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THEME 1

New Applications of Informatics in the Construction Industry

Applications récentes de l'informatique dans l'industrie de la construction

Neuere Anwendungen der Informatik in der Bauindustrie

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Impact of CAD/CAM Systems on the Construction Industry

Implications de la CAO/FAO dans l'industrie de la construction

Erfahrungen bei der Einführung von CAD/CAM-Systemen in der Bauindustrie

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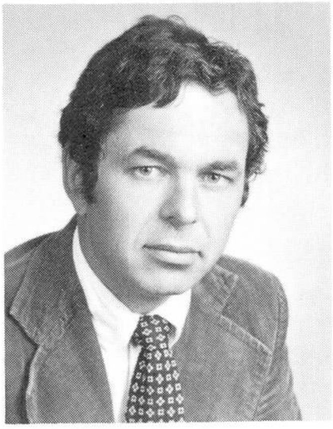

Wolfgang Haas was born in 1942, and obtained his civil engineering degrees at the Universities of West Berlin and Stuttgart. He was engaged on various projects concerning the development and application of EDP-programs to civil engineering problems. Wolfgang Haas is general manager of RIB.

SUMMARY
Although CAD-systems have been used increasingly by designers and structural engineers in the design stage, there exists little experience about the application of CAD/CAM-systems in the construction phase by contractors. The paper describes results and conclusions obtained by the application of such a system by contractors to a major construction project.

RESUME
Les systèmes de CAO (Conception assistée par ordinateur) sont de plus en plus fréquemment introduits dans la phase d'élaboration de projets de construction. Par contre, il existe peu d'expériences sur la mise en place, dans les entreprises, de système de CFAO, qui interviendraient au niveau de l'organisation et de la réalisation des travaux, (Conception et fabrication assistée par ordinateur). Ce rapport fait état de résultats et de recommandations tirés de l'application d'un tel système dans le cadre d'un projet important.

ZUSAMMENFASSUNG
CAD-Systeme werden in zunehmendem Umfang für den Gebäudeentwurf eingesetzt. Dagegen existieren nur wenige Erfahrungen über den Einsatz von CAD/CAM-Systemen für die Bauplanung und Bauwerkserstellung durch Bauunternehmungen. Der vorliegende Bericht beschreibt Ergebnisse und Schlussfolgerungen, die beim Einsatz eines derartigen Systems für ein Grossbauvorhaben gewonnen werden.

1. INTRODUCTION

CAD-systems are increasingly used by designers and structural engineers in the design stage. Various reports [1], [2], [3] describe the programs, applications and the market. In the English speaking countries, this trend towards CAD-systems is more marked than in the German speaking countries.

This situation is in a remarkable contrast to the rather few applications of CAD/CAM systems by construction companies especially during the construction phase. This is certainly due to the fact that the program developing institutions have stressed their efforts on the design problems of buildings and paid less attention on manufacturing problem. However, if the complete information of a building is stored in a data base, these information can be exploited in many ways, to produce drawings and lists which enable the contractor to rationalize the construction site.

2. PRINCIPLES OF MODELLING

The project to which the CAD/CAM sysem is applied consisted mostly of prefabricated concrete members. Cast in place concrete is rarely used. The following sections of the paper refer only to the structural elements (hollow core planks, girders and columns) of the project.

For the modelling of the building, a volume orientied 3D-system [4] is used. The principles of the modelling of the shape of the building are shown in Fig. 1.

The lowest modelling level is the level of geometric primitives, i. e. cubes, prisms, cylinders. In the second level, these geometric primitives are assembled to combinations of geometric primitives to model for example different haunch types. In the first level, the structural members are modelled as geometric primitives and assemblies of geometric primitives. In the building level, the structural elements are located in the building. From this pattern we see that three levels (level 1 - 3) are used to model the structural members, and one level, the building level, to locate the structural members inside the building.

In Fig. 2 the complete information, stored in the different levels is shown. Since the location of any structural member can be given in relation to a rectangular regular construction gird; the information needed, to locate a structural member is basically information about the grix axis together with the pointer to the corresponding structural element.

In the first level, the information about the shapes of the structural elements is stored as pointers to combinations of geometric primitives and to geometric primitives together with pointers to the corresponding reinforcement units in level 2 and to the corresponding embedded items in level 3. In addition the different amounts of labour which are needed for different fabrication steps of the prefabricated members are stored in this level.

In level 2, combinations of geometric primitives are stored as pointers to geometric primitives together with units of reinforcement as pointers to reinforcement primitives and in level 3, the geometric primitives are stored together with the reinforcement primitives and the embedded items.

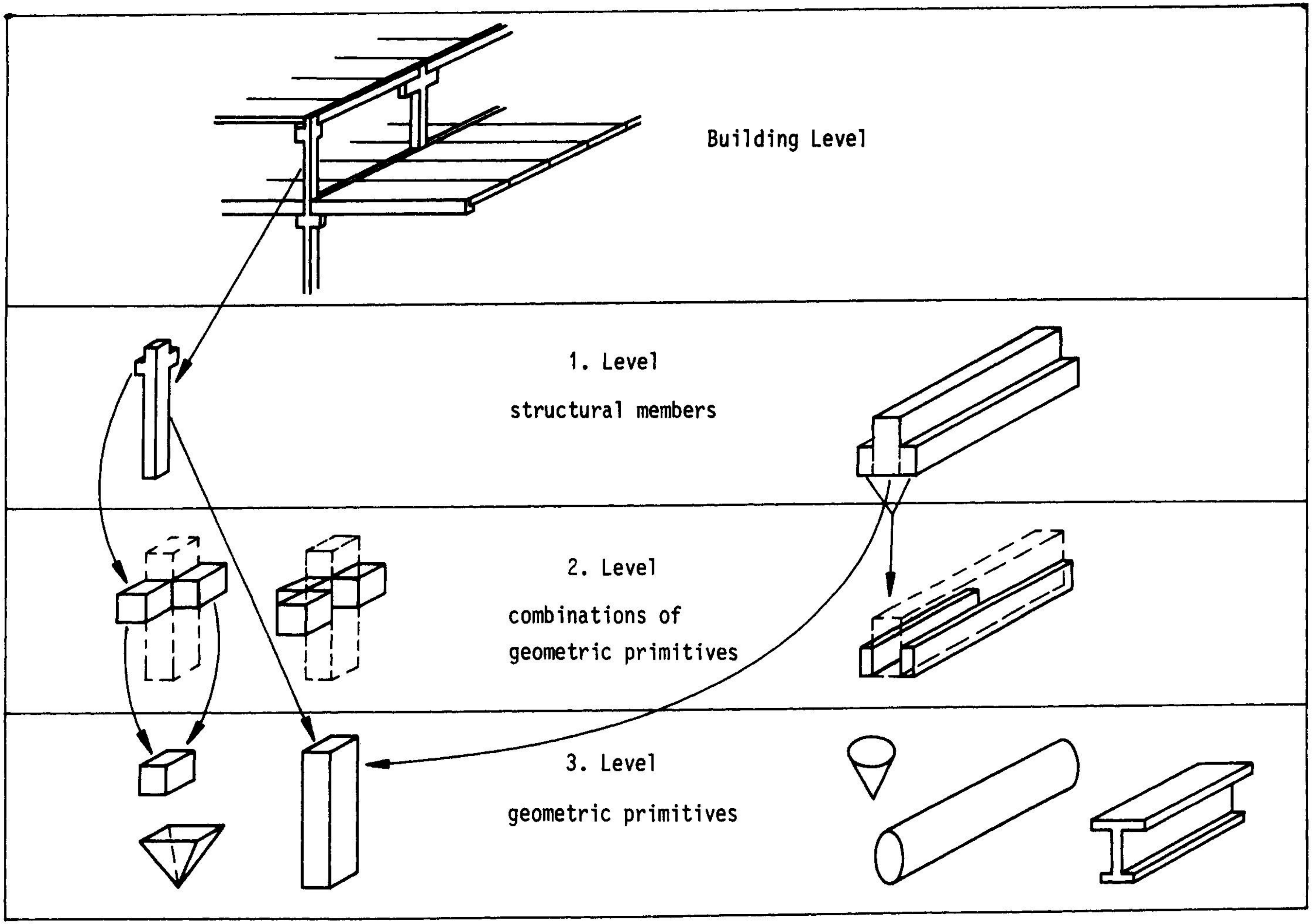

Fig. 1 3D-modelling of buildings

modelling level	information stored
building level	locations of structural members
1. level structural members	pointers to combinations of geometric primitives and to geometric primitives pointers to reinforcement units pointers to embedded items amounts of labour (hours)
2. level combinations of geometric primitives and reinforcement units	pointers to geometric primitives pointers to reinforcement primitives
3. level	geometric primitives (s. Fig. 1) reinforcement primitives embedded items

Fig. 2 Modelling levels and corresponding levels of information storage

In Figs. 1 and 2 one can see that the informations are structured in a hierarchical way and therefore a hierarchical data base concept was used to store the data.

3. USER INTERFACE - INPUT

Since ground plans were available at the beginning of the project, a batch oriented input is chosen, to prepare the input data. In most cases, one line of input is needed to describe one structural element and its location.
One line of input data consists of the following information

- grid numbers for the location

- keys for cross sections, haunches, reinforcement, embedded items etc.

Special schedules are developed to prepare the input data. The input data are prepared by structural engineers and entered in the computer by data typists.

4. CHECKING LISTS AND DRAWINGS

4.1 Structural checking

In order to detect errors in the input data and in the original plans, the CAD/CAM system is able to check the structural elements and assemblies of structural elements. A typical check of a structural element is to compare the shape of a structural element with the corresponding reinforcement unit. If for example the reinforcement unit is longer than the structural element, an error message is given to the user.

A typical check of structural assemblies is shown in Fig. 3.

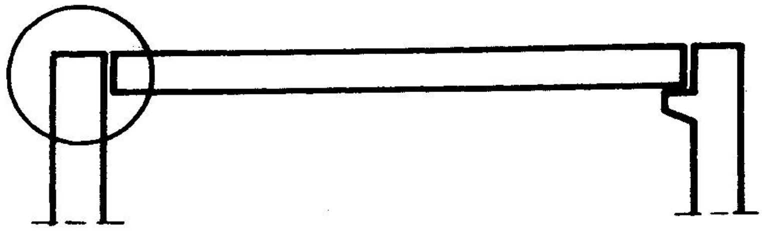

Fig. 3 Example - Structural Checking

The program checks in this case whether a column has a haunch at the location where a girder should be supported by the column.

By these checking routines errors can be detected which are either in the original plans or which occurred during the preparation of the input data.

4.2 Automatic Type Numbering of the Structural Members

Since the engineer who prepares the input data does not know whether the structural member for which he just prepares the input data is already located at other places the CAD/CAM system checks all the already existing structural members in level 1 (see Fig. 1) whether one existing structural member is equal. If a structural member with equal shape, reinforcement and embedded items is found the new structural member gets the type number of the already existing one which is equal. Otherwise, the new structural member gets a new type number and the corresponding information is stored in the different information levels.

This automatic type numbering is of great importance since it ensures that equal structural members have equal type numbers and thus great series of equal elements can be identified which enable a cost effective fabrication of the structural members.

4.3 Work Shop Drawings

Two different types of drawings were produced by the system.

- erection layout (1 : 200)
  This plan showes the structural members for a specific building, level and section. The plan containes also the type numbers of the structural members but not the more detailed information about haunches and embedded items etc.

- erection layout (1 : 50)
  This plan showes more details on the erection layout (1 : 200) such as haunches of girders. It is used for difficult sections of the buildings.

Because the plans are modified during the application of the CAD/CAM system the drawings are produced several times. The modification are done, using the plans produced by the CAD/CAM system.

4.4 Reports

Various types of lists and reports are produced by the system. Typical examples of these lists are

- lists of the structural members, sorted according to buildings, levels, and sections of the reference grid
- structural members in specific buildings, levels inside specific sections of the reference grid. The building sections for which the lists are produced usually refer to the production of prefabricated members of one week
- summation lists of structural members for the production

On the basis of these lists, the production of the prefabricated members can be planned effectively. This information is stored on a magnetic medium and formes the basis of a program system for the updating and control of the production.

This description of the effective use of building data in a CAD/CAM system is by no means complete. Its main purpose is to demonstrate that these data can be used to rationalize the planning and fabrication process of buildings made of pracabricated concrete members.

5. FURTHER DEVELOPMENTS

The CAD/CAM system described in this paper does not cover the design stage. Currently such a program development is almost completed. Thus in the near future, a program system will be available which covers the interactive modelling of buildings, the production of drawings and the report and list generation with regard to rationalize the construction stage.

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Automatisation of Drawing-Office Activities

Automatisation des activités d'un bureau de dessin

Automatisierung im Entwurfsbüro

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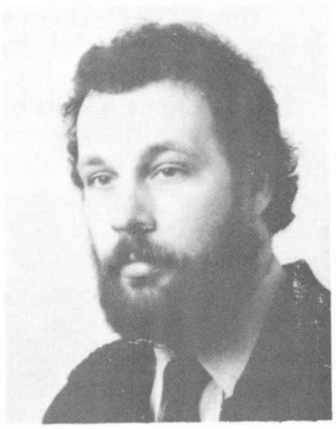

Harry Wagter, born in 1946, obtained his degree in Building Engineering at the Eindhoven University of Technology in the Netherlands. He has had several years of practice in a major engineering office, he later joined CIAD as a staff-member and became projectleader since 1978.

SUMMARY
After a short introduction of CIAD, the paper presents the findings of two CIAD projectgroups on the subject of automation of drawing office activities and the experiences gained during the testing of twenty CAD turnkey and software packages. It ends with recommendations for requirements to be met by systems for technical draughting.

RESUME
Après un bref aperçu des activités du CIAD (Association pour les applications de l'ordinateur dans la pratique des ingénieurs), cette publication présente les résultats de deux projets de groupes du CIAD, réalisés sur le thème de l'automatisation des bureaux de dessin, notamment les expériences tirées des tests d'une vingtaine de postes de travail et de systèmes logiciels CAO. Les conclusions mettent en évidence les exigences principales auxquelles devraient répondre ces systèmes.

ZUSAMMENFASSUNG
Der Bericht behandelt die Ergebnisse zweier CIAD-Projektgruppen, die sich mit der Automatisierung im Entwurfsbüro befasst haben. Zwanzig «turnkey» CAD-Systeme wurden untersucht und die dabei gemachten Erfahrungen werden erläutert.

1. CIAD
1.1 Association for computer applications in applied engineering

CIAD is a Netherlands independent non-profit-making organisation devoted to the effective use of computer applications in applied engineering. It has been active since 1968.
The members of CIAD are consulting engineers, contracting companies, government departments, educational and research establishments, computer centres and software houses.
In the Association the members find common interests and aims. By mutual discussion and collaboration they tackle problems that they would otherwise have to face alone.
The activities undertaken by CIAD for its members include:

- The collection and arranged distribution of information concerning computer programming, existing and new techniques, hardware and various matters supporting the efficient use of the computer.
- To establish and maintain contacts with national and international organizations and public services with similar interests and take part in their activities, thus forming a communication channel and voice for all CIAD members.
- To stimulate, co-ordinate and accompany direct project groups formed by its members, providing them with a framework for purposeful co-operation for studies, program development and promotion of other common interests within the overall objectives.
- To conduct consultations with the general and specialised education institutes and to contribute to an adequate education in the field of informatics, which plays a large role in engineering practice.

One of the most active project groups that CIAD ever had is the project group on Automation of Draughting Office Activities.
This group is a good example of co-ordination between the members of the organisation; a rather expensive investigation that could hardly be paid by a single concern, is being financed by 23 firms now. The group started in 1979.

A small work group formed itself and put forward a proposal for the project group on the automation of draughting office activities.
Fourteen members subscribed to the first. Two meetings were required to draw up the work plan for the project group. Nineteen CIAD members reacted positively.
The overall objective is:

- To promote knowledge and understanding of the potentialities and limitations of the automation of draughting-office activities for draftsmen/ designers in architectural and civil engineering.

From this, the following specific objectives have been derived:

- to gain knowledge in the field of existing hardware and software
- To make a compilation of wishes and needs with the help of present and future users.
- To make recommendations for methods and procedures in the use of systems for the automation of draughting processes.
- To investigate the social consequences of automated draughting and to formulate recommendations about procedures in introducing such systems.
- To try out the recommendations by means of a test.
- To draw conclusions and to report on the group's activities.

In 1980 a number of extensions took place as a result of the enormous interest which the project has aroused. One reflection of this was the increase in the number of participants to twenty-three, which meant that plenary meetings were attended by some thirty-five people. Partly because of the size of the project group, it was decided at a fairly early stage that the actual work would be

done by working parties, which would receive intensive assistance from the CIAD-secretariat.
Recently the project group finished its final report.
In this report conclusions and recommendations are formulated concerning the introduction of CAD-systems at the building and engineering offices. The report also gives a discription of eighteen CAD-systems. Besides this, fiftheen systems were tested on aspects concerning 2D-draughting facilities and the possibility and quality of features as linking graphical and alphanumerical programs.
It is a comprehensive report that is of use for all the participants including the suppliers of CAD-systems, who all received a free copy.
We learned many lessons by this project. One of the most important is mentioned here:

> The one who is thinking about doing all, or part of his draughting work by computer, cannot just listen to vendors. This does not mean that one cannot trust them, but the big problem is that they don't understand what, in this case an architect, is doing, they haven't the slightest idea what that job implies. It is absolutely necessary to play a very active part.
> At the same time the next problem is indicated: users and of course future users are not able to formulate their wishes in a manageable way. In this field associations like CIAD can be able to bridge the gaps.

2 PROCEDURE FOR ASSESSING REQUIREMENTS

There are a number of stages to be gone through before a new working method or new equipment is introduced at a firm or in a department. Having heard of the new idea, and having come into contact with it several times, possibly only fleetingly, a potential user has to investigate whether it is suitable for his firm or department.
In other words the need for it must be determined.
There are two aspects of the need. In the first we have to find out whether the need exists in general terms, and if so we have to investigate how this need can best be met, in other words which system or equipment is best suited for the firm or department in question. There is nothing new about this, but for the automation of draughting office activities the relevant CIAD project group considered that it would be useful to set up a procedure which could be followed to determine the need, as mentioned above. This procedure is divided into a number of stages, and the content of each stage is described briefly below.

2.1 Nine stages

The first stage of course has to give an answer to some general questions and is a brief investigation within the company to find out whether there is any point in a more detailed study of the need for automation of draughting office activities and to make the user of the procedure aware of the aspects that are linked to these activities.

- Is the type of draughting work suitable to apply computers?
- Is enough workload available for it?
- How many draughtsmen are in the firm and what will be the influence on their number and the quality of their working atmosphere?
- What will be the organisational effect anyway?
- How much money can be spend and what will be the productions costs after the investment has been made?

It is quite possible that an organisation never reaches step two.

In the second stage firms will have to realize what draughting with the use of a computer exactly means. This is a more fundamental orientation, a logic step after the first one.
In this stage we will learn about the differences between turnkey-systems and software packages.
What is the interactive way of working, the only type of working we want to talk about in this study.
Applying software packages, what does this mean for other applications that run on the already existing computer.
Probably the firm is in this the phase already, they might know the differences between storage tubes, raster- and vector-scan-tubes, plotter types etcetera.
Some of the people inside an organisation are already familiar to all those aspects, than it will be necessary that they formulate all this to help other people within that organisation.
It will soon appaer that most of them don't have the faintest idea of all the possibilities and consequences, sometimes step two will be a continuous story that runs simultaneous during the total process.
In order to judge which part of the existing amount of draughting work can be handled by computers one needs to analyse the existing situation (stage three).
An extra difficulty here is that working in a new way opens new possibilities.
For instance there is no need to make draughtings on different scales any more, one is enough, or it might be possible that the savings in the organisation don't effect the draughting work, but the more economic way of storing draughtings, because this firm is involved in very complex projects for instance. This are just some possibilities, there are plenty more.
On the basis of a survey of the quantity of draughting work for each kind of work, an estimate can be made of the capacity that the firm, or department, currently uses to carry out draughting activities.
The study gives a tool by offering a checklist and a method to measure the activities.
For every activity one has to find out which possibilities he wants a draughting system to posess. This is step four.
From the matrix we build up this way the specific demands can be read.
We can also make a kind of advanced matrix by using some weight-ratio, which could be the result of an internal questionnaire, in such a way that everyone involved can give his own accents. After all not everyone is making the same products.
Designers working on a small scale will show specific demands, that will differ from demands shown by designers that have to handle large dimensions or high accuracy.
Stage five that comes next, is testing the facilities of the various systems against the specific requirements.
Within the frame work the project group made an investigation of some 20 CAD-systems. The experiences on this test will come up for discription later on.
When the possibilities found out in step five are combined with the specific demands formulated in step four, we have a soft tool that tells us about the productivity ratio of each specific system to our specific demands.
It is realized that this procedure gives a result that is a little bit academical, but it gives an impression that is based on a realistic situation.
Besides this it will make sense to combine the result with running a bench mark on two or three selected systems.
Stage seven is a special one called social aspects.
It has everything to do with ergonomics, division of labour, working atmosphere, older draugthsmen and new technics, and how to introduce these modern tools in an organisation.

A special working group with specialists in it was formed. They visited several firms in the Netherlands, where these modern tools are already in use. They spoke with managers, draughtsmen and operators and what they got out of it was very confusing.
Here some (cautious) conclusions:

- The learning period before users feel familiar with the system is between a few months and six months.
- Correct lighting of the workroom to prevent reflections is highly important.
- Long response times are extremely annoying.
- Working with the system is not felt to be routine. It calls for more concentration, but is not seen as making the job difficult.
- A lot of attention must be paid to preparing the drawing work, but this is not regarded as inconvenient.
- The quality of the draughting work is more constant and is generally more highly regarded.
- Draughting becomes more effective as use can be made of previous elements, i.e. standards.

Some of the most demotivating aspects pointed out were:

- Hardware and software problems in the most general way.
- Supplier promises that are not kept.
- The 'speed' of a slow plotter.

A difficult phase too is step eight, the making of an economic analysis.
We are now trying to compare the decrease of production costs by working in a more efficient way to the increase of those costs by the purchase of an expensive system. The comparison is difficult to make, for we must realize that a draughtsman is only making draughtings for about half of his time.
The costs of the system are to be shared over initial and periodic costs. In principle this doesn't differ from procedures on other buyings, but there are some striking differences one should considerate.
Just mentioned were the high initial costs for training and the time that must be bridged between the date that the equipment is carried into the premises and the date that all runs smoothly. Mostly this will take more than half a year.
Maybe one gets a new kind of organisation, more uniform and flexible, but also more complex and vulnerable.
Besides all these aspects the computer might or will also have its influence on the design process itself, and we have to be honest to ourself if we want to.
It is realized that sometimes this paper is not very optimistic.
Well, step nine might be the most frustrating: the conclusions from all we did and the decision we propose to our management.
Perhaps we started with five systems, we ended our evaluation with three and propose one or two.
A problem seen in many organisations is the difference in approach between technicians and management. Very expensive evaluations, mostly carried out by a technical team, suddenly seem to be of interest no longer, when the stage of decision is reached, the stage where the commercial games are played.
Suddenly strange things happen.
Suppliers start sending cable grams during board meetings, in which they propose all kind of new possibilities, cheaper workstations, proposals to co-operate etcetera.
Suddenly all those technical evaluations seem to be of no interest any more; we came into a rather agressive network of commercial tricks. This game might be very frustrating for technical people involved in the selecting, and they must be prepared for it.

3. TESTING THE FACILITIES OF VARIOUS CAD-SYSTEMS

As mentioned already at stage five of the previous procedure, it is necessary to test the facilities of the various systems against the specific requirements. A special 'CIAD-test for electronic draughting' was designed for this purpose.
This test is in three parts:

1 A general draughting
2 Test of response time and disc capacity
3 Making a menu.

The test was send to the suppliers concerned well in advance of being carried out.

3.1 General draughting

In order to arrive at a general test draughting by means of which draughting operations could be tested, the existing working method was analysed. It transpired that there is a heavy emphasis on corrections and alterations. Starting with the basic draughting a variety of additions and corrections are made.
The various operations are described step-by-step in the test.
Obviously every user or future user can decide for himself the importance of the various subjects, such as mirroring, rotating, reducing and scaling. The test shows whether these operations are possible or not, and if so the standard to which they are performed.
Other features covered are:

- How lines are built up internally (hardware- and/or software-generated)
- Draughting in layers
- Draughting to scale
- Lettering
- Dimensioning
- Hatching
- Splines

In the last stage of this test the time taken for a total projection is measured.

3.2 Test of response time and disc capacity

To find out in a simple manner how quickly the system can project a draughting and how much space such a draughting occupies on disc, a simple standard draughting has been designed; this draughting is built up in four stages:

1 500 horizontal lines
2 500 vertical dashed lines
3 500 times the lettering 'ABC'
4 500 circles with a diameter of 10 mm.

In terms of information quantity, the final result is equivalent to a simple standard draughting as prepared in civil engineering and structural engineering firms.
The accuracy of the systems is then tested with the aid of a triangle with sides in the proportion 3-4-5.
Starting with sides of 3333 and 4444 units at right-angles to each other, the triangle must be dimensioned; the sloping side must then be 5555 units. If this is the case, the number of 3s and 4s is continually increased untill the accuracy limits of the system in question are exeeded. The readings achieved are an indication of the accuracy.

3.3 Making a menu

The project group attached particular importance to the facilities for linking graphic and alphanumeric information. The purpose of the third part of the test is to establish the possibilities and qualities of the various systems in this respect. The test involves draughting a small ground plan in which reinforcement must be laid.
The program to be linked must then present a sorted bill of materials for the reinforcement.

3.4 The test in retrospect

While carrying out the various tests it became apparent that there are in fact three aspects to testing:

1 Testing whether the basis for making the draughtings is indeed correct
2 Testing the person operating the equipment
3 (finally) Testing the draughting system.

It emerged that compiling a good test is a difficult matter. On close inspection various questions were not clearly answered, but on the other hand information sometimes emerged that no one had thought of at the outset.

3.4.1 Projection speed test

Taking as a reference a draughting consisting of the above mentioned 500 lines, lettering and circles, we find that sometimes more than one minute may be needed to project the draughting. Obviously this is too long for the operator. Usually, however, it need not take so long. Often all that is required is an indication of the draughting on the screen, so that 'a window' can be defined in which the eventual draughting work will be done. For the above reasons it may be important to be able to terminate projection of the draughting before it is complete.

3.4.2 Storage on disc

People were generally badly informed about the characteristics of the equipment. Nevertheless it was found that the data occupies much more space than might be expected.

3.4.3 Line thicknesses and line types

It emerged that a distinction must be made between line thicknesses and line types on the screen and the plotter, and between hardware-generated lines and software-generated lines.
For example, a Tektronix 4014 screen has five hardware line types and two line thicknesses. The draugting system may or may not make use of this hardware option.
What are the advantages and disadvantages of using the hardware-generated lines?
Suppose a dashed line is to be displayed on the screen. If the draughting system uses hardware lines, the computer need only send the start and end coordinates with line type and line thickness. The Tektronix then projects these as a dashed line. In terms of time it is immaterial whether a solid or dashed line is being drawn.
The draughting system may also generate the lines itself (software lines). In that case the coordinates of all short dashes must be transmitted, together with line thickness. This results in a long projection response time.

In the projection response test it is usually important to know, for the projection of the 500 dashed lines, the number of dashes that go to make up a dashed line. However, the test made no provision for this.
Various suppliers projected the dashed line in the form of only a few short lines.
A disadvantage of using the Tektronix hardware lines is that there is a limit of five line types. This applies to the screen. For the plotter the lines are usually generated by the draughting program. Often more line types are then possible on the screen.
To make the whole matter even more complex, even more techniques are in use for the above facilities. The draughting program may generate everything but the projection time may nevertheless be short. In this case the draughting station is usually extensive, with seperate facilities.
If the draughting station has its own (local) intelligence, the computer need only send supplementary and/or altered data to the draughting station. The work is projected on the screen from the draughting station itself, and the projection time may be very short.

3.4.4 Layers

It is not sufficient to ask whether a system can draw in several layers; the subject turns out not to be so simple. All the systems so far tested offer a large number of layers, but it is important to establish what function the user can give to the various layers. It is also important to establish whether the draughting system has already assigned functions to the layers, and if so, which. Some systems for example use the layers to place the various line thickness in.

It is also customary, and practical as a means of switching off a layer during intermediate projection on the screen, to use a layer for the following, for example:

- Normal lines
- Lettering
- Dimensioning
- Hatching
- and so on.

Users often wish to use layers to draw the following by layers, for example:

- Shape of a floor
- Reinforcement in the floor
- Drains in the floor
- and so on.

After this summing up it will be clear that not every draughting system offers the layer technique required.

3.4.5 Rotation and Mirroring

At some systems lettering appears upside down, at other systems all text will disappear completely after a rotation or mirroring action.

3.4.6 Scaling

Two methods are used for locking up the coordinates:

- All coordinates are locked up in actual size
- All coordinates are locked up to scale.

For the draughtsman everything appears to be the same. In both cases a dimension of, for instance, 1000 mm must be stated as '1000'. However, practice shows that the differences in results can be very great. In systems that use actual-size storage, draughting with several scales on one draughting is usually impossible, or only possible in a fairly roundabout manner. When working with actual-size storage the height of the lettering must be taken into account. If lettering 5 mm high is to be used on a draughting to be plotted on a scale of 1:100, the draughtsman must enter the lettering height as 5 x 100 = 500 mm.

The above comments on the use of several scales on one draughting generally also applies to scaling. In draughting systems with actual-size storage, scaling itself is often possible, but afterwards it is usually no longer possible to dimension automatically.

3.4.7 Interfacing own programs

If a draughting system is to be used in the CAD (computer-aided design) field, it should be possible to interface user programs to the draughting program. It must be possible to transfer information from the draughting to the user program and to add information to the draughting from the user program. In order to try out all these features, a test was designed for making a program (menu) for interactive draughting of concrete reinforcement.
According to the survey, user program can be interfaced to the draughting program of all draughting systems. As our findings show, things are somewhat different in practice.
Beside this point the group found out that this matter is more complex.
It appeared that there are two principles of doing computations during draughting work.

1 Linking (Fortran) programs
2 Using a so called macro language

When a system works according to the last mentioned principle, it is not certain that one can connect already existing programs to one's draughting.
This complexity of this issue had been underestimated.
For this reason a second CIAD projectgroup added a part to the test they developed.

4. A SECOND PROJECTGROUP

The line of approach of the previous mentioned projectgroup was architecture and civil engineering.
A second CIAD projectgroup on the subject of draughting office automation has its origin in mechanical design. It is obvious that many experiences of this group are very useful in the field of structural design as well.
The test program that this group developed can be seen as a completion of the first.
The final report of this projectgroup is published in september 1982.

4.1 The test program

The test program covers three important issues:

1 Three dimensional capabilities
- Definition of elements, library facilities, wire, plane and solid models.
- Combination and separation of elements
- Manipulation of elements: move, rotate, copy, mirror, replace, change

- Views and sections, perspective, hidden lines removal.
- Computation: spacings, radii of curves, centres of gravity, volumes, moments of inertia.

2 Linking facilities for (own) Fortran programs.
- Call-up program from graphic workstation
- direct processing by this program of graphic data displayed on the screen
- Direct display op program output as graphic data on the screen
  The program to be called is given. This program should be defined as a Fortran main program and is not just a Fortran sub-routine, unless this figures out to be the only way to handle the problem.

3 System diagrams and database management.
- Production of drawings using basic elements
- Linking of attributes to elements
- Definition of alpfanummeric files
- Data input into alphanummeric files
- Production of various listings with input from graphic database
- Production of various listings with input from alphanummeric database
- Additions to alphanummeric database
- Production of report using 'report writer'

	system	test 1	test 2
1	AD-2000-CDC	X	X
2	Anvil 4000-L	X	X
3	Applicon	X	X
4	Autotrol GS-1000	X	
5	Cablos-VM 1	X	
6	Cablos-VM 1/Medusa		X
7	Cadam	X	
8	Cadam/Catia		X
9	Calma	X	
10	Computervision	X	X
11	Desikon	X	
12	EIDS		X
13	Euclid		X
14	G.D.S.	X	
15	Gerber	X	
16	Gri-2D	X	
17	IGS-Siemens	X	
18	Intergraph	X	X
19	Kongsberg CDM 100		X
20	Mc Auto Unigraphics	X	X

The systems tested by the two CIAD project groups.

4.2 The second test in retrospect

The projectgroup that ran the second test was formed by seven organisations. All of them stated that their main goal in joining the group was to get an instrument in making a decision in chosing a CAD-system for their own organisation.
After the closing of the test program one of the main conclusions was that they all overestimated the possibilities of the systems tested.
Especially the possibilities of 3D-modelling are much more modest than expected to be.

4.2.1 3D Modelling

Constructing and working with 3D computermodels turned out to be much more complex than expected.
The best results have been achieved with surface models combined with a hidden line algorithm.

4.2.2 3D Manipulations

Manipulations on so called solid models are simple to execute but claim an enormous amount of computertime.
The test is build up with a very simple design. Nevertheless took some operations more than thirty minutes on a big mini-computer, in spite of the fact that the test was the sole activity at that moment.
On wire or surface models all kind of operations operate much faster. Here problems might occur when a user zooms in at particular details and looses clarity.
All the lines have the same intensity and it is not possible to get a good judgement on which lines are in the front or at the backside of the model.
This problem can partly be solved by using colour or automatic hidden lines removal.

4.2.3 Different principles

Several different principles can be found when studying the way how 3D models are build up in the several systems. Sometimes manipulations can only be carried out in one certain plane, e.g. the X-Y plane.
In other systems one can only work in the 2D projections of the model.
Problems might mainly occur when a user wants to build up double curved surfaces.

4.2.4 Linking Fortran programs

One should pay attention to the fact that linking (Fortran) programs to the graphical database is not selfevident possible. Some systems offer very simple procedures, other very complicated. In this case only very advanced programmers can use this facility.

4.2.5 Database management

In this part of the test a small project consisting of several draughtings is simulated. If figured uot that only a few systems were able to produce the requested listings. Most systems only have facilities to make so called connector lists.
Some could run this part of the test rather efficiently but for most of this group comprehensive programming work had to be carried out.
Later was found out that problems might occur when elements in the draughting have been copied or mirrored. Mostly all the connected alpha numerical data is lost after such an operation.

5. BASIC REQUIREMENTS TO BE MET BY SYSTEMS FOR TECHNICAL DRAUGHTING

To formulate basic requirements to be met by systems for technical draughting is probably just as difficult as developing such a system. During the many contacts that took place as the project group carried out its activities it became abundantly clear that the suppliers had no idea of the sort of draughting work carried out by CIAD members. In this case CIAD members means the members of the project group, the majority of whom are active in the architectural, civil engineering and geodetic fields.

It must be pointed out at the same moment that the members of the project group have little experience of computer draughting. The exchange of information between the two parties was therefore laborious. The problem was acknowledged by both parties. Without wishing to go into undie detail, the purpose of this chapter is to attempt on behalf of (future) users to formulate the basic requirements that draughting equipment must meet. Some of the points mentioned in the CIAD report are listed below.

5.1 Entry of dimensions and dimensioning

Almost everything is drawn to dimensions, and the entry of the dimensions is therefore highly important. Automatic dimensioning is essential. Generally the end of the dimension lines is indicated by points and sometimes by dashes or arrows. It must be possible for the user to specify the length and termination of the auxiliary lines. If a dimension will not fit between the auxiliary lines, it must be possible to displace it easily.

5.2 Line types

Several line types with associated line thicknesses are necessary. For architectural draughting, five line types are normally sufficient. For surveying work as many as 20 types may be needed, and it is important that the user can design the lines himself, and that the lines may also consist of symbols.

5.3 Lettering

Several lettering heights with associated line thicknesses, upper and lower case must be possible.

5.4 Layering

Layering as a two-dimensional technique. An example of this is given below.

Example of layer numbering

	Lines	Lettering	Dimensioning	Miscellaneous
Drawing of the floor	0	1	2	3
Drains of the floor	10	11	12	13
Electrics in the floor	20	21	22	23
Miscellaneous	30	31	32	33

5.5 Coordinate size and accuracy

For architectural draughting work, systems should allow for a largest coordinate of 1000 m with an accuracy of 1 mm. For surveying draughting work the largest coordinate may amount to hundreds of kilometres to an accuracy of 1 mm.

5.6 Hatching

Hatching must be possible, with line type, distance and angle to be chosen by the user. It must also be possible to draw hatching with symbols developed by the user.

5.7 Repetition

It must be possible to make repetitions in drawing elements easily by means of a repetition factor.

5.8 Mirroring and rotation

This must be possible about any axis. This applies also to lettering and dimensioning, but these must not appear in mirrored form. The text must remain in the imaginary mirrored rectangle that surrounds it. After mirroring, numbers in the dimensioning must remain on the same side of the dimension line as before mirroring. In other words they must stay on the dimension line.

Rotation through any angle must be possible, and it must also be possible for rotation to be determined by the draughtsman or from the database. This applies also to the lettering and dimensions, but these must not appear upside down. On the drawing, it must be possible to read the lettering and dimensions from the bottom upwards and from left to right.

5.9 Several scales on one drawing

It must be possible to work with several scales on one drawing, and the digital data must remain intact.
It must also be possible to scale (make larger or smaller) an existing drawing, and to choose whether the scaling is to include lettering and dimensions.

5.10 Response times

The response times are a function of the size of the drawing and the number of active work stations. The 500 lines, letterings and circles as processed in the second part of test one test drawing one should be taken as a standard for drawing size. Response times are divided into search time and display time. Long response times cause the draughtsman to lose concentration.
It is difficult to specify how long it should take for a drawing to be displayed on the screen. A display time of a mimute or more for the above drawing is too long for the draughtsman and is economically unattractive. As a general rule it can be stated that it should not take longer than 10 seconds for the primary information of the drawing to be displayed on the screen.
Among the features that contribute to a short display time are:

- fast hardware and software
- the ability to interrupt display
- the ability to suppress lettering, dimensioning and hatching
- schematic representation of circles, splines and cells (symbols)
- displaying software-generated lines as hardware lines.

5.11 Security

In the event of breakdowns, no results, or only very few results, may be lost. There must be protection against unauthorised use of the drawing data.

5.12 Ergonomics

The following points ought to be considered:

- clear arrangement of working space
- distance from eye to screen
- lighting
- working in daylight
- space to spread out drawings
- posture
- screen brightness
- and so on.

5.13 Interchangeability

Since drawings are usually made, used and processed by persons from several disciplines, it is essential that it should be possible for drawings to be transferred from one system to another.

Information (digital data) must be stored with an unambigious dimension unit, so that interchange is possible. The digital data is a mathematical model of an object consisting of coordinates of angle points, interconnected by metrological constructions.

5.14 File management

It must be possible for several work stations to work simultaneously on the same project, and for the results thus obtained to be recombined to form a single entry. It must be possible to increase or reduce the file size as required.

5.15 Temporary enclosures

It must be possible to mark out areas within which any lines can be removed up to the boundary of the area, or displaced as whole.

5.16 Speed of manual operation

It must be possible to combine several commands and parameters into one command.
Example: the following parameters are usually needed to position lettering:

- lettering type
- lettering height
- lettering width - line thickness
- lettering justification
- layer number.

It must be possible for the user to combine several combinations that occur in his work into a number of individual commands so that it is not necessary to specify parameters.

5.17 Linking programs

It must be possible, and easy to manage, to link excisting (Fortran) programs to the graphical database.
Besides this a so called macro language can be very useful.

5.18 Database management

It must be possible to link alphanumerical data to graphic elements. This data must be protected when a user excecutes certain manipulations. Various listings must be possible from graphical and alphanumerical database. It must be possible to connect pointers to the graphical elements.

6. A CLOSING REMARK

Selecting CAD-systems that can be used in a structural engineering environment is more complicated than expected at first sight. This also turns out to be the experience of existing users declaring that sometimes it lasted more than a year before all the features of their systems were known.
The execution of comprehensive investigations in joint effort as described in this paper can be very useful for the parties involved.
It illustrates the benifit of user-associations like CIAD.

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European Workstation for the Building Industry

Poste de travail européen destiné à l'industrie de la construction

Europäischer EDV – Arbeitsplatz für die Bauindustrie

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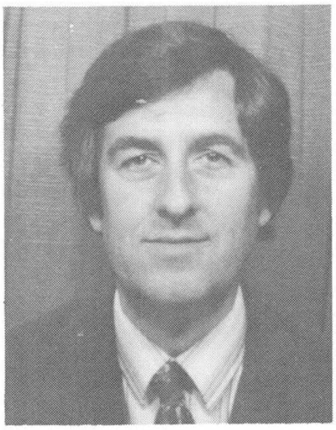

The author graduated in architecture at Cambridge university and worked in practice in London, USA and India. He is a member of the RIBA and the British Institute of Management, and has managed CICA since its formation as DOC in 1973. CICA is a user association for the building industry.

SUMMARY
This paper presents the results of a study carried out for the European Community. It identifies three levels of computer workstation suited to the needs of architects, engineers and constructors, and provides a specification of the hardware components and software systems required to make use of new technology in the next five years and ensure portability of software. A possible design is presented and recommendations for further work which could be supported by the Community.

RESUME
Ce papier présente les résultats d'une étude faite à la demande de la Communauté Européenne. Trois catégories de postes de travail informatisés, adaptés aux besoins des architectes et des ingénieurs constructeurs, sont identifiés. Puis des spécifications concernant les composants matériels et logiciels de ces systèmes sont établies dans le but de mettre à profit les nouveautés technologiques prévisibles dans les cinq prochaines années et d'assurer le développement de logiciels transférables. Une esquisse de solution est présentée accompagnée de recommandations pour la poursuite de l'étude.

ZUSAMMENFASSUNG
Dieser Beitrag behandelt die Ergebnisse einer Studie für die europäische Gemeinschaft. Drei verschiedene EDV-Arbeitsplätze werden vorgestellt, die den jeweiligen Bedürfnissen von Architekten, Bauingenieuren und Konstrukteuren angepasst sind. Zusätzlich werden die für die nächsten fünf Jahre benötigten Hardware – und Software Komponente spezifiziert. Eine mögliche Lösung wird vorgestellt und Vorschläge für weitere Arbeiten auf diesem Gebiet werden gegeben.

1. SYNOPSIS

1.1 Local processing

Computing power, even for large analyses and computer-aided design, is rapidly becoming economic to locate at the engineer's workplace. At the same time good programs and reliable data remain expensive, and good systems of communication and widely accepted standards are also needed to provide all the computer facilities required by the engineer.

1.2 Three levels of workstation

A workstation includes all the computer equipment used by one person at one time. Its specification was the basis for a project sponsored by the European Community and managed by the Construction Industry Computing Association. Three levels of workstation were identified to meet the range of needs of building industry offices from word processing to interactive graphics.

1.3 Recommendations in the report

The Report produced in May 1982, was published to influence those designing workstations and to indicate the needs of, and size of market represented by, the European Building Industry. Recommendations for further work emphasised the need for further studies of some technical developments and, particularly, development of systems software and software tools to make best use of multi-processing. A permanent exhibition of linked workstations in national centres was seen as the best means of providing a living demonstration of the potential benefits of computers to the building industry.

2 INTRODUCTION

2.1 Scale of the construction industry

While one aim of the project was to stimulate the European computer industry, the European Construction industry is about ten times as large and the economic benefits of making it more efficient are potentially greater. The project therefore studied user requirements to see how these were being met and whether the needs of construction were different to those of other industries.

2.2 A previous EC Study

This project resulted from one of the recommendations of a previous study "The effective use of computers within the building industries of the European Community' published in 1979. This was based on a survey of applications and data processed by different types of organisation in the industry.

2.3 The Project Team

A smaller study formed the first part of this project and selected organisations in computing and construction in the various countries were questioned by the following:

R W Howard	CICA	UK and Ireland
J Amkreutz	I3P Systems	Holland and Denmark (with C Grau)
T von Verschuer	Tech U. of Munich	Germany
Dr G Deprez	Univ. of Liege	Belgium & Luxembourg
M Louf, M Theron	Matra, Datavision	France
A Lagattolla	Systems consultant	Italy & Greece (with J Dominos)

The first three of these carried out the analysis of this data and produced the final report 'The specification of a building industry computer workstation' published by the EC and available from centres in the main EC countries.

2.4 Construction and Computing

While the study started from the needs of architects, engineers and contractors, a specification looking five years ahead was likely to be affected more by developments in computing than by a rather static building industry. Studies were made of several aspects of computing particularly displays, multiprocessing and software tools and the project was concerned with merging these developments with building industry needs to produce a broad specification allowing a response by computer system suppliers. To explore the ergonomic aspects one possible design solution was developed in detail but this should not be taken as an ideal.

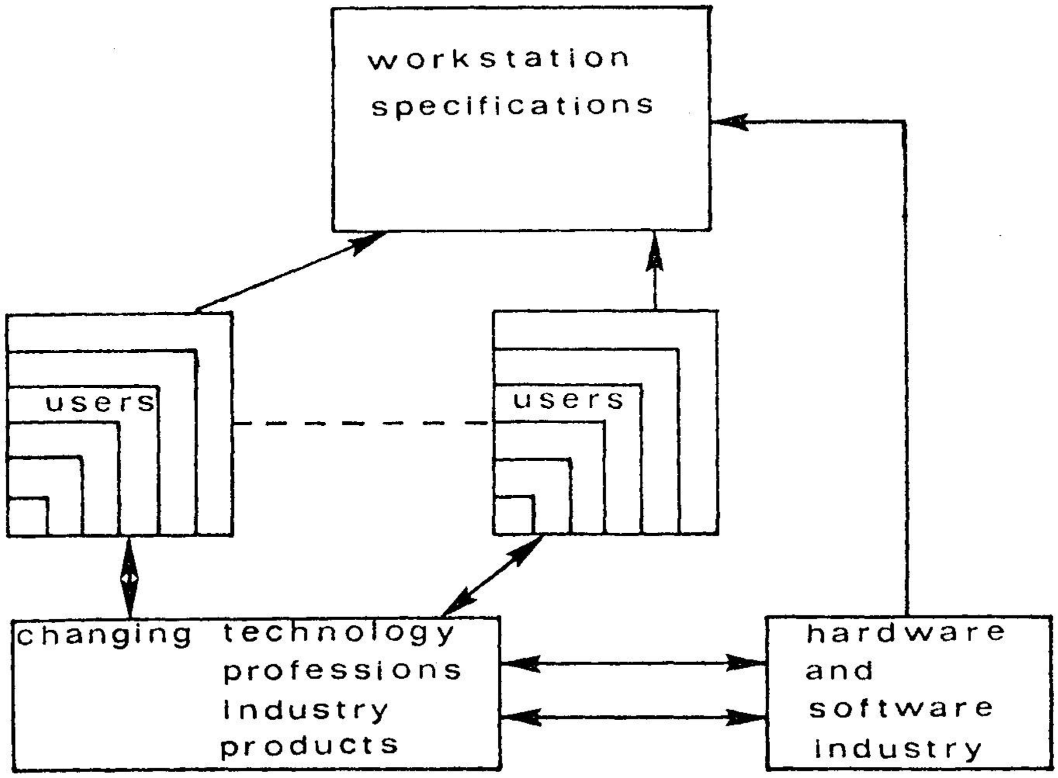

Fig 1. Relationships between users and a changing technology

3 DATA COLLECTED AND DERIVATION OF LEVELS

3.1 Application used

Although the project was not concerned with applications, any changes in the type of program being used would indicate trends in user requirements. The data for the previous study gathered in 1978 was compared with that collected from different companies in 1981 and indicated a general increase in design calculations, draughting, management and data banks. Architects use of computers appeared to have increased in the period while that of engineers had merely continued at their previous high level of usage and it was assumed that they were waiting for more powerful 16 bit micros.

3.2 CAD usage

Various studies of CAD systems were referrred to since CAD was likely to have the greatest effect on the workstation design. The trend towards lower cost systems based on raster graphics displays with greater use of colour was detected. The need for easier integration of CAD systems into smaller offices was also noted and for better ergonomics.

3.3 Analysis of applications

It was obvious from an early stage that, to serve the needs of building industry offices engaged in word and data processing, structural design and analysis, data base management and 2D and 3D graphics, a series of modular components would be necessary to provide a series of related workstations.

By grouping applications into those requiring common facilities, three levels were identified.

FACILITIES FOR:		Input/Output		Disktype	Precision	Language
		Alpha	Graphic	Floppy /Hard	8/16/32/ bit word	Business Scientfc
LEVEL 1	Budgetting	*		F	8	B
	External info	*		F	8	B
	Word process	*		F	8	B
LEVEL 2	Job costing	*		H	8	B
	Project man.	*		H	8	B
	Internal info	*		H	8	B
	Tenders/Bills	*		H	8	B
	Schedules	*		F/H	8	B
	Data banks	*		F/H	16	S
	Design calcs	*		H	16/32	S
LEVEL 3	Drawings	*	*	H	16/32	S
	Concept design	*	*	F/H	16/32	S

Fig 2. Applications grouped by common facilities

3.4 Relationships between the levels

The three levels needed to relate in the following ways:

* Having common components for upgrading and maintenance

* Standard interfaces, storage media and communications protocols to allow linking on public and area networks.

* Standard systems software for transfer of applications

* Using similar commands and Input/Output conventions to avoid the need for retraining when moving from one level to another.

The development of networks means that noisy or unique peripherals can be located away from a workstation and shared between several, but standards become even more vital for linking them.

4. TECHNICAL SOLUTIONS

4.1 General developments

The following are some of the general trends which were considered over the next five years, while three areas were investigated in greater detail and are summarised in 4.2 - 4.4.

Input devices - keyboards will still remain necessary although character recognition and voice recognition of some commands are likely to be useful.

Displays - A4 upright bit-mapped screens are proving very flexible and the 19" diagonal screen with high resolution seems to be the optimum for graphics.

Output devices - dot matrix printers are becoming more precise and can combine text and graphics. Cheap colour hard copy is still a problem and will limit the use of colour for the present.

Intelligence and communications - Distribution of intelligence by multi-processing and intelligent peripherals will increase the response of systems.

Storage and software - hard disks are now widely available and video disks will be able to provide fast back up. Standard systems software and tools to aid the development of applications are essential to making best use of new hardware technology.

4.2 Raster and other types of display

In spite of reservations by some users about the quality of line, raster displays are expected to take 95% of the market by 1985. But, by then, resolutions of 4000 x 4000 points would be available. New screen technologies continue to be explored and a large, flat, interactive screen replacing display and digitiser, would solve a number of ergonomic problems. Within the five years being studied such screens using liquid crystal or plasma techniques were unlikely to be economical, however.

4.3 Multiprocessing

This is one of the new developments most difficult to grasp but likely to have a major effect on the response of systems. It will enable the following:

* Systems to be upgraded more easily
* Provide access to a system for several users
* Improve the response of overloaded systems
* Help upgrade systems to meet new requirements

As yet, those developing software are not used to these facilities and there is a need for greater awareness and better software tools.

4.4 Software tools

Conventions for input and output to allow transfer of data between programs were the subject of a parallel report to the EC by RIB Stuttgart. These would be relatively cheap to develop but would need wide promotion.

Some of the software tools proposed for the workstation were:

* Screen editing and forms handling
* Printer special functions management
* Network control
* Software implementation tools
* Printed output formatter
* Editing of plotting data
* Multiprocessor control
* Graphics macro definition
* Graphical objects data base
* Zooming
* Fetch nearest point and highlight

5. THE SPECIFICATION

5.1 Distributed systems

Recent developments of computer systems have included timesharing and dedicated mini computers. The advantages of these are now being combined in distributed systems providing powerful word processing and good communications to other processors, data storage and peripherals.

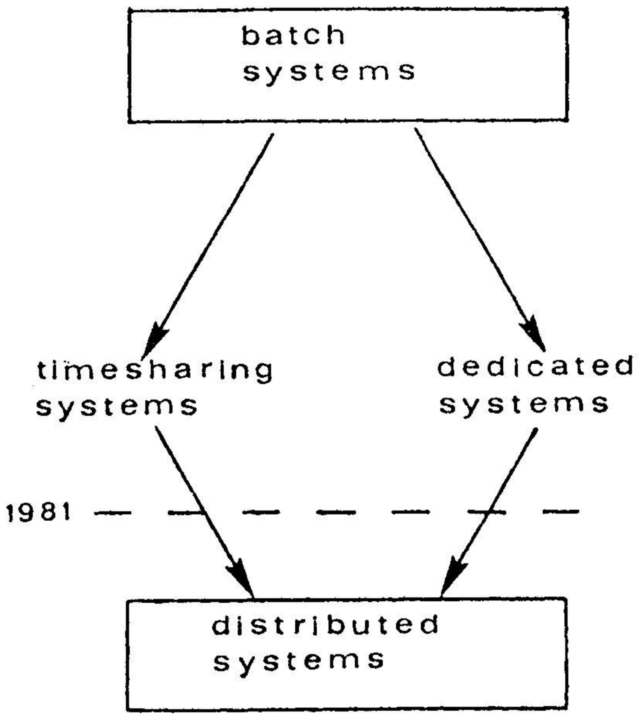

Fig 3. Development of computing from batch to distributed systems

The workstation specified is based on this architecture and provides the following advantages:

* Expandibility by adding extra nodes on the network
* Linear increase in performance with investment
* Response times do not increase with number of users
* Tasks can be executed concurrently

5.2 Portability

The ability to exchange software between systems is essential for the speed of computing in a specialist field like building. Standard operating systems were felt to be the best means of ensuring this with CP/M for 8 bit systems at level 1 and UNIX for 16 bit systems at levels 2 and 3. The ADA language may provide the optimum solution ultimately but this is not likely in the five year period considered. It should be evaluated for its suitability for CAD.

5.3 The Specification

Although the original aim was to provide a performance specification only, it was necessary to specify some components in detail. Manufacturers putting forward designs providing a similar performance would be acceptable.
The specification is summarised in the following diagram:

COMPONENTS	LEVEL 1	LEVEL 2	LEVEL 3
INPUT	Keyboard Funct keys	Keyboard Funct keys Cursor A3 Tablet	Keyboard Funct keys Cursor A2 Tablet
DISPLAY	Raster A4 vertical 80 char.wide	Raster A3 horizontal 132 char.wide 800x400 pts 8 colours	1.Raster A4 vertical 80 char.wide 2.Poss.Vector A3 horizontal 1024x780 pts Full colour
OUTPUT	Matrix printer or Daisywheel	Matrix or Electrostatic printer A3 250 char/sec	Electrostatic printer A3 A0 plotter available
INTELLIGENCE	1 OR 2 8-bit CPU 64K Memory	Several 16-bit CPU 256-512 KB	Multi CPU 16/32-bit 1 MByte +
STORAGE	Floppy disk 1 MByte or hard 10 MByte	Hard disk 30 MByte or floppy 5 MByte	Hard disk 80 MByte Back-up
SYSTEMS SOFTWARE Min language requirement	Standard Op. system CP/M Enhanced BASIC	Standard Op. system UNIX like FORTRAN, Pascal,ADA	Standard Op. system UNIX like FORTRAN, C Pascal,ADA GKS Graphics standard

Fig 4 Summary of the levels of workstation and their components

6. A POSSIBLE WORKSTATION DESIGN

6.1 Ergonomic considerations

Consultants CCD Ltd were asked to illustrate a possible design based on the specification above, conforming to good ergonomic practice and allowing easy integration into the office of modular configurations.

They recommended the use of standard furniture with separately supported displays and tiltable layout space. Displays were of two sizes; A4 vertical for alphanumerics and A3 horizontal for graphics and these were combined differently for each level. Noisy components such as large disks, plotters and printers could be located remotely but the simplest workstation at level 1 is assumed to be self contained and portable.

6.2 Level 3

Design concentrated on Level 3, the CAD workstation, which posed the greatest ergonomic problems. Levels 2 and 1 were developed from this.

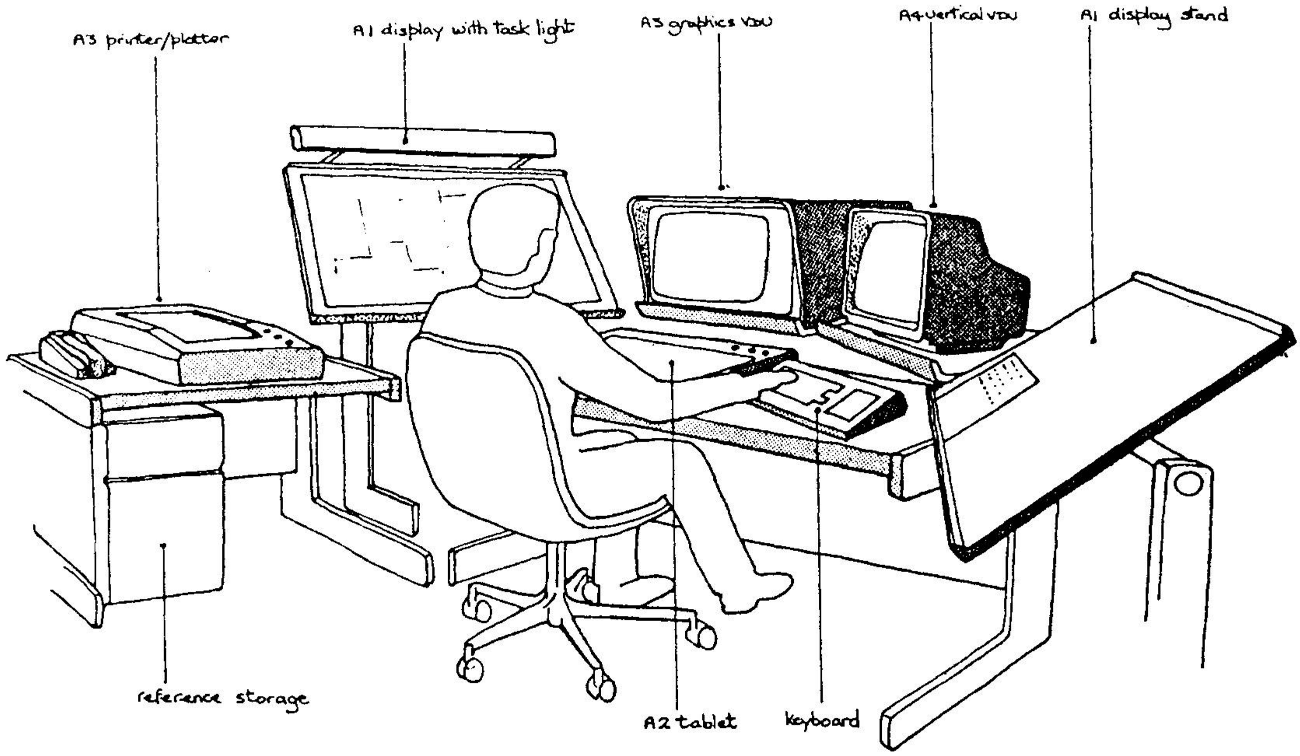

Fig 5 Sample workstation layout for Level 3

6.3 Level 2

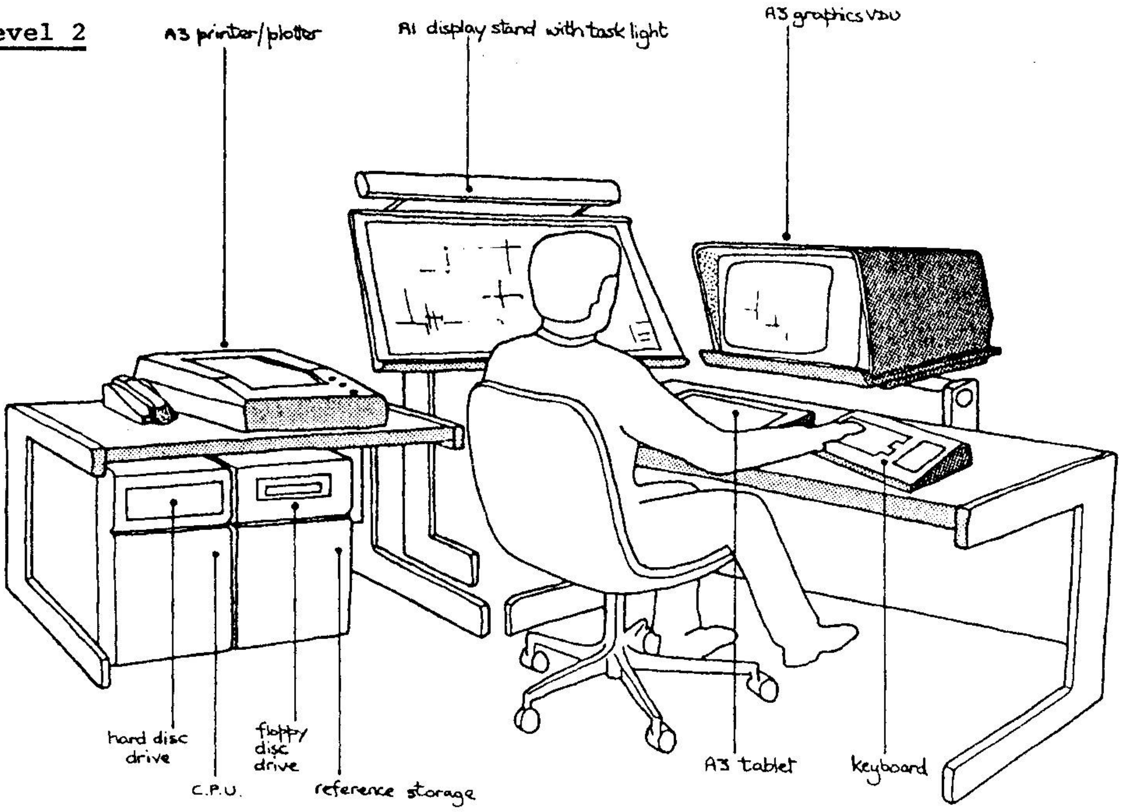

Fig 6 Sample workstation layout for Level 2

6.4 Level 1

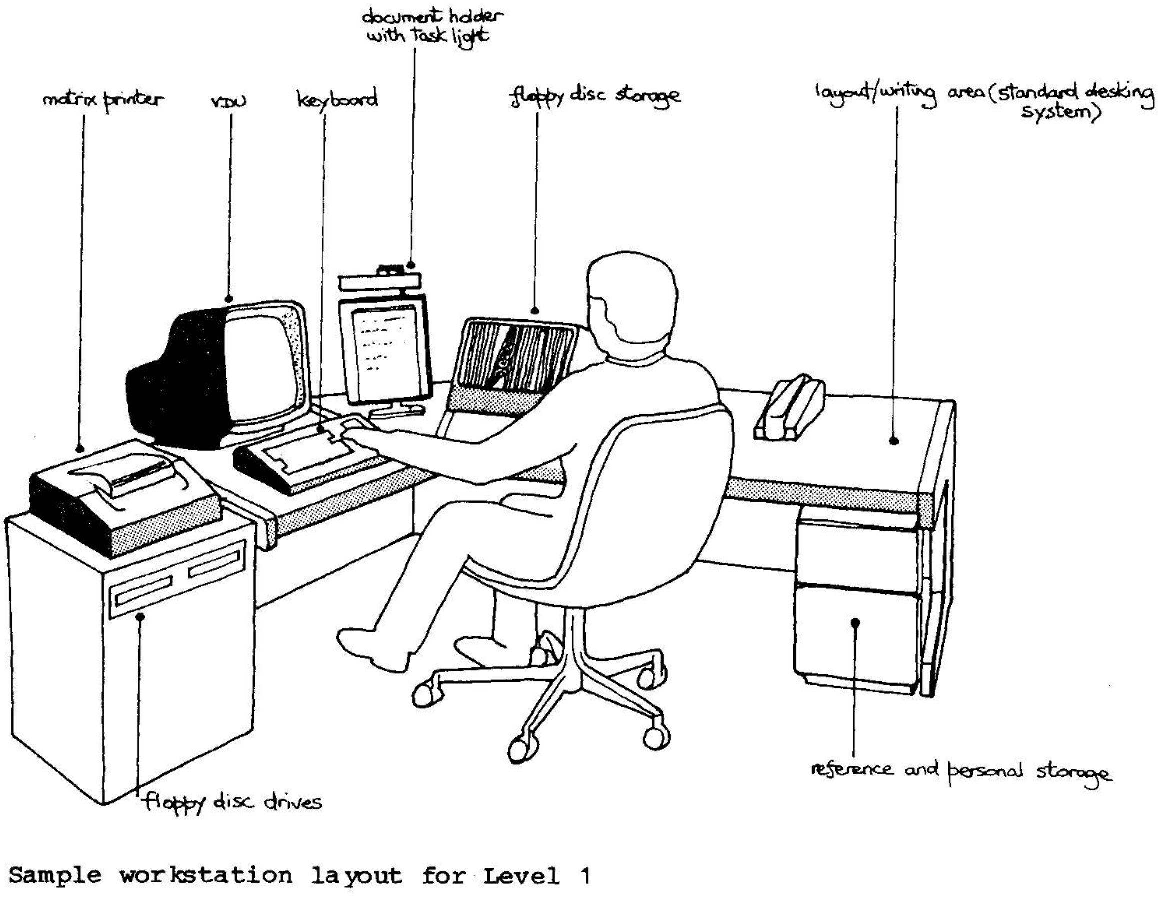

Fig 7 Sample workstation layout for Level 1

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

One of the main objectives was to indicate the size of the potential market represented by the European building industry. The number of firms capable of justifying the purchase of one or more systems like those specified by 1986 was estimated at 600,000 for Level 1 and 100,000 for Level 3.

Workstations will continue to be used by suppliers as a means of marketing software but they must be encouraged to develop open systems allowing greater portability of programs and data.

In order to benefit the European building industry and take advantage of new technical developments in the USA and Japan, Europe must use the new technology from wherever it comes.

European needs and those of construction are more specialist with regard to applications but the European computer industry could benefit from export of complete systems. The combination of workstation hardware assembled if not wholly manufactured in Europe, systems software and tools conforming to international standards and locally produced applications, could provide great benefit to European users and suppliers alike.

7.2 Recommendations

The following recommendations were made to the European Commission:

That the report should be published and distributed widely.

That a response from systems suppliers should be stimulated by mounting an exhibition of workstations conforming to the specification.

That the EC should not try to certify such workstations but concentrate on providing the right environment for use of the best systems.

Studies should be carried out on particular areas of hardware technology.

Specifications should be sponsored for systems software and software tools and an evaluation of ADA for CAD applications is needed.

A permanent, living exhibition of linked workstations in national centres should be mounted to demonstrate the potential of communications.

To support these main recommendations user groups could be used to promote awareness and training in the use of computers, to help distribute data and standards and to collect better statistics on levels of computer usage.

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A Software System for the Workstation in Structural Engineering

Un système logiciel adapté à la station de travail européenne

Ein Software-System für den EDV-Arbeitsplatz im Bauingenieurwesen

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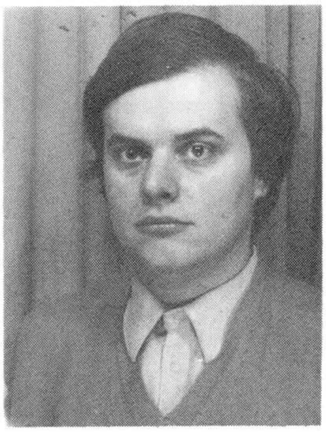

Th. v. Verschuer born 1953, obtained his computer science degree at the Technical University of Munich, F. R. of Germany. For five years he was involved in data management within software systems in the area of structural engineering.

SUMMARY
Description of the software system SYRAKUS and its aims:
1. Uniform, but user specific man-machine dialogue
2. Use of structural engineering software that has been successful hitherto
3. Software tools for more cost effective development of CAD-Systems that respond to increasing user requirements.

RESUME
L'article décrit le système logiciel SYRAKUS et ses buts principaux de réalisation. Il comprend:
1. Un dialogue homme-machine uniforme mais spécifique à l'utilisateur
2. L'utilisation de logiciels éprouvés dans le domaine du génie civil
3. Des outils de développement de systèmes CAO permettant de répondre aux exigences croissantes des utilisateurs de façon plus efficace.

ZUSAMMENFASSUNG
Es wird das Software-System SYRAKUS mit folgender Zielsetzung beschrieben:
1. Einheitlicher, jedoch benutzerspezifischer Mensch-Maschine-Dialog,
2. Einsatz bisher erfolgreicher Programme des konstruktiven Ingenieurbaus,
3. Softwarehilfen zur Minderung des Aufwandes für künftige CAD-Lösungen, die den steigenden Benutzeranforderungen gerecht werden.

1. INTRODUCTION

In the last few years desktop computers have been increasingly used in engineering practices. The computer at the individual workdesk has proved the most effective way of using data processing in day to day design work. The increasing use of this type of equipment has led to a substantial demand for design supporting software /4/.

Many good programs are now available in this area. They have proved to be operative through several years and many installations. On the other hand they follow such different principles in man-machine interaction, that programs from various sources can hardly be used in parallel.

Software houses thus try to provide complete program libraries for microcomputers. They do not only have to develop means for the management of construction data and their relationship but also do provide programs again that have already been made elsewhere.

The German Ministry for Research and Technology has sponsored the development of a software concept for the use of the structural engineer. This project takes the situation depicted above into account: on one hand, it attempts to exploit the existing software in the structural engineering area, on the other hand, the dialogue between man and computer is standardised.

This system is called SYRAKUS. It will be able to manage all of the information needed for one engineering project. It will supervise data interdependencies in order to make shure, that the data representation of a structure always remains consistent with the user's views.

2. HARDWARE DEVELOPMENTS

The concept of a software system for the desk of the structural engineer must take the hardware situation of the next 4-5 years as a reference. Trends of hardware development must be analysed. The functions available in future are to be considered, not the actual spectrum of hardware items.

SYRAKUS relies on the following functions of a workstation:

2.1 Input devices

The keyboard as it is used today will continue to be the main device for data input. Speech and character recognition are not of great significance. Touch sensitive tablets and key-pads are increasingly used for graphical and also non-graphical applications.

2.2 Displays

The 24 row by 80 column screen will remain widely in use. For text processing A4 upright screens have growing importance. For graphical purposes the raster technology 19 inch 1024 x 780 pixel screen will be most widely accepted.

2.3 Output devices

High speed dot matrix printers are likely to be the most versatile and cost effective means of output for some time. They are also capable to reproduce graphics and will be used for intermixed text and graphics output. For real letter quality output, low speed daisy wheel printers will remain in use. Plotters are not expected to reduce significantly in price. Bigger buffers and increasing intelligence will increase online throughput.

2.4 Local intelligence

Local intelligence stands for the capabilities of the programmable devices available at an individual workplace in addition to some intelligence, which might be available at a remote place. There must be sufficient local intelligence to handle all functions which are critical in response time (key servicing).

2.5 Local storage

Where complex file and data management tools are not available, a manually driven management in form of libraries of floppy discs will remain in use.

2.6 Distributed intelligence

Distributed intelligence is going to play an essential role in future CAD Systems. Three forms are already in use today:

- Use of programmable intelligence in peripheral devices,
- Use of a common system backplane bus in which additional intelligence can be added in the form of wired boards,
- Local area networks, where one participant can take advantage of what ever intelligence is on the net.

The advantages of distributed intelligence are obvious:

- Short respone time due to the local processor managing the dialogue,
- high modularity because new requirements can be met adding new intelligence,
- common acces of several users to expensive peripherals.

2.7 Communication

In the design process, communication between the involved people is essential. Workstation software must therefore look closely to the emerging technology:

- several workstations must have access to common utilities and devices (i.e. Database management, plotter, high speed processing)
- data exchange between the workstations envolved in one project greatly enhances throughput and management efficiency.
- access to public databases keeps the designer well informed and allows quick reactions to market changes.

3. SOFTWARE DEVELOPMENT

Increasing software prices and decreasing hardware prices yield rationalisation in the field of software development. A good approach for this is the use of application independent software tools. As these tools are widely used, they can be highly sophisticated and low priced at the same time. Today, such tools mainly exist in the area of systems software, data base management and graphics.

CP/M and UNIX are becoming de facto standards. Future developments in operating systems will tend to stay close to one of them. Distributed operating systems are under development, but will not have great impact on the near future.

For data base management the MDBS system finds increasing acceptance as it operates under various environments. The UNIX file management system is well adapted to tree-like data access mechanisms.

For graphical data processing the GKS ('graphical kernel system') /3/ has become an international standard. The American CORE system is just becoming important in the US.

In the area of man-machine interfaces there is up to now little consensus about input/output conventions. Mask generators like in commercial dp are not commonly usable in the technical field. A study commissioned by the European Communities /2/ and SYRAKUS try to show possible solutions.

4. REQUIREMENTS FOR THE WORKSTATION

Under contract by the Commission of the European Communities a study aimed at 'The Specification of a Building Industry Computer Workstation' was carried out. Final results were available by May '82 /1/.

In this study, the workstation is defined as the computer facilities needed at an individual workplace to aid design, construction and costing of buildings. The study specifies configurations for three levels of workstation:

Level 1 provides simple design calculations, information retrieval, small office management, word processing and data preparation and checking.

Level 2 provides complex analysis and data base management and uses graphical output.

Level 3 provides interactive graphics for conceptual design, space planning, production drawings and 3D modelling. Figure 1 shows the potential market in the European Communities for the three levels.

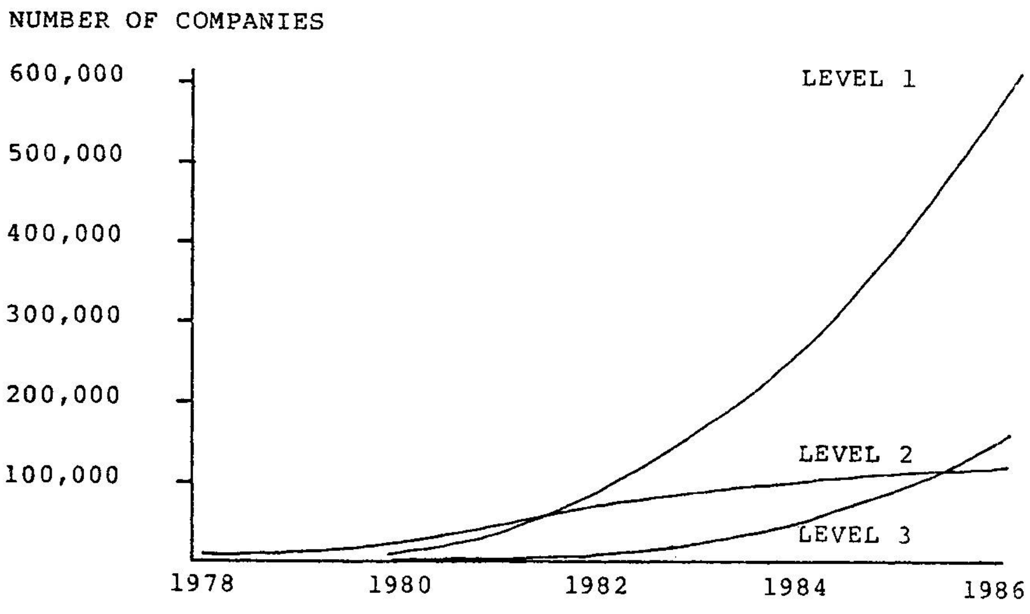

Fig. 1: Potential market in building for the workstations

5. THE SOFTWARE SYSTEM SYRAKUS

On the basis of the expected hardware developments exposed in chapter 2 the software system SYRAKUS is currently beeing developed at the Technical University of Munich in the F.R. of Germany /5/.

SYRAKUS also takes into account, that application independent software modules have to be carefully separated from application specific ones as is exposed in chapter 3.

SYRAKUS will be a powerfull tool for system houses to aid them in the development of specific application programs. These houses have to provide interface modules to:

- the required type of dialogue with the user (User),
- existing application programs, that will be integrated to the system because of their well proved quality and reliability (Methods Base),
- the required types of output forms and devices (Output),
- the data base management system to be used.

These interface layers are very small in the overall system, and skeleton interfaces are provided with SYRAKUS.

SYRAKUS suits the level 2 workstation of the European study well, smaller versions of it could run on level 1 equipment but it is aimed at systems with distributed intelligence. Most parts of SYRAKUS could be integrated into level 3 workstation software.

5.1 Interfaces to the system environment

The environment is composed of the four major components of civil engineering specific design processes:

- the user,
- the methods base,
- the database management system and
- the output.

5.1.1 User

The interface between user and computer is the man-machine dialogue. This dialogue must be conceived for minimum user load and minimum error rate by using

- adequate input devices and
- adequate forms of dialogue.

User load can be kept down by using uniform input structures for all programs to be used independently.

5.1.2 Methods base

The methods base contains good quality programs for a variety of engineering applications. It therefore inevitably contains programs from different sources. The interface between methods base and system is conceived in such a manner that adaptation work is kept to a minimum. The main condition for this is, that a program has a line oriented type of input.

This gives the engineer the opportunity to take advantage of the availability of a big number of programs, without beeing limited to one software source. This also is one step towards stabilisation of the software market, as only really good programs will then be adopted by the user community.

5.1.3 Data base management

For todays computers there always is a database management system (DBMS) available which is well adapted to the specific hardware environment. This is why SYRAKUS does not incorporate a data base management system. It merely takes advantage of an existing system if some minimal requirements are met. There are aids for the construction of interfaces to DBMS, but the interface is to be established for any DBMS to be used.

5.1.4 Output

The usual types of output from engineering work are texts (technical calculations, bills of quantities etc.), and line drawings (sketches, graphical representations of results, production drawings). The output environment is composed of plotters for drawings, daisy wheel printers for printing, matrix printers for text and graphics, all possibly of different manufacturers. Output is to be organised for the whole environment.

5.2 System structure

SYRAKUS is the management system that controls all the environment components named above. This task is shared by four communication modules (Fig. 2):

- USERCOM at the users side
- PROCCOM at the methods base side
- DATACOM for the data base management system
- OUTCOM for output.

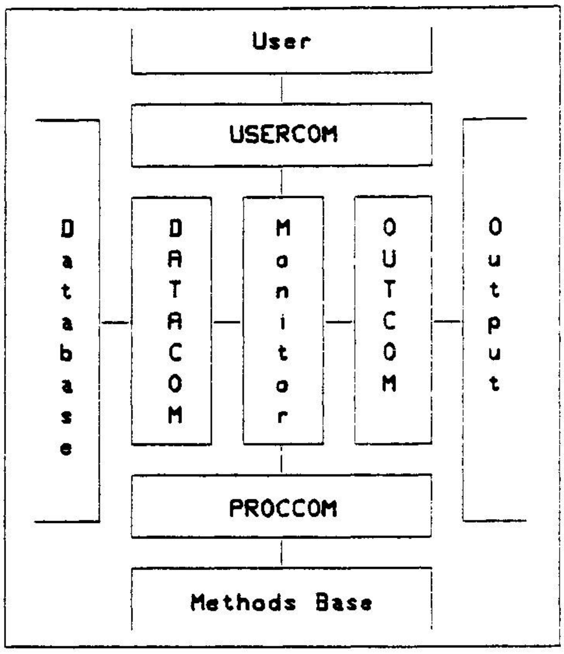

Fig. 2: Structure of the system SYRAKUS

These communication modules keep their independency as far as possible. For adapting SYRAKUS to special user requirements, special application programs, to a special DBMS or specific forms of output, special interfaces must be written.

Communication between modules takes place on the basis of standardised messages. These messages are processed by the modules in order to influence their specific environment. Interaction from the environment are processed and coded into messages to other modules if necessary.

Message routing is done through the central monitor. This module synchronises message transfer. In a single processor multitask system it stands for the physical network in multiprocessor systems. The monitor is not a system kernel as one can find it in some software systems, it does not have any control functions.

The following paragraphs describe the functions of the communication modules more in detail.

5.2.1 User communication (USERCOM)

USERCOM is in charge of the dialogue with the user (Fig. 3)

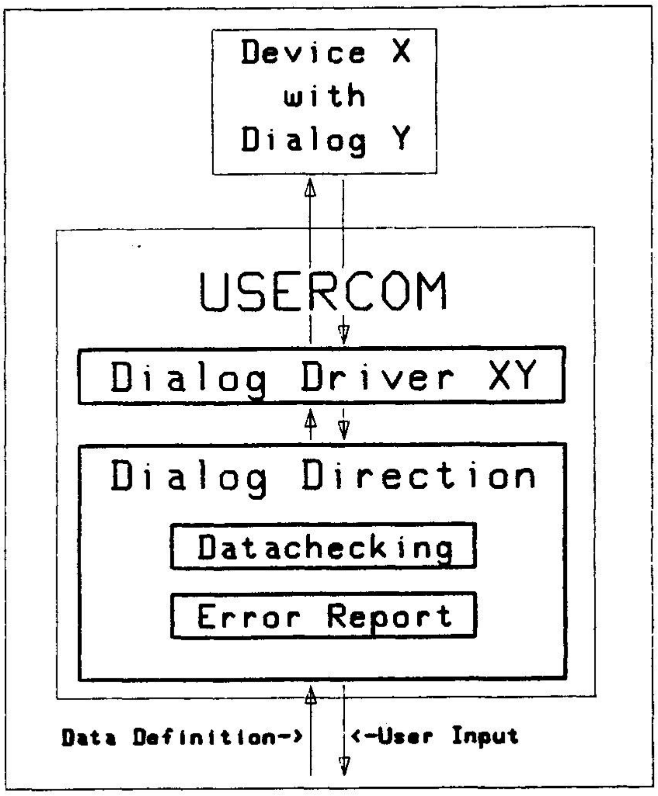

Fig. 3: Structure of the USERCOM

USERCOM accepts messages for the management of input from the keyboard. It is capable of doing a certain amount of data checking in order to give quick response to input errors. These messages contain the following:

- information about the data to be input,
- information about checks for completeness and consistency of data,
- error report mechanisms,
- user information mechanisms.

The parts of USERCOM are:

- dialogue driver XY, drives a dialogue of form X (Masks) on equipment of type Y (a certain VDU with keyboard),
- dialogue controller for data checking and error reporting.

Fig. 4a shows the message which directs USERCOM to provide a section number SNR. USERCOM processes the message and displays the text 'S-NUMBER' at the display row 4, first column. The value to be provided by the user must be in the range of 1 to 99. If the user gives an allowed value, a message indicated in Fig. 4b is returned.

a)
BI MO US SNR --- 10 ------ I3 01 04 BZ 08 S-NUMBER B1 01 99 01
EN

BI	Message is data input description
MO	Message is sent by MONITOR
US	Message is received by USERCOM
SNR ---	Short name is SNR (6 characters)
10	Prompt takes 10 positions on screen
------	Unit
I3	Type integer, 3 digits
01	Prompt starts in column 1
04	row 4
BZ	Prompt followes
08	8 characters long
S-NUMBER	Prompt
B1	Range specification type 1 followes
01	from 1
99	to 99
01	step 1
EN	End of message.

b)
WE US MO SNR--- 5

WE	Message is a value transfer
US	Message is sent by USERCOM
MO	Message is received by MONITOR
SNR---	Short name is SNR (6 characters)
5	Value is 5

Interspersed blanks are not transmitted, they are inserted for better readability. Underlined parts are binary coded, all others are ASCII code. Hyphens indicate obligatory blanks.

Fig. 4: Example of messages: a) to USERCOM, b) from USERCOM

5.2.2 Process communication (PROCCOM)

This subsystem is in charge of the data flow from and to application programs. Overall system activity is loosely controlled by PROCCOM because the requirements of individual application programs yield control of input, output and data storage activities. PROCCOM initiates input for one application program. All data input by the user is stored into the data base. As soon as the information is complete, it is converted into the input form for the specific program and the program is started. Information relevant to the relationship of the individual calculation run to the whole engineering system is put in front of the output (i.e. name of position, table of loads etc.).

After a successfull run of the program, output data relevant to future decisions is transferred back to the data base, the output files are routed to OUTCOM.

5.2.3 Data base communication (DATACOM)

This subsystem is in charge of the data flow to and from the data base. On request it provides all information needed by the other subsystems (i.e. input item descriptions for USERCOM, values for PROCCOM, tables of contents for OUTCOM). DATACOM manages the underlying data structures and is therefore able to determine the amount of information to be provided following a request itself.

Other subsystems can put forward such questions as 'what do you know about xxxx

DATACOM also handles data dependencies and is therefore able to determine which values are to be deleted, once an amendment is made to a specific data item.

DATACOM is in charge of the consistency of units of measurement.
Database drivers are the modules for communication between DATACOM and the underlying data base management system. Any installation will contain one such driver for the DBMS in use on that system.

5.2.4 Output communication (OUTCOM)

OUTCOM is in charge of the data flow to the output devices. PROCCOM routes output files to OUTCOM. Here, they are processed in order to standardize the page layout. Then, the filename is incorporated to an OUTCOM file directory. The user is given the opportunity to process a file with a text system prior to starting output.

Graphical output is treated much the same way as is alphanumerical output. Graphical data is routed in the form of text files containing plot macro calls in textform. The skilled user is able to process these with a text system too. For output, the macros are resolved into calls to GKS primitives /3/ and output using the GKS software available on the computer (Level OB required).

For installations without GKS implementation, a raw version without the whole processing spectrum is provided.

6. SUMMARY AND CONCLUSIONS

In the future, the effective use of computers will essentially depend on the availability of appropriate software. Our capacities for software development will soon be exhausted if software is continued to be developed for individual users, on individual processors and with individual peripherals.

The software system SYRAKUS which is currently beeing developed at the Technical University of Munich aims at several purposes:

- The user communicates with the system in a program independent manner.
- The form of dialogue (mask, prompt, keyword etc.) can be chosen by the user with respect to his skills and experience.
- Any form of dialogue can be achieved on any input device as far as physically possible.
- Existing experienced software in the area of structural engineering can be used with a minimum of adaptation.
- All relevant information is stored in a program independent manner yet consistent with an overall model.
- Output is standardised for an individual installation and highly independent from specific applications programs. The system is open for a variety of available and coming output devices.
- New software developments can rely on the powerfull software tools developed for SYRAKUS. They can use them for establishing an entirely new system or for easy adding of specific applications to the existing system.

As SYRAKUS is more a method, based on a range of readily available software development tools for a wide variety of hardware items, than a closed system, it has a wide basis for application.

SYRAKUS was developed with the coming generation of distributed intelligence systems in mind.

The support of the German Ministry of Research and Technology in this future oriented project is gratefully acknowleged.

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SESSION I

DISCUSSION (1st part)

October 6, 1982 - Morning

Chairman: J. BLAAUWENDRAAD (The Netherlands)

M. FANELLI - I would like to ask from Dr.Haas whether he could spend a few more words about the integration of the quality control process into the automated management system.

W.R. HAAS - The quality control was not part of the system. We didn't do anything like numerical control of the machines,or quality control;we only provided the means to plan and to supervise the process of producing the prefabricated members. For example,we provided means to keep track with the actual production, but the supervising engineer had to look at the prefabricated member and to decide whether a prefabricated member was of good or poor quality. If the prefabricated member was of poor quality, he had to enter data in the system which indicated that the prefabricated member of poor quality had to be fabricated once again.

M. FANELLI - Anyway I suppose all information that came out of this quality control process was stored into the data base.

E. ANDERHEGGEN - I have a question to Prof. Werner. I want to know at what level this system is working, within the operating system of the computer. Are you talking about a new operating system, which is not based on an other one (like UNIX), or is it just a job superimposed to an existing operating system? Another question is: on which hardware do you implement your system?

H. WERNER - First to the last question: the computer we are using is the HP1000L with 512 kbytes and the RTE/XL operating system. On the input side,we have three different devices: Televideo, Televideo with graphics and a HP graphic terminal. On the storage side,we have a ten Megabyte harddisk and the database management system Image 1000. The output side consists of a matrix-dotprinter and a small HP plotter. In the methods-base there is a well proved software suite for structural engineering.
Now to the first question: Syrakus is not a new operating system. We take it that an operating system is given. Our software works between the operating system and the application programs,written e.g. in FORTRAN. We have to write some small layers for adapting it to a special operating system like RTE, UNIX or CP/M. The operating system RTE/XL allows the user-communication-module to work in the foreground,while the more time-consuming calculations are done in the background of the computer.

D.D. PFAFFINGER - I have a question to Dr. Haas or to Dr. Werner, I don't know. The system you explained is basically a draughting and construction system. I am wondering on the feasibility of extracting from such a system the data which are necessary for the structural analysis, which is a further step of idealization. Could you comment on this?

W.R. HAAS - In the project which I described,the structural analysis had already been done so we didn't make any effort to close the gap between the design data and the input data for the structural analyses. In principle, it should be possible, of course. We investigated it in one special case. We constructed walls and columns and above the walls and columns a flat slab. We then semiautomatically extracted the structural system for the analyses of the flat slab from the geometrical data of the walls, columns and slabs. That's the only case that we did such an investigation.
In other fields of application, there are links between CAD systems,or modelling systems,and systems for structural analysis (for example finite element analysis). The CAD system produces a solid model which is subdivided in a finite element mesh by a mesh generator and then analysed by a finite element program.

H. WERNER - I think your question was a question on specific applications and this specific applications belong to the base of the methods.

H. PIRCHER - I have two questions to Dr. Haas. The first question is: if you should have a similar project, how much manpower would you expect to save to do it? And the second is: what is the minimum size of a building to use such a system?

W.R. HAAS - Well, to the first question, we have now a lot of experience which we would use in the second project. We also have now a better 3D modelling system and we also have many programs for generating lists for bills of quantities. If a similar project would come, we would use our experience and the existing program library and I think we would now be able to produce a softwere package, specially tailored to the new project in much less time, I would say 1/3 of the time needed for the first project.
The second question concerns the project size. I think it is not so much a question of size but of type of the buildings. I think rather small projects of prefabricated members can be handled with our system, whereas for projects with cast in place concrete buildings the software must be changed to a great extent.

D.P. GREENBERG - Question to Dr. Wagter. You made some statements with respect to how difficult it was to use some three-dimensional modelling systems in civil engineering practice. There may be 45 minutes computational times for some of the modelling routines. I wonder if you could comment on some of the causes of the inefficiency in the computation behind the systems which you investigated.

H. WAGTER - We stated that we looked at the systems as users, we did not get involved in algorithms and efficiency of the computer program itself. We just tried to define, I think, a few simple programs and to look at how that works out in three-dimensions. The only difference we met was the difference between wire models, surface models and solid models and that has various connections to the algorithm of course. We found out that nearly all the complications in solid modelling took a lot of computing time for the algorithm itself. Doing all kind of manipulation in surface models, you have to use a hidden line algorithm; this problem is automatically solved in solid modelling. It takes a lot of time and I did not see any wire model that can use a solid model as yours has to look quite through it. So I cannot give an exact answer to your question because I can't give an answer about the efficiency; it has directly to do with the amount of information that has to be taken into account and this directly depends on the type of model examined and the algorithm used internally.

D.P. GREENBERG - I have seen and had similar reactions to many of the commercially available systems, what I am trying to find out are the causes of inefficiency, which really gets down to either data structures or the algorithmic method, which you use. I am not sure what they are.

H. WAGTER - One of the main reasons of inefficiency mostly occurs when different users are working on the same system. For this reason we were happy to be able to test several times as an only user on a rather big system, and even then we got high response-times. It must be said that the number of users and the kind of work they are doing on one system have also big influence to it. It just must be stated that solid modelling is very complicated; it needs complicated computations.

P.J. PAHL - Both the development and the maintenance of software systems of the types which you described for workstations cost considerable effort. I would like to ask all four gentlemen what type of organization do you see as preferable for the development and maintenance of such software?

J. BLAAUWENDRAAD - This is a very nice question. You ask for organization for two purposes: the development and the maintenance.

W.R. HAAS - I think such systems should be developed at Universities with one experienced programmer, because it takes a lot of effort and the commercially working software house is too expensive to do such a thing; we also are doing that, because we don't see any kind of this development in Germany. Maintenance and marketing should of course be done by an experienced software-house.

R.W. HOWARD - I shall reply from my backround, which is a user association which has had to do many things in its time, and succeded with some and failed with others. When we were first formed - about ten years ago - people thought we would act as a focus for joint-development of software, that groups of members would come together, that they would specify their requirements and we would develop software. Now the problems of joint-specification and development are considerable in that everybody asks for any possible requirement that they might want; and the specification becomes so large that it doesn't meet anybody's requirement sufficiently. So I think the best place for development and specificatiion of software is very close to the user. You always have to get one user to say I have a problem, rather as - I think - RIB have done in their example. Having solved some particular problem, you can then generalize it for other users, but they start with a very clear specification of the need in mind, so I think development has to happen very close to a single user and very close to a particular need. Maintenance: well, again I think that the people who develop the software really have to be responsible for the maintenance. Another thing we were asked to do in the past, was to collect together a library of software and provide support and maintenance for users. Now, you have to know a lot about a piece of software, to provide adequate maintenance and, if you are trying to do that for a range of systems from different sources,it's impossible; so again I think that the maintenance has to come from very close to the developer, who should be very close to the user and that means an engineering company, or software-house, specializing in the construction industry or engineering.

H. WAGTER - I agree in this difficult question with Mr. Howard. I think that the main part of the development should take place at the engineering offices for they are the users. It has been stated that a lot of problems in computer aided design have its origin in the fact that people that develop the software are not the users. Besides that - and I know it is a bit of a danger to say it in an audience where 50% consist of professors - the experience is that the programs developed at universities are mostly very bad documented and do not have a very efficient background of people who made it. It is the same for maintenance; I think and I agree again with Mr. Howard that it should be done at engineering offices who developed the software. An other aspect of that is the maintenance of the hardware that should be carried out by the hardware firm of course.

H. WERNER - I think we have two main, partly overlapping,phases in software development; the first one is the development of new methods, e.g. Finite Element methods. I think especially universities should be involved particularly in this task. But that does not mean that specific application programs, which are part of the second phase, can not be developed at universities. A close connection to the practice, e.g. to an experienced conductor, is necessary in that case.

P.J. PAHL - Let me comment first on the question of university involvement. I think it has been correctly stated that it depends essentially on the degree to which the universities are willing to accept the task of documentation. In several comments it was stated that those who wrote the program should also be involved in maintenance. Universities - as a rule - are not in position to do this. Therefore the transition of software from the universities to the maintaining organizations is one of our problems, at least in Germany. I wonder if others have experience in this area which they would care to share.

G. KRUISMAN - I have some questions to Mr. Haas. The CAD system you described seems to be a production preparation system; production in the sense of building a building. In mechanical engineering you would call such a system a CAM system. Have you considered to name it a CAM system? It would be nice to have in the building industry CAM system too. The CAM system seems to be rather product bound and, in this context, I would like to ask you: was the building method programmed into the system? Was it the building method of the contractor? And was the building designed before the contractor came into the picture, or was it designed by the contractor?

W.R. HAAS - Why didn't I call it a CAM system? It is more than 50% a CAM system, you are correct, but building means modifying and so frequently some parts of the buildings were modified and redesigned and that is the CAD part of the system: so we have a mixture, we have some CAD capabilities and some of CAM capabilities. The original design was done by an American consulting engineering office. The design, however, was not detailed enough for the contractor,for example the consultant did not do a complete typization of the prefabricated members. So the more detailed design had to be done by the contractor, for example the complete typisation of these prefabricated members. It was done with the aid of this systèm.

S.J. FENVES - I was going to ask a question to Dr. Werner, but I would like to comment on the previous discussion. One thing we have to learn from computer science, which is widely practiced in that profession, is the idea of throw-away programs. The majority of the programs, especially those in universities, are intended to be thrown away at the completion of the student's study. If there is something more valuable in the student's thesis, it should come out later, through the marketplace and other mechanisms. It is totally unrealistic to think about universities converting themselves into software-houses.

W.R. HAAS - I think the 3D-modelling situation shows very clearly what I mean. What we need are basic methods and algorithms, for example for calculating intersection lines, for all the boolean operations of the volumetric oriented primitives. A lot of work must be done in this area which should be done by universities. We would like to have the same situation as we have in the finite element field, where we can take SAP or any program of this kind and build an application layer around it, which fits the situation inside the market where we act.

S.J. FENVES - I agree with you that the concepts have to come out of universities, but the program that embodies that concept need not be the final program that runs in a production mode, on a variety of equipments and in a variety of enviroments. Very few SAPs, ICESes, etc. are restricted today to the one particular hardware and programming language enviroment in which they were originally developed. They were good programs and therefore it was worthwhile for somebody to implement, improve and translate them.
I would like to know more about the database part of your system, and particularly its interface with the application programs. Did I understand you correctly that only two interchanges occur between the database and the application program; when all the data are in, they are moved to the application program and, when the application program is done, it dumps its results in the database?

H. WERNER - That's not all: at first the database contains information describing the masks. Its second task is to store the input data and the relations between them. The third one is to deliver on request these input data to the application programs. The output of an application program is given to an output file routed by OUTCOM. Information on that output and data relevant to further activities are recorded by the database.

M. KUWAGATA - I would like to ask Dr. Howard: you show us three drawings of three levels of workstations, on each drawing I can find a telephone handset on the desk. Is that used for simple telephone communication or is it used as acoustic coupler for data transmission? I am not sure which purpose it is used for, so please teach me.
An other question is as for the network of data communication. A work station constitutes a network, so we have to solve the communication network problems. That is, for example, data communication network architecture. So have you solved such a problem or not? For solving this kind of problems, we need some

counterparty engineer, I mean telecommunication or datacommunication engineer. I'd like to ask you what type of counterparty you have.

R.W. HOWARD - We did not specify a telephone on the desk. I think this wasn't a specific instruction to the person who did the economic study and I suspect it is for the user to ring his wife to say he is going to be home late. The connection to the network would obviously be an hardware connection and we were a bit cautious about which network, because I think that is very much up in the air at the moment, but obviously there are some standards which are becoming very strong contenders, as the standard network configuration. But basically, apart from looking at the relevant standard in the Telecom area for the public network side of things, again we were rather evasive there; we think at the lowest level something like Teletex, which is the international Telecom standard for linking wordprocessors, is going to be quite useful for exchange of documents; but, obviously, for sending larger quantities data and the standard for sending graphic data between systems, apart from looking at DKS, IGES, etc., we stayed a bit on the fence, as far as some of these standards were concerned, but we are aware of what is going on in that area.

J.P. RAMMANT - I have the impression that there is a war situation created here between software houses and universities. As a software house I would like to ask some naughty questions to the University of Münich concerning Syrakus. I have a serious doubt that this system really can do anything. The first question is: it's hightly modular, very well, I like that, but I fear it will be very very slow in application because there are a burdain of things you take with you, which are, as far as I believe, unnecessary. Second question: you are using ten megabytes. On ten megabytes you cannot do a lot of things, so please convince me and give me some examples of applications which you have done. I would appreciate that.
So, the first question is: it is highly modular and you are using database techniques. Is this really necessary? All these methods, all these burdain of things make the programme very heavy and slow.

H. WERNER - What I wanted to show is that in future it is necessary to use application-independent software; Looking at the practice you see programs written for a specific computer with a specific input form. If they are to be installed in an other computer or if another input form is to be used you have to rewrite these programs.
The overhead of our independent software is not big. Look at the message which defines the input form or look at the message which transmits the input value. You have to write small layers which convert the message into the specific mask on the screen or which convert the second message into a specific input form of an application program. When using another application program this last converter has to be changed.

J.P. RAMMANT - As software developers, we also use standard routines for input and output and layout of databases.

H. WERNER - Can you tell what is the standard input?

J.P. RAMMANT - We are using straight forward subroutines which are, I think, rather simple; the subroutines manage the input and the screen outline. But I think the principal statement I would like to make is: I don't care about hardware; if an engineer wants to buy our system, he buyes the hardware along with the software, because the hardware is much cheaper than the software. Also it is clear I don't think you can make programs really independent on hardware; there is always some dependence. If you want to have a nice and good interactive program, you are hardware-dependent; that is my experience.

H. WERNER - That's quite write, it is impossible to have independent software which runs all the computers. Our aim is to narrow the adaption work.

J.P. RAMMANT - The last question is on your applications. I am still not convinced. What applications have you done?

H. WERNER - The system is still in development and the first issue will be a reduced version without a database running on a CP/M operating system. The connection to a database is part of the second stage. In the first version we use a throughput of the input data to the application program. We are just finishing this issue and we are going to present it within three months.

H. PIRCHER - I would like to add a question to this discussion. I think we all agree that there is a need for standardization and, if somebody creates this standard, the first question is how to convince the others to use it and also - I am a software developer - if they would like to use it. Therefore the question is how and when Syrakus will be supplied to other developers and how to convince them to use it. That is a big problem of time scheduling and organization.

H. WERNER - With this question we come back to the question about the relation between universities and software-houses. Our aim is to give tools to the software houses. To your question about time scheduling: I think the whole systems will be ready in the middle of 1983 and then we can offer it to the software houses. To the question about convincing the software houses to use it: we will demonstrate one working system; Syrakus is not an abstract model. Software houses cannot be convinced by abstract models,they want to see a working system. We will be able to show a short version in a quarter of a year and the whole system in one year.

R.W. HOWARD - I have a general question. Which sorts of standard do get adopted? I think we have one successful example which is the CP/M operating system for microcomputers. Nobody ever designed it as an official standard, but it was made available al low cost for the people developing 8 bit micros; they couldn't afford to develop their own operating systems so it is very widely adopted and now even IBM gives an option of the CP/M operating system. And so I think official standards always have to exist, but the ones that really have an effect on the way things work are what are called today "de facto" standards and I would reccommend, if Prof. Werner wants Syrakus to become a general standard, he makes it available at very low cost, makes sure that people are aware of its existance and hopes it gets taken up for very practical reasons.

W.R. HAAS - I would like to comment on the question of standardized input conven

tions. We have established such a standardized input convention in 1976 and it is rather widely used in Germany because 24 program developing institutions stick to it, but it has one shortcoming which reflects the computer situation at the year of 1976: it is not interactive, it is batch oriented,it has powerful possibilities for generating data but it has no prompting. So we now have some difficulties at the market. We managed to establish the "de-facto" standard by selling a software package at very low costs to the software developing institutions which does all the free format handling.
There was a second question concerning portability. I think portability is not so difficult to achieve. If you stick to ANSI FORTRAN IV of 1966,you can achieve a high degree of portability. We have one program running on 16 different computers in an almost unchanged form.

H. **WAGTER** - The subject of communication and standardization between systems has also been a subject of investigation I talked about and I must say I am very pessimistic about any development in this field. At this moment, it really is a disaster to link systems. I think it is necessary to do developments in this field together with hardware development. There is one system, one development going on in the United States, called IGES. Studying the IGES reports you soon will find out at what a low level the IGES specification is written. The only things all systems have in common are just lines and points and you have to write thousands of all kind pre and post processors to achieve a practical value. This is a result coming out of the existing situation and most of the people here are talking about standardization in a future situation. About CPM, what is called a degector standard, that is correct, but there is also a CPM2 and and a CPM2.2 and a CPM 2.24 and that illustrates a little bit that also here we will see problems. Nevertheless I agree that we shouldn't stop doing work on this field.

C. **NUTI** - I have a general question, I heard speaking of time but what do we mean for time? CPU time or general time? Because, in general, in engineering the important thing is not the CPU time, but the cost is due to the total time.

H. **WERNER** - I would like to answer your question in terms of the system Syrakus. If you have an interactive input to a big computer via one terminal you can correspond with the computer directly. You have the computer for yourself all the time. If there are three, four or, may be, ten terminals corresponding with the computer and each of them expects a quick response on each wrong character like "This chapter is wrong" then it is possible that a big computer can ba overloaded just by these activities. That way of employing a computer is not effective, I think. The better way is to have some local intelligence within the terminals for checking the input and for giving a quick response. So, if you use software suitabled to the coming network solutions you can save computer time for more number crunching activities. That way the relation between CPU time and total computer time can be improved.

R.W. **HOWARD** - I see a number of examples in recent use. Companies have gone out and bought some very small computer, because people always look at the hardware first and buy the hardware and then think how they are going to solve their problems; entirely the wrong way to do it. But it has resulted in some very ingenious solutions; people who found the limitations of a small computer when faced with large analysis-means, either then you take a long time to solve the problem in elapsed time, or take a lot of data on and off disks and in some companies, perhaps small companies, where the computers are not needed continuously, people write programs, which they start off one day and they come back the next morning and it is finished, that may suite a certain sort of working enviroment. So I think you have to design the system to suite the type of office: if it is one man-office,then he is quite happy to leave it to work all the night and get results the next day, provided, as Prof. Werner said, he checked the data to start with, so that he knows he is going to get these results. In an other company there might be people waiting to use that machine and it must work fast and therefore time is very critical.

H. WAGTER - I just wanted to say that you should not underestimate the frustration limit coming out of long response-times. When I am talking of time in my paper, I just mention CPU time, although I understand that the turn around-time during the project may be much more. For a simple handling on the computer, an operator designer just expects the system to response in zero seconds. He has a very complicated job, he has some understanding for the difficult time the computer might have that moment, he accepts some ten seconds. If it is reasonable or not when it is longer, the man gets a little angry about it and the effect of this should not be underestimated.

B. BONI CASTAGNETTI - I have four questions. The first one is for Mr. Howard about the tube he suggested as a raster tube for level-three workstation. For what is my experience in construction and engineering works, the storage tubes with dynamic refresh capabilities are more useful,since the resolution is higher and the screen is larger too. I would like to have your opinion about this fact.

R.W. HOWARD - Well, I think we are very much going from recent surveys which reckon that, probably supported by the television industry, 95% of displays will be raster in four or five years and - once the television industry gets itself set up to sell raster screens, and once the resolution improves I think they would become more acceptable. We felt that they would probably be adequate for level two - level three - we said that storage tubes should also be available, because we now have a lot of people, a lot of users who just won't accept the lack of precision of raster screens at present. People like Tektronix and I think they are coming back to raster screens with refresh buffers and colours. It certain will be interesting to see which technology wins, but I think there is an enormous investment behind raster technology and the resolutions will improve and become more widely acceptable by the users.

B. BONI CASTAGNETTI - At the present time, for what is our experience, 1024 resolutions of the ruster tubes are surely not acceptable by designer, practical designer in construction.

R.W. HOWARD - I think that,if you have the right facilities for zooming, you can get round some of the limitations of raster graphics, but the resolution really needs more time.

B. BONI CASTAGNETTI - The second question was directed to Mr. Haas. Have you any productivity-ratio conventional figures versus computer aided design about your project?

W.R. HAAS - No, we don't have any figure concerning our project.

B. BONI CASTAGNETTI - The usual three to one, ten to one.

W.R. HAAS - I know published figures which begin with 20% increase of productivity up to a factor of 10. But in our project I don't know the figures because the design wasn't done in parallel in conventional way. We got the job because we could convince people that it could be done much quicker with less engineers using the CAD system.

B. BONI CASTAGNETTI - The final and most important question is about the choice between what we can call open system and a close system. Open system is a workstation integrated in general purpose computer and close system is the so called tanky system. For what is my experience, close systems are less useful in a computer aided design, than the open systems because design is a chain, I think: at the beginning a conceptual phase, which is the analysis, then the draughting phase and then the bill of quantity, the bill of material phase. In an actual application, these three phases can be carried out only if you can dialog between the graphic-software and the application-software in a Fortran environment - for instance - which usually are application software, written directly by the final user. I would like to ask the opinion of Dr. Wagter, or Howard.

H. WAGTER - It would have been the beginning of the questionnaire, because it is a very complicated question. Shortly, I agree with you in your opinion that the open system, as you called it, is much more flexible. In a turnkey system you get a lot of software you never use and a lot of software you use is not available. This is a general remark of course. The question is too complicated to be answered with just "yes" or "no".

R.W. HOWARD - Well, again, I am not quite clear about your distinction between open and closed, but I think certainly systems should be open to allow one to exchange information between different systems, and of course a lot of standardization has to be done to make this more possible, at least it should be possible to get inside the system to see how it works in order than this might happen. But, in terms of what might be called closed, your work-station at least having local intelligence, has to be under the control of the user. I think that, with the distributed processing, you can have a lot of intelligence at relatively low cost locally. The problems of response on current day small systems are limited, but he has through his network perhaps access to a greater processing power, if he needs it for large analyses, on occasions.

Approach to Automated Construction Cost Estimating

Approche d'une estimation automatique des coûts de construction

Automatisierte Kosten-Kalkulation

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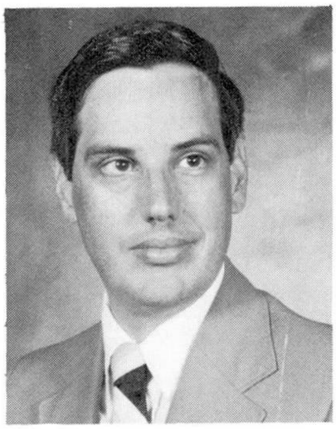


Robert Williamson, born 1946, B.S. degree in aerospace eng. at Park College of St. Louis Univ., M.S. degree in eng. management at Univ. of Missouri – Rolla. For the past 13 years, involved with developing and implementing project management scheduling and cost control systems. Currently responsible for MCAUTO's new construction cost estimating system.

SUMMARY
The article describes a computerized construction cost estimating system. The system uses a comprehensive cost data base composed of more than 37000 detail items, labor wages rates and major material prices which may be supplemented or overridden by the estimator. Work packages calculate quantities and select the proper items from the cost data. The equations and logic of the work packages may be modified without reprogramming. Flexible reporting is achieved by selection criteria which control selecting and sorting of reports.

RESUME
Un système informatisé d'estimation des coûts de construction est présenté. Il met à contribution une base de données des coûts portant sur plus de 37000 articles, ainsi que sur les taux horaires et les prix des matières premières par région. Ces données peuvent être complétées ou modifiées par l'utilisateur. Le système calcule les quantités et extrait les valeurs appropriées de la base de données. La logique et la formulation des fonctions peuvent être modifiées sans reprogrammation. L'édition des rapports est flexible, elle peut être effectuée sur la base de critères de sélections multiples et de tri.

ZUSAMMENFASSUNG
Dieser Bericht beschreibt ein EDV-Kosten-Kalkulationssystem für Bauwerke. Das Programm benützt eine umfassende Kosten-Datenbank, bestehend aus über 37000 Detail-Einheiten, örtlichen Arbeitslöhnen und Materialpreisen, die vom Kalkulator hinzugefügt oder überschrieben werden können. Verschiedene Programmteile beschreiben die Mengen und wählen die richtigen Einheiten aus den Kosten-Daten. Die einzelnen Abhängigkeiten können ohne Neuprogrammierung geändert werden.

INTRODUCTION

In January 1980, a team was formed consisting of the R. S. Means Company, McDonnell Douglas Automation Company (MCAUTO), and Comprehensive Management Services, Inc./Smith, Hinchman, & Grylls (CMSI•SH&G). The objective of the partnership was to develop a powerful, comprehensive automated tool to aid in the preparation of detailed construction estimates. The system was to be flexible and would allow the estimator to use his judgement in easily overriding standard cost information and equations used in the system. Another major design consideration was to make the system flexible and open so that it could be easily adaptable to systems and budget level estimates without reprogramming. ESTEK is the result of the combined efforts of the three organizations.

The R. S. Means Company has been the United State's leading publisher of construction cost books for the past 40 years. They are responsible for the cost data base used by ESTEK.

CMSI • SH&G are members of the Smith Group, an affiliation of ten architectural/ engineering firms. They are responsible for the algorithms and decision logic used in ESTEK's work packages.

MCAUTO, a division of McDonnell Douglas Corp., is one of the leading data processing service bureaus. MCAUTO's responsibilities are for the system analysis, programming, data processing services, and support of ESTEK. Figure 1 shows the basic system outline of ESTEK.

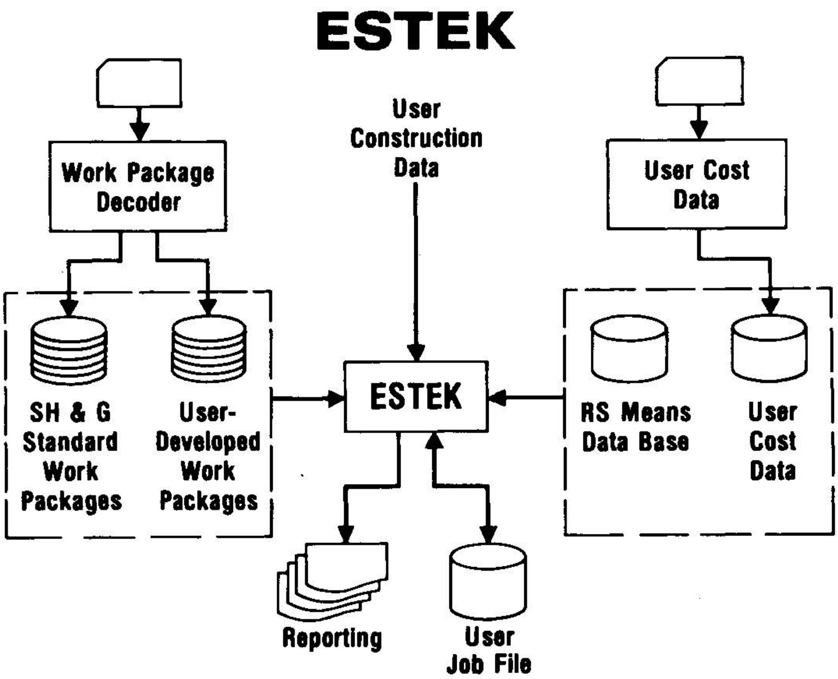


Figure 1

COST DATA BASE

The ESTEK Cost Data Base has more than 37,000 line items developed from the R. S. Means publications, Building Construction Data and Mechanical & Electrical Cost Data (see Figure 2). Labor rates for 46 trades are used to compute the installation costs. Material prices are derived by contacting manufacturers, dealers, and distributors throughout the United States and Canada.

Line Item Analysis

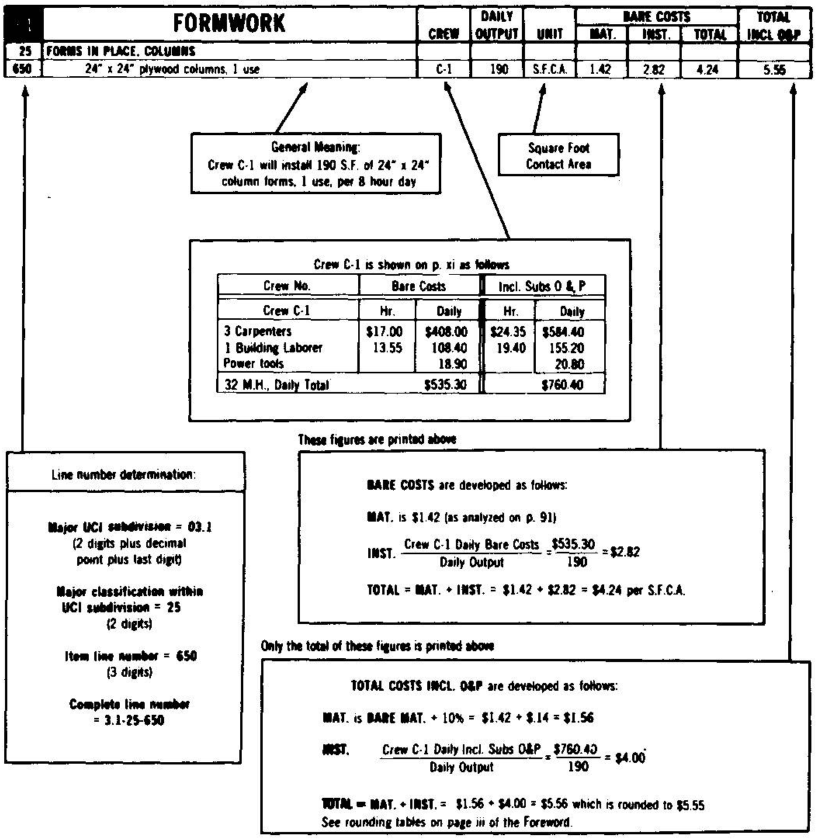


Figure 2

The labor rates for 46 construction trades and material prices for 109 key materials have been used to develop zip code location factors. These factors are used to compute the cost for any specific location defined by the first 3 digits of the Postal Zip Code.

The format of the ESTEK Cost Data Base is illustrated in Figure 3. The definition of the column titles is as follows:

1. UCI Code is patterned after the 16-division Uniform Construction Index, adopted by the American Institute of Architects, Associated General Constructors of America, Inc. and the Construction Specifications Institute, Inc. The system is widely used by most segments of the building industry.

   (Example 03.1-250-6500) = FORMWORK

2. UNIFORMAT Number is a U. S. Government General Services Administration (GSA) logical numbering framework for classification of building systems. It redefines the 16 Trade Systems into 12 Building Systems.

   (Example 0311) = SUPERSTRUCTURE STRUCTURAL FRAME

Building Construction Cost Data

(1) UCI CODE	(2) UNI-FORMAT	(3) DESCRIPTION	(4) MAT CODE	(5) MAT FACTOR	(6) WKMEN COMP	(7) CREW CODE	(8) DAILY OUTPUT	(9) UNIT	(10) BARE COSTS MAT	INST	TOTAL	(11) TOTAL INCL O&P
03.1-250-5000	0311	FRMS IN PLC COL PLY 8" SQ 1 USE	PBB6	.0029	5213	C1	165.00	S.F.C.A.	1.80	3.24	5.04	6.60
03.1-250-5050	0311	FRMS IN PLC COL PLY 8" SQ 2 USE	PBB6	.0015	5213	C1	195.00	S.F.C.A.	1.03	2.75	3.78	5.05
03.1-250-5100	0311	FRMS IN PLC COL PLY 8" SQ 3 USE	PBB6	.0011	5213	C1	210.00	S.F.C.A.	.78	2.55	3.33	4.48
03.1-250-5150	0311	FRMS IN PLC COL PLY 8" x 8" SQ 4 USE	PBB6	.0009	5213	C1	215.00	S.F.C.A.	.65	2.49	3.14	4.25
03.1-250-5500	0311	FRMS IN PLC COL PLY 12" SQ 1 USE	PBB6	.0025	5213	C1	180.00	S.F.C.A.	1.60	2.97	4.57	6.00
03.1-250-5550	0311	FRMS IN PLC COL PLY 12" SQ 2 USE	PBB6	.0014	5213	C1	210.00	S.F.C.A.	.92	2.55	3.47	4.63
03.1-250-5600	0311	FRMS IN PLC COL PLY 12" SQ 3 USE	PBB6	.0010	5213	C1	220.00	S.F.C.A.	.69	2.43	3.12	4.22
03.1-250-5650	0311	FRMS IN PLC COL PLY 12" SQ 4 USE	PBB6	.0008	5213	C1	225.00	S.F.C.A.	.57	2.38	2.95	4.01
03.1-250-6000	0311	FRMS IN PLC COL PLY 16" SQ 1 USE	PBB6	.0024	5213	C1	185.00	S.F.C.A.	1.46	2.89	4.35	5.70
03.1-250-6050	0311	FRMS IN PLC COL PLY 16" SQ 2 USE	PBB6	.0013	5213	C1	215.00	S.F.C.A.	.84	2.49	3.33	4.46
03.1-250-6100	0311	FRMS IN PLC COL PLY 16" SQ 3 USE	PBB6	.0009	5213	C1	230.00	S.F.C.A.	.63	2.33	2.96	4.00
03.1-250-6150	0311	FRMS IN PLC COL PLY 16" SQ 4 USE	PBB6	.0008	5213	C1	235.00	S.F.C.A.	.52	2.28	2.80	3.81
03.1-250-6500	0311	FRMS IN PLC COL PLY 24" SQ 1 USE	PBB6	.0023	5213	C1	190.00	S.F.C.A.	1.42	2.82	4.24	5.55
03.1-250-6550	0311	FRMS IN PLC COL PLY 24" SQ 2 USE	PBB6	.0013	5213	C1	220.00	S.F.C.A.	.81	2.43	3.24	4.35
03.1-250-6600	0311	FRMS IN PLC COL PLY 24" SQ 3 USE	PBB6	.0009	5213	C1	235.00	S.F.C.A.	.60	2.28	2.88	3.90
03.1-250-6650	0311	FRMS IN PLC COL PLY 24" SQ 4 USE	PBB6	.0008	5213	C1	240.00	S.F.C.A.	.50	2.23	2.73	3.72
03.1-250-7000	0311	FRMS IN PLC COL PLY 36" SQ 1 USE	PBB6	.0027	5213	C1	200.00	S.F.C.A.	1.53	2.68	4.21	5.50
03.1-250-7050	0311	FRMS IN PLC COL PLY 36" SQ 2 USE	PBB6	.0015	5213	C1	230.00	S.F.C.A.	.86	2.33	3.19	4.25
03.1-250-7100	0311	FRMS IN PLC COL PLY 36" SQ 3 USE	PBB6	.0011	5213	C1	245.00	S.F.C.A.	.64	2.18	2.82	3.81
03.1-250-7150	0311	FRMS IN PLC COL PLY 36" SQ 4 USE	PBB6	.0009	5213	C1	250.00	S.F.C.A.	.53	2.14	2.67	3.62
03.1-250-7500	0311	FRMS IN PLC COL STL PLY 8" SQ 4 U/M	PBB6	.0006	5213	C1	290.00	S.F.C.A.	.54	1.85	2.39	3.22
03.1-250-7550	0311	FRMS IN PLC COL STL PLY 10" SQ 4U/M	PBB6	.0005	5213	C1	300.00	S.F.C.A.	.43	1.78	2.21	3.01
03.1-250-7600	0311	FRMS IN PLC COL STL PLY 12" SQ 4U/M	PBB6	.0005	5213	C1	310.00	S.F.C.A.	.36	1.73	2.09	2.85
03.1-250-7650	0311	FRMS IN PLC COL STL PLY 16" SQ 4U/M	PBB6	.0004	5213	C1	335.00	S.F.C.A.	.34	1.60	1.94	2.64
03.1-250-7700	0311	FRMS IN PLC COL STL PLY 20" SQ 4U/M	PBB6	.0004	5213	C1	350.00	S.F.C.A.	.30	1.53	1.83	2.50

Figure 3

3. DESCRIPTION is the general description of the item written in a maximum of 35 characters.

   (Example FRMS IN PLC COL PLY 24" SQ 1 USE)

4. MATERIAL CODE is a four-digit alphanumeric code that represents a material similar to the main material in the line item.

   (Example PBB6) is 3/4" PLYFORM, BB CLASS I that has a unit of measure of MSF.

5. MATERIAL FACTOR is generated on January 1 of every year, based on the Means 30-city average rate for the particular material that is being referenced.

   (Example: Material Code PBB6) = $592.30 1/1/82

   $$\frac{\text{Jan 1, 1982 Line Item \$1.42}}{\text{Jan 1, 1982 Material \$592.30}} = .0023 \text{ Factor}$$

6. WORKER'S COMPENSATION Insurance is a four-digit number assigned to each different work classification. The rates vary by trade, state, and contractor (see Figure 4).

   (Example 5213) = CONCRETE WORK - NOC, TEXAS - 6.38

7. CREW CODE is the trade or trades required to install the described item. The C-1 Crew is shown in Figure 2 with 3 carpenters, 1 building laborer, and some power tools. The crew will always show:

   a) The number and type of tradesmen required
   b) The number, size, and type of equipment required, if any.

Workers' Compensation

STATE	CARPENTRY — 3 stories or less 5651	CARPENTRY — interior cab. work 5437	CARPENTRY — general 5403	CONCRETE WORK — NOC 5213	CONCRETE WORK - flat (flr. sdwk.) 5221	ELECTRICAL WIRING — inside 5190	EXCAVATION — earth NOC 6217	EXCAVATION — rock 6217	GLAZIERS 5462	INSULATION WORK 5479	LATHING 5443	MASONRY 5022	PAINTING & DECORATING 5474	PILE DRIVING 6003	PLASTERING 5480	PLUMBING 5183	ROOFING 5551	SHEET METAL WORK (HVAC) 5538	STEEL ERECTION — door & sash 5102	STEEL ERECTION — inter., ornam. 5102	STEEL ERECTION — structure 5040	STEEL ERECTION — NOC 5057	TILE WORK — interior (ceramic) 5348	WATERPROOFING 9014	WRECKING 5701
AL	5.31	2.68	5.04	4.91	2.86	2.31	4.12	4.12	4.29	4.21	2.64	3.93	4.00	14.72	3.98	2.37	8.54	2.75	3.72	3.72	6.86	6.93	2.68	2.13	15.29
AK	7.93	6.86	8.54	6.60	8.73	6.12	8.42	8.42	13.24	9.20	6.74	11.83	8.06	20.96	8.77	6.16	20.59	6.95	10.19	10.19	25.11	20.04	5.14	3.88	39.18
AZ	10.49	7.86	13.53	12.33	6.45	5.71	6.01	6.01	9.36	12.30	5.79	9.02	6.09	25.95	13.28	7.37	31.27	7.40	11.58	11.58	12.55	16.35	5.60	4.97	43.89
AR	6.84	3.77	6.90	5.77	4.03	2.72	6.41	6.41	5.41	5.21	4.14	4.00	5.23	24.28	4.35	3.62	12.25	5.33	6.14	6.14	18.84	9.55	3.30	3.20	29.45
CA	NA	NA	9.64	8.94	NA	3.46	4.87	NA	8.38	10.94	5.80	8.63	7.01	17.12	9.54	5.37	18.73	5.42	7.28	7.28	14.00	13.91	4.83	7.56	NA
SC	5.55	3.84	10.14	4.50	3.73	3.32	4.43	4.43	4.78	4.73	3.30	5.29	6.63	9.82	4.14	2.61	9.60	4.65	4.03	4.03	22.28	11.79	2.66	1.88	23.17
SD	3.28	2.62	4.87	3.70	3.06	1.79	4.47	4.47	4.15	3.65	2.68	2.98	3.34	10.50	3.54	3.12	9.93	2.94	3.33	3.33	9.14	8.47	2.57	1.73	14.42
TN	5.49	2.83	4.95	3.72	3.04	2.47	4.12	4.12	3.42	4.02	3.52	3.55	3.52	10.74	3.22	2.62	8.14	3.69	3.91	3.91	7.96	6.36	2.85	2.18	16.60
TX	8.72	5.01	8.72	6.38	5.32	3.68	5.55	5.55	5.29	8.51	4.60	4.78	5.01	21.01	8.55	4.46	16.21	7.83	6.30	6.30	27.63	9.66	4.34	4.76	27.23
UT	NA	NA	4.88	5.89	3.00	2.08	2.82	2.82	4.42	3.66	3.23	4.46	3.48	11.59	3.57	2.74	9.04	2.62	3.75	3.75	NA	6.57	2.29	2.22	45.11
VT	3.91	2.98	4.17	6.37	3.12	2.33	4.86	4.86	4.46	4.19	2.92	3.72	3.92	13.19	3.95	2.38	9.33	3.32	3.69	3.69	16.04	12.21	2.58	1.99	23.63
VA	5.28	6.45	6.64	9.11	5.03	4.07	6.63	6.63	5.61	7.04	5.59	6.97	7.02	15.19	6.11	4.02	15.63	5.77	6.39	6.39	20.87	17.33	3.56	2.71	23.10
WA	4.86	4.86	4.86	3.74	3.74	1.68	3.80	3.80	4.89	5.01	4.95	4.66	4.96	8.05	4.95	2.61	5.12	2.09	6.01	4.48	6.01	6.01	3.64	4.66	6.10
WV	4.60	4.60	4.60	4.60	4.60	2.24	4.48	4.48	4.60	4.60	4.60	4.60	4.60	3.92	4.60	2.02	4.60	4.60	10.55	10.55	11.23	4.60	4.60	.89	11.23
WI	4.04	3.36	7.32	5.44	3.95	2.14	4.06	4.06	4.53	6.15	3.42	4.27	4.09	10.82	4.14	2.58	11.30	3.46	3.67	3.67	7.91	6.28	2.84	2.03	18.42
WY	4.04	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
AVG.	7.88	5.16	8.98	8.55	5.55	3.81	7.01	7.13	7.13	6.67	4.97	6.98	6.73	17.81	6.53	4.73	16.07	5.75	7.23	7.10	20.27	16.10	4.88	3.86	30.90

Figure 4

8. DAILY OUTPUT indicates the number of units the crew will produce in one 8-hour day. This is an average figure, and job conditions will determine the actual field productivity. ESTEK provides ways to override the average productivity with the user's own (see Figure 2).

9. UNIT is the unit of quantity by which the items are measured and priced.

10. BARE COSTS consist of 3 columns that tabulate the unit costs of the items not including the subcontractor's overhead and profit.

    a) MATERIAL is the average contractor purchase price for the items, including delivery to the job within a 10-mile radius.
    b) INSTALLATION is calculated by dividing the daily bare crew cost by the daily output, as shown in the Figure 2.
    c) TOTAL Bare Costs are the arithmetic total of costs from a) and b).

11. TOTAL, INCL O&P represents the total price for the item, including the installing contractor's overhead and profit. It is determined in the following manner (see Figure 2):

    a) Material cost is the bare material cost plus 10%.
    b) Installation cost is calculated by dividing the crew cost, including subcontractors' O & P, by the daily output.
    c) The TOTAL, INCL O & P is the arithmetic sum of a) and b) above.

R. S. Means statisticians maintain the Data Base Material File with quarterly pricing surveys from across the United States and Canada. This file also allows monitoring the state sales tax for fine-tuning the estimate. The quarterly material cost data is keyed to the first three digits of the postal zip code (see Figure 5) for adjusting an estimate to any specific location.

The labor prices used in the ESTEK System are from the Means' Labor Rate File, Figure 6. The rates include the union local number, base wage, plus the fringe benefit package. There are over 360 cities that report on the 46 building trade rates. This amounts to over 16,500 current rates. The file can provide historical as well as future wages under contract with trade unions.

Zip Code to City Cross Reference

ZIP CODE	STATE	CITY	LABOR CITY CODE	MATERIAL CITY CODE
726	ARKANSAS	HARRISON	ARLR	
727	ARKANSAS	FAYETTEVILLE	ARFS	
728	ARKANSAS	RUSSELLVILLE	ARFS	
729	ARKANSAS	FORT SMITH	ARFS	
730	OKLAHOMA	OKLAHOMA CITY	OKOC	
731	OKLAHOMA	OKLAHOMA CITY	OKOC	
734	OKLAHOMA	ARDMORE	OKLW	OKOC
735	OKLAHOMA	LAWTON	OKLW	
736	OKLAHOMA	CLINTON	OKOC	
737	OKLAHOMA	ENID	OKEN	OKOC
738	OKLAHOMA	WOODWARD	OKEN	OKOC
739	OKLAHOMA	GUYMON	OKEN	OKOC
740	OKLAHOMA	TULSA	OKTL	
741	OKLAHOMA	TULSA	OKTL	
743	OKLAHOMA	MIAMI	OKTL	
744	OKLAHOMA	MUSKOGEE	OKTL	
745	OKLAHOMA	MCALESTER	OKOC	
746	OKLAHOMA	PONCA CITY	OKEN	
747	OKLAHOMA	DURANT	OKOC	
748	OKLAHOMA	SHAWNEE		
749	OKLAHOMA	POTEAU	TXBY	TXHS
			TXHS	
750	TEXAS	[illegible]ON	TXGL	TXHS
751	TEXAS	BEAUMONT	TXBM	
752	[illegible]	BEAUMONT	TXBM	
[illegible]	TEXAS	BRYAN	TXBY	TXAS
779	TEXAS	VICTORIA	TXCC	
780	TEXAS	SAN ANTONIO	TXSN	
781	TEXAS	SAN ANTONIO	TXSN	
782	TEXAS	SAN ANTONIO	TXSN	
783	TEXAS	CORPUS CHRISTI	TXCC	

Figure 5

Labor Rates

* HOUSTON, TEXAS 1,232,802

BUILDING CONSTRUCTION TRADES	LOCAL UNION NO	JANUARY 1, 1982 BASE WAGE RATE	FRINGE BENEFIT PACKAGE	TOTAL WAGE RATE	[illegible]
COMMON BUILDING LABORERS	18	10.85	1.66	12.51	92.5
AIR TOOL	18	10.03	1.66	11.69	84.6
ASBESTOS WORKERS	22	15.05	2.36	17.41	92.7
BOILER MAKERS	74	14.80	2.28	17.08	89.3
BRICKLAYERS	7	15.05	2.21	17.26	98.0
HELPERS	18	11.34	1.56	12.90	93.3
CARPENTERS	213	14.90	2.02	16.92	99.5
CARPET & LINOLEUM LAYER	1863			E16.20	98.5
CEMENT FINISHERS	681	14.50	1.88	16.38	98.7
ELECTRICIANS	716			E20.50	104.8
ELEVATOR CONSTRUCTORS	31	13.90	3.16	17.06	91.4
EQUIPMENT OPERATORS-HEAVY	450			E17.55	98.5
EQUIPMENT OPERATORS-MEDIUM	450	15.09	2.09	17.18	99.5
EQUIPMENT OPERATORS-LIGHT	450	13.32	2.09	15.41	94.1
EQUIPMENT OPERATORS-OILERS	450	12.39	2.09	14.48	98.0
EQUIP OPERATOR MASTER MECH	450			E18.40	99.8
GLAZIERS	1778			E16.49	98.3
LATHERS	224	14.90	1.39	16.29	99.0
MARBLE SETTERS	20	13.67	1.50	15.17	90.5
MOSAIC & TERRAZZO WORKERS	20			15.17	92.4
MOSAIC & TERR HELPERS	108	9.45	1.30	10.75	80.0
MILLWRIGHTS	2232	15.29	2.02	17.31	99.0
PAINTERS ORDINARY	130	14.44	2.23	16.67	1C3.3
PAINTERS SPRAY	130	14.81	2.23	17.04	101.3
PAINTERS STRUCTURAL STEEL	130	14.81	2.23	17.04	1C1.7
PAPER HANGERS	130	14.44	2.23	16.67	101.6
PILE DRIVERS	2079	14.90	2.02	16.92	98.8
PLASTERERS	79			E16.65	1C1.0
PLASTERERS HELPERS	18	11.34	1.56	12.90	91.6
PLUMBERS	68	15.12	1.69	16.81	87.1
PLUMBERS HELPERS	68			E11.79	€6.9
RODMEN (REINFORCING)	84	14.76	2.60	17.36	94.3
ROOFERS, COMPOSITION	116	11.83	1.48	13.31	82.6
ROOFERS, PRECAST	116	12.71	1.48	14.19	86.8
ROOFERS, TILE & SLATE	116	12.71	1.48	14.19	86.8
ROOFERS HELPERS (COMP)	116			E11.60	95.1
SHEET METAL WORKERS	54	15.26	1.98	17.24	91.3
SPRINKLER INSTALLERS	669			17.11	90.3
STEAMFITTERS/PIPEFITTERS	211	15.20	2.02	17.22	88.4
STONE MASONS	7	15.05	2.21	17.26	98.1
STRUCTURAL STEEL WORKERS	84	14.76	2.60	17.36	93.8
STRUCTURAL STEEL WELDERS	84	14.76	2.60	17.36	93.6
TILE LAYERS (FLOOR)	20			15.17	93.2
TILE LAYERS HELPERS	108	9.45	1.30	10.75	82.2
TRUCK DRIVERS-LIGHT	1111	10.79	1.85	12.64	91.7
TRUCK DRIVERS-HEAVY	1111	11.21	1.85	13.06	92.9
[illegible]				16.66	95.3

Figure 6

USER-SUPPLIED COST DATA BASE

ESTEK is not limited to using only the R. S. Means cost data. The estimator may supply his own information to be used exclusively or in conjunction with the Means data. The types of data that can be supplied include labor rates, crews, major material prices, and the basic line items. ESTEK has multiple options for determining which cost data is used: only user-supplied cost, only R. S. Means cost data, or a combination of both. In this manner, the estimator may supply only a portion of the cost data base and rely on Means for the remaining information.

WORK PACKAGE CONCEPT

ESTEK uses work packages to simplify the preparation of estimates. A work package describes a grouping of related construction tasks that are required to install a particular building system. It computes quantities and logically determines which items are to be selected from the cost data base.

To use a work package, estimators supply dimensions and pick appropriate choices from a matrix describing construction methods and quality of materials. Figure 7 shows the work package (SD03050) used for taking off concrete walls, columns, and piers. This work package routine calculates quantities for concrete walls used in exterior or interior construction, retaining walls, and foundation walls. The package will also calculate quantities for columns and piers (round or square), including capitals. Other capabilities of the work package include descriptions of forms and form liners, reinforcing, moisture protection, curing methods, finishes, accessories, and insulation.

An example of the use of this work package is to describe a wall 10 feet high (3.05m) by 30 feet long (9.14m) by 1 foot thick (.30m) with vertical reinforcing, #6 bars every 12 inches (305mm) and horizontal reinforcing, #4 bars every 18 inches (457mm). Other specifications for the wall are 4000 psi concrete (27575 kPa), 1-inch (25.4mm) urethane sheet insulation, and a 5-foot (1.52m) by 4-foot (1.22m) block out.

The required input to ESTEK would first be the dimensions:

A Wall Length
B Wall Thickness
C Wall Height
E Vertical Reinforcing
F Horizontal Reinforcing
L Block-out Length
M Block-out Height
Q Insulation Thickness

Next the appropriate choices are picked from the decision matrix:

Several choices in the decision matrix, particularly columns 4, 5, 7, and 8 on concrete placing method and forms, are not given in the specifications or dimensions. The estimator has to bring his knowledge of construction to the preparation of the estimate, but the decision matrix also serves as a handy reminder or checklist. Figure 8 is the Quantity Survey Report showing the takeoff produced by this example.

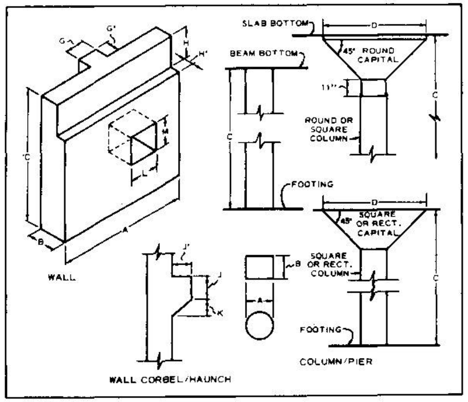
Extensive error checking is also performed by the work package routines. Illogical errors, such as conflicting decision matrix choices or out-of-scope dimensions, produce messages of various error severity (from informational messages to major error conditions).

CONCRETE WALLS, COLUMNS, AND PIERS

SD03050

Calculates quantities and costs for concrete walls used in exterior and interior construction, retaining walls and foundation walls. The package also calculates round and square columns and piers including capitals. Other capabilities include:

- forms and form liners
- reinforcing
- curing and finishes
- accessories and insulation



VARIABLE NAME	DEFINITION	UNIT OF MEASURE
A	WALL LENGTH -OR LONG SIDE OF SQUARE/RECT COLUMN -OR ROUND COLUMN DIAMETER	FEET FEET FEET
B	WALL THICKNESS -OR- OTHER COLUMN SIDE	FEET
C	WALL OR COLUMN HEIGHT	FEET
D	LONGER SIDE OR DIAMETER OF CAPITAL	FEET
E	VERTICAL BARS:WALL- SPACING (INCHES) (POS 1-4) AND SIZE (#) (POS 5-6) -OR- :COLUMN- NUMBER (EACH) (POS 1-4) AND SIZE (#) (POS 5-6)	
F	HORIZONTAL BARS-WALL SPACING (INCH) (POS 1-4) AND SIZE (#) (POS 5-6) -OR WALL REINF. ALLOWANCE (POS 1-4) -OR COLUMN REINFORCING ALLOWANCE (POS 1-4)	
G	PILASTER WIDTH OR DIAMETER (POS 1-4) AND PROJECTION (POS 5-6)	INCHES
H	BEARING LEDGE - HEIGHT (POS 1-4) AND WIDTH (POS 5-6)	INCHES
J	CORBEL/HAUNCH - CAP HEIGHT (POS 1-4) AND WIDTH (POS 5-6)	INCHES
K	CORBEL/HAUNCH HEIGHT	INCHES
L	BLOCK-OUT LENGTH OR DIAMETER	FEET
M	BLOCK-OUT HEIGHT (ZERO IF ROUND)	FEET
N	LENGTH OF ACCESSORIES	FEET
P	WATERSTOP WIDTH (4, 6 OR 9 IN)	IN
Q	INSULATION THICKNESS	IN

DECISION MATRIX

SD03050

Concrete Walls, Columns, and Piers

	1 WALL TYPE (CHOOSE ONE)	2 COLUMN / PIER TYPE (CHOOSE ONE)	3 CONCRETE REGULAR WEIGHT	4 CONCRETE PLACING METHOD	5 FORMS (WALLS)	6 FORM LINERS WALL- ONE SIDE COLUMNS - ALL	7 FORMS (COLUMNS)	8 FORM USE	9 REINFORCING WALL / COLUMN	10 FINISHES	11 MOISTURE PROTECTION W/ PROTECT. BOARD	12 CONCRETE CURING	13 ACCESSORIES	14 WALL INSULATION (APPLIED-ON)	15 CONCRETE ADDITIVES
0	FOUNDATION WALL	RECTANGULAR OR SQUARE COLUMN	2000 PSI	DIRECT POUR	MODULAR PREFAB PLYWOOD & STEEL FRAMED	AGED WOOD	PREFAB PLYWOOD & STEEL FRAMED	RENTED - 1 USE PER MONTH	WALL - 1 FACE SPACING & SIZE STOP WITHIN WALL	POINT & PATCH	BITUMINOUS DAMPPROOFING 2 - COAT BRUSH	LIQUID MEMBRANE	CHAMFER STRIP	GLASS FIBER SHEET 1/2 TO 3 IN	HIGH EARLY CEMENT
1	BASEMENT WALL	CIRCULAR COLUMN	2500 PSI	CRANE & BUCKET	MODULAR PREFAB PLYWOOD	FRACTURED ROPE RIB	JOB BUILT PLYFORM	2 USE PER MONTH	WALL - 2 FACE SPACING & SIZE STOP WITHIN WALL	BURLAP RUB WITH GROUT	SILICONE DAMPPROOFING	WATERPROOF PAPER	FLASHING REGLET	POLYSTYRENE SHEET 1/2 TO 3 IN	SET ACCELERATOR ADMIXTURE
2	EXTERIOR WALL (STRUCTURAL)	RECTANGULAR OR SQUARE COLUMN WITH RECT/SQ. CAPITAL	3000 PSI	PUMP	JOB BUILT PLYFORM	RIBBED LOOK 1/2.3/4 IN DP	ROUND FIBER TUBE 8 - 48 INCHES	3 USE PER MONTH	WALL - 1 FACE SPACING & SIZE WITH FLOOR LAPP	CARBORUNDUM DRY RUB	CEMENTITIOUS DAMPPROOFING (CEMENT PARGING)	PLSTIC SHEETING	DOVETAIL INSERTS	URETHANE SHEET 1/2 TO 3 IN	WATER REDUCING ADMIXTURE
3	EXTERIOR WALL (NON-STRUCTURAL)	RECTANGULAR OR SQUARE COLUMN WITH ROUND CAPITAL 4 - 7 FT DIAM	3500 PSI	CARTS	RADIAL SMOOTH	STRIATED RANDOM 3/8X3/8 IN DP	ROUND FIBER TUBE SEAMLESS 8 - 48 INCHES	4 USE PER MONTH	WALL - 2 FACE SPACING & SIZE WITH FLOOR LAPP	CARBORUNDUM WET RUB	MEMBRANE WATERPROOFING	BURLAP	UNISTRUT INSERTS 7/8 IN DEEP	FOAMED GLASS SHEET 1 TO 3 IN	INTEGRAL WATERPROOFING
4	INTERIOR WALL (STRUCTURAL)	CIRCULAR COLUMN WITH ROUND CAPITAL 4 - 7 FT DIAM	4000 PSI	CONVEYOR BELT	RADIAL 2 FT CORD	SOLID BOARD FINISH UNIFORM	ROUND FIBERGLASS 12 - 36 INCHES	JOB BUILT 1 USE	WALL - LB/SF ALLOWANCE BY ESTIMATOR	BUSH HAMMER GREEN CONCRETE	METALLIC WATERPROOFING (IRON OXIDE)	CURING BLANKET	UNISTRUT INSERTS 1 3/8 IN DEEP	PERLITE BOARD 1 TO 3 IN	WHITE CEMENT
5	INTERIOR WALL (PARTITION)	RECTANGULAR OR SQUARE PIER	4500 PSI		SLIPFORM STRAIGHT	SOLID BOARD FINISH NON-UNIFORM	ROUND STEEL 12 - 60 INCHES	2 USE	COLUMN - NO OF BARS & SIZE STOP WITHIN COLUMN	BUSH HAMMER CURED CONCRETE	BENTONITE CLAY WATERPROOFING (PANELS)	ELECTRICALLY HEATED PAD 10 W PER SF	KEYWAY - VERTICAL WITH BULKHEAD FORMS		WARM-TONE CEMENT
6	PITS & TRENCHES	CIRCULAR PIER	5000 PSI		SLIPFORM RADIAL	RUSTIC BRICK PATTERN		3 USE	COLUMN - NO OF BARS & SIZE WITH FLOOR LAP	SANDBLAST LIGHT PENETRATION	BENTONITE CLAY WATERPROOFING - TROWELED ON ADMIXTURE	ELECTRICALLY HEATED PAD 20 W PER SF	KEYWAY HORIZONTAL		INTEGRAL COLORS (REDS)
7	TUNNEL WALLS	CONCRETE ENCASING OF STEEL COLUMN RECT/SQUARE	FIELD MIX 2250 PSI					4 USE	COLUMN - LB PER LF ALLOWANCE BY ESTIMATOR	SANDBLAST MEDIUM PENETRATION			VERTICAL KEYWAY & PVC WATERSTOP 4,6,9 IN DEEP		INTEGRAL COLORS (BLACK)
8	SITE STRUCTURES WALLS	CONCRETE ENCASING OF STEEL COLUMN ROUND	FIELD MIX 3000 PSI						WALLS/COLUMNS PROGRAMMED - LB PER CY ALLOWANCE	SANDBLAST HEAVY PENETRATION			HORIZONTAL KEYWAY & PVC WATERSTOP 4,6,9 IN DEEP		INTEGRAL COLORS (GREENS)
9	RETAINING WALLS								STEEL COLUMN WRAP	ACID ETCH			EXPANSION JOINT PRE-MOLDED FILLER		

Figure 7

TAKE-OFF ORIGIN	VARIABLE CODE	U.C.I. CODE	TAKE-OFF NUMBER	UNIFORMAT NUMBER	QUANTITY	UNIT OF MEASURE	DESCRIPTION	TOTAL $ (BURDENED)
SD03050		03.1-650-2550		041100	609.00	S.F.C.	FRMS IN PLC JOB BLT PLY TO 16' 4USE	2,051
		03.2-040-0720		041100	0.60	TON	REINFORCING GRADE 60 WALLS	429
		03.3-120-0300		041100	11.04	C.Y.	CONCRETE, REDI MIX REG WT 4000 PSI	741
		03.3-160-0250		041100	6.00	S.F.	CONCRETE CURING PLASTIC SHEETHING	1
		03.3-280-0010		041100	600.00	S.F.	FIN WLS BREAK TIES & PATCH	213
		03.3-280-0700		041100	300.00	S.F.	FIN WLS SAND BLST LT PENTN	173
		03.3-380-5200		041100	11.04	C.Y.	PLC CONC&VBRT WALLS 12" THK C&B	229
		07.1-700-0100		041100	300.00	S.F.	SILICONE/STEARATE SPRA ON MASON 2CT	157
		07.2-800-1500		041100	300.00	S.F.	WALL INSUL RIGID URETHANE N BKG 1"T	194
SUBTOTAL(SD03050)								

Figure 8

Table 1 lists the 48 work packages that are currently available in ESTEK. These work packages are divided into the major categories of General Conditions, Civil, Architectural, Structural, Mechanical, and Electrical.

WORK PACKAGE DECODER

One of the more important features of ESTEK is that it allows the user to modify the algorithms and logic of the work packages and to add new work packages. This is accomplished through the work package decoder subsystem of ESTEK. The estimator (not a programmer) may modify or create work packages directly without reprogramming the system. The types of functions available with the decoder are:

- Input definitions of variables
- Decision matrix definitions
- Internal or intermediate variables
- Equations with algebraic, trigonometric, and logarithmic functions.
- Logic conditions
- Table lookups
- Error message definitions

The basic function of the work package is to compute quantities from the input dimensions and to determine logically which UCI codes the quantities should be assigned. The work packages also allow the user to create or modify the production rate and the Uniformat code of the takeoff item selected from the cost data base.

Available as part of the user documentation of ESTEK is a set of manuals containing all of the inputs used to define the standard work packages. By modifying the standard work packages or creating new ones, the estimator may develop his own private library of work packages that satisfy his own special requirements.

UPDATING/FINE TUNING AN ESTIMATE

ESTEK is designed so that any processing of the system may include a mix of work package executions, updates to previous takeoffs, updates to control information (i.e., labor rates, major material, and prices) and report requests. The updating process was designed to be flexible and to allow fine tuning of the estimate easily. The types of updates available fall into two categories: control information (global changes) and line item information (detail changes). When a new estimate is started, all the required control information (labor rates, major material prices, equipment rates, and overheads) is initialized from the R. S. Means or the user-supplied cost data bases. The estimator may modify any of this control information and cause all of the appropriate values on the detail takeoff items to be recalculated.

Table 1 Work Packages

General Conditions
- Personnel
- Job Requirements

Civil
- Site Earthwork
- Excavation
- Piles and Caissons
- Sewers
- Site Utilities
- Site Paving

Structural
- Foundations
- Concrete Walls, Columns, and Piers
- Concrete Beams and Slabs
- Slab on Grade
- Masonry, Stone Work, and Accessories
- Structural Steel Framing
- Miscellaneous Metals and Stairs
- Metal Deck and Concrete Fill

Architechtural
- Built-up, Single Ply, and Fluid Applied Roofing
- Shingle, Metal, and Special Roofing
- Roof Accessories
- Interior Finishes (Floors and Ceilings)
- Interior Finishes (Walls)
- Plaster Work (Walls)
- Drywall Work (Walls)
- Washroom Accessories
- Elevators

Mechanical
- Ductwork
- Piping (HVAC)
- Piping (Waste, Vent, and Storm)
- Plumbing Fixtures
- Piping (Water, Fuel, and Lab gases)
- Fire Protection Piping Systems
- Mechanical Controls

Electrical
- Conductor and Conduit
- Busway Systems
- Busway Devices
- Switchboard and Distribution Panels
- Circuit Breaker Panel Boards
- Transformers
- Wiring Devices (Receptacles)
- Wiring Devices (Switches)
- Motor Controllers and Connections
- Cable Trays
- Under Floor Duct
- Under FLoor Duct (Trench)
- Lighting Fixtures
- Emergency Power Sources
- Electric Heating
- Motor Control Centers

On individual takeoff items, the estimator may adjust the production rate, quantity, and the various unit prices (labor, material, equipment, bare total, and burdened total). Whichever values the estimator chooses to update, ESTEK will automatically perform the necessary recalculations. This allows the estimator to exercise his judgement and modify any of the information contained within the estimate.

REPORTING

ESTEK produces a variety of reports that can be segregated into three categories: processing diagnostics, file maintenance, and analysis reports. The processing diagnostics convey information about the status and execution of the system. These are used by the estimator to ensure that the input data and processing of the system is correct. These reports are produced automatically or semiautomatically.

The file maintenance reports are used to verify the results of the system, but they are primarily used for turnaround documents. The Update Report, for example, is in a format that may be marked up and used as a data entry document.

There are a variety of analysis reports produced by ESTEK. In general these reports may display detail or summarized information. In addition to the basic formats of the reports, selection criteria options allow the estimator to tailor the reports to his needs by means of sorting, selecting, and titling features. Figure 9 is an example of the Quality Survey Report. It displays all the takeoff items and quantities produced by the work packages. The major sort order is by work package ID so the estimator may verify the quantities calculated.

Figures 10 and 11 are examples of the Project Cost Report. This report can be used for analysis and as a final reporting document. The information may be displayed in detail or summarized formats by UCI or Uniformat codes. Figure 10 is a UCI detail format, and Figure 11 is a summarized Uniformat report. The Project Cost Report also has various options for displaying subcontractor and general contractor overheads and profits.

Another example of the type of reports available is Figure 12, the Labor Hours Analysis Report. This report can produce detail or summarized information (as shown) for each labor trade. The report displays statistics, such as number of hours, average base rates, fringe, and overhead rates, and the distribution between foremen, journeymen, and apprentices.

The ESTEK reporting features are designed to display information in a variety of formats so the estimator may choose those that satisfy his needs. These standard reports, when used with the selection criteria options, allow flexible reporting.

QUANTITY SURVEY REPORT
FILE NAME = PAPER2
FILE NUMBER = 001

E S T E K
QUANTITY SURVEY REPORT EXAMPLE
HOUSTON TEXAS

PAGE 5
05/26/82

TAKE-OFF ORIGIN	VARIABLE CODE	U.C.I. CODE	TAKE-OFF NUMBER	UNIFORMAT NUMBER	QUANTITY	UNIT OF MEASURE	DESCRIPTION	TOTAL $ (BURDENED)
SUBTOTAL(SD10000)								2,217
SD15150		15.2-320-2960		081400	2.00	EA.	LVTRY/FTG WHT VNTY VTCHN 20"X17"1BL	317
		15.2-560-8200		081400	1.00	EA.	SHOWER ENAM STEEL RECEPTOR 30"SQARE	155
		15.2-680-0050		081400	1.00	EA.	URNL WHNG PECI FLSHPIP&STRAIN4'X18"	535
		15.2-800-1000		081400	2.00	EA.	WC TNKTYP VCHN,SET SUP&STP FLR 1 PC	1,170
SUBTOTAL(SD15150)								2,177
SD15200		15.1-401-1180		081100	90.00	L.F.	PIPE COPR TYPE K 50/50 SOLDR 3/4"	511
		15.1-410-0120		081100	15.00	EA.	PIPE COPPER 90<EL WROUGHT 3/4" SDR	154
		15.1-410-0500		081100	6.00	EA.	PIPE COPPER TEE WROUGHT 3/4" SDR JT	97
		15.1-800-3440		081100	9.00	EA.	VALVE BRNZ GATE 125# THD 3/4"	231
		02.3-030-1310		082100	4.58	C.Y.	TRENCH BACKFILL BY MACHINE W/EXCAV	3
		02.3-180-0400		082100	2.43	C.Y.	EXCAVTG TRCH4'WX8'D3/4CY HYDLC BKHO	5
		15.1-551-0580		082100	30.00	L.F.	PIPE STL BLK SCH 40 THREDED 1"	159
		15.1-560-5100		082100	1.00	EA.	PIPE 90<EL THD BLK MI 150# 1"	16
		02.3-190-2100		081100	30.00	L.F.	CHAIN TRENCH AND B/F 6" WD 18" DEEP	10
		15.1-401-1180		081100	30.00	L.F.	PIPE COPR TYPE K 50/50 SOLDR 3/4"	170
		15.1-410-0120		081100	6.00	EA.	PIPE COPPER 90<EL WROUGHT 3/4" SDR	62
SUBTOTAL(SD15200)								1,419
SD16000		16.0-200-1871		091200	5.00	L.F.	CONDUIT TO 15' HIGH GALV. 2"	38
		16.0-200-2130		091200	2.00	EA.	COND ELBOW GALVANIZED 2" DIA	66
		16.0-200-5021		092100	1,443.82	L.F.	CONDUIT TO 15' HIGH EMT 3/4"	591
		16.0-200-5041		092100	110.66	L.F.	CONDUIT TO 15' HIGH EMT 1"	278
		16.0-200-6220		092100	119.00	EA.	EMT CPLNG SET SCREW STEEL 3/4" DIA	101
		16.0-200-6240		092100	11.00	EA.	EMT CPLNG SET SCREW STEEL 1" DIA	15
		16.0-200-6520		092100	70.00	EA.	EMT BOX CONN SET SCR STL 3/4" DIA	48
		16.0-200-6540		092100	2.00	EA.	EMT BOX CONN SET SCR STL 1" DIA	7
		16.0-550-1000		091200	4.00	EA.	CONDUIT LOCKNUT 2" DIA	3
		16.0-550-1500		091200	2.00	EA.	CONDUIT BUSHING STEEL INSUL 2" D	39
		16.0-550-2960		091200	1.00	EA.	CONDUIT EXPANSION COUPLING 2"D	123
		16.1-100-1500		092100	3.50	C.L.F.	WIRE 600V THWN COPPER STR #2	469
		16.1-100-4110		092100	18.48	C.L.F.	WIRE 600V TW COPPER STRANDED #14	85
		16.1-100-4120		092100	6.68	C.L.F.	WIRE 600V TW COPPER STRANDED #12	190
		16.1-100-4130		092100	26.67	C.L.F.	WIRE 600V TW COPPER STRANDED #10	276

Figure 9

PROJECT COST REPORT
FILE NAME = PAPER2
FILE NUMBER = 002

E S T E K
PROJECT COST SUMMARY EXAMPLE - DETAIL UCI REPORT
HOUSTON TEXAS

PAGE 1
06/16/82

UCI SUBDIVISION DESCRIPTION	QUANTITY	UNIT OF MEASURE	TOTAL UNIT $	TOTAL MATERIAL $	TOTAL LABOR $	TOTAL EQUIPMENT $	TOTAL $ (BURDENED)
02 - SITE WORK							
02.1 - SITE CLEARING & EXPLORATION							
CLEAR & GRUB BRUSH	1.03	ACRE	1,437.085	0	613	1,129	1,742
SUBTOTAL (BURDENED)				0	613	1,129	1,742
02.3 - EARTHWORK							
BACKFILL BY HAND NO COMP LIGHT SOIL	4.98	C.Y.	10.032	0	59	0	59
BACKFILL COMPACTION VIB PLATE ADD	4.98	C.Y.	2.404	0	11	3	14
TRENCH BACKFILL BY MACHINE W/EXCAV	4.58	C.Y.	0.675	0	1	3	4
BACKFILL DOZER BULK 300' AIR TAMPED	249.98	C.Y.	4.746	0	416	981	1,396
BORROW BANK RUN GRAVEL SPREAD/ D-7	68.89	C.Y.	7.261	353	75	161	589
BORROW COMMON BORROW SPREAD/ D-7	833.33	C.Y.	5.304	2,329	919	1,955	5,202
EXCAVTG TRCH4'WX5'D1/2CY TRCTR BKHO	300.58	C.Y.	0.000	0	0	0	0
EXCAVTG TRCH4'WX8'D3/4CY HYDLC BKHO	2.43	C.Y.	2.129	0	3	3	6
EXCAVTG TRCH TRIM SIDES/BTM REGULAR	5.86	C.Y.	0.000	0	0	0	0
CHAIN TRENCH AND B/F 6" WD 18" DEEP	30.00	L.F.	0.349	0	6	6	12
GRADING HAND GRADING FINISH	413.78	S.Y.	1.876	0	914	0	914
HAUL.DISPL.EXV.MAT ON SITE 4LOADS/H	300.58	C.Y.	0.000	0	0	0	0
HAULING SOIL 16CY DP TR 4M RT1.6L/H	958.33	C.Y.	2.370	0	788	1,885	2,673
SUBTOTAL (BURDENED)				2,682	3,192	4,997	10,869
DIVISION TOTAL (BURDENED)	10.56% OF TOTAL PROJECT $3.15 PER SQUARE FOOT			2,682	3,805	6,126	12,611
03 - CONCRETE							
03.1 - FORMWORK & EXPANSION JOINTS							
FRMS IN PLC COL RD FIBTU 8"D 1 USE	10.00	L.F.	7.326	31	54	2	86
FRMS IN PLC FTGS CONTIN WALL 4 USE	642.00	S.F.C.	0.320	242	0	0	242
FRMS IN PLC EDGE FRM TO 12" H 4 USE	32.67	S.F.C.	2.226	21	63	2	86
FRMS IN PLC JOB BLT PLY TO 16' 4USE	1,219.00	S.F.C.	3.367	709	4,022	100	4,831
SUBTOTAL (BURDENED)				1,003	4,139	104	5,245
03.2 - REINFORCING STEEL							
RESTL IN PL:FOOTINGS #4-#7	0.44	TON	887.566	262	198	0	460
REINFORCING GRADE 60 WALLS	1.20	TON	714.318	685	324	0	1,009
WELDED WIRE FABR ROLLS 6X6 #8/8	37.24	C.S.F.	23.785	475	567	0	1,043
SUBTOTAL (BURDENED)				1,422	1,089	0	2,512
03.3 - CAST IN PLACE CONCRETE							

Figure 10

PROJECT COST REPORT E S T E K PAGE 2
FILE NAME = PAPER2 PROJECT COST SUMMARY EXAMPLE - SUMMARY UNIFORMAT REPORT 05/26/82
FILE NUMBER = 001 HOUSTON TEXAS

UNIFORMAT LEVEL		TOTAL MATERIAL $	TOTAL LABOR $	TOTAL EQUIPMENT $	TOTAL $ (BURDENED)
063 - SPECIALTIES		799	135	0	936
DIVISION TOTAL (BURDENED)	2.86% OF TOTAL PROJECT $0.83 PER SQUARE FOOT	1,839	1,318	140	3,301
08 - MECHANICAL					
081 - PLUMBING		2,008	1,390	5	3,408
082 - H.V.A.C.		4,620	1,008	4	5,637
DIVISION TOTAL (BURDENED)	7.83% OF TOTAL PROJECT $2.26 PER SQUARE FOOT	6,628	2,398	9	9,045
09 - ELECTRICAL					
091 - SERVICE & DISTRIBUTION		4,703	2,169	0	6,878
092 - LIGHTING & POWER		10,964	3,389	0	14,362
DIVISION TOTAL (BURDENED)	18.40% OF TOTAL PROJECT $5.31 PER SQUARE FOOT	15,667	5,558	0	21,240
12 - SITE WORK					
121 - SITE PREPARATION		1,978	1,970	4,220	8,169
DIVISION TOTAL (BURDENED)	7.08% OF TOTAL PROJECT $2.04 PER SQUARE FOOT	1,978	1,970	4,220	8,169
*** TOTAL (BURDENED)	$28.85 PER SQUARE FOOT	67,835	41,031	6,453	115,380
*** MAIN OFFICE EXPENSE OVERHEAD					8,884
*** GENERAL CONTRACTOR'S PROFIT					11,538
*** PROJECT TOTAL	$33.95 PER SQUARE FOOT				135,802

Figure 11

LABOR HOURS REPORT E S T E K PAGE 1
FILE NAME = PAPER2 LABOR HOURS ANALYSIS EXAMPLE - SUMMARY REPORT 05/26/82
FILE NUMBER = 001 HOUSTON TEXAS

LABOR CODE DESCRIPTION				TOTAL HOURS	BASE RATE	FRINGE RATE	FIXED O/H RATE	TOTAL
BRHE - BRICKLAYER HELPERS	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	376.0	11.235	1.660	2.014	5,607
BRIC - BRICKLAYERS	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	373.6	15.050	2.210	2.698	7,457
CARP - CARPENTERS	10.04% FOREMEN	89.96% JOURNEYMEN	0.00% APPRENTICE	123.0	14.950	2.020	2.952	2,452
CEFI - CEMENT FINISHERS	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	54.7	14.500	1.880	2.716	1,044
CLAB - COMMON BUILDING LABORERS	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	100.0	10.850	1.660	2.099	1,463
ELEC - ELECTRICIANS	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	162.6	18.084	2.416	3.046	3,831
EQHV - EQUIPMENT OPERATORS, CRANE OR SHOVEL	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	4.5	15.423	2.127	6.243	108
EQLT - EQUIPMENT OPERATORS, LIGHT EQUIPMENT	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	18.1	13.320	2.090	2.420	323
EQMD - EQUIPMENT OPERATORS, MEDIUM EQUIPMENT	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	32.6	15.090	2.090	2.822	654
EQOL - EQUIPMENT OPERATORS, OILERS	0.00% FOREMEN	100.00% JOURNEYMEN	0.00% APPRENTICE	4.5	12.390	2.092	5.018	89
PLUM - PLUMBERS	0.00% FOREMEN	83.16% JOURNEYMEN	16.84% APPRENTICE	66.1	14.611	1.685	2.573	1,251

Figure 12

CONCLUSION

A comprehensive cost estimating system is comprised of three important components.

1. A cost data base that is:

   - Comprehensive in scope and able to cover all items of cost
   - Easily adjusted to local unit prices
   - Maintained with up-to-date information by an experienced staff
   - Accurate.

2. Computer software that:

   - Is designed to minimized the takeoff effort
   - Allows for easy adjustments to the estimate
   - Is opened ended by allowing the user to customize the algorithms and logic used in computing quantities
   - Has flexible reporting to meet a variety of needs.

3. Support that is:

   - Continuous, for development of new enhancements and features
   - Available to train and assist users of the system.

ESTEK was designed by R. S. Means Company, CMSI•SH&G, and MCAUTO as a comprehensive construction cost estimating tool.

Evaluation Methods for Design Alternatives

Méthodes d'évaluation des solutions alternatives d'un projet de construction

Bewertungsmethoden für Bauentwürfe

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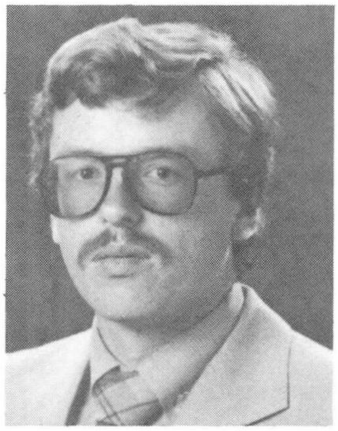
Heinz Schwarz born 1923, Civil Engineer since 1949. Different positions in structural engineering till 1969. Doctorate in 1962. Since 1970 Professor of Information Processing in Building and Civil Engineering Organisations.



Friedrich Steiger born 1953, got his civil engineering degree at the Technische Universität Berlin in 1977. In different positions with Bilfinger + Berger Bau AG, Frankfurt. Since 1980 scientific assistant at the TH Darmstadt.

SUMMARY
Computers may support the (structural) design engineer's work far more than simply proving safety against failure and drawing the plans. Selecting the most favourable among several competing shapes of a design object (e.g. of a structure) is one of a creative engineer's most important jobs. There are methods to support decision making under risk conditions, appropriate to this purpose, which can be easily made available by computer programs. Some fundamentals of these methods are presented and their application is illustrated by examples.

RESUME
Le rôle de l'ordinateur dans le processus de travail de l'ingénieur dépasse largement le contrôle de la sécurité à la rupture et le dessin de plans. L'activité créatrice de l'ingénieur débouche sur l'élaboration et la confrontation de solutions concurrentes pour un même projet. Le recours, grâce à l'ordinateur, aux méthodes d'aide à la décision dans un contexte de risques est précieuse au niveau de l'évaluation. Les principes fondamentaux de ces méthodes sont présentés et leur application illustrée par des exemples.

ZUSAMMENFASSUNG
Computer können die Arbeit der (Tragwerk-)Entwurfsingenieure erheblich weitergehend unterstützen als durch Nachweisrechnungen für die Standsicherheit und Zeichnen von Plänen. Das Auswählen der geeignetsten unter mehreren konkurrierenden Gestaltungslösungen eines Entwurfsobjekts (z.B. eines Tragwerks) gehört zu den wichtigsten Aufgaben schöpferisch tätiger Ingenieure. Es gibt Methoden zur Unterstützung des Entscheidens unter Risiko, die für diesen Zweck geeignet sind und durch Rechnerprogramme leicht verfügbar gemacht werden können. Einige Grundlagen dieser Methoden werden dargestellt und ihre Anwendung wird an Beispielen erläutert.

1. UNCERTAINTIES IN DESIGN DECISIONS AND THEIR REASONS

1.1 Introductory remarks

Computer aided design often is understood only as the generating process of geometric data which describe a three dimensional model and/or two dimensional images of the design object. Thus the design work is merely reduced to drafting. When regarding engineering work that way, structural analysis appears to be a separated task and the "structural analyst" to be the scientific trained partner of an intuitively acting "designer". From our point of view however, designing is the whole creative process of shaping and dimensioning an engineering object, and the computer should support more than the analytic and the drafting part of it.

The design process as a whole might be structured to four phases:
- Searching for appropriate solutions, which includes clarifying the requirements of the client or user
- proving the suitability of those solutions, which are going to be evaluated
- selecting the most useful solution
- preparing the construction documents

In each phase the computer may assist the designing engineer. In the first one this could be done by retrieval processes in documented material, which contains information on experiences of the engineer's organization with similar projects and/or published constructions. In the second one calculations of the design object's properties - in case of structures of its safety against failure - and drawings, which prove its suitable performance might be produced by help of computers. The third phase can be supported by computer assisted procedures of optimal decisions, if the engineer has knowledges in this field. And in the fourth phase once again drawings, but also documents in the form of texts and lists might be produced by help of computers. If computer assistance is organized optimally, the engineer might use data processing equipment to store and to manage all the data which he receives, produces and interchanges with his partners, the design process in most cases beeing an interacitve one.

So far there exists a lack of knowledge with designing engineers in general and with structural engineers especially concerning the methodology of the first and the third phase as well as of the structuring and management of data bases. For this reason the discussions in meetings like the one to which this paper is presented should not be reduced to problems of computer usage in a narrow sense. "Informatics" should rather be understood in a broader sense. This should include methods of information processing (which means more than data processing) in all those phases of the - structural - design process, systematically ordered knowledge of which civil engineers regularely do earn neither by education nor by professional experience.

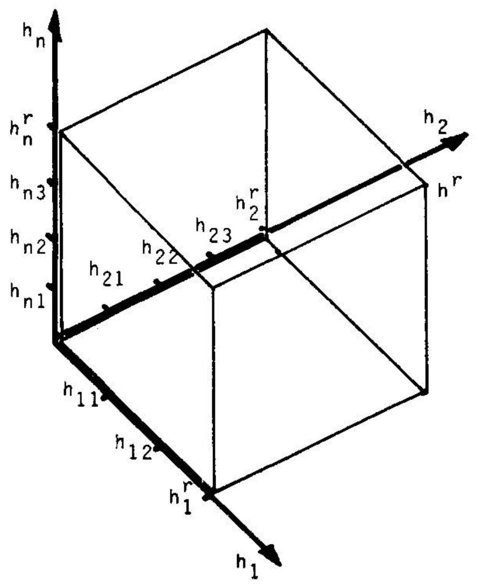
This paper as well as another contribution to this colloquium [1] present dedicated proposals to supply the want of evaluation and selection methods for competing design solutions. For this purpose we need a certain taxonomy of concepts to order the "data material" which engineers use in the process of design. This will be supplied in the following subchapter. An instrument to document and to retrieve information in the "know-how data base" of engineering organisations has been developed at our Fachgebiet Informationsverarbeitung im Bauwesen an der Technischen Hochschule Darmstadt [2, 3]. We hope that there will be an opportunity to report on this important and interesting part of engineering tools at an other time.

1.2 Fundamentals of a taxonomy of design variables

In order to give as exact a description as possible of the evaluation and selection procedures' embedding in the design process we arrange the variables which the designer has to deal with, in four classes, which we term as follows:

Design variables	h_i
Environment-describing variables	w_i
Behaviour-describing variables	e_i
Evaluating variables	q_i

Design variables are those whose values describe the design object ready for construction. These include, above all, geometrical characteristics such as lengthes and angles, but also material, processing and type specifying characteristics. The designer determines them in two steps. The first of these steps we term the shaping, the second the dimensioning of the design object. If we take each design variable h_i as one axis of a system of coordinates, then we can say that shaping means "spanning" an n-dimensional design space (see fig. 1) since the values of n measures and specifications have to be indicated in order to describe the object ready for constructions. This space contains a set H of points, each representing a particular combination of measure and specification values, i.e.a specific design object conceivable within the frame of the selected shape. Dimensioning then means selecting exactly one of these objects for construction.



$$H_k = \{ h_{k1}, h_{k2}, \ldots, h_{ks} \}$$

$$H = \{ h^i \mid h^i = (h_1^i, h_2^i, \ldots, h_n^i) \} \supseteq \mathop{\times}_{k=1}^{n} H_k$$

Fig. 1: Design Space

However not every point of the design space is accorded a useful design which fulfils the established minimum requirements. Unfortunately, only in rare special cases can these requirements be expressed in the form of constraints which immediately limit the useful area in the design space. Generally they limit the permissible behaviour of the design object in its application. The characteristics for the behaviour of the design object in the application process we call behaviour-describing variables e_i and we attach each of them to an axis of coordinates in a so called behaviour space E. Constraints then will be represented by surfaces $q_i(e^i) = 0$, which limit the permissible area in the behaviour space.

Now, the behaviour of the design object in its application does not only depend on its shape, on the material from which it is constructed, and on its dimensions, but, not least of all, on extrinsic effects to which it is subjected. We call the characteristics of these effects environment-describing variables w_i, whose values we attach to scales at the axes of coordinates of an environment-describing space W. Each point $w^j = (w_1^j, w_2^j, \ldots)$ in thia space therefore represents a combination of environment effects which the object might be subjected to.

Systematically, each pair of points, one h^i in the design space and one w^j in the environment-describing space, is then mapped into one point e^{ij} in the behaviour-describing space, which can either be situated inside the permissible region or outside of it.

We now want to illustrate the relations of concepts described up to this point by means of an example taken from strutural design. Let us consider the main girder of a steel railway bridge which spans over a medium-wide opening, to be our design object. Then there is one main alternative of shapes: a welded web girder or a truss. In the case of a truss there are additional possibilities for its shape and for the framework pattern. To each of these possibilities another design space has to be attached.

To describe the shape of a web girder, the coordinate axes of the design space have to be labelled with the possible values of variables like: total girder height, thickness of chord, web plate and welding seam, dimensions and positions of stiffeners, steel grade etc. For each shape of a truss and for each framework pattern, the distances of the nodes, the specifications of the rolled profiles of the members, measures of connecting means have to be dimensioned as design variables. In any case we have to consider the specifications of rust prevention as additional design variables.

Environment-describing variables are, in this example, the dead load from the track and from the secondary girders, the live load from traffic and wind, amplitudes of temperature changes as well as characteristics of meteorological and other effects influencing corrosion. In addition to the "external" environment we have to consider the design variables of other members of the structure, which we have previously designed and which have to be compatible with the member under design, as "inner" environment. In this example the inner environment includes the elements of the track and the secondary girders with their connections to the main girder, as well as the bearings of the latter.

The variables which describe the external environment have, in contrast to the design variables, largely stochastic rather than determined values. In the case of live loads and meteorological effects this is immediately clear. Moreover in practical design processes it is usual to consider deterministic m o d e l s of the environment rather than the complex and probabilistic reality. Those deterministic models are used especially for the approval of structural safety. In most countries quasi-deterministic environments of structures have been layed down in technical building codes in the form of design loads and of provisions concerning their simultaneous or alternative consideration. In our example, provisions for railway bridge loads are given for the Federal Republic of Germany by the "Vorschrift für Eisenbahnbrücken und sonstige Ingenieurbauten" (DV 804/1) of the Deutsche Bundesbahn.

From the design variables and the environment-describing variables the designer determines values of the behaviour-describing variables of his design object. In our example these include inner forces, stress and strain due to the load as well as characteristics for maintenace requirements. In the case of determined environmental effects the designer receives, for each designed solution he examines, just one set of behaviour-describing variables. Or, put another way: each solution is made up of one point h^i in the design space and one point w^j in the environment-describing space, both of them having as a common mapping one point e^{ij} in the behaviour-describing space. However, the behaviour description thus obtained is generally not exactly that, which one could observe if it were possible to apply the model environment to the structure. This is because, even in cases as simple as our own, the designer can only determine the behaviour of a further simplified model. To calculate the bearing behaviour of a structure he uses its so-called statical system as his model. Depending on the qualitiy of the model and on that of the algorithm he uses, the behaviour of the object model will correspond more or less closely to that of the real object. The point he has determined in the behaviour-describing space is therefore more or less far removed from that indicating the behaviour of the real object unter the influence of the model environment. Normally he cannot give any exact information on size and direction of this discrepancy. It is usual to choose models which make sure, that the object behaviour will be estimated on the "safe side" but it is impossible to say how far.

When taking into account the influences of a probabilistic environment, one gets not only one point in the environment-describing, space but a "cloud of points". The probability of the appearance of each point in the cloud should be given in this case. Since each pair of points in the design space and the environment-describing space has one mapping point in the behaviour-describing space, in the latter we have a cloud of points too. In our example this situation occurs when we evaluate the behaviour-describing variables of the maintenance requirement. Only stochastic indications can be given about the influences by weather and corroding agents. When making a selection between a truss and a web-girder, the amount of maintenance requirement is relevant since these two differ not only in their different surface areas, but also in the different expenditure of maintenance work per square unit and. more importantly, in the higher risk of corrosion in the edges and corners of the connecting points of a truss.

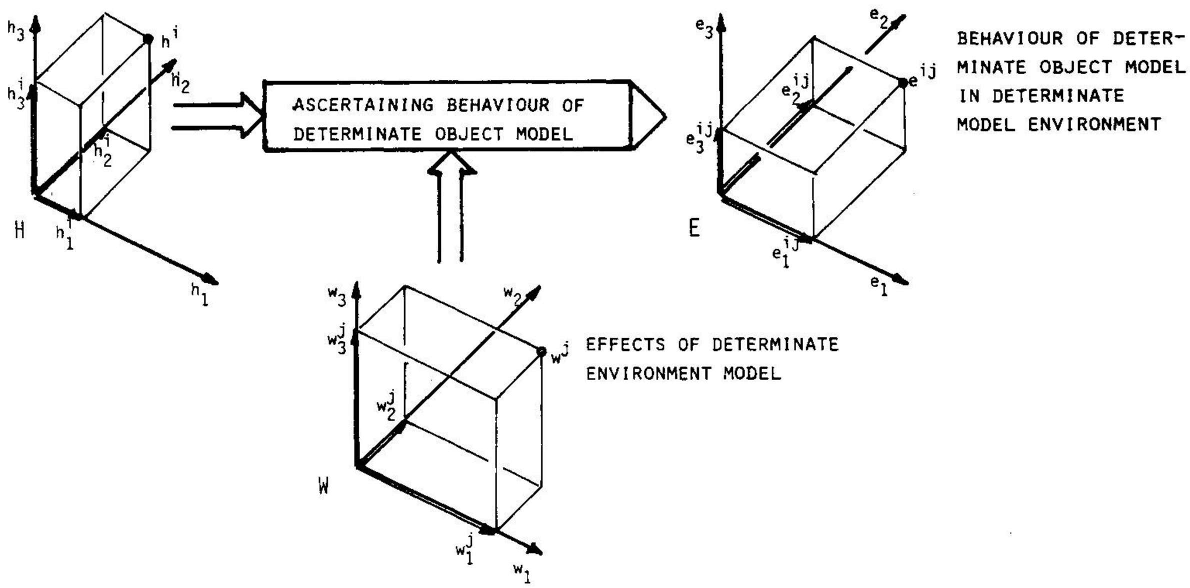


Fig. 2: Ascertaining behaviour of determinate object model in determinate model environment

The idea of mapping into the behaviour describing space in the cases of deterministic and probabilistic environment descriptions, shall be illustrated by fig. 2 and 3 respectively. In both of the two figures isometric representation and three-dimensional examples of design space, environment-and behaviour-describing spaces are used for the sake of clarity. Fig. 2 illustrates the mapping of one pair of points into one behaviour point which is shifted due to the estimating by means of an object model. Fig. 3 on the other hand is meant to show the mapping of the stochastic environment 'point cloud' into behaviour-describing point cloud, which is once again shifted.

For the comparative evaluation of alternative designs we need characteristics of those behaviour-describing variables, the values of which are relevant to evaluation. These we call e v a l u a t i n g v a r i a b l e s. In a realistic evaluating approach more than one of these variables have to be included. Besides the price of the object - if the contractor does the evaluation on his own, the production costs respective - evaluating variables have to be defined,

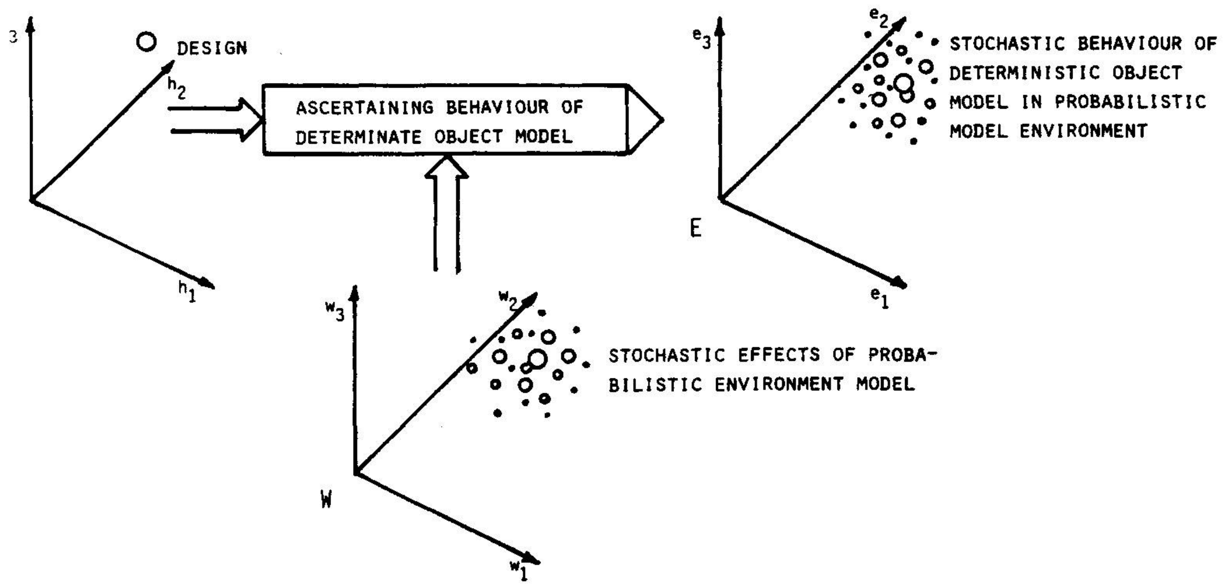


Fig. 3: Ascertaining behaviour of determinate object model in probabilistic model environment

which describe the quality of the object. With constructions the primary function of which is the bearing of load such as the railway bridge in our example, once their reliability in this function is established, mainly secondary characteristics of behaviour may be used as quality describing evaluating variables. This could be, for instance, the volume of noise due to vibrations or the intensity of elastic reactions to impulses.

To compare buildings and other constructions, the employment processes of which are more complex, construction costs and characteristics of operating quality have to be considered as competitive evaluating variables. These include in any case the maintenance and running costs, in buildings often climatic properties of rooms and envelopment, finally aesthetic features and other effects of the construction on its environment. In most cases the values of these different variables cannot be totaled by simple addition, to get a basis of comparison. This cannot be done even with construction costs on the one hand and maintenance and running costs on the other since, in the designing stage, all prices and expenses are stochastic variables. Even if the design is done by the engineering office of a contractor, the construction cost can only be roughly estmated, since local and organizational peculiarities of the construction process cannot be predicted in all details.

If the client himself, a consulting engineer or an architect does the design, they have to take into account the uncertainty of the construction market at the time of placing the orders. Besides that, the maintenance and running costs are affected by other risks as well. The maintenance costs are influenced by the construction's susceptibility to trouble and by the level of repair costs during the life time. The running costs are influenced by price developments in the in the energy and service market. Because of the uncertain development of the operating process these risks do not allow one to summarise expected values or other parameters of the probability distributions of the different price and cost items, if different usable design solutions differ significantly regarding their maintenace and running expenses. As to those evaluation variables which cannot be transformed directly into monetary terms, it is quite clear that it is impossible to summarize them to prices and costs in order to get one single evaluation unit.

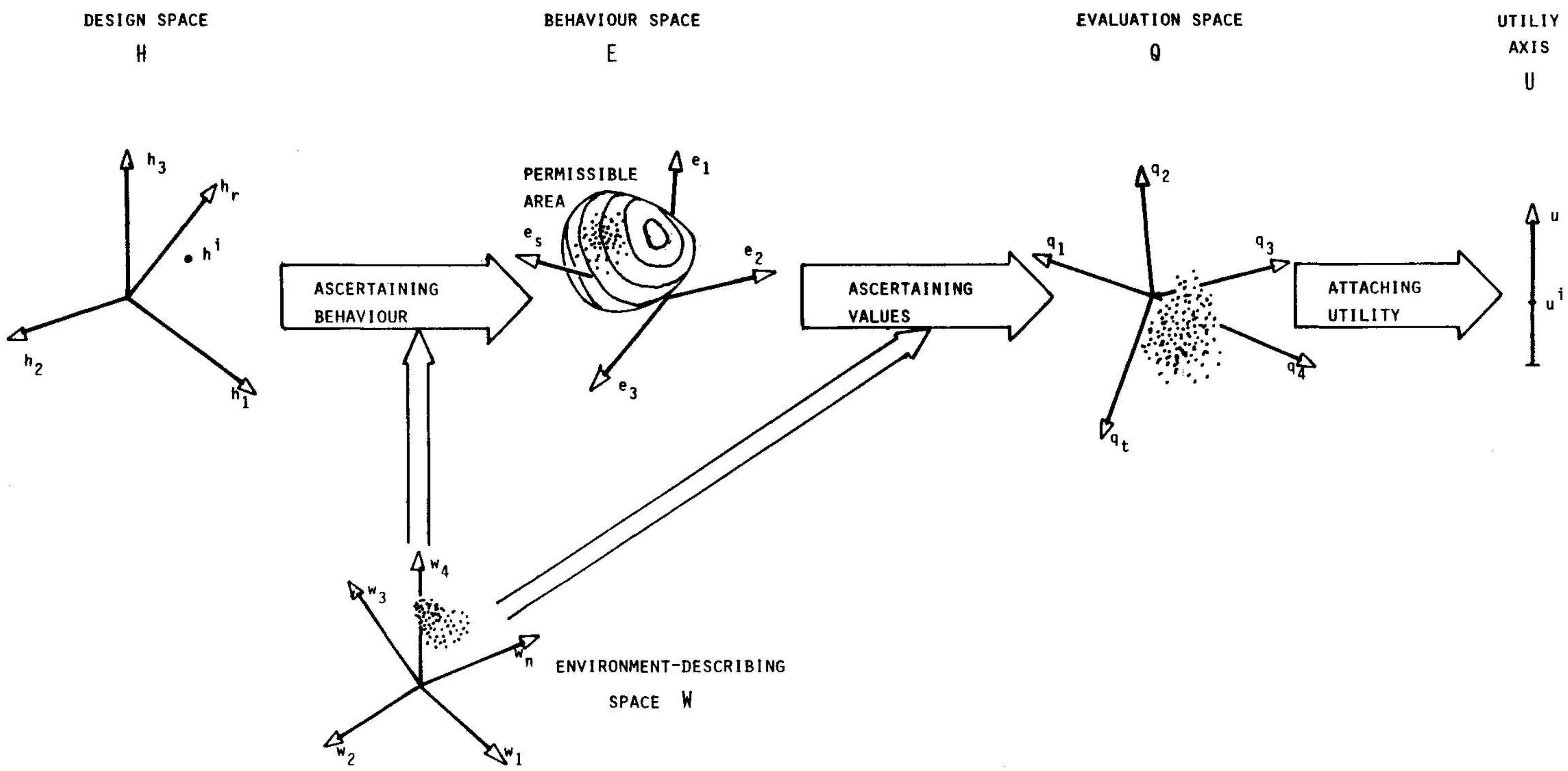


Fig. 4: Synoptical illustration of the design procedure variables' taxonomy

At first we therefore regard the different evaluation variables again as different dimensions of an evaluation space Q. To each design object s one single point $q^s = (q_1^s, q_2^s, ...)$ of this space is attributed, if all evaluation-variables have determined values. If at least one of them has stochastic values, we get again a cloud of points with a probability of its appearance attached to everyone.

The principles of the treatment of the evaluation problem have been prepared in the theory of rational decision-making under risk conditions in connection with the utility theory. The task is to compare a number of spatial probability distributions, i.e. to attribute each of them with a single value of a utility functional $u(q_i, P(q_i))$. This functional should give the highest value to that solution which holds the highest rank in the preference of the deciding subject. This rank depends on the "location" of the point cloud in the evaluation space, as well as on its density distribution. The utility functional can therefore only be formulated if the deciding subject is able to weigh up the evaluation variables against each other and if this subject additionally is willing to make mathematically convertible statements on his risk attitude.

Fig. 4 gives a synopsis of the previously presented taxonomy of design variables inclusing the mapping from the evaluation space to the utility axis.

1.3 Shaping decisions and optimal dimensioning - a pair of dual problems

As we pointed out at the beginning of the previous subchapter and in the railway bridge example, s h a p i n g of a design object means to choose one of several competing sets of design variables -each of which spans one design space - for realization. To select one point in the chosen space - that means to assign a specific value to each design variable - we call d i m e n s i o n i n g. The latter task may be supported by the use of optimization algorithms, especially if we are allowed to ignore the stochastic influences. In this case the utility functional is reduced to a determinate objective function. The problem then is to find an algorithm or a strategie which is suitable to search within the multidimensional design space. This problem is complicated by the fact, that as we already pointed out the constraints in regular cases are given by functions of the behaviour describing variables and cannot easily be mapped "back" to the design space. The mathematical definition of an optimization problem always presumes the constraints to be functions of the decision variables themselves. In the already mentioned second contribution to this symposium we describe a strategy which is suitable to dimension the members of a certain class of building systems optimally.

Neglecting the stochastic aspects will never be suitable during the shaping phase which precedes the dimensioning, especially as long as the whole design object or large parts of it are subject of the work. At this state the consequences of a shaping decision can only be roughly estimated. Thus, if we want to rationalize the evaluation and selection procedure we urgently need tools which enable us to cope with uncertainties.

We can say, that shaping decisions and optimal dimensioning are dual problems, not in a strict mathematical sense, but regarding the conditions under which these problems have to be solved. When we have to select one of different shapes we must not go into the quantitative details of the object's properties as long as we are sure that there is at least one feasible point in the respective design space. But we need a basis to estimate parameters of the relevant evaluation variables' probability distributions attached to that space. In other words we have to concentrate on the rightmost of the "mappings" shown in fig. 4. When on the other hand searching for that point in a design space which delivers the highest value of the utility function we must be able to establish an appropriate quantitative model of the objects behaviour. If possible we try to divide the object into small parts - to decompose the optimization problem as we say. Thus we can hope that in most cases only one of the evaluation variables depend on variations of the regarded part's design variables and that we are prepared to establish a determinate objective function describing this interdependence. So we concentrate on the mappings shown in the left part of fig.4.

2. A FEW BASIC CONCEPTS OF UTILIY THEORY AND DECISION ANALYSIS

In this chapter we just report some assumptions, ideas and proposals, given by distinguishad authors in the field of decision making. Especially we use the concepts of Ronald A. Howard and the school of thought at Stanford Research Institute [4, 5]. An excellent tutorial is given by John W. North in [6].

Usually there is no -or only an unsufficient- data-base to derive a probability distribution of evaluating variables. The importance of uncertainty is revealed when we realize that decisions in situations where there is no random element can usually be made with little difficulty. Only when we are uncertain about which of a number of possible outcomes will occur do we find ourselves with a real decision problem.

One of the key-factors in the decision making process is the establishment of the value to be attached to each of the various outcomes of a decision. When faced with two completely specified future sequences of profits, costs or other consequences, the decision maker must be able to say which he prefers and to state his preference in quantity terms. In business problems the desirability of any outcome will usually be measured in terms of money, either directly in costs or implicitly assigned as valuing costumer's goodwill and employee's satisfaction.

The mathematical theory concerned with assessment of value is called the utility theory. Although this theory is not so widely known as probability theory, it is based on probability theory and on some additional axioms. The first of these axioms, for example, is the axiom of transitivity. This axiom states that if the decision maker prefers outcome A to outcome B and if he prefers outcome B to outcome C, then he must prefer outcome A to outcome C. The theory will not be useful to a person who does not subscribe to this tenet.

Since the domaine of utility theory is evaluing decision alternatives with uncertain outcomes, most of the axioms deal with the handling of probability distributions of outcomes. Usually propositions with uncertain outcomes are called "lotteries". A user of decision analysis must be willing to compare different lotteries with each other. Furthermore he has to assign to each lottery his personal "certain equivalent". This is the value of a certain outcome, which he regards equivalent to the participation in the lottery. The possible outcomes of a lottery are called "prices".

We shall soon show that an individual whose preferences satisfy the utility axioms may encode those preferences in a u t i l i t y f u n c t i o n that assigns a utility number to every price. This utility function has two important properties:

- The utility of any lottery is the expected utility of its prices.
- If the decision maker prefers one lottery to another then it must have the higher utility.

A so called Bernoulli Utility Function, which realizes these properties enables the decision maker to express his risk preferences exactly and logically. We can think of the utility function as a "preference thermometer". The utility numbers have no meaning in themselves; they serve only to compare the desirability of of lotteries. Because of the linear properties of expectation, we can multiply the utility function by any psoitive number and add constants to all utilities without changing the preference they express. If all the prices are measured in terms of a commodity, then the utility function can be expressed by a curve that assigns a utility number to every value of the commodity. If, furthermore, this commodity is such that more (or less) is always better, for example money (or costs) then the utility curve will be monotonically increasing.

How can an individual establish a utility curve of the Bernoulli type for himself or for his organisation? This we shall show by an example.

Let us suppose that we wish to assess some individuals utility curve for amounts of the order of less than hundred DM. We might begin by assigning the utility 0 to the amount zero and the utility 1 to the amount of 100 DM,

$$u(0) = 0 \; ; \; u(100) = 1$$

We may now use the so called equiprobable lottery methode and investigate the shape of the curve within the (0, 100) region. We could ask him : "What is your certain equivalent to an equiprobable lottery on zero and 100 DM ?" and he might answer: "25 DM". This causes

$$u(25) = 1/2\ u(100) + 1/2\ u(50)$$
$$u(25) = 0.5$$

Next we ask him for his certain equivalent for an equiprobable lottery on 0 and his answer to the first question, 25 DM. If he replies, "10 DM" then there follows

$$u(10) = 1/2\ u(25) + 1/2\ u(0)$$
$$u(10) = 0.125$$

At last we ask him for his certain equivalent to an equiprobable lottery on 25 DM (his first answer) and 100 DM. He then might set his certain equivalent at 40 DM and we state

$$u(40) = 1/2\ u(100) + 1/2\ u(25)$$
$$u(40) = 0.75$$

These figures will allow us to determine a rough path of the curve. It is plotted in figure 5, curve 1 . We see that this utility curve is generally concave downward, indicating that the individual is risk averse (in this region of values). Curve 2 and 3 in figure 5 show the utility curves of a risk indifferent and a risk friendly decision maker respective. With the described method we also also will able to value different lotteries. For example:

$$L1 : (0.3,\ 80\ DM;\ 0.2,\ 70\ DM;\ 0.5,\ 0\ DM)$$
$$L2 : (0.1,\ 90\ DM;\ 0.3,\ 50\ DM;\ 0.6,\ 20\ DM)$$

describe two lotteries, the first of which offers 80 DM with a probability of .3 70 DM with a probability of .2 und nothing with a probability of .5, the second one may now be interpreted by the reader. In case that the decision maker is risk indifferent the utilities are equal to the expected values:

$$u(L1) = 0.3 \times 80 + 0.2 \times 70 + 0.5 \times 0 = 38\ DM$$
$$u(L2) = 0.1 \times 90 + 0.3 \times 50 + 0.6 \times 20 = 36\ DM$$

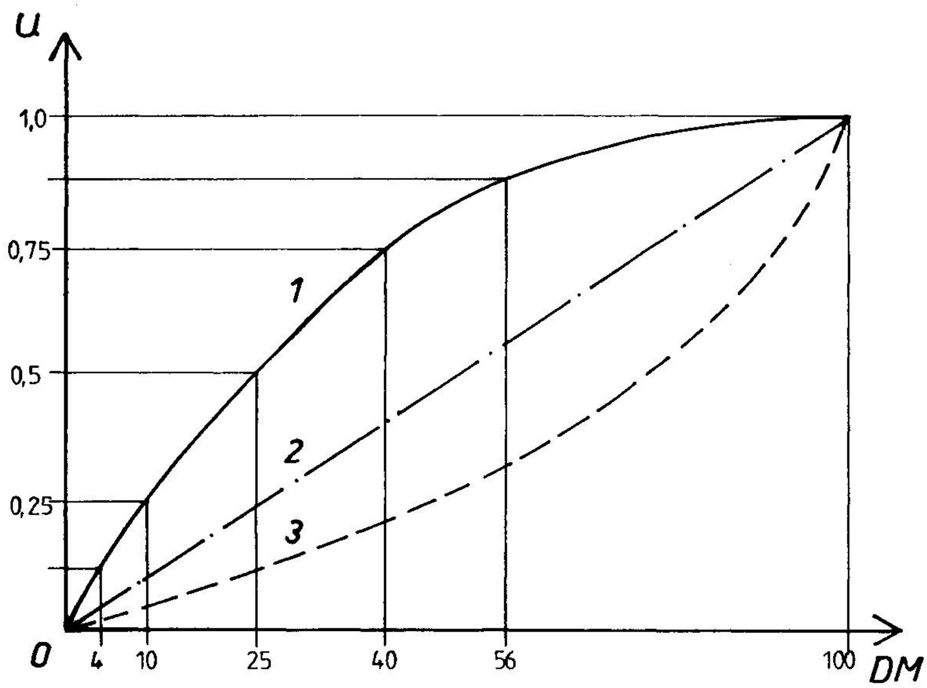


Fig. 5: Examples of utility curves

and consequently he would prefer the first one.Should he not be indifferent, but risk averse according to curve 1 in fig. 5, then his preferences follow from the different utility values of the prices:

u(80 DM) = 0.92; u(70 DM) = 0.875; u(0 DM) = 0
u(90 DM) = 0.96; u(50 DM) = 0.79 ; u(20 DM) = 0.39

Hence

u(L1)= 0.3 x 0.92 + 0.2 x 0.875 + 0.5 x 0 = 0.44
u(L2)= 0.1 x 0.96 + 0.3 x 0.79 + 0.6 x 0.39 = 0.55

and now the decision maker prefers L2 to L1.

An objection to the demonstrated method might be, that there is a significant difference between answering questions on certain equivalents and making momentous business decisions. But the method will have an important learning effect. At least it may show the sensitivity of a decision to the risk attidude of the decision maker, when it will be applied repeatedly with changing utility curves. For this purpose a quadratic interpolation between 3 values as demonstrated in the examples of chapter 5 might be a sufficient approximation of utility curves.

It shall be emphasized that it is principally possible to establish a utility function concernig other continuous varying measures of evaluation variables' outcomes, e.g load bearing reserves of a structure. By this means we can produce a certain equivalent of each evaluation variable in a multi dimensional evaluation space and thus reduce the "point cloud", attached to each shape of a design object to one representative point. But we have to admit that this reduction implies several problems concerning the question in what cases a spatial probability distribution may be represented by the union of its axial distributions. Here is not the place to deal with these questions and therefor we shall reduce the following considerations to the case of one single evaluation variable, which in most cases will be the price or the production costs of the object.

3. ESTIMATING THE RISK IN EVALUATING VARIABLES BY BETA DISTRIBUTIONS

Utility function and decision analysis can only be employed successfully to shaping decision problems if we have at hand adequate probability distributions of evaluating variables. In most practical cases data bases from which those distributions could be derived are not yet available.We therefor have to estimate the outcome of the evaluating variables like we are used to do all the time, whenever we make a decision.

But instead of estimating just one value of every variable which we could assume to be a determined one in a deterministic evaluation model we have to estimate as much parameters as necessary to define a probability distribution of the type we want to use. In case we want to describe the possible outcome of a variable by a continuous symmetric normal distribution we need two establish two parameters, e.g. the mean and the variance. But this will not be easy to do if we are not very experienced in the matter of statistical estimation.

Perhaps a designer will rather be able to estimate a lower and an upper limit as well as the most probable value of an evaluating variable. In this case he might establish the so called ß-distribution, which is well known from PERT (program evaluation and revue technique, a special method of network planning technique) [7] . This distribution has several important advantages for practical purposes as we are going to show.

We call the three previously mentioned values of an evaluating variable

q pes - the most unfavourable value

q med - the most probable value

q opt - the most favourable value

To the ß-distribution a density function is attached which is defined by

$$f(q) = \frac{1}{F} (q - q\ pes)^{\alpha} (q\ opt - q)^{\gamma}$$

within the range

$$q\ pes < q < q\ opt$$

This function fulfils the presuppositions of the probability arithmetic with

$$F = \int_{q\ pes}^{q\ opt} (q - q\ pes)^{\alpha} (q\ opt - q)^{\gamma}\, dq$$

Furthermore

in case $\alpha \neq 0$ and $\gamma \neq 0$

we have $f(q\ pes) = f(q\ opt) = 0$

and in case

$$\frac{\alpha}{\alpha + \gamma} = \frac{(q\ med - q\ pes)}{(q\ opt - q\ pes)} = \frac{\delta q}{\Delta q} \qquad \frac{df}{dq}\Big|_{q\ med} = 0$$

We may use then $\alpha + \gamma$ as a parameter to vary the "slimness" of the density curve.

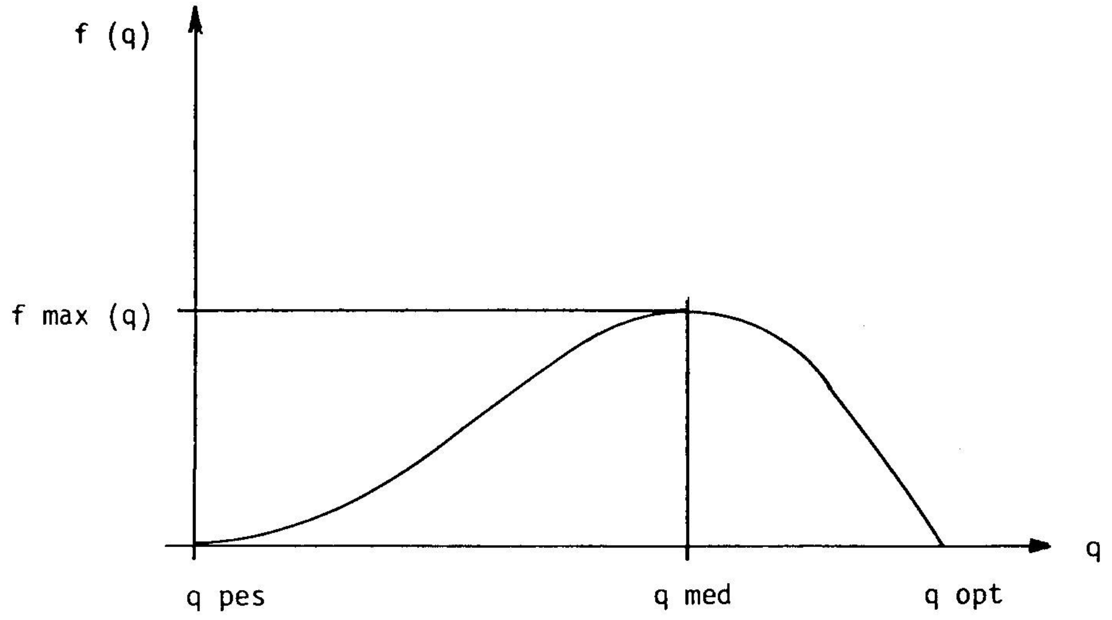


Fig. 6: A typical density curve of a ß-distribution

Fig. 6 shows a typical image of a density function of that type. For practical applications the facits interesting, that the expected value of such a distribution may easily be calculated by

$$\frac{q\ exp - q\ pess}{\Delta q} = \frac{\alpha + 1}{\alpha + \gamma + 2}$$

From the point of view of utility theory now such a density funtion attached to the values of an evaluating variable represents a lottery with a continuous spectrum of prices. Hence its certain equivalent may be obtained by integrating the product of the density ordinates and the respective utility ordinates

$$U(f(q)) = \int_{q\ pes}^{q\ opt} f(q)\ u(q)\ dq$$

With this type of calculation structural engenineers are quite familiar. It is very easy to write a small computer programm which evaluates a utility function, a density functions of the ß-type, multiplies the respective values and integrates numerically over the range from q pes to q opt.

This can be done with the of the evaluating variables' density functions of all the competing shapes of a design object, using a utility function, which attaches "zero" to the most unfavourable of all pessimistic and "one" to the most favourable of all optimistic outcome estimations. Figure 7 gives a flow diagram which orders the designer's and the computer's actions together.

Obviously this procedure will not bring additional information in cases where all of the three estimated values of one distribution are better than the respective ones of an other. Every risk attitude will come up with the first mentioned solution having a higher rank in the preference order than the second one. But there are many practical cases where the most probable values of several shapes are equal or at least adjoining. If there are larger differences in the optimistic and/or pessimistic estimations, these will be the cases in which the proposed method will be most helpful. Two examples will show similar cases and may illustrate the advantages of the procedure.

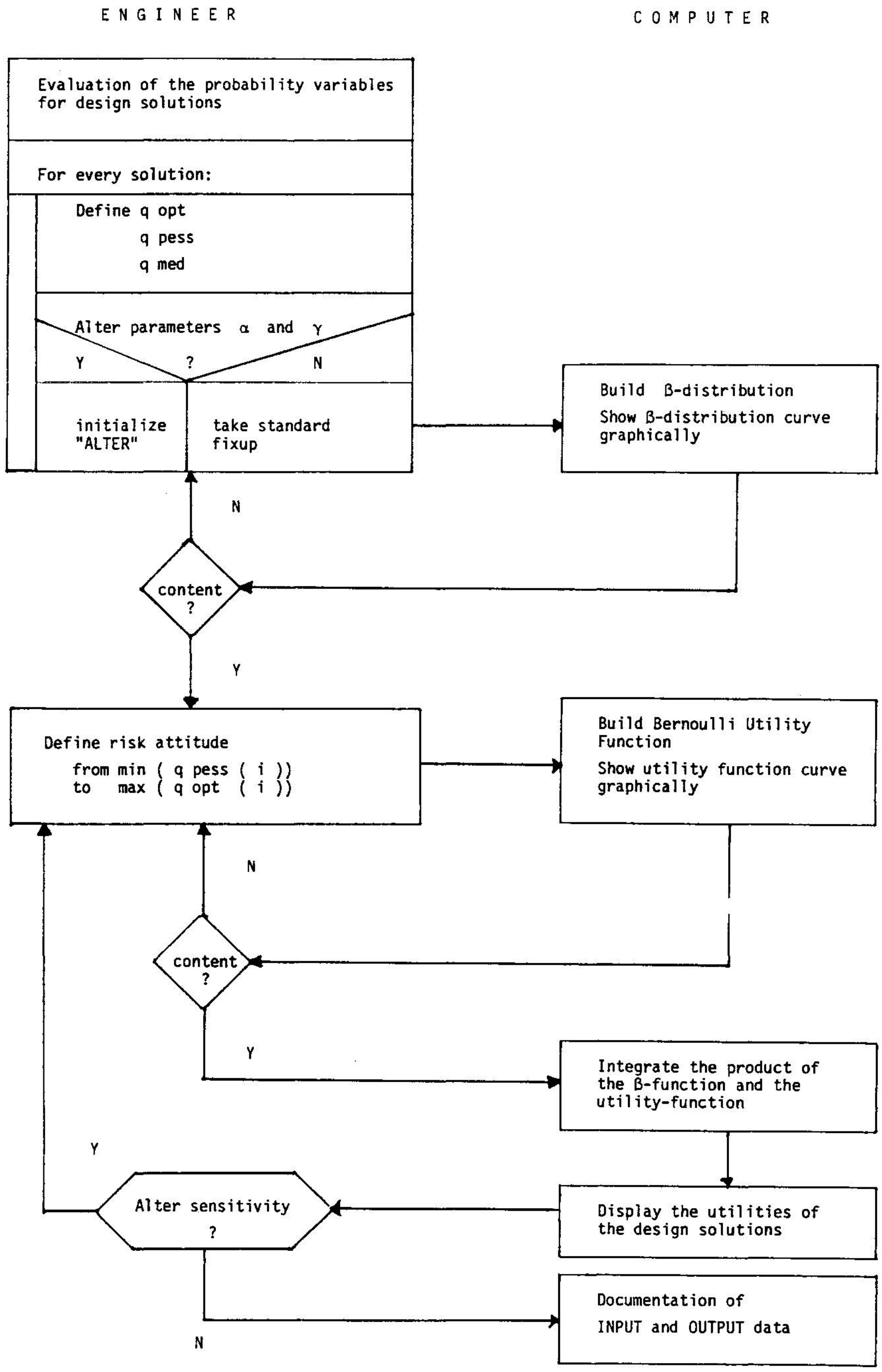


Fig. 7: Flowchart of an interactive process to value design solutions

4. TWO EXAMPLES

4.1 Comparing two concrete bridge structures

During the design phase of a bridge structure there shall be decided whether the cross section of the prestressed main girder shall have the form of a hollow beam like figure 8.1 or of T-beams like figure 8.2. Due to the girder's span the estimated most probable values of the price are equal.

Fig. 8.1: Hollow beam cross section Fig. 8.2: T-beam cross section of a bridge girder

q pes = -1.700 DM/m2
q med = -1.300 DM/M2
q opt = -1.100 DM/m2

q pes = -1.500 DM/m2 carriage way area
q med = -1.300 DM/m2
q opt = -1.200 DM/m2

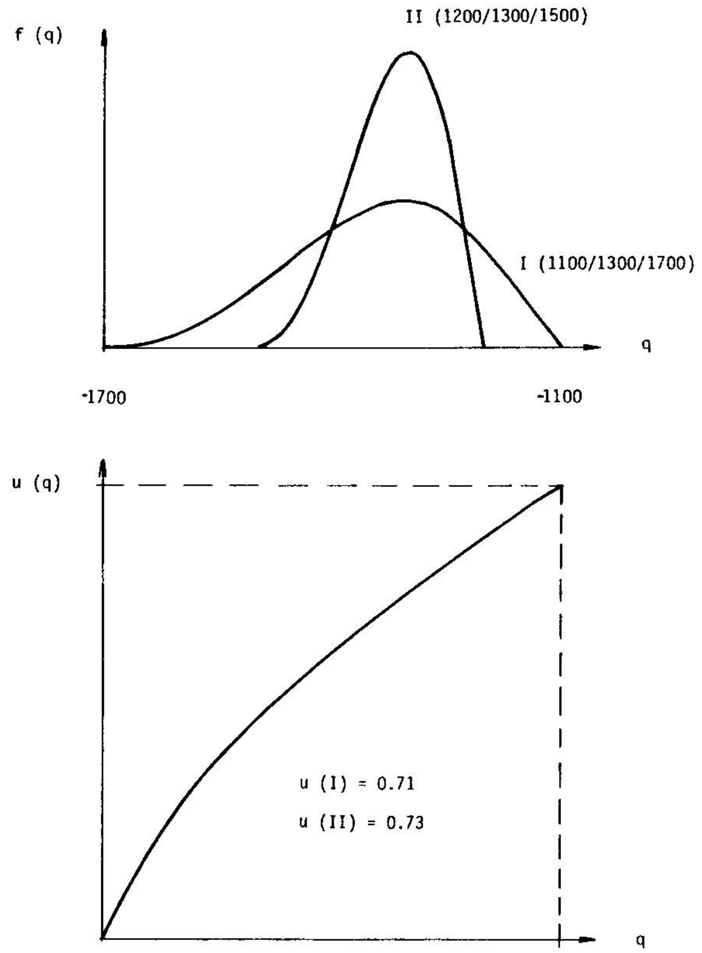


Fig. 8.3: Density and utility curves to the bridge example

We assume, that - like this will be the case in most real situations - the decision maker is risk averse. The measurement of his risk aversion is that he wants to reduce the price of a equiprobable lottery by 15% of the total difference against the mean, as shown in the utility curve of fig. 8.3, which is drawn by a quadratic interpolation between the points (-1.700;0), (-1.550;0.5) and (-1.100;1.0).

A person or institution with the established risk attitude should prefer the T-beam solution, since the integration delivers

u(1) = 0.71 u(2) = 0,73

4.2 Comparing two shapes of a building structure

Let us assume that we have to decide whether the framed structure of a multi story building should be assembled from prefabricated elements or cast in situ. The most probable values of the prices shall once again be estimated to be equal. But the difference between the pessimistic and the optimistic outcome estimation may be much higher with the prefabricated structure than with the other one. So we get for the structure

prefabricated	cast in situ	
q pes = -200 DM/m3	q pes = -170 DM/m3	(price per unit
q med = -150 DM/m3	q med = -150 DM/m3	cubic capacity
q opt = -100 DM/m3	q opt = -130 DM/m3	carcase only)

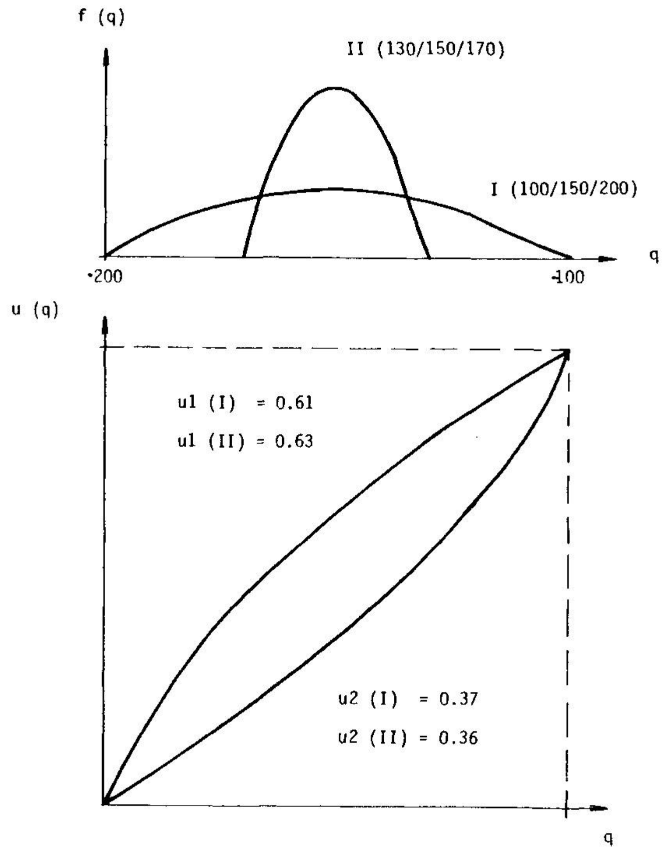


Fig. 9: Density and utility curves to the building example

Both these distributions are obviously symmetric and have equal means. Hence the decision depends on the designer's (or employer's) risk attitude. If he will be risk averse as represented by the upper utility curve in fig. 9 then he will decide in favor of casting in situ. Should he be willing to take a risk - hoping actually to come out with a lower price - then he might prefer the prefabricated solution.

The calculated utility values are

u(pref,av) = 0.61 u(situ,av) = 0.63
u(pref,fr) = 0.37 u(situ,fr) = 0.36

5. CONCLUSION

This contribution should emphasize to the fact, that computers might assist the (structural) designing engineer far more than by analysing the object's properties and by drawing some plans. Their efficiency allows him to investigate and compare a greater number of variants and therefor he also needs assistance with the selection and optimization procedure. One of the two main application problems of the previously described methods, the lack of price and cost data may be solved by computer assistance too. It will be possible to assemble those data in data bases and to maintaine these bases by data base management software. And to solve the second one of the application problems, computers may contribute by a "training service": By frequently repeated, controlled attempts designers and employers can learn to express their risk attitude properly in terms of their certain equivalent.

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Computer-Based Systems for the Assessment of Structural Damage

Système informatisé d'estimation des dommages des constructions

Computer-System für die Einschätzung von Bauschäden

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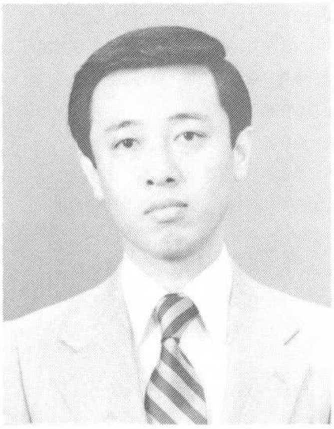

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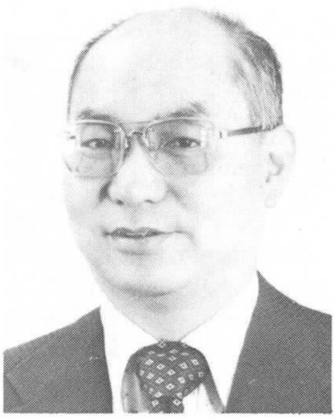

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SUMMARY
To solve the problem of assessment of structural damage, the approach of production system is used to decompose the complex problem into a number of simpler sub-problems. These sub-problems are fitted to knowledge units of human experts. A preliminary version of a program called «SPERRIL-I» is introduced herein to illustrate the feasibility of systematic computer-based damage assessment systems.

RESUME
L'évaluation des dommages d'une construction passe par une décomposition du problème, dans toute sa complexité, en sous-problèmes plus simples, selon l'approche des systèmes de production. Les sous-problèmes doivent correspondre à des domaines de connaissances et d'expérience bien délimités. La version préliminaire du programme «SPERRIL-I» est décrite afin d'illustrer la faisabilité d'un système d'évaluation faisant un usage systématique de l'ordinateur.

ZUSAMMENFASSUNG
Um das Problem der Einschätzung von Bauwerkschäden zu lösen, wird das komplexe Problem in eine Anzahl von Teilproblemen unterteilt. Diese Teilprobleme sind dem Wissensumfang menschlicher Experten angepasst. Eine vorläufige Version des Programms «SPERRIL-I» wird vorgestellt um die Durchführbarkeit eines computerunterstützten Systems für die Einschätzung von Bauwerkschäden zu illustrieren.

1. INTRODUCTION

One of the important problems in structural engineering is to decide whether and how a given structure should be repaired. To assist structural engineers in making such decisions, it is desirable to develop more rational and computer-based systems for the damage assessment of existing structures. The state-of-the-art of this subject matter was reviewed recently [1].

In this paper, several methods including those of Wiggins and Moran [2] Culver et al [3], Bresler et al [4], and Ishizuka et al [5] are critically examined and reviewed. Writers believe that all these methods are based on engineering judgement and professional experience. The correlation and calibration of these and other methods are yet to be performed.

2. METHOD OF BALANCED RISK [2]

In 1971, Wiggins and Moran developed a procedure for grading existing buildings in Long Beach, California. A total of up to 180 points is assigned to each structure according to the evaluation of the following five items:

- (a) Framing system and/or walls (0, 20, 40 points) - A well-designed reinforced concrete or steel building less than three stories in height is assigned a zero-value. On the other hand, an unreinforced masonry filler and bearing walls with poor quality mortar is assigned a value of 40 points.
- (b) Diaphragm and/or Bracing System (0, 10, 20 points) - As an example, zero values correspond to well-anchored reinforced slabs and fills. On the other hand, incomplete or inadequate bracing systems correspond to the high 20 points on the scale.
- (c) Partitions (0, 10, 20 points) - Those partitions with many wood or metal stud bearings rate zero points. On the other hand, unreinforced masonry partitions with poor mortar will draw 20 points.
- (d) Special Hazards (0, 5, 10, 15, 20, 35, 50 points) - The high hazards include the presence of non-bearing, unreinforced masonry walls, parapet walls, or appendages.
- (e) Physical Condition (0, 10, 15, 20, 35, 50 points) - The high hazards include serious bowing or leaning, sign of incipient structural failure, serious deterioration of structural materials, and other serious unrepaired earthquake damage.

For each building thus inspected, all these five numbers are added. Rehabilitation is not required if the sum is less than 50 points (low hazard). Some strengthening is required if the sum is between 51 and 100 points (intermediate hazard). Demolition or major strengthening is necessary when the sum exceeds 100 points (high hazard).

Detailed guidelines are given for the assignment of numbers in each category. Therefore, this method is relatively simple to use even for inspectors who are not trained as engineers. However, it is difficult to develop such a simple procedure to include all special cases. Moreover, the demarcation between low, intermediate, and high hazards is rather arbitrary for these verbal terms which cannot be clearly defined.

3. FIELD EVALUATION METHOD [3]

In 1975, Culver et al [3] proposed the field evaluation method (FEM) which is applicable even when building plans are unavailable. A rating of 1 through 4 is assigned for each (a) general rating, GR, for grading the materials of the frame; (b) structural system rating, s, for combining ratings of connections, roofs, and floors, etc.; and (c) Modified Marcalli Intensity I. Then a composite rating, CR, is computed as follows:

$$CR = \frac{GR + 2s}{3I} \qquad (1)$$

If CR<1.0; the building is said to be in good condition, if $1.0 \leq CR \leq 1.4$; it is in fair condition, if $1.4 \leq CR \leq 2.0$; it is in poor condition, if CR>2.0; it is in very poor condition.

In addition, a more detailed methodology was also presented for survey and evaluation of existing buildings to determine the risk to life safety under natural hazard conditions and estimate the amount of expected damage. There are four major parts in this report as follows:

- (a) generation of site loads,
- (b) generation of a structural model,
- (c) computation of response, drift and ductility, and
- (d) assessment of damage.

The damage on i^{th} story, D_i, resulting from extreme natural environments is expressed in percent of total damage as follows:

- $$\mu_i = \frac{\Delta_i}{(\Delta_y)_i}, \text{ and} \tag{2}$$

- $$D_i\% = 100 \times F(\mu_i) \tag{3}$$

where $(\Delta_y)_i$ = user specified interstory drift to yield of i^{th} story.

- μ_i, Δ_i = calculated interstory ductility and drift of i^{th} story, respectively, and
- $F(\mu_i)$ = distribution function of ductility to yield of i^{th} story.

The damage is classified into three categories: structural, nonstructural and glass. It is further subdivided into frame, walls and diaphragms in the case of structural damage.

In this study, a simple method as well as a more elaborate method are proposed. However, even the more elaborate method cannot take into account all the complicated behavior of complex structures. Moreover, there exists a lack of calibration of these methods against any standard case studies.

4. STRUCTURAL AND FIRE EVALUATION MODEL [4]

In 1980, Bresler et al described their structural and fire evaluation model (SAFEM), which was developed to provide a broad overview of potential safety problems for more than 10,000 buildings for a governmental agency in the States. A building can be classified into (a) "green" requiring only routine scrutiny, (b) "yellow" requiring some attention, and (c) "red" requiring immediate attention and improvement. Authors emphatically stated that "SAFEM is not a substitute for an engineering analysis, but it directs attention to buildings which require engineering analysis on a priority basis".

The procedure consists of (a) collection of such data as building size, cost, number of occupants, address, and predetermined exposure to natural hazards; (b) ranking buildings on the basis of priorities; (c) choosing buildings which should undergo field surveys; (d) performing field surveys and recording survey results in the computer file; (e) re-ranking buildings on the basis of priorities and requesting engineering studies for buildings with the largest potential problems, (f) performing engineering studies and producing the final priority rankings, and (g) allocating funds for upgrading these structures following these priorities. A detailed computer program is developed on the basis of professional experience to combine numbers ranging from 0 to 9 for hazards (geophysical, intrinsic, and local), exposure, and vulnerability. The SAFEM profiles include one each on fire, structural, and miscellaneous (glass safety, cladding failure, electrical system, elevator system, etc.)

Writers are very much impressed by the broad scope and detailed considerations of this program. However, it is difficult to follow how the computer program is developed because of the many subjective inputs involved herein.

5. SPERIL-I [5]

Recently, Ishizuka et al suggested a rule-based damage assessment system called SPERIL version I. Although (a) the current performance of SPERIL has not yet been examined sufficiently for practical applications and (b) the implemented rules are expected to be updated with more accurate and more specific rules, it can be said that this first version demonstrates the feasibility of a systematic approach for the computer-based damage assessment system.

Efficient knowledge utilization of human experts is the most important issue in an expert system in which artificial intelligence techniques are applied to solve complex problems in the real world. The expert system basically consists of a knowledge base and an inference machine. A knowledge base is a storage in a computer, in which useful knowledge is stored in a stylized form suitable for the inference. An inference machine is a control process which deduces an answer from a given problem situation by using the knowledge stored in the knowledge base. Fig. 1 shows a simplified diagram of the expert system.

In the inference process, questions are initiated to obtain additional information in case of need. Those procedures are analogous to, for example, medical diagnosis, in which a physician draws a conclusion by integrating many observed symptoms and his/her knowledge. Expert systems for medical consultations are described, for example, in [6-9].

In a complex problem, it is an efficient way to express relevant knowledge as a collection of many small pieces of knowledge. The problem reduction method [10,11] can be used as a guideline to decompose a problem into simpler subproblems, which are further decomposed into even simpler subproblems. Hence the whole problem can be described hierarchically, and it has its own final goal to be achieved. Likewise each subproblem has its own subgoal to be achieved from available information.

The production system approach [12,13] provides a convenient way to express a piece of knowledge for the inference process which infers a higher subgoal from observed evidences and lower subgoals. In the production system, a piece of knowledge is written as a production rule in the following basic form;

- Rule: IF X,
- THEN H,

where IF and THEN clauses are called premise (condition) and action (conclusion), respectively. The function of the rule is that if the premise is satisfied, then the updating action of the subgoal state takes place.

In the real-world decision-making problems, situations are not always clear and there exist two kinds of uncertainties. One is the uncertainty associated with the observed data or evidences; the other one is the uncertainty associated with the expressed rules. Consequently, the inference procedure which can deal with uncertainties in an effective manner becomes necessary. In addition to AND/OR relations, combination relation denoted by COMB becomes important in the decision-making problems with uncertainties. The combination relation refers to such a situation that the goal is supported separately from more than two evidences. As a result, the problem can be described by AND/OR/COMB graph as shown in Fig. 2. Corresponding rules to Fig. 2 can be represented as listed in Table 1 where C_1, C_2,.... are certainty measures between 0 and 1.

Inference for AND/OR relations is rather simple; min and max operations on a certainty measure can be adopted, respectively. Therefore, inference for COMB relation is required to be defined along with the certainty measure.

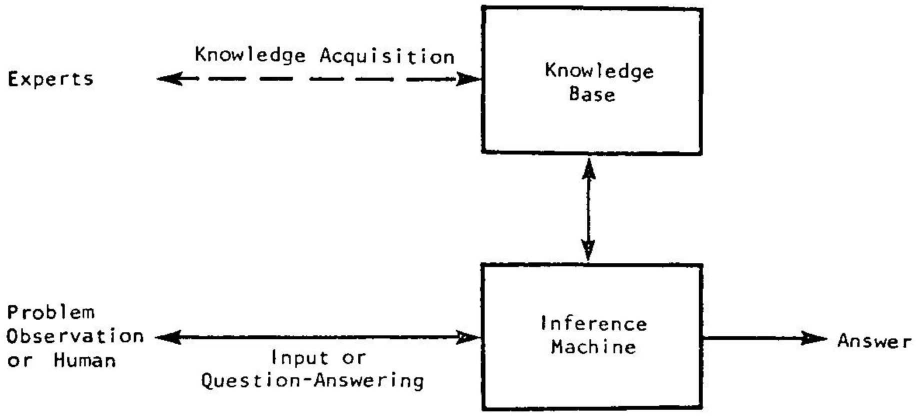

Fig. 1 Expert system.

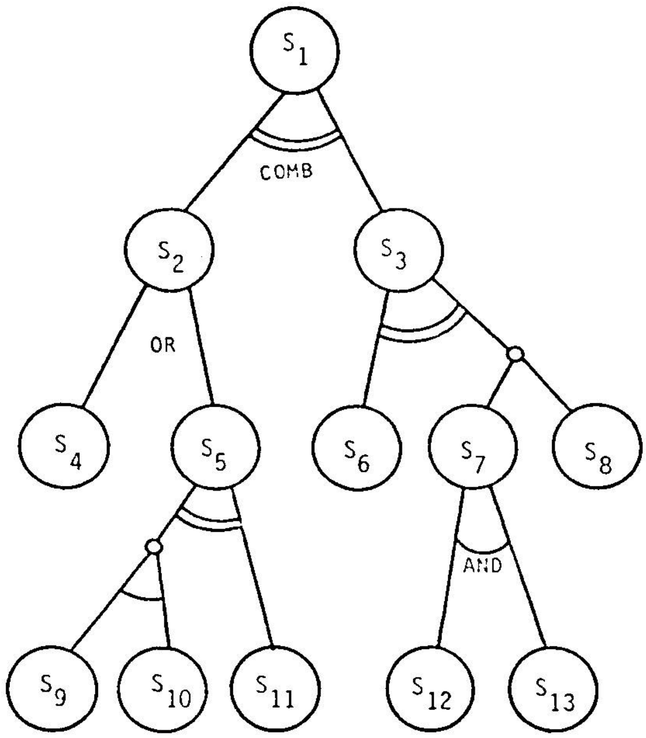

Fig. 2 An example of AND/OR/COMB graph for a problem with uncertainty.

Table 1. Rule representation for Fig. 2

Rule	IF: S_2
	THEN: S_1 with C_1
Rule	IF: S_3
	THEN: S_1 with C_2
Rule	IF: S_4 and S_5
	THEN: S_2 with C_3
Rule	IF: S_6
	THEN: S_3 with C_4
Rule	IF: S_7 or S_8
	THEN: S_3 with C_5
Rule	IF: S_9 and S_{10}
	THEN: S_5 with C_6
Rule	IF: S_{11}
	THEN: S_5 with C_7
Rule	IF: S_{12} and S_{13}
	THEN: S_7 with C_8

Table 2 Example of rules in SPERIL

```
Rule0201
      IF:MAT is   r/c
THEN IF:STI is   dest
   THEN:GLO dest 0.6
ELSE IF:STI is   seve
   THEN:GLO seve 0.6
ELSE IF:STI is   mode
   THEN:GLO mode 0.6
ELSE IF:STI is   slig
   THEN:GLO slig 0.6
ESLE IF:STI is   no
   THEN:GLO no   0.6
   ELSE:GLO uk

Rule0501
      IF:MAT is   r/c
THEN IF:ISD <=   -8.9
   THEN:DRI uk   1
ELSE IF:ISD <=   0.4
   THEN:DRI no   0.9
ELSE IF:ISD <=   0.8
   THEN:DRI slig 0.9
ELSE IF:ISD <=   1.3
   THEN:DRI mode 0.9
ELSE IF:ISD <=   2.0
   THEN:DRI seve 0.9
ELSE IF:ISD >    2.0
   THEN:DRI dest 0.9
   ELSE:DRI uk

Rule0901
      IF:MAT is   steel
THEN IF:S01 is   yes   (partial collaps)
   THEN:VST dest 1
ELSE IF:S02 is   yes   (buckling of column)
   THEN:VST dest 0.5
    and:VST seve 0.5
ESLE IF:S03 is   yes   (buckling of girder/beam)
     or:S04 is   yes   (buckling of diagnal bracing)
     or:S05 is   yes   (deformation or loosing of joint)
   THEN:VST seve 0.9
ELSE IF:S06 is   yes   (spalling/crack on shear wall)
   THEN:VST mode 0.8
ELSE IF:S07 is   yes   (spalling/crack on exteria/interia wall)
     or:S03 is   yes   (spalling/crack on floor)
   THEN:VST mode 0.5
    and:VST slig 0.5
ELSE IF:S01 is   no
    and:S02 is   no
    and:S03 is   no
    and:S04 is   no
    and:S05 is   no
    and:S06 is   no
    and:S07 is   no
    and:S08 is   no
   THEN:VST no   1
   ELSE:VST uk
```

Abbreviations

dest	destructive
seve	severe
mode	moderate
slig	slight
no	no
uk	unknown
r/c	reinforced concrete
GLO	damage of global nature
DRI	damage due to drifting
STI	damage of stiffness
VST	visual damage of structural member
MAT	material of structure
ISD	interstory drift
S01 ⋮ S09	check items of visual structural damage for steel

An intuitive combining function is employed in MYCIN [6,14] for this inference purpose. Duda, Hart and Nilsson [15] proposed an inference method for the case where subjective Bayesian probability is used as a certainty measure. The combining function for Bayesian and modified Bayesian probabilities has been reported by the authors [16]. The usefulness of Dempster & Shafer's probability [17,18] is recently recognized by the authors and others for the handling of ignorance in expert system approach. Dempster & Shafer's theory, which is adopted in SPERIL version-I, enables us to deal with uncertain information in an effective and rigorous manner. As an alternative of the statistical inference methods which often requires idealized conditions such as independency of evidences, the inference procedure based on fuzzy logic [19,20] becomes effective.

Once the inference procedure for the COMB relation is defined as well as that for AND/OR relations, the certainty measure can propagate through the hierarchical inference network. Eventually, we can obtain the degree of certainty of the hypothesis in the final goal, which will provide a reasonable answer for decision-making purpose.

SPERIL is a rule-based damage assessment system of existing structures particularly subjected to earthquake excitation. In SPERIL version-I, separate evidential observations are integrated on the basis of the extended Dempster & Shafer's theory for fuzzy subsets. Useful information for the damage assessment comes mainly from the following two sources; (i) the visual inspection at various portions of the structure and (ii) the analysis of accelerometer records taken during the earthquake. The interpretation of these data is influenced to large extent by the particular kind of structure under study, such as the material, height and design of the building. The useful pieces of knowledge have been collected under the organization of Fig. 3 and expressed in a stylized rule format in the knowledge-base.

The rule format is designed so that both human and computer can interpret it easily as exemplified in Table 2. The first two digits of each four-digit rule label are rule set number corresponding to the node number in Fig. 3. To express the knowledge with fuzzy grade, the following fuzzy subsets are allowed:

- no, slig (slight), mode (moderate), seve (severe),
- dest (destructive), uk (unknown - universe set),

the membership functions of which can be defined. In rule interpretation, the fundamental function of production system, that is, "if premise is satisfied, then action takes place", is emphasized. The action in this case is an updating process of short-term memory corresponding to the subgoal.

Short-term memories are working memory spaces for inference, in which input data or inferred data are stored. In SPERIL version-I, the following four types of short-term memory are used:

- type - 1 certainty measures of fuzzy damage grades,
- type - 2 linguistic data,
- type - 3 numerical data,
- type - 4 yes - no data.

When the short-term memory is accessed, the type of short-term memory is referred to proceed to an appropriate interpretation of the rule statement.

Because the inference network is not deep, no heuristic or sophisticated strategy of rule invocation is adapted. The sequence of rule set invocation is preassigned as follows:

- "05", "06", "07", "08", "09", "10", "02", "03", "04", "01".

This corresponds to a bottom-up search rather than top-down or goal-oriented search.

The control and inference process finds and examines a relating rule in the

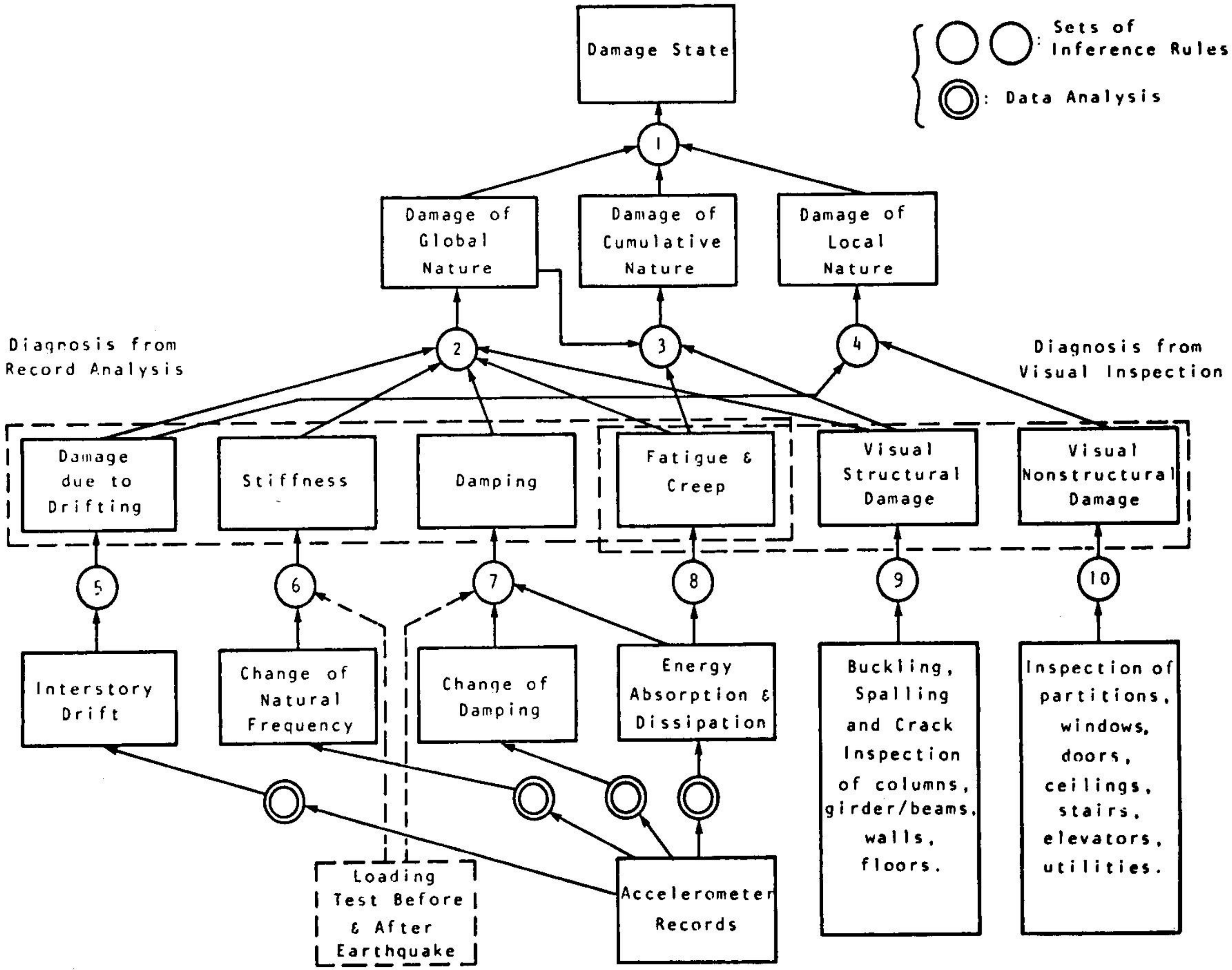

Fig. 3 Inference network of SPERIL.

rule-base. If short-term memory is found in the examination of the premise to be unanswered, a question is initiated to get data. The question is generated by referring to a question file in which an appropriate question sentence is stored for each short-term memory which has the possibility of accepting data from operator rather than from the inference process. To avoid the situation of annoying and unnecessary questions, "skip pass" is provided in the control flow for the case that there is no possibility for later action statements to be taken. Thus, only a minimum number of necessary questions is initiated for the purpose of inference.

After one rule is processed, the result is used to update the short-term memory indicated in the action statement. For type-1 short-term memory, the updating is executed by the extended Dempster & Shafer's theory to integrate independent evidences. The final decision is made according to DS's lower probabilities of the fuzzy subsets in final goal which is the damage state. If no fuzzy subset has lower probability larger than a certain threshold (0.2), SPERIL selects no appropriate answer. Therefore, the answer is one of the following:

- 1) no damage,
- 2) slight damage,
- 3) moderate damage,
- 4) severe damage,
- 5) destructive damage,
- 6) no appropriate answer.

More detailed implementation of SPERIL is described in [5]. The control and inference part of SPERIL is written using UNIX Language-C. SPERIL is currently running on a PDP11/45 which can be accessed through the EE computer network at Purdue University.

6. SUMMARY REMARKS

With the advancement of computer technology, there have been several attempts to produce computer programs for the assessment of structural damage. Because of the complexity of the problem and the relative difficulty in summarizing the abundant information collected in such cases, all these systems are primarily based on professional experience and engineering judgment in the decision-making process. Wiggins and Moran [2] can be considered as pioneers in such efforts, and so are Culver et al [3]. The work of Bresler et al [4] is the most comprehensive one today, and it is almost entirely extracted from expert knowledge. On the other hand, Ishizuka et al [5] attempted to formulate the problem in a rational manner. At present, these latter two groups of investigators are in the process of collaborating with each other. It is hopeful that more meaningful results can be obtained in the foreseeable future.

ACKNOWLEDGMENTS

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SESSION I

DISCUSSION (2nd part)

October 6, 1982 - Afternoon

Chairman: J. BLAAUWENDRAAD (The Netherlands)

J.P. RAMMANT - To Mr. Williamson: concerning the ESTEK package, I have some questions about the applicability of this program in the european industry. Your system is functioning on the work you are doing at McAuto. I ask myself if the european industries are willing to accept people having to pass the cost estimating data through your files, while in Europe people like to handle this kind of things in their own home. Could you comment on that topic?

R.W. WILLIAMSON - I don't mean my presentation to be a sale picture or anything like that; so I didn't mention anything about how we offer ESTEK; obviously we are software house, we are selling software. ESTEK is available on McAuto computers for people who just want to come in and process it, but we also licence the software and, if you have your proper machine, we will licence and install the system on your machine. On other software packages, in various areas in the whole world, we do have our software installed on service bureaus. There is some in Scandinavia,there is some work in France and we have work in England. If somebody wants to get to the system, they will be aware of doing it.

J.P. **RAMMANT** - Can you give some estimate about the necessary hardware?

R.W. WILLIAMSON - Currently ESTEK processes on IBM main frame environment. Machine who are very known are 30/33, the operating system is NVS (and it is compatible with OS VS1 operating system); it is an IBM based system. We are looking at it and evaluating moving ESTEK on to selected microcomputer systems. We have ESTEK as a part of our family of software, scheduling project majoring software. Other systems have just been made available on VAX 11/780/750/730 series machines; so - I suspect our management hasn't approved the convention - I expect next year we will start with the conversion and migrate to the VAX environment also.

D.D. PFAFFINGER - I have a question to Prof. Yao. If I understand your presentation correctly, your main concern is assessing the damage when has already occurred. Is that right? How do you judge the possibilities of assessing the damage from structural analysis, say predicting the probability of a certain damage from the probabilities of the exciting loads?

J.T.P. YAO - As I stated earlier in the presentation, there are two parts in the research program. One part has to do with the present state of structural safety, which I tried to illustrate (was LST or TO) in this paper,and the second part is knowing what the initial condition is, or the present state of the damage is; and can I get the hazard function, which will tell me, from now until twenty years from now what kind of deterioration, or the chance of surviving the loading conditions may occur? Most of my talk here was devoted to the first problem, which is to find the state of damage at the time of inspection.

The second part of the problem: actually the work has been going on since the theory of structural reliability has been introduced. One approach is to use random processes and you assume during this period certain type of earthquakes may occur; there is also an approach called first passage probability or the barrier problem; if you are interested, I can find a list of references to communicate to you. The problem that I have on this regard is that only special cases of those mathematical problems have been solved. For those special cases the structures involved are higherly idealized; they are not really for actual structures. I think the best,the present methods we have can give us,is an estimate. Besides,I am not sure whether we can get the kind of hazard function we need. I guess there are ways of doing it now, but I personally think there are good opportunities for further improvement.

R.W. HOWARD - This is a very general sort of question, an observation; I would like some response if possible from Dr. Yao and from Mr. Steiger and it is about the fact that, over the history of computing in engineering, we tried to define the way we design things in a rather precise way, using digital techniques. I think this question of indeterminacy, which has come up in both the papers, has led us to talk about expert computer systems, where the opinions of experienced engineers can be built into programs. Also I think, talking on the computer aided manufacturing side,perhaps analog inputs where the subtlety of the control of the human hand - for instance - can be built into computer aided manifacturing systems. Have you got any comments on this? Shall we say realizing that the human skills have to be built back into the systems, which attempted to try to mechanize, as you said, human processes in the past.

J.T.P. YAO - This is a very interesting comment to me. I have two ongoing research projects: the one I described is one of them. The other one - in my own mind - is an even longer range project; it has to do with so called structural control, how to apply control theory to reduce or minimize the structural response. There are two objectives: one is for comfort purposes, one is for safety purposes. In fact, there are two tall buildings with passive control devices installed now in the United States that I know of. One is the John Handcock building in Boston, the other one is City Corp Building in New York, where they have a huge block of heavy mass installed on upper floor in both buildings. They they have hydraulic ramps to move it around whenever it is needed and the block would be floating on oil. Now, if you talk to the manifacturers of the system, they say it is working very well. But, if you talk with someone else, they have questions about these devices. Such applications are for comfort control, so even if the device doesn't perform perfectly, there is no real harm then, people just get sick. There are many cases of motion sickness in these flexible top buildings on windy days. So the feedback is already implemented into those systems because when wind blows the motion exceeds certain levels, then the machine starts operating and the oil will pump up the block which is floated and then moved. In 1979, there was an IUTAM Symposium on Structure Control in Waterloo and more then 50 people showed up to exchange ideas on this subject area and we are now thinking about organizing the second one possibly in 1985. I also worked with analog computer and I think it is a useful device that many people overlook.

F. STEIGER - I think your question can be answered in terms of optimization.

It is a question whether safety and reliability is a constraint,or objective function of designing. I think it should be a constraint, because we have to look to other important things by designing not only in the sense of structural engineering, but also of architecture needings etc. And so, in the decision making process, we have to include these other needings and, from my point of view, it is difficult to value other needings, than costs or prices, because they depend on decision maker interest, or on the interests of his organization. So the paper I present should only be an example that the decisions are done with uncertainties and there are some tools to value these uncertainties. They should not be given into mathematical equations and I think that it is important to know that we cannot make decisions or make design only by computer, but that the decision maker has to select before the important shapes. That depends on this special experience and so these tools may be only helpful for an experienced decision maker.

G. KRUISMAN - I have a little question for Mr. Steiger. We have seen a nice overhead foil saying how you have to meet in an objective way the design criteria and it was indicated that minimum requirements of the client as well as standards and regulations are to be satisfied. What I miss in the statement shown was the satisfaction of the designer. Can you give a method to measure or determine the degree of satisfaction of the designer or is he satisfied if he satisfies others?

F. STEIGER - I think the satisfaction of the designer is a very important thing, but there are borders for him which are very important and the satisfaction of the designer cannot be measured. I think one part of his satisfaction should be that his task is to choose the design-solutions which are possible generally and to choose one, or more provisions, which satisfy all these things you mentioned and his own interests. I think that should be his own satisfaction.

P. LENGYEL - I have a question to Prof. Yao. First of all I think that your primary aim was to make us interested in the question you have presented, and to see what a huge and difficult problem it is. I feel you succeeded in doing so, but the next step would be to get a little closer to it and I do not know which is the best side to be chosen for the approach . I think your paper might be a good starting point. Here you have written, that you used C language for programming many parts of program SPERIL. For me this choice is very interesting, so it would be nice to hear the specific reasons.

J.T.P. YAO - Well, the language was chosen by my first co-Author, Dr. Mitsuru Ishizuka. He preferred it as the computer language for this particular one: the SPERIL I. As I mentioned before,it is given for the purpose of illustration or demonstration. I have tried with some obvious cases to answer those questions, and - three times out of five - the answer that came out in my own mind was correct. What I am trying to say is that the details right now need a lot of improvement, that is why we are collaborating now with practicing engineering firms. If you are interested, it is much easier if you start writing your own program, rather than you try studying and follow the details of our program. Of course I will send you a copy of the listing in case of need. In fact, I have one copy with me, but please use it with caution, even if you can put it on your computer, because it was written by an electronical engineer even though

I collaborated with him. We just do not have all the details; I don't have all the answers and we are still in the stage of trying with different methods of combining and interpreting the answers. Also, as we all know, there are many different types of civil engineering structures and we do not have in most cases duplicates of a given design. So there is only one Sear Tower, one Golden Gate Bridge and so on. That's why I said it takes at least another ten years before we may have something practical. This is one of the reasons I volunteered to go anywhere I can to tell people about the problem and I really believe this problem is too big for me, or my friends at the university. Let me also say: there are people who are already solving these problems. There have been people doing it all these years, so there are solutions, practical solutions already, but what we are trying to do is to whether we can get it organized in such a way that less experienced people - like myself - can learn this process easier without having to work for specialized consulting firms for thirty or fifty years. At that time, I would be a hundred years old. So I like to encourage anyone interested to work on this problem, and I also believe that the approach we presented is not the only approach. That's why I concluded by showing you different people doing different works,using different approaches. I believe that eventually some combination of these different approaches might make it work better. Therefore, if you are interested, I am most willing to correspond with you and I will give you names and addresses, and I will write letters to my friends to correspond with you also. I really believe that, if more people work together, then there is more chance of solving the problem with more useful results.

S.J. FENVES - You just used a word that requires some explanation; you said you wanted to organize this information. A characteristic of heuristic systems is that they represent the expertise of a particular person or a particular group of people. In SPERIL,do you want to emulate the thinking of a particular person, such as Boris Bresler? Or do you have the expectation of generating a common set of heuristics that is agreed upon by all structural engineers?

J.T.P. YAO - I think it is a very good point, but at the moment we are trying to understand the thinkings of a few experts associated with Wiss Jankey Elstner in Chicago, Illinois. Because we have built up quite a few different methods to combine these simple answers to simple questions, we are going through their files to use them as a calibration - I am not sure if I am using the right word - or to use it as a test to these various methods of combining answers. Once we have a better idea which method works better with these few experts and the government will continue to support these long-range programs, I would like to expand, to include other experts and eventually, I think, your second alternative. We started out with very few experts but we would like to make something which would be aggreable to most structural engineers,or experienced structural engineers. There is a subjectiveness in the selection of experts also.

Impact of Computer Graphics on Architecture and Engineering

Implications de l'infographie pour l'architecte et l'ingénieur

Einführung von Computer-Graphik in der Architektur und im Bauingenieurwesen

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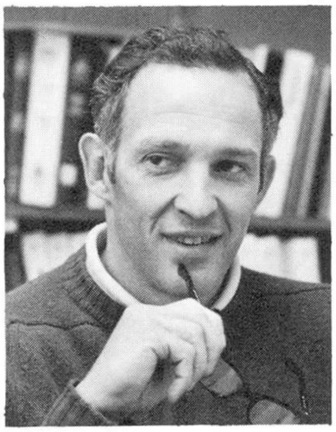

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SUMMARY
The presentation illustrates many uses of computer graphics which will affect the architecture and engineering professions. The illustrations are examples of pilot programs and research projects which have been conducted at Cornell's Program of Computer Graphics. Difficulties with using this enormously powerful technology are described, as well as the changes which are currently occurring within the computer industry. These changes will result in new, single-user work station environments for the designer and engineer. Some remarks are presented on the effect that these technical advances may have on both professions.

RESUME
La présentation porte sur l'illustration des usages de l'infographie qui sont en mesure d'affecter les professions d'architecte et d'ingénieur. Elle se réfère aux projets pilote et aux recherches qui ont été conduites dans le cadre des actions entreprises à Cornell dans le domaine de l'informatique graphique. Les difficultés de mise en œuvre de l'énorme potentiel technologique dans ce domaine sont mises en évidence, ainsi que la rapidité de l'évolution dans l'industrie de l'informatique. Cette évolution conduit au développement de stations individuelles destinées au concepteur.

ZUSAMMENFASSUNG
Es werden verschiedene Computer-Graphik-Anwendungen beschrieben, welche den Beruf des Architekten und Bauingenieurs in der Zukunft beeinflussen werden. Die Beispiele stammen aus Pilotstudien und Forschungsprojekten, die an der «Cornell's» Schule für Computer-Graphik durchgeführt wurden. Schwierigkeiten, die bei der Verwendung solcher wirksamen Technologien entstehen, werden beschrieben und es wird auch über Veränderungen berichtet, die gegenwärtig in der Computer-Industrie vor sich gehen. Als Resultat dieser Veränderungen wird eine «single-user» Arbeitsplatz-Umgebung für den Ingenieur und Architekten hervorgehen. Zum Schluss werden einige Bemerkungen über die Auswirkung dieser technischen Fortschritte bei beiden Berufen gemacht.

I. INTRODUCTION

During the past two decades, a number of important technological advances have occurred in the computer industry and structural engineering, and these advances have changed our methods for analysis and design. Finite element analyses are now standard procedures which have been widely accepted. Unfortunately, current implementation of these techniques require our spending excessive time on the wrong aspects of the problem.

The time required to accurately define the information necessary for a computer analysis is large. Probably, the major portion of the typical cost of a finite element analysis is in the input task. An even worse problem exists in the interpretation of the results. One sometimes spends many hours searching through pages of computer output trying to understand and interpret the analysis. The time spent on the conceptual and creative part of the process has unfortunately been proportionally reduced.

On the other hand, despite the computerization in structural engineering, the architecture profession has not yet leaped into this technological foray nor taken advantage of these technological advances. There are several reasons for this.

- The capital investment required to start is still excessive.
- The structure of the architecture industry is fragmented. Drawings are copied, consultants perform their tasks independently, and communication between disciplines of the building process is poor.
- It takes a long time to attain leadership roles since the profession is historically based on apprenticeships. Thus, principals of firms, who earned their positions over many years, have not been educated in computer technology.
- Perhaps, most importantly, there exists a natural and skeptical resistance to the intrusion of a powerful machine technology into a heretofore aesthetic domain.

Unfortunately, the net result of the traditional approach with its inefficient labor-intensive procedures, is also the wrong allocation of time. Too much effort and cost is spent in the production of drawings when compared to the time allotted for design concepts.

Now, however, several factors imply that the architecture profession is ready to also accept the new technology.

- Skilled draftsmen are difficult to find, and the production of drawings is both time-consuming and expensive.
- The cost of computing is decreasing exponentially.
- New architectural employees have grown up in the era of television and video games, and are no longer afraid of the technology.
- The mystique of the computer is attractive to clients. Computer-aided design systems are now being used as a sales tool to obtain new commissions.
- Lastly, at least in the United States, some of the major clients such as the government and the aircraft industry now require machine-readable data in their contract specifications.

All of this has led to a renewed interest by the architecture profession in the computer-aided design field. Market surveys now predict that the fastest-growing segment of the entire computer-aided design industry will be in the architecture/engineering profession.

It is my belief that the future of the design fields, both engineering and architecture, will rely on the uses of INTERACTIVE COMPUTER GRAPHICS and information will be defined pictorially. We live in a visual world. Our ability to comprehend graphical information far exceeds our ability to understand verbal or numerical information. In short, "a picture is worth 1024 words!"

It is important to emphasize the meaning of the word "interactive" in computer graphics. When graphical operations and commands are specified, it is necessary to have response times fast enough to provide a continuous communication dialogue with the user. For three-dimensional investigations or dynamic problems, continuous motion displays are necessary. In order to fully understand complex geometries, one would like to simulate walking around the structure, like taking a model in your hands and turning it around to examine it. This requires the rapid generation of perspective images, maybe 30 or 40 times per second, in order to imply motion. Color is also useful, not only to provide a realistic three-dimensional image, but to display results.

Some of these concepts will be illustrated by showing you the results of several research projects which have been conducted at Cornell's Program of Computer Graphics.

II. VISUAL PRESENTATION - SLIDES

III. CURRENT TRENDS IN COMPUTER-AIDED DESIGN EQUIPMENT

It is useful to review the recent trends in computer-aided design. Ten years ago, most computer-aided design systems started with large time-shared computers, many users, a common database, and generally poor response. The poor response occurred for several reasons.

- It was difficult for a single user to get the machine's attention in a time-shared environment.
- The amount of data required to generate a picture is very large, and the "bandwidth" required to transmit this data rapidly was not available.
- Furthermore, the cost of vector refresh display systems was too expensive.

To eliminate some of these deficiencies, a new line of computer products became available in the mid-1970's. Graphic display stations, using raster technology, were introduced. These devices have the advantage of being primarily dependent on the cost of computer memory which is decreasing very rapidly. Furthermore, they also provided the unique opportunity for displaying color at little additional cost. A great amount of intelligence was also put into the display terminals. Capabilities for dynamic rotations, perspective image generation, clipping, vectorization, filling polygonal areas, etc. were all introduced. By having these operations performed locally, the amount of data which is necessary to send from the host computer to the display device is substantially reduced and therefore graphic response times were improved. However, the basic problems related to time-shared environments are not solved.

Today, new devices called "ENGINEERING WORK STATIONS," are being introduced. These consist of 32-bit microprocessors with virtual memory addressing capability. Physical memories may range from one to four megabytes, with mass storage devices of tens or hundreds of megabyte capacity. These "work stations" are sufficiently large, in terms of their storage capacity and their speed, to handle real-world problems. A number of computer companies currently market these systems. Two specific characteristics related to these work stations are important to emphasize. The first is that their networking capability is absolutely essential, and must be incorporated into their hardware designs and operating systems. Almost all manufacturers are leaning toward networking architectures which will transmit data in the range of ten megabytes per second. This means that users on the network can share resources, and even have processing accomplished on idle components, with results returned to the user's station. Perhaps even more important is the fact that these new "work stations" are using raster displays, where the images are refreshed directly from the local machine memory. Therefore, one is no longer bandwidth-restricted when data is sent from the processor to the display device.

These new systems will have a tremendous impact on the engineering and architecture professions. It is my contention that, in this decade, all professional engineering and architecture firms must move in this direction. The designer of the next decade will have his own machine and work station, using interactive graphics to solve his problems. Since the systems will be inexpensive and modular, it will be easy for everyone to get started, incrementally building up their private networks. The uses of graphics will be paramount, since the transmission and understanding of information is so fast. Color will be available for free, and thus will be greatly used to interpret results.

Aside from the descriptions of how the technical uses will change, a greater impact may be on the structure of the two building professions. For the first time, small firms will be able to afford the luxuries which previously only larger companies could attain. For the first time, the two and three person firms will be able to bid for the same jobs that previously were only the domain of larger companies. This will clearly make the industry more competitive. But also, one hopes, this will once again place a greater importance on the creativity and design capability of the individual and, hopefully, improve the quality of our built environment. Thank you for your attention.

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SESSION II

DISCUSSION (1st part)

October 6, 1982 - Afternoon

Chairman: H. WERNER (Federal Republic of Germany)

R.W. HOWARD - A question of predicting the future, having tried in the project I mentioned this morning. We are trying to do just that and it is relatively easy to say what will happen in the future, but to say when it will happen and when it will be widely used in industry is much more difficult thing, I think. For instance, the pictures you showed of that building at Cornell campus were done in 1969 with 3D color modelling. Well I think there are probably very few people in this room who used color graphics in 1969, or perhaps even in 1979. Colorgraphic display - I think hardly any - appeared on a large scale in Europe in the last year or so and the time lag between advanced research and the things, even becoming available on the market before being widely used in practice, is quite long. To take up one point of your question for future workstation specification, the flat interactive display. Again it will come, the technology is there and provides small displays and,in rather specialist research environments, but certainly we felt it would still be very much an advanced research tool in the more sophisticated user environment and within five years in Europe. I would like to know if these things are used in practice in the States at the present time ,or what stage of research they are in, because ergonomically they would help the design of workstations, but I think their appearance in the engineers' offices on a large scale is some way off.

D.P. GREENBERG - I am not exactly sure of what your question is. I think there are two things that you said. One is related to the development of flat interactive screens. Currently, to my knowledge, there are a number of companies which have perfected these capabilities for displaying a reliable 256 by 256 flat panel. The technological difficulties increase beyond that, but it makes no difference, as it is not a difficult task to combine those elements. You could really put together four 256 by 256 panels and have the resolution which you currently have in television. Westinghouse and Xerox and I am not sure which japanese firms are working on this and have already shown these products. Most of them have been in black and white because it is apparently quite difficult to be able to get the inert gases for the blue color. With respect at how much this has been used in the architecture and engineering profession,it hasn't! You are absolutely correct. In fact very few firms are even using computer aided design in architecture although they certainly are in engineering. Most companies justify their initial plunge into this field on the basis of the economics of the drafting system. However, from my point of view, the real difficulty is the fact that we are approaching the problem too traditionally and that's perhaps why a lot of those systems are not being used. One of the major problems, at least in teaching students in architecture and in engineering, is trying to make sure they understand the three-dimensionality of the problem. There are a lot of students who think they understand, but have difficulties of just visualizing three dimensions. If we would talk of working in three dimensions at the start, I would feel that these systems would be used much more heavily.

And the last comment of course is the economics. That has been too expensive.

W.R. HAAS - First of all I would like to admit that I felt a little bit as if I was acting in the computer middle ages when I heard you talking. I have two questions. At the beginning you showed us the structure of your computing center; you had a VAX in the center and you have attached PDP 11/44. How did you manage to get this real time speed in your program? What did you do on the PDP 11/44? What was done on the VAX? Did you use any attached hardware or didn't you use it?

D.P. GREENBERG - That's a good question. When you are dealing with computer graphics, the basic problem is first to define a three dimensional model. Once you have a numerical description of the three dimensional model, the ability to generate perspective images, to rotate it, to dynamically zoom in and out of it is a very simple problem. In fact all graphic display manufacturers in the next three years will be implementing this capability in either hardware or microcode. Once you have the model, it is easy to do manipulations. The difficulty is, if you have a time sharing computer, you must pay attention to those needs. Particularly when there are fifteen other users. You cannot get the response you need, so the logical solution is to offload the timesharing computer by placing as much intelligence to the user stations. We looked around in 1977 and there were no intelligent graphic stations at that time,so we bought our 11/34s or 11/44s, threw away the DEC operating system,and bought some vector display devices from Evans and Sutherland and some color frame buffers, we put in our own graphic software and our own intelligent operating system, that were unique for our graphic environment. Then what you do is to describe your object geometrically and the user can do all manipulations which you saw: all the rotations, perspectives, zooming in and out, even some editing changes. The VAX computer doesn't know anything about it and only when you change the geometric description or the topology of the object, do we have to go back and make sure that we update our database. Does that answer your question?

W.R. HAAS - The first part, but not the second part whenever you used any attached hardware or retrocessor.

D.P. GREENBERG - I am already "biting off more than I can chew" in terms of what we can develop our laboratory and so I made the subject decision that we would only use commercially available hardware. We have not modified any hardware and I do not have a floating point array processor to help with the computation.

J. BLAAUWENDRAAD - I have a question which is connected to the last one. I got the impression that you could achieve the results because you did not decide to make it hardware independent. What about that point?

D.P. GREENBERG - I think that is true. This is very definitely hardware dependent. We had only certain types of devices which were in the laboratory and clearly our software was designed to run on those pieces of hardware most efficiently. Your comment is correct.

J. BLAAUWENDRAAD - A next question is: what possibilities do you see to spread it in building industry in the future? How can you reach the situation that others use it a lot of times, so they try it?

D.P. GREENBERG - It is a very valid question. Let me go back first to one of my original statements. What I tried to show today was the result of a research laboratory, and it's really experimental. The approaches, which we use or used, I believe are the correct approaches for dealing with interactive three dimensional graphics and I believe that the manufacturers now are coming to the same decision. I have had a good fortune in the United States, I guess, to be able to work with a number of the manufacturers, so I feel fearly secure on that statement. They will be microcoding lots of these operations in their own pieces of equipment. The ability for rotation, for perspective transformations, for zooming in and out will all be part of the hardware and will not be software code any more. Even hidden line operations will be part of the hardware. That may be two years off but it will be part of the hardware. Thus, the ideas will move into the profession but it will not move in by taking software which is developed at a university. I don't mean to say that everything we have done is correct. One of the major contributions is that we have been able to tell manufacturers what we did wrong. I am not showing any of that.

H. WERNER - Can I give a short comment on this? Last week I attended a seminar on GKS (Graphical Kernel System) at Darmstadt. Up to now, there are several installations of this graphical Kernel system on several types of hardware. Just one example: in Berlin a program for representing three dimensional models has been developed on top of GKS. It was brought to Darmstadt on a tape and there it was installed on a quite different hardware in less than one hour. This is the main advantage of such a standardized graphics system. The transmission of developments from one computer to an other will cause less problems.

H. WAGTER - One of the conclusions of your talk is that hardware is going to be very cheap, hardly free, storage is also free. This gives me the impression that hardware suppliers are preparing their own funeral now. What is your reaction to this? There is a tendency, I guess, in Europe that software firms and hardware firms are combining and doing efforts to keep their combination expensive to share incomes.

D.P. GREENBERG - My personal opinion is that your observations are very astute. You are right. The hardware manufacturers are beginning to recognize that the cost of the equipment is going to be so small that that's not where they are going to make their profits. During the last year or two they seem to have made the major recognition that most of their profit is going to be having software which runs on their systems. If you start to examine some of the recent strategies of hardware manufacturers such as merging with software companies, or subcontracting software development to software companies, or more importantly trying to get an installed-user base, so that it makes very difficult for users to change manufacturers. That's all a strategy which assumes that software is going to be the only expensive portion.

E. ANDERHEGGEN - Because the software is so much expensive than hardware, what could you suggest in order to reduce software development costs? I am thinking about two things. First: some programming language better than Fortran, which is a very old theme of discussion. Second: may be some brute force approach to the problem of modelling, for instance the octrees approach,which was studied

I think at Renselear. It requires a heavy lot of data to describe a model, but a much simplier software. Could you comment on this?

D.P. GREENBERG - I think so, but they are really two separate questions. The first one relates to how does one try and reduce the enormous software costs which would be necessary. I wish I had an answer to that, I don't know. If you find the solution I would love to hear it. With respect to brute force approach,I don't think that we would find those approaches to be very satisfactory in the future. All the brute force approaches which you would see are really based down to the resolution of the display. They can get away with a lot graphycally in term of 512 by 512 displays. You can even get away a lot in terms of 1000 by 1000 displays, but that's not sufficient for engineering data. You may use those approaches, but only for display and not for modelling. That's my own personal opinion.

SESSION II

DISCUSSION (2nd part)

October 7, 1982 - Morning

Chairman: H. WERNER (Federal Republic of Germany)

H. WERNER - Are there any questions to Prof. Shimada on his theme "Safety Inspection Systems on Existing Structures"?

D.D. PFAFFINGER - In your last example you showed the experimental determination of the cross-correlation of the structural response between X and Y direction, if I understand correctly. The question is: did you also perform similar investigations on the cross-correlations of earthquake excitations?

S. SHIMADA - Yes, in every case of experimental measurement and whenever the data are prepared in computer readable data.

D.D.PFAFFINGER - Therefore you could certainly run earthquake recordings through the same procedure and determinate the spacial correlations between earthquake excitation components. The question is if you also considered that type of problems.

S. SHIMADA - Yes, the same problem, but unfortunately we can not take the data from an actual earthquake and we obtain data from the random information from the excitation induced by heavy duty trucks; for earthquake analysis it is necessary to obtain the earthquake data at the site of the structure (but it is always difficult). So we extract the data from the ground and the structure motion, by using several apparatuses, such as shaking machines. Usually we get the shaking from heavy duty trucks moving around the structures.

G. KRUISMAN - Mr. Shimada, you are studying the dynamic behaviour of existing structures. Is the reason purely scientific knowledge generation, in order to be able to make better designs in the future, or are there other incentives to do so? For instance: expected heavier earthquakes in the near future, or higher demands for new regulations, or other reasons? What is the exact reason you look at existing structures? It seems to be longstanding practice to built something and to leave it there until it is damaged.

S. SHIMADA - I tell you some of the comments and could you please correct my answer? I am much interested in the design of structures and also in verifying the capacity of the designed structure to resist actual loading. This research has been extended in getting in site data. I found that portable inspection systems should be convenient for the use of field inspection. I found several parts of very dangerous structures. Sometimes the structures were destroyed by our prospects and some of the structures are coming to loose their capacity. I am thinking of the systems to be used under construction work, since many failures occur in the construction work. I am now trying to built a very handy and conveninent system for field workers, to test the safety of the members at the construction-site; because, you know, we can get some safety by beating something, but unfortunately the failures occur at very low frequency, that can never be felt by human sense. So some kind of strong devices are required. An other example is found by testing the soil capacity to bear the weight of the structure. Unfortunately we have many claims for soft foundations on which structures sometimes set unfavourably. But, by the test of the ground motion, we can find some unfavourable soil state.

J.T.P. YAO - I noticed the very small amplitude in your test data. I just wonder what kind of noise-signal ratio you had and whether and how you filtered such noise-polluted data before you analyzed them.

S. SHIMADA - It depends on the system set up and on the equipments used for the error correction method. The noises have the tendency of some spectra, we compare these noises and can extract them from the original data. The random waves are very fruitful data for me, because they have many frequency elements. The noises have some typical frequencies which can be identified by interactivity and some of the very strange properties of the sensors is also extracted. So, by comparison of the various data, we can get the correct data and properties from the random waves.

H. PIRCHER - This is not a question, it is a short comment. Near the town I leave, 15 years ago a bridge was built and one year ago there was political decision to change the line of the motorway and to blast the bridge. Before blasting it, it was decided to make some experiments. A vibration test and a calculation of vibration were carried out and there were some differences in the results. After blasting we could see that there was one zone in the bridge where the injection in a part of the prestressing cables was not good. I don't know details about it but I think this is interesting in this context.

S. SHIMADA - Much interesting, and we are gathering many such vibration data and, if possible, would you send these data to my address?

H. BALDAUF - The construction industry is said to be a conservative industry.

I think the main reason for this is that we are largely concerned with individual rather than mass production. If one has mass production, as with prefabricated elements, then there is an impressive array of examples,as Mr. Haas showed yesterday. As for individual products, if well described modules, like continuous beams, slabs in highways, are being considered, there also exist adequate examples for graphic design. It becomes difficult, however, if we look at the concrete industry and try to include the dimensioning process in graphical design. Furthermore, we have to cope with the National Codes for dimensioning and you know the difficulties which can arise when these codes and their philosophy are changed. In the past we had to throw away programs because of these changes, but it is unthinkable to have to replace graphical design programs for this reason. What we need are methods with a very high flexibility, methods which will suffice for 80/90% of graphical design and be capable of being adapted to the reminder by hand. Otherwise I believe the development of these programs will become too expensive. I have a further question. You said that for graphical design it is necessary to have a complete 3-D description of the building. For the calculation we need a model of this construction. You also said it is necessary to separate the calculation model from the graphical description, or perhaps I did not understand you correctly. Could you make some comments on this please?

P.J. PAHL - Let me start with the comments on the construction industry which you made at the beginning. I think you emphasized the point which I really tried to make. The point is that there are very special properties of the construction industry which one must take into account when planning developments and estimating the market for a particular development. The area of application for most of our work is not standardized. I am not aware at the moment of any development which has the flexibility addressed by you in the first part of your statement. The problem lies in the interelationship between the geometric model and the functional model in structural engineering. That is the peculiarity of structural engineering. We cannot simply describe the geometry without describing other properties as well. Both the size of the problems we have to solve and the volume of the software we need to obtain the necessary flexibility are a problem which, at the moment, we are not capable of handling even in principle. Computer graphics is for the construction industry essentially an area of research and not an area of development or application. This contrasts strongly with graphics support for finite element work.

H. WAGTER - In your paper you present a state of the art of all the programs you know. You also mentioned that those programs are fairly standardized on certain aspects. It has always been my impression that not even the size of the manuals has been standardized. Could you explain a little bit more what you mean with standardized in this respect? And the second thing I wanted to ask is: you are talking about disappearance of drawing boards at the engineering offices and I think in your story you are using the drawing just as a communication mean for people who are making actually building. What do you think of the role of that drawing? Is it just a representation of the model you are working with? Because I think that is the field in which the drawing board might disappear.

P.J. PAHL - Let me go first to the question of standardization. In my paper,

there was no reference to similarity in implementation. There is a similarity in the type of functions which are made available, not in the methods by which they are made available. I agree with you that there are very large differences in implementation. This is demonstrated by some of the points made yesterday in connection with accuracy and size problems. I can give you another example in that area. If you look at a perspective of a steel structure and compare the dimension of a flange with the dimension of the building as a whole, you realize the accuracy problems we have with most of the perspective drawing programs. So I fully agree with you that the method by which we implement is not yet standardized, but I think that the kind of problems we have to solve are fairly standardized.
The second question concerns the drawing board. I think one should first put the question: is drawing the appropriate mean of communication in computer environment? At least at our universities, I see the problem that many students can no longer draw. They can analyze very well, they can handle programs, provide them with input and look at the output, but they are loosing the conceptual facility because they loose the ability to visualize structural behaviour and structural details. I do not anticipate that drawing will be replaced to a very large extent because we are using computers. The problem I see is that of the discrepancy between the speed of development in numerical analysis and that processing, and the lack of speed in the development of graphical computer applications. I did not want to make the point that the drawing board cannot be replaced; on the countrary, I want to make the point that we have to be very careful how we replace the drawing board.

J.P. RAMMANT - I have two questions. You said that one of the topics in research is that we should keep the data management ourside the application software. Now, the question is: are the current available database management syustems suitable or will they suite it to cover our technical databases, or should we redesign databases? Then I come back to your comment. Should not that be included in the application software? The second question is: does it make any sense to do draughting on its own in the construction industry? Should drafting not always be connected to design?

P.J. PAHL - There were two aspects of database management. The first aspect is the managing of design variants. That is a problem which one can handle in the application program if only the basic decisions "Yes, I use the variant; no, I do not use the variant" are made in the application program and a database management system is called to make all of the modifications required to either retain or to reject the data of the alternative. Then the database management is a considerable help to the application program developer. The second aspect is that of distributed databases: the problem of lending a part of a dataset to a workstation and reintegrating the modified data in a central project file. This problem also is one which potentially one could solve, at the application level, but I would like to put the question wether it is not more reasonable to solve it at the level of the database management.
The second question refers to the connection between drafting and design. If one tries to start with drafting after the design has been completed and to input the data in that phase, most of the economy of computer drafting is lost. Design and drafting must use the same dataset. In that connection, let us look at the traditional ways of describing structures on drawings. We find that they

are not complete: there is a great deal of information, which is implied and not explicitly shown on the drawing. It is anticipated that whoever is going to interpret that drawing will make deductions and judgements. If the information is to be processed on the computer, that information must be made explicit. In this respect, there are big differences between the way structural and architectural drawings are prepared on one hand and the way in which mechanical drawings are prepared on the other hand.

P. LENGYEL - I would like to put you two questions. The first one concerns the traditionality of building industry and your very bad experiences about automated drawing in design offices. The obvious arises: which will be the proper way to go ahead? An answer might make use of the contractor being very strict to the standards. Don't you have the feeling that CAD is always used in places, where the national standards allow to do so? Moreover, if there is such a standard - for the application of CAD - included in the standards of engineering, then it promotes automated graphics, too. I would appreciate your comments on this. The second question refers to your comment about finite element drafting, saying that here you have to get all the stresses in an order of points, so as to be able to make a drawing. My question is: why?

P.J. PAHL - Let me start with the second question. Many of the algorithms that are used to draw isolines, use interpolating functions within finite elements. To use the algorithms, one requires nodal values of the variables. We also are interested in the values of stresses on the surface of a body. Normally that requires nodal stress values. We obtain the nodal stresses by beating the computed displacements of a normal displacement analysis, as imposed displacements in a mixed model (principle of Hellinger-Reissner). Using compatible element stress variations, we then compute the stress values directly at the nodes. Instead of computing the displacements by differentiation within the elements, we compute them with the same accuracy as the displacements at the nodes.
Concerning your first question, that of introducing symbolism to as large a degree as possible in graphics: if one uses standard reinforcement shapes, and if that standard changes, that it is not a big problem, because usually programs are designed in such a way that non-standard shapes can be incorporated. This simplifies the adjustment to a new standard. The problem lies not so much with the standards, but with flexible digital models for structures. This seems to me to be the problem: the appropriate structural data for drafting.

S.J. FENVES - I don't know yet if this is going to be a comment or a question. It seems to me that there is one thing that you left out of your presentation, and that is that, in structural engineering, we have a multiplicity of symbols for the same things, and, at various stages of our thinking, we have different symbols-images of the objects we are dealing with. Now, it depends whether you are an optimist or a pessimist. If you are a pessimist, you get the impression that this complicates the problem even beyond the rather negative picture that you presented. If you are an optimist, this may be a way out, because, as we develop our specification of a structural model at early stages of design, we can get by with very simple symbols. It is only at later stages of the design that we flesh out these symbols with more and more information. Your example of the perspective display is a good example. At the level of showing the perspective of a building, you don't care about the detailed dimensions of a wide-flange beam; all you need is a very simple representation of an object that stands as a column. It is very late in the design process that things like flange dimensions, etc. enter. My colleagues in architecture, who are dealing exclusively with geometric modelling, cannot understand that a center line dimension and a few functional properties, such as moment of inertia, are perfectly adequate models of a beam until a very late stage of design. It seems to me that this kind of thinking may be the way out of the dilemma that you posed.

H. WERNER - I would like to stop the discussion on this topic and pass over to the next topic, to the presentation of Prof. Okukawa "The application of sensor technology and computer use for setting a large caisson on the sea bed".

M. FANELLI - I was very much interested in your presentation Prof. Okukawa. There is one point that was not clear to me. You essentially monitored the different quantities about the positions of the caisson, the force of the different winches and the status of the water flooding the various compartments, and then you got information on which to base the next move of the controlling apparatus. How was the forecast of the next motion of the caisson evaluated? Was there a model of the equations of motion of the caisson, implemented in your computer system that predicted the next step and compared the prediction with the observed position and took corrective actions or what? It seems to me that it would be natural, once you have a computer system, to incorporate such a predictive model of the actions, that you take on your controlling system, into your overall controlling system. And then another question. As long as I understood it, the actual operation of the controls, such as the winches and pumps, was manual. Did you ever consider making it automatic, based on the information and the processing done by the computer?

A. OKUKAWA - For your two questions, perhaps, you will have the same answers. The part of the next following operation in these controlling systems should be depending on the operators and the director. There is no estimation for the next following operation, because the conditions of the contruction site are very changeable, then complete automation system is not applicable.

S. SHIMADA - I can help him for his answer. Perhaps the computer program has no dynamic programs forecasting the movements. I think the manager, or director, controls the pump pressure.

M. FANELLI - Can I make another comment or another question? It seems to me that to try to incorporate in your computer system a situation like this, the equation of motion of the caisson in order to forecast the next movement and the effect of the operations that you are going to effect on the controlling apparatus, would be beneficial to the stability of the operation. Moreover, such a model would be very helpful in simulating offline the performance of the system and to train your operator. Is it clear?

A. OKUKAWA - Such system, that satisfies all conditions of the construction site, will be perhaps cast very expensively. For the purpose of training, before the final setting of the caisson is done, the workers are examined on an other site like the actual construction site, I think.

H. WERNER - Are there other questions on this topic? So, we pass over to the next two topics. Are there any question to Mr. Steiger or to Dr. Nuti on "Optimum design methods" or on "A computer program for the analysis and design of prestressed concrete structures"?

G. SCHMIDT-GOENNER - I have a question to Mr. Steiger. I think I got the main thought of your presentation that not always the cheapest single element will give the cheapest global solution, but I think the main problem may be to get realistic prices for the single member in connection to the whole. You understand what I mean. It may be quite an other thing,if you have the same beam for example in a thousand members or in ten members, and now you try to get the cheapest solution. If you use this member only once, you will have an other price as if you use it, may be, a thousand times just even if it is not the cheapest, or not the lightest as in your example. So I think that it will be a very big invent if you get all these decisions a man normally does , when he is planning and calculating for his construction,in a computer program.

F. STEIGER - You are quite right. You can never extimate in the situation of a designer, who is not the man who has to build the construction, he is not employed in the company, in a building company. In our example, we made a case study and all these objectives you mentioned have been examples based on these objectives. The results have been obtained inserting realistic figures for materials and equipment prices of summer 1981. The question that a beam is more cheap if you can make a hundred or thousands of the same type, is right and it is the task of the decision maker to give an upper and lower level of these prices, including this special case naturally. We can never estimate exactly the prices. Yesterday I talked about a method to evaluate these upper and lower limits and so come to a result.

Safety Inspection System of Existing Structures

Système d'inspection pour la sécurité des structures

Inspektionssystem für die Sicherheit von Bauwerken

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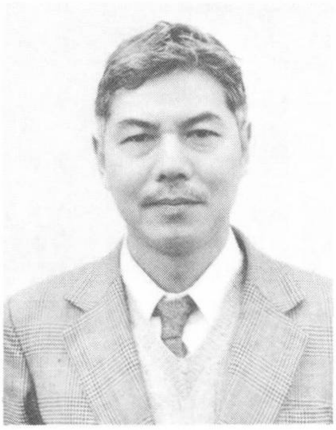
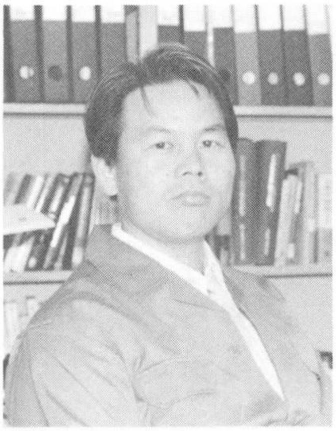
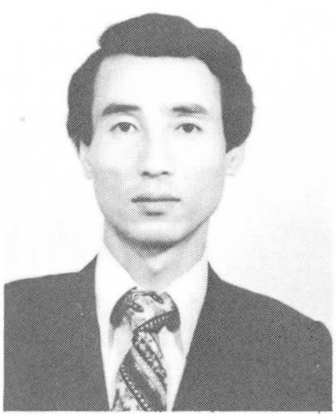


Shizuo Shimada, born in 1931, got his Dr. of. Eng. at the University of Tokyo. After five years as a Lecturer there, he joined the Nagoya University in 1963 and was promoted to full Professor in 1977. He worked with bridge engineers as a special numerical analyst on many practical problems.



Tadaaki Tanabe, born in 1940, got his Dr. of Eng. at the University of Tokyo, worked with Reese Consult. Eng. in USA and then at the Central Research Institute of Electric Power Industry, Japan. He joined the Nagoya University in 1981 for the research of concrete structures.



Masafumi Kato, born in 1947, got M.Sc. at Nagoya University. He worked at the Technical Research Laboratory, Takenaka Co., Ltd., Japan. He the joined Nagoya University in 1978. He is now working on structural measurement systems.

SUMMARY
Over the past 18 years, the authors have been involved with the analysis of vibration data obtained from existing structures. Recently some comparison have been carried out on data measured twice within ten year period on the same structures. The method of statistical analysis is established into an inspection system which makes graphical representations with the aid of standardized computer programs.

RESUME
Forts d'une expérience de dix-huit ans dans l'auscultation des ouvrages soumis à des vibrations, les auteurs ont entrepris récemment la comparaison systématique de séries de mesures effectuées sur un même ouvrage pendant une période de dix ans. La méthode d'analyse statistique utilisée a été généralisée pour être introduite dans un système d'auscultation qui fournit des résultats graphiques à l'aide de programmes standardisés.

ZUSAMMENFASSUNG
Seit 18 Jahren befassen sich die Autoren mit der Vibrationsanalyse von Bauwerken. In den letzten Jahren wurde eine Methode ausgearbeitet, welche die am gleichen Bauwerk gemessenen Daten von zwei 10-Jahresintervallen vergleicht. Mit der Methode der statistischen Analyse wird ein Überprüfungssystem festgelegt, das die Resultate graphisch mit Hilfe des Computers darstellt.

1. INTRODUCTION

It is usually a problem of man's sensibility to comprehend the safety of something. One says it is safe and another insists it is dangerous. As to the existing structures of civil engineering, no practical reasons could be found for repairing or reconstructing until some unfavourable failures would occure. For an instance of aseismic design of structures, the theory will be proved when an earthquake fortunately attacks a structure as an expected magnitude, but our interests are laid how existing structures are safe or not at present before an earthquake attacks them. Therefore, real vibrational characteristics are needed to evaluate the theoretical assumption.

Formerly, the measurement of natural frequencies is beyond of practical procedures because structures are too large to be excited by a shaking apparatus. Thanks to the recent development of electronic techniques, faint vibration is able to amplify for data recording. Random vibration, which is ever ignored as nonsense, has become fruitful data for the statistical analysis. This is possible only by the use of an electronic computer.

Our first systematic test was carried out in 1968 along with a load capacity test of an old bridge. Strain measurement was carried out under traffic control in midnight. However, our measurement of the bridge vibration was carried out in daytime under usual traffics. The method aimed not only the safety of field works, but also to develop a new non-destructive testing of existing structures. It was found that our procedures are easy and safe for field works, reasonable on costs and of good accuracy for estimating natural frequencies of the bridge.

The Jpapn Expressway Corporation is ever earnest to test bridge vibration in order to take the data for a loading design. On occasions of new bridge construction, a huge shaking apparatus is set for measurement. It is, however, more expensive than our method, but the authorities are not allowed to abandon the machine instantly. So that we have had several occasions to cooperate the tests, and which proved precise agreement between two results.

Since 1969, the corporation constructed an expressway for Nagoya from Tokyo with many bridges of various shapes. From the point of view of our research interests, we were allowed to test them before public uses. Random excitation on bridges was done by a heavy duty truck under construction work. In 1981 after eleven years, We tested the same bridges by the same method at the same positions and under usual traffics.

Experienced by a lot of tests these years on many structures, we have become a counsellor of structural safety how they are. Most of requests are concerned, more or less, with the interaction of structures against foundations, because structures are never built under standardized earth condition. For the sake of mutual understanding among clients, a standardized method is required to show them the facts clearly, and to compare relatively how it differs or meets. We named the method as a safety inspection system.

The system is consisted of a measuring system, a data management system aided by computer graphics, and some knowhows to make engineering decision. The first two systems are able to standardize physically as hardwares and softwares. The last article depends on many examples ever experienced.

Recently some comparison has been carried out between the data of structures that measured twice with ten years interval; bridges as mentioned above and a tall concrete chimney, respectively. We will explain several interesting topics obtained by our measurements in the following two chapters.

2. CHARACTERISTICS OF BRIDGE VIBRATION

2.1 General properties

No structures vibrate more analogically to the theoretical assumption than bridges. There is a relationship between the natural frequency and the length of span due to the design specification that limits the maximum deflection against bridge span.

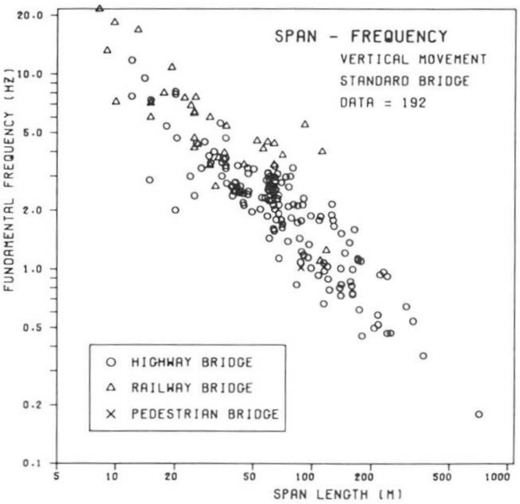


Fig.1 Relationship of fundamental frequency to span.

Fig.1 shows statistical distribution of natural frequency along bridge spans summarized from many reports. As a matter of theoretical facts, a maximum value of static deflection due to its own weight is proportional to the square of period of its natural oscillation. That is 25 cm to 1 second, 1 metre to 2 seconds, and so on. The fact meets approximately with any kind of vibration even in horizontal direction, where the static deflection should be calculated by loading of its weight horizontally. This is the reason why a natural frequency is an important parameter to know the structural stiffness.

2.2 An arch span with less horizontal stiffness

Unexpected low frequencies are often detected in horizontal direction on a long girder, because a bridge is basically designed to bear the vertical loading. Stresses are checked in design against horizontal as well as longitudinal loadings, but nothing is specified for those movement.

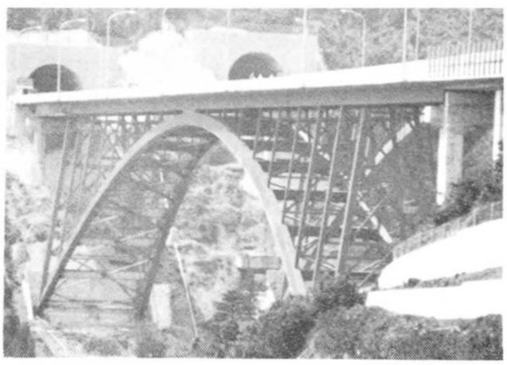


Fig.2 An arch bridge that caused lateral vibration.

An expressway(Fig.2) was constructed over a valley with a 160 metres arch rib. Gentle breeze is enough to excite the horizontal vibration with a period of 1.3 second. Moreover, longitudinal movements were eminent at both bridge ends. Because of 2.4% down slope of roadway, the lower end moved greater than the upper. An erection engineer confessed us that the bridge should have been designed to be more strengthened for the sake of concrete casting. The joint with a bearing system was damaged soon after public uses by the twisting of the floor system in a horizontal plain.

2.3 A failure test of a prestressed concrete span

When a bridge is losing its bearing capacity, natural frequencies will decrease relatively. An interseting failure test was carried out in 1980 on a small prestressed bridge over an expressway. It was removed for the sake of a new bypath construction afterwards.

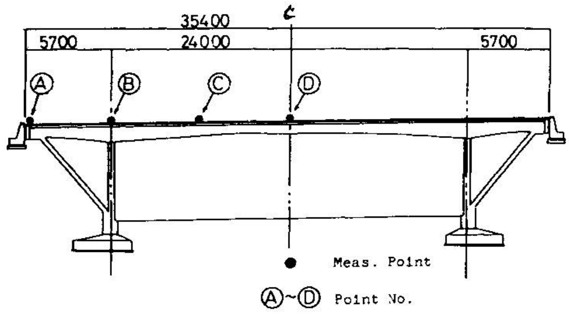


Fig.3 An over-bridge for load capacity and vibration tests.

An oil jack supressed a girder with anchored rods. After every release of loading, the natural frequency was measured. It decreases as 5% at 60% loading of the maximum capacity and it reached to 17% at 95% loads. The lateral vibration decreased as about 8% at final stage.

Usually, a structure has several number of frequency modes. The lowest cycle is much concerned with the bearing capacity of a structure. The higher modes are little affected relatively to the first mode. A spectrum analysis is, therefore, worth to know the decrement of a principal frequency among others.

2.4 Long term surveys of expressway bridges

As introduced in the previous chapter, the data of the expressway bridges were taken twice with eleven years interval. The data were compared carefully from the point of view on frequency decrement. Steel bridges showed no remarkable difference, but the second test was unfortunately carried out after strengthening works of floor systems which damaged by about eightyeight million traffic vehicles during ten years, where heavy trucks increased as about 30% to 48%. The concrete slabs were strengthened by intermediate stringers.

On the contrary, a prestressed long bridge showed about 5% loss of value on a principal frequency. The bridge is consisted of three each two spaned continuous girders. A pier with 31 metres height is fixed to a girder forming a T-shape with each 90 metres span. The bridge took any mending but asphalt pavement. The test results do not seem serious on accounting other properties, but it is recommended to test again after more ten years. We have several other concrete bridges for the second test.

2.5 Medium span bridges

A lot of short and medium span bridges are important to test their security by comparing natural frequencies and damping parameters. We have little for twice tests, but many of various ages. A simple prestressed girder bridge is so elastic at its completion that a truck driver of field works once asked us its security. Medium span highway bridges with about 50 metres are often notorious for public users because they feel uncomfortable vibration.

A man feels very sensitive when vibration ranges about 3 to 4Hz, which is the principal frequency of such bridges. As far as they are notorious, they seem to be safe at present because they have small values of damping parameter. Characteristics of vibration on small bridges are much affected by the composite system with piers, abutments, foundations and filling earth.

Many people think that abutments never move dynamically, however, it is natural to observe some degree of vibrations, in which we found rarely unreasonable movements. Generally speaking, a new structure seems to be laid softly on the earth. It becomes hard as if it is tightly connected with the earth. This is comparatively observed in the spectrum analysis as the increase of high frequency elements. An abutment, for an instance, showed lateral movement when measured at its completion, however, it was detected little after ten years.

Another abutment is situated at the foot of a hill as if it retains the landslide of the hill. The vibration was observed when a heavy duty truck ran around the active area ranging to about 200 metres distance. The bridge was reconstructed to escape from this area.

Japanese civil engineers are very often requested to construct a structure on the soft alluvial layer. Short span bridges are then designed for saving the large concentrated reaction against the earth. Hammer action on a pile gives good information to know the characteristics of earth and to decide whether or not the pile has sufficient bearing capacity during works.

3. A STUDY ON TALL CONCRETE CHIMNEYS

3.1 A breaf history

In 1914, a mining company constructed a tall concrete chimney with 155.4 metres near HITACHI city by the national technology. In 1916, another concrete chimney, 165.6 metres, was erected at a smeltry plant in KYUSHU by the international contract. The latter was the tallest in the far east. The chimneys are ever being in use more than a half century without any mending, or almost impossible to do something. The tallest chimney was attacked by twice earthquakes in 1968 and caused 12 metres loss of height by the second earthquake.

The mining company asked us in 1969 if there could be any method to test its safety by non-destructive inspection. We had no prospects at that time that vibrational measurements might be effective to sound chimney safety, however, it seemed worth to do something on picking up vibrational phenomena. Since the chimney is in dangerous state to climb up over the shaft, sensors were set at the basement. Shaking on a chimney was expected by the natural wind due to von Kármán's vortex excitation.

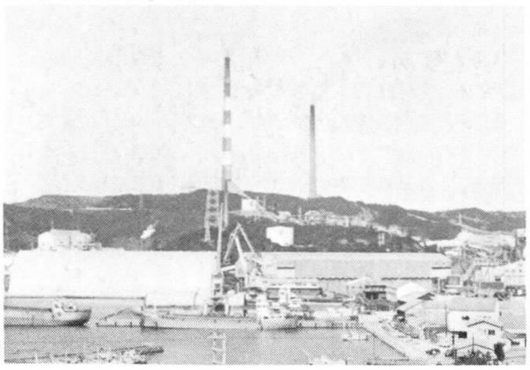


Fig.4 The broken old chimney and the new chimney, KYUSHU.

It was our first experience to take data on such a structure, but the data were in good quality for the statistical analysis. The same procedure was taken at the first chimney in 1974. Moreover, the second measurement was carried out in 1981 on that broken chimney after 12 years use. By that time the mining company erected a new chimney, 200 meters height, in 1974 in the same yard. It was also measured. A contractor of the new chimney had carried out a vibration test at its completion by a shaking apparatus, therefore we can make assess our method relatively.

3.2 Natural frequencies

We had feared that the sensors would not work at the bottom of chimney. Thanks to the calm environment, sensors catched faint random vibration that were breathing whenever the wind blew. The data were identified to have several eminent frequencies. The running spectra were displayed in the first time for our analyses, successfully. The data were random, however, we could find out possible frequencies on the graphical pattern. One of them is swaying to and fro along time axis. It is supposed that the chimney has a little different bending stiffness in two direction. Another one varies its intensity so as to appear and disappear.

The broken chimney had its principal frequency as 0.39 Hz when measured in 1916 by a seismogram. It showed 0.31 Hz in 1969 after the loss of height by earthquake, and 0.30 Hz after more twelve years in 1981. The second natural frequency, about 1.2 to 1.7 Hz, dropped as about 5% during 12 years, however the third and fourth increased a little.

In order to compare theoretically, an elastic model is assumed with respect to the rocking basement. The numerical results teaches us that the first mode of vibration is delicately affected by the condition of the earth. On the other hand, higher mode of frequency could be more concerned with the materials of chimney shaft.

The first natural frequency of the chimney vibration is not so important as that of a bridge. It gives a reference value for static stability standing on the earth. A series of natural frequencies are to be compared relatively where the first one is reduced into a unit. The series becomes as about 1, 4, 10, 18, 30, respectively. Such series are calculated by several theoretical models so as to demonstrate the measured values. The data of other two chimneys are reasonable. The broken chimney seemed to have less effective height because the third and fourth frequencies are relatively large.

3.3 Discussions on the safety

We were requested by the owner of the broken chimney how it be. Materials test was also carried out on the fallen specimens. The dynamic response was calculated by a theoretical model against the random excitation of earthquake. It teached us that the broken chimney should be assumed as not an elastic beam along the whole shaft, but as to be a stacked block with little strength over high shaft. We concluded in 1969 that the chimney would cause loss of height about ten or twenty metres by a next strong earthquake, but would remain safely along the sufficient height.

Comparative studies among three concrete chimneys have clarified the characteristics of vibration more practically. When a chimney is elastic, it has several frequency modes. The highest frequency which could be observed is about 10 Hz, and this plays an important roll for possible chimney failure against an earthquake. The first natural frequency should be considered as a parameter for static stability that cause a chimney turn over. A series of natural frequencies will teach the distribution of stiffness along the shaft.

Our studies have been supported by the powerful aid of an electronic computer. For instances, the running spectra are able to calculate practically by the FFT method. Unless shown graphically, we could not identify the higher frequency mode definitely. The FEM helps much for theoretical models.

4. MEASURING SYSTEM

4.1 Concepts for the system

Vibrational data of a structure are valuable only when they are measured at the structural site. Since we have students, field measurements should be safe and easy for their collaboration. Moreover, it is desirable not to disturb field works under construction or daily uses of a structure. A precise instrument designed for the laboratory use is not always suitable for rough circumstance in the field. Formerly, one of the most important tasks was to keep the reliable electric power supply for the instruments. Sensors, for an instance, apply a moving coil system which generates voltage output without any amplifiers.

Since 1960th, a battery driven instruments has appeared that suits for a movable laboratory in a motor car. Among several fabricators, we adopted a SONY data recorder by the following reasons. It uses a standard audio tape which is able to purchase at any place. The company will keep the same specification for a long period. It is expected to exchange a data tape among many researchers, and so on. We have about 200 original data tapes during these 15 years.

A measuring system is basically consisted of three sensors and a data recorder with 4 recording channels, the fourth of which is for voice recording. Two or more same but absolute systems are recommended to make a synchronized measurement at several positions for the sake of field workability.

4.2 Self-recording sensors

A portable sensor is sometimes required at a distant position from an equipped car. For an instance, at the work site of a long span bridge, a sensor is equipped with a cassette recorder. A fabricator of oceanographical instruments makes us good advices for our ideas, however, it costs a little expensive yet.

Accounting the recent development of a micro-processor with large memory chips, a satelite data accumulating system is becoming practical with reasonable costs which could enough to pay for extension cables. The vibration data are directly recorded into a cassette tape or a disquette as digital values. A personal computer makes intelligent procedures even in a field office. Such a system will become popular in near future.

4.3 Use of a vibration level meter

Standardized by ISO, a vibration level meter is able to use as a sensor. The meter indicates, however, mean magnitude of vibration that may make feel a man's sensibility. It is useful to know at a position instantly whether or not it vibrates. As a preliminary survey of the chimney, we had checked by a meter that the chimney basement was certainly vibrating.

For the inspection of structural stability, a natural frequency is reqired. A low frequency less than 1 Hz is difficult to feel physically, and this is more important when a structure or a structural member becomes dangerous. As mentioned in the article 2.1, possible maximum deflection of an elastic structure depends to its natural frequency, therefore a very simple frequency meter shall be fabricated along with a level meter.

5. SOFTWARES FOR DATA ANALYSIS

5.1 BASIC language interpretor as a manager of programs

Several number of libraries on computer programs are prepared for our researches, where usual structural analysis by FEM is included for estimating the dynamic behavior of a structure. The VIBDAP, vibration data processing, is a program package for data handling under the support of a graphic library. Storage and retrieval of vibrational data are of important works. It needs special peripherals for digitalizing the analog records into the computer readable formats.

In order to carry out the inspection reasonably, some standardized procedures are required so that various results are relatively compared or emphasized among a lot of data. On the other hand, special analysis is very often required on every case when a man is interested to look over the data from the different stand point. His demands could be impatient for waiting a new computer program. For instance, looking at a graphic screen, he may ask a figure instantly more enlarged, with different scales, or being transformed by functional relationship. For this purpose, we use a language interpretor 'NUCE-BASIC' as an interactive processor for the management of various procedures.

Considering on the explosive increase of computer users who learned BASIC language on a personal computer, any of problem oriented programs could become more convenient if they are controled under a BASIC language. A user is to learn only special commands which are prepared by an engineer for additional procedures. Such idea is possible whenever a BASIC language processor allows to refer other program units. NUCE-BASIC is composed by standardized FORTRAN and able to work alone interactively as like that of a personal computer. Its principal purpose is, however, to make other FORTRAN subprograms easy to refer under BASIC statements.

Another processor 'COMMAND-EDITOR' is prepared for an engineer who composes a problem oriented BASIC lnaguage interpretor with additional FORTRAN sub-programs. This is a generator of a program which ensures to refer additonal sub-programs with necessary arguments. For instance of a SUBROUTINE SUBA(A,B,C), BASIC statements allows to say SUBA A,B,C. A function sub-program such as FUNCB(X,Y) is able to use in mathematical expressions. Well known libraries such as of the TEKTRONIX's graphics are useful whenever they are supplied as a set of sub-programs. Accounting of the user's manner of language, keywords could be referred by alias names.

As a supervisor of research activities on computer programming, we have been troubled many years for making better manuals so as to collaborate together among program developers. It is cumbersome to comprehend manuals which are supplied by a programmer with not always the kindest manners. The idea of NUCE-BASIC is helpful to share the duties among engineers, program developers, supervisors as well as users.

Common users are requested to have the knowledge of a BASIC language in the least sense, which could be trained by a personal computer without toil. They are informed by an engineer that the current processor is intelligent with additional commands, specification of which is only the manual to be referred.

A program developer is to compose several sub-program units independently for definite procedures. He may be asked to decompose sometimes a large program unit into a set of simple procedures. Rules for programming, as used in common software companies, become more understandable whenever he comprehends his shares to contribute one of BASIC commands. On the contrary, an engineer is to take care of syntactic design so that a user is easy to operate on his keyboard.

5.2 Usage of computer graphics

Our safety inspection system is basically supported by visualisation techniques aided by computer graphics. Since vibrational phenomena are invisible, nobody could exactly understand them unless he might be experienced again on a shaking bed. But his understanding is subjective to his personal experience. Several properties such as natural frequencies and damping parameters are decoded for the sake of mutual understanding among engineers who are trained how they mean.

Since graphical media are able to inform a lot of properties at a glance, various kind of graphical reports will help to inform the vibrational phenomena objectively. However, they seem alike the art of impressionism to a client who asks the safety of a structure. It is required, therefore, to show him a lot of examples how they meet together or differ relatively so that he is convinced on the facts measured.

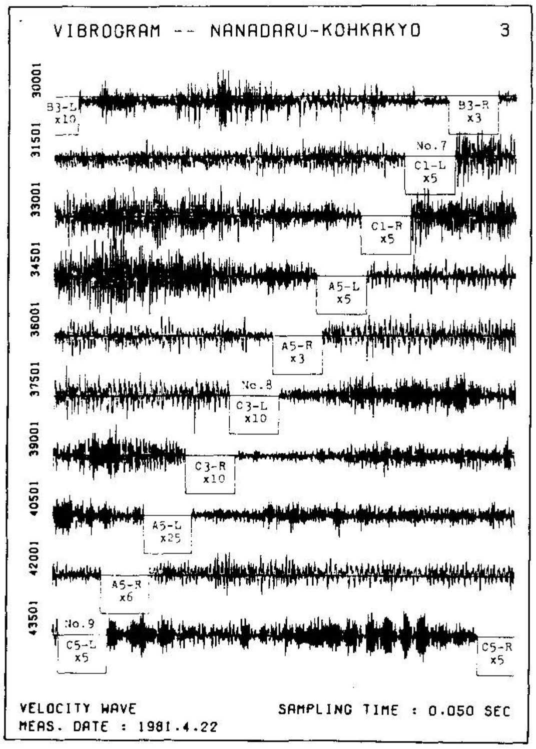


FIG.5 Catalogued oscillogram.

An oscillogram gives basical information on the vibrational data. All of digitalized waves are drawn graphically so as to edit a catalogue of measured data. An A4-sheet has length of ten minutes records with reference counters of digitalized values on a magnetic tape, by the aid of which any position of data groups may be extracted for another analyses(Fig.5).

The catalogued oscillogram is a long continuous record, physically. But it is consisted of many logical records which are terminated by DC signal clearly different against the wave data.

The tape has several files. At the beginning of each file, literal information is added on the measurement as well as the data format so as to help the file read from a program.

The first impression is very important as like looking at man's face to estimate the randomness on an oscillogram. Usually, a new elastic structure gives fine images. It becomes rougher and less active after years. Concrete structures seem to become older than steel structures.

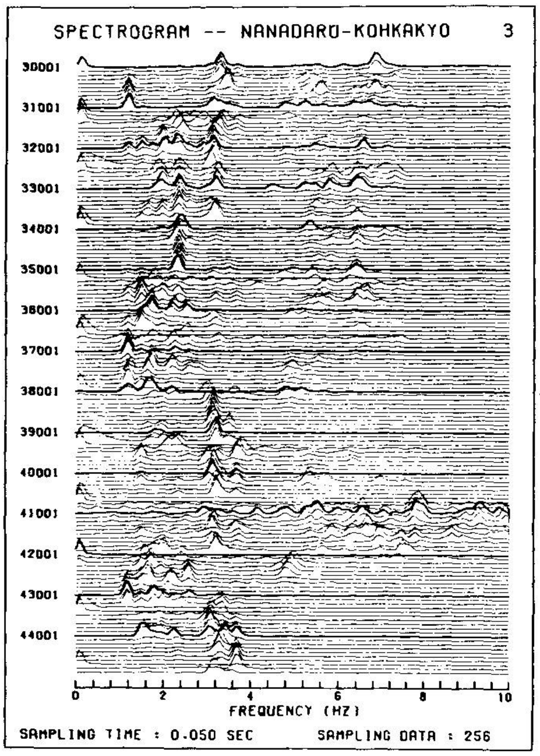


Fig. 6 Running spectra

EL CENTRO NS IMPERIAL VALLEY

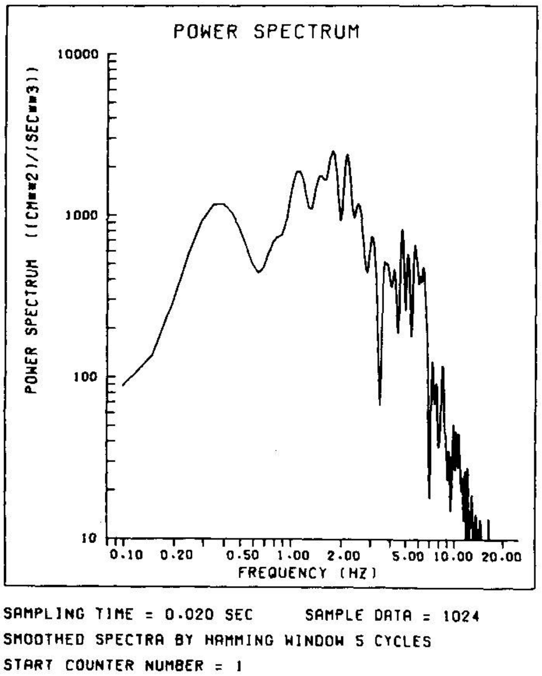


Fig. 7 A spectrum drawn with logarithmic scales.

The spectrum analysis is one of the powerful tool in order to extract the periodical properties that are hidden in randomness. However, it is delicate with respect to the numerical procedures. From the administrative point of view, running spectra are convenient along with the catalogued oscillogram.

Without accounting illogical boundaries between data, spectra are calculated at every 4 seconds using each 256 samples by the FFT method. The spectra are drawn sequentially from top to bottom on an A4-sheet so as to correspond to the oscillogram.

Each line of spectra is not so accurate as to determine the periodical properties, but it helps to say that this peak is true and the other may be false as error, because the true peaks are found at the same distance along the frequency axis(Fig.6).

More precise spectrum analyses are carried out on a series of records chosen from a catalogue. This is, so as to say, static against running spectra. There are many possible ways on the graphical presentation, because a result will make quite different impression if, for instance, scale axis is transformed logarithmically. Several methods are standardized for the sake of relative comparison among records as well as to the theoretical background.

For the aids of engineering decision making, various kinds of measures or scales are prepared graphically. A simple pendulum with a spring and a dashpot is assumed as a theoretical dynamic model in the first analogy of a measured structure. Fig.7 shows an example of a spectrum which has a pendulum system with a period of about 3 seconds and a damping parameter of about 0.2, because an overall shape of the spectrum seems to be overlaid on a small hill. Since the axes are drawn logarithmically, graphical calculation is able to extract the effect of such pendulum using the theoretical measure. In this example, we concluded that it is the properties of the ground on which a structure stays.

5.3 Interactive handling

Well educated knowledge is required for an analyst of structural safety. He must know some previous information on a respective structure how it may behave dynamically. There will appear many reasonable peaks on a spectrum, but he must decide them whether or not they correspond to those of theoretical prospects. One of natural frequencies could be found faintly in a record or be magnified in another record. He then extracts partial length of records from the catalogued file in order to carry out more precise investigation.

Looking at a graphic screen, a record created in an array V(N) is displayed by a command under the BASEC interpretor, Moreover, several commands are served for interactive procedures (Fig.8). Each procedure is so simply programmed that an analyst can choose any possible transformation on a record, while he can observe the record graphically at any moment. The characteristics of graphical shapes is more important than the numerical values during the procedures. He can enlarge or reduce the values instantly so that the record may become better graphical quality. He then tries to find out some typical graphical patterns which coincide with those of theoretical ones.

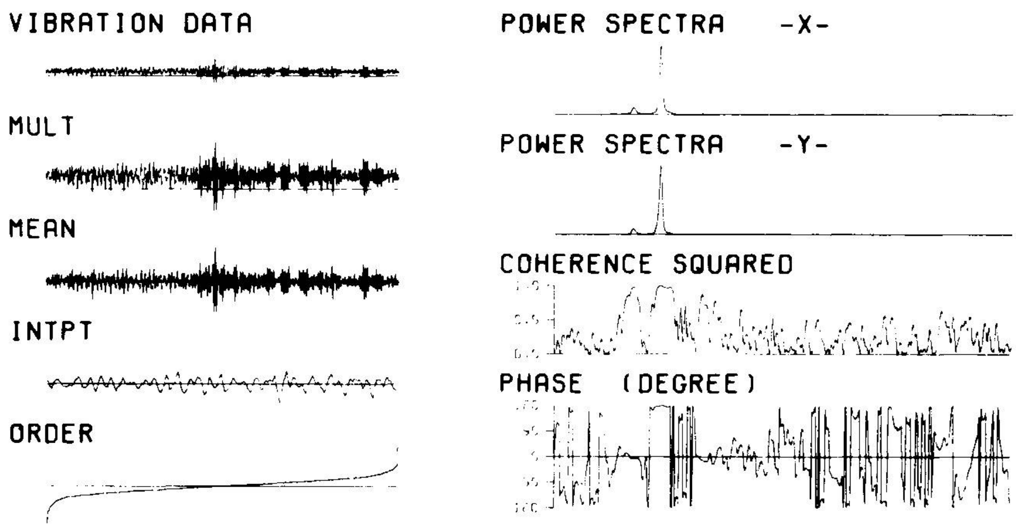


Fig.8 Examples of interactive procedures of vibrational data.

The above interactive procedures are usually carried out on the analog record by expensive electronics instruments while looking at a cathode ray tube. A phenomenon runs on a CRT dynamically. Therefore, it needs careful preset on the instruments throughout the measurement and the analysis. In order to avoid mishandling on an instrument, this is required to be automatic, clever and consequently of high costs. Whenever the analog records are digitalized, we need not hasten to catch up with the time dependent phenomena.

The original record should be taken correctly by measuremts, but a few instruments are enough to ensure the field works. A sensor, for an instance, may have non-linear response against forced vibration. An equalizing amplifier is required from the sense of analog procedure. But, it is unnecessary because the same procedure is carried out digitally. Prior to the digital procedures, however, the response properties of a sensor are given as the least information. This the reason why the field works are carried out by reasonable costs.

As found in common BASIC interpretor, the NUCE-BASIC allows to run after programmed statements. This is a local program which a user may compose. A user is not, however, obliged to do much on his keyboard as a programmer, because many preset commands are supplied by FORTRAN written sub-programs which are able to refer directly or indirectly in BASIC statements.

Practically, a user has at first little idea how a datum should be processed. He is allowed to try anything on his keyboard until he finds a reasonable result. A log makes a record, if necessary, of his keyboard input so that he can remind his jobs how he did. He can reuse the log as texts of BASIC statements by the least effort. Such procedure is applied to all other activities of computer aided design.

5.4 Methods to determine values

5.4.1 Natural frequencies

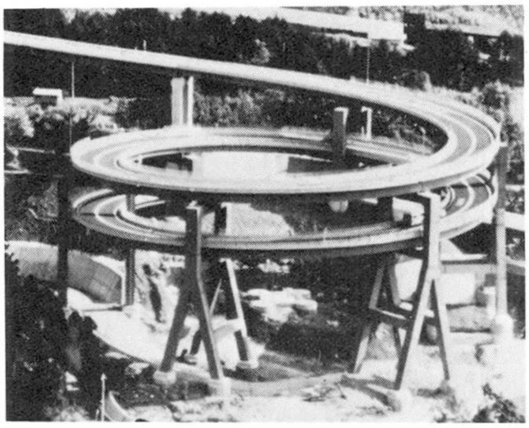


Fig.9 A spiral bridge.

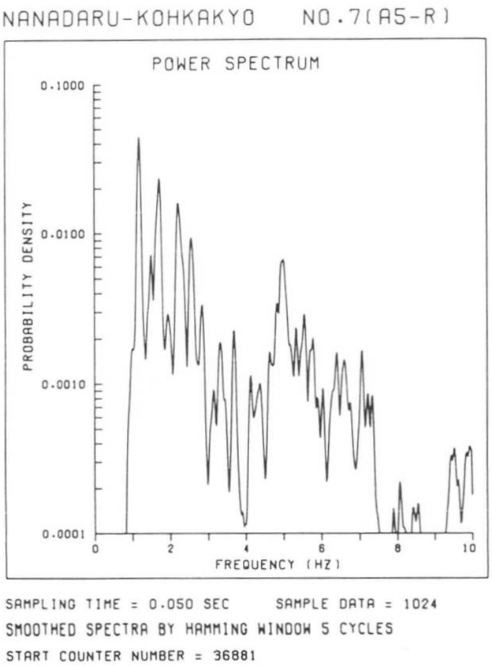


Fig.10 An example spectrum having many peaks.

It is easy to find a peak and to read its frequency on a spectrum if there exists only an eminent hill. It is also possible to point out several peaks by a program, however, unreasonable peaks due to noise are chosen out interactively only by visual aids looking at a graphic screen.

Many natural frequencies are found on a spatial structure. Two or more synchronized measurements are required at several positions where each vibrational mode could be emphasized. Fig.10 shows an example spectrum with many peaks obtained by the measurement of a spiral road bridge(Fig.9).

Correlation is then calculated between two data and compared graphically. In order to identify a value which is possibly subjected to a frequency mode, some discussions are necessary with taking account of amplitudes, phases as well as theoretical estimation.

We have identified six elements of spatial frequency mode where sway, twist and oval deformations of the spiral structure are included. Four other frequencies are identified to be subjected to local vibration of girders which are sustained by columns. Numerical calculation by FEM showed good agreement, therefore the structure is confirmed it is safely designed and constructed.

5.4.2 Damping parameters

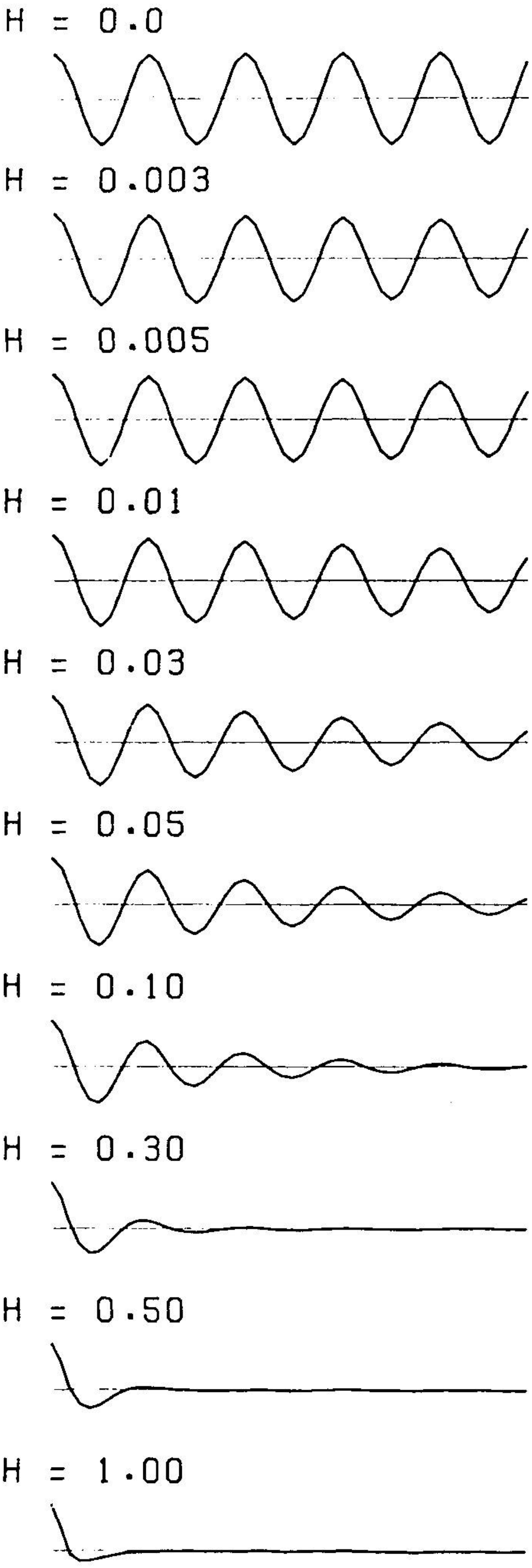


Fig.11 Response of a simple pendulum with a dashpot.

A damping parameter is one of the leading values to evaluate a structure whether cohesive or not against dynamic loading. As for practical procedures, three methods are used together or respectively. One is a half power method that evaluates a damping parameter from the width of a spectrum hill at a half of its height.

The second method is more graphical than the above. A spectrum should be drawn by the logarithmic scales both on power and frequency axes. Looking at a graph, we are going to find out several hills, the shapes of which may be proportional to those of theoretical patterns. An example is shown in Fig.7.

The third method is also graphical. An auto-correlation function is calculated from the vibration data. We use the properties of this function that it is nearly proportional to the free oscillation of a structure excited by an impulse. Compairing to the theoretical patterns, which are prepared graphically, a damping parameter is decided as of the most proportional pattern. This method is very practical to identify a high cohesive damping parameter(Fig.11).

An auto-correlation function is convenient practically to compare dynamic response among different structures or different occasions on the same structure. When a structure is new and elastic, a fine sinusoidal figure is obtained. Something spoiled after public uses, such as increase of cracks on concrete floor of a bridge, then becomes the shape of function more steep and less periodical.

The behavior of earth structures is interesting. Vibrations are measured under piling works or by artificial excitation of a heavy duty truck at the site. The soils seem to become more elastic and harder after years. We found an example case at a bridge foundation which seemed in good settlement during ten years.

5.4.3 Error correction

As far as the statistical analysis is concerned, a probable value may not true. It may emphasize unrealistic images. We must be so clever as to identify the facts out of ghost images. There occure many errors by the following causes;

a) non-linearlity of sensors,
b) inappropriate sampling,
c) inevitable noise,
d) numerical errors,
e) human errors, and so on.

The first two items are carefully considered on the design of a measuring system to cut off the high frequency level. A velocity sensor prefers rather than an acclererometer. Some degree of non-linear properties are visually detected and corrected interactively as shown in Fig.8.

A figure of a response spectrum is important whenever it is drawn on logarithmic scales, because it is able to use as a sliding scale on a computed spectrum to subtract the effect of a sensor.

The same method is carried out by a transparent paper on which Fig.12 is drawn. Fig.13 is measures that gradu ates the natural frequencies of an elastic beam under several support conditions. This is used to find out some possible peaks on a spectrum.

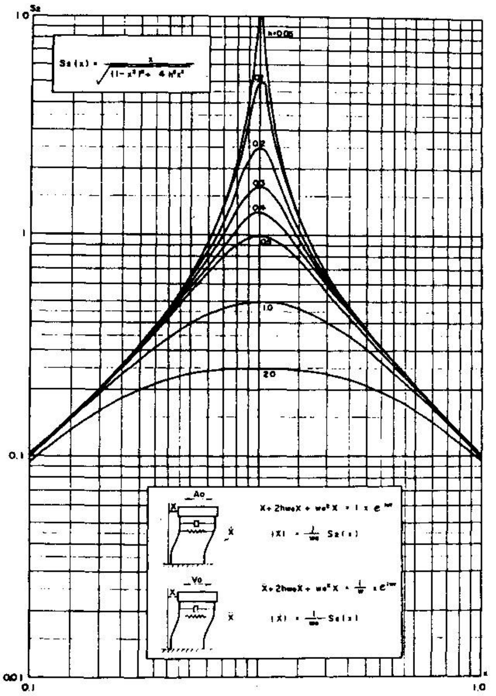


Fig.12 A monogram of response.

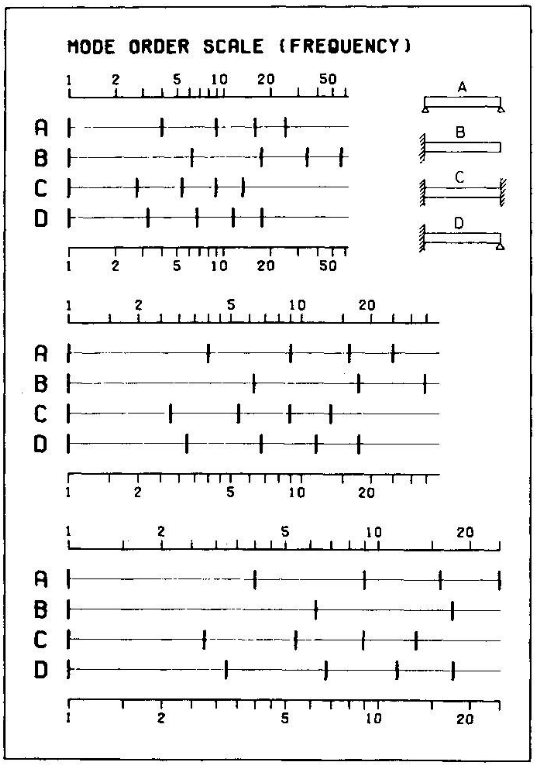


Fig.13 Frequency scales.

The item c) is an important datum that should be recognized clearly in the analysis. A spectrum shows, for an instance, very sensitive peaks against partial amount of data, but it becomes not always correct even when a sufficient length of data are used for calculation. A graphical method suits therefore to tell us some possiblle property without a word. The use of colour graphics is under consideration in our research activities.

In order to avoid errors by mishandling of data or by misunderstanding, standardized procedures are recommended. In addition a lot of experience helps to correct misunderstanding. By our experience, the data measured in the past are often reviewed when nearly the same structures are tested. Theoretical analysis has become practical in recent years. The mode of frequency, for an instance, is often misunderstood as other.

6. CONCLUSIONS

In order to make administrative decision on the safty of a structure, there is no measures to compare the remainder of its life. If unexpected unhappy occures, man says 'it happens at its centenary'. A boy often puchases a tiny tortoise without living a few days. His father consoles him that it should have had a hundred years old.

Since structures are never mass produced as machinery parts, the statistical method of design criteria will not ensure the safety of a structure at its circumstance. Therefore, every structure should be inspected at its site. As like a medical doctor inspects a human body through a stechoscope, safety of structures could be assured by means of vibration tests and data processing. Same as the word 'medical electronics', systematic setup of structural electronics will be required in both hardwares and softwares.

A lot of information should be summarized for the inspection not only by the vibrational measurements, but also by other non-destructive methods. Comparative studies among the facts teach us only practical knowledge on the structures. Standardized methods are therefore necessary so that data may be relatively compared.

Vibrational phenomena are rather difficult for common people to understand the characteristics with respect to structural safety. We have introduced several examples in this paper how the measured data are analysed by the use of an electronic computer.

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Graphical Data Processing in Civil Engineering

Traitement graphique de l'information en génie civil

Grafische Datenverarbeitung im Bauingenieurwesen

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SUMMARY
Graphical data processing in structural engineering lags behind alphanumeric computer applications. Advances in graphics supporting structural analysis and in implementation of presentation methods are contrasted with difficulties in digital modelling of physical objects. Topics for research and development to promote graphical data processing in structural engineering are presented.

RESUME
Le traitement graphique de l'information n'a pas suivi le même rythme de développement que les applications alphanumériques. La réalisation de progrès dans le domaine de la représentation graphique liée à l'analyse des structures se heurte aux difficultés inhérentes à la modélisation sous forme digitale des objets physiques traités. L'auteur cite les thèmes de recherche et de développement les plus prometteurs dans ce domaine, notamment pour les applications de l'ingénieur constructeur.

ZUSAMMENFASSUNG
Die graphische Datenverarbeitung ist hinter den alphanumerischen Anwendungen der Rechner zurückgeblieben. Fortschritte in der graphischen Unterstützung statischer Berechnungsverfahren und in den graphischen Darstellungsmethoden stehen im Gegensatz zu Schwierigkeiten mit den digitalen Modellen physikalischer Objekte. Es werden Themen für Forschungs- und Entwicklungsvorhaben zur Förderung der graphischen Datenverarbeitung im konstruktiven Ingenieurbau angegeben.

1. THE SIGNIFICANCE OF GRAPHICAL DATA PROCESSING

The drawings of Leonardo da Vinci mark the beginning of modern technology. Since that time, drawing has remained the language of engineering. The structural engineer uses diagrams and drawings extensively. Insight into structural behaviour is gained from diagrammatic representations of computational or experimental results, ranging from simple bar charts to perspectives of principal stress conditions in bridge decks and in thick containers. In structural design, which is creative rather than analytical in nature, the engineer relies heavily on sketches and perspectives. The information required on the construction site is transmitted primarily in the form of construction drawings. The production and use of diagrams and drawings is therefore an integral part of structural engineering.

The traditional process of drawing on paper at a drawing board is extremely versatile. Simple tools are used with little effort. The draftsman and the engineer are in complete control of the contents of the drawing. Once the skill has been acquired, relatively few conventions have to be observed in performing the work. All efforts can be concentrated on the contents of the drawing. The traditional method does, however, suffer from the limitation that human effort is required to perform tasks which could potentially be performed by machines:

- Human effort is required to collect the data from which drawings are constructed.
- Human effort is required for purely mechanical tasks in the drafting process, such as shading, lettering, construction of perspective views, enlargements and reductions in size and copying of parts of drawings.
- Human effort is required to collect data from drawings for use in other phases of the construction process.

Graphical data processing on computers offers the opportunity to eliminate some of these limitations. The geometric data and the computational results can, for instance, be used to draw isolines of stress automatically. Care must, however, be taken that this is not done at the cost of restraints on the creative process. In particular, the nature of the available software should not limit the engineer to specific types of structures or behaviour. Computer hardware and software must offer a degree of comprehensiveness and flexibility in graphical data processing which is comparable to that of paper and the drawing board. Where this is not acheived, the engineer is inhibited by the tool and will resist its introduction. The elimination of mechanical tasks is not an adequate compensation for the loss of creative freedom.

The wideranging application of computers to support analysis and text processing in structural engineering is an established fact. Negative influences on structural engineering must be expected if we are not successful in acheiving a comparable level of graphical data processing. Powerful numerical tools and reduced computer costs have already led to heavy emphasis on structural analysis at the cost of reduced emphasis on structural design. Effective methods of graphical data processing are urgently required to restore the balance between structural analysis and design.

2. THE FUNDAMENTAL PROBLEM OF GRAPHICAL DATA PROCESSING

During the last three decades, new technologies have created a wide range of functions for computers and communication networks:

- Collection and presentation of data,
- Storage of data so that they can be automatically processed,
- Processors for logical, numerical, text and control data,
- Transfer of data between devices, locations and persons.

Applications in structural analysis, text processing and machine control have been highly successful. This raises the question why applications in graphical data processing have been less successful. The differences between the development of graphical data processing and other branches of digital data processing must be attributed to very fundamental differences between images and symbols. This is demonstrated by the following examples.

Any given value, for instance the letter E, can be regarded either as a symbol or as an image. The distinction is essential. The symbol E is identified by a unique code, which is defined within the context of a set of symbols. The image E consists of a set of pixels or a set of vectors. These geometric elements individually do not posses a meaning related to the letter E.

The keyboards, printers and terminals of computers contain built-in standard sets of symbols. Symbols are therefore entered and displayed in a computer with minimal effort. The color values of the pixels of an image are also readily scanned and displayed. The recognition of the relationship between the pixels is, however, assocated with considerable effort. This effort increases as more irregular images, eg. the lines of a freehand sketch, are interpreted.

The relationships between symbols differ significantly from the relationships between the geometric elements of an image. As an example, it is noted that the symbols of a text are ordered implicitly from left to right in a line and from top to bottom on a page. Seperators are defined for words as well as sentences. The variables in arthimetic and logical expressions also are related through simple operators and conventions. In contrast herewith, the geometric arrangement of the components of a drawing must be registered explicitly. Seperators comparable to blanks in a text are not available. Thus the plan of an office geometrically consists of a series of polygons. Logically it consists of walls, floor panels, furniture, dimensions and text. The same polygon represents both the edge of the floor and a face of the wall.

These simple considerations point to the fundamental problem of graphical data processing. The symbolic contents of drawings tends to be low compared to that of text and computation. The low percentage of implicit information makes it necessary to store a considerable amount of data explicitly and to apply powerful algorithms to relate and transform these data. The resulting demands on computer hardware and software lie more than one order of magnitude above those for alphanumeric applications. It is not suprising that graphical data processing has lagged far behind other applications of computers in structural engineering.

3. THE STATE OF THE ART

Graphical data processing on computers has not been able to replace the drawing board in structural engineering practice to a significant extent. The development of software packages and individual applications have not yet been followed by general acceptance in the profession. Of a wide variety of graphics packages offered at computer conferences and fairs, only a limited number is specifically suited for structural engineering. Figure 1 shows a summary of such packages offered at the SYSTEMS'81 in München.

In view of the high symbolic contents of diagrams, it is not surprising that efficient graphic tools are available primarily for schematic representations. Typical applications are shown in Figure 2. Structural analysis on computers involves a large volume of input data and computational results. The checking and interpretation of these data without graphics capabilities is tedious and susceptible to error. The functions listed in Fig. 2 are therefore of great practical value in the analysis and evaluation of structural behaviour. Nevertheless, they represent only a small volume when compared to the drawings required in structural engineering

FIDES, München

DLT	Reinforced Concrete Drawings, Reinforcement Lists
EUKLID	Perspectives, Hidden Lines
SHELLS	Shells of Revolution

Prof. Werner, TU München

PLOTSET	Geometry, Displacements, Stresses, Forces, Envelopes

T-PROGRAMM, Reutlingen

STFPLOT	Geometry and Reinforcement of Prefabricated Elements
FEPP1	Geometry, Displacements, Stresses, Temperatures for FEM

RIB, Stuttgart

MENOS	Perspectives, Intersections, Hidden Lines
MINOS	Reinforced Concrete Drawings, Reinforcement Lists
DUPLAZ	Reinforcement Drawings for Floor Slabs
RIBKON	Interactive Drafting for Building Construction

IKOSS, Stuttgart

FEMGEN	Interactive Finite Element Generator
FEMVIEW	Viewing of Nets and Results, Hidden Lines

CALCOMP, Düsseldorf

GTB	Drawings of all Types without Dimensioning
EDS	Technical Drawings with Dimensioning

FIG. 1: Graphics for Structural Engineering at SYSTEMS'81[14]

1. Graphs of a function of a single variable
- Load displacement curves
- Time history of displacements, strains or stresses at selected points in the structure
- Variation of displacement, stress or force on cross-sections and along the axes of structures members.

2. Isolines of a function of two variables
- Lines of equal displacement
- Lines of equal stress or equal min/max principal stress.

3. Presentation of principal values
- Crosses representing direction and magnitude
- Orthogonal nets tangential to the directions of principal stress.

4. Eigenshapes of structures
- Dynamic analysis
- Stability analysis.

5. Influence lines and envelopes
- Frame structures
- Plate structures.

6. Finite element nets on selected surfaces
- Numbering of elements, nodes and materials
- Undeformed and deformed geometry.

7. Projections onto developable surfaces
- Finite element nets
- Isolines
- Crosses of principal stress.

8. Isometric and perspective views
- Validity checks on computational models
- Deformation patterns illustrating structural behaviour.

FIG. 2: Graphical Functions for Schematic Representations

design, particularly the drawings for formwork and reinforcement of concrete structures or the workshop drawings for steel structures.

Graphics software packages have also been developed to support the analysis and design of particular structural elements or of complete structures, eg. floor slabs, beams and columns, cores of high rise buildings, cylindrical tanks and steel frames. These packages tend to be adapted to the requirements of a particular design office or construction company, and to reflect the specific knowhow, organisation, procedures and equipment on which the business of their originators is based. Even such basic components of working drawings as bar shapes, reinforcement mats, prestressing systems and connections for steel structures are standardized to a limited degree only, and companies tend to implement their own specific preferences.

General purpose computer-aided design systems with comprehensive graphic capabilities for a wide range of structural engineering problems are less likely to be developed and accepted in the near future than similar systems in related areas such as automibile engineering, electronics or aerospace engineering. This is documented by the large volume of graphics packages already being offered [14] for computer applications in these industries, which benefit from close ties between computer-aided-design and computer-aided-manufacture, concentration of production in factories and the production of articles in larger numbers than is usual in the building industry. It is, nevertheless, essential to undertake strong efforts to develop graphical data processing in structural design in order to preserve the creativity of structural engineers in the computer environment.

4. TOPICS FOR RESEARCH AND DEVELOPMENT

4.1 Improvements of the Symbolic Contents of Drawings

A primary objective of basic research in graphical data processing is the expansion of the symbolic contents of graphic data. By enlarging the set of available symbols and the volume of information associated with each symbol, the storage requirements for graphics are reduced, the development and maintenance of graphic application packages is facilitated and the portability of the packages between devices, operating systems, manufactures and users is enhanced. The following examples illustrate this type of research:

1. The basic graphical elements and functions are standardized to give them a symbolic character comparable to that of the operands and operators in algebraic or logical expressions. In order to request the operations associated with a particular function, it is sufficient to store the function code and to identify the operands. The operands, in turn, posses standardized attributes comparable to the type and length attributes of algebraic values. Additional functions are defined to set and to modify these attributes. The graphical functions in the Information System of Technology (IST) [1,2,3,4] and the Graphical Kernel System (GKS) are research efforts of this type [5,6,7]. The Graphical Kernel System is summarized in Fig. 3.

2. Groups of basic graphical elements and functions are combined to create higher level graphical functions. These functions are usually independent of specific applications and may be compared to subroutines for the solution of linear systems of equations or eigenvalue problems. Such higher order graphical functions are, for instance, used to plot functions and isolines; draw and annotate axes; hatch specified areas; create representations of space curves, three-dimensional surfaces and intersections; draw projections and perspectives; remove hidden lines and surfaces. These functions, like the basic functions, can be requested by specifying their code and an appropriate set of arguments. Due to the volume of the data involved, it is frequently necessary to define a data structure for the arguments. The graphics display system MOVIE [8] contains functions of this type. It is summarized in Fig. 4.

CONCEPTS

Two-dimensional graphics on vector and raster devices.

Input and output at graphical workstations.

Definition, transformation and administration of pictures.

Intermediate storage of segments independent of workstations.

Long term storage of graphical information in metafiles.

Implementation of functional capabilities in levels

FEATURES

Output primitives:	polyline, polymarker, text, fill area, etc.
Input primitives:	locator, valuator, string, pick, etc.
Input types:	request, sample, event
Segment capability:	Group of primitives with pick identifiers
Operations for segments:	Create, transform, insert, close, rename, delete
Segment attributes:	Visibility, detectability, highlighting, priority
Segment transformations:	Scaling, rotation, translation
Coordinate systems:	World (WC), normalized device (NDC), device (DC)

FIG. 3: Summary of the Graphical Kernel System[5]

CONCEPT

Interactive system to generate and manipulate three-dimensional models consisting of polygonal elements, and to display the models on vector or raster graphics devices.

FEATURES

DISPLAY:	Perspective display of polygonal elements Scaling, translation and rotation of models Removal of hidden lines and surfaces Node and element numbering Coloring, shading and highlighting of images Animation of scaling, translation, rotation, deformation
UTILITY:	Generation and editing of element models File management for geometric, scalar and vector data
TITLE:	Generation of two- and three-dimensional characters
SECTION:	Slicing of models to expose internal surfaces Extraction of surface data for DISPLAY
MOSAIC:	Construction of polygonal elements from contour lines
COMPOSE:	Creation of multiple image line drawings.

FIG. 4: Summary of the Graphics Display System MOVIE[8]

3. Drawings are composed of elements [9]. New methods are being developed to describe the relationships between the elements of a drawing. The elements may, for instance, be associated with fictive layers. By specifying appropriate combinations of layers, it is possible to selectively draw subsets of the total information associated with the drawing. Thus an undeformed finite element net, the deformed finite element net, the numbers of the nodes, the numbers of the elements and the numbers of the materials used may be associated with different layers. It is then possible to determine at execution time whether element numbers are desired or the deformed net is of interest, and to draw the appropriate information by selecting the corresponding layers. In interactice graphics, extensive functions [5] are required to set and pick markers, to set the visibility and detectability of elements of a drawing and to pick, duplicate and transform elements.

4. The classical symbolism of structural engineering is enhanced. Existing conventions for schematic diagrams are generalized, eg. the symbols for bar shapes, bolt diameters, welds and steel profiles. Within each area of application, it is then possible to create additional higher graphical functions for these symbols. Some graphic packages, eg. CADIS [10], contain functions which permit the definition and use of new symbols by the user himself at execution time. Thus the various shapes of T-sections for concrete beams may be treated as variations of a symbol defined by the user. Groups of symbols can be combined to define new, expanded symbols. This could, for instance, be an assembly of T-beams and other elements to form the cross-section of bridge. The logic involved may be compared to that of multi-level subroutines in alphanumeric data processing.

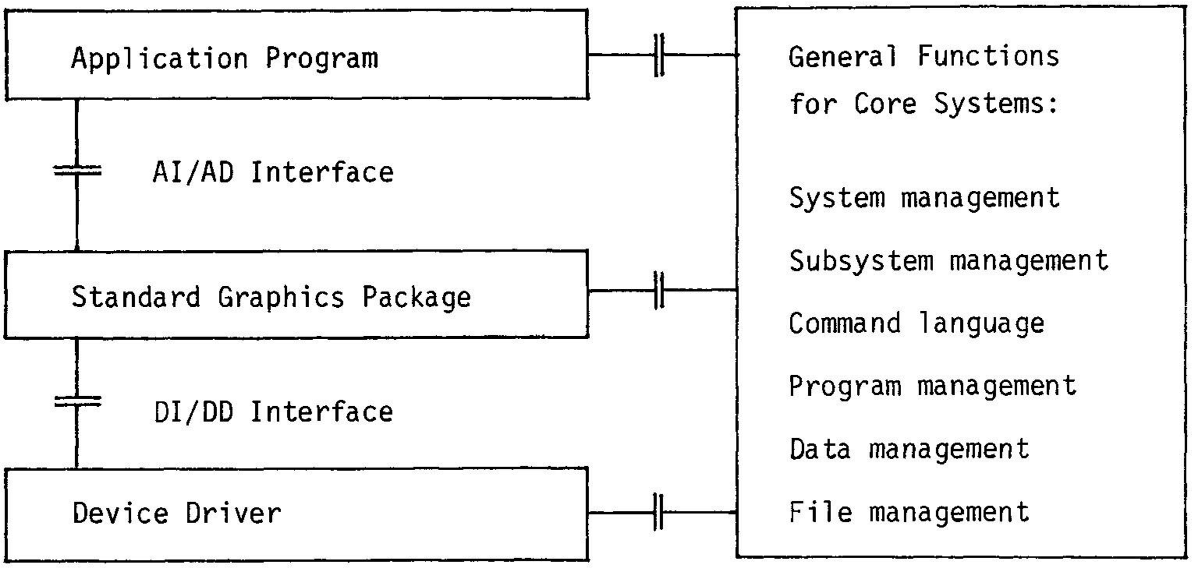
4.2 Advances in Data Technology

Advances in data technology create new opportunities for graphic data processing in structural engineering. As the capabilities of the graphic work stations expand and their integration into the standard software of computer systems is improved, new applications become economically feasible. The following examples illustrate this development:

1. The design, analysis, construction and maintenance of structures posses a common data base. Through this data base, graphic data processing is related to all other aspects of computer-aided structural engineering [1]. Software for graphic data processing should therefore be designed in conjunction with the software used for data and file handling, procedure management, command language interpretation, etc. The modular concept of graphics software is illustrated in Fig. 5. In particular, unnecessary duplication of data management functions in graphics packages should be avoided. Graphic and nongraphic functions should be clearly seperated by defined calls and exits. As well-structured software packages for computer-aided structural engineering with core functions for data and procedure management become available, the implementation of graphics capabilities is greatly simplified.

2. In order to facilitate the interaction between engineer and computer, graphic data processing should be decentralized where possible. The decentralization of functions and devices could be readily implemented if it were associated with a decentralization of the data. Yet a central data base is required for each project in order to assure the coordination of the design process. Local processing therefore demands temporary local files and validity checks when local files are reintegrated into the central file. For example, the reinforcement design of a beam may be accomplished with a local file which becomes part of the central project file unless a project modification at another local workstation has changed the length of the beam while it was being designed. The large volume of data involved, the high rate at which changes tend to be made and the fast response times required for efficient design all place high demands on the operating systems and on the organisation of the design software.

STRUCTURE



OBJECTIVES

Portability of application packages (AI/AD Interface)

Standardization of programming methods (Standard Graphics Package)

Minimization of device dependence (DI/DD Interface)

Portability of graphical representations (Exchangeability of Drivers)

AI/AD: application independent / application dependent

DI/DD: device independent / device dependent

FIG. 5: Modular Graphics Software Systems

3. During interactive design, the engineer frequently decides not to use the results of an analysis or design step because he is not satisfied with the result. He then wishes to return to the status quo ante, and to try a different solution. This is not possible if conventional data technology is applied, since the data base is changed in the execution of the analysis or design step. Efficient methods are required to store temporary intermediate data and to integrate these data into the permanent data base if the design step is successful. The large volume and generalized structure of graphic data complicate the solution of this problem.

4. Applications of interactive graphics in structural engineering have been restricted mainly to individual computers or to local computer networks. In order to avoid the unnecessary effort involved in setting up independent data bases if several companies work on a common project, or if the design is to be checked by the authorities, it is likely that geographically extended networks will be used in the future to transmit drawings or data bases from which drawings are generated at the receiving end. It has not yet been possible to establish national or international standards for graphic metafiles, which are a prerequisite for the successful operation of such global networks with graphical functions. Efforts are, however, under way in connection with plans for a German Research Network [11].

5. Reports in structural engineering are composed of numbers, texts and diagrams. These elements are related through their geometric arrangement, for instance their location on a page. They are also related in their meaning: thus dimensions specified in diagrams are used as input for computations, whereas remarks in a text may influence a construction drawing. Such mixed systems require special data structures, which remain to be developed and to be investigated with respect to their suitability.

6. The capacity and the flexibility of graphical devices for computers are not yet comparable to those of the drawing board. In particular, the market does not offer economical electronic storage media comparable in simplicity, visibility, capacity and changeability to graphite on paper. It is unlikely that plotters, digitizers and storage tubes backed by disk storage will satisfy the full requirements in the near future, since a drawing of 100x100 cm at average resolution already contains on the order of 10^8 Pixels. In order to compensate these deficiencies, efforts are under way to develop methods to compress raster data, for instance by conversion into vector data. The problem lies in the efficient modification of compressed data.

4.3 Digital Models of Structures

The successful application of graphical data processing in structural design depends on the development of simple and efficient digital models for structures [12]. While the geometric relationships between the elements of a drawing describe its syntax, the digital model describes the semantics of the object shown. Thus the digitial model indicates that a particular polygon is to be interpreted as the outline of the cross-section of a beam, whereas geometrically it is simply a sequence of straight lines.

1. Digital models of structures frequently are structured as assemblies of structural elements, each of which is described by a digital model of its own. The digital model of the element describes its geometry and structural properties, whereas the digital model of the complete structure specifies the elements and their location in the structure. Models of this type are suitable for wood and steel structures as well as prefabricated concrete structures. Typical elements of such models are:

- Beams, columns and ties
- Slabs, walls and panels
- Flat plates and foundations
- Reinforcing bars, cages and mats
- Connection plates.

2. If a structure is monolithic, the decomposition into structural elements becomes ambiguous. Thus the slabs, beams and columns of a monolithic concrete frame intersect geometrically, and the same concrete may be used structurally to act both as slab and as flange of the concrete beams. Reinforcement can no longer be associated with individual elements, since it frequently continues between elements. In this case, it can be advantageous to define the digital model of the concrete for the structure as a whole without decomposing it into elements. In such models, a set of nodes, center lines and planes is defined and the structural dimensions are specified with respect to this geometric reference frame. Reinforcement bars, mats and cages are then defined as elements and located with respect to the geometric reference frame.

Considerable research and development effort is required to develop and propagate digital models of structures so that they acheive broad acceptance. Success depends essentially on the simplicity of handling of the models, on their adaptability to the needs of the individual design office, construction company and project and on their interface with other phases of the computer-aided structural analysis and design, architecture and construction.

4.4 Development of New Algorithms

The basic algorithms for graphic presentations are well developed. Nevertheless, improvements remain possible:

1. Some of the algorithms for graphic data processing impose high demands on CPU-time and storage capacity. Typical examples are algorithms for perspective views, for the detection of hidden surfaces and for pixel-vector transformations (recognition of the elements of scanned drawings). Research is being conducted to enhance the efficiency of algorithms for these tasks.

2. As the capabilities of communications networks expand, the gap between technical computer graphics and general image processing will narrow. The development of raster graphics contributes to this trend. Considerable research is required on algorithms for transformations between raster and vector data as well as for correlation between vectors and digital models.

3. Effective algorithms for smooth representations of space curves and space surfaces defined by the coordinates of selected points are of great practical importance. The algorithms for smoothing such curves and surfaces are closely related to the finite element method for the bending of frames and plates. Advances in the finite element method can therefore be transfered to graphic data processing, for instance to the construction of smooth isolines and continuous tone images.

4. In some cases, the algorithms providing the input data for graphical representation can be changed so that their results become more suitable. For example, most finite element systems determine the stresses at selected points in the elements. Algorithms for isolines require nodal stress values. Averaging techniques for the stresses in adjoining elements can lead to loss of accuracy. As an alternative, it is possible to regard the results of a displacement analysis as initial displacements for an analysis based on the Hellinger-Reissner-Priciple, treating the stresses at the nodes as system variables. At the cost of an additional analysis, improved nodal values are obtained directly.

5. CONCLUSIONS

The trends which are presented in this paper lead to the following conclusions about the present state and future perspectives of graphical data processing in structural engineering:

1. Graphics support of structural analysis is well advanced. Particularly the graphical functions for finite element packages have become fairly standardized and are available in a variety of program packages.

2. The digital modelling process in structural engineering must be seperated from the viewing process. Modelling is concerned with the generation of data structures representing the physical object in the computer. Viewing is concerned with the geometric representation of objects whose digital model is stored in the computer.

3. The implementation of the viewing process has been structured and standardized. Basic functions are provided as core functions by systems like GKS, higher functions in standard graphics packages like MOVIE. These interact with the application packages and with the general functions for computer-aided-engineering through well defined interfaces.

4. Graphical data processing in structural design depends on suitable digital models for structural elements and complete structures. Considerable further effort is required in this area.

5. Current trends in the prices and capabilities of graphics devices favor the expansion of decentralized graphical data processing in structural engineering. It cannot be foreseen, however, when the drawing board will be replaced to a significant extend by computer devices.

The evolution of graphical data processing in structural engineering will span several decades. It will be a success if the drawing remains the language of the structural engineer.

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Setting a Large Caisson on the Sea Bed

Mise en place de caissons sur un fond marin

Setzen eines Senkkastens auf den Meeresboden

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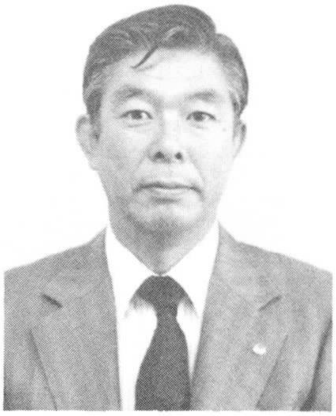

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SUMMARY

This report describes the information processing system used for placing a large caisson on the sea bed. With this system, the floating steel caisson which is a kind of cofferdam and form for the required under water concreting of the main tower pier foundation of a long suspension bridge was set precisely on the sea bed at a water depth of 32 meters and with a 2.2 m/sec. tidal velocity.

RESUME

Le rapport présente le système d'information utilisé pour le contrôle de la mise en place d'un grand caisson sur fond marin. Par ce système, un caisson d'acier flottant est mis en place avec grande précision, à 32 m de profondeur, en présence d'un courant marin de 2.2 m/sec. Il remplit la fonction d'enceinte de protection et de coffrage pour la construction de fondations en béton du mât prncipal d'un pont suspendu.

ZUSAMMENFASSUNG

Dieser Bericht beschreibt ein EDV-System für die Ausführung von Senkkasten auf dem Meeresboden. Mit Hilfe dieses Systems konnte ein Stahlkasten, welcher als Fundament der Pylonen einer weitgespannten Hängebrücke dient, bei einer Strömungsgeschwindigkeit von 2.2 m/sec und einer Wassertiefe von genau 32 m an die geplante Stelle gebracht werden.

1. INTRODUCTION

Presently in Japan, several long suspension bridges are under construction across the straits of Seto Inland Sea. The details of these projects were already presented at past IABSE meetings [1] [2]. As the undersea foundations of the South and North Bisan Seto bridge which is one of these suspension bridges, the method of laying down a caisson has been adopted [2]. Since the substructure work began in October 1978, it is now in progress smoothly, and in October 1980, the first caisson at No. 5 pier site was set carefully on the sea bed in 32 meters water depth. One of the most important requirements in the laying down of a caisson is how to set the caisson precisely and safely at the required position against high tidal velocity. In order to answer the above mentioned requirement, each operator must have correct understanding and exact information about all motions of the caisson during the setting. Moreover, they must continuously conduct proper and effective operation according to the motions of the caisson, but these manual operations seem to be very difficult in the rough condition of the construction site. To solve these problems, we developed a measuring system which consists of computer processing and sensors.
This report describes the electronic measuring system used for setting a caisson on the sea bed.

2. SETTING OF A CAISSON

2. 1 Procedure of the method of laying down a caisson

The procedures of the method are as follows.

(1) Underwater blasting of weathered seabed rock to the setting level of foundation.
(2) Excavation of blasted rocks by large-scale grab dredgers.
(3) Leveling of bedrock surface by using a large diameter rotary drilling machine.
(4) Touring, mooring and setting of the caisson which is prefabricated at a dry dock in ship build up yeard.
(5) Casting of the pre-packed concrete in the caisson. Among each above mentioned procedures of construction, the details of setting of the caisson in item (4) is as follows.

2. 2 Caisson

The Steel caisson is required to be a kind of cofferdam and form for the underwater concreting. As the weight of this caisson is about 10,000 tons, it is not possible to lift up and carry a caisson by a floating crane. Thus, the caisson is divided into two sections (the inner and outer) as viewed on a horizontal plane section. The outer section of the caisson is used as ballast tank in order for it to float stably by itself. The outer section is also divided into ten partitions restracting free water flow at the laying down stages. The caisson is equipped for touring, mooring and setting at a shipyard.

2. 3 Setting of caisson

The positioning and setting of the caisson is conducted during a period of about 3 hours when the tide turns. The laying down of the caisson is conducted by pouring water into ten partitions of the caisson hull with twenty individually controlled water pumps, and the positioning of the caisson is controlled by eight wire cables with 80 mm diameters and eight mooring winches, as shown in Fig.1. The allowance of setting the caisson is expected to be within ±50 cm in position by using the following information processing system which is provided in the control room installed on the deck of caisson.

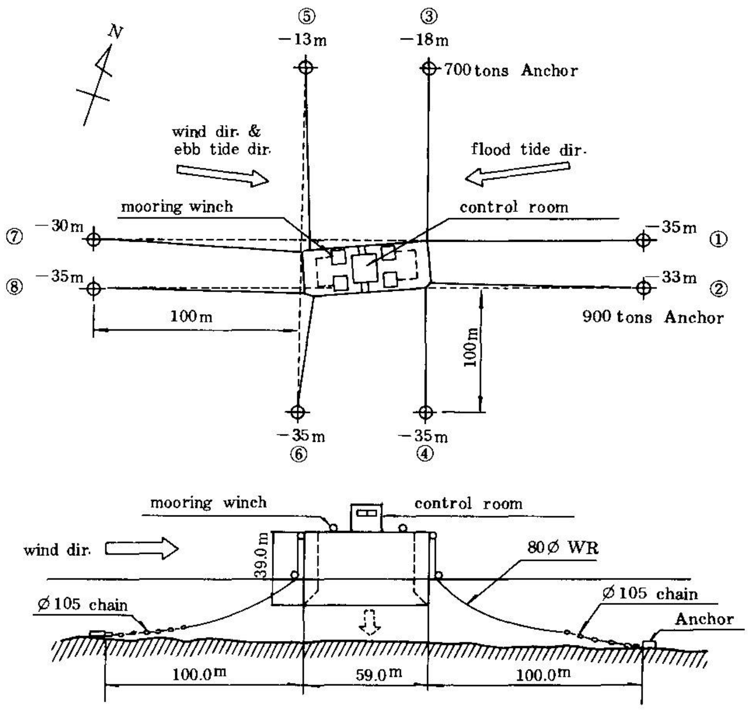


Fig. 1 Mooring of caisson

3. INFORMATION PROCESSING SYSTEM FOR CAISSON-POSITIONING

3. 1 Principal concepts

In order to precisely locate the floating caisson to the required position, the operators would need to know in detail much information, that is, i) the difference between the present position and the required one (in vector), ii) the actual movement status of caisson (in vector), iii) the following position expected by the present position, iv) the following operation on the basis of iii), v) any abnormality of machines when it can be detected and/or how to react to a crisis.

Under the consideration of the above mentioned requirements, the principal concepts for designing the information processing system for caisson positioning are as follows.

(1) The conventional surveying techniques which are commonly used in the state of repose can not be applied as is, because the caisson floats and its position is every-changing.

(2) The informations required for the setting work are i) the positions in plane, ii) the positions in height, iii) draft, iv) gradient, v) ballast tank waterlevel and vi) winch and pump operation status.

(3) The accuracy and the resolution of measuring the position of caisson is within 10 centi-meters and 1 centi-meter respectively. So, triangulation is adopted using two optical distance meters and one digital theodolite. Surveying apparatuses are installed on the land station. The data of surveying are transmitted to the control room on the deck of caisson by radio as shown Fig. 2.

(4) The draft and the water depth against the specified seabed are measured at four corners of caisson in order to obtain the caisson-position in height. The measuring accuracy of water depth is required to be ±1 cm.
(5) The gradient accuracy is required to be ±0.01 degree.
(6) The accuracy of the ballast tank water level is required to be ±0.5% F.S..
(7) The renewable interval of measuring data is required to be 5 seconds considering the measuring period of the distance meter and editing time of the such picture in CRT display.
(8) Software is composed of functions as data collection, data processing, hazard monitor, alarm, CRT display, record, storage of review data and review.
(9) CRT display has six kinds of pictures in seven colors. Each one of these pictures (e.g. the picture of plane position management, height position management and so on) is selected as)
(10) This information processing system is limmited to processing and display of various informations. The operations of mooring winches and water pumps are conducted by each operator who works a operation panel under the order of the director. However, the operation status of each machine is pictured together with the other data on CRT display.

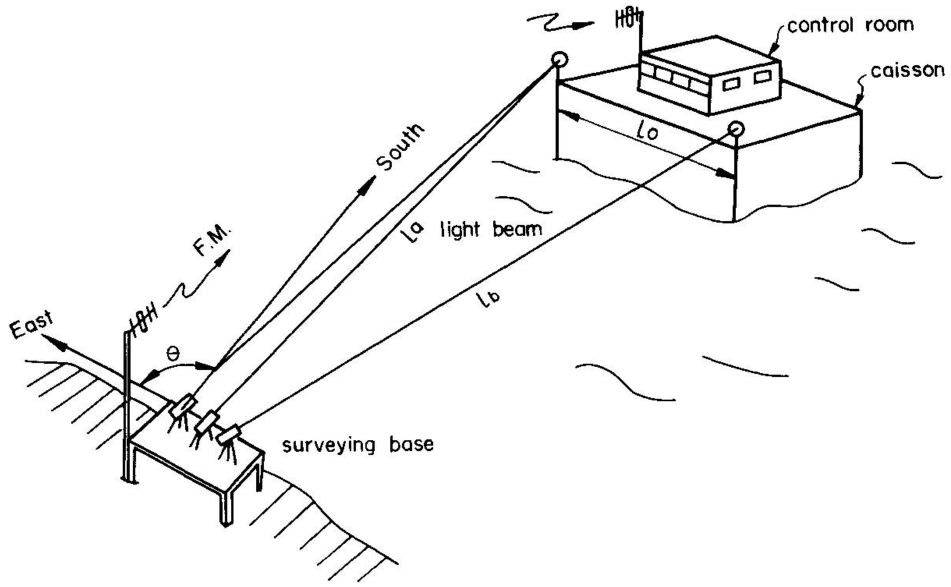


Fig. 2 Surveying system

Table 1 List of equipments

Equipments	No. of set	Main specification
Central Processor	1	Memory Capacity; 128 kw, 16 bits/oneword, microprograming controll system
Input-Output Device	1	Input-oneput interface; which connects between data of sensors and CPU
Paper Tape Reader	1	Speed; 30000 words/min.
Typewriter	1	Speed; 120 words/sec.
External Memory	1	Memory Capacity; 300 k bite, 2 units
CRT	1	20 inches size, 7 colors
FM transminitor	1	Radio frequency; 400 MHz band, Speed; 1200 bits/sec.
Optical Distance Meter	2	Accuracy; 1 cm
Digital Transit	1	Accuracy; 3 sec. in horizontal, 6 sec. in vertical
Depth Sounder	4	Resolution; 1 cm
Diferencial Pressure Pick up	14	Accuracy; ±0.5% F.S.
Diferencial Tranceducer Gradient Pick up	2	Accuracy; ±1/300 F.S.

3. 2 Hardware

The list of the equipments composing this system is shown in Tab. 1. The processing unit consists of a central processor, input-output device, PTR (Paper Tape Reader), and CMT (Cassette Magnetic Tape), which are set in the machine room on the deck of caisson.

These range finders are set in the datum points at the surveying station, which is about 200 m away from the position of setting caisson. Each surveyor, respectively, aims at and persues the targets which are set on the caisson. The data sent from these sensors are collected every one second under the control of the central processor.

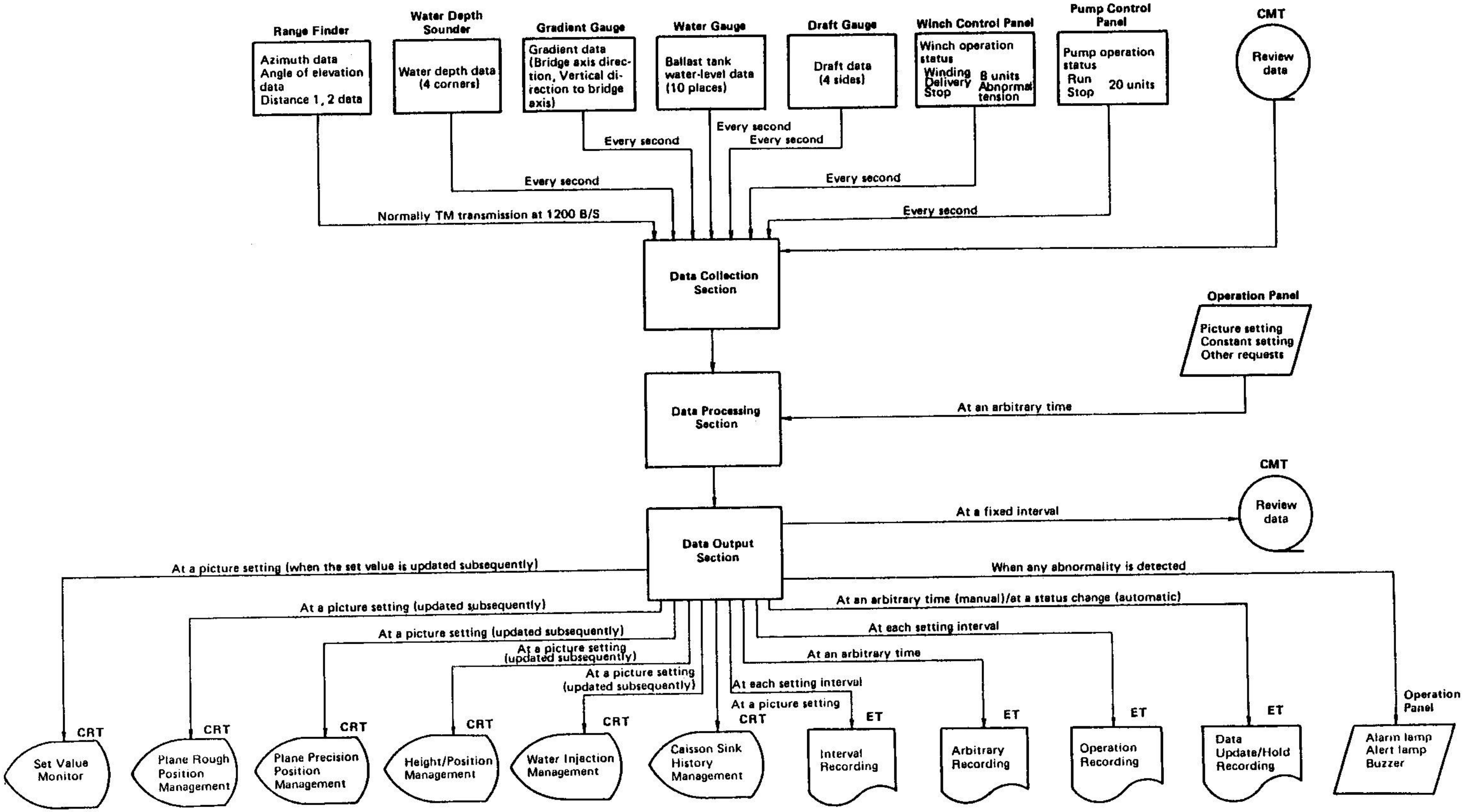
3. 3 Software

Software for this system consists of main system program, caisson position watching program and review program.

(1) Functions of main system program are made up of data collection, data processing, hazard monitor, alarm, CRT display, record, storage of review data and review, as shown in Fig.3. The details of each function are as follows.

i) Data collection section collects both the measured data and the observed data. The measured data are taken from range finders, water depth sounders, gradients guages, ballast tank waterlevel guages and draft guages. The observed data are the winch operation status and the pump operation status.

Fig. 3 Schematic diagram of software



ii) Data processing section has functions of correcting the water-depth by both water temperature and inclination of caisson, and correcting the distance data by the weather conditions. Then it calculates the momentary caisson position.

iii) Hazard monitor has function of finding the abnormal data of updated caisson position, gradient and sinking speed in comparison with the preset limit. And then if abnormality is detected, the monitor puts a light to the alarm lamp or the alert lamp, and rings the buzzer. Then the messages of the abnormality are printed out.

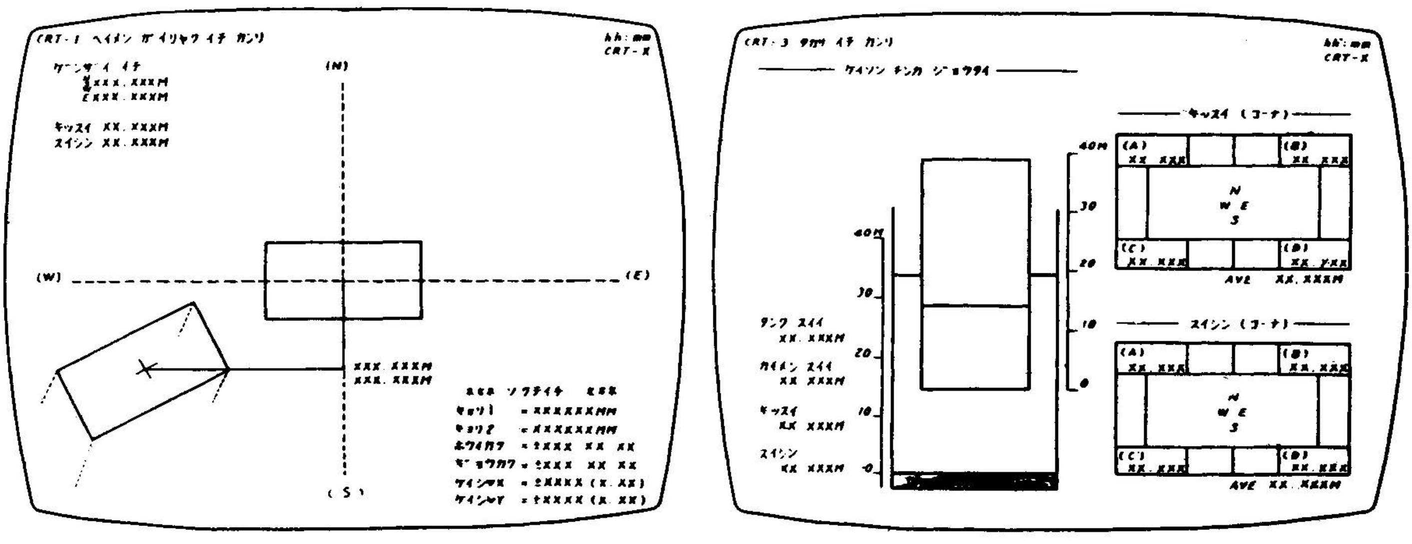
iv) CRT display function edits six kinds of pictures which are the set value monitor, the plane rough position management (Fig. 4(a)), the plane precision position management, the height position management (Fig. 4(b)), water injection managerment and caisson sink history management.

v) Record function edits the results of calculation and prints out the fixed interval recording, the arbitrary recording and operation recording.

vi) Storage function of review data stores the measured data, the observed data and caisson position data in the CMT at the initial preset interval.

(2) The program is prepared in order to check the run of this system and also to confirm the position of caisson before or after the setting of caisson. This program calculates the position of caisson on the basis of the data which is mainly obtained by the conventional surveying. The data for this program is input by means of a key board. This program can run parallel to the main processor system program.

(3) Review program is prepared to review the history of the status of setting of caisson by calling the data from CMT, after the main system is carried out.



(a) Plane rough position (b) Height position

Fig. 4 CRT display format

4. RESULT OF SETTING OF CAISSON

At 10:28, in October 3 1980, the setting of the steel caisson at No. 5 pier site was completed to scheduled time. The position of caisson after the completion of setting was measured precisely by means of the conventional surveying method. Fig. 5 shows the results which were obtained by conventional surveying one week after the setting. The difference between the CRT display values and the results of conventional surveying is about 3 centi-meters. The positioning errors of caisson are zero in rotation against a vertical axis and several centi-meters at the center of the bottom of caisson from the required position. It is considered that this information processing system for caisson-position is available, because the work of setting of caisson was conducted smoothly to scheduled time.

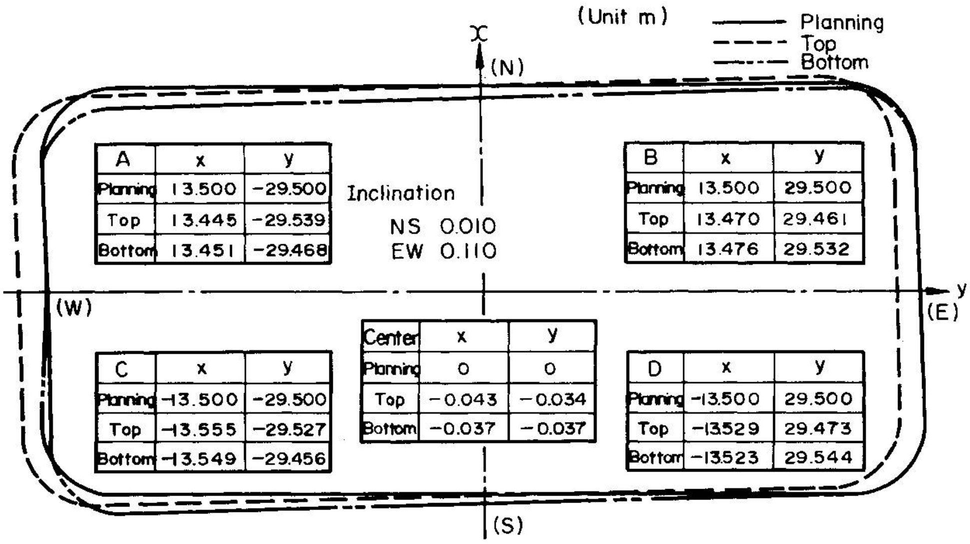


Fig. 5 Error of setting-caisson

5. POSTSCRIPT

The information processing system for caisson-position in this report was developed for the purpose of the specified work, that is, positioning and setting of a large steel caisson with about 10,000 tons. However, it is expected that this technology can be sufficiently applied to the dynamic measuring system for various offshore construction works.

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Method for Optimum Design of Building Systems

Méthode d'optimisation des constructions

Optimierungsmethode für Bausysteme

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SUMMARY

The optimum design of larger building systems as a whole encounters computational limitations even if big computers are utilized. Decomposition of the optimization models to elements, which can be treated separately, maintaining their mutual interdependence by coordinating variables is applicable to a certain class of systems. A pragmatic approach to optimize such members of that class, the elements of which cannot be treated parallely and independently for each set of coordinating variables, is presented. This approach yields an upper and a lower limit of the optimum and shows immediately the reachable optimization profit.

RESUME

La conception optimale de grandes constructions, dans leur ensemble, se heurte à des limitations de calcul même sur un ordinateur puissant. La décomposition du modèle à optimiser en éléments traités séparément, mais dont les interdépendances sont traduites par des variables de coordination est applicable à une certaine classe de systèmes. L'article propose une approche pragmatique permettant l'optimisation, dans les situations où les éléments ne peuvent pas être traités parallèlement ou indépendamment, pour des valeurs données des variables de coordination. Cette méthode permet d'obtenir une enveloppe dans laquelle se situe l'optimum et fournit immédiatement le gain prévisible de l'optimisation.

ZUSAMMENFASSUNG

Beim optimalen Entwerfen grösserer Bausysteme stösst man sehr bald an Grenzen des Rechenaufwandes, auch wenn sehr leistungsfähige DV-Anlagen eingesetzt werden. Dekomposition der Optimierungsmodelle in Elemente, die getrennt behandelt werden können, wenn ihr Zusammenhang durch Koordinationsvariable gewahrt wird, lässt sich auf die Angehörigen einer bestimmten Systemklasse anwenden. Ein pragmatischer Ansatz zum Optimieren solcher Angehöriger dieser Klasse, deren Elemente bei gegebenen Werten der Koordinationsvariablen nicht parallel und unabhängig voneinander behandelt werden können, wird vorgelegt. Er liefert eine Ober- und Untergrenze des Optimums und zeigt unmittelbar den erreichbaren Optimierungsgewinn.

1. INTRODUCTION

Every building or civil engineering work may be considered to be a system, consisting of several subsystems which are mutually interconnected by their functional contribution to the whole building's performance. The optimum design of such a system as a whole encounteres computational limitations because its model has to be described by a large number of decision variables and complicated behaviour functions. If on the other hand a system has certain special properties, then its optimization model might be decomposed to elements which can be treated separately, maintaining their mutual interdependence by coordinating variables.

The decompostion method may be applied to systems with rather loosely connected elements. In [1] such a class of building systems is beeing defined. The defining property of all systems belonging to this class is that their elements can be put in a unique sequence according to the direction of the decisive effect's flow through the system. The decisive effect is the one which the system has to transmit mainly and which has to be regarded in the constraints. Typical examples are statically determinate structures which carry loads "top down" without feedback. Similar system behaviour show inter alia pipe nets and heat supply - heat accumulation systems.

Another property of this class of systems can be derived from the systems's optimization model. As is well known, a mathematical optimization model consists of the objective function and several constraints, all of them beeing functions of the decision variables.

The sets of decision variables describing systems which are members of the class under consideration characteristicly may be divided into disjoint subsets.One of these subsets contains all the coordinating variables which are assigned to more then one subsystem. Each of the other subsets assembles the local variables which are assigned to just one of the subsystems. Hence the whole vector of decision variables x falls into subvectors: y (of the global variables) and zi (of the p subsystems):

$$x = (y, z1, z2, \ldots, zp), \quad (p = \text{number of subsystems})$$

$$zj \cap zk = \emptyset \text{ for } j, k = 1, 2, \ldots, p, \quad j \neq k$$

A system may be optimized by coordinated decomposition if (1) the total number of local variables is much higher than the number of the coordinating ones, if (2) the objective function is either of the additive type

$$f(x) = \sum_{i=1}^{p} fi(y,zi)$$

or of the muliplicative one

$$f(x) = \prod_{i=1}^{p} fi(y,zi)$$

and if (3) the constraint matrix shows a special pattern.

The constraint matrix is a binary valued one, indicating the decision variables' occurence in the inequations which describe the constraints. Each of its columns is assigned to one of the decision variables, each of its rows to one of the constraints. A non zero element announces, that the contraint, to which the respective row is assigned, is a function of the variable, to which the column is assigned (fig 1). Arranging the constraints (the rows) appropriately we may try to produce either a cascade (fig.2.1) or even a quasi-block-diagonal pattern (fig. 2.2) both of them indicating that the system belongs to the class under consideration.

	y_1	y_2	...	y_n	$z1_1$	$z1_2$	...	$z1_{m1}$	...	zp_1	zp_2	...	zp_{mp}
R_1	1	0	...	1	1	0	...	0	...	1	0	...	0
R_2	1	1	...	0	0	1	...	1	...	1	0	...	1
.	.	.		.	.	.		.		.	.		.
.	.	.		.	.	.		.		.	.		.
R_r	0	1	...	1	0	0	...	1	...	1	1	...	1

Fig 1: Constraint Matrix in a general case

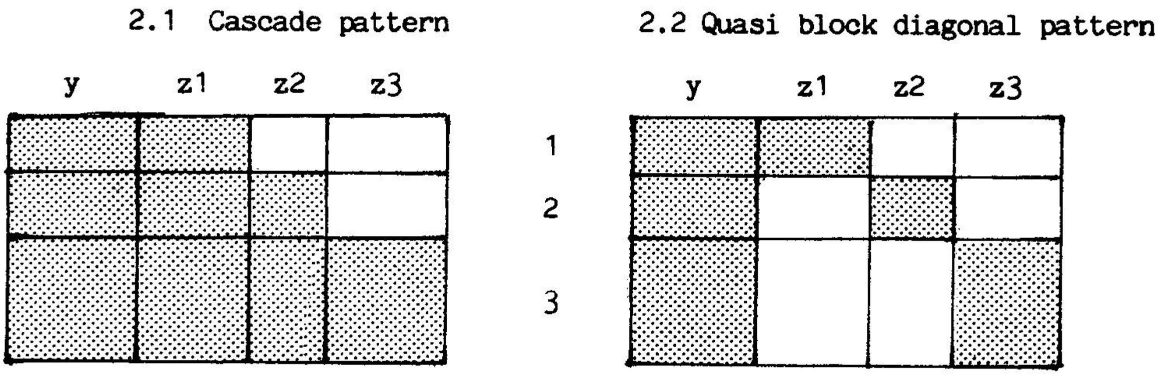

Fig. 2: Significant patterns of the constraint matrix' occupation

Different optimization methods may be used to solve such problems in different cases. If the constraint matrix shows a quasi-block-diagonal pattern a two level optimization method may be applied ([2], see fig. 3). This method is based at the separation of coordinating variables from the local ones . The values of the variables are then optimized at two levels: those of the coordinating variables at the upper one and those of the local variables at the lower one. A detailed description of this method, illustrated by a case study, is given in [3].

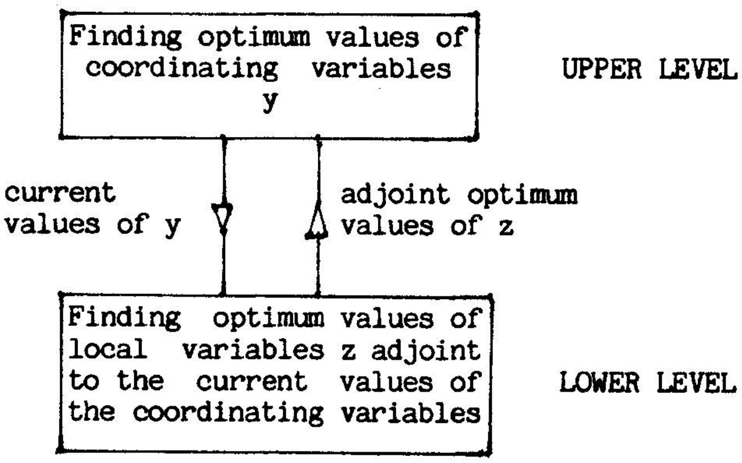

Fig. 3: Two - level optimization

In the case of a system with a cascade patterned constraint matrix one cannot optimize the subsystems parallely and independently at the lower level. A pragmatic procedure for optimizing such systems is presented below. It delivers an upper and a lower limit of the whole system's optimum.

2. A PRAGMATIC APPROACH TO OPTIMIZE SYSTEMS WITH A CASCADE PATTERNED CONSTRAINT MATRIX

If the amount of the decisive effect which at least one of the subsystems emits significantly depends upon the values of this subsystem's decision variables, then it will not be possible to arrange the rows of the constraint matrix such that a quasi block diagonal pattern occurs. With structures e.g. this happens if the variations in the elements' own weight caused by modifications of their size during the optimization cannot be neglected.

The cascade pattern indicates that the subsystems cannot, as this is possible in the case of the quasi block diagonal pattern, be optimized independently from each other, once a set of values of the coordinating variables is chosen. It then might be possible that less 'optimal' subsystems at the beginning of the effect's flow sequence cause a better optimization of the whole system. In case of reinforced concrete framed building structures for example it may happen that to the cheapest construction belong the lightest permissible floor slabs which - depending on the reinforcement-concrete-price-ratio - must not be the cheapest ones in any case.

Generally: If (1) the contribution of a subsystem to the objective function's value is decreased by 'forewarding' an increasing amount of the decisive effect and if (2) decreasing the contribution of that subsystem to the decisive effect causes decreasing its contribution to the objective function's value as well, (a maximum value of the objective function assumed to be optimum) then the following process yields an upper and a lower limit of the optimum:

At the lower level, that means for each chosen set of coordinating variables' values, the subsystems will be handled sequentially according to the flow of the decisive effect. Each subsystem will be optimized twice:

- Once charged by that amount of effect which is emitted by the sum of suboptima of all the subsystems 'upstream' and

- a second time charged by the minimum possible emission of effect from each of the subsystems 'upstream'.

The sum of objective function's components obtained by the second procedure will - according to the presuppositions - be higher than the respective sum of the first one. But the subsystems belonging to that sequence are not compatible to one another, since each of them would feed a higher amount of effect to the flow than this is assumed when dimensioning the following ones. Thus we get an upper limit of the objective function's value which is higher than the strict optimum one really is. The latter will lie between both sums. Only if the suboptima of all subsystems emit the minimum amount effect as well, then the first procedure yields the strict optimum immediately.

The proposed process does not only yield the limits between which the strict optimum is to be found, and therewith the span of reachable optimization profit, but also the contribution of each subsystem to the objective functions's value. Thus the designing engineer will be enabled to decide whether further optimiztion efforts shall be invested and if so, to which of the subsystems.

Some details of the proposed process are going to be illustrated by the following case study.

3. A CASE STUDY: DIMENSIONING A SUPERMARKET BUILDING'S STRUCTURE OPTIMALLY

The roof structure of a single floor supermarket building shall be dimensioned optimally. The building with a plan area of 80 x 80 meters is sketched in fig. 4 Its structure shall be assembled by a few types or prefabricated reinforced concrete elements: ribbed floor slabs, T-beams and columns. The column's reinforced concrete footings shall be cast in situ. Details of the elements are given in fig. 5.

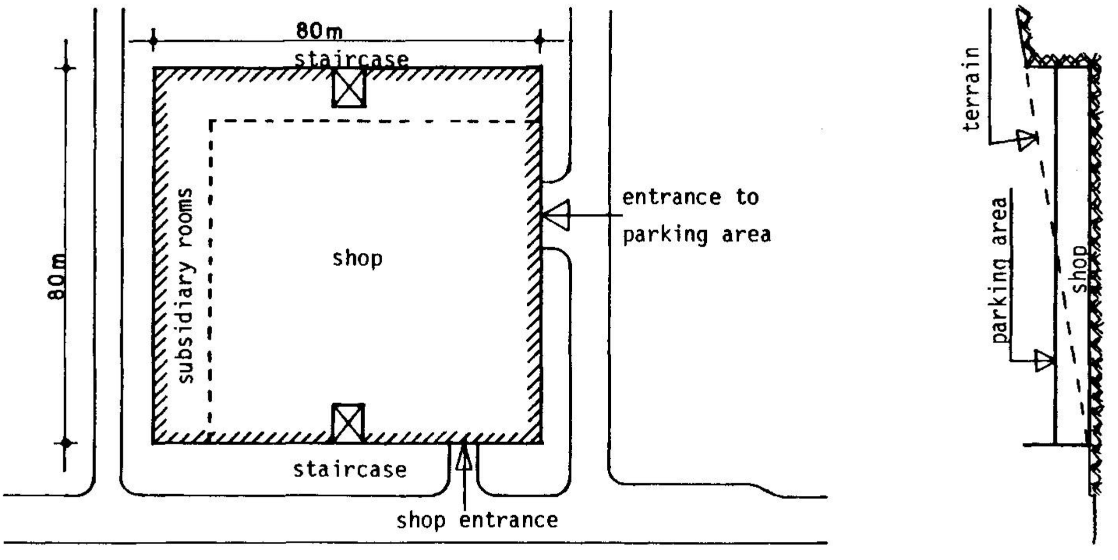

Fig. 4: Lay-out skech of the supermarket building

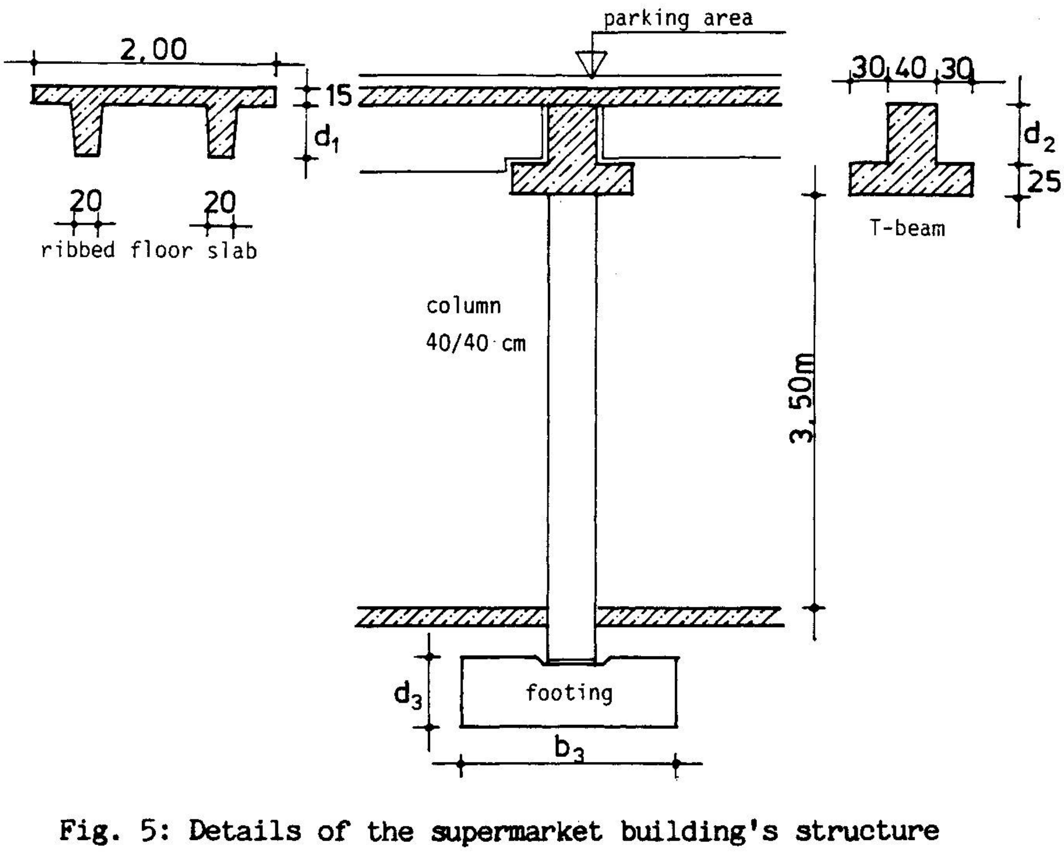

Fig. 5: Details of the supermarket building's structure

The function of this structural system is to carry the live loads acting at the building's roof, which in this special case originates not only from wind and snow but mainly from traffic load, since the roof plane shall be used as a parking area. Load is the deciding effect flowing through the system. Since the structure may be modelled to be a statically determinate one the system falls into the class under consideration. That is because the effect which the elements have to 'foreward' through the system flows sequentially (without feedback) from one element to the next, namely from the floor slabs via the beams, the columns and the footings to the soil.

Some of the structural elements' dimensions are given by the forms used in the prefabrication. There remain therefore only a few design variables the values of which may be altered for the purpose of dimensioning the structure optimally. These are (cf. fig. 5):

d1 : height of the floor slab's rib (1st subsystem)
d2 : web height of the T-beam (2nd " ")
d3 : thickness of the column's footing (3rd " ")
b3 : width of the (square) footing. (3rd " ")

The column does not appear as an independent subsystem since its external dimensions are fixed totally in advance. In addition to these subsystem variables there are coordinating variables too. These are the distances between the columns in both directions, x and y . x is measured in the direction of the ribbed slab's spann, y is the span of the T-beams. Both of them may not be altered continouosly because of some restrictions from the shelves in which the goods are presented. This is to be seen from fig. 6.

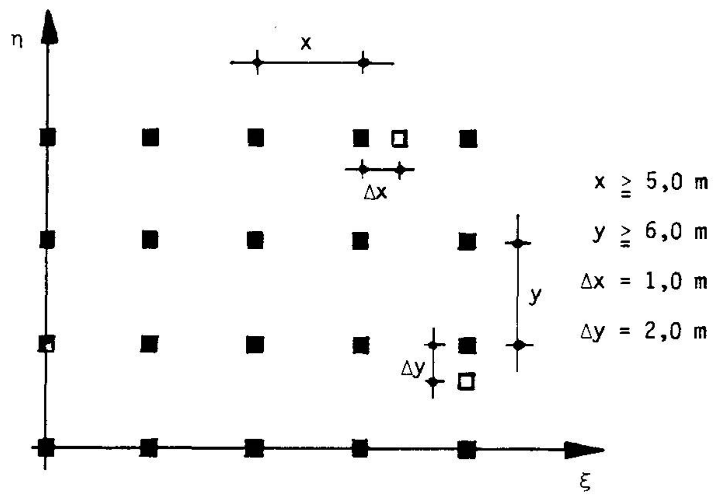

Fig. 6: Structural grid of the ground floor

The objective function is defined under the producer's point of view. He wants to reduce the production and erection costs and is not interested in the building's maintenance costs. That function is a nonlinear one and of the additive type, depending on all the coordinating and the subsystem variables:

$$\min_{x,y,d1,d2,d3,b3} (\overline{f1}(x,d1) + \overline{f2}(x,y,d2) + \overline{f3}(x,y,d3,b3))$$

The third component of this function mappes the casting costs of the footing to the objective function. These costs increase monotonuously with the footing's width b3. Therefore the optimum structure always contains the footing with the lowest permissible value of b3, which depends, given all the other variables' values, on the permissible pression in the foundation bed only. Hence it has not to be considered as a (free) decision variable.

The optimization model of the building's structural system contains three subsystems, each of them having just one decision variable (see below in brackets)

1. Floor slab (d1)
2. Beam and column (d2)
3. Footing (d3),

two coordinating variables

x and y (grid dimensions),

the objective function

$$\min_{x,y,d1,d2,d3} \left(f1(x,d1) + f2(x,a,d2) + f3(x,y,d3) \right)$$

and the constraints

$$g1(x,d1) \geq \Theta 1$$

$$g2(x,y,d1,d2) \geq \Theta 2$$

$$g3(x,y,d1,d2,d3) \geq \Theta 3.$$

g1, g2 and g3 are sets of constraint functions for the subsystems 1, 2 and 3 respective, $\Theta 1$, $\Theta 2$ and $\Theta 3$ zero-vectors of the respective dimensions.

The constraints are determined by demands of structural safety, compatibility of the subsystems and exploitation of the reinforcement. They are nonlineare functions in general. Neither the latter nor the components of the objective function can be outlined here.

The cascade pattern of this problem's constraint matrix is shown in fig. 7.

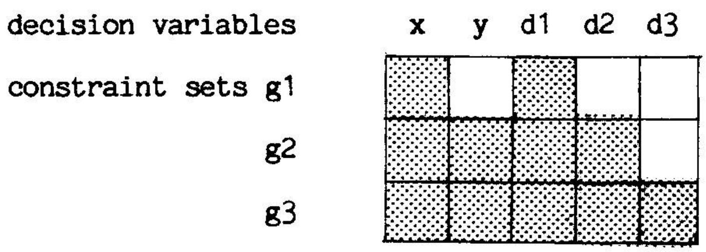

Fig. 7: Pattern of the constraint matrix

Searching for the optimum dimensions of the structure, one has to vary the values of the coordinating variables and for each pair of them to optimize the subsystems' dimensions. Increasing values of these variables cause increasing amount of the decising effect (i.e. the load) and at the same time increasing costs. Therefore it has to be tested, whether lighter ribbed slabs than the cheapest ones will cause lower total costs because of savings with the beams, columns and footings.

It is not possible to show the optimization process totally, because a lot of steps have to be gone at the upper level. For the optimal pair of coordinating variables only the results of both procedures, optimizing the subsystems in the sequence of load-flow, first considering the own weight of the cost-minimal preceding subsystems and second considering the own weight of the weight-minimal ones, shall be presented. All branches of the tree in fig. 8, which are directed to the right represent results from a cost-minimizing step, those directed to the left the results from a weight-minimizing one.

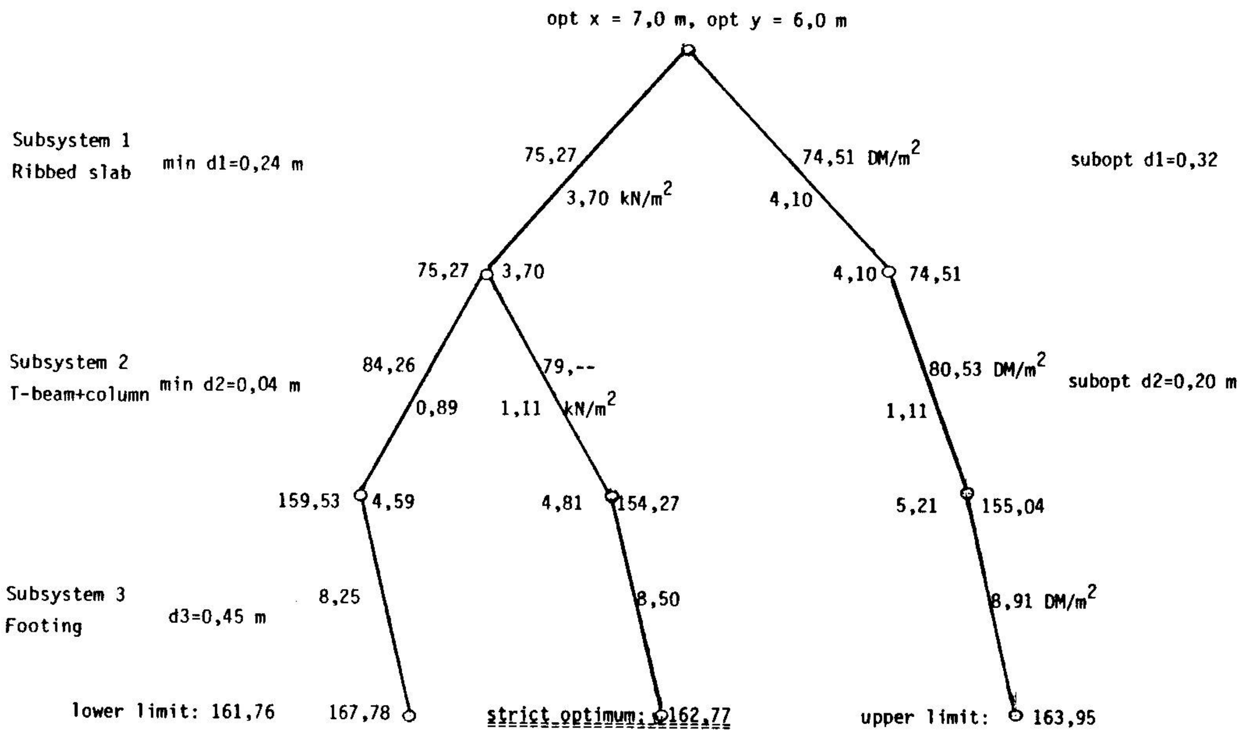

Fig. 8: Establishing upper and lower limit of optimum at the lower optimization level by a binary tree

These result have been obtained inserting realistic figures for wages, materials' and equipment's prices of summer 1981 in the Federal Republic of Germany, in practically usefull costing algorithm. The constraints have been derived from the German building codes. Fig. 8 should be interpreted as follows:

The optimal (= cost minimal) pair of grid dimensions (= coordinating variables) is x (= ribbed slab's span) = 7.0 m, y (= T-beam's span) = 6.0 m. At this grid the cost minimal ribbed plate has a rib height d1=0.32 m, an own weight of 4.1 kN/m2 and costs 74.51 DM/m2. The weight minimal slab on the other hand has a rib height d1=0.24 m, weighs 3.7 kN/m2 and costs 75.27 DM/m2. Then pursuing the right branch: The cheapest T-beam which can take the load of the cheapest slab costs 80.53 DM per m2 plan area and increases the own weight of the structure by 1.11 kN/m2. In this case a footing is needed which brings additional costs of 8.91 DM/m2. Thus the sequence of cost minimal elements, mapped to the rhigt branch of the tree, costs 163.96 DM/m2 totally. Now pursuing the left branch: The lightest T-beam to take the lightest slab's own weight (in addition to traffic and roof plane dead load of course) costs 84.26 DM/m2 and weighs 0.89 kN/m2 additionally, such that a cost minimal footing with a price of 8.25 DM/m2 will be needed. (The weight minimal footing is of course out of interest). Hence the sequence of the lightest elements, mapped to the leftmost branch, brings total costs of 167.78 DM per m2 plan area.

If we chose the cheapest T-beam to carry the lightest slab then this one costs 79.- DM/m2 and weighs 1.11 kN/m2. Now we may establish the lower cost limit - which is adequat to the upper limit of a positive objective function - by adding the cost of the cheapest slab, of the cheapest beam to carry the lightest slab and of the cheapest footing to carry the lightest slab and beam. This sum does not contain the costs of a permissible structure, but shows, whether there could be a solution which takes lower costs than the sequence of the cost minimal elements. Since this limiting sum is 161,76 DM/m2, we may expect, that we could find the absolute cost minimal structure at one of our tree's middle branches.

This one is easy to find in our simple example. We only need to take the footing beyond the cheapest beam bearing the lightest slab. Its cost minimum is 8.50 DM/m2 and then we have the strict optimum total costs of 162,77 DM/m2.

4. CONCLUDING REMARKS

The example presented above shows in a few figures the course of the pragmatic approach to optimize building systems which are members of the class under consideration. Though the results do not seem to be very impressing it could be proven, that systems with a cascade patterned constraint matrix cannot simply be optimized by following the course of suboptimal subsystems. If we had taken a multi story building instead of a single floor one and/or an other ratio of wages and material prices, such as this could appeare in develloping countries, then we should have got larger margins of optimization profit. We prefered the presented case as well since we just wanted to have the example as realistic and as simple as possible.

So far we did not mention the use of computers. But it seems very clear that a two level optimization process as described here can only be realized in an interactive mode of data processing. If the system consists of many subsystems and if there are many coordinating variables then the designing engineer needs a tool to just control the different types of steadily repeated steps. At the upper level he has to search for the best direction in the coordinating variables' space, at the lower one to do the same with the decision variables'space of each subsystem and afterward to investigate the binary tree of subsystem's combinations. This has to be done repeatedly and would not be possible without using a computer.

As was outlined in [4] this is one of the computer aided design tools helping the designer to select the most useful solution of his problem. It would be possible to bring this type of tools together in a subsystem of an information system which provides all the instruments the designer needs in the course of his work from searching for appropriate solutions to preparing the construction documents.

5. ACKNOWLEDGEMENTS

This paper presents a part of the results which we obtained during a period of intensive research co-operation which was made possible by a grant of the D e u t s c h e F o r s c h u n g s g e m e i n s c h a f t. We want to thank for this support and we hope that we shall be able to continue the work in this field. For his proposals concerning the example, his advices and his active co-operation during the preparation of the case study we have to thank Dipl.Ing. Robert P e t c z e l i e s, whose experience in the prefabrication helped us to set up a realistic optimization model of this struture.

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Analysis and Design of Plane Steel Structures

Conception basée sur la sécurité appliquée aux structures planes en acier

Berechnung und Entwurf ebener Stahlkonstruktionen

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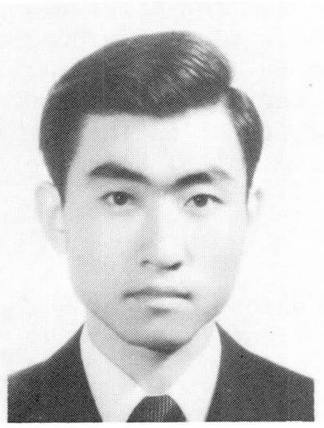

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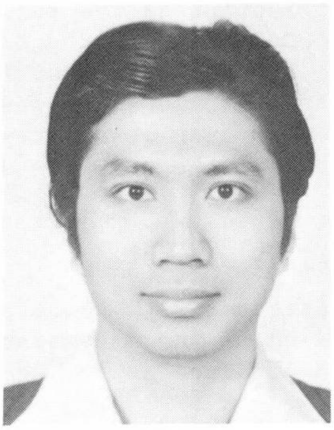

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SUMMARY
A computer program which can be used to find the probability of failure of the structure under consideration has been set up. The weakest link model is assumed and is applied to either statically determinate or statically indeterminate structures for the failure stage. Lognormally distributed loadings consisting of dead load, live load and impact effects are assumed. A series expansion technique is used in order to avoid the table checking work. The probability of failure of each member as well as the whole structure can be found.

RESUME
L'article traite d'un programme destiné au calcul de la probabilité d'observer une défaillance au niveau d'une structure. Le principe de l'étude du maillon le plus faible de la chaîne est appliqué aux structures statiquement déterminées ou indéterminées, au stade de la ruine. Les charges distribuées selon une loi lognormale sont: le poids propre, les surcharges et l'effet d'impacts divers. Une technique d'expansion de séries est utilisée afin d'éviter le parcours de table de vérification. Les probabilités de ruine de chaque élément ainsi que de l'ensemble de la construction sont déterminées.

ZUSAMMENFASSUNG
Ein Computerprogramm wird vorgestellt, das die Versagenswahrscheinlichkeit eines Bauwerkes berechnet. Dabei wird das Modell des schwächsten Gliedes in der Kette sowohl für statisch bestimmte als auch für statisch unbestimmte Bauwerke für den Zustand des Versagens angewendet. Lognormal verteilte Last, die aus Eigengewicht, Nutzlast und Aufpralleffekten besteht, wird angenommen. Die Versagenswahrscheinlichkeit kann für jedes einzelne Glied sowie für das ganze Bauwerk gefunden werden.

1. INTRODUCTION:

For a long period, many contributors devote their efforts in the field of optimum design of structures. Criterions they used generally are weighting consideration, i.e., the optimum design of a structure is the design which need minimum weight of the materials while provide equal function of the structure required. Recently, there is another argument, followed by the rapid development of reliability design concept, that the optimum design should be the design which possesses the minimum probability of failure in different designs which have equal functions. Furthermore, the argument states that the best design is a design that individual members of the structure possesses equal probability of failure. So as to give a rational and economical design which assure equal safety of all parts of the structure.

A simple flowchart of the reliability design is shown in Fig.1. From the figure we see that one contribution of the reliability design is to check the different preliminary designs and calculate the probability of failure both for individual elements and for the whole structures. It is obviously that there are so many choice when we are in the process of design. "Which one is better and which one is the best?" is the question we are trying to answer. Probability of failure calculated iteratively in the computer should be a method we can follow to solve the above question.

2. APPLICATION OF SAFETY MARGINS:

Fig.2 shows a prismatic bar with resistance R and subject a tension force S. R and S are considered to be random variable. Thus the probability of failure of the member can be obtained as

$$P_f = P\ (\ M.S. \leqq 0\ ) = \int_o^\infty f_S(s)\ F_R(s)\ ds \qquad (2\text{-}1)$$

or $$p_f = \int_o^\infty (\ 1 - F_S(r))\ f_R(r)\ dr \qquad (2\text{-}2)$$

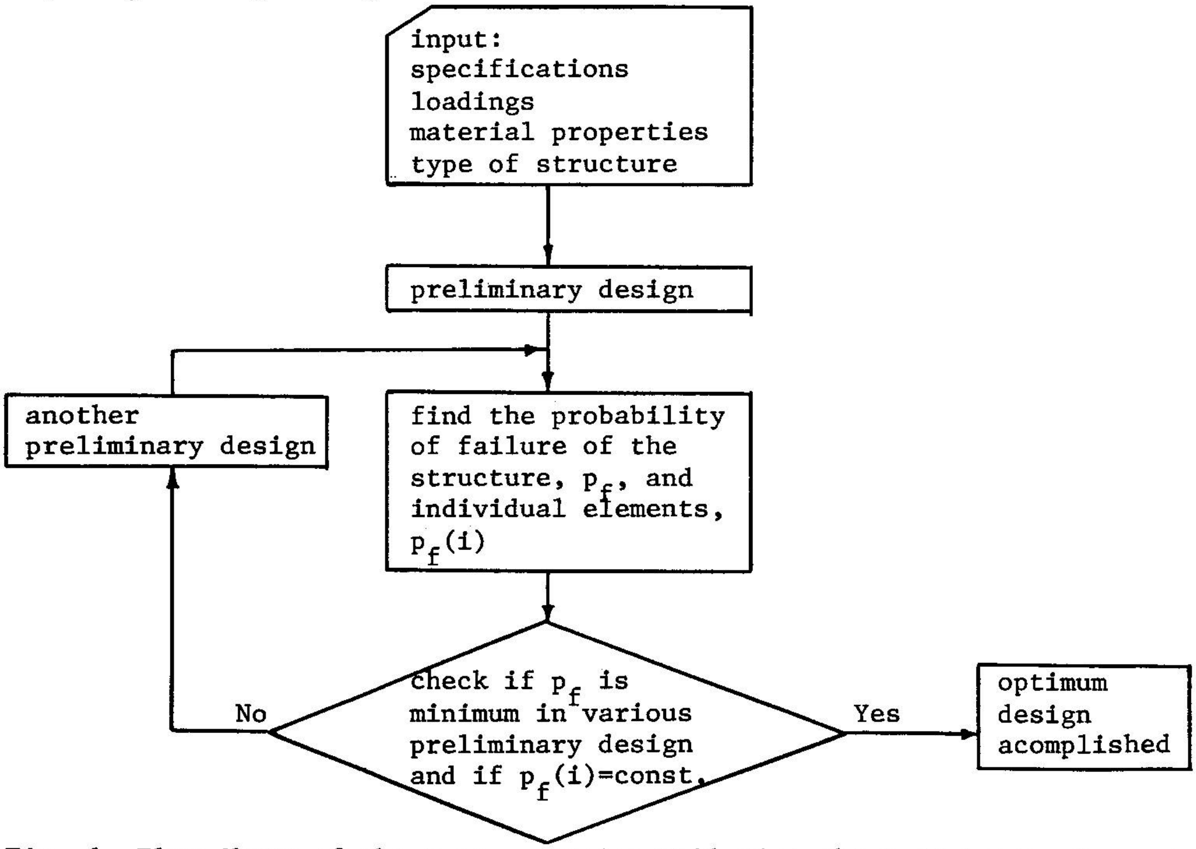


Fig. 1 Flow Chart of the Optimum Design Following the Reliability Concept

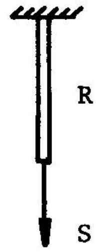


Fig. 2 Prismatic Member with Resistance R and Load S.

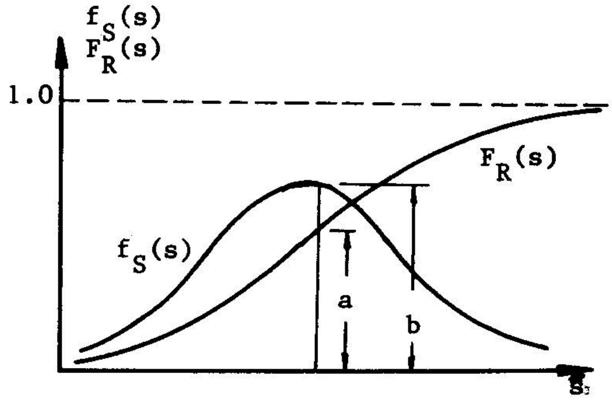


Fig. 3 Relationship Between Load and Resistance

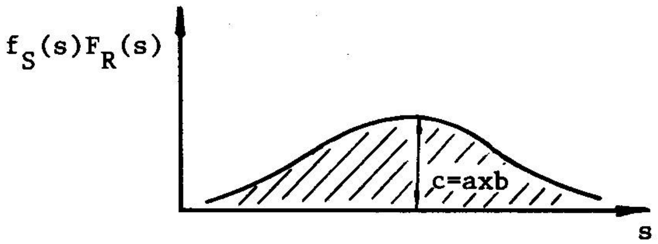


Fig. 4 Probability of Failure with R and S in Fig. 3

where P(.) means the probability of .; f_S and f_R are the probability density function of S and R, respectively; F_S and F_R are the cumulative distribution function of S and R, respectively. The relationship of S and R and the meaning of probability of failure are showed in the Fig.3 and Fig.4.

In case of S and R are all normally distributed, p_f can be obtained by substituting $\mu_{M.S.}$ (mean value of the safety margin) and $\sigma^2_{M.S.}$ (Variance of the safety margin) into the normal function

$$p_f = P(M.S. \leqq 0) = P(R - S \leqq 0) = \Phi\left(\frac{0 - \mu_{M.S.}}{\sigma_{M.S.}}\right)$$

$$= 1 - \Phi\left(\frac{\mu_{M.S.}}{\sigma_{M.S.}}\right) = 1 - \Phi\left(\frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}}\right) \qquad (2-3)$$

where μ_X and σ_X^2 are the mean value and the variance of the random variable X, respectively. If loading are the combination of the dead load(S_D) and live load(S_L), and they are assumed to be statistically independent random variables, then we have

$$\sigma_S^2 = Var(S) = Var(S_D + S_L) = Var(S_D) + Var(S_L) + 2Cov(S_D, S_L)$$

$$= \sigma^2_{SD} + \sigma^2_{SL}$$

Thus equ(2-3) will be

$$p_f = 1 - \Phi(\mu_{M.S.} / \sigma_{M.S.})$$

$$= 1 - \Phi((\mu_R - \mu_S) / \sqrt{\sigma_R^2 + \sigma_{SD}^2 + \sigma_{SL}^2}) \qquad (2-4)$$

or

$$p_f = 1 - \Phi(\beta) \qquad (2-5)$$

where $\beta = \dfrac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_{SD}^2 + \sigma_{SL}^2}}$ is named as safety index by Ang(1).

More rational expression is considered that R and S are following lognormal distribution. In this case, safety margin is R/S instead of R - S in the equation (2-3) and

$$p_f = 1 - \Phi\left(\frac{\ln\left(\frac{\mu_R}{\mu_S}\right)\left(\frac{1 + V_S^2}{1 + V_R^2}\right)^{\frac{1}{2}}}{\sqrt{\ln(1+V_R^2)\,(1+V_S^2)}}\right) \qquad (2-6)$$

Value of $\Phi(.)$ can be obtained from the normal distribution table. $\Phi(.)$ is expanded into series herein thus the value of $\Phi(.)$ can be easily obtained in computer.

3. WEAKEST LINK MODEL:

For statically determinate structure, failure of any member will cause the failure of the whole structure. For example, collapse of a statically determinate truss occurs simultaneously when any member in the truss failed. The terminology "failure" herein means totally plastic reached for a section, thus the member will deform continuously without any increasing of load. The probability of failure of this type of structure can be obtained by using weakest link model. And the formula of the weakest link model is

$$p_f = \int_0^\infty F_R(x)\, f_S(x)dx = \int_0^\infty \; 1 - \prod_{i=1}^{n} [1 - F_{R,i}(x)dx] \;\; f_S(x)\, dx$$

$$= 1 - \prod_{i=1}^{n} (1 - p_f(i)) \qquad (3-1)$$

For statically indeterminate structure, there are many modes and the failure paths depends on the degree of indetermenacy. Yao and Yeh(2) shows even for satically indeterminate structure, weakest link model can still be properly adopt and leads very small error. So equation (3-1) is used herein for calculating the probability of failure both for statically determinate and statically indeterminate structures.

4. FAILURE CRITERION:

Galambos and Rarindra(3,4) suggest limit equations of bar element in plane structures are

$$1. \quad \frac{R}{Ru} + \frac{C_m M_o}{M_p(1-(R/R_E))} \leqq 1.0 \qquad (4-1)$$

$$2. \quad \frac{Mo}{1.18M_p} + \frac{R}{Ry} \leqq 1.0 \qquad (4-2)$$

$$3. \quad \frac{R}{R_u} \leqq 1.0 \qquad (4-3)$$

where

$$R_u = \begin{cases} AF_y\,(1 - 0.25\lambda^2) & \text{when } \lambda \leqq 2 \\ AF_y / \lambda^2 & \lambda \geqq 2 \end{cases}$$

$$R_E = \frac{A\pi^2 E}{(\frac{KL}{r})^2}$$

$$\lambda = \frac{KL}{r}(\frac{1}{\pi})\sqrt{F_y / E}$$

$$M_p = ZF_y$$

$$C_m = 0.4 + 0.6\ n$$

M_1, M_2 are member end moments.

M_o = the larger one of M_1 and M_2

$$n = \text{moment ratio} = \frac{M_o}{\text{moment at the other end}}$$

$$R_y = AF_y$$

5. DETERMINATION OF THE RESISTANCE FACTOR, ϕ:

There are certain relationship between the expected resistance R_m and nominal resistance R_n. For instance, for A36 steel, its nominal resistance is 36 ksi. Generally, the expected resistance is greater than the nominal resistance. Galambos and Raindra(3,4) suggest their relation be

$$R_m = (\frac{\text{Test strength}}{\text{Prediction by theory}})_m \times (\frac{\text{Prediction by theory}}{\text{Prediction by interaction equation}})_m \times (\frac{\text{Prediction by interaction equation}}{R_n})_m \times R_n$$

$$= B_{EX}\ B_{TH}\ B_{MAT}\ R_n \qquad (5-1)$$

where the interaction equation are the governing equations (4-1), (4-2), and (4-3). B_{EX}, B_{TH}, B_{MAT} represent the "bias" of "experiment", "theory", and "material", respectively. Galambos suggests that the mean value of B_{EX}, B_{TH}, B_{MAT} be 1.005, 1.01, 1.05, respectively, and the coefficient of variation of B_{EX}, B_{TH}, B_{MAT} be 0.093, 0.04, 0.10, respectively. R_n in the equation (5-1) can be solved from equations (4-1), (4-2), and (4-3).

The criteria of L.R.F.D. (Load and Resistance Factor Design) is

$$\phi R_n = \sum_{k=1}^{n} r_k\ S_{nk} \qquad (5-2)$$

when dead load and live load are considered individually, equation (5-2) will be

$$\phi R_n = \sum_{k=1}^{2} r_k\ S_{nk} = r_E\ (r_D S_{DL} + r_L S_{LL}) \qquad (5-3)$$

where ϕ is the resistance factor, r_D, r_L, r_E are load factors related to dead load, live load and uncertainties including impact effect. Galambos (4) suggests the resistance factor ϕ can be determined by

$$\phi = (\frac{R_m}{R_n})\exp(-\alpha\beta V_R) \qquad (5-4)$$

where

$$V_R = \sqrt{V_{EX}^2 + V_{TH}^2 + V_{MAT}^2 + V_F^2} \qquad \alpha = \frac{\sqrt{\sigma_{SD}^2 + \sigma_{SL}^2}}{\sigma_{SD} + \sigma_{SL}}$$

$$\beta = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_{SD}^2 + \sigma_{SL}^2}}$$

V_F = Variance of other factor with out considered clearly

6. SERIES EXPANSION OF $\Phi(.)$:

For a normal distribution random variable X, the cumulative distribution function of X can be written as

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{1}{2}\xi^2\right) d\xi \qquad (6-1)$$

Equation (6-1) can be expanded by Taylor's series as

1. when $\beta \geqq 4$:

$$P_f = 1 - \Phi(\beta) = \frac{1}{2} - \frac{1}{\sqrt{\pi}}\left(\frac{\beta}{\sqrt{2}} - \frac{\beta^3}{1!\cdot 3\cdot(\sqrt{2})^3} + \frac{\beta^5}{2!\cdot 5\cdot(\sqrt{2})^5} - \frac{\beta^7}{3!\cdot 7\cdot(\sqrt{2})^7} + \ldots\ldots\right) \qquad (6-2)$$

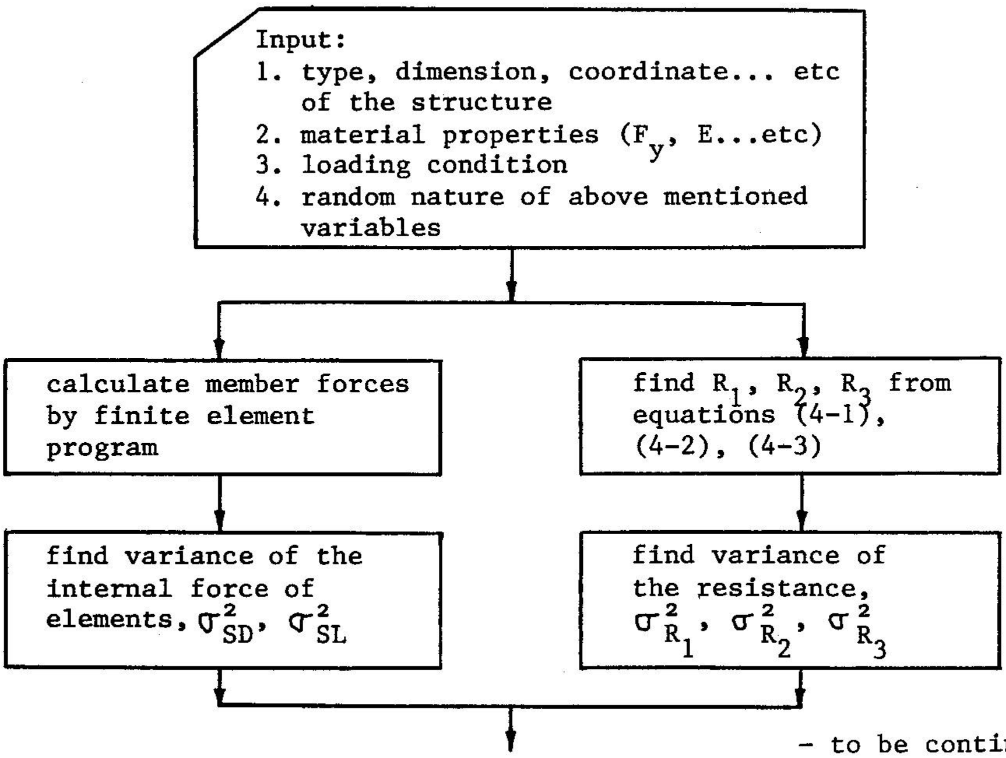
2. when $\beta > 4$:

$$P_f = 1 - \Phi(\beta)$$

$$= \frac{1}{2}\,\frac{1}{\sqrt{\pi}} \exp\left(-\left(\frac{\beta}{\sqrt{2}}\right)^2\right)\left(\frac{2}{\beta} - \frac{(\sqrt{2})^3}{2\cdot\beta^3} + \frac{1\cdot 3\cdot(\sqrt{2})^5}{2^2\cdot\beta^5} - \frac{1\cdot 3\cdot 5\cdot(\sqrt{2})^7}{2^3\cdot\beta^7} + \frac{1\cdot 3\cdot 5\cdot 7(\sqrt{2})^9}{2^4\cdot\beta^9} - \frac{1\cdot 3\cdot 5\cdot 7\cdot 9(\sqrt{2})^{11}}{2^5\cdot\beta^{11}} + \frac{1\cdot 3\cdot 5\cdot 7\cdot 9\cdot 11\cdot(\sqrt{2})^{13}}{2^6\cdot\beta^{13}} - \frac{1\cdot 3\cdot 5\cdot 7\cdot 9\cdot 11\cdot 13\cdot(\sqrt{2})^{15}}{2^7\cdot\beta^{15}} + \ldots\ldots\right) \qquad (6-3)$$

7. FLOW CHART OF THE PROGRAM:

Two flow charts will be introduced following, one is for the calculation of the probability of failure both for individual element and for the whole structure, and the other is for the goal of optimum design. They are shown in Fig.5 and Fig.6.



- to be continued -

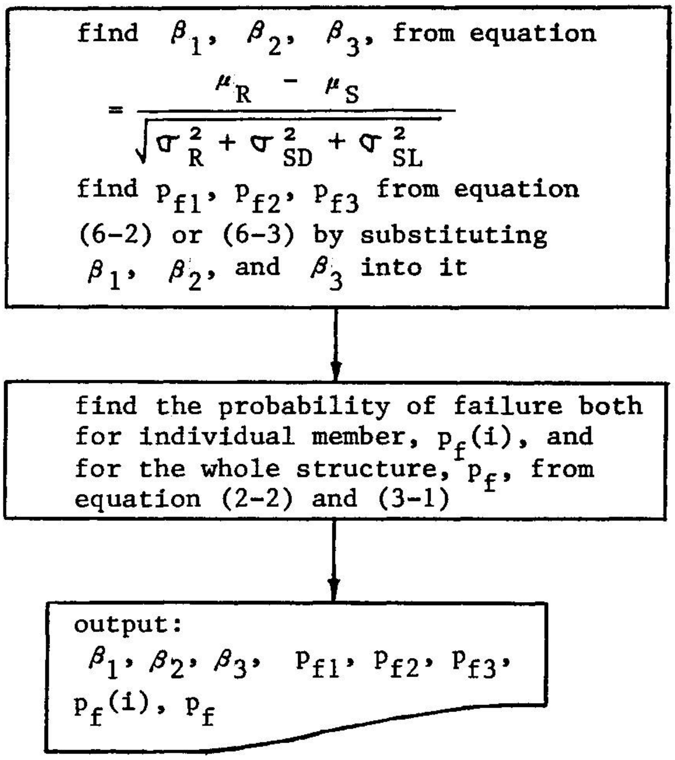


Fig. 5 Flow Chart of the Program for Calculation of the Probability of failure

8. CONCLUSIONS:

The probability of faiture for each member can controlled in expected ranges, say, 10E-6 to 10E-5. It is the goal of an optimum design. Variance of the variables can be properly considered in reliability design. So the reliability design is actually more rational than the conventional design which treat all variables to be constant. Well developed computer program is necessary for future design work in different types of the structures especially in the field of reliability design.

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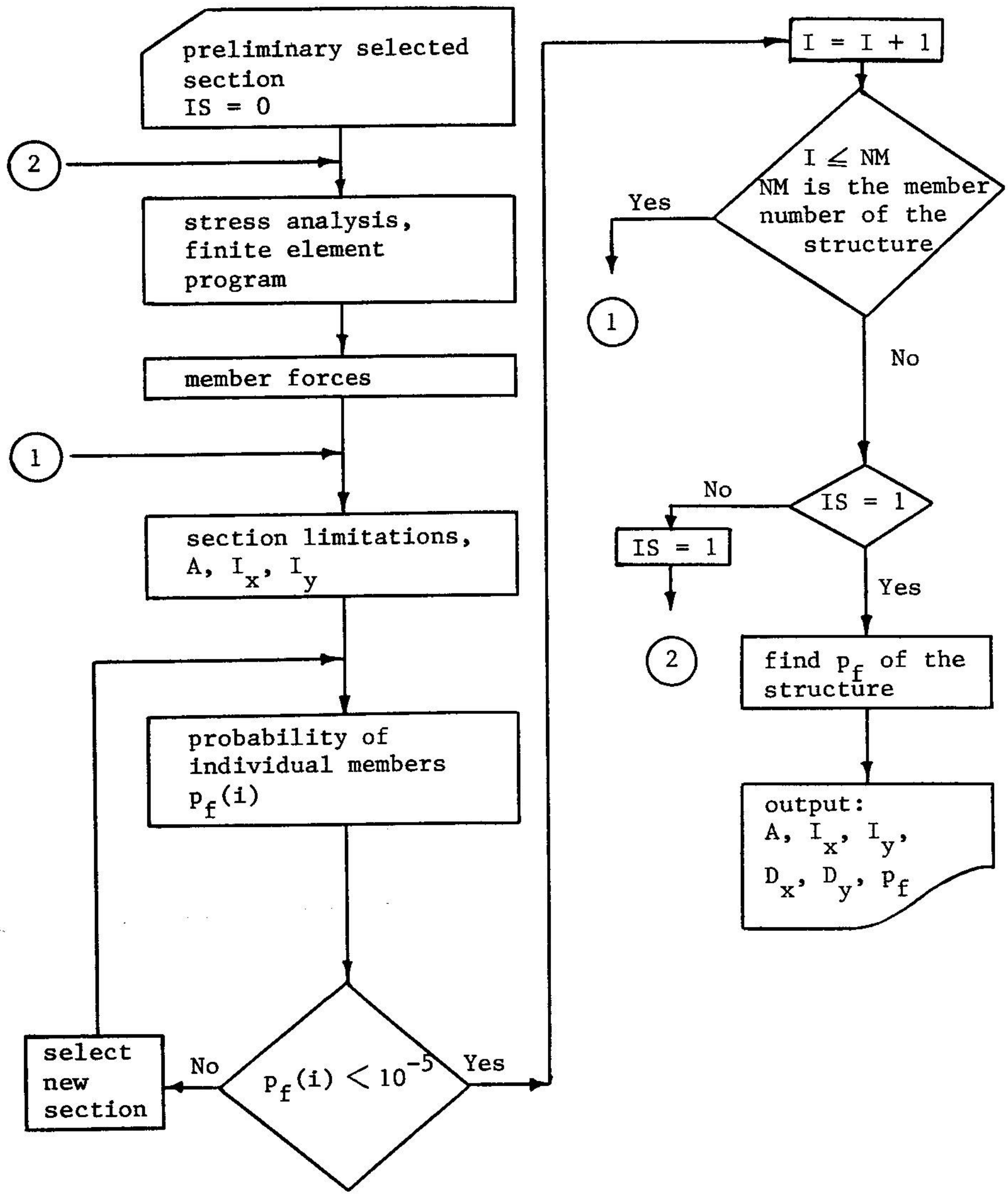

Fig. 6 Flow Chart of the Program for Optimum Design to Select Proper Sections

Stability of a Bowstring Bridge with Twin Inclined Arches

Stabilité d'un pont bowstring avec arcs inclinés, contreventés en clé

Stabilität einer Bogenbrücke mit zwei geneigten und am Scheitel verbundenen Bogen

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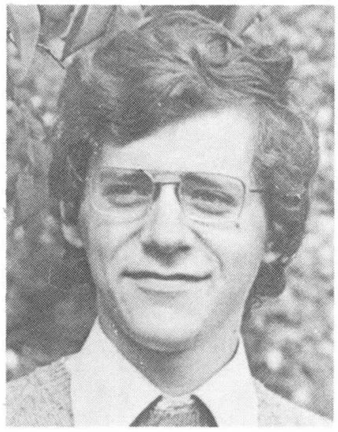

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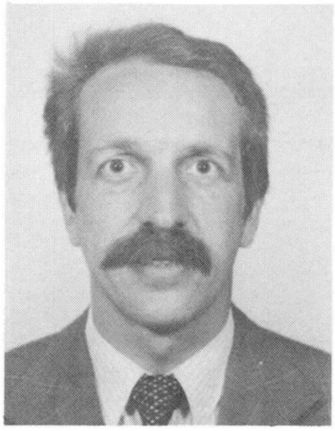

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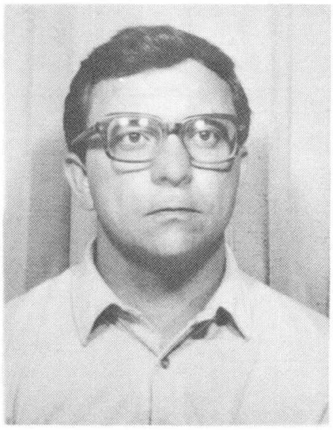

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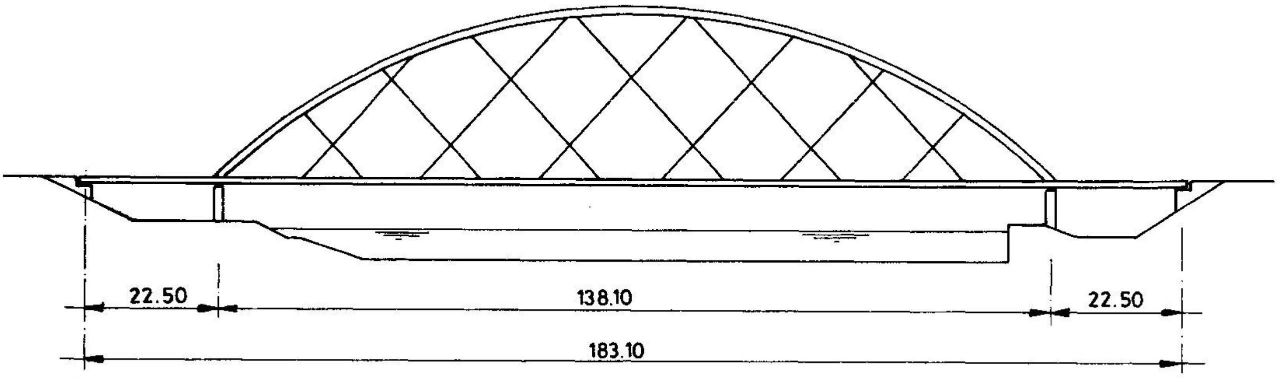
SUMMARY
Several finite element analyses, of increasing sophistication, are used to analyse the stability of a special bowstring bridge: the deck is carried by a widely spaced lattice of hangers, the arches are inclined and connected at their crown by a single bracing strut. The computations emphasize the importance of correctly simulating the role of this strut. if done so, plane finite elements can be used to model the three-dimensional behaviour.

RESUME
La stabilité d'un pont métallique bowstring d'un type particulier (les deux arcs, à suspensions croisées, sont inclinés et liés en clé par une seule entretoise) a été étudiée au moyen de divers types d'éléments finis de sophistication croissante. Les calculs montrent l'importance d'une simulation correcte de la liaison en clé. Sous cette condition, des éléments finis plans permettent d'obtenir une bonne approximation du comportement tridimentionnel.

ZUSAMMENFASSUNG
Die Stabilität einer metallischen Bowstring-Brücke von einem besonderen Typ (die beiden Bogen mit gekreuzten Hängestangen sind geneigt und am Scheitel mit einem einzigen Querträger verbunden) wird mit immer komplizierteren finiten Element-Modellen analysiert. Die Computerberechnungen zeigen die Wichtigkeit einer korrekten Simulierung der Scheitelverbindung. Nur so erlauben es ebene finite Elemente das dreidimensionale Verhalten gut zu erfassen.

1. INTRODUCTION

The King Albert Canal which links Liège and the port of Antwerp is being widened to allow traffic of 9000 T pushed barges. This requires replacement of several bridges, among them the one at Hermalle with a main span of 138.10 m. Choice was made of a steel bowstring bridge carrying the deck by means of a widely spaced lattice of hangers ; the two box girder arches are unusual because they are inclined with an angle of 9.44° degrees and connected at their crown by a single bracing strut. (Fig. 1).



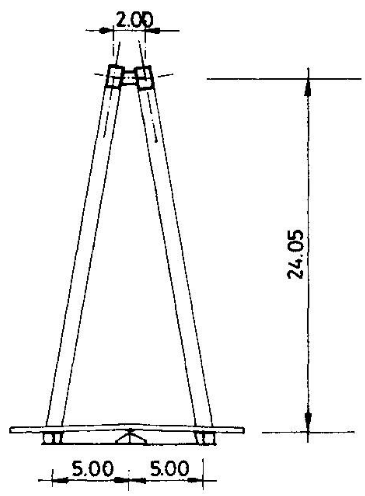


Figure 1 Side view and cross section of the bridge

Simple calculations have shown that in-plane instability is not to be feared. But out-of-plane instability of the arches must carefully be studied taking into account the appropriate components of the hangers forces acting on the arches and the elastic support provided by the short bracing strut at their crown.

A nonlinear finite element program, especially well suited to metallic structures, has been developed at the University of Liège by the Structural Division of the Civil Engineering department [1], [2], [3], [4]. It has already been successfully used for several research projects [5],[6].

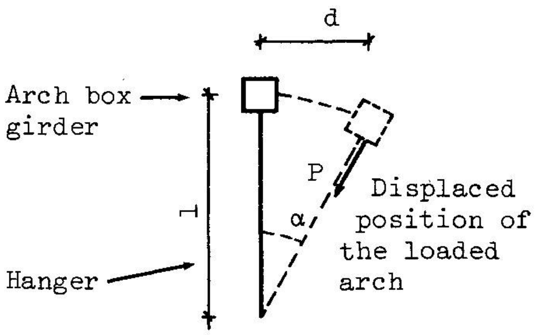
The purpose of the present contribution is to show how the University and the consulting bureau, working hand in hand, have used this program and increasingly sophisticated finite elements to predict the behavior of the arches with increasing accuracy, while minimizing computation costs which could have skyrocketed if the most advanced techniques had indiscriminately been used.

2. STEP-BY-STEP COMPUTATION OF AN ARCH IDEALIZED AS A STRAIGHT BEAM.

2.1. Idealization.

For the preliminary design, one wished to use only the simplest version of the non linear program and plane beam finite elements. To do so, one single arch was developed and the hangers were idealized as elastic supports.

The stiffness of these elastic supports is due to the fact that, under a lateral displacement of the arch, the hangers become inclined with respect to the original arch plane; this induces a non linear pull-back force which is simulated by means of springs the stiffness of which is modified according to the arch displacements (Fig. 2).



P = force in the hangers
d = out-of-plane displacement of the arch
= l.tan(α)
F = pull-back force on the arch due to P
= P.sin(α)
k = stiffness of the spring idealizing the pull-back force
= F/d
= P.sin(α) / l.tan(α)
≃ P/l : stiffness varying as force P with α << 1 rad

Figure 2 Pull-back forces of the hangers

The idealized structure is shown on fig. 3.a ; the springs are vertical bars on the drawing ; the two stubby beam elements at the ends of the developed arch simulate the restraints caused by the floor beams at the arch ends. In this first approach, *the central node is considered as fixed against transversal displacements to simulate the crown bracing.*

2.2. Loading.

The loading is considered to be proportional even though it actually results from the superposition of dead and live loads. The distribution of the axial forces in the arch is obtained by means of a plane linear elastic analysis. These axial forces are then induced in the fictitious straight beam by means of appropriate external loads applied to its nodal points ; their longitudinal distribution is supposed to retain its overall shape while their intensity varies, because in-plane deformations of the arch are very small.

These simplifying artifices thus enable to use plane beam finite elements to study the out-of-plane instability of an arch loaded in its own plane.

Two successive deformed shapes corresponding to increasing load steps are shown in fig. 3.b and c : of course an antisymmetrical mode does appear.

Load-displacement curves for a typical point of the arch are drawn in fig. 4. They exhibit the instability by divergence behavior undergone by the out-of-plane displacements. It must be noticed that, under wind load (curve c), out-of-plane displacements appear very soon because of the presence of lateral forces but these same forces oppose one of the half sine instability wave and restrain the intensity of the displacements.

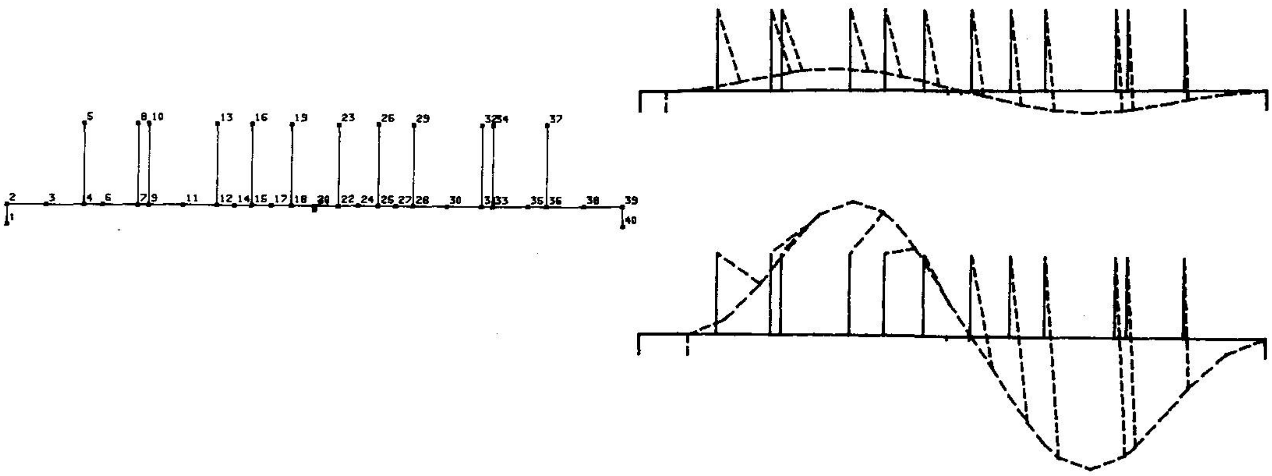


Fig. 3 Idealization of an arch by means of a fictitious straight beam and typical deformed shapes.

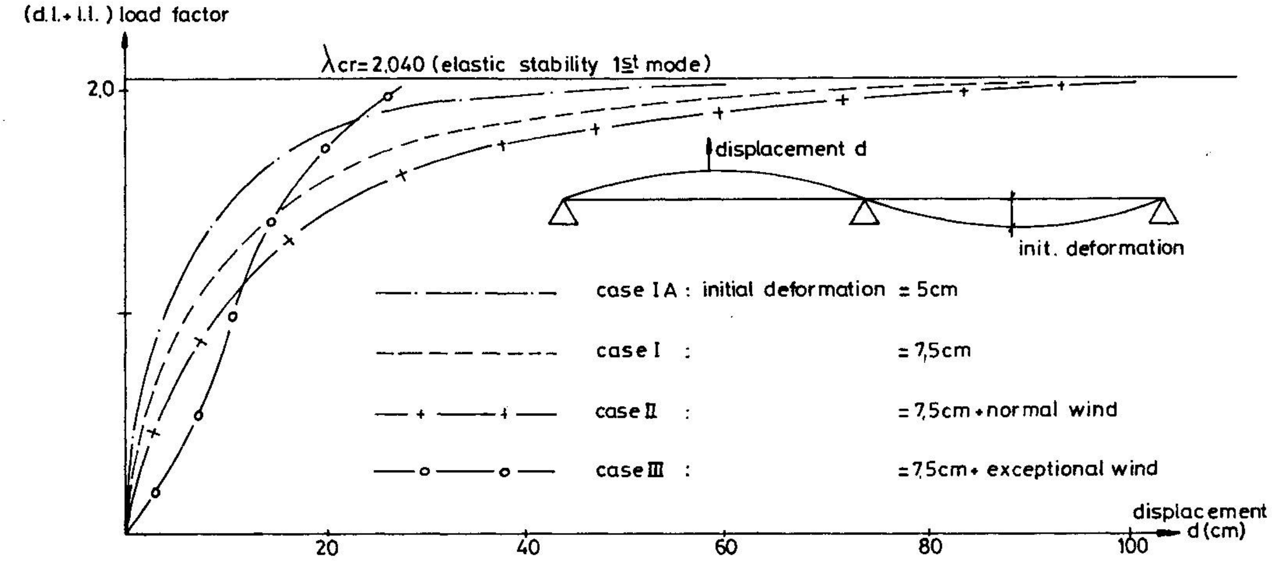


Fig. 4 Load factor versus out-of-plane displacement curves under different step-by-step loadings.

3. STABILITY COMPUTATIONS FOR A SINGLE ARCH.

Considering the important approximations made in this simplified analysis, a checking was deemed necessary even for the preliminary design. As a verification, the critical load was computed for a single arch *simply supported at is crown*. This time the idealization used space beam finite elements and truss bars (the prestressed hangers always remain under tension and are considered as truss bars with an adjusted elasticity modulus); the idealization is shown in fig. 5.

A linear elastic computation enables to form the structural stiffness matrix K_0 and to find the necessary stresses to form the initial stress matrix K_σ; from this, assuming again a proportional loading, one can find the critical load factor, by means of

$$\det [K_0 + \lambda K_\sigma] = 0$$

The first two critical load factors and the corresponding instability modes are shown in fig. 7. The lowest critical value of λ is also represented as a horizontal line in fig. 4 ; it perfectly confirms the results of the incremental non linear analysis. This excellent agreement can be attributed to the smallness (and hence the weak influence) of the displacements under loading prior to out-of-plane instability.

On the other hand it is rather disappointing to discover that the first critical load factor for the arch with a simple support at the crown is little different from the first critical load factor for the arch without a crown support as shown in fig. 6. This is due to the pull-back effect of the hangers : they strongly oppose a single wave instability mode because they slope at a larger angle than in the case of a double half wave. In such bowstring bridges, the crown bracing strut seems to be of little benefit. But, until now, *one has neglected the rotational restraint due to this crown bracing.*

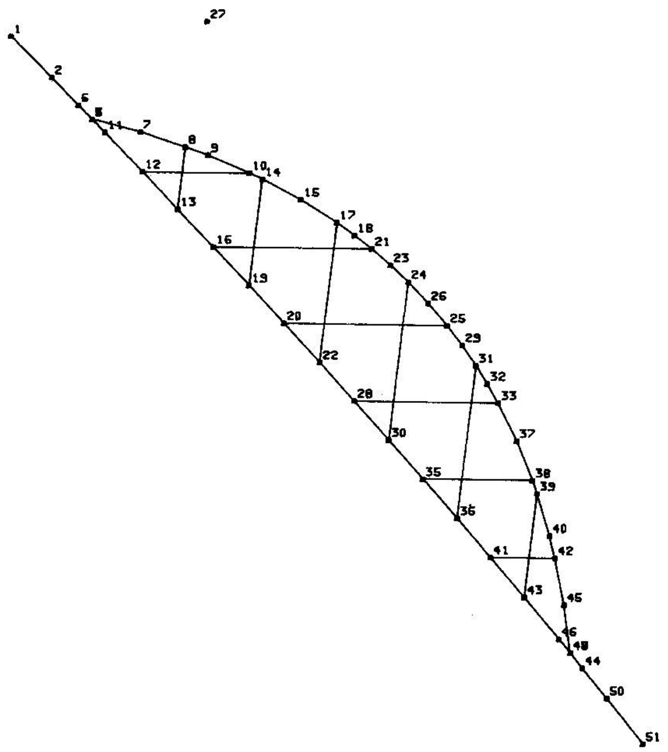


Fig. 5 Single arch idealization

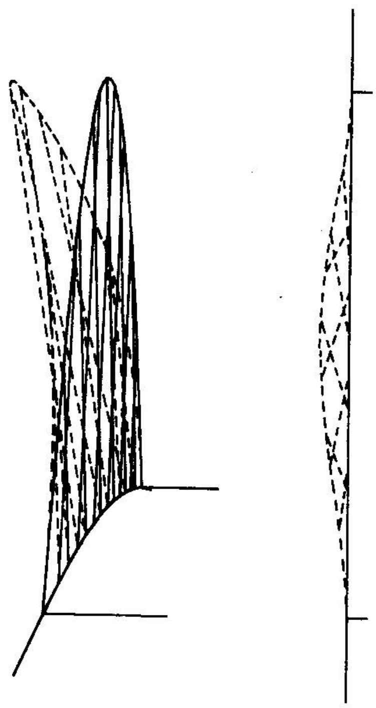


Fig. 6 First instability mode without a crown support $\lambda_1 = 2.0001$

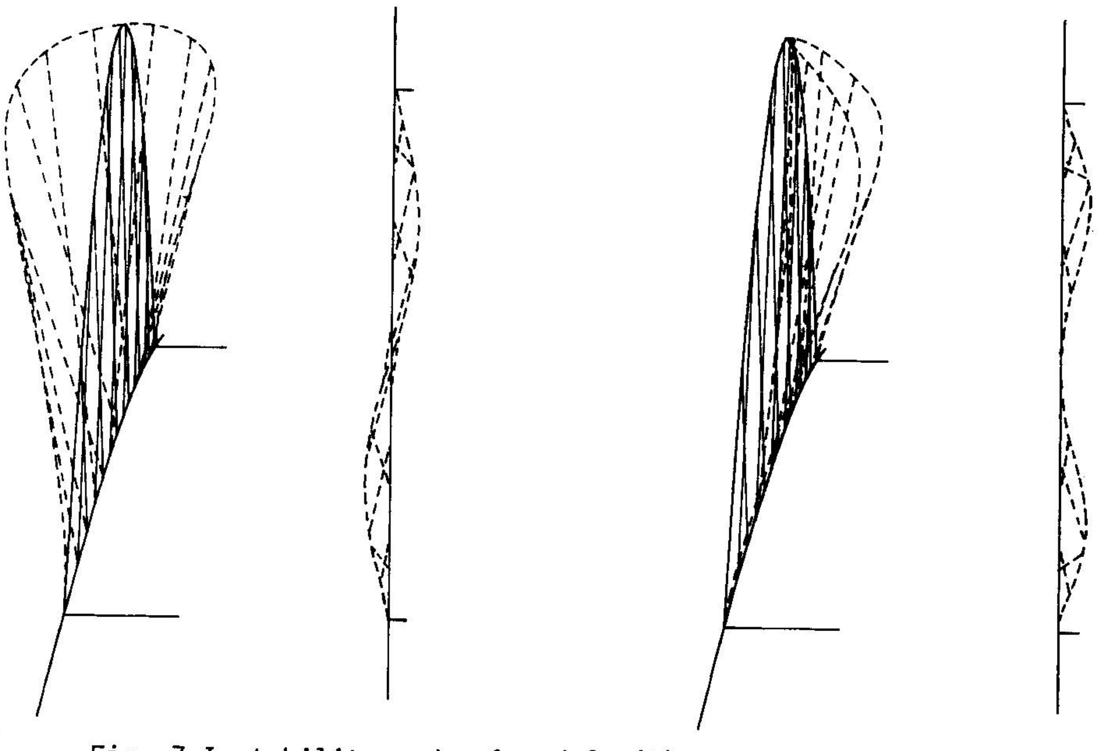


Fig. 7 Instability modes 1 and 2 with crown support. $\lambda_1 = 2.04$ - $\lambda_2 = 4.211$

4. STABILITY COMPUTATION FOR THE WHOLE STRUCTURE.

To clear up this problem of the crown rotational restraint, a three-dimensional analysis of the whole final design was performed by means of truss bars finite elements (for the hangers) and beam elements (for the arches, the girders, the crown bracing strut and the floor beams including a contributing width of the reinforced concrete deck): fig. 8.

For this idealization again, only the instability modes were computed. The first two are illustrated on a plan view in fig. 9. They exhibit an obvious similarity with modes 1 and 2 in the case of a single arch restrained by a simple support at its crown. But, because of the crown bracing strut, the symmetry of displacements about the central point of the bridge entails longitudinal displacements of both arches at their crown against which they oppose a strong stiffness: the critical load multiplier is raised from $\lambda = 2{,}04$ to $\lambda = 2{,}60$; this emphasizes the importance of a *correct simulation of the elastic support provided by the crown bracing strut.*

An alternative design with two bracing struts instead of a single one, located at third span of the arches, brought an additional benefit of 14 % for the same first instability mode but was discarded for technological reasons.

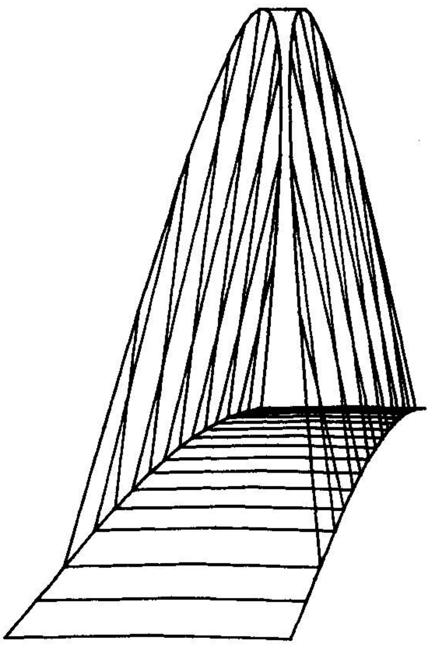


Fig.8 Idealization of the whole structure

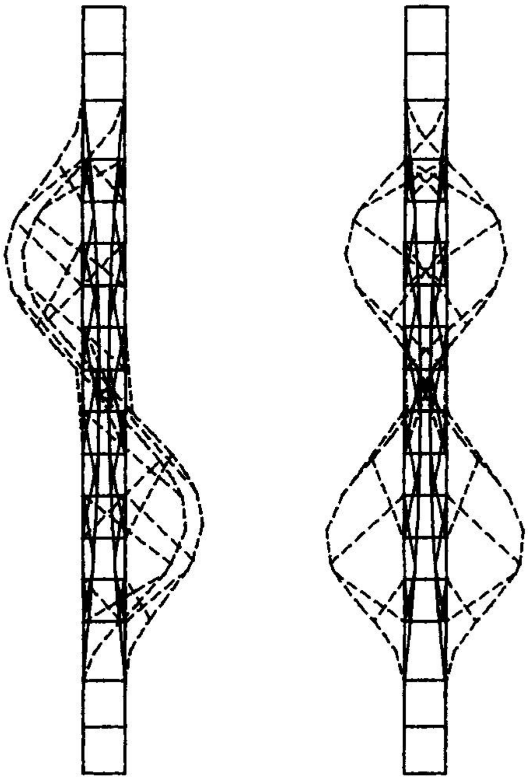


Fig. 9 Instability modes 1 and 2. $\lambda_I = 2.665$ - $\lambda_2 = 3.465$

5. NEW STEP-BY-STEP COMPUTATION OF AN ARCH IDEALIZED AS A STRAIGHT BEAM.

A step-by-step computation of the whole structure was possible albeit costly for the whole tridimensional structure. The confidence gained with the preliminary design computation led the consulting office to prefer a step-by-step analysis of a new fictitious straight beam. At midspan however the bracing strut is simulated by a simple support preventing out-of-plane displacements and an elastic spring restraining the rotation about a vertical axis. This rotational spring was given a stiffness of 5000 T x m/radian, value arrived at in two

different ways giving identical results :
- by correctly estimating the rotational stiffness at one end of the crown bracing strut ;
- by adjusting this rotational stiffness parameter until the same critical load factor λ be obtained for the fictitious straight beam as for the previously computed three-dimensional structure.

The results of the step-by-step computation possess the same general outlook as those already shown in fig. 4 ; given the same loads however the displacements are smaller and the instability asymptotic line is raised : this is understandable since the stiffness of the crown bracing strut is better taken into account.

This step-by-step computation is useful to check the magnitude of the second order out-of-plane displacements under service loads. It also gives the axial stresses and second-order out-of-plane bending moments in the arch. These beam forces are in turn used to check that the resulting stresses in the arch box-girder are acceptable and to justify the fact that the elasto-plastic part of the computer program was inactivated.

6. ADDITIONAL COMPUTATIONS.

Local buckling may occur in the arch box-girders, namely in the flange plates which are axially compressed along their direction of curvature. Use was made of the results of a previous study performed by finite elements on compression curved plates [7].

Vibration modes and eigenfrequencies were also computed for the three-dimensional model of fig. 8. As expected, similar shapes are found among the vibration and instability modes : modes 1 and 2 in particular exhibit nearly identical shapes (fig. 9).

7. CONCLUSIONS.

Much simplified finite elements models, namely fictitious plane beams idealizations, were used to analyze the three-dimensional stability of a bowstring bridge of unusual design. Research of instability modes and step-by-step analyses, in the case of the fictitious beams, single arches and three-dimensional structures, including tentative computations, took less than 1850 seconds of CPU time on an IBM 370-158 Machine.

The bridge is now being completed (fig. 10). To avoid interference with the traffic on the King Albert Canal, the bridge was erected on the bank, shifted on barges and floated into place during the summer of 1982.

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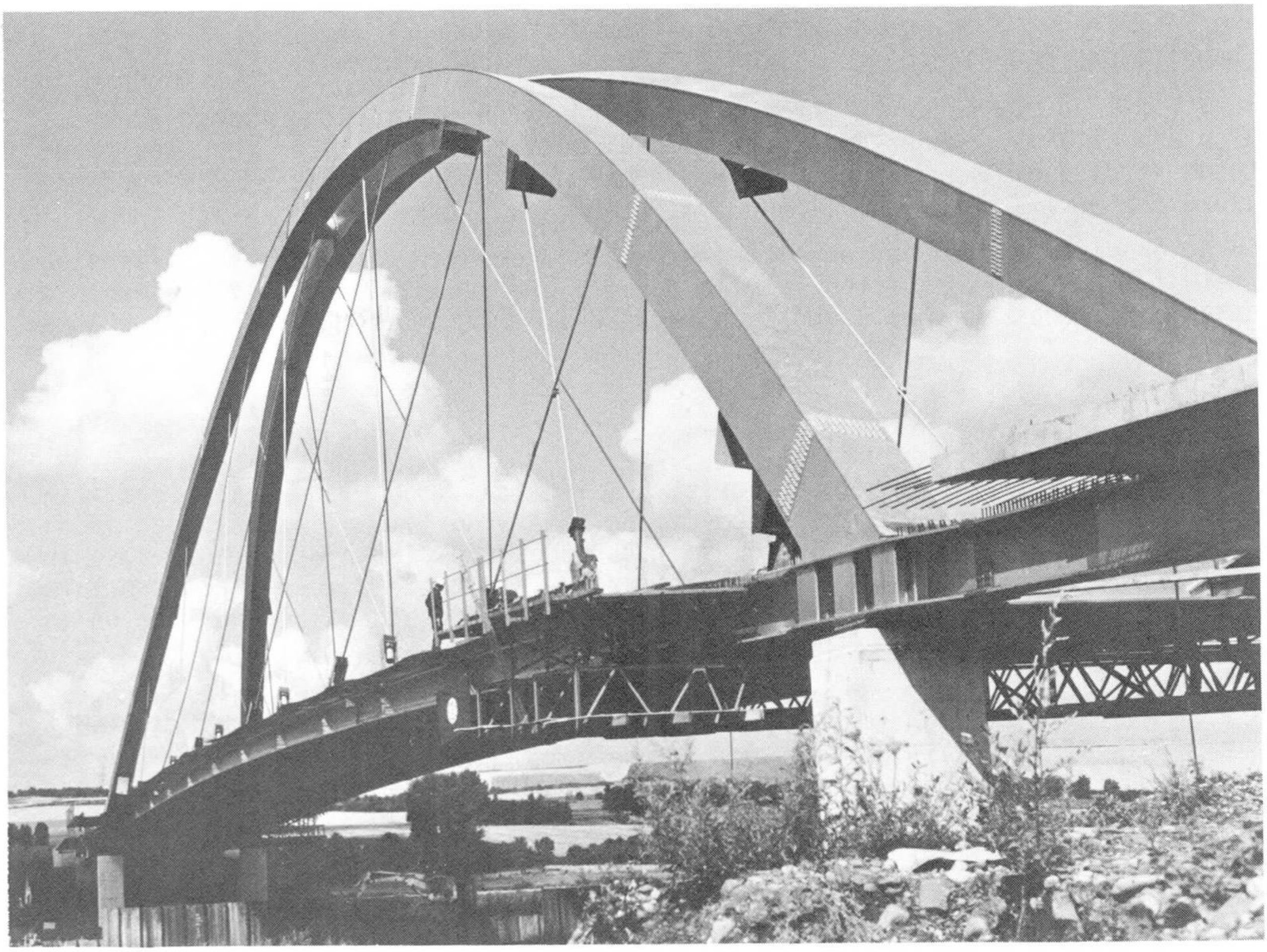

Fig. 10 Bridge at Hermalle.