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Developing a Computerized Aging Management System for Concrete Structures in Finnish Nuclear Power Plants

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Abstract. Finland has four nuclear reactors units in two power plants. The first unit started operation in 1977 and in the early 1980's all four units were in use. During the last few years the aging management of the Nuclear Power Plant's (NPP) concrete structures has grown an important issue because the existing structures are reaching the end of their licensed operating lifetime (about 40 years). Therefore the nuclear power companies are developing aging management systems to avoid premature degradation of NPP facilities and to be able to extend their operating lifetime. This paper is about the development of a computerized ageing management system for the nuclear power plants concrete structures. The computerized ageing management system is built upon central database and implementation applications. It will assist the personnel of power companies to implement the aging management activities at different phases of the lifetime of a power plant. It will provide systematic methods for planning, surveillance, inspection, monitoring, condition assessment, maintenance and repair of structures.

1 Basic idea of the computerized ageing management system

In context with applying an extension to a plant operating license it is especially important for the applicant to know the current condition state of concrete structures. That is only possible by continuous inspection of structures and a management system able to store and treat the inspection reports in a systematic way. An applicant of a licence shall be able to present a comprehensive ageing management programme with a description of how the design and qualification of the components and structures, their operation and operating experience, in-service inspections and tests, and maintenance are integrated logically and systematically [1].

The idea is to build up a software platform in respective to the ageing management system activities recommended by the IAEA Safety Standards [2]. The computerized ageing management system provides access to the structural, material and environmental information and to various design applications with appropriate methodologies and optimisation processes, which are required for the designers and maintainers of a nuclear power plant. It will also provide the basis for planning, surveillance, quality management, inspection, monitoring, condition assessment, maintenance and repair of structures. The basic idea of the computer aided IAEA ageing management system is shown in schematically Fig. 1.

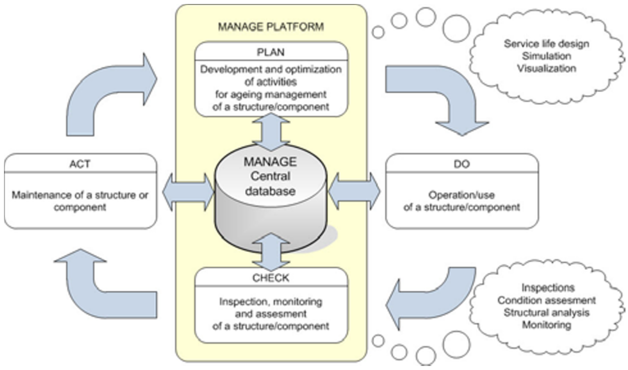

Fig. 1. Basic idea of the computerized ageing management system (CAMS).

2 Computerized ageing management system platform

The computerized ageing management system is accessed through the Graphic User Interface (GUI) which connects the user to the various applications and the central database. The applications are currently the visualization module, the ServiceMan tool for life cycle analysis [3], and the inspection database access module. An overview of the computerized ageing management system platform is presented in Fig. 2

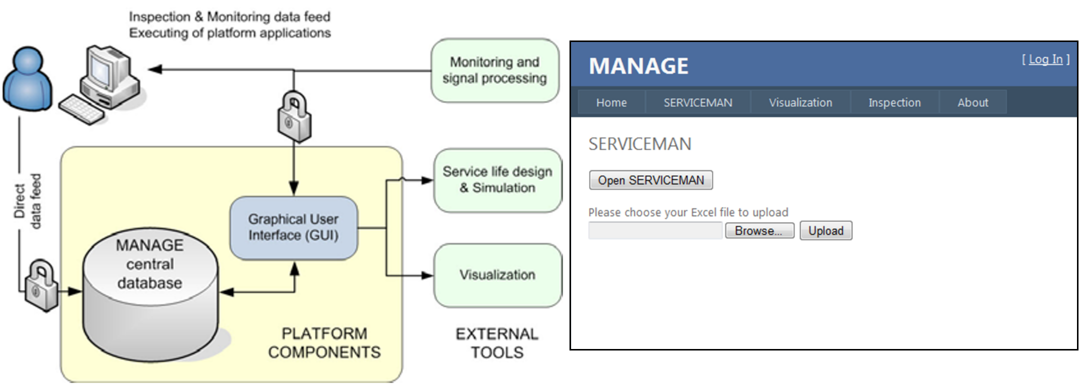

Fig. 2. Overview of the computerized aging management system platform.

2.1 MANAGE central database

The MANAGE central database is developed for assembling and systematically organizing the information gathered from structural design, maintenance activities, repairing of nuclear power plants (NPP) structures, operating and environmental condition, in-service performance and other type of data.

The goals and objectives of the MANAGE central database are to (1) collect the essential and up-to-date data of the condition and the performance of the NPP concrete structures, (2) store and update these data effectively, (3) allow sophisticated search strategies, (4) produce detailed reports automatically for the condition and the performance of the NPP concrete structures and (5) enable data transfer to other software for further analysis: for example act as a data source for estimation of the service life of the NPP concrete structures.

2.1.1 *Analysis of the MANAGE central database*

The components of the aging management system central database are organized into a series of sub databases relating to the aging management system of the nuclear power plants concrete structures, as shown in Fig. 3. These sub-databases are:

- Visualisation database for dealing with the geometrical input and out for the visualisation tool.
- Service life management database for the input and output data for the service life calculation application (ServiceMan).
- Structural database for storing information about the structural types and components of the NPPs concrete structures.
- Inspection database for the data gathered from the investigation and the diagnosis of the NPPs concrete structures.
- Monitoring database for monitoring and simulating the performance of the NPPs concrete structures.

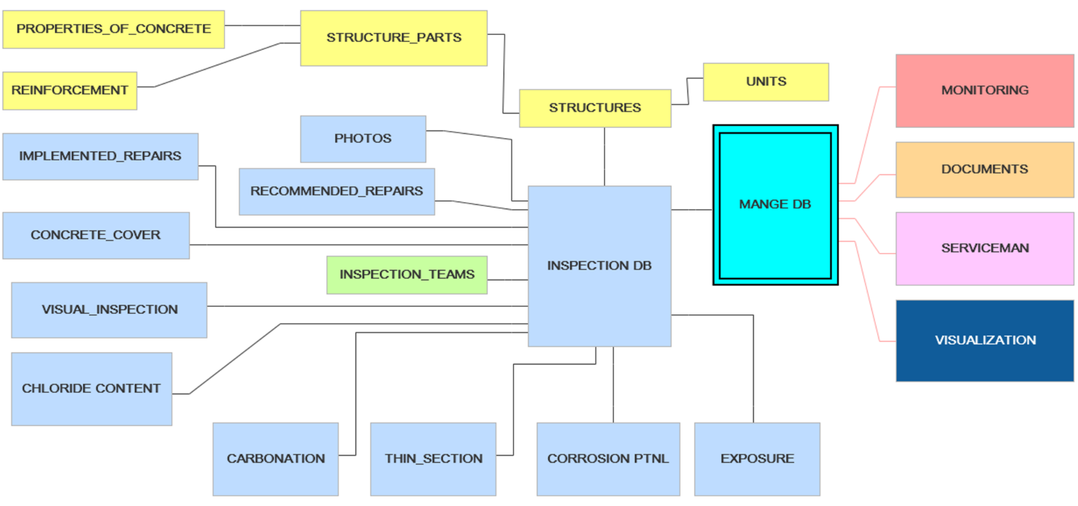

Fig. 3. Conceptual design of the MANAGE central database.

The authorized users of MANAGE central database come in two levels: the database administrators, and end users. Administrators are responsible for managing the database system and have full access to modify the database code and design. The end users are the persons that use the database for querying, updating, generating reports, etc.

The scope of visualization module is to propose an interactive system for visualization of nuclear power plant information. The proposed visualization environment is able to provide multi-scale representations driven by appropriate software that take advantage of the database content. It is also able to provide direct access to all the digital content, both in terms of physical access to the structural data files as well as in terms of searching and retrieving information.

The structural data of the nuclear power plants is classified into three levels. The first level describes the physical location of the plant and the number of units in each plant. The second level is dividing each unit into structures. A structure here is a generic term and it can have several, varying functions and can be made up of different materials. The third level is dividing the different structures into structural parts for the analysis and planning processes.

The service life management tool (SERVICEMAN) characterizes the utility of the nuclear power plants with the following information, (i) present condition state of structures, (ii) predicted condition of structures over the licensed operating time, (iii) predicted service life of structures and (iv) predicted maintenance and repairs and their timings during the whole operating time, and the costs of maintenance and repairs.

As shown in Fig. 4, a condition survey can be divided into a review of documentations, visual inspection, destructive tests, non-destructive tests and laboratory investigations. The main objective during the visual inspection phase is to locate and define areas where concrete degradation occurs by gathering readily available information on the structure. All of these symptoms could easily be detected visually by inspecting the concrete structure during an initial walk around.

Further investigations can then be divided into either advanced visual inspection or destructive and non-destructive testing of the concrete structures. Advanced visual inspection involves the accurate mapping of cracks, construction faults and all other surface defects noticed during the survey. Basic examinations such as the measurement of geometry and deflections, displacements, crack dimensions, location of spalls and disintegration could also be included. The purpose of NDT is to determine the various relative properties of concrete such as strength, modulus of elasticity, homogeneity, and integrity, as well as conditions of strain and stress, without damaging the structure [4].

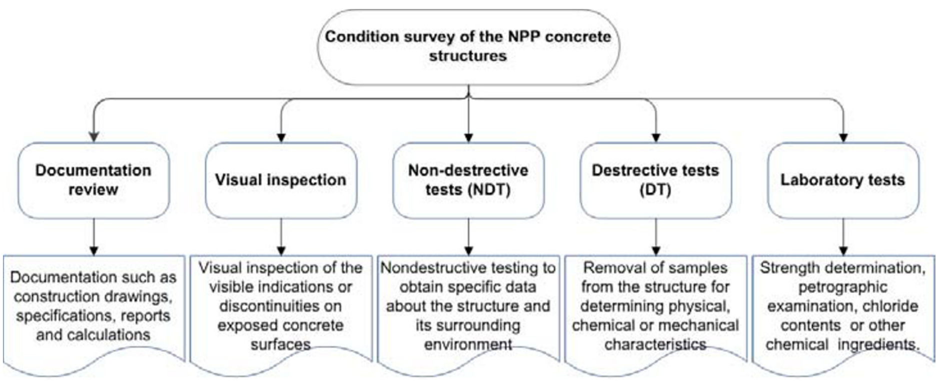

Fig. 4. The objectives of investigation and condition survey of concrete structures [4].

Nuclear power plants structural monitoring is implemented for detecting the changes to the material and geometric properties of a structural system, including changes to the boundary conditions and the system's performance. The monitoring process involves the observation of a system over time using periodically sampled measurements from an array of sensors, the extraction of damage-sensitive features from these measurements, and the statistical analysis of these features to determine the current state of system performance.

2.1.2 Design of the MANAGE central database

The design of the MANAGE central database involves two phases, the definition phase and the implementation phase [5, 6]. In the definition phase, the structure of the database is established. The implementation phase involves raw data collection, validation and harmonization for general use. The development of the central and inspection database begins with the conceptual design, then logical and physical design, and final system implementation.

The data modelling is one part of the conceptual design process. The data modelling focuses on what data should be stored in the database. To put this in the context of the relational database, the data model is used to design the relational tables. The data collected for the aging management system of the nuclear power plants concrete structures is analysed and arranged into data collections for each element of the central database. The conceptual data model identifies the highest-level relationships between the different entities of the MANAGE central database.

The logical designing of the MANAGE central database involves two processes. The first process is to understand the requirements of the end users such as the need for the database, the achievement of the database and what kind of the real-world process the database is designed to emulate. The second process is to create a technical solution – a set of tables, complete with columns, each of which has the correct data type. The logical design of the MANAGE central database is shown in Fig. 5.

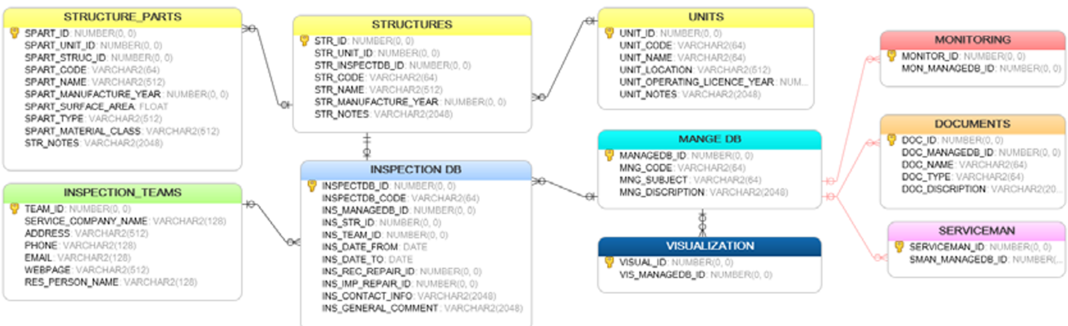

Fig. 5. Logical design of the MANAGE central database.

The system analysis is a logical description of the database data sources. The logical design includes the design of the database, specifications for data extraction tools, data loading processes, and database access methods. The physical design involves the creation of the entity/relation (E/R) model and the determination of data storage techniques.

Physical data model of the MANAGE central database represents how the model will be built in the database. A physical database model describes all table structures, including column name, column data type, column constraints, primary key, foreign key, and relationships between tables. The physical data model of the MANAGE central database is still under progress. An example of the physical design of the MANAGE central database using Oracle XE database application is shown in Fig. 6.

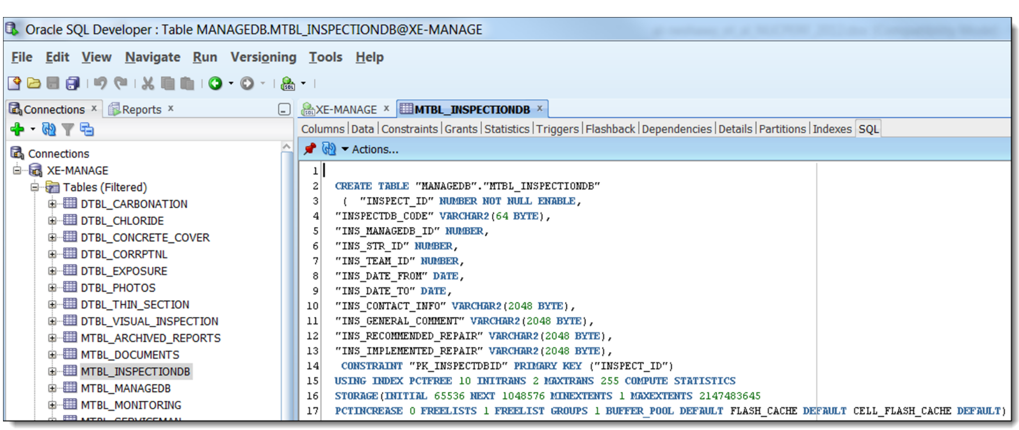

Fig. 6. Example of the physical design of the MANAGE central database.

2.1.3 Implementation and testing of the MANAGE central database

This database is developed to run on the nuclear power plants data management system computers. A user interface is provided in the form of edit screens of the MANAGE central database. Once the installation of the database is complete, the integrated system is tested. Training workshops is to be implemented by the design team for all user groups on the using of the MANAGE central database.

2.2 Service life management tool for life cycle planning

The service life management tool ServiceMan assists in the life cycle planning of concrete structures in nuclear power plants. It is able to predict the degradation of concrete structures and to evaluate the timing of necessary maintenance and repair actions over the remaining licensed life time of the plant or longer (extended life time). The tool can also be used for planning, organizing and optimizing the maintenance strategy of concrete structures in NPPs [7]. The service life management tool is developed using the Visual Basic for Application programming language. An interface between Excel and MANAGE central database is done through the GUI. The application can read and write from database and make calculations using ServiceMan tool. The interface between Serviceman and MANAGE central database is presented in Fig. 7.

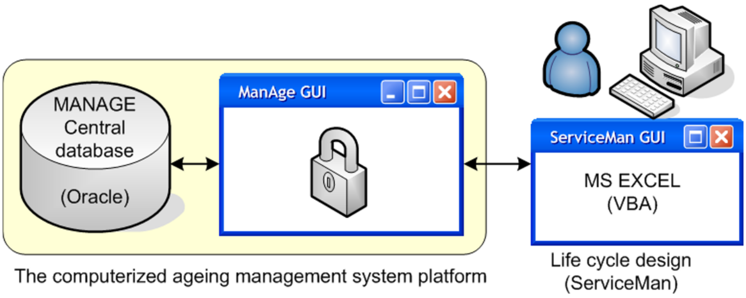

Fig. 7. Example of the physical design of the MANAGE central database tables and E/R relationship.

2.3 MANAGE Visualisation tool

The visualization of the NPP concrete structures is useful for the users to import the geometrical data of the structures and report the in-service condition of these parts as attached notes to the geometry drawings. The MANAGE platform is currently using the simplest way of implementing visualization by keeping the 2D and 3D geometry in its native format and using external visualization application that is able to interpret the data. Practically, any kind of original CAD file (e.g. DWG, DXF, DGN) can be stored in the central database and linked to the structure it represents. The platform interface will enable users to download process the drawing in an external application and then save the processing results and the original file in the MANAGE central database.

Using external visualization application brings always unnecessary costs since the drawings as well as the application have to be updated regularly. Moreover, the software provider of the application and the owner of the drawing's native format specification have to support this format in the future, otherwise it may become useless. Therefore the shift to integrated solution with unified and preferably open data format is foreseen. One of the possible file formats is IFC (Industry Foundation Classes) that is already well-established [8] and standardized [9].

2.4 MANAGE Monitoring of concrete structures

The thermal and moisture performance of the NPP concrete structures are monitored by using the one-wire technique. One-wire technology is used to connect the temperature and relative humidity sensors to a computer via a microcontroller. Special monitoring application is used for the temperature and relative humidity data acquisition and analysis. An interface between the monitoring application and MANAGE central database is done through the GUI. A schematic diagram of the monitoring system is shown in Fig. 8.

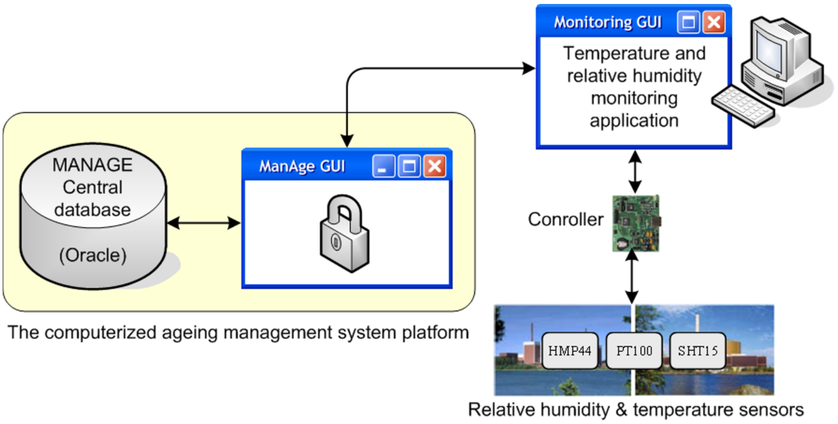

Fig. 8. Schematic diagram of the monitoring system.

3 SUMMARY

This paper presents the development of the computerized ageing management system which is a part of the research project "Aging Management of Concrete Structures in Nuclear Power Plants (MANAGE)". The computerized ageing management system consists of MANAGE central database and interface applications that connect several applications to the central database. These tools are condition assessment, monitoring, visualisation and service life assessment tool.

The components of the MANAGE central database are organized into a series of sub-databases relating to the aging management system of the nuclear power plants concrete structures. These sub-databases are user's management database, visualisation database, service life management database, structural database, inspection database and monitoring database.

The design of the MANAGE central database involves two phases: the definition phase where the structure of the database is established and the implementation phase that involves the raw data collection, validation and harmonization for general use. The development of the computerized ageing management system platform is still under progress. Once it is developed, the platform will be integrated to the expert system of the Finnish nuclear power plants in order to support decisions in ageing management tasks.

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