Postprocessor for Fire Analysis Finite Element Program

DAN PINTEA, RAUL ZAHARIA
Department of Steel Structures and Structural Mechanics
The “Politehnica” University of Timisoara
P-ta Victoriei no. 2, 300006 Timișoara
ROMANIA
dan.pintea@ct.upt.ro, raul.zaharia@ct.upt.ro http://www.ct.upt.ro/

Abstract: - The paper presents the DIAMOND program developed by the first author at the University of Liege, Belgium, for post processing the results from a specialized fire analysis computer program. The fire analysis program uses an advanced computation method based on the finite element model for the analysis of 2D and 3D structural models subjected to fire. The postprocessor uses the information obtained from the main program to display the output and to interact with the structural model. The main capabilities of the 3D postprocessor and the principles used in their implementation are presented.

Key-Words: - Finite element program, fire analysis, rendering engine, 3D postprocessor

1 Introduction

The first version of the DIAMOND post processor was released in 1997, when the first author obtained a grant at the University of Liege, and worked with Prof. Jean Marc Franssen, the author of SAFIR [1], a specialized finite element computer program for modeling structures under fire action. At that time, SAFIR was already a worldwide used program for the fire modeling and design of complex structures. The problem was that the program relied on third party rendering engines to produce a graphical output. Not only the results were far from satisfactory, but this involved also the preparation of the SAFIR output to be churned by the third party tool.

Prof. Franssen proposed the creation of an independent full featured 3D postprocessor specially designed for the SAFIR output, to enhance the capabilities of the software. The first release was written in Visual Basic 4.0, and dealt only with 2D models, being very limited in options. From that point on, the software was updated, and more features were added for dealing with complex 3D problems and to keep up with the development of the SAFIR, in the frame of collaboration between the “Politehnica” University of Timisoara and the University of Liege.

The last release of “DIAMOND” is written in Visual Basic 6.0 and C language. Visual Basic is used mainly for the interface and some minor computations, while the 3D rendering engine which is computationally intensive, is written entirely in C for speed. The program is highly interactive and user friendly having implemented most of the features found in commercial finite element packages.

2 Fire analysis of structures

2.1 Principles of fire design

The basic principle in determining the fire resistance of a structural element is that the elevated temperatures produced by the fire reduce the materials strength and stiffness until possible collapse. When the temperatures on the cross-section of a structural element produce the reduction of the element resistance bellow the level of the effect of actions for fire design situation, it is considered that that element lost its load-bearing function under fire action. Three methods are available in the European standards for fire design (Eurocodes) in order to evaluate the fire resistance: the tabulated data method, the simple calculation models and the advanced calculation models.

The tabulated data method is based on observations resulted from experimental study. It is the easiest to apply, but it is limited by the geometrical conditions imposed to the composite cross-section. The simple calculation models compute the ultimate load of the element by means of formulas or design charts, established on the basis of experimental data. The advanced calculation models suppose an advanced numerical analysis of the elements or of the entire structure under fire, using specialized software for the mechanical analysis of structures under elevated temperatures. The advanced calculation methods should include separate calculation models for the determination of:

- the development and distribution of the temperature within structural members (thermal response model);
- the mechanical behavior of the structure or of any part of it (mechanical response model).
Advanced calculation models may be used in association with any heating curve (fire model), provided that the material properties are known for the relevant temperature range, and may be used with any type of cross-section. Advanced calculation methods for mechanical response should be based on the acknowledged principles and assumptions of the theory of structural mechanics, taking into account the changes of mechanical properties with temperature.

The thermal response model used to determine the heat transfer from fire to the cross sections of the structural elements, should consider the relevant thermal actions specified in EN 1991-1-2 [2] and the variation of the thermal properties of the given material with the temperature.

A structure, substructure or element in fire situation may be therefore assessed in the time domain, where the failure time must be higher than the required fire resistance time. The failure time is the time for which the resistance of the structure (or substructure, or element, as considered) under elevated temperatures reach the effect of actions for the fire design situation, considering the combination of action in fire situation, as given in the corresponding Eurocode for the basis of structural design EN1990 [3].

2.2 The implementation of advanced fire calculation methods in SAFIR program

The SAFIR program [1], developed at the University of Liege, is a special purpose advanced calculation tool for the analysis of structures under ambient and elevated temperature conditions. SAFIR accommodates various elements for different idealization, calculation procedures and various material models for incorporating stress-strain behavior under elevated temperatures and fulfills all conditions imposed by the Eurocodes for fire design, to be considered an advanced calculation model. The program was validated through comparison with experimental tests and by means of benchmarks, in comparison with other existing computer codes and experimental data.

The analysis of a structure exposed to fire, using SAFIR program, consists of two steps. The first step involves the prediction of the temperature distribution inside the structural members, referred to as “thermal analysis”. The second part of the analysis, termed the “structural analysis” is carried out to determine the structural response due to static and thermal loading.

Basically, upon performing a thermal or structural analysis, SAFIR will produce an output file with all the information regarding the response of the structure under the loadings.

The program, which is based on the Finite Element Method, can be used to study the behaviour of two and three-dimensional structures. The elements include the 2-D SOLID elements, 3-D SOLID elements, BEAM elements, SHELL elements and TRUSS elements. The stress-strain material laws are generally linear-elliptic for steel and non-linear for concrete.

For any analysis using SAFIR, data files acting as input files to the program are prepared. For each analysis type (thermal, torsional or structural analysis), the user prepares one data file. This is an ASCII file, created with a text editor, in a word type processor.

These data files contain information such as calculation strategy, time discretization, loads, node coordinates, types of finite elements used, material properties, etc. The structural data file specifies the names of the output files created during thermal and torsional analyses and in which the temperature data are written.

3 The Diamond 3D Postprocessor

The DIAMOND postprocessor is a stand alone application that reads the output of SAFIR thermal and structural analyses. The postprocessor has the ability to plot the topology of the model (nodes, elements and contours), the constraints and the external actions (fires, fixed degrees of freedom, imposed displacements or loads) and the analysis output values (temperatures, displacements, internal forces and stresses).

The plot can be saved as a vector graphic in Windows metafile format or as a bitmap. Three more tools are at the users disposal: an animation tool for creating an avi type file with the evolution of displacements of temperatures in time, a charting tool to plot an evolution in time of an output value and a spy tool for inspecting the plotted value on the screen.

The user can further change several parameters of the program through the Options dialog box accessible from the Tools menu, as shown in Fig. 1.

![Fig. 1. The “Options” dialog box.](image-url)
The DIAMOND interface consists of five areas:
- Menu bar
- Toolbar
- Canvas (main plot area)
- Legend Bar
- Status Bar

One of the most important parts of the interface for manipulating the output is the Legend Bar. The Legend Bar has four panes:
- Legend
- Viewpoint
- Selection
- Options

The Legend pane is by default and displays information about the model, as shown in Fig. 2.

The Viewpoint pane allows the change of the view vector (the vector defined by a point in the 3D space that passes through the origin of the model), the rotation of the model in 3D space about the Cartesian axes using Euler angles, or to select some preset views (Front, Side, Isometric projection). The trackball is accessible through the Viewpoint pane. This feature is based on the work of Shoemake [4] and Pletinckx [5] on quaternion calculus (see Fig. 3).

The Selection pane has controls that allow the user to select or deselect parts of the model, based on some selection criteria. For example, the user can select from the model to plot only the elements having a certain material. The selection can be based also on the geometry of the model, or on the position of a part of the model, related to the coordinate system. For example, on the model in Fig. 4, a selection criteria has been applied to plot only the elements having the global Y coordinate smaller than a given value.

The “Options” pane depends on the type of the model. For a thermal analysis, DIAMOND will have a Temperature group. The user may select the display of the temperatures using either the Automatic or User Defined mode, the number of different colors, and the plot using either Filled Color mode, Filled Gray Mode, or Linear Plot using Isolines. The Filled Color Mode is exemplified in Fig. 3 and 4.

Two capabilities that every graphical postprocessor needs to implement is panning and zooming. Several zooming options are available. By default, the Zoom Window is accessible at any time when a model is loaded.

The user can also select a zooming command either from the Display menu or through a right click anywhere on the canvas, as shown in Fig. 5.

Zooming can be carried out also by using the Mouse Wheel if present. When the user scrolls the mouse wheel button, the model will be zoomed in or out depending on the direction of the scroll. Zooming will be performed so as the point on the screen where the cursor is located is placed exactly in the same position after the zoom operation. Panning can be done either using the middle mouse button if present,
or using a combination Shift key + Left mouse button.

Diamond implements three basic algorithms for solving the hidden surface determination in 3D. The first one is Backface culling. Since meshes are hollow shells, not solid objects, the back side of some faces or polygons in the mesh will never face the camera. Typically, there is no reason to draw such faces. This is responsible for the effect often seen in computer and video games in which, if the camera happens to be inside a mesh, rather than seeing the “inside” surfaces of the mesh, it mostly disappears.

The second step in the hidden surface determination is the sorting of polygonal faces and drawing them in reverse order, back to front. The Painter’s algorithm sorts polygons by their barycenter and draws them back to front. This produces few artifacts, when applied to scenes with polygons of similar size, forming smooth meshes and backface culling turned on. The cost here is the sorting step and, of course, the fact that visual artifacts can occur. By default, DIAMOND uses this algorithm for determining the hidden surfaces. The problem as mentioned above is that sometimes visual artifacts occur (see Fig. 6). The advantage is that the algorithm is very fast and for most cases it produces good results.

However, sometimes the visual artifacts can be annoying and, especially when creating final images of the model, this could be a drawback. For this reason, the 3D engine has been enhanced to a full Painter’s algorithm with polygonal surface splitting, based on the work of Newell et al. [6] as presented in Foley [7].

As already mentioned, several tools are at the users disposal, namely the Spy for inspecting the values onscreen, the Charting tool for plotting an evolution of a data value in time and an Animation tool to produce an avi file with the evolution in time of a data value (Temperature or displacement).

The Spy tool can be activated or deactivated from the context menu. When the Spy is on, hovering the

![Fig. 5. The “Zoom window” command](image1.png)

The cartesian coordinate system is interactive. The user can position the origin anywhere on the screen. The coordinate system has two built-in positions: in the lower left corner of the Canvas or in the origin of the model, as shown in Fig. 3 or 5.

The heart of the 3D postprocessor is the 3D engine. Several choices were available to the developers from the start, either to use a general Z buffering engine like DirectX or OpenGL, to use a third party 3D engine, or to develop a new one that suits the need of the program.

Having all the pros and cons taken into account, the decision was made to create a 3D engine from scratch. The benefits of creating a 3D engine from scratch is that it can be adapted to apply to the needs of the program, it can be enhanced when it’s needed to have access to the whole code and last but not least, the price.

One other thing that favored the writing of a 3D engine was that the users of DIAMOND should have the ability to save images of the model in vector format. DIAMOND saves the 2D snapshots of the model in Enhanced Metafile Format. This would have been very difficult to achieve in OpenGL and almost impossible in DirectX without writing a supplementary code (which would amount to a proper 3D engine).

In the first releases, the 3D engine was written in Visual Basic 5.0 and later on ported to VB 6.0. Extending the postprocessor to deal with large 3D models proved to be a challenge for VB, so in the end the decision was take to port the 3D engine to the C language. From release 5.0, the 3D engine was written entirely in C and resides in a separate Dynamic Link Library (DLL). The subroutines and functions from the DLL can be called from VB to perform the computational intensive tasks.

![Fig. 6. The Painter’s algorithm without full sort.](image2.png)
a point of the model, will bring on a Tooltip window with relevant information about the point in question (see Fig. 7).
The user can plot the evolution in time of up to five data values (temperatures, displacements or stresses) using the Charting tool. To create a chart, after the selection of the Chart command from the Results menu, in the opened dialog box the nodes for which the data values are to be plotted must be entered. In this manner, the postprocessor will create a plot of the evolution in time of the selected values (see Fig. 8).

4. Conclusions
The authors presented a full featured 3D postprocessor written in Visual Basic and C for displaying the output from the finite element analysis program SAFIR. The main features of the program as well as some of the basic algorithm that are implemented in DIAMOND were presented. The program proved to be a very useful tool for worldwide SAFIR users. Its development on a period of more than a decade, rendered it solid and bug free.

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References: