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THE TVO PIPING AND COMPONENT ANALYSIS AND MONITORING SYSTEM (PAMS)

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ABSTRACT

To make fitness, safety and lifetime related assessments for piping and components, the amount of necessary input data is considerable. At the same time it is essential that the data is reliable, up-to-date, well traceable and easy to obtain. Often the information that is necessary for a specific project has to be collected in a very short time.

This paper presents an outline of the contents of a piping and component database system, consisting of separate geometrical, material, loading, result and reference-document databases. The main contributors to this development have been TVO and VTT, but also smaller contributors are involved, like FEMdata. The system under development is intended to facilitate the analyses of piping and components and to generate well-documented appendices comprising input and output for these analyses.

KEYWORDS: database system, piping, components, geometry, properties, materials, design loads, combination of load-cases, automation of stress and fatigue analyses, ageing management, RI-ISI.

1 INTRODUCTION

In existing power plants, the number of people responsible for load, strength and vibration related projects might be very limited. This means that tasks related to obtaining starting points, doing analysis and preparing documentation might be the responsibility of just one or a few persons. They will get questions like:

- We want to make a change, what are the implications?
- We had an abnormal event, what are the implications?
- As part of the inspection planning we want to make a risk assessment, where do we get the starting points (RI-ISI)?
- We need up-to-date valve loading data to order a new valve, please supply?
- Will the existing piping system take the changed loads induced by the new valve and visa versa?
- During the inspection we found a crack, can we run until next year's outage or even longer?

These are short questions with often not much longer answers, but a lot of work and an adequate and up-to-date documentation are necessary to support the answer. The latter may be a real problem for several reasons, such as:

- Load and strength analyses for different systems have been done over tens of years time span.
- These analyses, often made by different companies, have been performed and documented by different persons in different ways using different tools and have even been archived in different ways and at different locations.
- During the lifetime of the plant, there may have been a power uprate, major piping and equipment exchanges and modernisation projects. The documentation may not have always been fully updated.
- Changes performed in the plant may not affect the as build structures, but may affect future changes.

Some or all of the above reasons may have led to a difficult-to-use load and strength archive. Still there may be many situations where reliable and up-to-date information is needed fast. For reasons like this the development of the

Piping and Component Analysis and Monitoring System (PAMS) was started at TVO more than 10 years ago and is continued still as a joint effort by TVO and VTT.

2 GENERAL INFORMATION WITH REGARD TO THE SYSTEM

The system presently under development is meant to contain all up-to-date information necessary to perform most of the standard analyses and monitor piping systems and components for an existing and operating plant [7]. For a start only the TVO OL1 unit was entered into the system. However also the OL2 and even the future OL3 plant will be entered. The system is basically an "as built" system and is not meant as a design tool although parameter studies will be possible. Therefore no flexible communication with CAD based design tools have yet been developed. This may however be the subject of future development as the use of PAMS during the design phase is considered.

All data in the system will be accompanied by the necessary information with regard to its source reference, dates, version and validity. In case the necessary historical data is entered in the database, it will be possible to generate models for every as-build situation that has existed under the history of the plant. This will be done utilising the actual construction date. It will also be possible to keep an "as-designed/standard" version and an "as-built/measured" version. The latter could for instance contain updated support information that has been acquired through vibration measurements and modal correlation [3]. Other versions could be kept as well. It is clear that this would require very sophisticated bookkeeping and the development of this part of the program will not be started before the more "technical" side has been developed much further.

In case a load definition is changed, a new load analysis and load summary report will be issued. These will make the old reports obsolete in the document database. This is done automatically in case a new revision of the old report is issued and has to be done by the user in case a completely new document is issued. Thus the system will "know" that the load analysis and subsequent strength analysis and the associated results are not valid anymore. The user of the system will be informed about this and it can also be seen from the list of source references in the analysis input file. It is very important that subsequent analysis, like fatigue and fracture analysis, uses up-to-date input. In that way, the remaining lifetime can be estimated and the need for further actions determined. And with a growing importance of parameter studies and probabilistic analysis it is more and more important to have the input data to the analyses in a flexible and readily available digital format [9].

The system will be built up of separate and stand-alone databases and program modules. The size of these databases and program modules were kept as small as possible while still maintaining a complete and logical entity. In the future they may even be divided into even smaller sub-modules. Thus, different parts can be used for their own purpose without the whole system having to be completed or in use. Furthermore it is important that different persons can simultaneously develop different modules or make version updates. This philosophy was developed early on in the project and was deepened more and more as it became obvious that independency shall be made as strict as possible. The next development in this area will be the independence of the development program language. This is necessary as the programming languages are developing very fast and modern tools shall be used as they give more possibilities. As the number of people that is simultaneously involved in the project is rather restricted it is impossible to always reprogram the program modules using the latest software, but the best software tools shall be used to new modules or major updates of existing modules.

Commercially available programs will be used as much as possible (database development, piping analysis, FEM, CFD, EN/PED related component analysis etc.). As the updates of these programs are handled by professional organizations adaptations to the latest developments will always be available. Only for very special purposes, customised software will be developed, like crack growth documentation and event monitoring.

3 VALIDATION AND VERIFICATION OF THE PAMS SOFTWARE

It is clear that at present all software development is subject to rigorous validation and verification programs. Taking into account that the system is developed by a rather small group and has no real quality system connected to it, a different approach had to be chosen. The main idea to this approach is that the user of the system has to take care of the validation and verification of the indata files made by the system like it was made directly from the background documentation and drawings by him or herself. In order to facilitate this, the indata-files contain specific references to all source documentation. Basically the indata-file will be build up as follows:

* General information with regard to the analysis.

* A complete and numbered list of all source references that are related to the indata presented in the indata-file. In this list it will be indicated in case the source document is obsolete. It is obviously still the responsibility of the user to decide whether or not to continue with the analysis.
* The indata, accompanied by numbers referring to the source references.

In this way it will be possible to very efficiently check the information contained in the indata-file and the responsibility of the PAMS-system will be reduced to the level of an archive dumping information onto a file.

With regard to the programming itself, the programmer will still perform extensive testing of the modules that are developed. Starting from language checks by the program development tools small parts of the modules will be run. Once larger parts are run the visualisation tools that are part of most modules will immediately provide feedback as to whether the module is functioning well. So these visualisation tools are not only of help to the users of PAMS, but also to the programmers. The figures that are presented later on in this article show some examples of these visualisation tools.

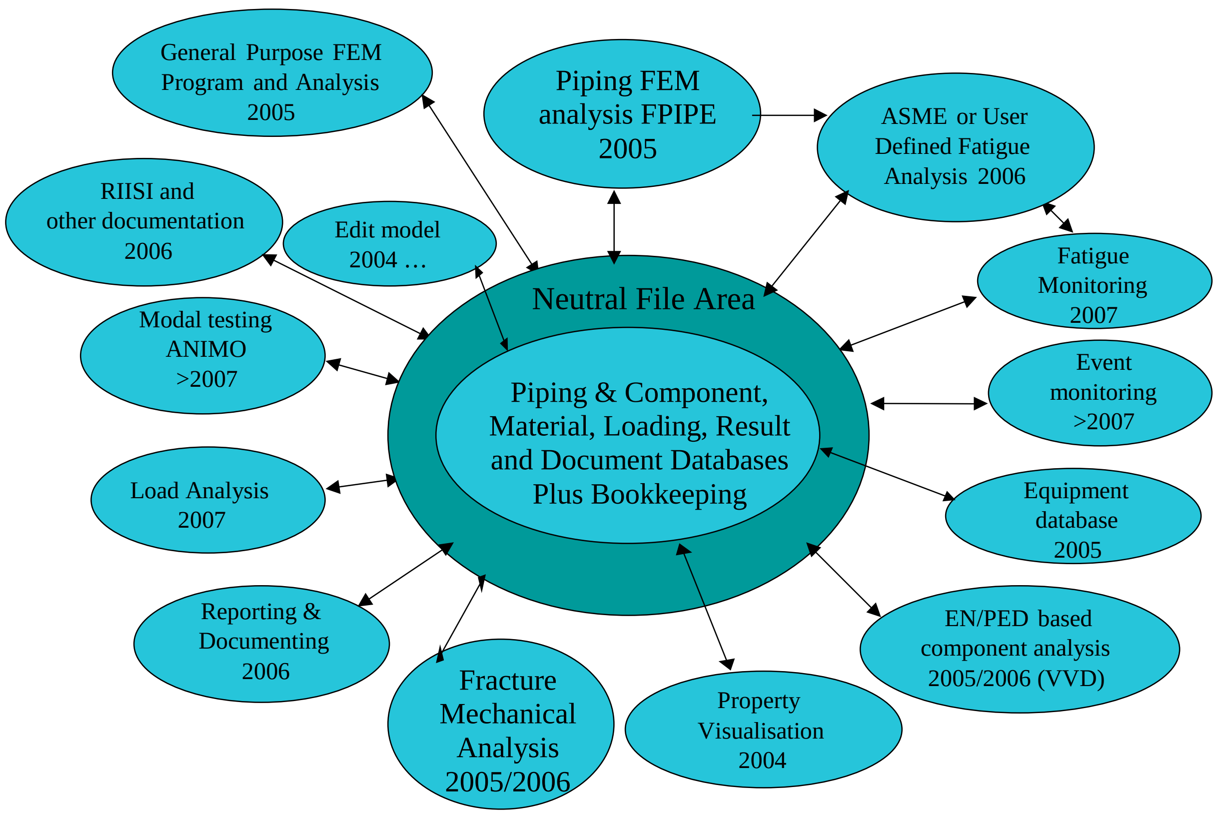

Fig. 1 Structure of the pipeline and component analysis and monitoring system

The pipeline and component analysis and monitoring system consists of the following main parts:

1. Database area

The core of the system consists of several interconnected databases and their user interfaces, and is called the database area. The contents of some of these databases are described in more detail in the next sections. The different databases are edited with their own user interface modules that are designed to give visual information alongside alphanumerical. According to the present plans, control and navigation is, as far as possible, handled from this level. The database area is envisaged to contain the following databases developed using Microsoft® Access 2000 [8]:

1.1. The piping and component database, containing information on or a reference to the geometry, material, contents, isolation, loading, boundary conditions, detected cracks etc. It will even be possible for the user to add new properties to nodes and elements without having to do any actual programming. This feature was already implemented for piping elements and includes the visualisation of the new property by means of colours. During this year this feature will also be implemented for nodes.

1.2. The material database, containing information with regard to the materials referred to in the piping database. These properties may be properties obtained from source documentation or measured ones.

1.3. The loading database [1] containing information with regard to loads, loading combinations, ASME design and service level limits, design events and the history of occurred events. During this year great effort will be made to enter this information into the system.

1.4. The result database containing all significant information with regard to the analysis results. Thus it is possible to perform subsequent analysis without first having to go through the stress analysis again. This development was started in 2003 and shall, according to the planning, be finalized in 2005.

1.5. The document database contains the documentation that is related to the above items. Input made to and documentation produced by the technical databases will refer to the associated documents from this database. The basic idea is that all information shall be entered to the database accompanied by a link to the associated valid source reference.

For the moment items 1.1, 1.2, 1.3 and 1.5 have been developed to such an extent that database/FEM-program data exchange testing can be performed. Actual plant data was entered to be able to do this testing on a realistic basis. Loading related data has only been entered for testing purposes. During the year 2005 item 1.4 will be developed and during 2006 the system will be tested extensively using only actual plant data.

2. **<u>The application programs</u>**

At the outer border of the system are the application programs. This is called the application program area. As far as possible these programs shall only use data from the databases and run in batch mode. However, if necessary, data from external sources can be used as well. This may be the case when data that is not relevant to the database is obtained with special purpose programs and used for studies with the actual plant data. Also large result files of for instance thermo-hydraulic analysis may be stored as files only. Basically, the application programs can be of two types:

2.1. Commercial programs to perform structural, flow, thermal, fatigue, fracture mechanical and/or other analyses.

2.2. Tailor made analysis modules to perform post processing of previously obtained results, event monitoring, fatigue monitoring, crack growth monitoring, definition of inspection intervals etc.

3. **<u>The neutral file area</u>**

So-called “neutral” files are used as an interface between the databases and the application programs. As simple to use and straightforward neutral files containing only the minimum necessary amount of data do not yet exist, a more basic approach was chosen. In this system a neutral file is defined as the batch-input file controlling the flow of and supplying the necessary input data to the application program. In fact this is the batch indata file and as such is made according to the rules given in the user manual of the application program. This means that an interface module is necessary to write the necessary data from the database into the neutral file and in the right format. This interface module was designed in such a way that the user of the database package, i.e. the engineer responsible for the analysis, and not the programmer behind it defines the layout, format and contents of the neutral file. Thus only one interface program module is necessary for all the possible application programs that are used through the database. A similar interface module will be made to extract significant data from the analysis program results back into the database.

4 ELEMENTS OF THE DATABASE SYSTEM

<u>4.1 Piping and component database</u>

The piping and component database consists of the geometry and is linked to all other information necessary to perform an analysis with one of the application programs. Therefore, it also contains information on for instance welds and equipment, loads, boundary conditions and the materials of, in and around the piping. The organisation of the piping and component geometry in the database is similar to the organisation of the TVO drawings that are associated to the piping systems and components and is thus well recognisable to all possible users at TVO. Also future digital drawings will be organised in the same way. The organisation is as follows:

* At the first level, the system is found with the system identification number. Examples are the feed water system (system 312) and the relief system (system 314). Drawings at this level are called system isometrics.
* At the second level, the main parts of the system are found. The feed water system for instance is divided into parts called 312 BAA-1, 312 BAA-2, 312 BCA-1 and 312 BCA-2. There are no separate drawings at this level.
* At the third level, the piping geometry is divided into isometric drawings and associated part lists. At this level, the drawings have a part name followed by a sequential number, like 312 BCA-2-1, 312 BCA-2-2 and 312 BCA-2-3. This is the lowest and most detailed level of piping drawings available at TVO. Geometry and general material and welding related information is entered at this level and linked to the isometric drawing in the document database. Every isometric drawing is entered into the system separately. Also the connectivity between the different isometrics is given.

In the database the geometry is described according to normal FEM convention. This means that the database contains nodes and elements with all sorts of associated properties. In this context "elements" refer to basic geometrical elements like straight piping or tank parts, pipe bends, reducers and even tank heads. On the other hand "nodes" refer to the point in the space that are necessary to define the location of these elements. This all means that a new element starts whenever there is a change of any of the element properties. Separate nodes will also be appointed to welds or nodes that shall be analysed later on. Every structure in the database is build up of these nodes and elements and the way different parts of piping and components can be entered is bound by a set of rules. Taking all rules into account is done by the person entering the data and is very important when making the database model. While entering data into the system this is visualised and it is easy for the user to see whether the data is sound, see figure 2, below.

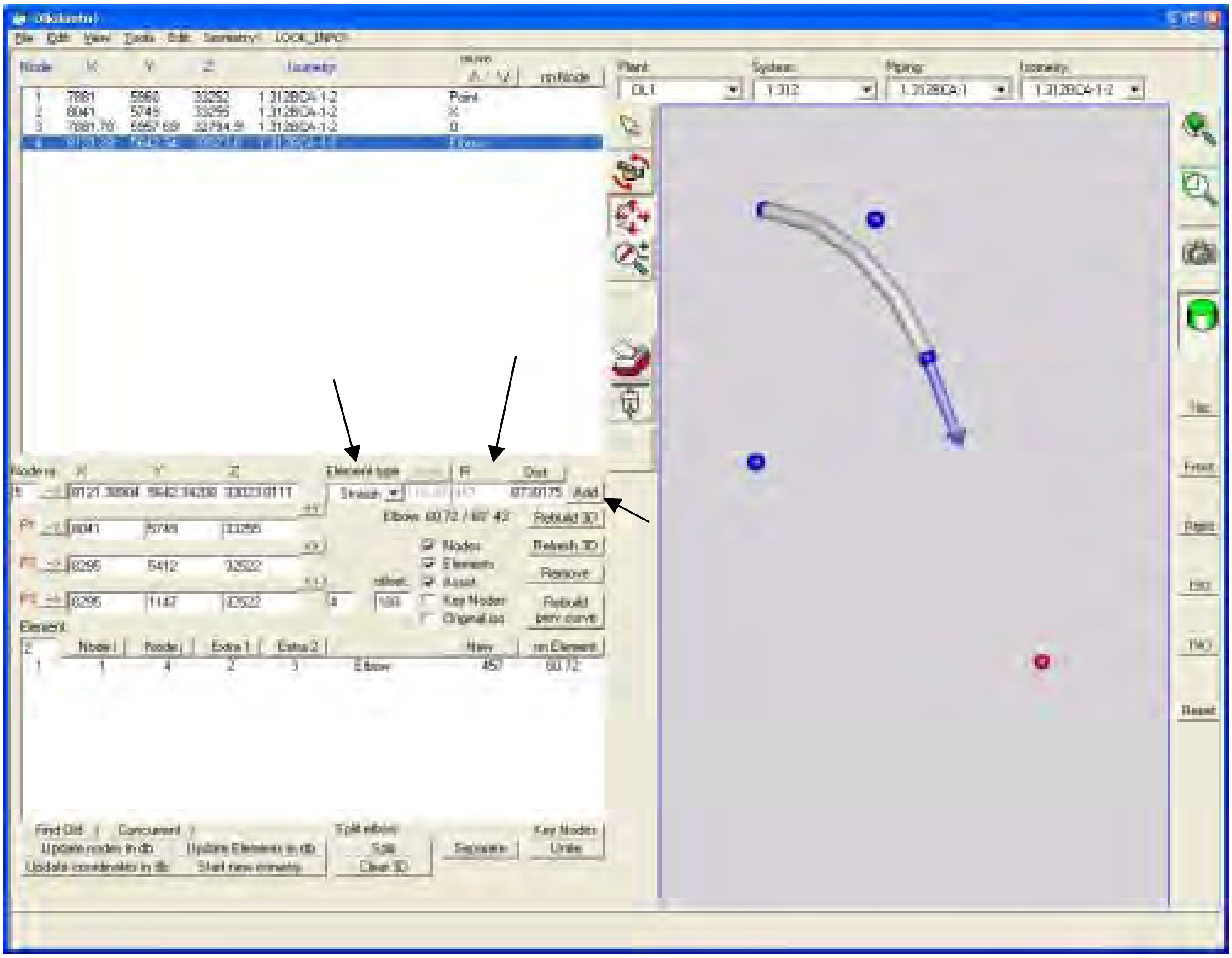

Fig. 2 Visualisation of piping geometry input while using the geometry pre-processor

By now it should be clear that the database model is not meant to be equal to the associated finite element model. For piping and component models it is meant to contain an as-build or as-designed representation of the geometry, see also figure 3. This means that for instance additional nodes that are necessary to perform a sound dynamic analysis will not be added in the database building stage but in the model building stage. To do this several approaches can be chosen:

1. Standard division of the elements in part with a maximum length that is defined by some rule. Some piping programs can also handle this, but this is also an option in the module generating the neutral file.
2. Choose a finite element program that automatically refines the analysis until a sound solution is found. For this case the FPIPE program [4] could be enhanced with routines to automatically change the model and, by the use of an iterative solution method, come to an optimum solution.

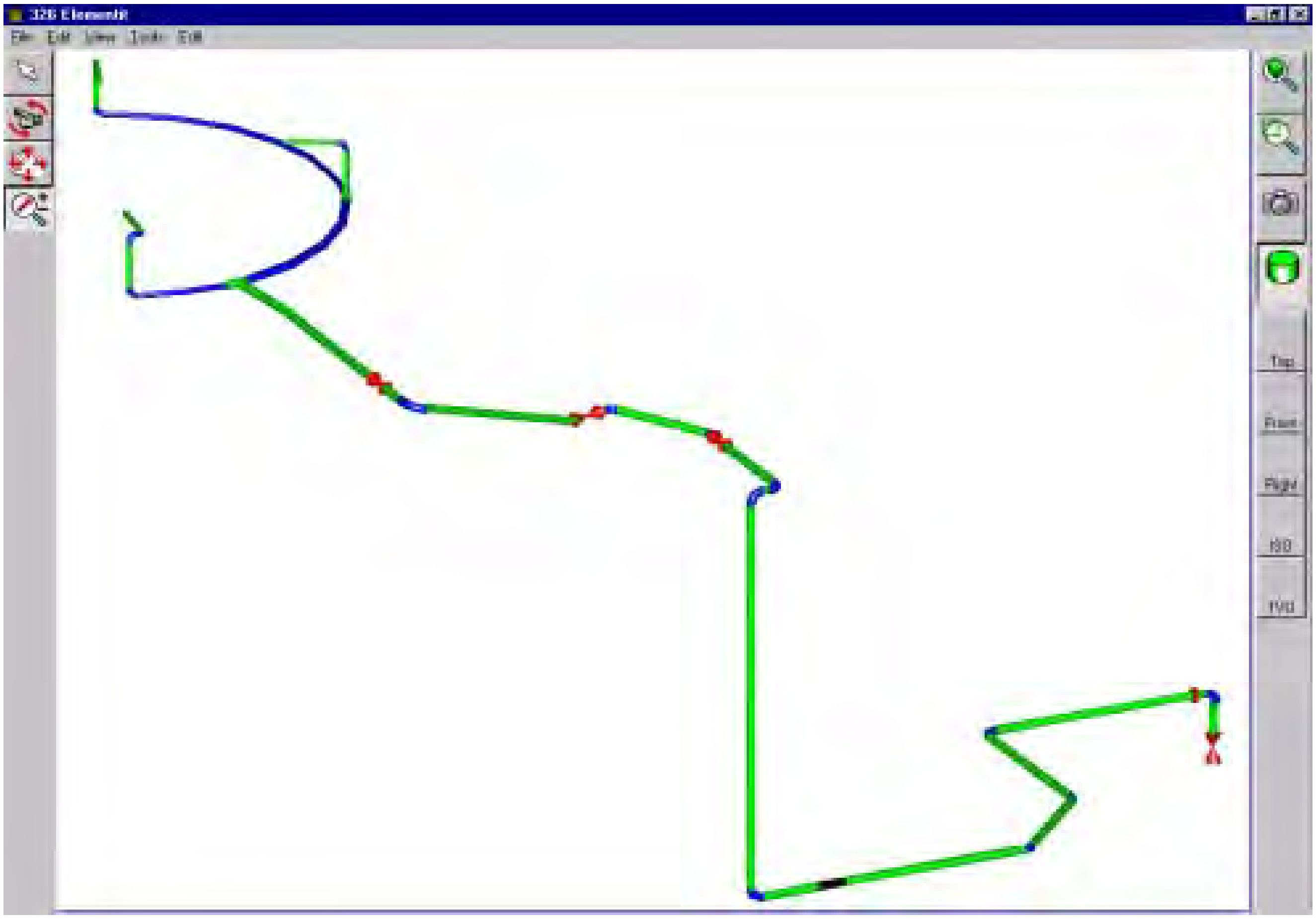
Fig. 3 Visualisation of piping using the piping database user interface

Examples of information associated with a node are:

* The node number, co-ordinates in the plant co-ordinate system and isometric number (document database ref.)
* Node element information like mass and associated stiffness and centre of gravity (simple valve case)
* Support information like stiffness, pipe whip restraint, stiffness matrix, gap or damping
* Reference to weld drawings inclusive weld (repair) information and dates
* Information as to what type of analysis shall be performed at the node (stress check, crack growth analysis, fatigue check etc.)

Examples of information associated with an element is:

* The element number, the nodes at the end of the elements and the isometric(s) to which the element belongs. As the isometrics can be found from the document database only a link to this database will be made.
* Cross sectional information like material designation, diameter and thickness of the pipe or other cylindrical part, the content designation and the isolation material designation. It should be noted that the designation of the material, contents and isolation is not more than a link to the material database. In this way one of the most important rules of database design, namely “no data shall occur more than once in the database system”, is fulfilled.
* The element type information like straight pipe, bend, T, reducer, expansion joint etc.

Even very specific information like detected or postulated cracks can be entered into the database, see figure 4. In this way the system can also be used to perform bookkeeping of all the findings made during the inspections.

Furthermore, it will be immediately available to perform subsequent analysis. During the, nowadays very short, outage, speed of analysis and adequate documentation is of great importance. As all the related starting points for such a subsequent analysis will be in the system the analysis should in fact not be more than a press-on-the-button.

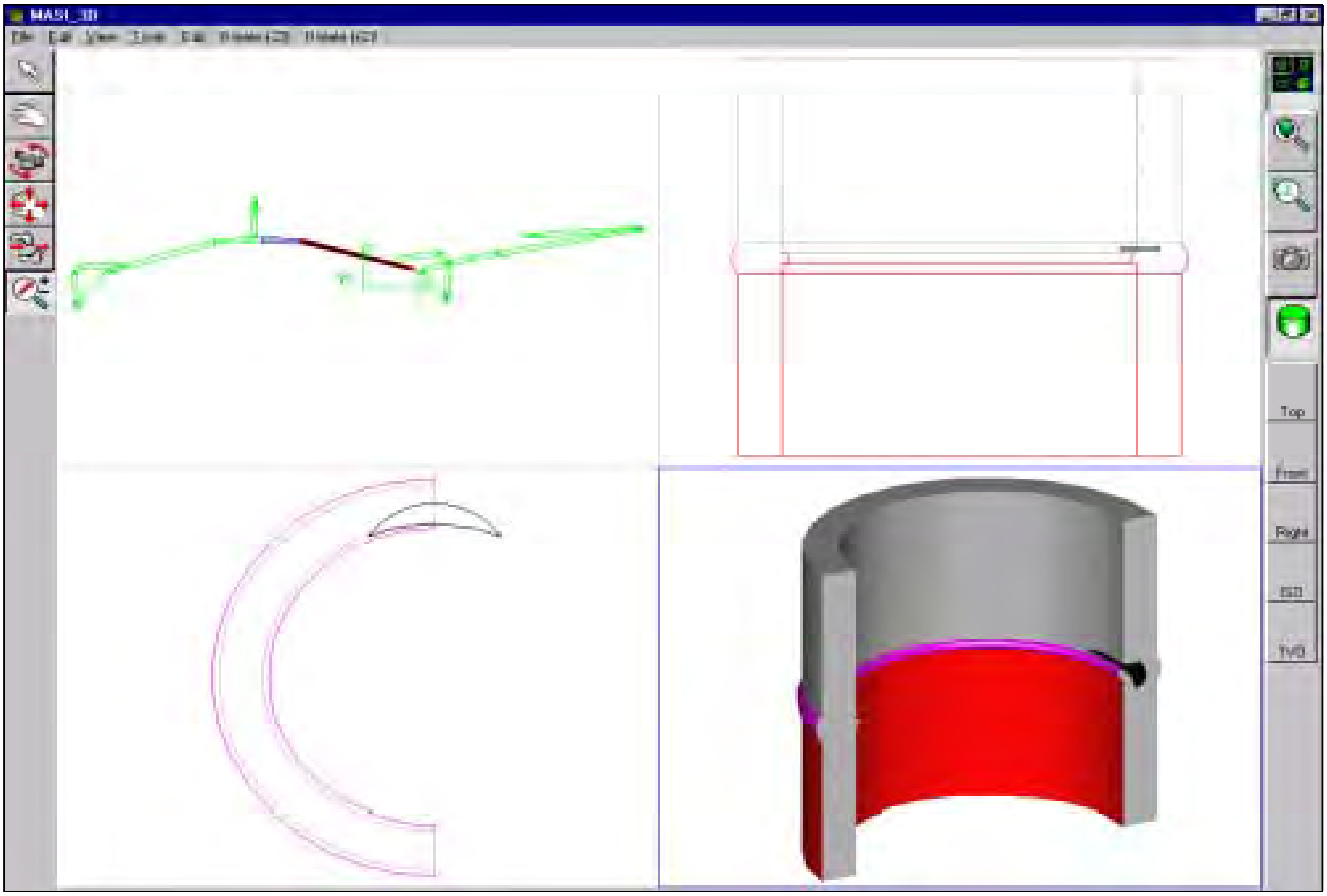

Fig. 4 Visualisation of a crack at a weld entered in the database.

4.2 The material database MATDBS

The material properties of the normally used materials at TVO are gathered in a database called MATDBS. The material database has been completely revised since the first revision was developed long ago. The material database is discussed in more details in [11]. A short description is given below.

It contains the material properties for pipelines and components and as such has a wider application area then for piping systems only. Components and system are defined in the pipeline database. Like the pipeline database the material database will have a combined alphanumerical and graphical user-interface to show the user which changes are made, see figure 5.

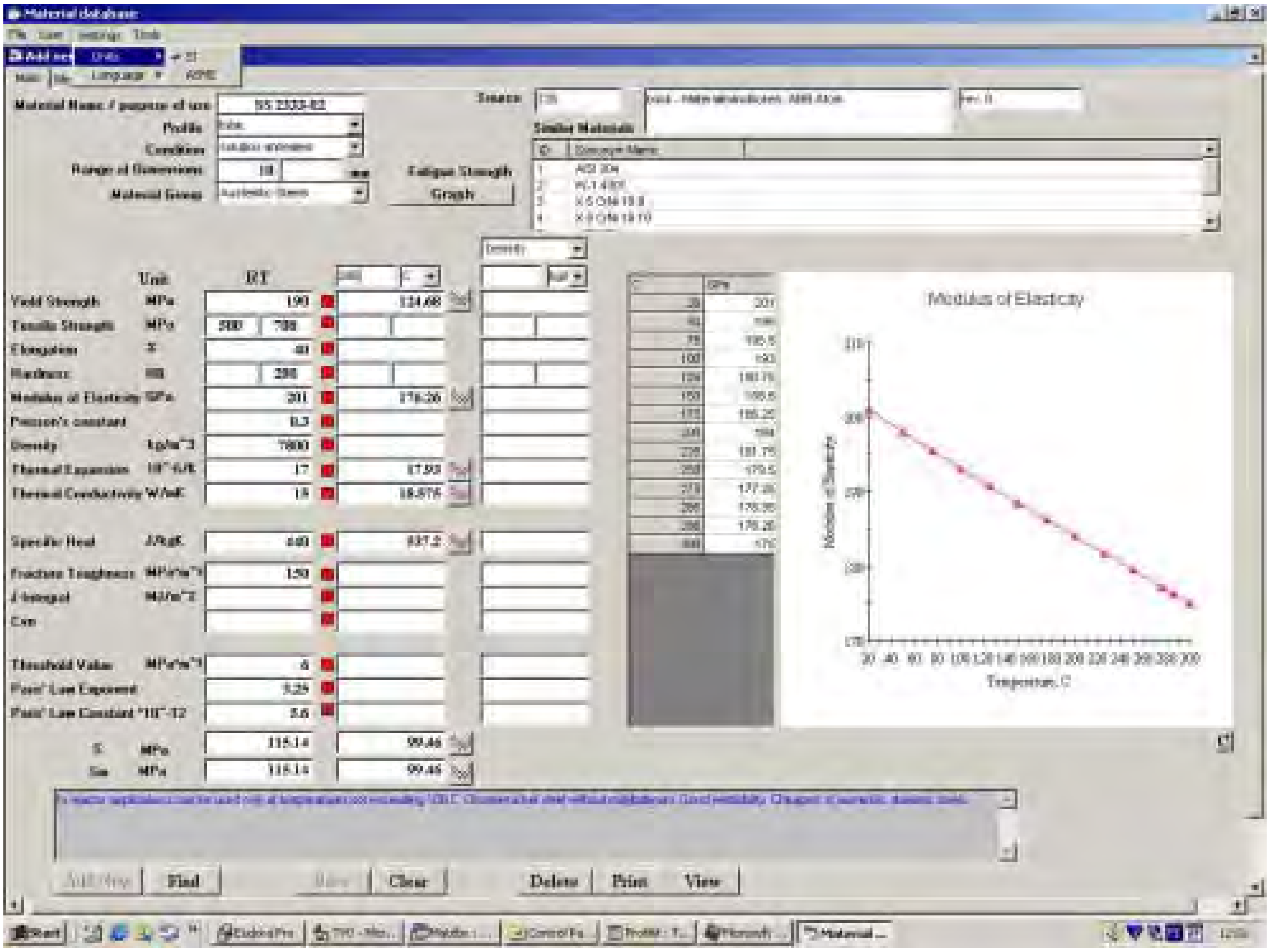

Fig. 5 Visualisation of material input

It is obvious that the same material name may also stand for a group of similar materials with a lot of different occurrences. For these occurrences also the material properties may differ. Furthermore the material name may stand for exactly similar materials with, as a result of a statistical distribution, different values for the same property. Below a detailed list is given of these possible differences:

a. For a number of test pieces and one or more material properties different test series are made and the results are saved into the database. This results in shorter or longer series of one or more properties. This data is not necessarily accompanied by official documentation and the reliability is the responsibility of a project or person. This data should only be available to material experts and not be released to other users.
b. In case the data test series is post processed and documented this may result in reliable data that should be written back into the database and released to other users. A typical example of this data type is crack growth data.
c. For one material batch and one or more properties one or more tests are performed. This type of test is required in conjunction with the manufacturing of some object and the test results are unique for the batch under consideration. This type of tests is typically accompanied by official documentation and very reliable. Normally the data will not be used for further analysis but in special cases it should be possible to do some special analysis for the object itself.
d. Some sources of reliable data that may be used for analysis are, in order of reliability:

i. National and international codes and standards.
ii. Reports, articles and textbooks.
iii. Handbooks containing technical tables.
iv. Special purpose material property summary documents.

4.3 The loading database

The loads, combinations, events and everything else related to it will, as far as reasonable, be saved in a loading database. This database is described in more detail in [1]. The load database is designed to:

1. Contain and document the actually valid design load specification inclusive service limits
2. Act as an input database to perform stress, flexibility, fatigue and/or crack analyses
3. Perform book-keeping of the load-cases and -combinations that are valid at a time and contain the connection between old and new data
4. Give the structure for the result database where the significant results of analyses are stored.

Load-cases and -combinations are fully user configurable. In the present application either static or dynamic pressures, temperatures, weight, or forced displacements can be included as basic loads. These are included in the database or coupled as structured files in case of large data quantities. Presently, the database structure has been designed and is implemented. The items 1, part of item 2 and item 3 of the above list are implemented.

An example of the program interface display is shown in Figure 3. A transient load can be entered and visualised as shown. In addition, the source of the information is input as a link to the document database.

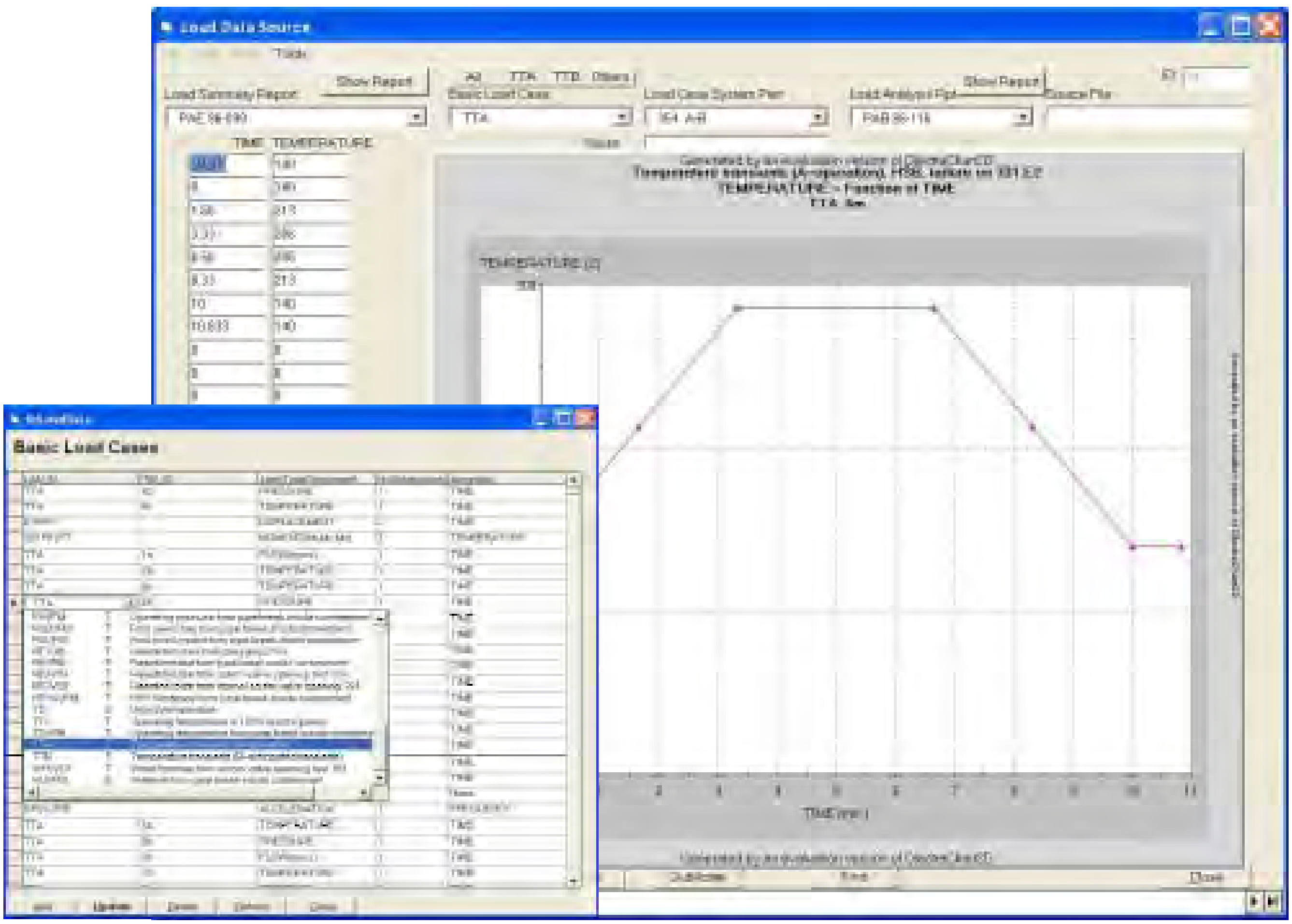

Fig. 6 Example of visualisation of the pressure-temperature load in the database

4.4 The document database

In order to find documents easily, a document database was developed. All documents that are related to any of the items within the TVO pipeline analysis and monitoring system will be gathered into this database. Once a document is part of the document database, it can be logically associated to any of the other databases. For instance, a load analysis report can be coupled to the load of the system (part) that it is related to, see figure 6. Also input data that was retrieved from an isometric can be coupled to the applicable revision of the isometric, see figure 2, and the associated material can be coupled to it's source reference, see figure 5. In this way data in the database will always be accompanied by an exact trace to the data source. In case the database document is available in digital format even this file can be coupled to the document database and will thus be readily available. An extra option in the document database is that activities and deadlines may be associated to the documents and reports can be produced showing future activities and deadlines.

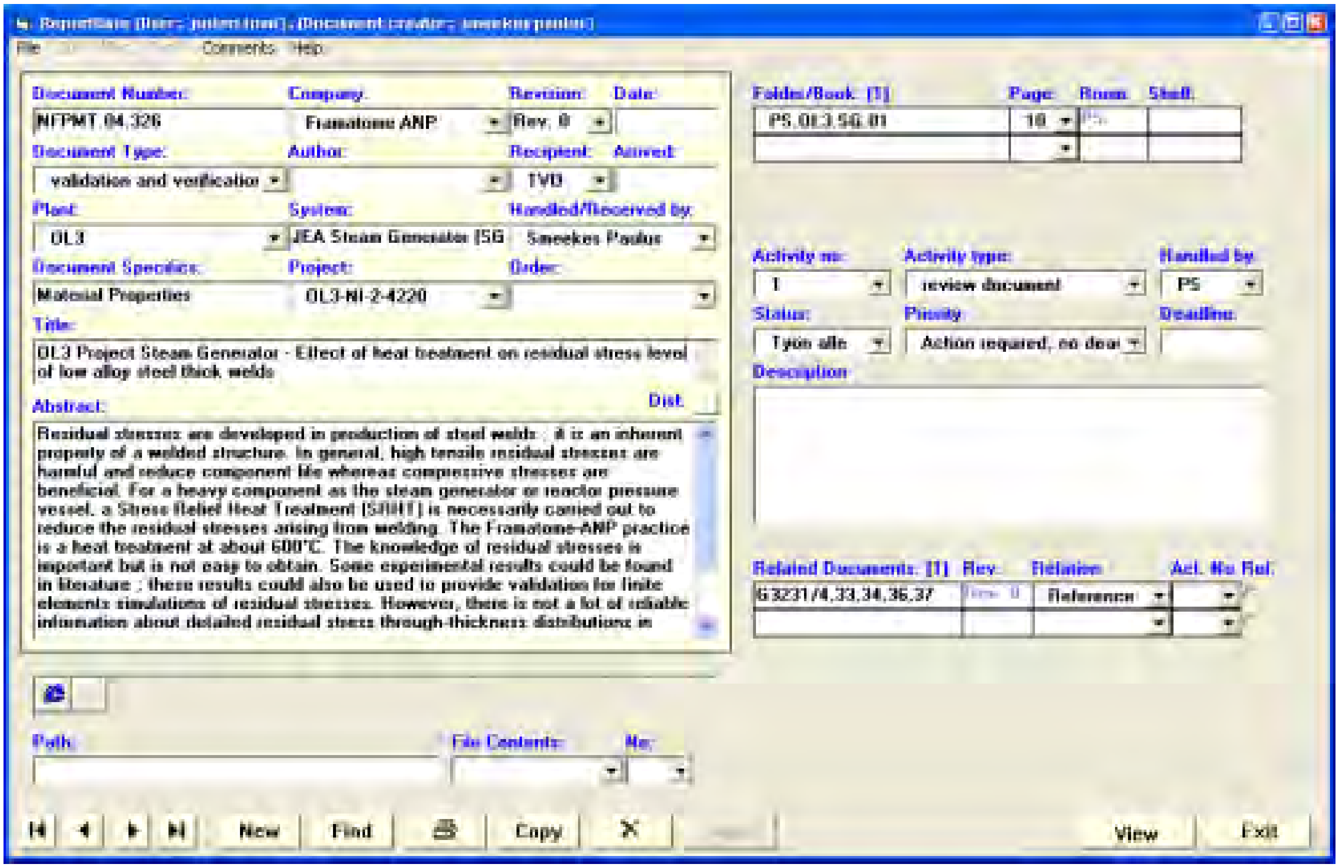

**Fig. 7 The main display of the document database.*

The document database even contains information as to the validity of documents. Other modules of the database system can read this information and produce warnings or errors to tell that the source reference is not valid anymore. A validity status can be added when a document is used as a source document when making an input file to an application program.

After making the associations that are described before it is possible to automatically add information with regard to the data sources to the documentation that is produced by the system. For instance the crack growth analysis that is mentioned later on is performed as a batch analysis and could automatically generate a complete report with source references. Please, note that this is still future.

5 ANALYSES AND APPLICATION PROGRAMS

5.1 Piping strength analysis

The piping strength analysis will be carried out with a commercially available piping analysis program and using the geometry, material properties and the loading as described in section "Elements of the database system". For the pilot phase of the project the program FPIPE [4] is chosen, see figure 8.

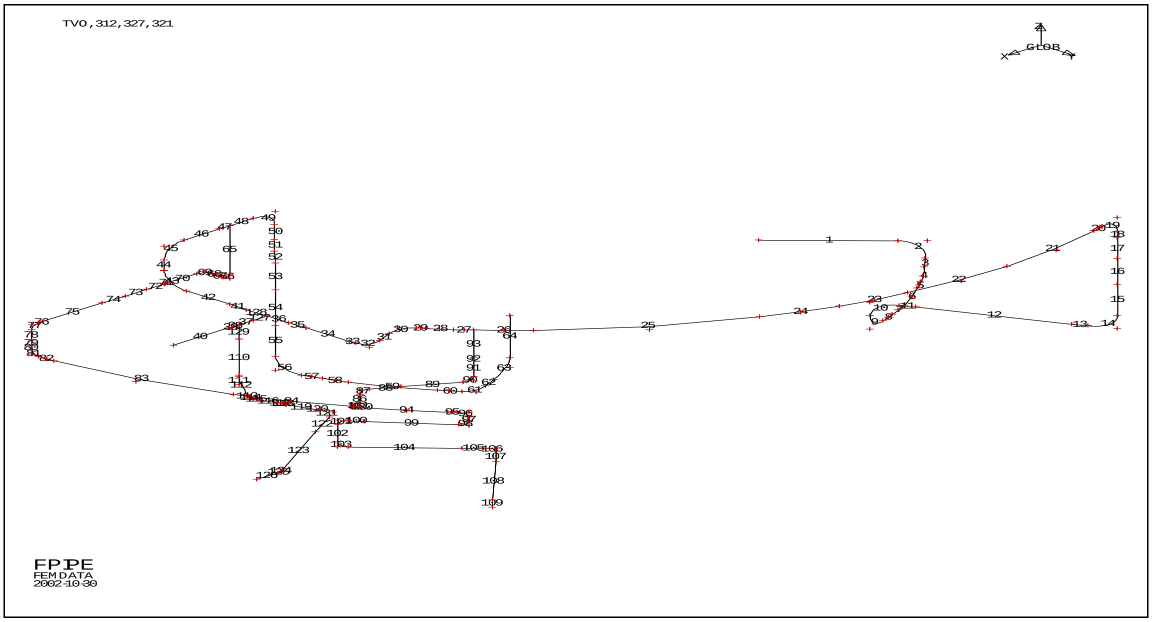

Fig. 8 Wire-frame model of a piping model in FPIPE..

In the future it shall be possible to use any piping program. An analysis was performed with ANSYS, see figure 9.

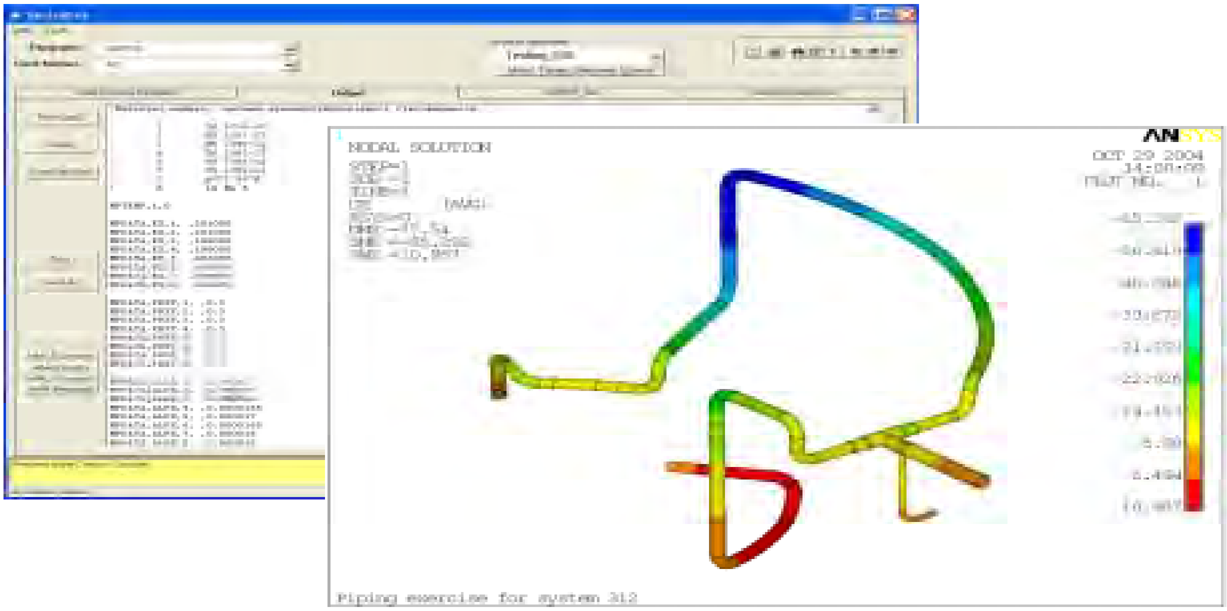

Fig. 9 Piping model in ANSYS..

Compared to a basic piping calculation program, some of the following additional features may be useful in the future and will be studied in more detail in the future:

* A very flexible loading definition enabling the loading to be directly defined by measured temperature data
* Automatic model improvement for a dynamic analysis.
* A transient analysis capability with a large number of time-steps for both analysis and output.
* Analysis with non-linear supports, gaps and friction and a dedicated bellow element, linear and/or non-linear.
* A capability to use integrated supporting structures or a matrix (from FEM-analysis) as boundary condition.
* A general linear elastic element with mass (valve, tank, etc.) shall be available. Replacement of an element by a matrix would be useful in case a more accurate finite element analysis has been performed to define this matrix.
* A capability to give shape factors for pipe-bends, T- and Y- joints, reducers and welds (from FEM-analysis).
* A Tee generation element automatically generating a shell or volumetric model that is integrated into the piping model. A test with this approach was made with help of the ANSYS program where a macro was developed to automatically generate a Tee and a tank with supports and master slave connections to the rest of the piping.

Note that some of these features are available in the FPIPE program and in other analysis programs as well.

5.2 Fatigue analysis

It may be necessary to perform a fatigue analysis according to the ASME, the materials' Wöhler diagram or any other method. FPIPE has a program module that performs fatigue analysis according to the ASME III –standard [6] for class 1 piping. The input for this program shall be taken from the input data and results of many of the programs mentioned above. Events causing loading shall be taken either from the design or historical event database. The strength analysis results for all locations analysed must be available. This development will be continuing during the years 2005 through 2007 and is a joint effort of TKK (Technical University of Helsinki), VTT (National research Institute of Finland) and TVO.

5.3 Fracture analysis

When performing fracture analysis, several crack growth mechanisms have to be considered, like crack growth due to cyclic mechanical loading or IGSCC. As these mechanisms are dependent upon the material and the environment these method(s) can be chosen automatically. These analyses may be performed using the VTT developed VTT-BESIT program [5] (developed to run in batch mode and as such fits well into the PAMS system) or some other program.

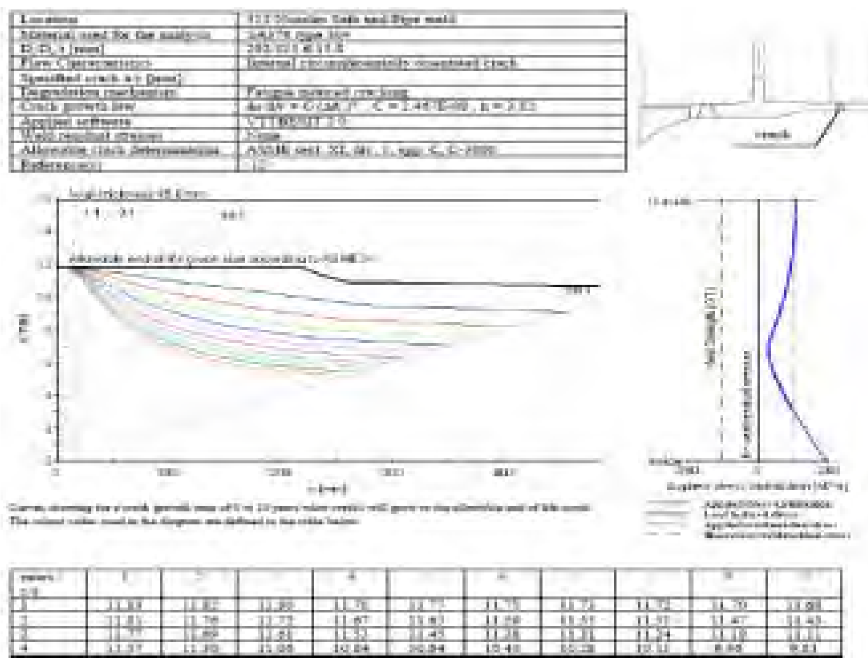

Fig. 10 Compact presentation of a crackgrowth analysis.

A conservative way to estimate the usage status of the piping may be made through the assumption of a postulated initial crack equal to maximum non-detectable crack at the least favourable location or then the worst detected crack. This crack shall, while including an appropriate safety factor, not grow to a critical crack before a planned crack or during lifetime. These cracks are assumed to grow from the last periodical inspection. The crack growth is estimated using the actual events at the station. Thus the worst possible crack growth can be predicted and necessary actions taken in due time.

5.4 Other developments

The following topics will be studied in the future:

* Transient thermal- and flow analysis and flow induced loads, like water hammer or pump transients and pipe break loads. Will it be possible to generate an input file to a thermo-hydraulic program and write the analysis results back into the database?
* Back coupling of pressure and temperature measurements. The inside temperature transients to be determined from the measured outside temperature transients. A study on available techniques and tools will be performed and the possible application studied.
* Coupling of a program that performs EN/PED piping and component analysis according to the European Standards.
* Bimetallic weld analysis. This would involve a complicated analysis to be coupled to the database.
* Transient and event monitoring based on events and/or measurements.
* Bookkeeping of inspection results.
* Analyses in conjunction with RIISI projects.

6 BOOKKEEPING AND VALIDATION

As the database will be quite complex, a good design and bookkeeping is very important. Records shall be kept for piping, equipment and other significant parts. The records shall contain such information as date of installation and possible exchange, as-build geometry and properties, welding, inspection and repair. Furthermore design loads and a complete load history shall be available from the database. Also the validity of the data shall be indicated. Thus analysis can be performed based on reliable and up-to-date information.

All information comprised in the database shall be accompanied by significant information related to date of installation or occurrence and reference documents. The date is important as for instance thermal cyclic loading that has occurred before a part was replaced shall be ignored with regard to the fatigue of the replaced part. Reference documents are important, as, in order to be significant, input data to analyses shall be traceable. Reports that are produced with help of the database shall contain references to the source of the information contained.

7 PROJECT ORGANISATION, TIME SCHEDULE AND PRESENTATION OF THE PROJECT

During the first years, TVO was the sole contributor to the project. During this period, the material database and the document database were developed, as was the base of the pipeline database. Up to this time, the interface was still alphanumerical. As test project, a pipeline geometry transfer was performed to a general purpose FEM-program. Since a few years, the project is a joint effort of TVO, VTT and FEMdata. In the project "Lifetime of pressure retaining components" [2] and it's successor projects a practical toolbox consisting of computational and experimental tools is generated for effective condition monitoring of process piping and estimation of its remaining lifetime. In future, the use of this kind of tools will be much facilitated by connecting them to the database system. New features to the pipeline database are: the development of the visual interfaces to the database, the input and visualisation of cracks, the loading database, the second generation of the material database and the module that enables the user to generate a neutral input file to run an application program in batch mode. Application programs that have been coupled to the database are the finite element method (FEM) based piping analysis program FPIPE developed at FEMdata Oy and ANSYS. As a part of the project, both application program systems are further extended and tailored to optimally fit the monitoring needs.

Developments for the near future are the result database and the bookkeeping features. Feasibility studies will be performed with regard to interfaces to one-dimensional pipe loading analysis programs, CFD-programs, modal analysis and update, general-purpose FEM programs and true neutral files.

8 ACKNOWLEDGEMENTS

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