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AN EXPERT SYSTEM FOR MANAGING EARLY AGE CONCRETE CRACK PREDICTION

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Abstract: This paper presents the achievements of an international collaboration within an EU project, aimed at developing engineering tools useful for contractors and designers for managing early cracking prediction in engineering practice. The research was funded by E.C. under the program Brite EuRam, Contract no. BRPR-CT97-0437 (IPACS).

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1. INTRODUCTION

This paper presents the achievements of a sub-task of the IPACS project, a research granted by the European Communities to evaluate, integrate and extend the existing knowledge about early age concrete crack prediction in engineering practice.

The sub-task was devoted to the design and development of software tools useful for contractors and designers for managing early crack prediction [1].

These tools consist of a software simulating basic early age transient concrete properties, and data bases for storing the same properties, standardised laboratory and field tests, and recommendations and specifications [2]. They have been collected and organised into an expert system (called IPACS) able to:

- support the evaluation of the cracking risk in concrete structures;
- indicate possible actions for optimisation of technical quality and economy.

The system is focused on assisting the engineer in the decision-making process, offering guidance in assessing critical conditions leading to cracking. It is an integrated and easy to use tool hosting various pieces of codes, data bases and logical rules (know-how) taken by experts in this field, which cannot be all represented by formal mathematical algorithms.

The software may simulate the concrete hardening and building processes taking into account all important factors of influence, such as climatic conditions, non-uniform maturity development, restraints imposed by adjoining structures etc.

2. The software architecture

IPACS has been developed exploiting the so called Internet technology, so that partners may easily share knowledge and data via Internet tools[3].

This solution is based on the development of a web site that embodies a database of information about concrete and intelligent tools to deal with these data, as well as with inputs provided by the users.

As a result, the system can be regarded as a client-server architecture over the Internet, where a server hosts the site and the partners may access it

[3] Note that in 1997, when we started the project, the choice of developing an expert system coupled with a large database over the Internet was not as trendy as it is now.

via a common web browser (the client). Each partner can get data from the system, process data and store data into the database.

The resulting site, that may run on Windows 9X/NT personal computers, comprises the following components:

- an HTTP server (that is a Web server);
- a set of HTML pages;
- a database developed in Access;
- a download area, where users can find: tools implemented by partners as DOS executables or spreadsheets; documents which explain how to run both the downloadable tools and the modules of IPACS; documents which introduce users to the theoretical background of the IPACS tools;
- a layer of Perl programs to access the database (via an ODBC driver) and build on-the-fly HTML pages for interfacing database management functions; these programs are executed on the server and their results are sent to the client (server-side computation); these programs are grouped in a library that is called IPACServer;
- a set of software tools delivered by partners as executable programs and a set of Perl programs to interface them; Perl routines run these modules and, if necessary, feed them with data extracted from the material database;
- a set of JavaScript programs, to run some of the procedures of the expert system (neural networks, knowledge based and numerical modules); these programs are downloaded from the server to the client and executed locally (client-side computation).

3. The functional architecture

The detailed design of the system proceeded from the layout shown in Figure 1, where the arrows show the flow of the data inside IPACS and each box corresponds to a specific module:

- *culvert N.N.*: this module receives from the users data that describe a culvert section (a wall on a slab), the environment and the kind of concrete, and *evaluates the cracking risk*; it exploits *neural networks* to predict the cracking index; different networks may be used, on the ground of available data: users are driven by a graphical interface to select the most suitable net for their purposes;
- *plate N.N.*: it gets from the users data that describe a plate, the environment and the kind of concrete, and *evaluates the cracking risk*; this module exploits the same techniques of the previous one;
- *knowledge based & numerical modules*: these procedures implement algorithms or rules of thumb with the purpose of studying cases not represented in the NN modules or to allow for a more engineering guided formalism of the early age response of the culvert and the plate cases; they comprise a module, exploiting both symbolic and neural processing, to *evaluate the restraint factor* for five main types of structure (structure facing ground, slab to slab, wall on slab, roof on wall, wall on wall) with several sub-cases; a graphical assistant to *simplify three-dimensional structures* for ap-

plying the proper case of the restraint evaluator; a *thermal solver*, to calculate the temperature evolution of a semi-infinite concrete wall during the hydration process; a *mono-dimensional solver for the viscoelastic problem*, that calculates the stress evolution and the resulting cracking risk for a mono-dimensional concrete specimen due to restrained thermal loading;

- *kind of structure*: it implements a choice point, where the users are given support to choose the processing module that is most suitable for their problem;
- *material database*: a relational database that collects data about concrete; the database comprises a main archive, containing records which describe concrete-mixes, eleven archives containing data related to concrete components (water, cement, ...), and two archives for test data and processed data;
- *material calibration module*: an interface module that allows for the material models calibration, by using data collected in the database; it can export data suitable to be managed by other processing modules. It may also export calibrated materials to an external finite elements code, to solve the thermo-visco-elastic problem with higher accuracy or when the problem is too complicated for the simpler solvers implemented in IPACS.

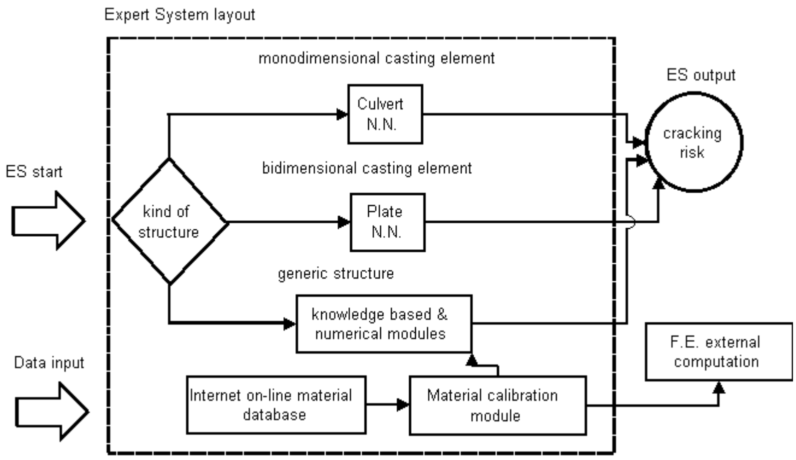

Fig. 1 The functional architecture

The neural nets used by IPACS have been trained on the ground of data generated by other tasks of the project or derived from literature. After the training they have been embodied as JavaScript code in the web pages of the system; some modules exploit a combination of results from different nets.

Each net is a *multiple-layer feed-forward net*, with 3 or 4 fully connected node layers. The *back-propagation* learning scheme has been used for training the nets. The input layers are made of nodes representing the input variables of the problem, whilst the output layer is made of one node, representing the result of the net (*cracking risk* for the modules for culverts and plates; *restraint factor* or *slip factor* for the restraint factor evaluation). One or more hidden layers are present with nodes that can be varied in number to reach the desired accuracy of the solution: the absolute average error ranges, according to checks performed on a set of test data, from 1.2% to 6.5%.

Users can find in a download area both tools implemented by partners as DOS executables or spreadsheets, and documents, which explain the theoretical background of the IPACS tools and how to run them.

Graphical tools and written explanations support users throughout the system (Figure 2): whilst advanced users may directly use the most suitable path through IPACS, less experienced users will find different levels of explanations to select the tools they need, to feed the procedures with the right data, to load the database with properly formatted files and so on. The explanations can range from short in-line notes, to graphics, to hypertexts.

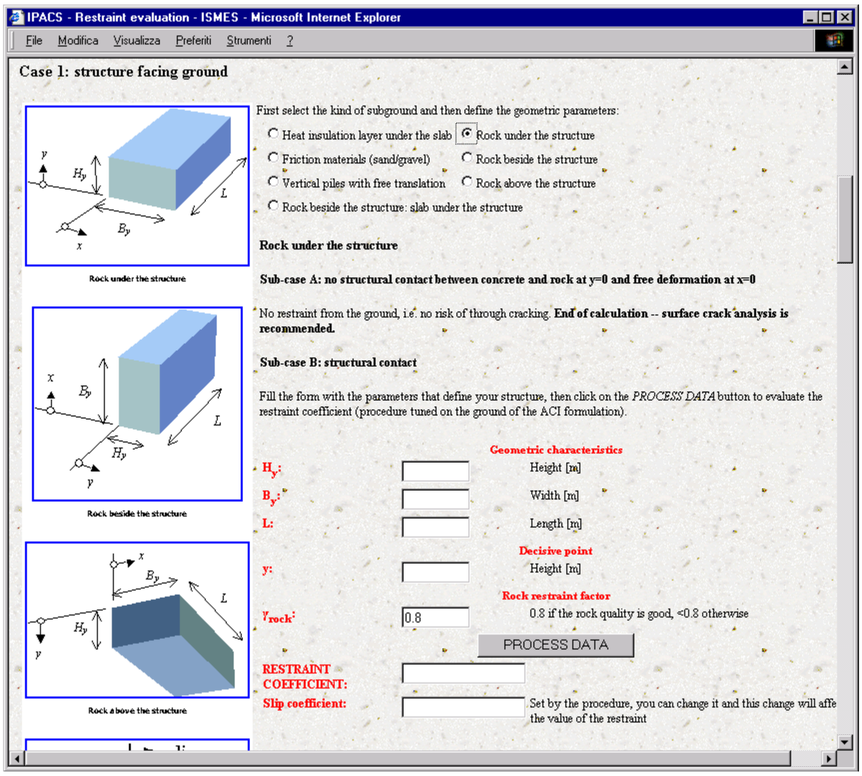

Fig. 2 The graphical interface to the neural networks

4. Conclusions

IPACS has been conceived and developed as a system where experience on the hardening of concrete of different kind is available to support users of different background: material science, constitutive modelling as well as structural modelling and construction technology are all embodied in the system. The software architecture has been developed as to allow for a wide exchange of data and to ease further incorporation of models/data.

References

[1] Dalmagioni, P., Lazzari, M., Pellegrini, R.: *IPACS - Final report of the task 6*, Lulea University of Technology, Lulea, Sweden, 2001.

[2] Salvaneschi, P., Lazzari, M.: Weak infrmation systems for technical data management, *Worldwide ECCE Symposium on Computers in the Practice of Building and Civil Engineering (European Council of Civil Engineers)*, Lahti, Finland, 1997, 310-314.