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Information Management Systems for Dam Safety Control. The Portuguese Experience

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Abstract

The safety of the system formed by the dam, its foundation, the reservoir, and the downstream area of the dam should be evaluated on its structural, hydraulic, operational and environmental components.

In particular, the structural safety assessment of an existing dam is based on the establishment of correlations between the main loads, its structural properties, and its structural responses. The values of observed responses are compared to predicted values obtained by structural behaviour models or by historical observations.

Over the years, new developments in technological devices have been introduced in this field, namely through the implementation of automated data acquisition systems. This evolution, associated with very important progresses in information systems technology, has raised new challenges, but has also provided new opportunities, such as the development of data management systems that allow the person responsible for dam safety to access data, interpret the information, and make decisions, as quickly as possible.

The National Laboratory for Civil Engineering (LNEC) has developed the GestBarragens system, which was designed and developed using a modular approach, based on a common data architecture that can be accessed through a Web interface.

This paper intends to show the improvements that the GestBarragens system provides to the activities related to the safety control of more than one hundred large concrete and embankment dams, including the observation of several physical quantities measured by the monitoring systems, the interpretation of the information and the transmission of warnings to the entities responsible for the dam's safety.

As the development of the GestBarragens system is an ongoing process, future developments will also be addressed in this paper.

Keywords: Information support system, Safety control, Monitoring, Warning system.

1 Introduction

The safety of the system formed by the concrete dam, the foundation, the reservoir and the downstream area of the dam should be evaluated on its structural, hydraulic, operational and environmental components.

The interpretation of the observed structural behaviour is usually based on the establishment of correlations between the loads, the structural properties, including material properties, and the structural responses. These responses, expressed in terms of displacements, strains, drained flow, etc., are compared with predicted values from the behaviour models.

The surveillance activities of concrete dams have a preventive purpose, to take timely decisions to prevent or minimize the consequence of abnormal behaviour. These activities include the necessary actions to understand the real condition of the dam, and in cases of abnormal behaviour, to adopt appropriate measures, including the conditioning of the exploitation, the construction activities for conservation and rehabilitation (FLORENTINO (1983)), or in an extreme case, to warn civil protection authorities in order to protect people and property downstream.

The continuous evolution of computers in terms of processing information provides improvements related to the analysis of large quantities of data. The need to review procedures of suitable data analysis for information extraction has become an important aspect for timely decision making.

In the safety control of dams with automated data acquisition systems, the analysis of a large quantity of data may become a difficult task. On the one hand, it is intended to ensure the safety control in real time, but on the other hand, human ability to process data information is limited. For these reasons, it is fundamental to provide to the person responsible for dam safety an information management support system to allow data access, interpretation of the information and decision taking, as quickly as possible.

2 GestBarragens

For many years, the Portuguese authority has recognized the importance of a support system for the safety control of concrete dams (GOMES (1981)). The first system developed, called SIOBE, essentially consisted of a group of programs for the management and analysis of data stored in data files, with the monitoring results of the large Portuguese concrete dams.

A new support system for monitoring, diagnosis and safety control of concrete dams, named GestBarragens (Figure 1), is under development since early 2000. Designed in Portuguese, its interfaces can easily be translated to other languages.

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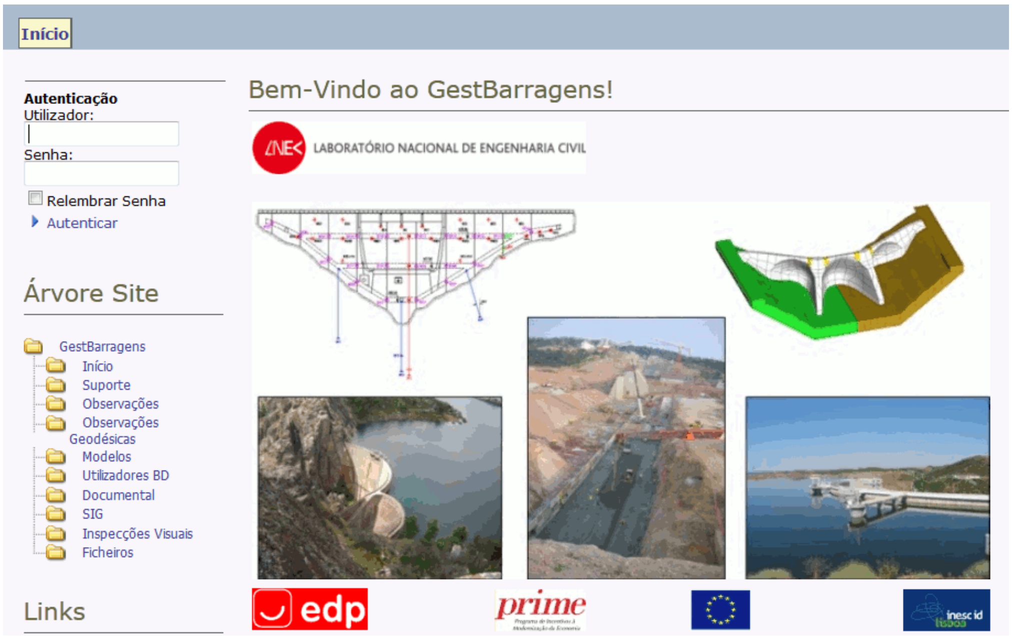

Figure 1 – Main web interface of the GestBarragens system.

The GestBarragens system is the result of a close collaboration of three Portuguese institutions: LNEC, INESC-ID and EDP. LNEC, a public institute of science and technology with responsibilities in the safety control of large dams, is the owner of the system; INESC-ID, a research institute specialized in new technologies was the developer of the system; and EDP, a Portuguese electricity company, owner of the majority of dams in Portugal, is one of the most important users of the system. Now, the system is also in use by INAG, the Portuguese authority for dam safety, and by EDIA, an important owner of dams for irrigation purposes, who manages, among others, the largest reservoir in Portugal.

GestBarragens is a modular information system that actually provides components to manage monitoring data from manual and automated data acquisition systems, visual inspections and technical documents, such as reports, pictures, etc. It provides a set of exploitation tools such as tabular and chart reports, and graphical visualization of information (PORTELA et al. (2005), SILVA et al. (2005), SILVA et al. (2006)). It was conceived to include, as quickly as possible, components to manage physical and mathematical models.

As dam safety control involves several levels of responsibilities, including the monitoring team, the dam owner's technicians and public authorities, appropriate permission levels of utilization are implemented.

Figure 2 shows a simplified deployment diagram of the GestBarragens system. It is a web-based system developed on top of the Microsoft .NET Framework[1], where the underlying data is stored and managed in an Oracle database management system[2].

[1] http://www.microsoft.com/net
[2] http://www.oracle.com/products/database

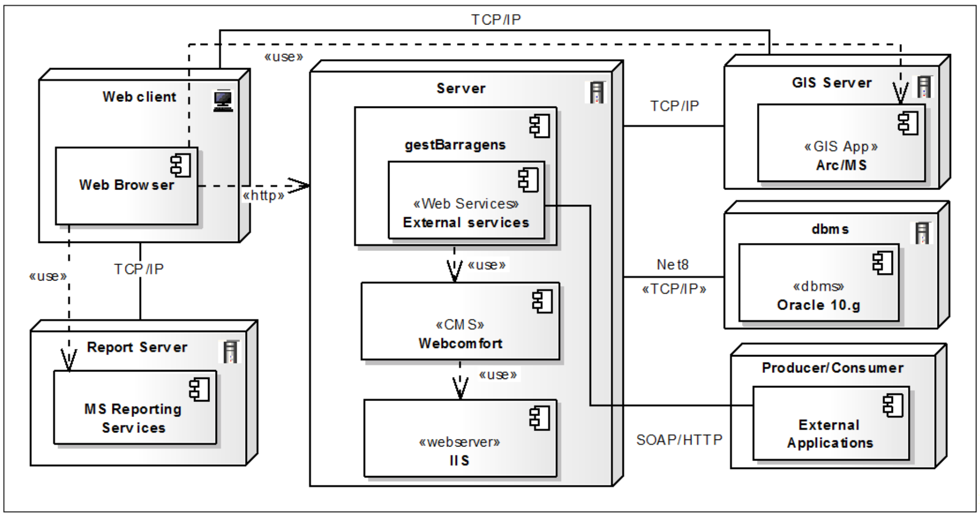

Figure 2 – Simplified deployment diagram of the GestBarragens system.

GestBarragens uses a Service Oriented Architecture[3] to provide and expose exploitation services as well as multiple ingest services. For example, observation data can be automatically inserted by multiple sources such as automatic monitoring systems and portable data terminals (Figure 3). GestBarragens also includes an application to export data to spreadsheets and generate large-period (e.g., 70 years) graphics in high-resolution representations.

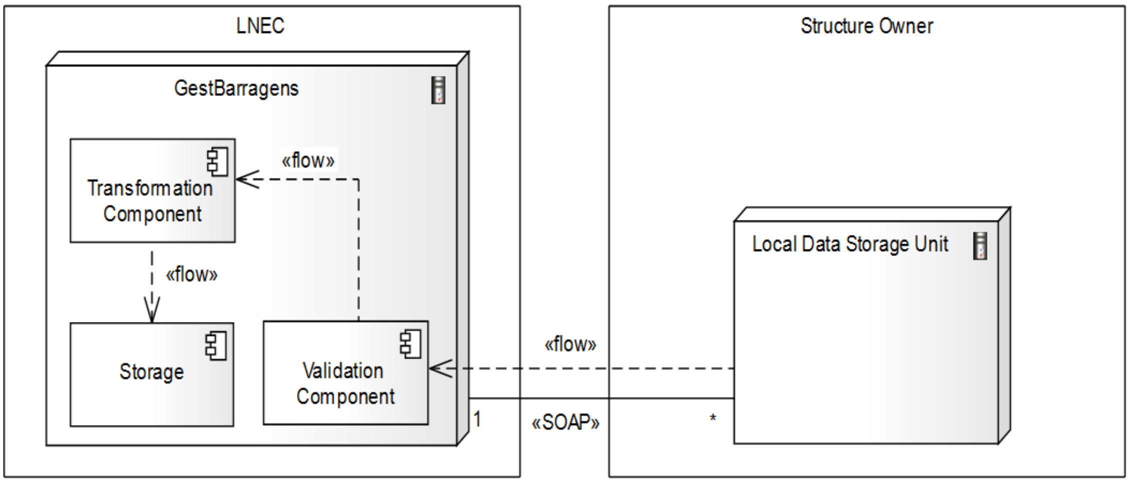

Figure 3 – GestBarragens system data acquisition diagram.

GestBarragens provides a number of solutions that are critical in the field of civil engineering, with the following key aspects: (i) Instrumentation: It integrates new observation instruments, supports the dynamic management of new types of instruments, and manages metadata about instruments. (ii) Types of observations: It manages geodetic data information, information concerning visual inspections, and data provided by

[3] http://www.oasis-open.org/committees/soa-rm

automatic monitoring systems. (iii) Data visualization and exploitation: It provides access to data through a set of reports designed to support the required types of data analyses, and allows a graphical representation of the data. (iv) Synchronization: It supports the deployment of the system in one or more locations (for example, LNEC and a dam owner) and the corresponding synchronization of data.

2.1 Data Representation

Table 1 summarizes an example of data concerning the dam safety of a large Portuguese dam. Currently, GestBarragens supports 32 different types of instruments with manual data acquisition and 25 different types of automatic monitoring instruments. Each of these 57 instrument types has its own characteristics, algorithms and calibration constants, and generates different types of processed readings and engineering quantities. Note that both the number and type of instruments installed in a specific dam depend on the stage of the dam's life and on hundreds to thousands of parameters that affect its behaviour.

Table 1 – Data concerning dam safety of a large Portuguese dam

Data Stage	**Description**	**# per day**	**Representation**	**Notes**
Raw	Depend on the instrument type (e.g. voltage)	Discarded	Proprietary to the sensor	This information is currently discarded by sensors and not registered during manual acquisition
Processed readings	Transformed from raw data	Approx. 3300 rec.	.xls, .mdb, PDT, ASCII	Sensors register data in .xls or .mdb and access a web service to send this information to LNEC. Manual acquisition is registered into a portable data terminal (PDT)
Engineering quantities	Calculated from readings	Approx. 3250 rec.	Oracle database	Algorithms to filter, clean and calculate engineering quantities are implemented as Oracle stored procedures (PL/SQL)
Analyzed	Tables, graphs	Varies	.html, .xls, .pdf, .dxf (CAD), .xml	Uses several tools, including reporting tools

At this time, raw data in automated data acquisition systems is not stored because the output of these systems is already a processed reading. In the case of manual data acquisition, raw data is converted by the measuring instrument making it impossible to be captured and preserved. Processed readings and engineering quantities are stored in a centralized Oracle database, while analyzed data is generated, produced and managed by technicians and researchers, using their own tools. Along with the need to manage a heterogeneous and large set of dataset representations, the volume of data is growing rapidly. Figure 4 visualizes the amount of sensor data acquired per year. In the last decades of the 20th Century, the construction of several large dams and the implementation of the first system for data archiving and representation caused the growth of acquired data in that period and a subsequent stabilization by 2005.

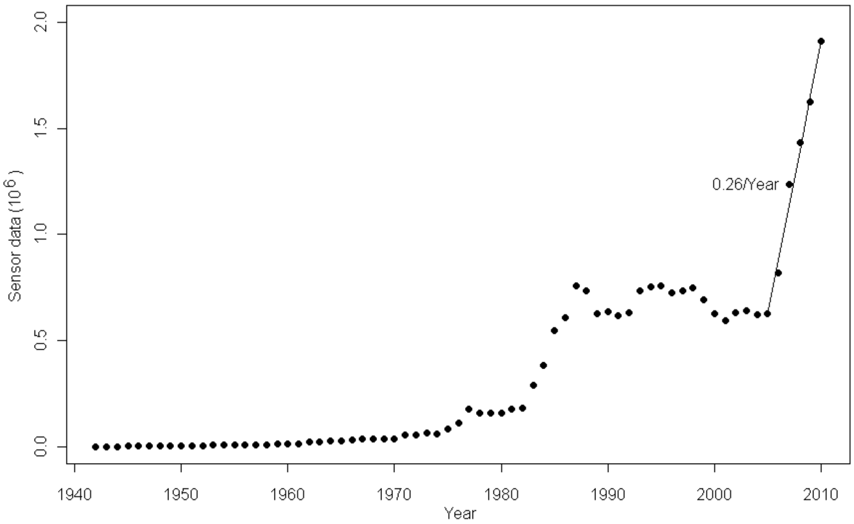

Figure 4 – Data stored evolution of the GestBarragens system.

From 2005 until now, we see an imminent deluge of data with a linear growth estimation of acquired records of 0.26×10^6/Year. This is mainly caused by the deployment of GestBarragens, which supports a larger number of instrumentation types. The legacy systems implemented 23 types of manual data acquisition instruments, while GestBarragens supports 32 of these and 25 types of automatic monitoring systems, as well as a larger number of instrument types. A recent investment in automated data acquisition additionally leads to a higher frequency of data acquisitions.

The current growth rate is expected to be steady or increase over the next years, since new large dams are currently under construction and the major dam owners are investing in new automated monitoring systems to further increase the real-time monitoring of critical infrastructures.

2.2 Data Synchronization Process

Since dam owners may want to have local copies of observation data gathered from their dams, the GestBarragens information system can be installed in the offices of the dam owner with specific data synchronized from the central GestBarragens at LNEC. The synchronization related processes are the following:

- Manual Data Synchronization - This process gathers a set of data to be synchronized between different instances of the system. The user selects the data to be synchronized and triggers the process.

- Automatic Data Synchronization - This process requires a pre-configuration to define the schedule of synchronization. The process periodically checks the existence of new unsynchronized datasets and synchronizes the new or updated information from the remote instance to the local one. This process is not bidirectional. In order to ensure that all instances are updated, automatic data synchronization must be programmed in all instances.

2.3 Applicational modules

GestBarragens is a modular system, composed of the following applicational modules: Support, Observation, Geodetic Observation, Documental and Visual Inspection (Figure 5).

Figure 5 - Modules of the GestBarragens system.

3 Observation module

GestBarragens allows several modes for data loading. In manual data acquisition systems (MDAS), instrument readings can be loaded through a specific interface, by loading data files that follow predefined templates, and directly from mobile data acquisition devices. All these modes include a data validation procedure, whose limits are defined by historical values. This procedure is useful to detect reading errors and/or typing errors. Automatic data acquisition systems (ADAS) data are directly loaded in GestBarragens through automated procedures implemented at the dam site.

3.1 Graphical visualization

Over time, information systems consolidate a group of basic functionalities and new functionalities are added as needed. GestBarragens is no different. One of the most used ways of data representation is obtained through graphs. An application was developed that allows representing, in series, the time evolution of measured quantities in the various instruments. This application also allows exporting data stored in the system to other CAD applications in order to make it possible to use other graph types. Thus, each user can

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take advantage of the tools that best serve their purposes of representation, such as CAD application, GID[4] or ParaView[5]. This application allows the user to:

- Draw time series of the results for all the instruments.
- Choose between automated or manual data collection.
- Create and save the settings to generate new diagrams, such as scale, size of the grids, the name of the graph and instruments to represent.
- Choose the date range represented in the diagrams.
- Export drawings in DXF format and data tables to Excel.
- Save the preferences of each user.

3.2 Quantitative analysis

This application allows the use of statistical models constructed by quantitative analysis methods, which are based on the establishment of functional relationships between observed responses and loads. These models consider that the total effect observed during a limited time period at a specific point can be approximated by the sum of three effects: the elastic effect of hydrostatic load; the elastic effect of temperature, depending on environmental thermal conditions; and a time effect, function of time, considered irreversible (Figure 6). As they provide a separation of the effect associated with each of the main loads, these models are of utmost importance in the interpration of dam behaviour and allow a first and quick validation of monitoring data.
This application provides tables and graphs in PDF format with all the information needed (Figures 7 and 8).

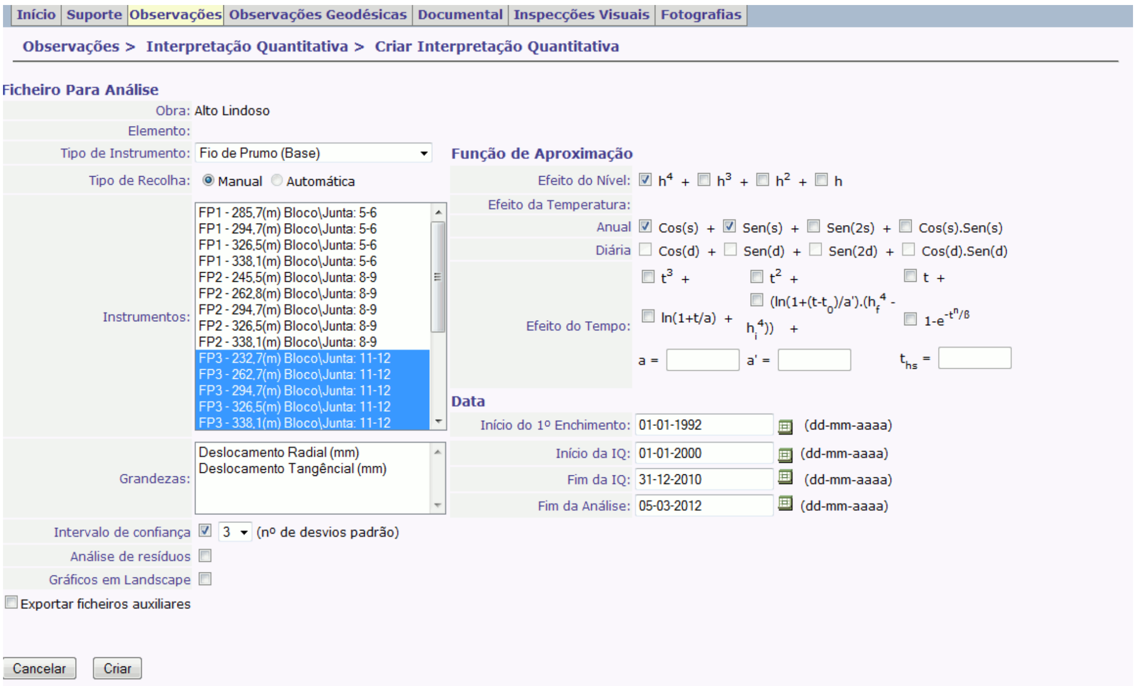

Figure 6 – Interface of the quantitative interpretation application.

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[4] http://gid.cimne.upc.es/
[5] http://www.paraview.org/

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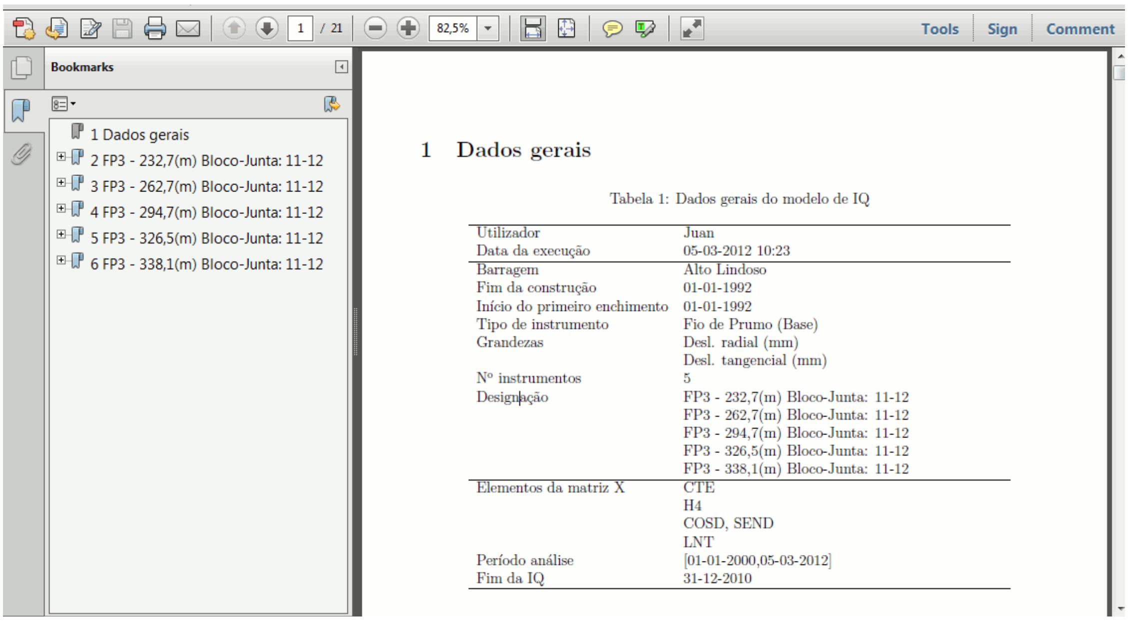

Figure 7 – Example of a main page of a PDF file with a quantitative interpretation analysis.

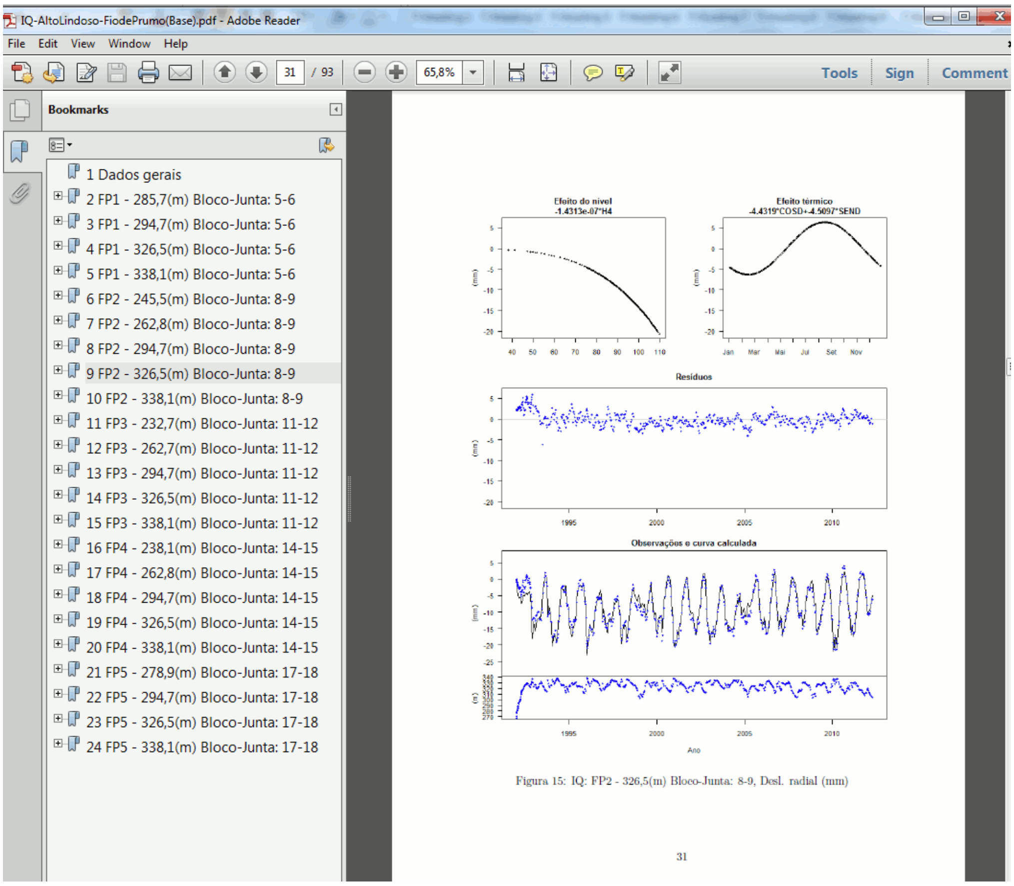

Figure 8 – Example of a graphical result of a quantitative interpretation analysis.

3.3 ADAS and MDAS comparison

This application (Figure 9) characterizes differences between measurements obtained by MDAS and ADAS based on historical data. It is based on the fact that the two sets of data (MDAS and ADAS) measure the same phenomena and should follow similar statistical distributions, including, in particular, similar averages, variances, and high correlations.

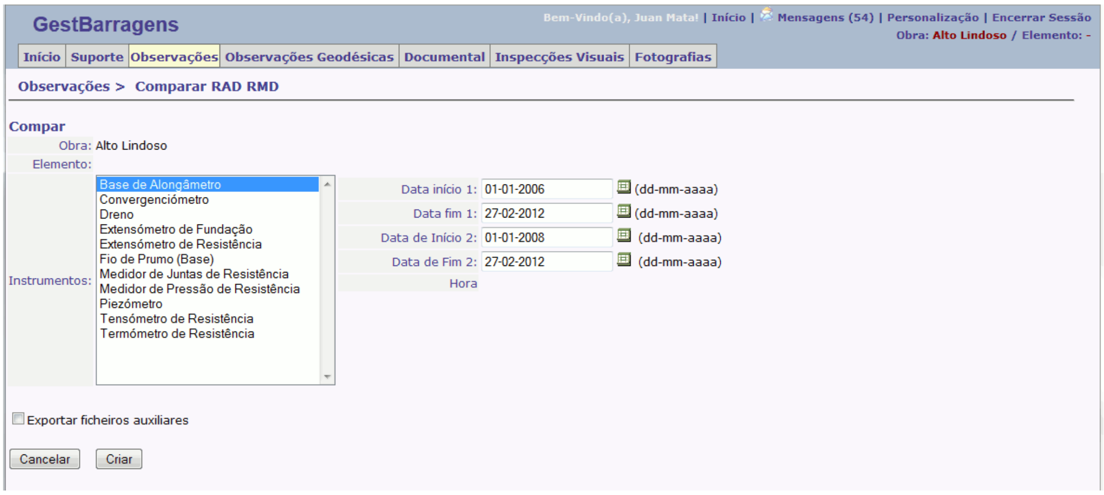

Figure 9 – Interface of the ADAS and MDAS comparison application.

The identification, for each measured quantity, of the potential sources of error is based on joint data analysis through the construction of graphs and tables with the calculation of averages, variances and correlations in the ADAS and MDAS data (Figure 10).

3.4 Warning management application

As referred, an increased number of monitoring data is loaded in GestBarragens every day, mainly from ADAS (and this number will increase after the conclusion of the new dams under construction), making a human validation of all the results impossible.

So, a timely validation of all this data requires, at least in a first phase, automated procedures to compare the monitoring results with limits defined in function of the main loads. Although for some quantities it is possible to establish limits based in behaviour models, for instance quantitative analysis interpretations, it is not possible to use this kind of model for other quantities.

GestBarragens provides a warning management application that, through the verification of validation limits predefined in function of the monitoring values recorded each month (Figure 11), validates all income data and sends a notification to the responsible for the dam safety if the observed values overpass the referred limits (Figure 12). Although almost all warnings refer to observations made with singular load conditions (for instance a water level atypical for that month), this application is useful to prioritize the attention of the technicians on the most unusual situations.

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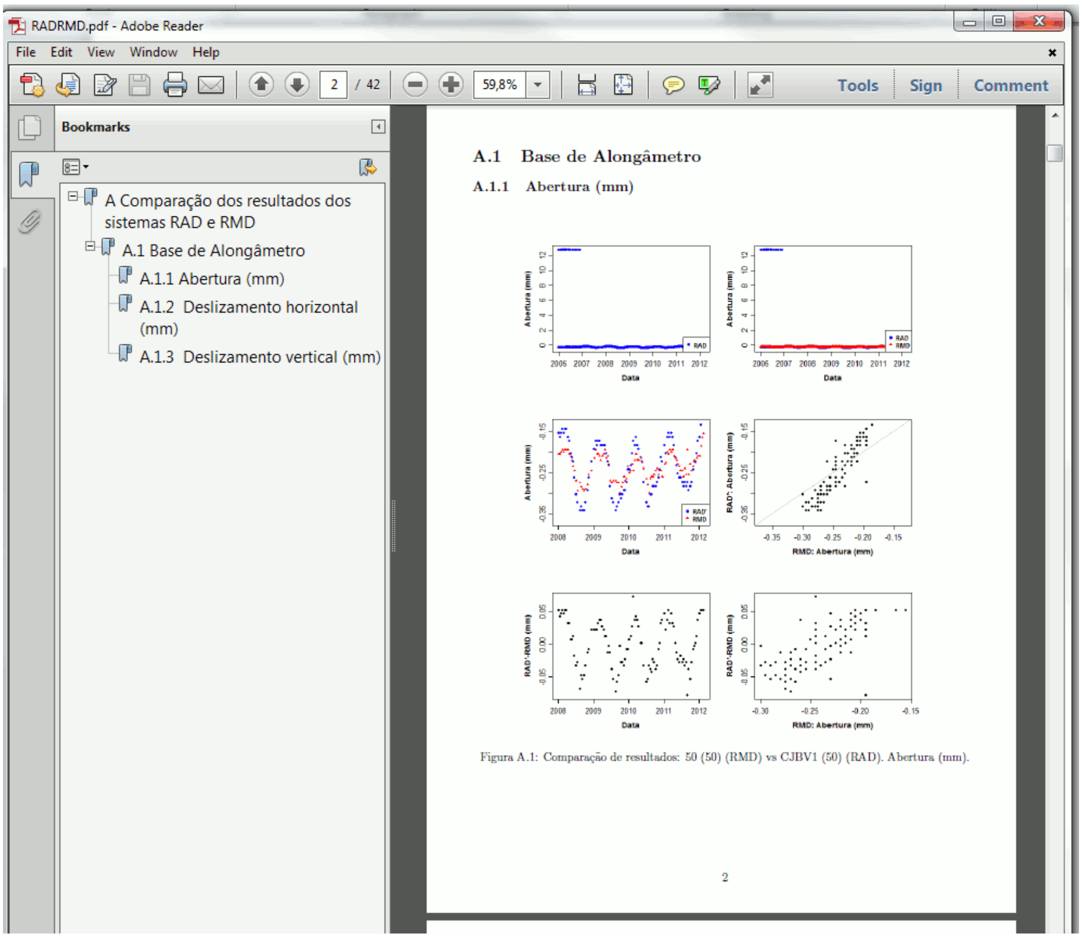
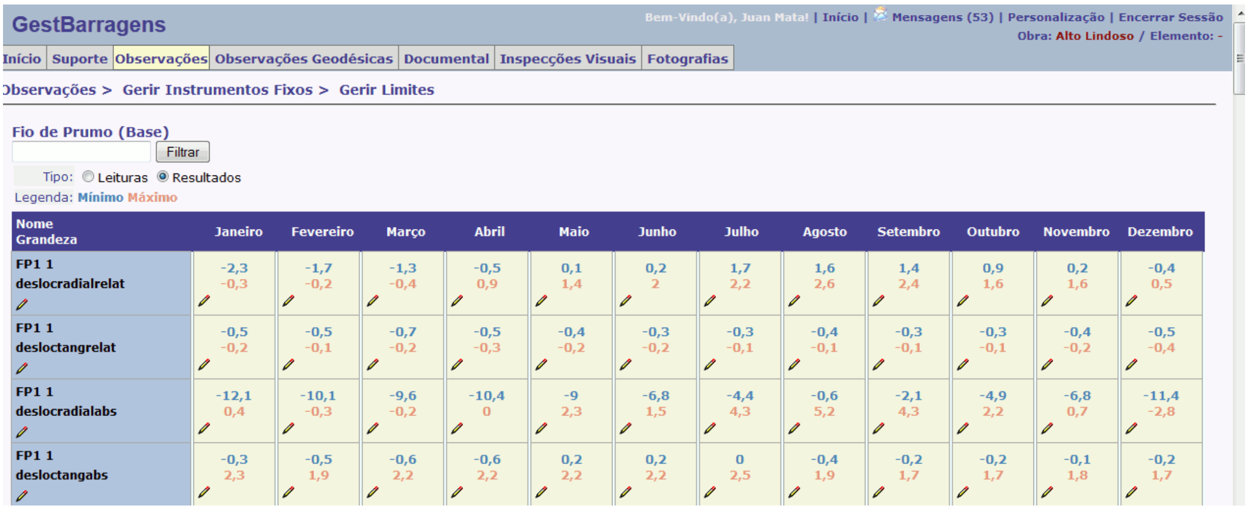


Figure 10 – Comparison of quantities measured by ADAS and MDAS.



Nome Grandeza	Janeiro	Fevereiro	Março	Abril	Maio	Junho	Julho	Agosto	Setembro	Outubro	Novembro	Dezembro
FP1 1 deslocradialrelat	-2,3 -0,3	-1,7 -0,2	-1,3 -0,4	-0,5 0,9	0,1 1,4	0,2 2	1,7 2,2	1,6 2,6	1,4 2,4	0,9 1,6	0,2 1,6	-0,4 0,5
FP1 1 desloctangrelat	-0,5 -0,2	-0,5 -0,1	-0,7 -0,2	-0,5 -0,3	-0,4 -0,2	-0,3 -0,2	-0,3 -0,1	-0,4 -0,1	-0,3 -0,1	-0,3 -0,1	-0,4 -0,2	-0,5 -0,4
FP1 1 deslocradialabs	-12,1 0,4	-10,1 -0,3	-9,6 -0,2	-10,4 0	-9 2,3	-6,8 1,5	-4,4 4,3	-0,6 5,2	-2,1 4,3	-4,9 2,2	-6,8 0,7	-11,4 -2,8
FP1 1 desloctangabs	-0,3 2,3	-0,5 1,9	-0,6 2,2	-0,6 2,2	0,2 2,2	0,2 2,2	0 2,5	-0,4 1,9	-0,2 1,7	-0,2 1,7	-0,1 1,8	-0,2 1,7

Figure 11 – Threshold definition interface.

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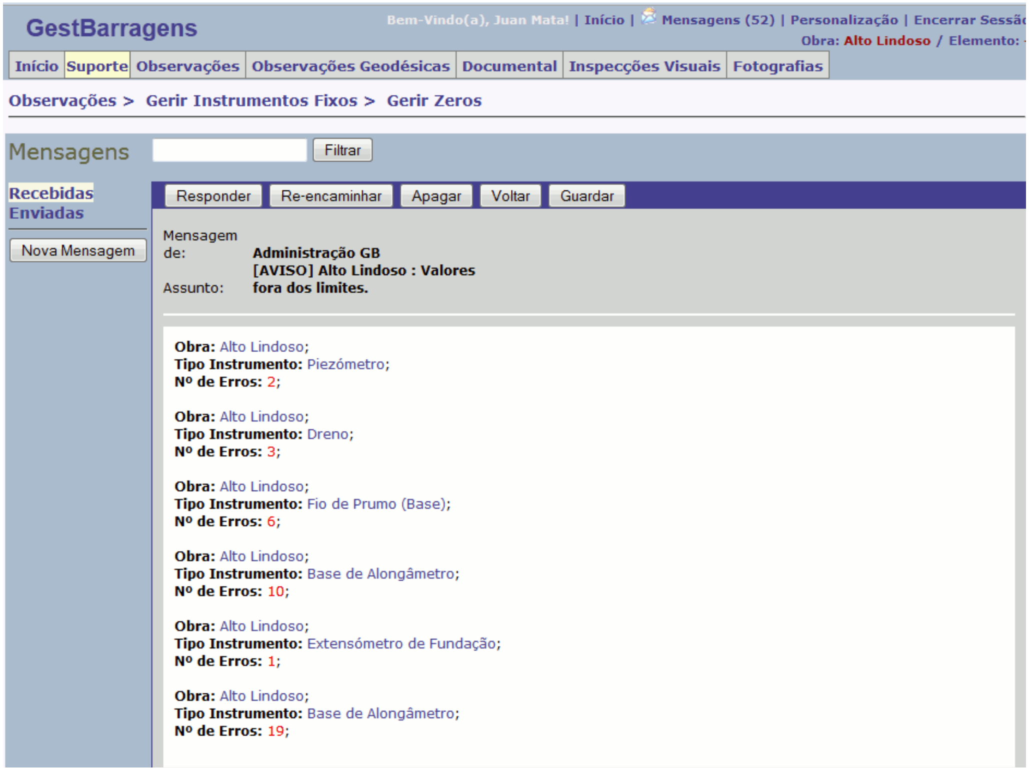

Figure 12 – Example of message application interface.

5 Conclusion and future developments

The core of dam safety activities includes, among others, the analysis of monitoring data collected along the life of the structures and the comparison between monitoring data provided by automated and manual data acquisition systems and corresponding results obtained with behaviour models, which are the base of a timely evaluation of safety conditions. This evaluation requires quick and easy access to all data, which cannot be done without appropriate information systems for data archiving, representation, and interpretation.

These are the main goals of GestBarragens, a modular system whose design allows an increase of its capabilities in accordance with the appearance of new types of instruments and the development of new tools. It is a web-based system that can be accessed everywhere and that does not require the installation of specific software in the user's machines.

Actually, the core of the system is the observation module, for the archiving, management and representation of monitoring data, but since its beginning the addition of new modules for several kinds of activities, such as the management of physical and numerical models and of geodetic monitoring systems, the archive of laboratory and in situ material tests, etc., has been planned.

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