Zeitschrift: IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

Band: 31 (1978)

Artikel: Tools for computer-aided design (CAD)

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DOI: https://doi.org/10.5169/seals-24899

IABSE
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COLLOQUIUM on:
"INTERFACE BETWEEN COMPUTING AND DESIGN IN STRUCTURAL ENGINEERING"
August 30, 31 - September 1, 1978 - ISMES - BERGAMO (ITALY)

Tools for Computer-Aided Design (CAD)

Outils pour le projet à l'aide de l'ordinateur (CAD)

Mitteln für Computergestützte Berechnung (CAD)

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Summary

Provided that a great number of computer programs for automatic analysis of structures is available it is a worthwile attempt to look for tools which enable the civil engineer to overcome two critical steps in the use of these programs: the generation of an analytic, computer oriented, description of the physical model and the transformation of the results of computation in a synthetic, man-oriented form. The paper is devoted to enable structural engineers to get a picture of how they could be helped by the use of software for computer-aided design, and to give a glance, at the same time, to the problems involved in the design of this kind of software.

Résumé

Aujourd'hui un grand nombre de programmes peuvent être utilisés pour le calcul automatique des structures; par conséquent l'ingénieur civil est très intéressé d'avoir à sa disposition des outils qui lui permettent de surmonter deux phases critiques pour l'emploi des programmes de calcul: la génération d'une description analytique, "computer-oriented", du modèle physique et la transformation des résultats du calcul dans une forme synthétique et facilement interprétable par l'utilisateur. Ce rapport passe en revue les différents moyens par lesquels un logiciel de CAD peut aider un ingénieur civil et, en même temps, des problèmes qu'on doit résoudre pour l'établissement de cette sorte de logiciel.

Zusammenfassung

Da eine grosse Anzahl von Computer-programmen für die automatische Berechnung von Tragwerken zur Verfügung steht, ist es der Mühe wert, nach Mitteln zu suchen, die es dem Bauingenieur ermöglichen, zwei kritische Phasen bei der Benutzung dieser Programme zu überwinden: die Schaffung einer analytischen Computer-orientierten Beschreibung des physikalischen Modells und die Transformation der Resultate der Berechnung in eine synthetische, Gebraucher-orientierte Form. Dieser Artikel soll den Bauingenieuren zeigen, wie die Anwendung von Software für CAD ihnen behilflich sein könnte und ihnen gleichzeitig erlauben einen Blick auf die Probleme zu werfen, die mit einem Projekt dieser Art verbunden sind.

1. INTRODUCTION

The availability of computers had a great impact on structural engineering as well as on other branches of engineering during the past twenty years. The methods of analysis underwent a rapid change which allowed design engineers to overcome the problems involved in the integration of differential equations and especially in the correct formulation of the boundary conditions. This evolution took place step by step. First of all a general approach was introduced which could be used for every structural idealization and exhibited two complementary aspects, called respectively forces method and displacements method. They are quite similar if we look at the analytic formulation and both base themselves upon the effects superposition. Afterwards the problem of analysing the behaviour of continua was faced by developing first the method of finite differences and then the finite elements method. The latter drew the attention of design engineers upon itself because of its effectiveness and flexibility.

At the present time the finite element method is the most sophisticated and powerful computer-oriented procedure available for the static and dynamic analysis of structures, and a great number of computer programs based on this technique is used in all major industries.

On the other hand the use of this kind of programs is strongly hindered by the need of generating an analytic, computer-oriented, description of the physical model and of translating the results of computation in a synthetic, man-oriented, form. We must realize that the procedures for data or instructions input to the computer and information output have been the main problem on the way of the efficient use of the computer since it appeared. Man thinks indeed in terms of words and numbers, or diagrams and pictures, whereas computer can operate only with coded digital representations of those entities. This fact causes difficulties in the communication between creative, slow and error-liable man and literal, fast and error-free machine.

Conventional interfaces between man and computer are punched cards for input and printer lines for output. Keyboard terminals and plotters represent an improvement of these conventional interfaces, but the introduction of third generation computers offering the availability of communication and interaction with the operator and the development of rather inexpensive storage C.R.T. graphic terminals give the opportunity to enable the civil engineer to overcome the critical steps in the use of structural analysis programs.

In the past few years tools for computer-aided design based on interactive computer graphics were developed and they have been transformed from an expensive curiouseness into a low-cost, useful and sometimes necessary instrument for structural engineers.

Now we will get a picture of how these people could be helped by the use of software for computer-aided design and we will give a glance, at the same time, to the problems involved in the design of this kind of software.

2. CHECK FOR DATA ERRORS

The conceptual simplicity of the finite elements method transforms the user's main problem from the need of finding an analytic solution for the mathematical model of a structure to breaking-down the geometry of the structure under consideration into suitable elements of regular shape (called the idealization).

A considerable amount of data must be prepared with corrispondingly large manpower requirements, particularly for three-dimensional analysis. Thus, when this whole task is performed manually, human errors are introduced adding further cost for abortive analysis runs and corrections. All the structural analysis programs automatically detect most of the input data errors before a large amount of internal computation is performed. However the automatically detectable errors are the formal ones or those which lead to some inconsistencies. Some typical user's errors, as wrong nodal points coordinates, wrong elements connections, overlapping or missing elements and so on, could not be detected by the errors cheking systems based on numeric evaluations.

In these cases only a graphical representation of the idealization of the structure would be helpful.

Such a representation should allow the user to :
- select the part of the idealization which has to be displayed,
- rotate, shift and scale the selected portion of the model,
- produce orthogonal, isometric and perspective views of the previously defined assembly of elements, with the ability of shrinking elements (a useful device for ensuring that internal elements are actually present) and displaying after magnification small areas of the selected portion of the model so that detailed investigations may be made (zoom),
- obtain elements and nodal points numbering,
- display any input numeric information regarding materials data, boundary conditions, substructures connections and so on,
- correct on line wrong data,
- add ar delete or modify elements.

It is quite clear that only the last two operations require the use of interactivity. However we must realize that the use of an off-line device, such as a plotter, is good only for final documentation. Selection and representation parameters may be wrong as well as corrections at modifications of the idealization. Therefore interactivity allows the user to try and try again until a satisfactory condition is achieved.

Moreover graphic interactivity can be very helpful in communicating with the computer because it works in a man-oriented fashion. It allows indeed the user to give or ask informations via a graphic device : by means of a light pen (a pencil-like device which the operator can use to point at something of interest on the screen of the graphic display terminal) or a joy-stick, a graphic tablet or other manually operated devices, the user can indeed communicate with the computer in a very direct manner without using any special language.

As far as the effectiveness of the picture is concerned, we must keep in mind that isoparametric elements commonly available in structural analysis programs have curved edges and curved surfaces defined by particular internal nodal points. Therefore a good treatment of curved lines in necessary : the points which define an edge are interpolated by special spatial curves, new points are considered on these curves and finally the edge is substituted by a sequence of straight lines. This operation must be performed in the 3D space when we deal with solid or shell elements, before any transformation to the 2D space representation is done.

Moreover, if we wish to eliminate hidden lines in the picture of spatial idealization also a good treatment of curved surfaces is necessary, after the general problem of hidden lines elimination has been solved. It is clear indeed that a surface can be visualized only by means of its edges : if it is plane no problems arise, otherwise new lines could delimitate its 2D representation depending on the point of space from which the user wish to look at it.

All these features of the visualization tool which enable the user to have a good picture require special efforts in designing and developing the necessary software.

3. DISPLAY OF RESULTS OF ANALYSIS

Corresponding to the large amount of input data required, many pages of output can be expected containing a great number of numerical informations. It is quite clear that this kind of informations has no physical evidence, therefore the engineer must examine the numbers in order to transform the analytical results of the analysis into significant patterns in graphic form.

If we consider this fact the usefulness of an automatic output data reduction is apparent. Its fundamental aim should be to produce pictures which compress the relevant informations.

As far as the output graphic device is concerned, also in this case we must realize that conventional permanent copy plotting is good for final documentation purposes while interactivity is preferable when looking for the most significant displays of the results. The choice of magnification factors to apply to deformed shapes, for example, or the best density of contours lines and so on, are not likely to be defined without some trials.

The capabilities of an efficient post-processor for structural analysis should not be different from those of a pre-processor with reference to the representation of the deformed shape of the idealization. Moreover the post-processor should allow the user to :

- display the deformed shape, magnified as much as required, superimposed on the undeformed one to give a clear impression of the overall distortion,
- display stress or strain contours with any desired density in two-dimensional idealizations and in any prescribed section, not necessarily flat, of three-

dimensional idealizations,
- produce diagrams showing displacements, stresses or strains along any line through the body.

Looking at the deformed shape it is useful that the whole mesh is represented to give informations about the displacements which occur in the interior part of the body. On the contrary, when representing the isostress or isostrain lines, the subdivision into elements is a disturbing fact and therefore it is necessary to eliminate the internal boundaries between elements while retaining the external boundary of the whole object along the chosen cut.

The diagrams of the various results of the structural analysis can be of different forms : they can have the standard aspect or a vectorial representation. In the latter case a set of straight segments are traced at right angles to the cut line, every segment having a lenght proportional to the size of the evaluated quantities.

These possibilities of representation require new efforts from the developers of the related software. It is necessary to provide for cutting of three-dimensional bodies along not flat surfaces besides implementing diagrams representations techniques.

4. BULK MESH GENERATION

The subdivision of the geometry of the structure into finite elements can be performed automatically. This means quick and easy generation of input data for programs based on the finite element method.

The characteristics of pre-processors devoted to this purpose should be :
- the availability of facilities in describing the geometry of the idealization by means of points, curves, surfaces, bodies, etc.,
- the automatic generation of nodal points coordinates and nodes and elements numbering,
- the easy change of element types and mesh coarseness.

If we restrict our interest to the meaning of an easy definition of surfaces, assuming that similar techniques can be used for curves and bodies, we must realize that a surface can be described in many ways. We can define many points, and then interpolate or approximate them by some suitable functions. For general surfaces this is the most appropriate method, but for commonly encountered structures it is too complicate. These structures consist indeed of parts of planes, cylinders and spheres. Using the analytical descriptions of these shapes a little amount of informations is needed to define a structure. A sphere, for example, is defined by its center radius. In the same way the most commonly used curves, as straight lines and circular arcs, can be defined by two or three points. When only a part of an analytically described surface is wanted, it should suffice to describe the border of the wanted surface. Because of the existence of an infinite number of surfaces having the same border, artifices must be provided to make the user sure about the surface that has been chosen.

At this point it is clear that serious problems arise for the developers of the software for this kind of automatic mesh generation. In any case the user must be enabled to build up the idealization from simple and natural objects like points, lines, surfaces and so on. If all these objects are given names, new objects can be defined merely by reference to those defined earlier. This natural geometric language should allow the user to define almost any kind of structure and to use any type of elements.

Some experiences achieved in producing software for automatic mesh generation showed that two rather opposite approaches are possible :
- a poor automatic discretization, requiring a refined subdivision of the body into many parts of rather simple geometric shape, but strongly subjected to the wishes of the user and therefore likely to give satisfactory results in almost any case,
- an effective automatic discretization with a reduced intervent of the user, but not always completely satisfactory.

From the user's point of view the difference between tho two approaches lies in the possibility of describing only the external boundary of the whole idealization against the necessity of subdividing it into smaller parts all requiring the description of the related boundary. It is apparent that, from the software developer's standpoint, the latter approach presents more difficulties than the former due to the presence of wider regions with irregular borders. In these regions of arbitrary shape it is not possible to use previously defined discretization patterns. To clarify this point we may spend some words to give a glance at how the first approach works. A given surface in three-dimensional space is described in parametric form such as to establish a close correspondence with a quadrilater or a triangle defined in the bi-dimensional space of the parameters. After the user has established the type of required elements and the distribution of elements coarseness, the discretization takes place in the parameters space and then is transferred to the spatial surface. The same happens for solid bodies. This way of working requires obviously a subdivision of the idealization into parts which can be described analytically as results of a transformation of very simple geometric forms. Being the discretization applied to these forms we can speak of an almost pre-defined discretization which strongly simplifies the problems encountered in the design of the related algorithm.

Reference was previously made to the capability of automatic nodes and elements numbering. It is a quite trivial operation if we do not consider the relevance of a numbering oriented to reduce the time required by the solution of the set of simultaneous linear algebraic equations built up by the structural analysis program. Most of these programs use direct methods which yield the solution by performing a fixed number of arithmetic operations. This number heavily depends upon the order in which the particular method eliminates the equations. When a front solution algorithm is used the order of elements is the important factor in increasing the efficiency of the elimination process while the node numbers are merely unique identifiers. This order should be such that elements topology is defined progressively through the structure in rows, in a way suited to make the longest row as short as possible. When other band algorithms are used it is necessary to order the nodes according to the previously explained criterium. In any case the automatic mesh generator should provide for a suitable numbering of elements and nodes which could take place after the completation of the discretization.

As far as the choice of elements is concerned it has to be remarked that an easy change of the type represents a valuable capability. The use of higher order elements where a discretization using lower order elements has already taken place is a common operation which wastes time when performed manually. All elements connections must be changed, new nodes coordinates must be defined, a general renumbering of elements and nodes is necessary. When performed by the computer this operation is rather simple and the development of the related software does not present difficulties.

Interactivity has a remarkable role in automatic mesh generation both in facilitating the description of the geometry of the idealization and in allowing the user to modify the automatically generated meshes when they are not satisfactory.

5. PROBLEMS IN DEVELOPING SOFTWARE

It is quite obvious that an interactive system must assure a response from the computer in a comfortable time, that is, balanced to the expectation of the user according to the complexity of the operations requested. Considering this necessity the algorithms for hidden lines elimination are likely to be critical while automatic mesh generation is not strongly limiting. We must consider indeed that the individuation of the parts of the idealization which are hidden from other parts requires many investigations. First of all these algorithms must recognize the so-called internal faces, i.e. those elements faces which constitute boundaries internal to the discretization and are therefore shared between elements contiguous one with other. After these faces have been removed the outer skin of the idealization must be examined to determine which parts could be viewed by the observer if they would not be hidden by other parts which can in turn be viewed. When we deal with elements having curved surfaces it could be necessary to split the curved faces into two or three parts delimited by curved edges which are not present in the idealization's description. Finally there is the need of considering all the edges which are common to faces which can be viewed and faces which cannot be viewed to establish the correct relations between them and determine what can be seen and what is hidden. Taking into account the possible existence of line elements, bi-dimensional elements and solid elements, we can easily realize that hidden lines elimination algorithms are quite complicate and require a considerable amount of time to give the desired results. For this reason when developing the related programs, we take care of showing intermediate results : first the outer skin of the idealization is represented, then the part of outer skin that can be viewed is shown (at this point the hidden line elimination is complete if we deal with a convex object), finally the remaining operations are performed until the elimination reaches its ultimate objective point.

Moreover the software developed for the previously described purposes must be tailored to the computer and the display devices used. We must recognize that the software of this kind offered tends to be computer-independent and output display device dependent at a very low degree. But this approach is valuable for those who develope software which has to be sold. When developing software for in-house applications it could be a worthwhile attempt to look for efficiency without taking care of a wide applicability. Generality can be achieved at a higher cost and therefore it may be disregarded. Anyway it must be clear that this choice affects only the structure of the data-base and the way of operating, while the algorithms of representation, mesh generation and hidden lines elimination constitute a know-how achievement valid for every new software development.