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POSTPROCESSING TECHNIQUES FOR 3D NON-LINEAR STRUCTURES

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ABSTRACT
This paper reviews how graphics postprocessing techniques are currently used to examine the results of 3D non-linear analyses, some new techniques which take advantage of recent technology, and how these results relate to both the finite element model and its geometric parent.

INTRODUCTION

The end result of most finite element postprocessing remains the interpretation of a single result quantity in the form of a single, static picture. Because there is a natural mapping between such plots and the increment-by-increment output data files produced in non-linear analysis, most such analyses today essentially treat individual steps and increments of non-linear analyses as degenerate cases for these linear techniques.

Current methods to view structural analysis results have their origins in display of univariate data for linear analysis. Indeed, the majority of techniques used in today's result displays came into use in the late 1970's and early 1980's, with incremental enhancements to take advantage of improving graphics display technology.

From a human perspective, areas for improvement in evaluating 3D non-linear results include improving one's insight into time-dependent behavior, rapidly finding critical behavior in complex 3D structures, and putting more result information into a given picture.

CURRENT POSTPROCESSING TECHNIQUES

Techniques used today in generating analysis result plots include the following:

1. Deformed shape plotting
These plots showing the deformation of a structure under load generally overlay deformed and undeformed plots, with a magnification factor applied for small displacements. Hidden line removal or boundary plotting is commonly employed to reduce the visual complexity of these plots.

2. Vector result plotting
Quantities which vary at points across the structure are displayed as arrow or line vectors. This technique is one of few which display the directionality as well as the magnitude of a quantity. On the other hand, such plots easily become "busy" and difficult to interpret unless applied to limited plot areas.

3. Contour line plotting
Like a topographic chart, lines are constructed on the surface of a structure to outline transitions between result levels. Either coded colors or alphanumeric labels are used to differentiate levels.

4. Shaded result plotting
In the late 1970's, when few of the color graphics devices in use could display more than 8 or 16 simultaneous colors, shaded result plotting essentially "filled in" the areas spanning contour levels with discrete colors.

Today, increased levels of color and firmware shading capabilities have made it easier to produce fully shaded plots showing the variation of a quantity in a smooth, continuous manner. Even as such capabilities become more of standard among display devices, plots using limited numbers of discrete colors remain popular - often, a discrete plot gives a more rapid overview of where critical behavior exists.

PROBLEMS IN 3D NON-LINEAR POSTPROCESSING
While techniques such as these are commonly used to look at single-frame results in 3D non-linear results, they carry with them a number of drawbacks as currently used. Some of these include:

-Range limits within a frame. Non-linear results can vary across a large range across time steps, yet each individual step may encompass only a small part of this range.

For example, if 16 colors are used to represent the full global range of behavior in a non-linear analysis, a given step might only use one or two of these colors. But more common is the opposite problem: each frame in an analysis maps its full range of colors to the LOCAL step data, making it difficult to correlate frame-to-frame behavior after the fact.

-Loss of time perspective. Evaluating non-linear behavior by review of individual frames carries with it the same loss of insight that differentiates nodal result printouts from graphic plots.

-In 3D structures, critical results may be interior or rearward-facing relative to a 2D plot image of its results. While it is often true that critical results occur on exterior surfaces, this is not always the case - and moreover, the ability to quickly evaluate interior results increases the design complexity which can be analyzed and interpreted within a given time frame.

Limitations such as these continue to exist in the non-linear area due to a number of factors. First, it has only been in the past two to three years that graphics display devices with extended color and three dimensional display capabilities have become common. Here, the key word is COMMON - technology for shaded and 3D display have existed since the early days of the computer graphics field, but only recently have they been available from major suppliers with the kind of price/performance relationship that would encourage common use among engineers.

Further hardware enhancements that affect this area, such as real-time 3D display of substantial models, and computer-driven animation hardware, still generally remain at the point where they are the domain of the well-funded and technologically courageous.

Second, as time progresses, we are seeing more of a "critical mass" of users in this area to influence CAE techniques.

As CAE has increased analysis productivity in general, there has been a trend towards increasing complexity in analysis. This natural progression has led to a wider interest in non-linear analysis - and often, more from design groups applying CAE for the first time to their traditional non-linear problems as well as existing CAE users expanding the scope of their activities.

Finally, CAE tools add changes to design procedure as well as increased productivity, and non-linear users have had to absorb the same existing tools as other analysis users over the past decade.

This latter point bears some explaining. While technology itself can certainly proceed in parallel for different applications areas, current acceptance of CAE makes it more possible to implement new techniques to assist result display. From the vantage point of a commercial software developer, the penetration of state-of-the-art display hardware and tools among non-linear users would not have justified advanced graphics development in the early 1980's. Today, acceptance of current CAE tools and equipment makes it economically feasible to develop more advanced tools.

ENHANCEMENTS TO ADDRESS 3D NON-LINEAR PROBLEMS

There are a number of areas which can be pursued to address improved productivity for non-linear analysis work. Some techniques that look attractive because they can provide more informative displays to cope with the larger data output of a non-linear analysis are as follows:

1. Translucency

Techniques to display surfaces which can be seen through have existed since early work by people such as Atherton(1) in 1981. Early scan-line based techniques in this area would sort surfaces into their requisite display pixel locations, applying a tint function to surfaces "behind" the translucent surface at a given pixel location. It was clearly limited to devices with a large number of simultaneously displayable colors.

Now that local rendering of polygons have become a common feature of graphics display devices, many devices and/or software now generate "translucent" polygons by displaying some, but not all, of a polygon's pixels, in a regular pattern.

Either approach makes it easier to make OPACITY an attribute of a result's color in a shaded result display. In this manner, interior critical results become more visible, as shown in the slide figure.

The technique has two apparent drawbacks: multiple layers of translucent surfaces may still obliterate the view of opaque results unless a very fine pattern of translucency is used, and such a technique requires display processing of interior surfaces which would normally be discarded in opaque processing.

2. Auto-clipping
This technique is also useful in looking at interior results. Here, hardware or software Z-clipping is used to remove surfaces which obscure the view of critical results. This is done by positioning the front and/or back clip plane at the first Z location where a critical result value is detected.

The slide figure example shown was performed using hardware Z-clipping capabilities in a Tektronix 4129 display system.

3. Animation
Two kinds of animation are clearly of interest in non-linear analysis: progressive display of incremental results data, and animation of a final state of behavior from rest. Slide figures show examples of animation frames for two engineering models.

Currently, many display devices allow what could be called "segment animation", where separate frames of animation are loaded into separate "segments" of display memory and then cycled through in sequence.

This technique is particularly effective on real-time 3D display devices, as it allows the user to dynamically adjust the view of a deforming or changing model. Unfortunately, such techniques have crude refresh rates in many cases, and severely limited display capacity at present in all cases.

More promising in the longer term is frame-by-frame animation, where individual frames of animation are computed, displayed, and then captured under software control on a medium such as film or videotape. Frame-by-frame capture hardware does exist today with media such as videotape and interactive read/write videodisk, but is very expensive, disjoint and lacks any unified vendors aimed at the engineering market.

Of further interest downstream is path of motion control for structural models as rigid bodies, for better visualization. Techniques exist at a practical level today, with primary issues being acceleration, decceleration and continuity of motion across changes in path. Reference (2) is one of a number of examples to further codify these kinds of motion.

The technology behind engineering animation is well in hand, and more limited by commercial hardware availability than anything else at this point. In the author's opinion, animation will become a major factor in CAE once low-cost frame-by-frame capture and display equipment exists which is supported by major CAE hardware and software.

4. Correlation of result plots with history data
Most discussion to this point has centered on model-based result plotting. Equally important in this application area is history data - plotted or printed output of result variables versus time or each other.

Graphics alone do not suffice in the engineer's determination of structural behavior. As stated in a recent issue of the Engineers' Digest in the UK (3), "While graphics have resulted in increased acceptance of the (FEA) technique, it is the print out that provides the proof to the purchaser.".

In designing an interactive display package, an emphasis must be placed on managing the duality between model and history data - particularly in making it easy to select history data based upon what is noticed and selected from model result plots.

5. Management of display data across steps
As mentioned earlier, the potential differences between local and global result ranges in a non-linear analysis require an intelligent approach to the use of color. Techniques under study include specification of macro versus micro color levels, as well as taking advantage of displays with larger numbers of simultaneous colors to modify display ranges locally via the color table.

Many of these techniques are still being evaluated at an experimental stage at present. A key component of the above efforts is the ability to tie directly into the database of an existing non-linear analysis package to manipulate the large amounts of data involved in input to these and other display functions.

THE RELATIONSHIP OF POSTPROCESSING DATA TO GEOMETRY AND FINITE ELEMENTS

To this point, we have primarily discussed postprocessing data as it relates to finite element level displays. For a large percentage of current ABAQUS users, this finite element model is created at least in part due to operations on a geometric model. Commonly, a solid modeling or other CAD system is integrated with a finite element modeler for creation of the analysis data.

Upon completion of the analysis, the question remains of how -

or, in fact, whether - to relate this information to this geometric database. Often, the geometric data is available across design disciplines, while its finite element model is specific to the individual analysis group.

In this era of automated adaptive analysis, meshes change - while geometry, generally, does not. The end result of an analysis is a state vector expressed at points which correspond to parametric or spatial locations in this geometry. In theory, the finite element mesh itself need not even remain as permanent data.

Some practical considerations interfere with this concept, however. The purpose of saving analysis data is to display or interrogate it later. Given the largely polygon-based methods of model result display, a polygonalization of some form will generally be required for graphics display - with preservation of this mesh data being an ideal polygon representation in most cases.

Furthermore, direct association of results with geometry removes a link to re-starting or replicating the analysis data from its final state - although, arguably, initial conditions alone combined with the same adaptive meshing approach would allow a reproduction to this point in theory.

Currently, most solid modeling systems which integrate FEM capabilities treat analysis results as purely an attribute of the mesh. While it of course relates ultimately to the geometry itself, both display and analysis techniques in use today clearly point to a representation where the geometry is the parent of the mesh, and the mesh is the parent of the results, with both parts of the linkage remaining intact.

However, at a database and user interface level, more work clearly needs to be done to make this linkage transparent to the user. Ideally, the user would rather not create or care about the finite element mesh en route to the overall goal of evaluating geometric behavior. While numerous obstacles remain on the way to this goal, the longer term goal is to eventually make this the level at which the user operates in postprocessing.

CONCLUSION

While graphics display techniques have done much to increase insight into non-linear 3D structural problems, these problems contain unique display issues which are not completely addressed by current techniques. Approaches such as translucency, clipping, animation and management of color have potential to increase understanding of these phenomena further. Moreover, in time these results must be treated to the user's view as an attribute of the user's primary medium of exchange, the geometric model itself.

REFERENCES

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SLIDES:

- -Review of current postprocessing techniques
  - -Geometry-based
    - -Deformed shape plots
    - -Vector plots
    - -Contour line plots
    - -Discrete fringe contour plots
    - -Continuous tonal plots
  - -Result-based
    - -XY plots
    - -3D data surfaces

- -Some newer techniques
    - -Translucency
    - -Auto-clipping
    - -Animation

- -Results as a sub-level to the mesh, as a sub-level to the geometry