damage - expressing a limit - is used to evaluate internal forces demand and, finally, the structures performance evaluation. This procedure will also be used in building and bridge structures.

Today, there are a certain number of key questions that must be considered when addressing the Performance-Based Seismic Design and Assessment Procedures. It is very important that a national research group works in this topic, closely following the latest and most relevant improvements in the subject and be able to cooperate and contribute at international level in the framework of this research domain.

The main purpose of the project is to define precisely and analyse the different steps of the Non-linear Static Analyses, attempting to identify and overcome the limitations of the methods, while defining a new version more adequate for design purposes. The project starts with the survey of the existing Performance-Based Design Procedures, summarizing the various difficulties encountered in the available methods and proposing ways to overcome them. Moreover, and regarding the Non-linear Static Analyses developed mainly for seismic evaluation and upgrade of existing structures, some additional research will be done aiming at proposing a new version to be used to design new structures. The DBD procedure will also be applied in building and bridge structures.

CONTACTS:

Prof. Rita Bento Tel.: +351 218 418 210 E-mail: rbento@civil.ist.utl.pt

REABEPA - Structural rehabilitation of masonry walls in old buildings

PTDC/ECM/100168/2008

KEY WORDS: Building rehabilitation; Seismic rehabilitation; Walls; Masonry

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Institute for Sustainability and Innovation in Structural Engineering (ISISE); Laboratório Nacional de Engenharia Civil (LNEC)

PERIOD: 01-10-2009 to 30-09-2011

FINANCING (€): 199.548 **IST/ICIST (€):** 103.320

COORDINATOR(S): Fernando Branco. **RESEARCHERS AND COLLABORATORS:** Alfredo Costa; António Gago; Daniel Oliveira; Ema Coelho; Graça Vasconcelos; João Roque; João Ferreira ; João Correia; Jorge Proença; Luís Guerreiro; Miguel Branco; Paulo Lourenço

SUMMARY

After the large destruction of Lisbon due to the 1755 earthquake, the city had to be almost completely rebuilt. The innovative “pombaline” buildings were then developed. This type of building is characterized by its structural interior “frontal” walls in elevated floors, constituted by a timber frame (“cage”) with vertical and horizontal elements, braced with X elements (Sant Andrew’s crosses) with a masonry infill. These timber elements were connected to the floors’ structure, forming a three-dimensional timber frame with improved stiffness and deformation capacity under seismic actions. Most of these buildings presently need to undergo seismic rehabilitation due to the following reasons: (i) its natural degradation with time; (ii) the need for adaptation to the present serviceability conditions, generally involving structural changes; (iii) former interventions with elimination or damaging of structural elements, affecting seismic resistance; (iv) the noncompliance with the new generation of seismic codes.

Due to the lack of specific codes, seismic rehabilitation is usually carried out based on empiric rules, essentially depending on expertise and experience of designers and contractors. The lack of knowledge on the walls seismic behaviour and on the effect of possible reinforcing solutions led to the absence of design procedures for seismic rehabilitation that could be universally accepted. The main objective of this project is to contribute to the development of knowledge in the area of seismic rehabilitation and reinforcement of old buildings, as a base for a better supported and more efficient design and construction practices. The achievement of the referred objective will involve: - Experimental tests to assess the in-plane seismic behaviour of “frontal” walls and to evaluate the effect of its components (timber frame, masonry, render), allowing for more thorough rehabilitation

projects, based on realistic parameters for the existent structure. - Experimental evaluation of the adequacy and efficacy of the four innovative seismic rehabilitation methods to be proposed based on: viscous dampers (VD); shape memory alloys (SMA); textile reinforced mortar (TRM) and steel reinforced polymer (SRP). - Development of numerical models, calibrated with the experimental results, to be used in seismic rehabilitation design of old buildings’ walls. Research approach and methods

The proposed research programme will involve the performance of experimental tests and the development of numerical models. Experimental tests aim to evaluate the actual performance of cage walls and to understand the role of their constitutive elements – timber frame, masonry, render – on the global behaviour. Besides, experimental tests will allow assessing the effect of the reinforcing proposed solutions on the seismic behaviour of such walls. The experimental campaign will include both monotonic and cyclic tests in quasi-static regime in order to allow identifying all phenomena involved in the behaviour of the tested elements. Tests on a 3D shaking table will also be carried out in order to evaluate the simple and reinforced walls’ behaviour under actual dynamic loading. The numerical models to be developed will constitute a design tool to evaluate the behaviour of non-reinforced walls and to design their reinforcing solutions.

The main innovative aspects of the proposed research programme are related to the: (i) seismic reinforcement solutions; (ii) experimental evaluation techniques of cage walls and to the (iii) numerical models to be developed. The innovative seismic reinforcing solutions proposed present important advantages in terms of ductility, energy dissipation capacity and resistance to seismic loads. Regarding the

experimental evaluation techniques of cage walls, the main innovation consists on the testing of specimens following the execution sequence (1st: timber frame; 2nd: timber frame + masonry; 3rd: timber frame + masonry + render), allowing evaluating the role of each constitutive element on the global behaviour of cage walls. The main innovation regarding numerical modelling is the multi-parametric macro-element to be developed that will allow reproducing the global behaviour of simple or reinforced wall panels with low



Cyclic test of a timber-masonry wall with an elastic-plastic dissipative device

computational effort. The design manual to be developed will provide the tools to implement the application of these innovations.

The main results to obtain in this research project are: i) Development of innovative seismic reinforcing techniques for old buildings; ii) Numerical models for simulation of cage walls behaviour, either simple or with the proposed reinforcement solutions; iii) Design manual for dimensioning of the proposed seismic reinforcing solutions.



Cyclic test of an ordinary timber-masonry wall

DELIVERABLES

Papers in Internacional Journals

“Timbered masonry for earthquake resistance in Europe./Mampostería con madera sismorresistente en Europa” A. Dutu, J. Gomes Ferreira (b), L. Guerreiro(b), F. Branco(b), A. M. Gonçalves(b), *Materiales de Construcción*, Accepted for publication in June de 2011

“Experimental evaluation of the behavior of timber-masonry walls” (in portuguese: “Avaliação experimental do comportamento de paredes de edifícios pombalinos.”), Ana Gonçalves, João Gomes Ferreira, Luís Guerreiro, Fernando Branco, *Internacional Construlink Journal*, n.º 27, Vol. 9, July 2011

CONTACTS:

Prof. Fernando Branco
Tel.: +351 218 418 230
E-mail: fbranco@civil.ist.utl.pt

RETURN - Rare Earthquake and Tsunami Recurrence

PTDC/CTE-GIN/67367/2006

KEY WORDS: Hazard, Earthquake, tsunami, recurrency

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-04-2007 to 31-12-2011

FINANCING (€): 199.987 **IST/ICIST (€):** 199.987

COORDINATOR(S): João Fonseca

RESEARCHERS AND COLLABORATORS: Ana Paula Flor; Carlos Sousa Oliveira; João Matos; Sandra Heleno da Silva; Susana Pires Vilanova; Paula Marques de Figueiredo; Pedro Miranda da Costa; João Cardoso Cabral; Martitia Tuttle; Stella Kortekaas; Thomas Rockwell

SUMMARY

Seismic hazard in Mainland Portugal results mainly from two contributions: a) Very large and (probably) very rare earthquakes offshore, possibly tsunamigenic like the M8.5 1755 earthquake, and b) rare, moderate to large earthquakes onshore, such as the M7 Lisbon 1531 earthquake or the M6.3 1909 Benavente Earthquake. Any well constrained seismic hazard assessment will require the evaluation of the relative importance of these two contributions. Historical records, albeit important, are clearly insufficient to fully characterize earthquake occurrence in Portugal. Seismic hazard assessment, both probabilistic and deterministic, rely ultimately on the characterization of seismic occurrence at a site. In both approaches it is commonly found that the hazard is dominated by large and rare events, often not captured by the historical record.

Concerning seismic activity onshore (Work Package 1), Project RETURN will use the tools of Active Tectonics and Paleoseismology to improve the understanding of seismogenic processes, targeting two seismically active areas: NE Portugal (the Vilarica and Régua Faults) and the LTV region (LTV Fault System). In NE Portugal, aerial photos will be used to study the geomorphology and identify geologically recent deformation, such as fresh scarps, anomalous drainage patterns, laterally offset streams, or displaced fluvial terraces. An estimated number of 10 trenches will be dug at selected sites for detailed analysis of the recent deformation. Special attention will be given to the estimate of mean slip rates, earthquake return periods, and fault segmentation. While trenching has already identified good indicators of tectonic deformation in the LTV region (POCTI Project TAGUS2, PI J. Fonseca), a final interpretation

requires insight on the geological structure at deeper levels (a few hundred meters), through geophysical prospecting, to discriminate erosional and gravity-driven features, on one side, from indicators of tectonic activity, on the other. With the guidance provided by the geophysical exploration, additional trenches will be opened and investigated. In parallel, Paleotsunami research along the Portuguese coast (Work Package 2) will improve our knowledge about past tsunamigenic earthquakes that affected Portugal, and respective return period(s). Published results concern only tsunami deposits of the Lisbon 1755 earthquake, in Boca do Rio, Martinhal and Lagoa de Óbidos. Similar tsunamigenic earthquakes in the Holocene and Upper Pleistocene should have left comparable traces in the sediment record and geomorphological features of the coast. An inductive approach will be taken, i.e., sediments and geomorphology will be studied at favourably located sites irrespective of historical accounts of tsunami inundation.

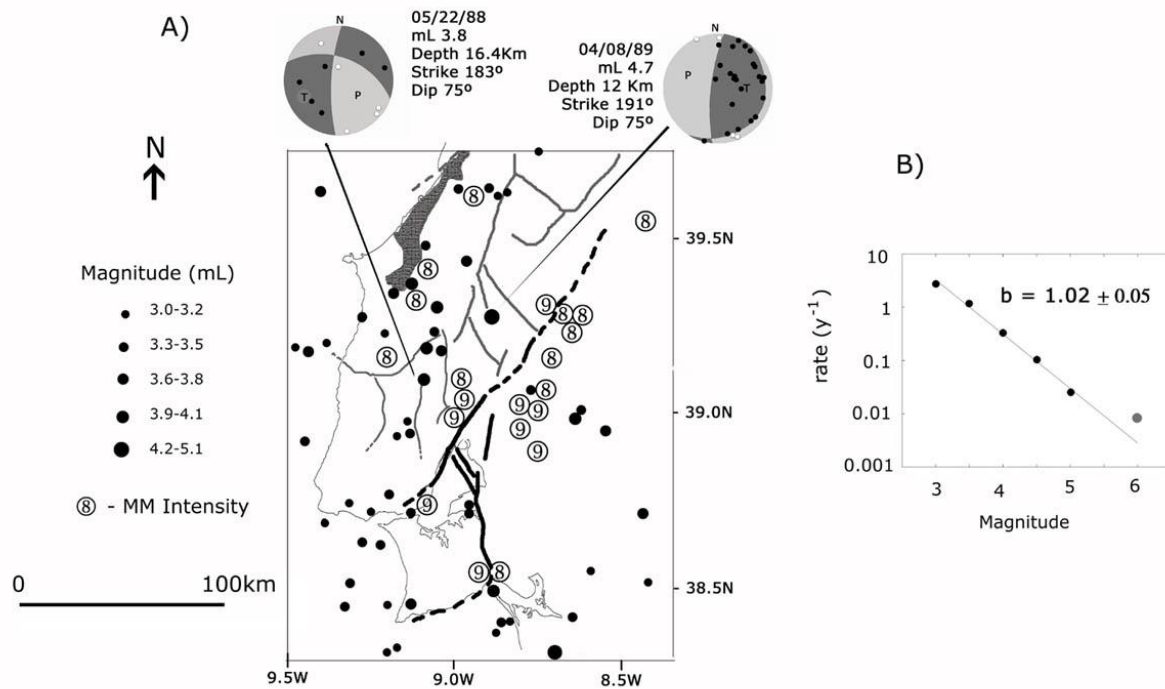
Together, Work Packages 1 and 2 aim at more accurate estimates of seismic hazard assessment. The relative importance of onshore and offshore sources will be better quantified. This has implications for earthquake engineering, since the two scenarios lead to different frequency contents of ground motion.

As a third vector (Work Package 3) Project RETURN will use ground deformation monitoring techniques (continuous GPS, InSAR, PSInSAR) to characterize ongoing ground deformation in the Lower Tagus Valley and to assess its significance for earthquake forecasting. Using radar images acquired by ERS-1 and ERS-2 satellites from 1993 to 2001 as part of the ESA GMES TERRAFIRMA Project, it was possible to detect

the uplift of a ridge on the NW bank of the Tagus River at a rate of about 1 mm/year. The uplift was confirmed by re-surveying old geodetic lines and comparing with old surveys (Project TAGUS2, PI J. Fonseca). Of particular interest was the observation that the strain rate is accelerating in the last few years. According to Scholz (2002), "it is of the nature of rock fracture and friction that the breakdown instability does not occur without some preceding phase of accelerated deformation".

Furthermore, microearthquake activity detected by the National Seismic Network has a minimum near the

deforming area, a pattern (the "Mogi doughnut") that has been reported elsewhere before large earthquakes. The current low level of micro-earthquake activity of the Lower Tagus Valley, in association with the observed acceleration of ground deformation, may therefore have a precursory meaning. The large stress drop associated with intraplate (hence longer return period) earthquakes may favour the use of ground deformation as an intermediate-term earthquake precursor.



Seismicity of the Lower Tagus Valley and surrounding region. The instrumental data correspond to the period 1961–2001 (source: IM, Lisbon). Modified Mercalli intensity data (circles with numbers) correspond to the M7 Vila Franca earthquake of 1531 (Justo and Salwa, 1998), the M6.3 Benavente earthquake of 1909 (Moreira, 1984) and the M7.1 Setúbal earthquake of 1858 (Moreira, 1984). The lower-hemisphere focal mechanisms correspond to the 16 km-deep ML3.8 earthquake of 22 May 1988 on the left (Fonseca, 1989) and to the 12 km-deep M L4.7

earthquake of 8 April 1989 on the right (Borges et al., 2001). B) Gutenberg-Richter relation for the seismicity depicted in A, showing the annual rate of events that exceed a specified magnitude. Cumulative rates for magnitudes in the range $3 < M < 6$ are estimated over a time interval of 41 yrs (1961–2000), and for magnitude 6 the time interval is 472 yrs (1531 to present). The moderate to large historical events ($M > 6$) deviate from the extrapolation of the weak seismicity, possibly indicating a characteristic behaviour.

CONTACTS:

Prof. João Fonseca
 Tel.: +351 218 417 535
 E-mail: jfonseca@ist.utl.pt

RIVERSAR - Exploiting SAR imagery to improve floodplain inundation models in the Tagus River

PTDC/CTE-GIX/099085/2008

KEY WORDS:

Synthetic Aperture Radar, River, Flood, Modeling

PROMOTING INSTITUTION(S):

IST-ICIST

PARTNER INSTITUTION(S): Administração da Região Hidrográfica do Tejo, I.P. (ARH); Laboratório Nacional de Engenharia Civil (LNEC); Centro de Estudos de Hidrosistemas (CEHIDRO/IST/UTL); Instituto de Sistemas e Robótica - Lisboa (ISR Lisboa/IST/UTL)

PERIOD: 01-10-2010 to 01-10-2013

FINANCING (€): 137.000 € **IST/ICIST (€):** 137.000 €

COORDINATOR(S): Sandra Heleno Silva

RESEARCHERS AND COLLABORATORS: Sandra Heleno Silva; Alexandre Gonçalves; Ana Fonseca; Ana Paula Flor; António Trigo Teixeira; Fernanda Néry; João Hipólito; Maria Silveira; Maria Vieira; Maria Rodrigues; Rodrigo Oliveira; Rui Ferreira

SUMMARY

Floods are one of the most deadly natural hazards worldwide, and by far the deadliest in Portugal in the last 100 years. The Lower Tagus (LT) River is the place where the largest floods occur in Portugal, in terms of inundated area. Floods are extremely frequent in this region, covering most of the floodplain every 2.5 years in average. In the last 40 years, 4 floods in the Tagus resulted in human deaths. Flood hydraulic models play a central role in urban planning, dam engineering design, floodplain management, and hazard evaluation studies. Consequently, the full grasp of the uncertainty in the modeling process is of paramount importance. RIVERSAR will focus on floodplain inundation models in areas pertaining to the LT River, and addresses the problem of assessing and reducing their inevitable uncertainty. Floodplain flow is usually tackled with 2D or 1D models, but given that for flood risk management computational efficiency is crucial, 1D models are the basis of most commercial hydraulic modeling software.

Actually, it has been shown that given the uncertainties affecting the simulation process, more complex models don't necessarily perform better, and instead the calibration of model parameters (typically floodplain and channel roughness) is the key procedure to improve the predictive performance of the flood simulation. Flood extent maps that are derived from satellite-born Synthetic Aperture Radar (SAR) sensors can provide the spatially distributed

data needed for validation of hydraulic models of river flood flow and have the advantage of working in all-weather conditions, as opposed to visible band sensors. SAR images may also be used to identify braided river reaches that frequently accommodate wetland vegetation, and whose evolution may be indicative of changes in the river sediment supply. In flood mapping applications, the ability to image the Earth surface through clouds is, of course, of critical importance, since flooding usually occurs in association with heavy rain.

From the late 1990s and recently, SAR imagery has been exploited towards the goal of reducing flood prediction uncertainties, but the relatively large number of degrees of freedom in the models allowed for different modeling approaches, input data and parameterization data to fit equally well insufficient validation data]. There is a call for the "major logistical exercise" of compiling high-resolution inundation extent validation datasets, supplemented by hydrometric records. Some effort has follow to expand the number of SAR-derived maps used in calibration but these have been more opportunistic rather than systematic exercises. The extremely high frequency of flooding in the Lower Tagus River, coupled with the large inundation extents observed, make it a good pilot region for such a data-driven, systematic calibration work.

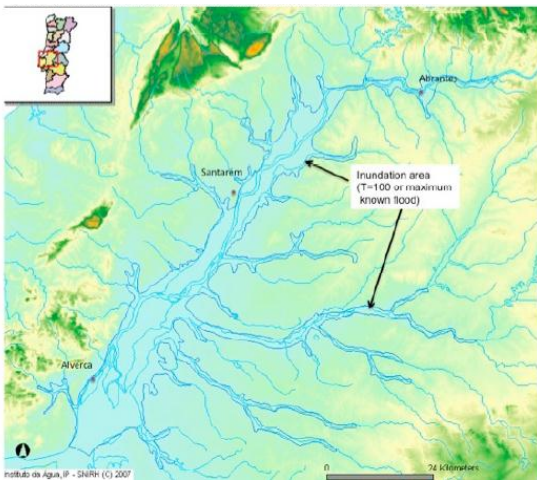
We thus propose to compile historical (1992-2008) satellite-borne SAR imagery (supplemented with hydraulic ground-based data) of past inundation events in the LT River, to derive flood extent georeferenced maps for retrospective and systematic validation of 1D and 2D hydraulic flood models. From a quick non-systematic inspection for some periods for which flooding was reported by civil protection agencies, we have already found SAR images documenting several floods in the Lower Tagus River. We propose to build the full dataset of SAR amplitude imagery for the LT River, resorting primarily to ESA's catalogue. For relevant flooding events, other providers (SAR or multispectral) will also contribute with images. Stage and discharge data from several gauging stations in the river will also be compiled. Then separation between water and land regions (for both "flood" and "base flow" categories of images) will

be achieved through "in-house" semi-automated methods developed by the project team.

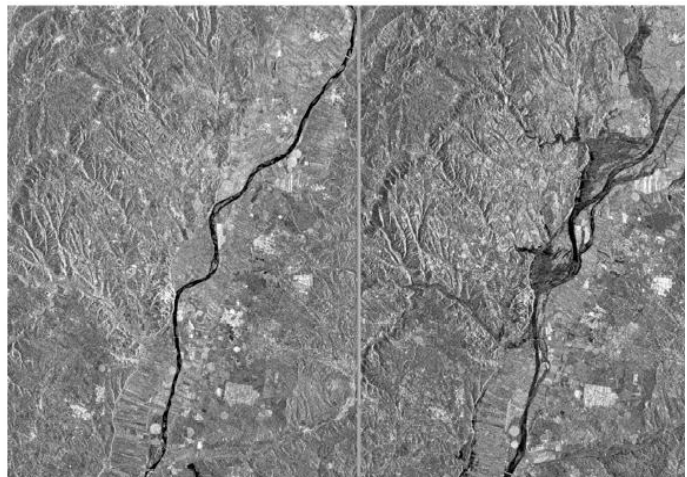
State-of-the-art commercial supervised algorithms will assess the performance and accuracy of the automated codes. Validation against the derived flood-extent maps will allow calibration of 1D and 2D hydraulic models, both commercial (widely used) software, and models developed by the project team.

We expect that this methodology will allow us to distinguish between competing modelling approaches. A more regional-scale, user-oriented result will be the production of flood extent and flood depth maps, georeferenced onto topographic maps, and overlaid onto land-use information.

Finally, the extensive dataset of SAR imagery collected will allow us to investigate the recent morphological evolution of the LT River, a region impacted by failing sediment supply.



Floodplain and inundated area during the 1979 flood (SNIRH data, 2007).



SAR images acquired before and during the 1997 flood near Santarém.

CONTACTS:

Inv. Sandra Heleno da Silva

Tel.: +351 218 418 330

E-mail: sandra.heleno@ist.utl.pt

SAFE_PC - Safety of Precast Structures: General Design, Connections and Seismic Behaviour

POCI/ECM/61017/2004

KEY WORDS: Precast Structures; Connections; Seismic action; Time effects

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Fundação da Faculdade de Ciências e Tecnologia (FFCT/FCT/UNL)

PERIOD: 01-01-2005 to 31-12-2007

FINANCING (€): 90.000

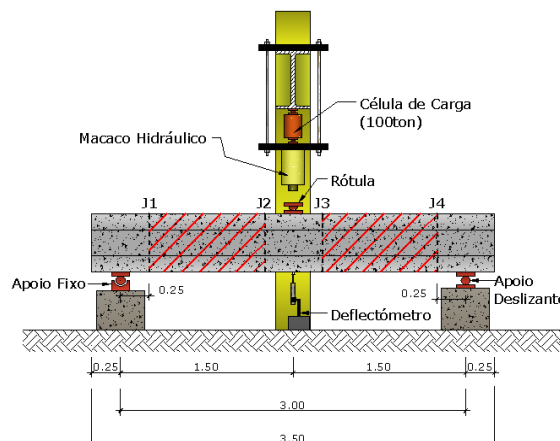
IST/ICIST (€): 90.000

COORDINATOR(S): José Câmara. **RESEARCHERS AND COLLABORATORS:** António Manuel Pinho Ramos; Jorge Miguel Silveira Filipe Mascarenhas Proença; Valter José da Guia Lúcio

SUMMARY

Precast structures in Portugal are becoming an increasingly attractive alternative to cast-in-situ RC structures. This competitiveness increase can be explained by the advantages inherent to the technological process. This argument has been supplemented by new ones, such as: it is easier to implement quality control procedures, and the environmental impact is reduced. The activities are located mostly within industrial environments with less "in situ" impact and there is also more potential for concrete recycling. New solutions for connections between precast elements are to be tested and studied. It is known that the potential for the practical use of precast solutions depends on the construction efficiency, in particular of the connections, and of its structural behaviour. From this point of view it is expected to rationalize the construction procedure with the stress variations with time, in order to improve efficiency on the design of these structures. The study of the efficiency of these connections for

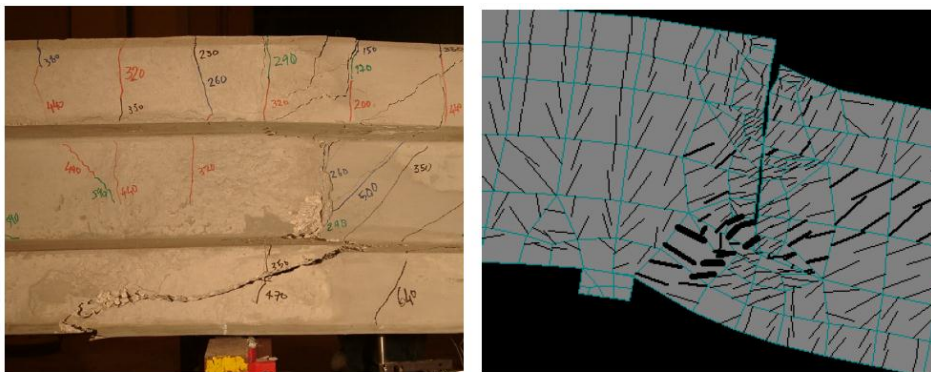
cyclic seismic actions is also envisaged. The connections over the supports in bridges and of columns to beams or slabs in buildings are to be studied, as well as the behaviour of hollow-core slabs. For these type of solution, the effects of in plane seismic forces with the mobilization of the diaphragm effect, and of concentrated vertical forces, are to be investigated. Two main Portuguese civil engineering research units are together in this project. The knowledge interchange of the results of this project, with the national and international professional and scientific community, will be ensured with the interchange with members of the Commission 6 - Prefabrication, and of the Working Group 1.1.3 - Design Examples for the Application of Strut and Tie Models da fib - fédération internationale du béton, organisation that co-ordinates the international research on concrete structures, to come to Portugal as consultants and co-operate in the research.



Modelos dos ensaios experimentais com simulação de juntas de pré-fabricação



Execução das vigas com construção por fases



Comportamento experimental e analítico das juntas de pré-fabricação

CONTACTS:

Prof. José Câmara
Tel.: +351 218418256

E-mail: jcamara@civil.ist.utl.pt

SANDWICHE - Rehabilitation of Building Floors with Lightweight High Performance GFRP Sandwich Panels

PTDC-ECM/113041/2009

KEY WORDS: GFRP - Glass Fibre Reinforced Polymers; Sandwich panels; Floors; Building rehabilitation

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): ALTO, Perfis Pultrudidos, Lda. (ALTO); Universidade do Minho (UM); Institute for Sustainability and Innovation in Structural Engineering (ISISE); Instituto de Polímeros e Compósitos (IPC/UM)

PERIOD: 01-03-2011 to 28-02-2014

FINANCING (€): 199.896 **IST/ICIST (€):** 105.552

COORDINATOR(S): Fernando Branco. **RESEARCHERS AND COLLABORATORS:** Albano Sousa; Ferrie van Hattum; João Ferreira; João Gil Nunes; João Correia; Joaquim Barros; José Sena Cruz; Maria Cristina Matos Silva; Maria da Glória Gomes; Salvador Dias; Vítor Cunha

SUMMARY

This project addresses the development of innovative sandwich panels for the replacement of degraded building floors, providing an easy solution for their rehabilitation. Prototypes of glass fibre reinforced polymer (GFRP) and hybrid GFRP-ECC (engineered cementitious composites) sandwich panels will be produced by an innovative vacuum infusion (VI) process and their mechanical behaviour and thermal and acoustic performances will be studied. Motivation Old masonry buildings usually exhibit timber-joisted floors that often need to be replaced. Rehabilitation with traditional materials introduces significant dead loads in constructions, increasing their seismic vulnerability, and poses constructive problems associated to transport, elevation and placement operations in narrow accesses. Fibre reinforced polymer materials (FRPs), including GFRP sandwich panels, present several advantages over traditional materials, namely their high mechanical performance, lightness, insulation properties, low maintenance, durability and increasingly competitive costs. These characteristics are particularly relevant for building rehabilitation, since the use of FRPs may avoid the need of elevation devices and introduce much less dead loads.

The research team has significant and relevant know-how in the subject of this project (see section 3.2.1). Team members from IST specialized in the behaviour of GFRPs and fibre reinforced concrete (FRC), being actively involved in international committees (IASBE; IIFC). IST team developed a vast expertise on the degradation, inspection and rehabilitation of old buildings, and includes experts on building physics. Team members from UM-ISISE have a strong background on FRC structures and structural

rehabilitation with FRPs, having a wide participation in international committees (ACI; fib). The group has also relevant expertise on numerical modelling, with some members having co-authored the FEMIX computer program. The UM-IPC team includes experts on composites engineering, with a strong background in composites manufacturing processes, material and process modelling and product development. The industrial partner of this project (ALTO) has vast experience in the development and manufacturing of composite materials.

Standard GFRP sandwich panels with rigid polyurethane (PU) foam are cost competitive, but their mechanical properties, in particular the shear strength of the core and the top skin susceptibility to buckling, may not be adequate for the envisaged application (building floors with spans of 4-5 m). The sandwich panels to be developed within this project will use rigid PU foam as core material, but featuring two innovative types of reinforcement: (i) a 3D network of fibreglass stitches, connecting the skins; and (ii) a grid of GFRP ribs. Both solutions are expected to increase the shear stiffness and strength of the core, simultaneously increasing the top skin buckling resistance. The GFRP skins will be produced using the innovative VI process, which guarantees better material homogeneity and much lower fabrication costs when compared with traditional techniques. An innovative GFRP-ECC hybrid solution will also be developed, with a GFRP laminate on the bottom tension skin, where it performs best, and an ECC layer on the top compression skin, preventing the occurrence of buckling phenomena, providing a ductile behaviour and allowing for an easy application of floor cover materials.

The research programme includes: (i) preliminary design and optimized manufacturing of GFRP and GFRP-ECC sandwich panels prototypes; (ii) extensive mechanical testing of panel prototypes, for both vertical and seismic loading; (iii) mechanical testing of connections between adjacent panels and panels to supporting elements; (iv) development of analytical and numerical models for structural design; and (v) experimental and numerical evaluation of thermal and acoustic performance. Expected results Innovative and improved GFRP and hybrid GFRP-ECC sandwich panels will be developed for the rehabilitation of degraded building floors, making use of their important advantages when compared with traditional solutions, in terms of structural/seismic performance, lightness,

durability, thermal insulation and low maintenance. The numerical models to be developed, calibrated with results of experiments, will allow simulating the mechanical behaviour of sandwich panels with arbitrary architecture and evaluating their acoustic and thermal performance, thereby constituting an important design tool. A user's manual will be prepared, providing design methods/rules and establishing the construction procedures and technical specifications for the installation of the developed solutions.

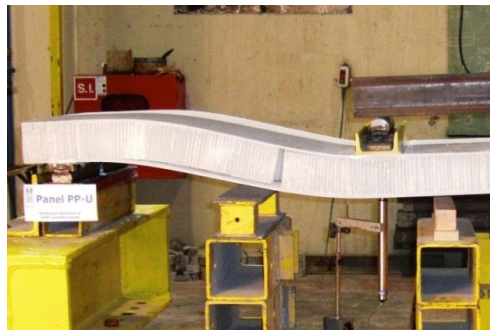
This project results from the revision of a previous application (PTDC/ECM/100819/2008), in which the comments from the evaluation panel were taken into account.



Flexural tests on sandwich panel: test setup.



Flexural tests on sandwich panel: shear failure in polyurethane core.



Flexural tests on sandwich panel: shear failure in polypropylene honeycomb core.

DELIVERABLES

Proceedings in International Conferences

J.R. Correia, F.A. Branco, J.A. Gonilha, D. Ferreira, L. Reis, "GFRP sandwich panels for civil engineering structural applications", 5th International Conference on Advanced Computational Engineering and Experimenting (ACE-X2011), (CD-ROM, paper 126, pages 50-51), Vilamoura, July 2011.

Internal Reports

M. Garrido, J.R. Correia, F.A. Branco, "Preliminary structural design of GFRP sandwich panels for applications in building floors", Relatório IST-1-1, Tarefa 1 do projecto PTDC/ECM/113041/2009, Outubro de 2011.

CONTACTS:

Prof. Fernando Branco
Tel.: +351 218 418 230
E-mail: fbranco@civil.ist.utl.pt

SCENE - Site Condition Evaluation for National Seismic Hazard Estimation

PTDC/CTE-GIX/103032/2008

KEY WORDS: Site-condition, Seismic-hazard, shear-wave-velocity, strong-motion

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Faculdade de Ciências e Tecnologia da Universidade de Coimbra (FCT/UC); Instituto Nacional de Engenharia, Tecnologia e Inovação (INETI); Instituto Pedro Nunes (IPN); Centro de Geociências (CG/FCT/UC); Centro de Geofísica (CG/FCT/UC)

PERIOD: 01-01-2010 to 01-01-2013

FINANCING (€): 124.344 € **IST/ICIST (€):** 101.662 €

COORDINATOR(S): Susana Vilanova. **RESEARCHERS AND COLLABORATORS:** Ana Paula Flor; Carlos Oliveira; Eliza Nemser; Glenda Besana-Ostman; Isabel Lopes; Jaime Santos; João Fonseca; João Carvalho; Mário Ferreira; Susana Custódio; Carlos Pinto; Jaime Rego; Manuel Caneiras.

SUMMARY

Probabilistic Seismic Hazard Analysis is a widespread methodology to evaluate the seismic hazard at a site. In contrast with deterministic studies, for which ground motion is calculated for a particular earthquake at a given distance from the site, the probabilistic approach accounts for all potentially damaging earthquakes in a region, and provides the probability that a specific level of a ground motion parameter is reached during a given time span. Seismic hazard maps, as spatial representations of ground motions for fixed probability levels, are essential tools to address land-use planning, engineering design and ultimately seismic risk mitigation. However, due to the important role played by site-conditions, a seismic hazard map produced for uniform site conditions, in particular in what concerns low frequencies, can be misleading in identifying areas with higher degrees of susceptibility due to earthquake effects. The inclusion of site-specific conditions in a regional sense is therefore important to adequately represent the seismic hazard.

Measuring and mapping shear-wave velocity (VS) is becoming the standard approach to evaluate near surface site conditions for ground motion amplification and liquefaction analyses. In particular, the thirty-meter average of shear-wave velocity (VS30) is used in classifying sites in recent building, in deriving strong-motion prediction equations and in addressing the applicability of the predictive equations outside the region that provided the ground motion data. Consequently, an effort has been made by the scientific community in order to provide VS30 measurements for the sites where strong-motion stations are deployed. A fast way of estimating VS30

has been proposed. This approach based on empirical correlations between available VS30 measurements and topography gradient can be very useful for producing seismic hazard maps that incorporate site amplification because topographic elevation data are evenly spaced and globally available. However, the applicability of such an empirical method requires careful validation; it is therefore important to calibrate VS30 velocities estimated by the topographic slope with in situ measurements.

One difficulty associated with the use of VS30 arises from the fact that, even though many methods exist to measure or estimate VS, no method provides an unbiased estimate. The methods for estimating VS depth profiles are usually divided in two categories, invasive, which require digging a borehole, and non-invasive, which involve the acquisition of surface or body waves at the ground surface and the use of forward or inverse modeling to resolve the subsurface. Due to the importance of applications of VS30 some attention has been devoted in recent studies to quantify the variability of VS estimates from different approaches. Authors have presented probabilistic seismic hazard maps for Portugal and identified the Lower Tagus Valley and Algarve as the most hazardous regions regarding earthquakes. This study also highlighted the importance of the ground motion model used to obtain the output value of peak ground acceleration obtained for the probability level analyzed. In Portugal, even though VS profiles and corresponding lithological information are routinely performed for engineering purposes, these data are not easily accessible. In addition, site-condition evaluation for strong-motion stations is based on

geologic maps, thus hampering severely the study of the applicability of sophisticated ground-motion models to the specific tectonic environment and crustal properties of Western Iberia.

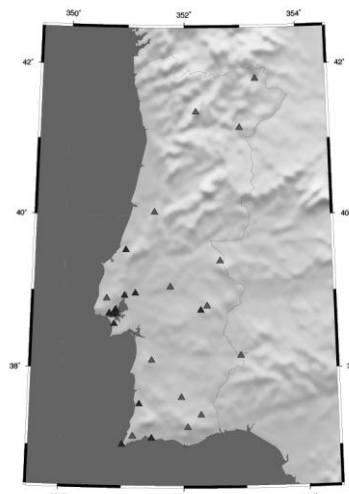
The present project aims at gathering disperse subsurface geophysical, geotechnical and geological information performed for specific purposes at a national level; and at acquiring geotechnical and geophysical data to characterize near-surface-soil conditions and shear-wave velocity profiles where strong-motion instruments are deployed. These data will serve a dual-purpose in terms of direct applications:

1) the characterization of strong-motion sites which is information required both to address the applicability

of sophisticated hazard-purpose ground-motion models, and to perform ground-motion modeling;

2) the development of a database relating near-surface lithology and shear-wave profiles for the upper 30 meters that would allow the inclusion of first-order site effects in regional seismic hazard maps, thus better representing regional susceptibility due to ground shaking.

In addition, by using different methodologies to characterize site-conditions at selected sites, the project will contribute for the scientific discussion about the lithology-dependent, inter-method variability of VS estimates.



Strong-motion network of IM and IST stations.

CONTACTS:

Inv. Susana Vilanova

Tel.: +351 218 419 214

E-mail: susana.vilanova@ist.utl.pt

Seismic vulnerability analysis of old masonry buildings

PTDC/ECM/100872/2008

KEY WORDS: Seismic vulnerability, Seismic fragility, masonry buildings, old buildings

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-07-2009 to 30-06-2012

FINANCING (€): 199.810 **IST/ICIST (€):** 199.810

COORDINATOR(S): Rita Bento. **RESEARCHERS AND COLLABORATORS:** António Gago; Mário Lopes; Helena Meireles; Ana Casanova; Jelena Milosevic, Ana Gabriela Simões.

SUMMARY

Portugal, alike southern Europe, has not adequately dealt with the vulnerabilities associated to risks such as the seismic risk, that occur suddenly but in a sharply manner, at an unpredictable time, location and severity. Lisbon, as an early settlement of populations, has witnessed along the centuries to a significant number of large events that have been narrated and are known to us nowadays. However, given that the time distance between events surpasses that of several generations, earthquake catastrophes tend to be forgotten... just until another one strikes. Conversely, given its centuries of History, the capital has a patrimonial value in old constructions, still standing in our days, of great importance and continuous need for preservation. Some of these constructions were built with anti-seismic concerns (for instance, empirically, care was taken to set the structures on hard rock sites and in other cases specific provisions were developed for the constructions so as to improve their seismic behaviour, the obvious example being the Pombalino buildings) while other old constructions have been designed to withstand gravity loads alone, presenting a vulnerable group at seismic risk (a recognized example would be the Gaioleiros buildings).

The response of this type of structures to strong earthquakes is still an open research subject. The analysis of the existing old masonry buildings in the light of the present seismic codes would lead to the conclusion that they are highly vulnerable to severe earthquakes; nevertheless, they behaved relatively well during past earthquakes, albeit with large variability of performances. Such discrepancies demonstrate the weakness of the available methods in accurately predicting the real behaviour of these types of buildings under destructive earthquakes. By the use of modern design techniques it is possible to apply many retrofitting schemes for the desired level of

strengthening, in most cases with questionable accuracy. Moreover the level of interventions is significantly limited due to functionality and architectural reasons. Furthermore, many of these buildings belong to the historical heritage or their initial structural system should be maintained or emphasized, thus limiting the level of applicable interventions.

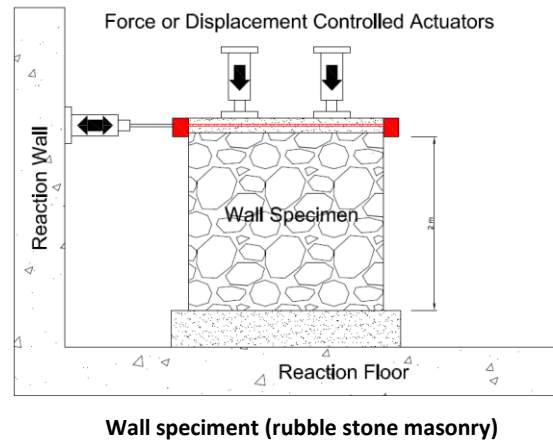
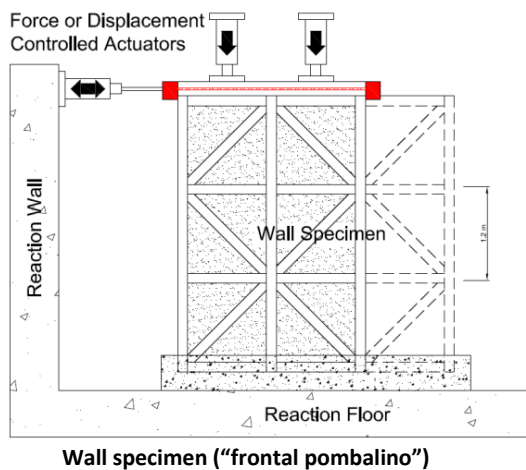
This project addresses the seismic hazard, the vulnerability it poses to old masonry structures (specially to Pombalino buildings) and possible retrofitting solutions. Masonry can be seen as a composite material for which a great variability can be encountered as a consequence of the different materials used, the different technologies applied and the several construction systems found. For this reason the masonry constructions, other than being a complex structure to analyse have many times a regional character. Within this general framework, specific objectives will be pursued.

A main concern will be the development of fragility curves based on the definition of classes of constructions for Lisbon's old masonry buildings. The development of such curves is essential as input for any loss estimation model currently being developed for the site. For such aim, analytical models will be developed of the representative construction of each class based on state of the art modelling approaches appropriate for masonry structures. Non-linear behaviour of masonry will be taken into account by running both non-linear static and dynamic analyses. Given that many of these buildings have undergone several interventions over the centuries, the most common interventions will be catalogued and modelled as well. It has been commonly recognised that experimental testing on structural components are a valuable contribute to the project. Experimental testing on relevant structural elements is also

proposed given the relatively scarce knowledge and data existing on the seismic behaviour of the typical masonry constructions existing in Lisbon. Wall and pier specimens will be tested under static cyclic and monotonic horizontal loading, the obtained results will enable structural characterization of the specimens, the identification of expected failure modes and the calibration of the developed analytical models. Furthermore, retrofitting schemes will be discussed with the most interesting ones being incorporated into the analytical models. Because some of the buildings to be analysed have a "critical" role (hospitals, fire-

stations, governmental facilities, etc.) detailed analytical models will be developed and additional care will be taken into defining appropriate limit states for analysis.

Finally, the project is also counting with the advice of known national and international experts on the field of earthquake engineering: Carlos Sousa Oliveira (from IST), Sergio Lagomarsino (from Genoa University), Andreas Kappos (from Aristotle Technical University of Thessaloniki) and Artur Vieira Pinto (from JRC and with a background on experimental activities).



DELIVERABLES

Papers in national journals

Casanova S., Bento R., Lopes M. 2011: "Comparação de Regulamentação sobre Avaliação e Reforço Sísmico de Edifícios Antigos de Alvenaria", Revista Internacional Construlink (RIC), Nº 26, Vol. 9, 48-63.

Papers in international conferences

Meireles H., Bento R. 2011: "Cyclic Behaviour of Pombalino Frontal Walls", Proceedings of the 14th European Conference on Earthquake Engineering (14ECEE), Ohrid, República da Macedónia.

H. Meireles, R. Bento, S. Cattari and S. Lagomarsino 2011: "The proposal of a hysteretic model for internal wooden walls in Pombalino buildings", Proceedings of the 2011 World Congress on Advances in Structural Engineering and Mechanics (ASEM11plus), The 2011 International Conference on Earthquakes and Structures (ICEAS'11), Seoul, Coreia do Sul.

Papers in national conferences

Meireles H., Bento R., 2010: "Comportamento Cíclico de Paredes de Frontal Pombalino", SÍSMICA 2010, 8º Congresso Nacional de Sismologia e Engenharia Sísmica, Aveiro, Portugal.

Casanova S., Bento R., Lopes M. 2011: "Comparação de Regulamentação sobre Avaliação e Reforço Sísmico de Edifícios de Alvenaria e Recomendações", Encontro Nacional sobre Conservação e Reabilitação de Estruturas - REPAR 2010, LNEC, Lisboa, Portugal.

Completed Theses

MSc Structural System of Lisbon's old masonry buildings: 'Pombalinos' and 'Gaioleiros', 2011.

CONTACTS:

Prof. Rita Bento
Tel.: +351 218 418 210
E-mail: rbento@civil.ist.utl.pt

Strong Site Effects in São Sebastião Volcanic Crater

POCI/CTE-GEX/58579/2004

KEY WORDS: Site effects; Earthquake; Dynamic characterization; Seismic waves

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Centro de Geologia (CG/FFC/FC/UL); Laboratório Regional de Engenharia Civil dos Açores (LREC-Açores)

PERIOD: 01-01-2005 to 31-12-2007

FINANCING (€): 65.000

IST/ICIST (€): 65.000

COORDINATOR(S): Jaime Santos. **RESEARCHERS AND COLLABORATORS:** Ana Maria Mota de Albergaria Pacheco Malheiro; Carlos Alberto Ferreira Sousa Oliveira; Filipe Miguel Palma Santos Passos Marques; Isabel Maria Baptista Moitinho de Almeida; Isabel Maria Figueiredo Lopes; Maria Manuela de Sousa Mendes; Rui Pedro Carrilho Gomes

SUMMARY

The Azores archipelago is located at the North America, Eurasia and Africa triple junction; the Mid Atlantic ridge separates the American plate from the others, while the Azores-Gibraltar fault zone is the boundary between Eurasia and Africa. The so-called Azores microplate is a part of the A-G fault with more or less a triangular shape, which includes a WNW-ESE spreading centre called Terceira rift, and a series of en echelon rifted basins. The high seismicity and volcanism of this area is a result of its location on an active plate boundary. Regarding seismicity, Terceira Island has been affected by several damaging earthquakes, such as the Praia da Vitória earthquakes in 1614 (Intensity > VIII) and in 1841 (Intensity > IX), and the 1980 January 1st earthquake (M= 7,2) (called Terceira earthquake), the strongest in Azores during the last century.

The shallow subsurface conditions may have a major influence on the seismic wavefield amplifying the strong motion and producing important damages (site effects), being due mainly to situations of low-velocity and poorly consolidated layers, sedimentary basins or special topographic conditions.

The seismic response of the São Sebastião volcanic crater, located at the SE end of Terceira Island (Azores), is characterized by an amplification of ground movements inside the crater with respect to the surrounding area. Inside this volcanic crater, with an average diameter of 1100m and a depth of about

50m, is located the village of São Sebastião that has shown an anomalous seismic behaviour in a more local expression, because some areas of the village have usually suffered more damage than others during the last earthquakes. This area can be considered a typical example of observation of site effects. The local geology and geotechnical characteristics of soil deposit probably play a strong role in the seismic ground shaking at the site: it is well known the importance of both the impedance contrast between soil and bedrock and basin edge effects.

Some previous studies were performed but the existing information is merely qualitative, so it is not possible to have a rigorous and well-defined model of the crater. This project was motivated by the challenge to provide high quality geotechnical data and instruments to measure earthquake motions. The geotechnical characterization will be performed by means of the most updated in situ seismic techniques (including high resolution seismic reflection, seismic refraction, spectral analysis of surface waves, and microtremors) and also laboratory cyclic shear tests (including resonant column and torsional shear tests). To measure the earthquake motions a seismic station composed by down-hole accelerometers will be implemented at the centre of the crater. This project will provide the necessary data for further numerical analyses to quantify the strong local site effects observed at São Sebastião volcanic crater.

DELIVERABLES

Papers in International Journals

SANTOS, J.A.; CHITAS, P.; LOPES, I.; SOUSA OLIVEIRA, C.; ALMEIDA, I.M.; NUNES, J.C. (2011) "Assessment of site-effects using acceleration time series. Application to São Sebastião volcanic crater", Soil Dynamics & Earthquake Engineering, Volume 31, Issue 4, pp 662-673.

Lopes, I.; Deidda, G.P.; Mendes, M.; Strobbia, C.; Santos, J. (2012) "Contribution of in situ geophysical methods for the definition of the São Sebastião crater model (Azores)" submitted to Journal of Applied Geophysics.

Papers in National Journals

LOPES, I.; SANTOS, J.A.; ALMEIDA, I.M. (2008) "The Surface Wave Method: acquisition, processing and inversion", Revista Geotecnia, Revista Luso-Brasileira de Geotecnia da SPG, ABMS e ABGE, nº 112, pp. 79-109 (in Portuguese).

Proceedings in international conferences

Lopes, I.; Mendes, M.; Deidda, G.; Strobbia, C.; Santos, J. (2010) "Site characterization of São Sebastião volcanic crater using geophysical tests", Near Surface 2010, 16th European Meeting of Environmental and Engineering Geophysics, Geotechnical Investigations Session, CD-ROM paper B18, 5 p..

Santos, J. A.; Lopes, I.; Chitas, P.; Oliveira, C. S. (2007) "Site characterization of a volcanic crater in Terceira

island – Azores", 4th International Conference on Earthquake Geotechnical Engineering, Thessaloniki, Junho 25-28, 2007, CD-ROM, Paper No. 1720, 14 p.

Proceedings in National conferences

CHITAS, P.; OLIVEIRA, C.S.; SANTOS, J. A.; GOMES, R. C. (2007) "Processing Acceleration Time Series: Procedures and comparing methods." 7^o Congresso de Sismologia e Engenharia Sísmica – Sísmica 2007, Paper n.º 095 (in Portuguese).

Lopes, I.; Almeida, I.; Santos, J.A. ; Malheiro, A. (2008) "Modelo geológico e geotécnico preliminar da Cratera Vulcânica de São Sebastião – Ilha Terceira", XI Congresso Nacional de Geotecnia, Coimbra, Vol 1, pp. 259-266.

CHITAS, P.; SANTOS, J. A.; OLIVEIRA, C.S. (2008) "Site-effect assessment of são sebastião volcanic crater, Terceira island, Azores", XI Congresso Nacional de Geotecnia, Coimbra, Vol 1, pp. 267-274.

LOPES, I.; ALMEIDA, I.; SANTOS, J.A.; MALHEIRO, A. (2008) "Preliminary geological and geotechnical model of the São Sebastião volcanic crater – Terceira Island", XI Congresso Nacional de Geotecnia, Coimbra, Vol 1, pp. 259-266.

LOPES, I.; SANTOS, J.A.; ALMEIDA, I. & OLIVEIRA, C.S. (2009) "São Sebastião crater characterization using the seismic surface wave method", 6^o Simpósio de Meteorologia e Geofísica da APMG, Costa da Caparica, Geophysics, pp. 74-78. (in portuguese)



CONTACTS:

Prof. Jaime Santos

Tel.: +351 218 418 418 E-mail: jaime@civil.ist.utl.pt

SUBSIn - InSAR detection and characterization of subsidence and landslides in the Lisbon region

PTDC/CTE-GEX/65261/2006

KEY WORDS: InSAR, subsidence, groundwater, landslides

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): Certitecna, Engenheiros Consultores SA (CERTITECNA); Musée Nationale d'Histoire Naturelle (MNHN), Luxembourg

PERIOD: 01-01-2007 to 30-12-2010

FINANCING (€): 131.568 **IST/ICIST (€):** 131.568

COORDINATOR(S): Sandra Heleno Silva. **RESEARCHERS AND COLLABORATORS:** Ana Paula Flor; Carlos Sousa Oliveira; João Fonseca; João Matos; João Paulo Ferreira; José Nuno Lima; Manuel José de Oliveira; Maria João Henriques; Nicolas d'Oreye de Lantremange; Pedro Bastos Bouza Serrano; Susana Pires Vilanova; Teresa Lobo Ferreira; Falk Amelung; Kervyn de Meerendre François.

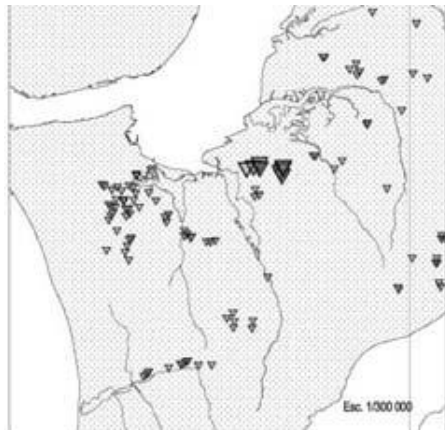
SUMMARY

We propose the use of SAR interferometry (conventional InSAR and PSInSAR) to measure ground displacements in urban areas. The Lisbon region was selected as study area due to its high urban density and favorable conditions for geologic or anthropogenic ground deformations. It comprises two sub-regions: to the North, Greater Lisbon, with almost 2 million inhabitants, and 9 municipalities (Lisboa, Oeiras, Cascais, Sintra, Amadora, Odivelas, Loures, Mafra and Vila Franca de Xira); to the South, the Setúbal Peninsula, with ~700.000 inhabitants, and also 9 municipalities (Almada, Barreiro, Seixal, Moita, Montijo, Alcochete, Palmela, Setúbal and Sesimbra). InSAR has proven to be a very effective technique for, among other applications, measuring ground subsidence related to groundwater pumping. Better results are achieved on areas that are, either sparsely vegetated and dry, or urbanized. The Setúbal Peninsula is mostly characterized by flat, dry, urbanized or otherwise sparsely vegetated terrain, making it a good study area for conventional InSAR. Until the present, there are no published InSAR studies for this area, which is part of the most large and productive aquifer system in the country, and whose groundwater resources have been important factors of development. InSAR can measure the typically small-magnitude, partly reversible, seasonal deformation occurring above stressed aquifer systems, which can be used to constraint aquifer system characteristics. No studies have tried to detect and measure the (probably significant) seasonal surface deformation in the Setúbal Peninsula. Over-exploitation of groundwater resources can aggravate significantly the ground subsidence scenario, and both

propitiate seawater intrusion in coastal aquifers. The Setúbal Peninsula is provided with a dense network of piezometers, substantially expanded in 1999, whose data has not been fully exploited for groundwater flow modeling or mass-transport modeling.

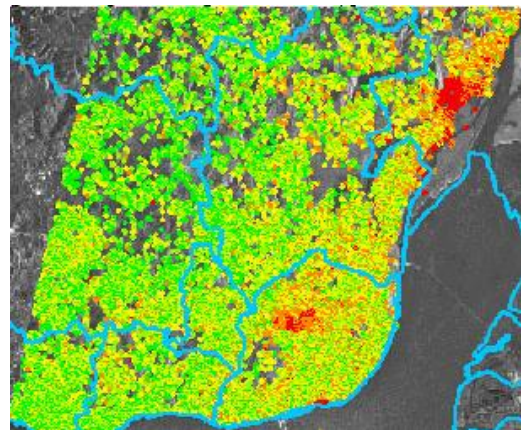
We propose to detect, quantify, and characterize ground deformation in the Setúbal peninsula with synthetic aperture radar interferometry (conventional InSAR), together with permanent and non-permanent GPS data. We propose also to model groundwater flow, mass transport, and elastic/inelastic surface deformation in the area. This will allow us to isolate the seasonal groundwater-related regional deformation from other possible origins (e.g. tectonic) and diagnose the possibility of aquifer/aquitard irreversible compaction in the Setúbal peninsula, and associated risks of ground subsidence or coastal aquifer salinization. Recently, InSAR approaches to measure ground deformation evolved towards the joint exploitation of large groups of SAR images, allowing the removal of the atmospheric effects at image pixels called "permanent scatterers" (PS), where decorrelation is minimal. Physically they correspond to stable natural or man-made reflectors (like the corner of a building, or a large rock). This procedure, known as PSInSAR, allows the detection of sub-milimetric movements of the ground in a "network of opportunity" that is very dense in urban environments (100-400 PS/Km²). PSInSAR is very effective in the detection of subsidence due to soil compaction, tunneling or other engineering works, and deteriorating structural foundations. Slow-moving landslides have also been successfully detected using PS data, even in non-urban areas. The north of Lisbon

is prone to landslides, and these have caused considerable economic losses in the past decades. PSInSAR results for the Greater Lisbon region are shown in figure 4 (TerraFirma Processing Report Lisbon, unpublished data, 2004). More than 200.000 “permanent scatterers” (PS density is 250/Km²) were identified in the area, each with a corresponding temporal displacement series, constrained by 55 ERS1-2 scenes acquired between 1992 and 2003. We



Ground water wells for human use (INAG, 1999).

propose to detect and inventory, with PSInSAR, localized cases of urban subsidence (edifices and structures) in Lisbon, and confirm/calibrate the results with data from databases of geodetic monitoring around tunneling or other engineering works in the area. PSI data will also contribute to improve landslide mapping in areas north of Lisbon, discriminate between active and non-active areas, and improve the understanding of landslide activation mechanisms.



PSInSAR results for Greater Lisbon (900 km²), with more than 200000 PS points identified, 250 PS/ km²: subsidences and uplifts.

DELIVERABLES

Proceedings in International Conferences

Heleno, S.; Carvalho, J.; Fonseca, J.; Falcão, A.P.; Cooksley, G., “Major (Active?) Fault Zones in the Lisbon Area Show Signature in PS Interferometry Maps”. *2nd International Seminar on Prediction of Earthquakes*, Lisbon, Portugal, 29-30 April 2009.

Heleno, S., Oliveira, L., Vicente, J., Falcão, A., Carvalho, J., Lobo-Ferreira, J., Cabral, J., Fonseca, J., Medeiros, A., Oliveira, M., Pinto, C., Mancuso, M. (2009). PSI Reveals Deformation Associated with Groundwater Withdrawal in the Lower Tagus Valley Tectonic Setting. *GMES. TerraFirma 5th Workshop*, ESRIN, Frascati, Italy, 25-26 March 2009.

Proceedings in National Conferences

Henriques, M.J., Lima, J.N., Falcão, A.P., Heleno, S. (2009). Validação com Nivelamento Geométrico da Subsidiência Detectada na Cidade de Lisboa com PSInSAR. *Actas do 2.º Encontro Nacional de Geodesia*

Aplicada, Laboratório Nacional de Engenharia Civil, Lisboa, 12-13 Oct. 2009.

Lima, N., Henriques, M.J., Heleno, S., Fonseca, J., Falcão, A.P. (2009). A Monitorização Altimétrica da Zona de Lisboa com GNSS e Nivelamento Geométrico. *Actas da VI Conferência Nacional de Cartografia e Geodesia*, Caldas da Rainha, Portugal, 7-8 May 2009.

Heleno, S., Henriques, M.J., Falcão, A.P., Lima, J.N., Fonseca, A., Mancuso, M., Fonseca, J., (2010). Measuring subsidence in the centre of Lisbon with Persistent Scatterers Interferometry (PSI), CGPS and levelling surveys. *European Space Agency Living Planet Symposium*, Bergen, Norway. SP-686 “ESA Special Publication” (SP series of Conference Proceedings).

Heleno, S., Oliveira, L., Henriques, M., Falcão, A., Lima, J., Cooksley, G., Ferretti, A., Fonseca, Lobo-Ferreira, J. (2011). Persistent Scatterers Interferometry detects and measures ground subsidence in Lisbon. *Remote Sensing of Environment*, Vol. 115, pp.2152-2167.

CONTACTS:

Inv. Sandra Heleno da Silva
Tel.: +351 218 418 330
E-mail: sandra.heleno@ist.utl.pt

Urban System under Earthquake Threat: An Integrated Global Approach. Application to the Azores (USuET)

POCI/CTE-GIN/58095/2004

KEY WORDS: Seismic Risk; Geographical Information Systems; Damage Scenarios; Socio-economic Impact

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S): LNEC; Universidade dos Açores

PERIOD: 01-01-2005 to 31-12-2006

FINANCING (€): 64.000

IST/ICIST (€): 64.000

COORDINATOR(S): Carlos Sousa Oliveira. **RESEARCHERS AND COLLABORATORS:** Alexandra Maria Rodrigues de Carvalho; Alfredo Peres de Noronha Campos Costa; João Carlos Carreiro Nunes; Jorge Miguel Silveira Filipe Mascarenhas Proença; Maria João Fraga Freire de Barros; Maria Luísa Raposo Magalhães Nascimento e Sousa Sotomayor; Victor Hugo Lecoq de Lacerda Forjaz; Mónica Maria Lopes de Sequeira Amaral Ferreira

SUMMARY

PPERCAS was a Project funded by FCT (Praxis XXI) in the period 1997-2001 aimed at contributing to the determination of the hazard and risk in the Central Group of the Azores Archipelago. It essentially consisted in launching a series of studies necessary to develop knowledge in those areas. The most important issues dealt with include:

- The creation of a strong motion network, which nowadays is formed by 15 stations spanning the entire archipelago. The FCT project (Re-equipment) SEISNETg, recently approved, aims at developed this network with the acquisition of another 15 stations and create a centre capable of managing all stations and data transmission;
- The compilation of most recent know-how on the seismo-tectonic environment with the identification of most active seismic zones and faults traces and the creation of a catalogue of earthquakes in the Azores (Catálogo Sísmico da Região dos Açores)
- Initiate a classification of most important volcanic soil categories in order to understand the zones more critical for soil amplification;
- Based on all available data, which includes strong motion records of the 1997 and 1998 earthquake crisis, a preliminary hazard map was obtained;
- Sparse vulnerability studies were performed for the traditional housing existing in the Azores, and a detailed inventory of buildings in 5 cities was performed. An application to Horta for the reproduction of the 1998 earthquake was also made.

CONTACTS:

Prof. Carlos Sousa Oliveira

Tel.: +351 218 418 202 E-mail: csoliv@civil.ist.utl.pt

The present project, in the continuation of PPERCAS, will develop a general methodology for creating earthquake-risk scenarios that takes into consideration the distinctive features of Azores Island. Particular attention will be given to the response of the urban centres behaving as an entire system, considering the economic impact and population reaction (Hollistic view). In order to achieve this goal some detailed methodologies will be developed to analyse the vulnerability of existing housing in large towns of Terceira, Faial and Pico, applying the EMS-98 macroseismic scale concepts among other techniques dealing with more related to physical modelling of houses.

The influence of the soil layers (geological and geomorphologic effects), slip in mapped faults and evaluation of the possible landslides and liquefaction will be taken into account.

A simulator to determine the damage inflicted by an earthquake characterised by a magnitude and an epicentral location based on a GIS, composes the whole system. This permits the end-user to carry out a complete seismic risk assessment and produce seismic risk scenarios and seismic risk maps at three geographical scales: "freguesia (city council)", "subsecção estatística (city block)" and individual building. The application of system analysis to urban centres in Azores will be an important tool to help emergency planning, online impact evaluation, and for urban and land-user planners

Virtual Reality Technology applied as a support tool to the planning of construction maintenance

PTDC/ECM/67748/2006

KEY WORDS: Virtual Reality, 4D models, construction maintenance, life-cycle cost

PROMOTING INSTITUTION(S): IST-ICIST

PARTNER INSTITUTION(S):

PERIOD: 01-10-2007 to 30-09-2010 (extended to 2011)

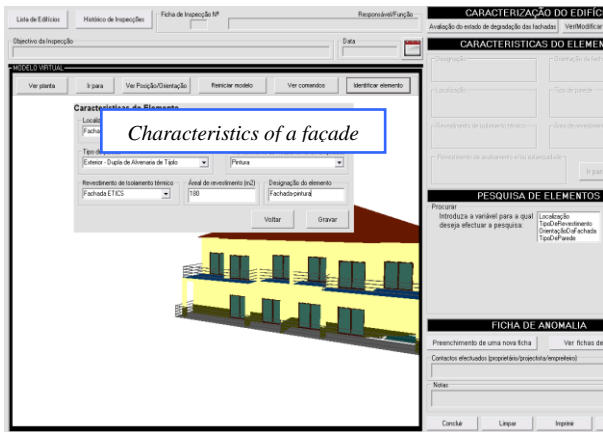
FINANCING (€): 63.750 **IST/ICIST (€):** 63.750

COORDINATOR(S): Zita Sampaio. **RESEARCHERS AND COLLABORATORS:** António Costa; Augusto Gomes.

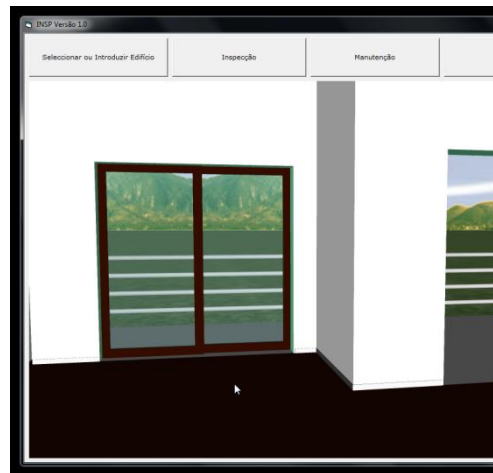
SUMMARY

The main aim of this investigative work is to develop virtual models as tools to support decision-making in the planning of construction maintenance. These virtual models will be given the capacity to allow them to transmit, visually and interactively, information related to the physical behaviour of materials, constituent elements of given infrastructures, defined as a function of the time variable. The interactive application will allow decisions to be made on conception options such as, for example, the materials to be used, the type of connections or the sequence to be established between the different elements of construction and in the definition of plans for maintenance, conservation or rehabilitation. Virtual reality (VR) is seen today as an integrating technology, with great potential for communication between project participants, and most recently, as a tool for the support of decision-making, made possible by the integration of distinct computer applications in the virtual model. In this context, the present proposal presents the development of a system based on that technology, with a high technical level both of investigation and innovation, involving knowledge of the physical aspects of materials, in particular, those which refer to wear and tear/weathering (a function of time, use and environmental factors) integrating them in digital spatial representations. In this way, the indisputable advantage of the ease of interpretation and perception of space provided by the visualization of spatial models, and the technical content underlying the real characteristics of the observed elements are brought together. The application of the virtual model to be developed, in each case and for a specified time t of the life-cycle of infrastructure,

allows the examination of the physical model, visualizing, for each element, the corresponding technical information concerned with the wear and tear aspects of the material, calculated for that period of time. In addition, the analysis of solutions for repair work/ substitution and inherent cost are predicted, the results being obtained interactively and visualized in the virtual environment itself. The aim is that the virtual system should be able to be applied directly over the (3D) spatial models of new constructions; in situations of rehabilitation, there will have to be a previous 3D survey, based on graphic documentation or, on site, by means of a 3D scanner. The practical usage of these models is directed, then, towards supporting decision-making in the conception phase and the planning of maintenance. This work is part of the activities of the Geometric Modelling group and the group of the Department of Civil Engineering and Architecture (IST) with projects already developed (POCTI/1999/ECM/36284 e /36300), involving the creation of virtual models of simulations of construction processes of façades and bridges. The proposed project constitutes a continuation of those pieces of work, adding to them the capacity to make interactive technical responses. The participation in the team of Alcínia Sampaio (Assistant Professor) and Augusto Gomes (Associate Professor) with relevant research in the areas of virtual geometric modelling and of new materials, respectively, guarantees the objectivity and applicability of the results of this project, which also numbers amongst its participants António Costa (Trainee Assistant), whose doctoral proposal includes some of the objectives of this project.



VR model supporting the maintenance of the closure of façades.



VR model supporting the maintenance of the closure of interior walls.

DELIVERABLES

Papers in International Journals

Sampaio, A.Z.; Henriques, P.G.; Cruz, C.O.; Martins, O.P. (2011): "Interactive models based on Virtual Reality technology used in Civil Engineering education", chapter 21 in "Teaching through multi-user virtual environments: applying dynamic elements to the modern classroom", Publ.: Information Science Reference, Ed. Giovanni Vincenti and James Braman., ISBN: 978-1-61692-822-3, 2010, pp. 387-413.

Sampaio, A.Z.; Cruz, C.O.; Martins, O. (2011): "Didactic models in Civil Engineering education: Virtual simulation of construction works", chapter 28 in "Virtual Reality", Ed. Jae-Jin Kim. ISBN 978-953-307-518-1.

Sampaio, A.Z., Santos J.P. (2011): "Construction planning supported in 4D interactive virtual models", Journal of Civil Engineering and Construction Technology, Vol. 2(6), pp. 125-137, June 2011.

Sampaio, A.Z.; Henriques, P.G.; Martins, O.P. (2010): "Virtual Reality Technology Used in Civil Engineering

Education", The Open Virtual Reality Journal ISSN: 1875-323X. Vol. 2, pp.18-25.

Sampaio, A.Z.; Ferreira, M.M.; Rosário, D.P.; Martins, O.P. (2010): "3D and VR Models in Civil Engineering Education: Construction, Rehabilitation and Maintenance", Automation in Construction, V. 19, No. 7, Ed. Elsevier Science, 19, August 2010. pp. 819-828. ISSN: 0926-5805 doi:10.1016/j.autcon.2010.05.006.

Sampaio, A.Z.; Ferreira, M.M.; Rosário, D.P. (2010): "Interactive data management concerning the lighting system in a building: a Virtual Reality application", International Journal of Applied Research on Information Technology and Computing, V. 1, No. 2, pp. 151- 159. ISSN : 0975-8070.

Sampaio, A.Z., Henriques, P.G. (2008): "Virtual Reality technology applied on the visual simulation of construction activities", The Open Construction & Building Technology Journal, Vol. 2, pp. 7-14. ISSN: 1874-8368, doi: 10.2174/187483680080201000

CONTACTS:

Prof. Zita Sampaio
 Tel.: +351 218418336
 E-mail: zita@civil.ist.utl.pt

ICIST