DAILY THEME B

Computer Aided Engineering

Ingénierie assistée par ordinateur

Computerunterstütztes Ingenieurwesen

Chairmen:	A.G. Frandsen, Denmark A. Jutila, Finland
Technical Adviser:	E. Anderheggen, Switzerland
Keynote Lecturers:	D. Taffs, UK W. Haas, Fed. Rep. of Germany

The theme will be introduced by two Keynote Lecturers and printed in the Post-Congress Report, which will be mailed to the participants after the Congress.

Le thème sera introduit par deux orateurs invités, dont les exposés magistraux seront publiés dans le Rapport Post-Congrès; celui-ci sera envoyé aux participants après le Congrès.

Das Thema wird von zwei eingeladenen Referenten eingeführt, deren Referate im Schlussbericht des Kongresses veröffentlicht werden. Dieser Schlussbericht wird den Teilnehmern nach dem Kongress zugestellt.

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Integrated Bridge Design with Applied CAE

Conception assistée par ordinateur pour le projet de pont

Ein CAD-System für den integrierten Brückenentwurf

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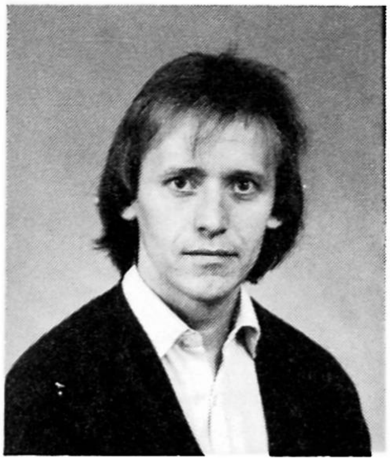

Leif Andersson, born in 1954 received his MSc in Civil Engineering and his PhD at the Royal Institute of Technology, Stockholm. His main interest has been research and industrial applications in conjunction with risk analysis and the finite element method. Leif Andersson is at present in charge of software development at NordCad.

SUMMARY
The paper presents a CAE system for integrated bridge design. The system consists of a number of integrated modules, for instance finite element analysis, reinforcement calculation, and CAD interface modules. For an input of approximately 1–2 pages of data, the system will produce more than 15 working drawings apart from graphical print-outs and lists of output data.

RÉSUMÉ
L'article présente un système de conception assistée par ordinateur pour le projet intégré de pont. Le système contient un nombre de modules intégrés, par exemple l'analyse par éléments finis, le calcul statique et le module interface de CAO. Le système donne plus que 15 dessins pour une entrée de données d'environ l ou 2 pages, en plus d'impressions graphiques et de listes de sorties de données.

ZUSAMMENFASSUNG
Vorliegendes Dokument präsentiert ein CAD System für den integrierten Brückenentwurf. Das System besteht aus mehreren Modulen, wie z. B. dem Modul für die statische Berechnung mit Hilfe der Finiten Element Methode, dem Modul für die Bewehrungsberechnung und dem CAD Interface Modul. Die Eingabe besteht aus nur ein bis zwei A4-Seiten. Mit diesen Eingabedaten produziert das System vollautomatisch mehr als 15 Konstruktionszeichnungen, Uebersichtspläne sowie eine geschlossene statische Berechnung in Listenform und in graphischer Form.

1. INTRODUCTION

Computer codes for structural analyses, e.g. finite element programs, have been in use for some decades, while CAD has emerged during the last ten years. It is widely recognized that improved efficiency would be achieved if computer aided structural analysis, design and drafting were to be integrated. This is the concept of CAE, computer aided engineering.

In spite of this recognition and focus on CAE, however, there is a lack of CAE systems except for research purposes. One great exception is VV541, a system developed for the design of skew frame bridges. This system has been developed by NordCad AB on behalf of the Swedish Road Administration.

2. OUTLINE OF VV541

Skew frame bridges are one of the most common bridge types in Sweden, with a production of approximately 100 annually. They are used for spans up to 25 m and are made of reinforced concrete.

Owing to its skewness, a skew frame bridge demands comprehensive calculations. This is one reason for development of VV541. Another reason is that variations in shape are limited by virtue of the structure being a bridge. For an input of approximately 1-2 A4 pages of data, the system will produce more than 15 working drawings apart from graphical print-outs and lists of output data. The drawings are automatically transferred to GDS, a general purpose CAD system developed by McDonnell Douglas. After some minor adjustments, such as the moving of text blocks which are in conflict with other text blocks or lines, the drawings are plotted.

VV541 is implemented on Prime and VAX computers. The system, Fig. 1, is fully integrated and includes a number of separate modules. Each run can start or restart any module, subject to logical restrictions such that the reinforcement module cannot be executed unless the finite element analysis module has been executed.

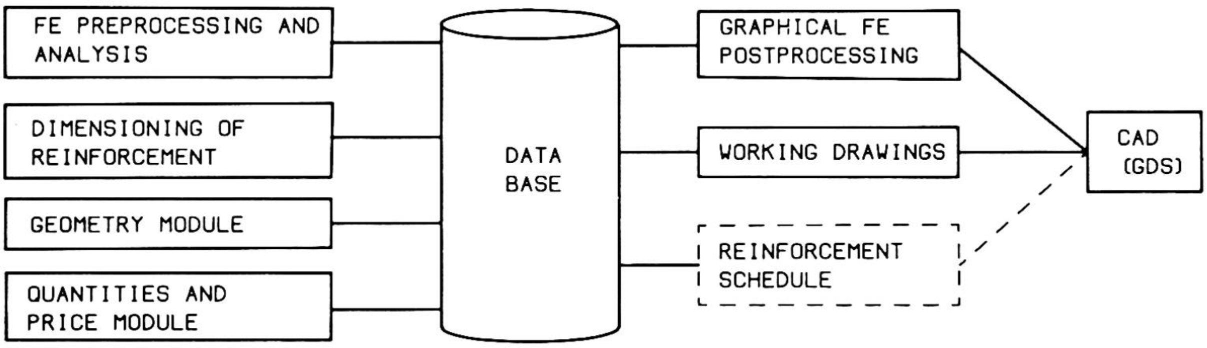

Fig. 1 The VV541 system

3. PROGRAM MODULES

3.1 Finite element preprocessing and analysis

A skew frame bridge is preferably analysed by the finite element method. The finite element system in VV541 includes shell elements and rigid links. The finite element coding is based on STRIP, a well known Swedish general purpose system.

The real benefit of this module lies in finite element preprocessing. In contrast to ordinary finite element systems, the user need not specify nodes and elements, but only the corner coordinates and dimensions of the slab, the abutment walls and the wing walls. This drastically reduces the time spent on the geometry conditions and, furthermore, the tedious calculations of nodal coordinates are performed by the preprocessor.

As regards the loading cases, the user need only specify the loads on the real system and not the loads on the elements which is the standard procedure. Furthermore, traffic loads are automatically generated in accordance with Swedish specifications. The traffic load is modelled as a uniformly distributed load and a group of 3 moving axle loads, with varying distances between the axles. All loading cases are automatically combined into a number of combinations. The total number of loading cases and combinations usually exceeds 50.

The results of the finite element analysis are presented in an output list, but only for the combinations to be used in the design process.

3.2 Graphical finite element postprocessing

It can be difficult to grasp immediately the thick piles of paper output from the analysis. Accordingly, in the postprocessing module there is an option for computer graphics. Any result of a load combination can be displayed graphically which, in turn, gives an inexperienced designer a unique opportunity to really understand the behaviour of a bridge under various loading conditions.

VV541 presents the graphical results either as iso curves, Fig. 2, or as vector graphs, Fig. 3. The abutment walls are tilted 90 degrees and are presented on the same picture as the slab. The result can be presented on paper or on a CAD screen. In the latter case the results can be presented in colour graphics with iso values ranging from dark blue to dark red.

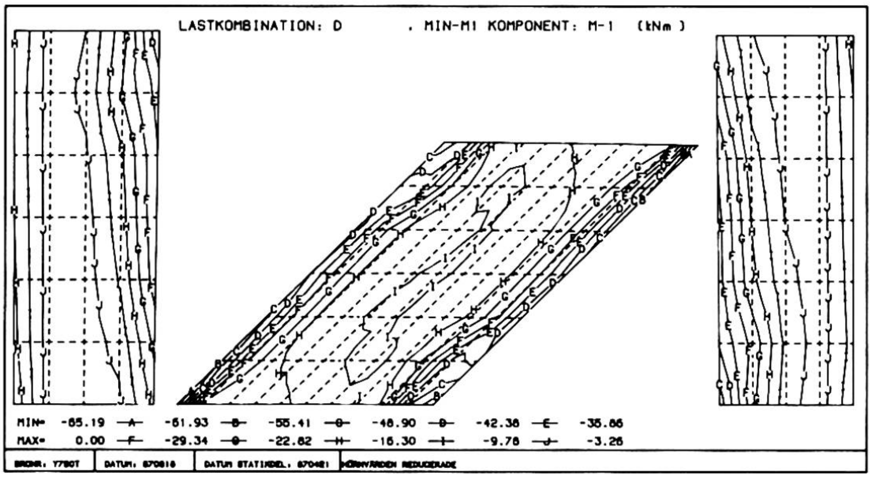

Fig. 2 Graphical postprocessing, iso curves

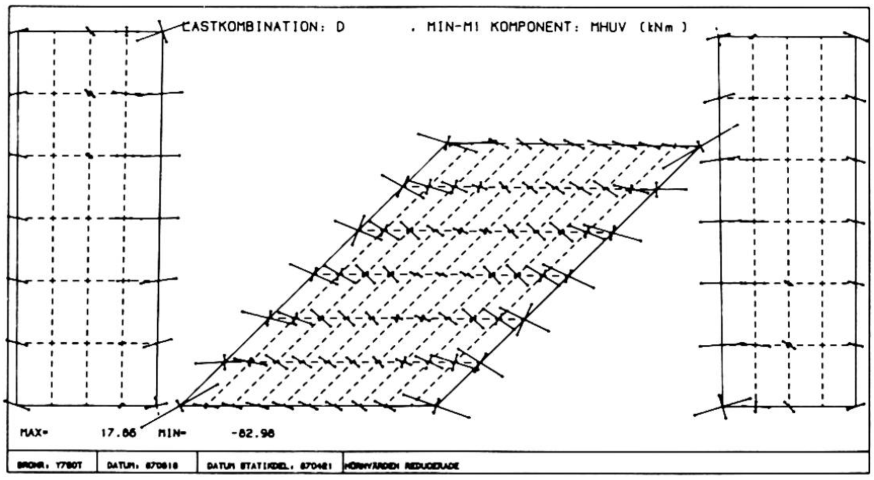

Fig. 3 Graphical postprocessing, vector graphs

3.3 Dimensioning of reinforcement

The reinforcement dimensions are determined on the basis of the static analysis, complemented by input data regarding the choice of concrete and reinforcement grades.

The structure is divided into a number of regions which are evaluated, including calculation of stresses and curtailment of the reinforcement. One example is the region in the principal direction of the top reinforcement on the left hand side of the slab.

Compared with the design of other structures, bridge design is somewhat more complicated. For instance, the layers of reinforcement in the slab will generally not be at right angles to one another. Special attention must be given to reinforcement in several layers and to an option of placing the principal slab reinforcement in a fan shape.

The results can be presented in various ways according to the options selected by the user. The calculated reinforcement is kept in the data base for further use in the production of the working drawings.

3.4 Geometry module

In order that the drawings may be produced, the input data must include the choice of edge beam, camber and so forth besides the coordinates and dimensions. However, the major information already exists in the data base in the form of general values for primitives such as points, lines, figures and reinforcement. These values must be changed into calculated values for the actual bridge structure.

A special program in the VV541 system generates these general values, but this program lies outside the control of the end user. The values are copied into the data base at the time of the first execution. This information amounts to approximately 11000 lines of text.

The geometry module preprocesses the drawings and will also present tables for setting out coordinates.

3.5 Quantities and price module

Based on the module for dimensioning of reinforcement and the geometry module VV541 calculates quantities and total estimated cost for the structure. The output is separated under headings as reinforcement, concrete, form face, ...

One advantage of this module is the possibility of getting a fast and accurate cost estimation of a redesign.

3.6 Working drawings and CAD

VV541 composes drawings out of figures in the data base. These drawings are automatically transferred into the CAD system GDS. This transfer is performed at a high level, which means that not only lines and text blocks are transferred but also a hierachical system consisting of objects. For instance, the command "query object" in GDS and the "hitting" of a reinforcement bar gives the answer: AWLT:REINFORC:EX133 which means reinforcing bar EX133 on figure AWLT (Abutment wall left side).

Furthermore, the Swedish Road Administration have made some special menus for VV541 within GDS. The purpose of these menus is to enable a user with no special knowledge of GDS to adjust the drawings. The adjustments should preferably be made on a colour screen, since VV541 makes use of the colour graphics option in GDS.

The drawings can be divided into reinforcement, dimensioning and setting out drawings. Fig. 4 and 5 show two examples of non-adjusted drawings.

4. ACKNOWLEDGEMENTS AND CONCLUSIONS

Automation of the design process is a very complicated and difficult task. Consequently it is of greatest importance to ensure that the system does not assume command but becomes an indispensable tool for the designer. It is hoped that this is achieved in the case of VV541 by print-outs at every level and by enabling the designer to adjust and modify the final drawings.

Development of VV541 started in the late seventies. At that time, interactive CAD-systems were almost unknown, which means that the development team has continuously had to adapt the system to the latest computer technology. As a matter of fact, the real breakthrough of VV541 did not occur until it was properly interfaced with CAD. This updating process can obviously be quite expensive, but fortunately this has been limited by the well designed systematization and modularization of VV541.

The coding has been quite complex, even though only skew frame bridges can be analysed. It is quite astonishing how much a "standard" structure can vary.

Finally, it can be stated that in VV541 a designer has a tool which facilitates the design process and a system which can easily evaluate the effects of an eventual redesign.

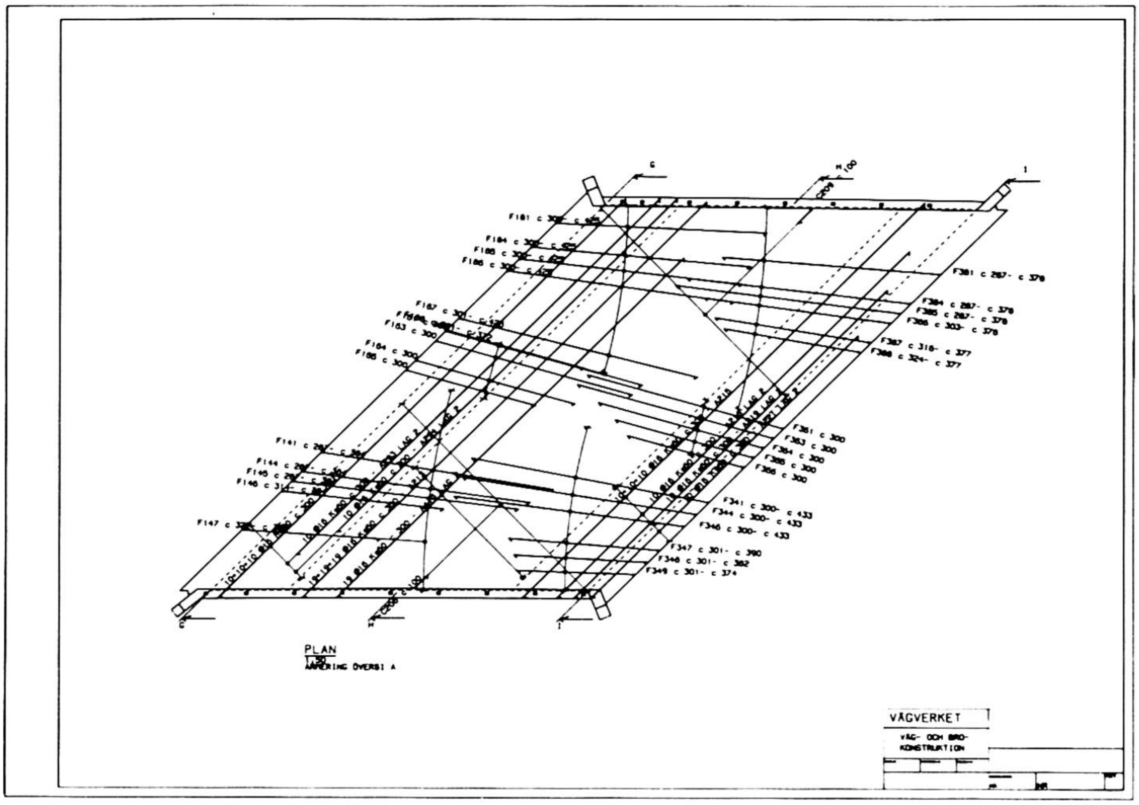

Fig. 4 Reinforcement drawing

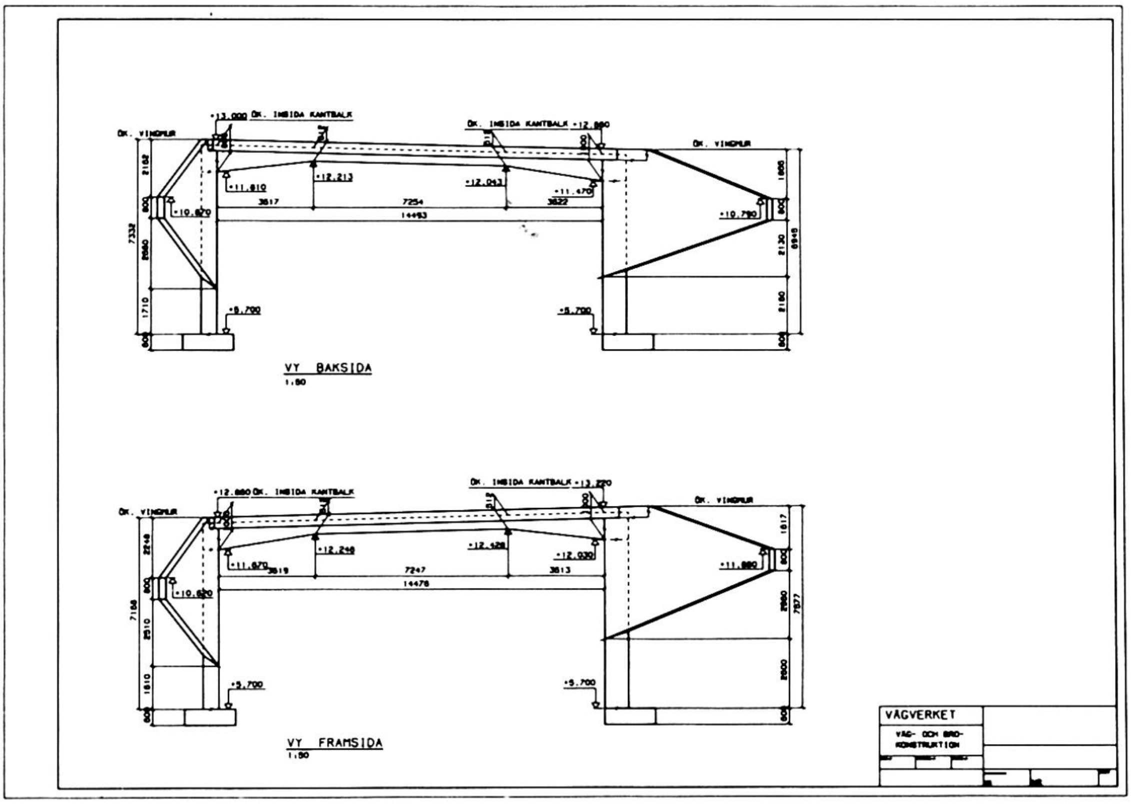

Fig. 5 Dimensioning drawing

Development of CAE System in Design of Hydraulic Structures

Système assisté par ordinateur pour les projets de structures hydrauliques

Computergestütztes Programm für den Entwurf hydraulischer Konstruktionen

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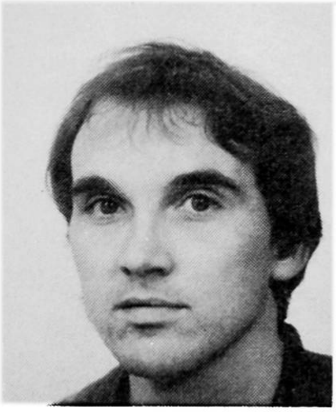
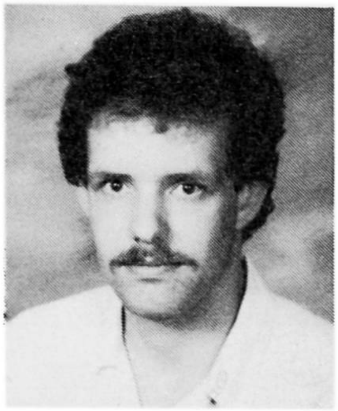


Matthe van Baalen, graduated at Delft university of Technology in 1984 and has worked at the same institute since 1979. He was detached to the university of Zambia for two years and is currently employed with Delft Geotechnics as project engineer.

Frank Engering received his mathematics degree at the University of Technology in Delft. For 8 years now, he has worked at Delft Geotechnics as a research engineer and specialised in technical-scientific computer applications.



Jan Mostert graduated at the institute of technology of Rotterdam in 1986 and is employed at Delft Geotechnics as system analyst.

SUMMARY
The analysis of geotechnical safety and the serviceability of new or improvement designs of hydraulic structures, such as river or sea dikes, breakwaters, large dams etc., generally involves the application of a variety of computational models. This paper contains a description of an interactive system and the experience with it in consulting practice.

RÉSUMÉ
L'analyse de la sécurité géotechnique et de l'aptitude au service de projets nouveaux ou améliorés de structures hydrauliques, tels que des digues fluviales ou maritimes, des brises-lames, des grands barrages etc., comprend en général l'application d'une variété de modèles mathématiques. Cette contribution contient la description d'un système d'analyse interactif, ainsi que son application dans la cadre de plusieurs études.

ZUSAMMENFASSUNG
Analysen der geotechnischen Zuverlässigkeit und Brauchbarkeit von neuen oder verbesserten hydraulischen Konstruktionen, wie z.B. Fluss-oder Seedeiche, Wellenbrecher, grosse Dämme u.a., erfordern im allgemeinen die Anwendung einer Vielfalt von Rechenmodellen. Dieser Artikel enthält die Beschreibung eines Programms im Dialog und die Erfahrungen damit bei der beratenden Tätigkeit.

1. INTRODUCTION

Being a geotechnical institute, the daily routine of Delft Geotechnics comprises the design and safety analysis of various soil structures. The generally complex design criteria require the application of a variety of computational models. For example, the design of embankment reinforcements involves the analysis of slope stability , settlement, consolidation, groundwater flow, etc. For each of these phenomena computer codes are available, which are applied and reapplied successively in the various design stages thus rendering an iterative design process.
The many repetitive actions concerning the preparation of input strings for the computer codes obviously are susceptible to human errors. In order to improve this situation an interactive computer system has been developed, which avoids complex and user-unfriendly input.
This paper gives a description of the interactive system, including software and hardware, and the experience with it in consulting practice.

2. THE SYSTEM CONFIGURATION

The hardware configuration, the so-called workstation with an on-line connection to the control mainframe computer (super minicomputer), consists of a digitizer board, a colour graphical display terminal with a hardcopy unit and a video display terminal.
An interactive control program enables the user to call or recall on geo-technical computer codes in any desired sequence by using screen orientated input facilities.

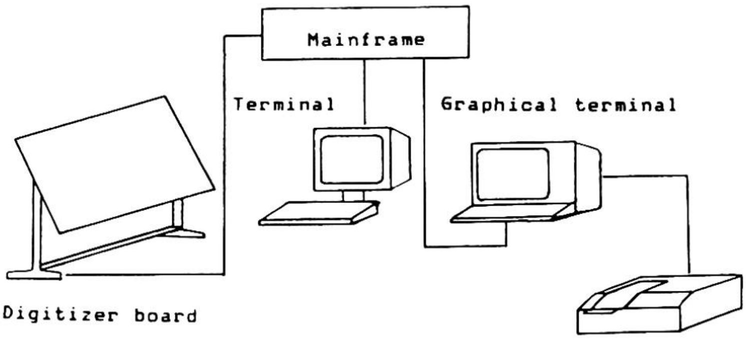


Figure 1: the system configuration

The general set up of the control program is such that any newly developed specific purpose computercode can be connected by means of a software inter-face.
At the present stage, the system enables analysis of stability and settlement of a geotechnical design, finite element analysis, including automatic mesh generation, groundwater flow, consolidation and deformation.

Different kinds of standard dump files are defined to achieve the communica-tion between the different computer programs. For example, a finite element post-processor uses these files to interactively compose a graphical presen-tation of the results.

Future extensions will, among other things, contain connection of computer codes for probabilistic analysis of stability and piping, and connection of a regional geotechnical and geological database and statistical procedures for interpretation of geotechnical data.

3. COMPUTATION PROCEDURE

The design and/or control computations for any geotechnical structure starts with the initiation of the geometry, by using either the digitizer board or the keyboard. The geometry is shown instantaneously on the colour screen. This way the user ascertains visually, whether the desired geometry is generated properly.

After the geometry is generated, the various geotechnical computations can be initiated. When the analysis necessitates the use of finite element computer codes the geometry firstly has to be subjected to a interactive mesh generator and can be altered if necessary. Also the boundaries are automatically determined to the conditions in the finite element calculations.
In all stages of the process the user is permanently visually informed about his activity, while the system scans the input for syntax errors or other irregularities.

With design calculations it is common, that the original geometry is fit for improvement. Dependent on the result of the geotechnical computations the geometry will be adjusted and readjusted in order to achieve the most favourable construction design.
The system allows a rapid alteration of the original geometry and reapplication of the geotechnical computations.
The input and output of the computations can easily be transmitted to either a plotter, printer or colour copy device.

4. CONSULTING PRACTICE

The ability of the system is best illustrated by the experience with it in the daily consulting practice. A suitable case demonstration is found in one of the routine consultations of Delft Geotechnics concerning the design of embankment reinforcements. Firstly, the general design process will be discussed, after which a special case will be demonstrated.

4.1 Design process

The initial design of an embankment is based on the hydraulic boundary conditions and experience with embankments in general.
The design water level (with an occurrence frequency of 1/10000 per year) as well as the wave propagation and runup determine the necessary embankment height and slopes.
Subsequently, the settlement of the embankment is determined and the original design will be altered such that the deformed structure will still satisfy the imposed boundary conditions.
In practice this means that the crown height will be increased according to the expected settlements.

The newly created geometry will subsequently be subjected to stability analyses using Bishop's slip circle method. The stability is investigated during and just after construction as well as long after construction, when excess pore pressures in the underlying soil strata induced by the sudden loading have all dissipated.
Hence, in addition to the deformation and strength of the soil parameters the input comprises a thorough description of the (excess) pore pressure distributions.
The safety against failure during construction should not be less than 1.1, while the long term stability should be guaranteed by a safety factor of at least 1.3.
Since the stability is investigated in various construction stages the geometry as well as the input parameters have to be altered accordingly.

When the calculated safety factors do not satisfy the abovementioned design criteria the geometry needs to be adjusted, by for instance, an additional bank.

4.2 Case demonstration

The case presentation concerns a shore protection structure at the coast of the receding Nile delta. The settlement of the embankment is calculated using a finite element computational model (figure 2).

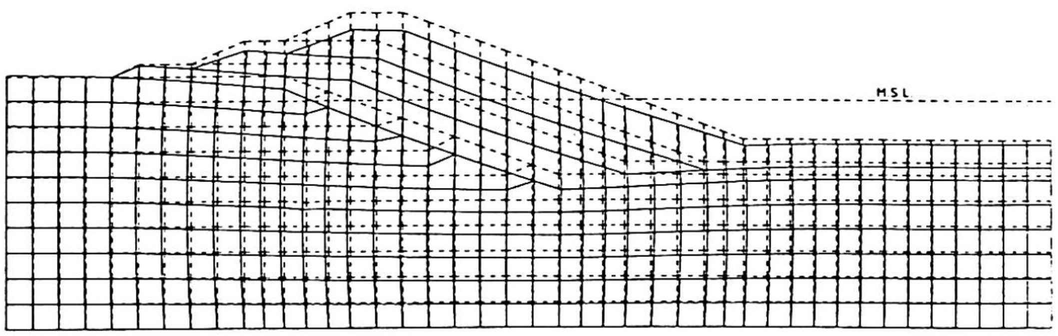


Figure 2: settlement determination using a finite element model.

The originally generated mesh in figure 2 is represented by the dotted lines, while the drawn configuration emphasizes the deformed structure. In order to account for the settlements the embankment is altered accordingly. Stability analyses on the altered structure indicated: insufficient safety factors during construction and long after construction. Figure 3 outlines the result of the slip circle analysis for the embankment long after construction.
Indicated are the block of analysed slip circle centres, the various tangent levels (dotted lines) and iso-safety lines. The minimum factor of safety turned out to be 1.08 and was found for the circle drawn in the figure.
In order to increase the stability of the embankment and satisfy the prescribed safety against failure, an additional bank is applied as shown in figure 4. Again the analysis of the long term stability is shown.
Due to the additional bank the safety factor increases from 1.08 to 1.54.

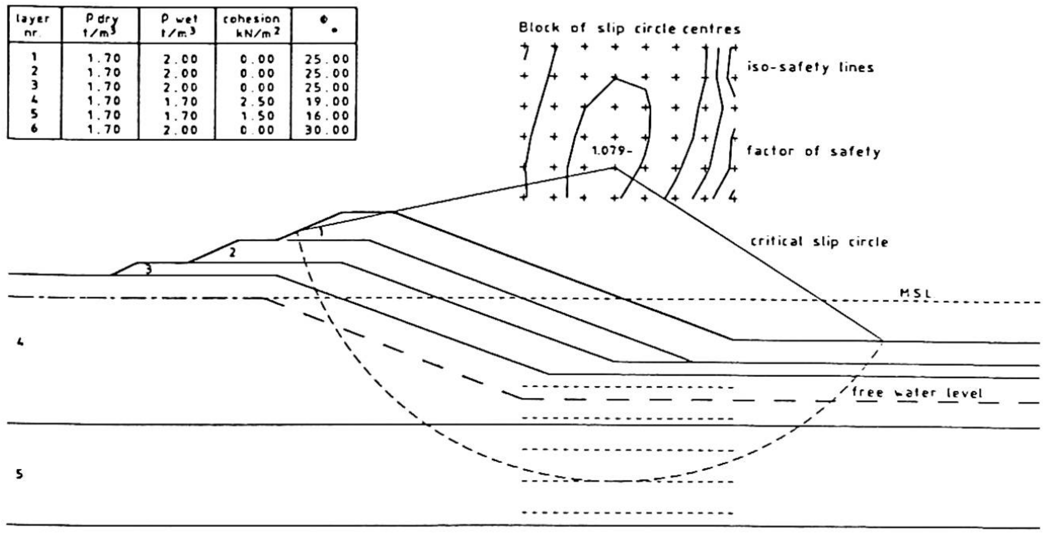


Figure 3: long term stability analysis

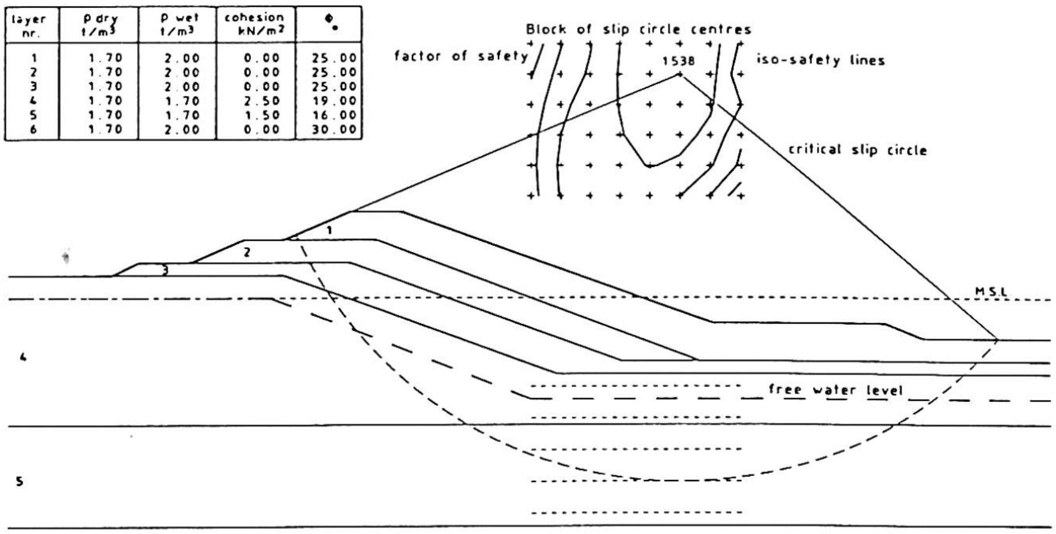


Figure 4: long term stability analysis with an additional bank.

5. CONCLUSION

Summarizing, the experience with the interactive system on design computations as described above has shown the evident advantages. Especially with a frequent alteration of geometry and input parameters to achieve the most favourable construction design the interactive qualities of the system result in a tremendous saving of time and money.

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On Computer Aided Project Design, Planning and Management

Conception, projet et gestion assistées par ordinateur

Projektierung, Planung und Management von Bauwerken mit Computern

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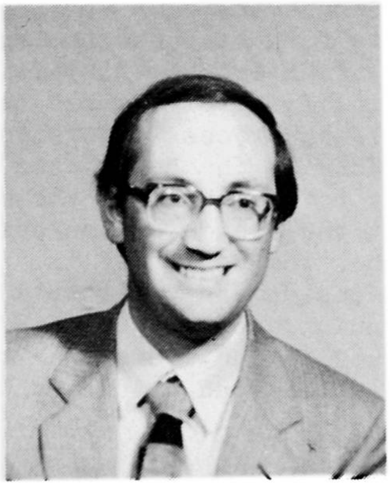


Čeněk Jarský, born 1953, received his MSc degree in Civil Engineering and the PhD degree in Technology of Structures at the Czech Technical University of Prague. For several years he has been working in building process modeling and control. Now he is responsible for research in the field of planning and execution of structures and project management.

SUMMARY
The procedure for the design of a project by a contractor is briefly described. Basic facts about an integrated computer system consisting of a CAD subsystem linked directly to a subsystem for planning and management of projects are given. The significant features of both subsystems are indicated. Main principles of a new network analysis method and its functions in the system are emphasized. Procedures for using databases and data transfers to on-site computers are mentioned. Further perspectives in developing an integrated expert CAD/CAM system are summarized.

RÉSUMÉ
La méthode de projet utilisée par un entrepreneur est passée brièvement en revue. Des données fondamentales sont rappelées pour un système intégré d'ordinateur composé d'un sous-système de conception aidée par ordinateur relié directement à un sous-système pour le calcul du projet et la gestion de la réalisation. Les éléments essentiels des deux sous-systèmes sont présentés. Les principes généraux d'une nouvelle méthode d'analyse de réseaux et ses fonctions dans le système sont présentés. L'article mentionne des procédés d'utilisation de bases de données et de transferts de données sur des ordinateurs de chantiers. De nouvelles perspectives dans le développement de systèmes experts pour la conception et la fabrication aidées par ordinateur sont présentées.

ZUSAMMENFASSUNG
Das Verfahren der Projektierung der Bauten durch einen Unternehmer wird kurz beschrieben. Die Grundprinzipien des integrierten Computersystems, das aus CAD Subsystemen besteht und direkt mit dem System für Planung und Management der Bauten verbunden ist, werden angegeben. Die Hauptprinzipen einer neuen Netzplanungmethode und ihre Funktion im System werden hervorgehoben. Die Vorgehensweise bei der Verwendung der Databasen und der Datenübertragung zu den Computern auf den Baustellen werden beschrieben. Weitere Perspektiven der Entwicklung das integrierten Expert-CAD-Systems werden zusammengefasst.

1. INTRODUCTION

When new structures are to be build it is necessary to visualize all the operations of the building process of the structure, arrange these operations in their proper sequence and achieve confidence that every participant of the building process, that means the investor, the architect and the contractor understand each of his tasks. Thus all projects have to be efficiently designed, planned and their building process has to be managed in optimum way.

For applying computers in all of these phases in Czechoslovak conditions an attempt to create an integrated computer aided project design, planning and management system has been made in Průmstav Prague, one of the biggest Czech contractors, recently. This firm has been chosen by the Ministry of Building Industry as a participant of an experiment that has to verify the possibilities of shortening and simplifying of the project design stage and of its direct linkage to the building process management with the help of computers. The project design phase done by the contractor who has his own architectural studios in this experiment covers not only the architectural and constructional part of the design but the design of the optimum procedure of production of the project as well. Thus the design of the project has two stages - architectural - constructional design and construction technology design with the direct linkage to the planning and management of the production process of the project. This integrated design system has to pass his outputs, especially those concerned with planning and production to the recent system of management of the firm described shortly in /5/ or /4/.

Because of lack of high quality computer hardware and CAD software in ČSSR the Norwegian firm ICAN of Kongsberg supported by Data Design System of Sandnes was chosen to cooperate in developing of the integrated design system. The Norwegian side offers the main hardware of the system which is a mainframe ND 505 minicomputer linked with working stations based on Datagraph PC AT microcomputers equipped with two displays (1 traditional and 1 colour graphic monitor with high screen resolution), a digitizer, matrix printer and plotter. The Norwegian firms afford also the main CAD software for the architecture - construtional phase of the design process. This software consists of the complete 3 D model of the building and enables to create a bill of quantity file automatically. This is the main linkage to the software for the construction technology design, budgeting, cost estimations and quantity surveying that has been developed by our Research and Development Establishment and by Průmstav Prague computer centre. Both software packages use input and feedback data bases. The outputs of the system are passed from the design establishment directly to the production establishments of the firm, the architectural part as drawings, the construction technology part either in computer printouts and drawings or on a floppy disc suitable for an 8 bit microcomputer of the Czechoslovak production which is at the disposal on larger building sites or in technical groups of the production establishments of Průmstav. This part is then used for the direct management of the production process of the project by updating and optimizing the course of construction processes and balancing costs and other significant resources flow.

2. BRIEF DESCRIPTION OF THE ARCHITECTURE-CONSTRUCTIONAL CAD SUBSYSTEM

The Data Design System, a separate company within Block Watne a/s, Norway's biggest housebuilder, has developed a sophisticated CAD software suitable for IBM PC compatible microcomputers, see /8/. This system includes a powerful General Draughting Program (GDP) and a series of application user oriented programs that have been adjusted according to conditions and requirements of Průmstav Prague for the need of an architect or a civil engineer.
The system has a "ghost drawing" feature that permits previously completed

drawings to be called up and important elements recorded. These elements can be freely referred to when creating a new drawing. The system maintains a continuous record of information about all rooms contained within the building. A "room table" can be called up and printed on the drawing in any position, giving a complete overview of all rooms in the building, including dimensional and other details.

The "genetic code" used in the general draughting program fully documents a 3-dimensional model of a building. Thank to this feature the system permits to create automatically a file of volumes of products used in the building that links the system directly with programs for bill of quantity calculation. Thus the system can be easily linked to existing programs for specification, cost control, planning, construction technology design and production management.

The GDP enables the establishment of libraries of standart components or details, corresponding to the actual production. The symbol libraries are usually kept in two detail levels according to scales and in 2 and 3 D. Libraries include components like doors, windows, wall panels, fittings etc. and are based on a database system. The stored data include not only graphical information but the technical - economical information, e. g. labour consumption, materials and their volume, prices, costs, etc., too.

The function for scaling, zooming, panning and the free rotation possibility around any three dimension axis are at user's disposal too. The GDP has good facilities to complete drawings, e. g. texting, area calculation, automatic or manual dimensioning etc. Hidden lines can be removed and shading can be performed according to a free position of the sun point. After generating the ground plan of the building the automatic production of cross-sections, elevations and perspective views is possible.

The general draughting program is complemented by application modules designed specially with respect of needs and requirements of architects and civil engineers. These modules have been adapted for special conditions of Průmstav Praha. They are oriented especially for module house design. They consist of the house, floor and wall panels program (HFW), heating, ventilation, air-conditioning schematics and installation program (HVSI), electrical schematics and installation program (ELSI), terrain program (TER), excavation program (EXC), foundation and basement program (FUB), concrete reinforcement program (CRE), hidden line and shading program (HLS) and bill of quantity main module (BQ).

All programs are written in FORTRAN 77 language and work under the MS DOS operating system. They require 640 kB of operating storage and a screen with minimum recommended resolution of 640 x 400 pixels. The inputs to the system are entered via flat menu , hierarchic menu , digitizer menu , alphanumeric menu , function keys, pen or mouse or a bar code reader.

3. BRIEF DESCRIPTION OF THE CONSTRUCTION TECHNOLOGY CAD SUBSYSTEM

3.1 Methodology of construction technology design

Basic documents in construction technology designs include files of planning cards (at the level of construction technology conceptual designs), files of technological standarts (at the level of construction technology operational designs). In both types of construction technology designs network diagrams are used which are closely linked with the quoted documents and permit to elaborate bar charts, line-of-production graphs and resource allocation graphs. The simultaneous elaborating of technological standarts and network diagrams is necessary for the construction technology CAD system, see /4/, /6/, as it precludes the processing of network diagrams without previous construction technology analysis and synthesis.

The technological standart determines the technological structure of the production process (sequence of construction processes, volume of production, labour and costs consumption, number and profession of workers etc.). It usually includes a bar chart which indicates the time structure of the production process; a technological diagram showing the spatial structure of the process is usually added. The construction technology design includes the quality assurance checklist which consists of instructions for the quality control of the resulting product at every significant construction process.

According to the duration of the processes, which is calculated according to the automated bill of quantities, number of workers and time standarts, and the minimum working space necessary it is possible to determine with regard to the directions of the course of processes the critical approximation of the processes and to link such processes immediately in optimum way in the network diagram.

3.2 Basic principles of the CONTEC network analysis method

For the mentioned subsystem a new construction technology (CONTEC) network analysis method was developed in our establishment. It is determined for simultaneous processing of technological standarts and network diagrams and for the optimization of linking the construction processes from the point of view of maximum use of minimu working space on site, /3/.

The CONTEC network analysis method uses the activity-on-node network diagram and it follows the precedence graph method. All four types of links introduced in the precedence graph method (finish - start, start - start, critical approach and finish - finish), see /1/, /7/, are included in the CONTEC method too. The main disadvantage of the precedence graph method is the necessity to know the actual values of lag times between every two activities that are linked while createing the network diagram. To exclude errors by usein the start - start link one has to know the durations of linked activities in advance before the network diagram is computed. This would make the concurrent computation of technological standart where activity durations are computed and of the network diagram where the terms of start and finish of activities are determined, impossible.

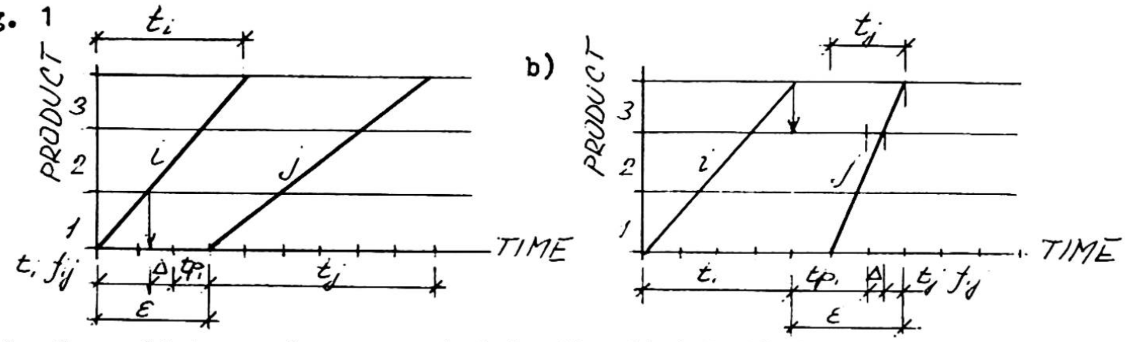
Therefore the CONTEC network analysis method introduces the 5th type of link, the construction technology link, that results from the condition of release of minimum working space on a structure by the previous work gang so that the following work gang could start their work as soon as possible. The lag time is not given by an actual time value but it is calculated according to the durations of linked activities and to the spacial structure of the building represented by a working space index f. This index is determined by the ratio of the minimum working space needed for the gang to the total working space in a building, e. g. in a 8storey block of flats the usual minimum working space are 2 storeys, so the working space index is 2/8, this is 25 %.

The situation of linking two activities i and j is illustrated in the line-of-production graph on fig. 1 a, b. Values t_i and t_j represent the duration of those activities, tp_i the technological pause after completing the i activity, f_{ij} is the working space index. In the first case (fig. 1 a) if the first activity i is shorter, that means $t_i \leq t_j$, the construction technology link can be transfered to the start - start link and the lag time ε can be automatically calculated according to formula (1). In the second case (fig. 1 b) if the

$$\varepsilon = t_i \cdot f_{ij} + tp_i + \Delta \qquad (1)$$

following activity j is shorter, that means $t_i > t_j$, then the construction

Fig. 1



technology link can be converted to the finish-finish link and the lag time ε can be calculated according to formula (2). The Δ value rounds the lag times up so that the work gang j would start their work at a certain time unit in the morning.

$$\varepsilon = t_j \cdot f_{ij} + tp_i + \Delta \tag{2}$$

Next the CONTEC network analysis method introduces the 6th type of link - the flow link that results from the condition of continuous course of a construction process on different products, e. g. sections, buildings etc. The situation is illustrated on fig. 2. Using the flow method of building a stage activity i with the duration of t_i and the time of launching T_i' works at the product 1 and proceeds continuously to the product 2 as the activity j. This can have ist duration of t_j and because of different spacial structure of product 2 its time of launching T_j' can be different of T_i'. Then the flow link can be automatically converted to the finish - start relationship and its lag time ε can be calculated according to formula (3).

$$\varepsilon = - T_i' \tag{3}$$

Introducing these links in the CONTEC method means not only a significant simplification of inputing the data about the network diagram but it permits a wide utilization of typical network diagrams for certain sorts of buildings and their modification according to the spacial structure of the actual building. Usually only three types of construction technology links are sufficient to evaluate all technological constraints in the building process. In the typical network diagram the values of the working space indices can be stated parametrically, e. g. as 0, -1, -2. While inputing data about the actual building the typical network diagram can be automatically modified by the system only by stating the concrete values of these 3 working space indices.

Using the flow link modified typical network diagrams can be automatically linked into a greater network that may represent the buildling process e. g. of the whole housing estate. In this case the flow links are generated by the system at activities that are performed by special work gangs that proceed from one building to another.

The CONTEC network diagrams can be calculated on the deterministic or stochastic bases.

3.3 USING CONTEC METHOD FOR PROJECT PLANNING AND MANAGEMENT

The principles of CONTEC method assure a significant simplification of data input while creating the network diagram of a new project. The direct connection with the architecture - constructional CAD subsystem via the bill of quantities file enables after certain aggregations to put in the data about volumes of production and costs for all activities automatically. The resource leveling option based on methods mentioned in /1/ is included in the subsystem. The main out-

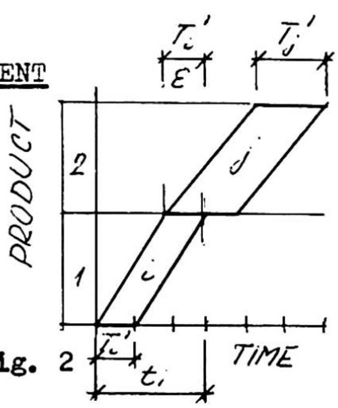


Fig. 2

puts of the CONTEC subsystem are: technological standart, network graph, bar-chart, line-of-production graph, resource allocation graphs and quality assurance checklist. Simultaneously, cost estimations and budgets can be calculated according to the bill of quantity file by other programs.

All programs of the CONTEC system are written in TURBO PASCAL language and work in connection with the architecture-constructional CAD subsystem on the IBM PC compatible computers under MS DOS operating system. The CONTEC itself can be used on 8 bit microcomputers under the CP/M operating system too. The data are passed to these computers on floppy discs. Thus the system permits simple updating of all documents according to the actual date and percentage of completion of construction processes on site. If there is a delay at the deadline of the project the computer may find where more resources are necessary to shorten them to keep the deadline.

The CONTEC system has been in use for project planning and management on many building sites recently, e. g. Czech National Council, Řepy housing estate, Police headquarters in Prague etc. Due to the optimization the total time of completion was decreased for 5 - 7 %, thus the total costs were dedreased too.

4. CONCLUSIONS

The first integrated system for the design, planning and management of projects in ČSSR was assembled as stated. This system practically follows the complete design and management chain: architect, civil engineer, contractor, supplier. Průmstav Prague is now at the beginning of utilizing the system. The first experiences gained are positive. But themes for further development occur. In the next future the system will be complemented by programs for static calculations, heat and energy loss calculations, new technologies of foundations calculations, optimum design of means of production in mechanized construction processes /3/ and programs for production program balance.

Thus, step by step an integrated expert CAD/CAM system for the structure design, planning and management of projects will be created. One can not count on that it will solve all problems in Czechoslovak civil engineering overnight, but it will surely bring a lot of progress for extending the total building production, shortening the terms of building and time, labour and energy savings and it will lead to higher standart of Czechoslovak structures.

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Computer Aided Design for Slab Bridge Decks

Conception assistée par ordinateur pour des tabliers de ponts-dalles

Computergestützter Entwurf von Fahrbahnen auf Plattenbrücken

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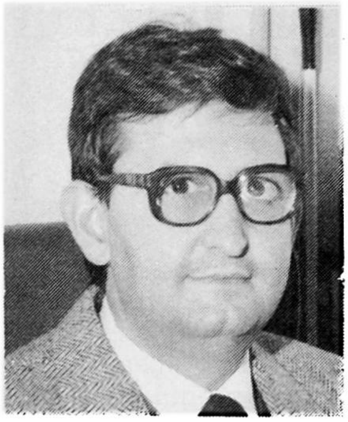
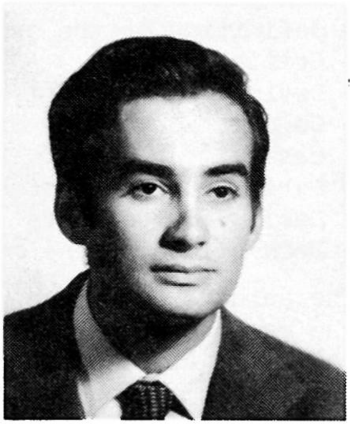


Alfonso Recuero, born 1944, obtained his doctorate in Civil Engineering at the University of Madrid. He has been working for the past 18 years in computer methods for structural analysis. He leads a research project on the Behaviour of R.C. Structures. Alfonso Recuero became blind in 1974.

Olga Río, born 1955, obtained her doctorate in Civil Engineering at the University of Tucumán, Argentina. She has been working in structural analysis at the Torroja Institute for the past six years.



Juan A. Tinao, born 1955, graduated from the University of Madrid with a doctorate in Civil Engineering. He has worked on design and analysis of bridges for the past six years.

SUMMARY
This paper presents the main characteristics of a CAD Program for the analysis of continuous multispan slab bridge decks. It allows the definition and drafting of the deck and produces all the data – geometrical, topological, mechanical and load cases including pre-stress forces – for a plane grillage used as the structural model for the bridge.

RÉSUMÉ
Cette étude présente les principales caractéristiques d'un programme CAO pour l'analyse des tabliers de pont de travées continues. Elle comporte la définition et le tracé du tablier et indique toutes les données – géométrique, topologique, mécanique et les cas de charges y compris l'action de la précontrainte – pour un grillage utilisé comme modèle structural du pont.

ZUSAMMENFASSUNG
In dieser Studie werden die wichtigsten Merkmale eines CAD-Programms für die Untersuchung durchgehender Fahrbahnen auf Plattenbrücken dargestellt. Dieses ermöglicht es, den Belag zu bestimmen und zu entwerfen, und es stellt alle Daten (die geometrischen, topologischen und mechanischen sowie die Belastungen, einschliesslich der Vorspannkräfte) für einen ebenen Trägerrost, der als Strukturmodell für die Brücke verwendet wird, zur Verfügung.

1. INTRODUCTION

The customary approaches for designing short or medium span bridges are either solid or hollow slab decks and precast girder bridges. The deck design is always done by the engineer when the option chosen is a slab bridge while for the precast girder option it is generally the girder manufacturer who supplies the design calculations. Slab decks, because of their "in situ" casting, can be more readily adapted to any layout arrangement, both in plant and elevation and they offer a more varied cross-section range. Furthermore, they make it possible to build continuous span bridges and provide greater freedom for pier location. All this requires that every bridge is studied carefully and treated individually and, for this reason, it is advisable that specific CAD programs are available for this type of bridge to help the engineer, not only in defining the type of bridge, but also to produce an adequate calculation model which, in most cases, would be a plane grillage.

The stages in the design of a slab deck can be summarised as follows:

- definition of the geometrical shape both in plant and cross-section
- Grillage layout
- Definition of the loads involved
- Calculation of the displacements or load effects corresponding to the above cases
- Determination of prestress forces
- Design load effects
- Deck reinforcement design.

The authors of this paper are working in the Instituto Eduardo Torroja (within the research project PR84/0199, with the financial support of CAICYT) on the development of a package covering all the above stages for straight slab span, multiple span and symmetrical slab bridge decks. These bridge types include a significant percentage of all highway bridges. This paper discusses the work carried out on Stages 1 to 5, where generally accepted criteria are recognised to exist.

2. DEFINITION OF GEOMETRICAL DECK CONFIGURATION

This program only deals with straight skew bridges where support lines may not be parallel to each other and have either a solid or hollow constant symmetrical cross-section which becomes solid along the support lines. This type does not allow direct treatment of curved plant bridges or of bridges with unsymmetrical cross sections or where the cross-section varies either in width or depth. But it is nevertheless possible to modify the grillage data provided by the program not using the computer in order to handle some of these cases.

To define the plant it is only necessary to provide the length of each span, the deck width and, for each support line, the angle it forms relative to a line perpendicular to the bridge axis and the width of the solid area over the support lines.

The most complicated exterior profile of the cross-section can be a trapezoid with two wings varying in depth linearly. The cross-section can be solid or hollow; in the latter case, hollows may be either circular or rectangular. Two hollow sizes can be considered, depending on whether they are located in the centre or at an end. The program requires a minimum number of geometrical data that are necessary for obtaining a cross-section shape in which the number and position of hollows are determined.

The program allows the bridge plant and cross-section to be drafted, either on the screen or on a plotter and both correctly dimensioned. Figure 1 shows the plant and cross-section of a two-span bridge whose cross-section has wings and circular hollows. The program also supplies a number of additional data on the

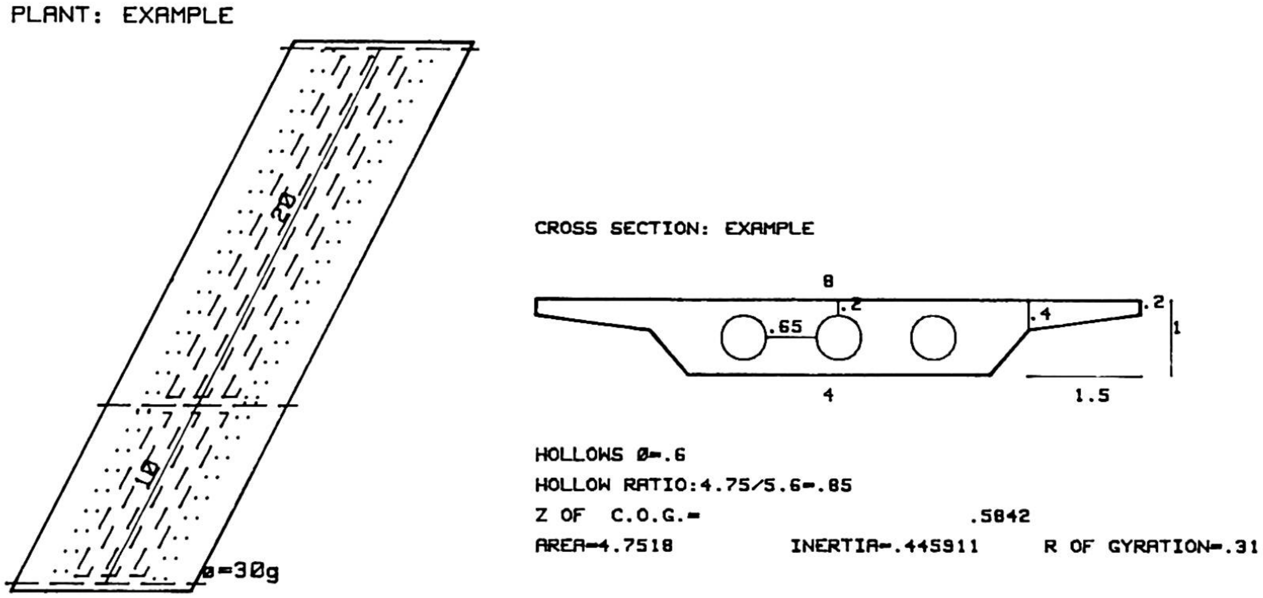


Fig. 1 Plant and cross-section of a two-span bridge

cross-section such as cross area, depth of centre of gravity, the moment of inertia relative to the horizontal axis crossing this centre of gravity, the turning radius, and the hollowing ratio. The designer may decide, in view of these data and of the cross-section and/or plant draft, to change the specifications in an interactive fashion and will immediately obtain the results of the modifications.

3. GRILLAGE DESIGN

The structural model selected to represent the behaviour of this type of structure is a plane grillage with longitudinal members parallel to the bridge axis and cross members that can be perpendicular to the longitudinal members or parallel to the support lines if these are parallel to each other (1, 2, 3). A further set condition is that longitudinal members must be uneven in number and symmetrical to the bridge axis.

The program automatically proposes a grillage where the longitudinal members correspond to a central hollow, the member axis coinciding with the hollow axis when the number of the latter is uneven or with the solid area between hollows when these are even in number. The remaining parts of the cross-section up to each end are carried by two members with their axes placed at 0.3 times the depth from the point where the wings start or, if no wings are provided, from the bridge edges. Cross members are perpendicular to longitudinal ones, intersecting them on the support lines and at regular intervals in each span; in addition, when a support line is not perpendicular to the bridge axis other members are then arranged representing such a line. As support conditions, the program proposes that all nodes falling on a support line are restrained in their vertical displacements and free in both rotations. The structural nodes are numbered according to cross members. Figure 2 presents the grillage proposed by the program for the bridge in Figure 1.

The grillage proposed can be modified by the designer in the following respects:

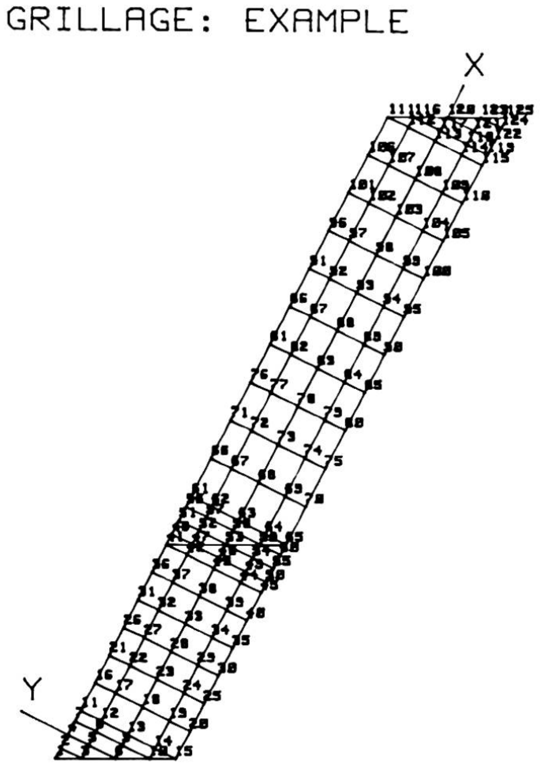


Fig. 2 Grillage

- changing the number and location of longitudinal members, i.e. grouping more than one hollow for each member
- if all support lines are parallel to each other placing cross members parallel to support lines
- changing the number of cross members for each span
- where cross members are perpendicular to longitudinal ones and support lines exist that are not perpendicular to the bridge axis, automatically eliminating alternating cross-member lines on support lines with the purpose of avoiding an excessive number of members where the skew angle is small
- numbering nodes lengthwise. This form of numbering, which may be advisable in some cases, gives a greater band width in the stiffness matrix, which is of no worth if the structural analysis program renumbers the nodes internally in order to reduce band width
- redefining support conditions for all grillage nodes, considering them as rigid supports or attributing to them elastic coefficients.

Figure 3 shows two grillage layouts for the bridge in Figure 1 where some of the abovementioned changes have been introduced.

The program produces all geometrical, topological and mechanical data of the grillage in accordance with accepted standards for this type of structure; it allows data to be listed and stored in a file directly available to a structural analysis program, and a grillage layout to be drafted on the CRT or on a plotter. Moments of inertia of members are given in respect of an axis placed at the same level as the centre of gravity of the cross-section. To calculate the cross-area and moment of inertia of longitudinal members, circular hollows are substituted by rectangular hollows of equal area and moment of inertia relative to the horizontal axis. This permits these constants to be accurately calculated when longitudinal members represent whole numbers of half hollows, as is normally the case,

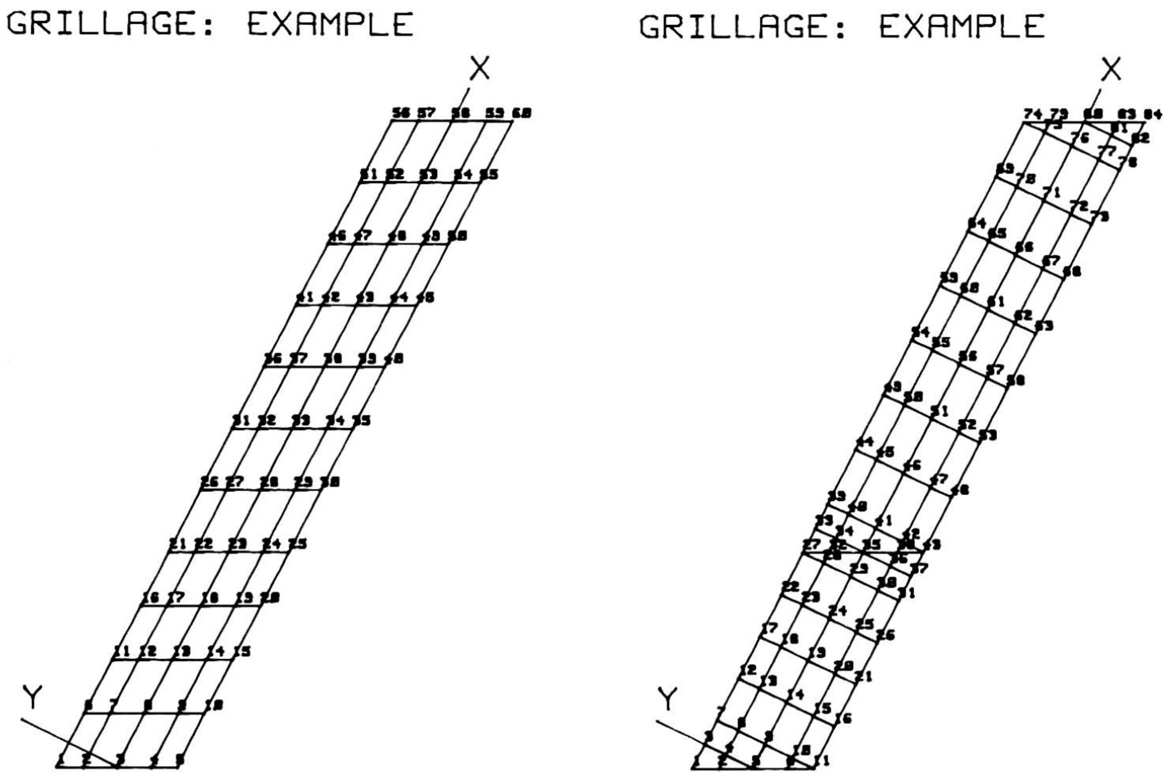


Fig. 3 Two grillage layouts for bridge

although when the opposite is true minor errors do occur. To calculate the moment of inertia of the cross-members only the upper and lower sub-slabs are considered, on both sides of a central hollow axis although, in the case of circular hollows these are changed for equal area square hollows. Members corresponding to support lines are assumed to be of solid square section.

For these calculations the width represented by each member is deemed to be up to the midpoint between adjacent members or up to the outer deck surface. Cross-members falling on nodes along the support line are assigned half the characteristics of the other members in the same line. Finally, the moment of inertia of the members is determined by a simplified procedure equal to twice the flexural moment of inertia.

4. DEFINITION OF LOAD CASES

The program automatically produces the most common load cases and provides for the manual introduction of new cases, at the designer's discretion, permitting changes to any of them.

The automatically produced load cases are:

- deck dead weight, as uniformly distributed load along longitudinal members
- dead weight of footpaths, pavings, parapets and guard rails
- service life loads at 400 kilograms per square metre, assumed to be uniformly distributed over each half carriageway on each span
- positions of the loading pattern, both centred at 40 cm from one of the carriageway edges, over the following lines: intermediate support lines; one depth away from the end support lines and on the centre line of each span. In addition, the following load types may be introduced at the designer's will:

- load distributed on a given deck area
- loading pattern placed at any point
- definition of pre-stress cable arrangement through calculation of vertical loads, loss of pre-stress and axial action effects, for a unit pre-stressing force.

5. CALCULATION OF DISPLACEMENTS AND LOAD EFFECTS

The program for calculating displacements and load effects in grillages takes its data from files storing grillage and load description, then calculates the displacements and load effects for each load case and stores them in the respective disk files. Later, the program allows the load cases to be classified as: permanent, those that must always be taken into account; variable, those that should only be taken into account when their effect is unfavourable; and exclusive, only one of which is to be so considered for each combination, that is the most unfavourable for the load effect being studied. The designer may decide the number of combinations to be carried out and the coefficients to be assigned to each case and with this the program determines the most unfavourable load effect combination for each cross-section.

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Experiences with an Integrated Building Design Software

Expériences avec un logiciel de conception intégrée en construction

Erfahrungen mit Integrierter Software im konstruktiven Ingenieurbau

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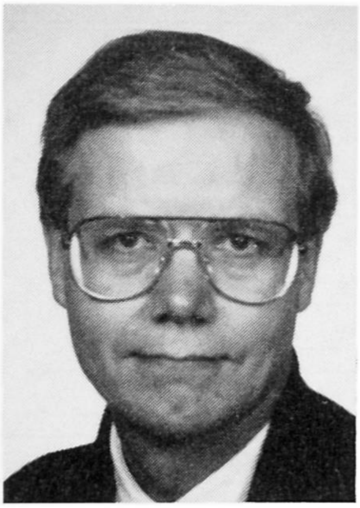


Risto Sajaniemi, born 1940, received his engineering degree at the Technical University of Helsinki, Finland. For twenty-three years he has been involved with computer applications in structural engineering. Now he is a manager in the leading Finnish engineering software company, Tekla Oy.

SUMMARY
A strategic long term concept will be presented for the integrated information processes in civil engineering and urban planning. This includes also some basic but very important guidelines. The integrated building design software package developed during 1984–1987 will be presented. Experiences achieved and the future of integrated building design will be discussed.

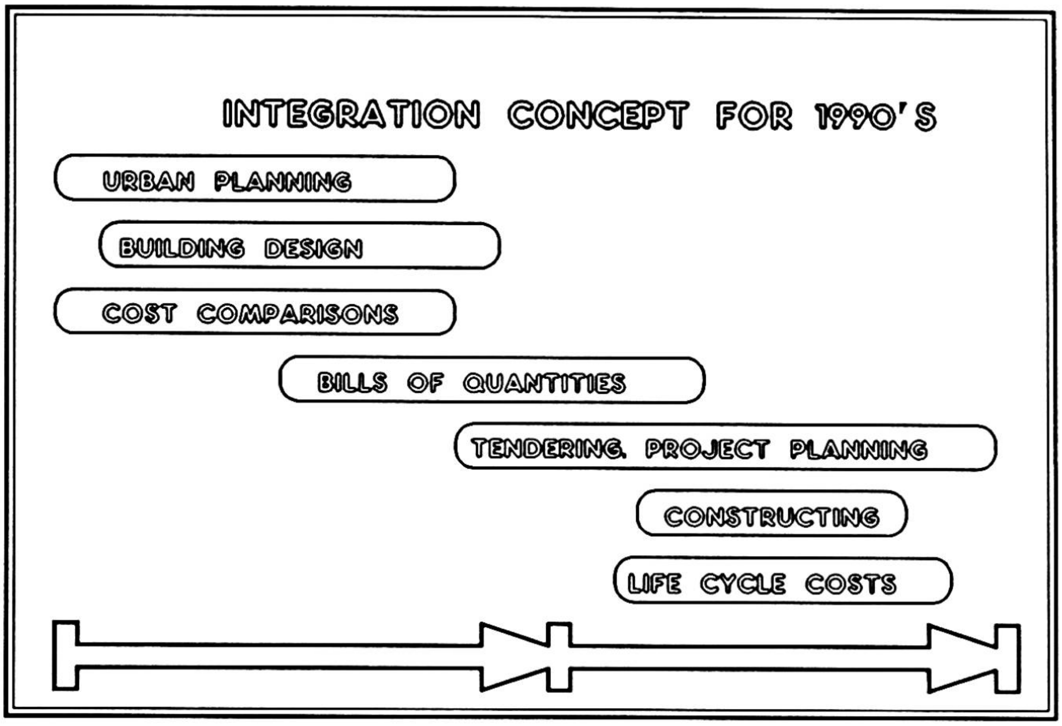
RÉSUMÉ
Une stratégie à long terme est proposée pour l'intégration de processus informatiques dans la conception de projets urbanistiques et dans le génie civil. Elle est constituée de lignes de conduite fondamentales mais néanmoins essentielles. Un progiciel de conception intégrée en construction a été développé de 1984 a 1987. La dernière partie montrera des réalisations terminées et ouvrira des perspectives sur la conception intégrée en construction.

ZUSAMMENFASSUNG
Es wird ein strategisches Langzeit-Konzept auf dem Gebiet der integrierten Informationsverarbeitung im Bauwesen und der Stadtplanung vorgestellt. Hierin eingeschlossen sind wesentliche Grundgedanken und wichtige Richtlinien. Anschliessend wird die integrierte Software für diese Anwendungen erläutert, die seit 1984 entwickelt wurde. Die gewonnenen Erfahrungen werden veranschaulicht und Zukunftsperspektiven des integrierten Entwerfens, Berechnens und Konstruierens aufgezeigt.

1. THE TOTAL CONCEPT

1.1 Civil Engineering and Urban Planning

The firm Tekla is creating an integrated CAD/CAM system for the area of civil and building design and construction (fig. 1). Every "bubble" - a part project - forms an integrated system. Each program has been developed by using consistent basic software, which secures the possibility to make further integration in the future.



1.2 The Basic Components

As a basis of this system Tekla has used ready made basic software:

- Design Office Graphics System - DOGS (PAFEC LTD., ENGLAND) for **graphics applications**
- Relational Data Base - RDB (DIGITAL EQUIPMENT CORP.) for **data base** applications

By basing the system on these, Tekla was able to concentrate on design and calculation applications, to achieve an easy user interface and to complete data management. Thus the resources are not wasted in reinventing of basic draughting and data base software.

One of the application systems called ALVISR, according to its Finnish initials of the corresponding design disciplines, is aimed at **building design**: architectural, structural, HVAC and electrical desing. The system consists of calculation, design and graphic programs, all of which use common data bases and the same data communication techniques. The application modules can be used separately, some even in PC micro computers, or as an integrated system in a computer network.

1.3 The Only Valid CAD Concept

The economic benefits are not achieved by automating only the drawing part of an engineer's work. The CAD system has to be intelligent, to know the contents and relations in a drawing. This means that the design object has not only to be drawn but rather to be modelled. This model, which is created using interactive graphics and application programs, is stored to data base. The drawing is merely one visual view of the model.

To achieve economic results all the three following components:

- interactive graphics
- engineering application programs
- data base management

have to be included in the CAD system and they have to run simultaneously in real time (fig.2). With modern software and hardware this is possible.

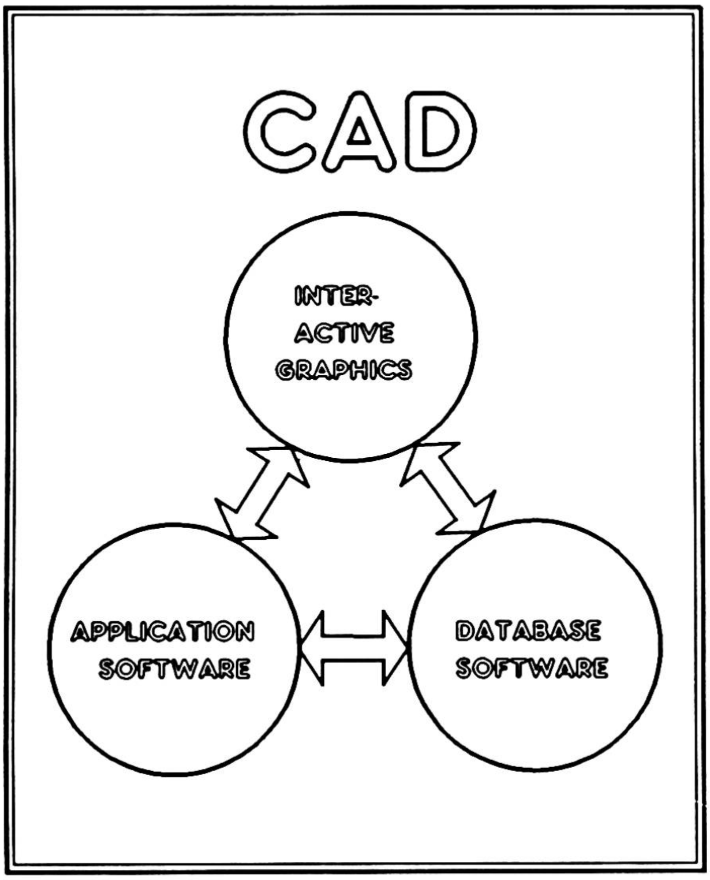
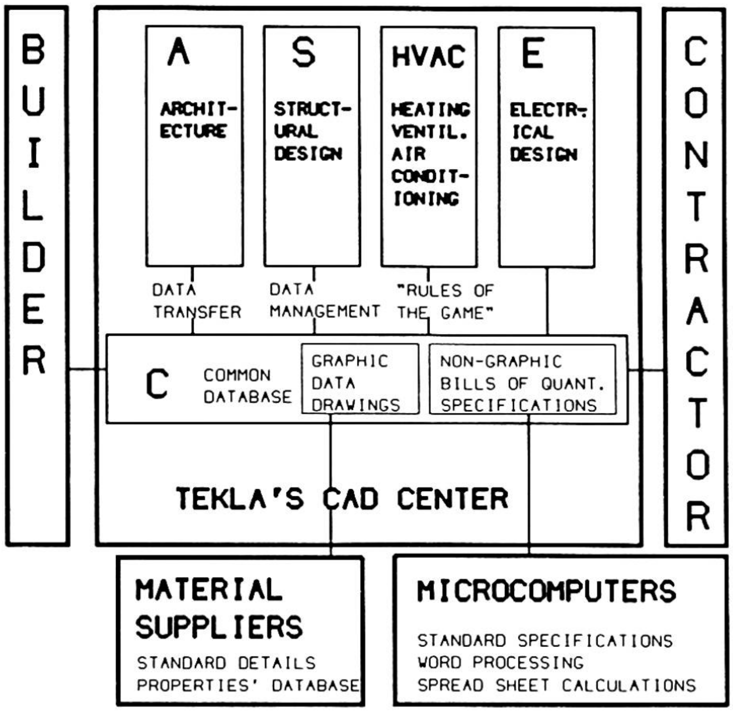


Fig.2 Computer aided design is an entity, of which computer aided draughting is only a part

Tekla is already prepared for the next phase of integration: the electronic information processing and transfer in the whole urban planning, civil engineering and construction environment.

2. THE INTEGRATED BUILDING DESIGN SYSTEM - ALVISR

Tekla's Integrated Building Design System is divided into several logical subsystems (Fig.3).



<u>Fig. 3</u> Integrated use of CAD in building design

<u>2.1 Common Data Base</u> C

This consists of the management of the graphic and non-graphic common data base, data transfer options and instructions for integrated building design.

The instructions include recommended rules for an integrated design process such as the use of plot layers and password practices. With data transfer options it is possible to transfer picture files between different CAD systems (DOGS, INTERGRAPH, MEDUSA, AUTOCAD). There are also connections to material suppliers and PC micro applications, standard specifications, word processing and spreadsheet calculations.

Using this subsystem all designers can exchange information between each other.

<u>2.2 Architect</u> A

The creative design and drawing work of an architect is made easier by symbol libraries, both parametric and non-parametric, and many drawing options even for 3D axonometric and perspective visualisations. The bills of quantities are automatically generated simultaneously with the drawing process.

2.3 Structural S

This part consists of complete steel and concrete design program suites and many CAD applications, especially for steel structures and concrete element structures.

2.4 Heating, Ventilation and Air Conditioning HVAC

This subsystem is described in greater detail in chapter 3. It contains all necessary design and drawing applications, symbol libraries plus a total data base system for the modelling of HVAC networks. It also contains both graphic and non-graphic HVAC component data bases.

2.5 Electrical E

This subsystem is similar to the HVAC module and is as complete.

3. AN IMPLEMENTATION EXAMPLE FOR ONE DESIGN DISCIPLINE

Fig. 4 shows more detailed contents of this integrated building design system - ALVISR.

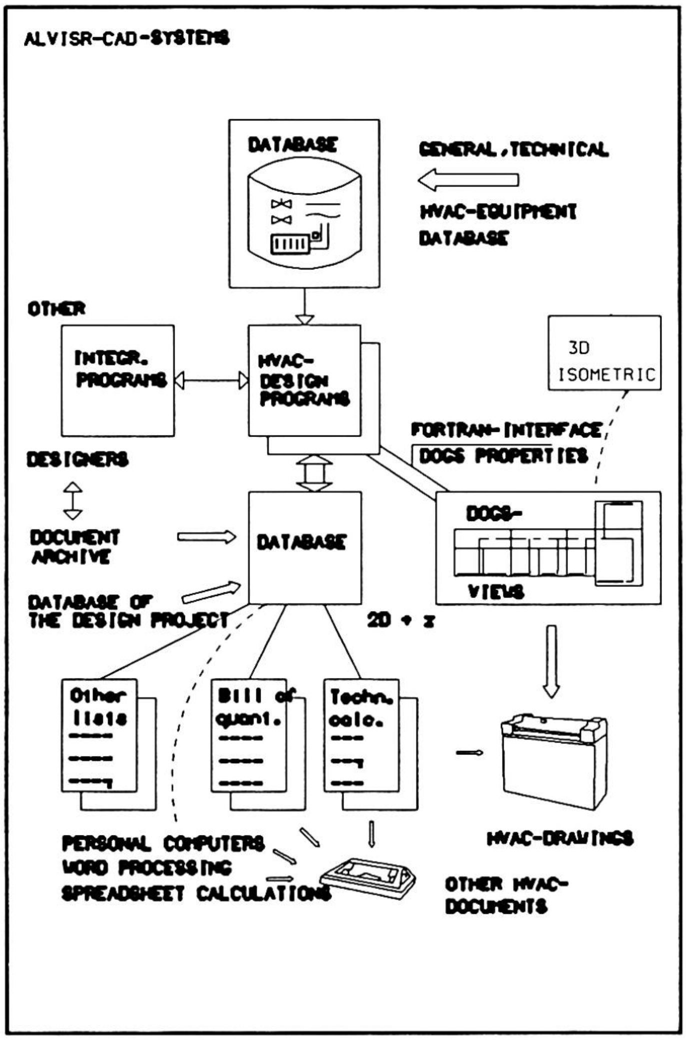


Fig. 4 HVAC design system

Uppermost in the picture are the HVAC component and equipment data bases. From these the designer may obtain the graphic and non-graphic information of selected items. These data bases are updated by material suppliers.

The middle of the picture shows the HVAC design programs: heating, water pipe and air conditioning networks. They are the nucleus of the whole subsystem. The designer communicates with these programs by using interactive graphics (DOGS). This essential interface has been done by using the unique DOGS/ FORTRAN interface which has been developed by Tekla Oy and is now accepted all over the world as a standard feature of DOGS.

All information that is created automatically during the drawing session is saved in the data base. This contains the x-, y- and z-coordinates, all attributes of pipes, lines, components, symbols etc. The drawing created during the session is only for visualisation. The design product itself is the model in the data base! With RDB data base it is possible to redraw the network, make logical checks, dimension the product, print bills of quantities and even draw 3D axonometries.

The bill of quantities can be transferred to a PC micro as shown in the lowest part of Fig. 4. A modern laser beam printer can combine text and pictures and print them on the same page. It also is a very useful hard copy device for printing drawings. The resolution of the laser beam printer is so good that no reduction of picture quality will follow even though the picture was enlarged to A2.

Via integration programs a designer can change information (drawings, messages) with other designers.

4. EXPERIENCES AND FUTURE TRENDS

CAD will affect design work in many ways. It affects even the making of design contracts and invoicing principles.
Are the builders interested in paying more, if they get a better and cheaper building? The usual answer is negative. So the benefits have to be achieved in direct design work, which will not get the best out of CAD's possibilities. The architect sees that his work is increased and other's decreased. This is due to the fact that an architect creates the drawings for the CAD system, while other designers can use these drawings directly without any redrawing.

Designer's work is affected by the fact that at the first stage, when inputting the design, there is almost no trace of increased efficiency. The possible copying features are the only positive options. At the second stage, when the logical checks, calculating, axonometric drawings, bills of quantities suddenly appear with "the press of a button", the efficiency factor is suddenly 10 - 100 ! To get all benefits the contractor should have a system for direct use of bills of quantities.

Thus Computer Aided Design cannot proceed very much further without the evolution of the design culture, or rather without the evolution of the building industry as whole!

Integrated Computer-Aided Building Design and Production

Conception et production intégrées et assistées par ordinateur

Integrierte computerunterstützte Planung und Ausführung von Bauwerken

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SUMMARY
The aim of the Finnish development is the national computer integrated construction management system. The results of the work include the model of computer-aided design process and the systematics of public databases, design database, data transfer, design documentation and systematics of building. The object-orientated hierarchical systematics serves all subsystems. The hierarchical, modulated technical systems of building fulfil the needs of compatibility between design and manufacturing process in the new generation of industrialised prefabricated building technology. Information transfer between subsystems of design and production is concretized through data systematics and conversion programs.

RÉSUMÉ
Le but de développement en Finlande est la conception nationale de constructions assitée par ordinateur. Les résultats du travail comprennent le modèle du processus de la conception assistée par ordinateur et la systématique des bases de données publiques, des bases de données de la conception, du transfert d'information, de la documentation de la conception et la systématique de la construction. La systématique hiérarchique et orientée vers l'objet sert à tous les sous-systèmes. Les systèmes de construction techniques, hiérarchiques et modulés correspondent aux exigences de la compatibilité entre les processus de conception et production, qui caractérisent la nouvelle génération de la technologie de construction industrialisée et préfabriquée. Le transfert d'information entre les sous-systèmes de conception et production est concrétisé par la systématique de données et par les programmes de conversion.

ZUSAMMENFASSUNG
Das Ziel der finnischen Entwicklung ist die nationale integrierte, computerunterstützte Planung von Bauwerken. Zu den Arbeitsresultaten gehören das Modell des computerunterstützten Planungsprozesses und die Systematik der öffentlichen Datenbank, der Datenbank für Planungen, der Datenübertragung und der Planungsdokumentation sowie die Bausystematik. Die objektorientierte hierarchische Systematik dient allen Subsystemen. Die hierarchischen, modulierten, technischen Bausysteme werden den Ansprüchen der Kompatibilität der Planungs- und Herstellungsprozesse gerecht, die der neuen Generation der industrialisierten Fertigteilbauweise eigen sind. Die Informationsübertragung wischen Subsystemen der Planung und Herstellung wird durch die Datensystematik und Konversionsprogramme konkretisiert.

1. MODEL OF THE COMPUTER INTEGRATED CONSTRUCTION PROCESS

The ongoing development process in Finland is aimed at the computer-integrated construction management system named "RATAS". The system will create the Finnish national open, distributed design, production and management system. The integration is achieved through the data transfer between different subsystems and common data systematics.

The development has been carried out in two projects: "Contrete element CAD (BEC)" and "Computer-aided building design and construction management system (RATAS)". Close cooperation between researchers, consulting engineers, companies and associations has been applied.

The computer-integrated construction includes the materials processing flow and the supporting information processing flow. The compatibility of the material process and information process is achieved through the technical systematics of building. The technical systematics is described as a modulated hierarchical system, which serves both the material process and the information process. The computer-integrated process is described in Figure 1.

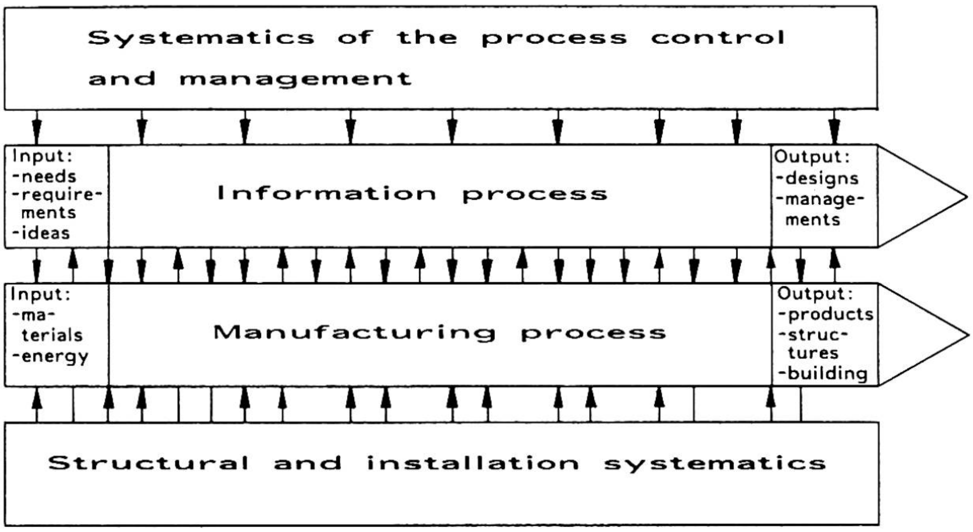

Fig. 1 Computer integrated construction described as information and material process with the support of building systematics

The national CAD system has been developed through projects in 1984-1987. The development will continue with pilot projects for practical applications beginning from the year 1988.

2. COMPUTER-AIDED DESIGN PROCESS

The aim of the design process is to produce successively the design database which includes all the information needed at the different phases of construction planning and production. The needs of all the parties of construction must be fulfilled at the right moment.

The accumulation of the design database must follow the development of the production process. Some information must be transferred also from the systems of contractors into the design database as back-up material of design. The information transfer between the design database and the systems of contractors is presented in Figure 2.

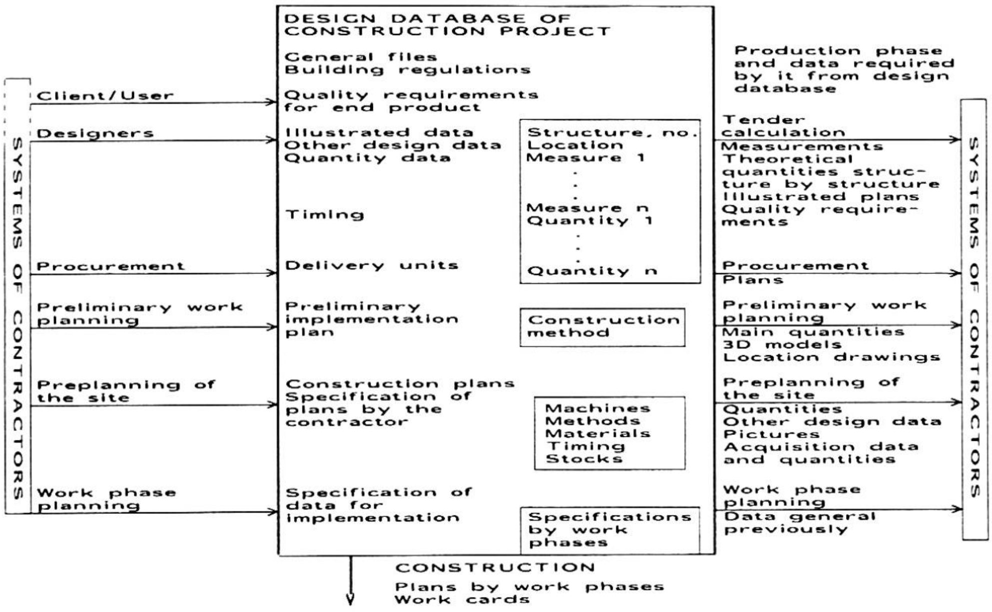

Fig. 2 Information transfer between the systems of contractors and the design database.

The second important partner in production is the element industry. The BEC (Concrete element CAD) -design system has been developed for a subsystem of the national CAD-system. The system scheme is presented in Figure 3. The BEC-system is connected with the design database system as well as the production planning systems at the element factory and on site.

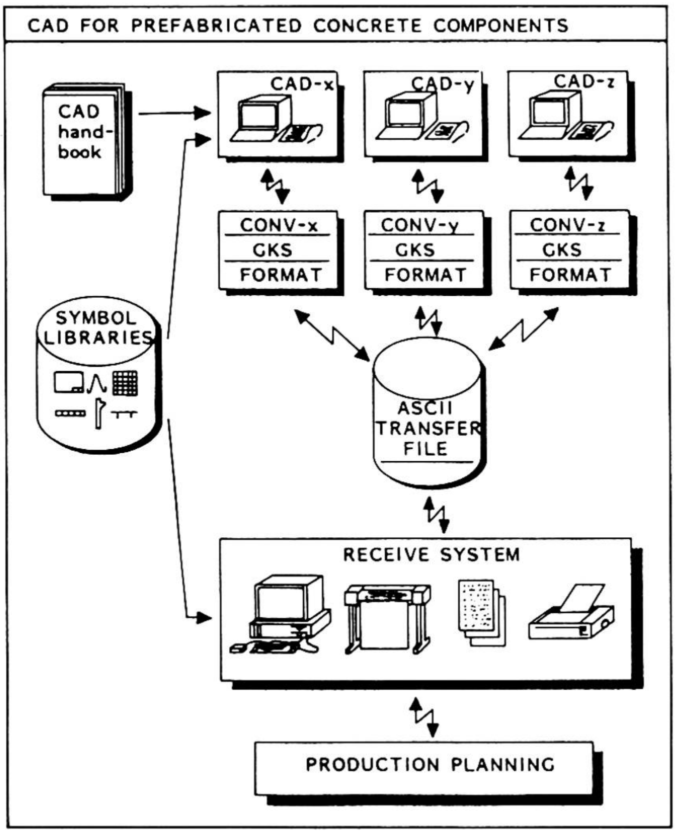

Fig. 3 Principle of the Finnish concrete element CAD-system (BEC)

3. SYSTEMATICS

The most important part of the development of the national CAD-system is the solution of common systematics, which guarantees the logical production of information and the fluent data transfer between partners in design and production process. The subsystematics are included in public databases, design database, data transfer, design documentation and systematics of building.

3.1 Systematics of public databases

Public databases include a vast amount of information on public rules, standards, products, design methods and manufacturing methods. Therefore an effective searching file of databases is proposed to be developed.

Public databases will be maintained by manufacturers and public authorities. Some databases will be established in computerized form and made available to users as diskettes or other media. A survey has been made on existing traditional databases. Traditional centralized public databases can hardly be successful in a design environment. With new technologies like CD-ROM memories the distribution of databases can be solved.

Most potential area seems to be product information published by manufacturers. Today printed leaflets are commonly used and distributed to designers.

Other areas are various design guides and codes. It is felt that a standardized format for knowledge in the sence on facts and rules of expert system technology is not yet realistic. Some guidelines only shall be defined to allow future adaption of expert system technology in the interpretation of design rules.

The formats of the public databases should be the same as for data transfer in order that the information could actually be extracted from the public data base and inserted to project data bases.

3.2 Systematics of design data base

The goal of the systematics is to define an overall logical data structure which makes it possible to build the design database by distributed designers and to meet the needs of different partners at the building process at different phases of the process.

Trying to cover various aspects of different organizations as well as time dependencies in a building project soon leads to extremely complex definitions. Therefore it was quite natural to select an object-oriented approach to the definition methodology. Objects are identified and all aspects of them are studied and defined without the necessity to keep track on the overall data architecture at the same time.

It should be noted that the adopted concepts are used as a definition methodology only and do not limit the development tools of practical software systems. Object classes make up hierarchical structures. Properties of a class are inherited by all it's subclasses. Besides being a convenient tool in the association of properties to objects object classes may also be related to various classification codes. In order to avoid complex codes we try to limit the number of parent classes that a class may have to one. Thus the classes are organized into a simple hierarchy specific to a project. Objects can be physical "things", spatial rooms, activities or abstractions.

An object may belong to one or more object classes.

Objects make up networked structures: an object may have several parent and child objects. The object hierarchy defines the topology of the whole project. The purpose of this topology is mainly to aid the designer himself during the design process. Topology can also be used as data search path.

Properties of objects are defined by values of attributes.

The existence of an attribute can be inherited through class membership or it can be defined individually for an object.

Most objects have attributes related to time. Rules on the interdependencies of the values of such attributes define the building planning process.

3.3 Systematics of data transfer

The goal of the systematics is to define file formats for the transfer of various types of data between computerised systems.

All transfer formats consist of visible ASCII characters. For some data types including vast amount of information the information is packed and not readable by human in order to compress file size.

The formats are defined separately for text array or table , vector graphics and raster graphics. Guidelines for the product model, geometric model and knowledge as expert systems are also presented. Comments and suggestions about the use of bar codes e.g. for printed product descriptions in various documents are given.

The data is fransformed into the transfer file with the conversation program of the sender and again into the receiver file with the conversation program of the receiver. The conversation programs have been developed until now for six different computer and program systems.

3.4 Systematics of design documents

The systematics is developed for the design documents of all partners in the building process but especially for the production in element factories and on site.

The task of this subproject is to formally define the logical contents of documents that are needed during the project by different parties. This evaluation should be independent of the format of present or future documents. Guidelines are outlined for future design practices so that the potential benefits of CAD could be better utilized. Also changed responsibilities of various parties due to new design practices are suggested. For demonstrative purposes some new types of sample documents are prepared.

3.5 Systematics of building

The systematics of building serves as the link between the design and manufacture. The goal is to allow economical and effective manufacture without remarkable limitations for the design. For the new generation of Finnish industrialised building technology, the hierarcical modulated systematics is developed. The systematics is the same for all technical and architechtural systems of the building including structural system and installations. The physical systematics of building is fully compatible with the systematics of the design data base of CAD presented above at point 3.2.

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Development of an Arch Bridge CAD System

Principes d'une conception assistée par ordinateur pour un pont arc

Entwicklung eines CAD-Systemes für Bogenbrücken

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SUMMARY
In this paper the concept, principles and structure of a System under development are presented. The management and establishment of the database, method of design optimization and algorithms are discussed.

RÉSUMÉ
L'article présente le concept général, les principes de base et la structure d un système pour la conception assistée par ordinateur de ponts – en cours de développement. La gestion, l'établissement de la base de données, les méthodes d'optimalisation et les algorithmes sont présentés.

ZUSAMMENFASSUNG
In diesem Artikel werden die Konzeption, Prinzipien und Struktur eines CAD-Systemes für Bogenbrücken dargelegt. Einige Probleme bei der Entwicklung wie die Verwaltung und das Aufbauen der Datenbank, Methoden der optimalen Programmierung und des Algorithmus, werden diskutiert.

1. INTRODUCTION

In China the application of the computer to highway bridge design was began recently at begining of 1970s, but has grown very fast. During the last ten years or so great results were achieved. Computers, especially microcomputers, have spread out over our native land. Many effective on bridge analysis and design application software programs, which provide powerful tools for engineers, have been developed. The situation regarding highway bridge design has presented a new face. Design has been speeded up and its quality has been improved. In addition to that, the computer has also helped us to design and construct new types of bridges, for example cable-stayed bridges.

But the existing software has a lot of shortcomings. They are mainly for calcula ions such as structural analysis, such tasks are essentially operations on numbers. In order to further improve the existing application software for bridges, the design offices have a great interest to drawing and human-computer interaction. Therefore development of a bridge CAD system is an urgent need.

Since 1986, under the direction of the Ministry ofC ommunication an integrated highway bridge CAD system is being developed. A complete bridge CAD system should inclunde each design stage, various bridge types, structure analyses and calculations, graphics and drawing, etc. So that to establish an integrated system we must develop a large number of programs.

The ABCAD System (Arch Bridge CAD) System is an application software, in o her words a subsystem, of the integrated CAD system. Chinese arch bridges have an ancient history, and is now adopted widespreadly . Developing arch bridge CAD system is a significant job.

The objects of ABCAD System are concrete (non-reinforced or reinforced) and stone arch bridges with purposes of design automatization and drawing. It can be recalled by the integrated system as a part of it, on the other hand, it can be operated all alone as a independent system.

2. BASIC CONCEPT

There are arch bridges of many and varied kinds in common use nowadays in China -- plate arch, box arch ,spine arch and so on, with filled solid or various hollow structure on arch. The system should be suited to various types of bridges.

Because of wide engineering practice over a long period of time, a rich deposit of design experiences for arched bridges exises, both theory and design method are mature and reliable, a complete set of standard drafts for short and middle span arch bridges was brought to success. Therefore, as a matter of fact for most short and middle span bridges the standard drafts are used. On the other hand, designing long span arches is related to more factors,and the standerd draft is not used. Considering that there are two categories of design method, the CAD for each category should be realized in a distinctive way.

For standard arched bridges having short and middle spans, the index way is employed. Processing and arranging the data of standard drafts and engineering information to form the graphic data, stored in a database. In the database the graphic processing information also was stored; thus the system will have functions of selection and making up arch type, using an analogy method to achieve designing drafts and output the results. Fig. 1 shows the chart flow of the index CAD.

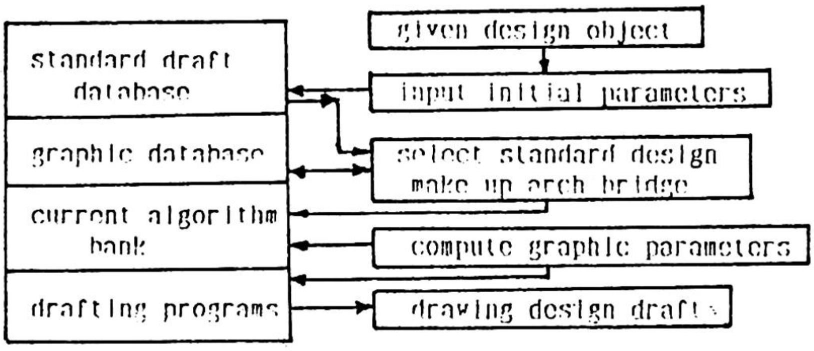

Fig. 1 index CAD

For non-standard arch bridges the method of automatic design and plotting by means of optimization is taken. The process of the design automatization system is shown in Fig. 2.

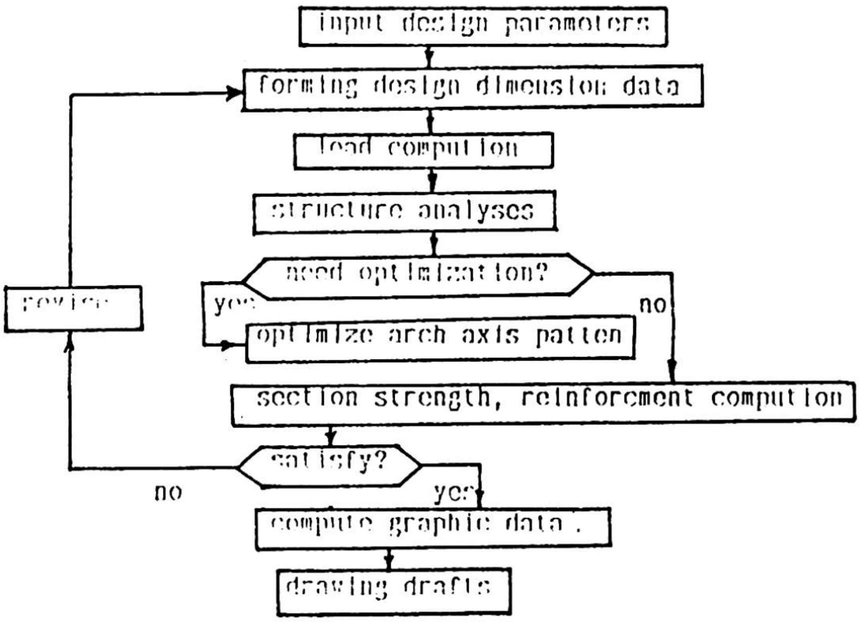

Fig. 2 design automatization CAD

Expect that while setting the structure to generate dimension data the interactive operation will be used partly, the batch processing is the basic method of execution.

3. FUNCTION ARRANGEMENT

The functions of ABCAD System are as listed below:

1) To generate data for design and calculation

* On the basis of design factors, the parameters of section and pattern of the arch axis inputted by the designer to automatically generate the data modelling the demensions of bridge and physical characteristics of the material.
* To layout the structure for an arch interactively, forming the dimension data of the structure and data about distributive state of dead load.

* To form the geometric characteristics and coordinates of elements for finite element analysis, dividing elements automatically.

2) Structure analysis

* Finite element solution for general plane frame
* Traditional simplified methods in Chinese common practice for arched bridge

3) Optimization of pattern of arch axis.

* To minimize the eccentricity of the arch axis to line of the pressure under dead load.

4) Design of cross section.

* To check the strength according to results of structure analyses.
* To design and check reinforcement automatically for RC arch bridge.

4) automatically drawing and graphing.

* To draw and plot general arrangement draft of the arch bridge.
* To show the arrangement of reinforcement and bars in detail.
* To display and plot some computional results by graphics.

5) Printing engineering documents and tables.

* Tables of the basic design data
* Tables of coordinates of arch axis and arch upper and lower edges
* Bill of materials, tables of engineering quantity
* Computional results of sectional forces and stresses, displacements of arch.

All documents and tables are in Chinese.

4. STRUCTURE OF SYSTEM

The design automatization software for arch bridges is divided into nine module blocks according to its function:

* Input management, given design factors
* Generating dimension data
* Structure analyses
* Optimization of pattern of arch axis
* Print documents
* Generating graphic data
* Drawing drafts
* Computing and plotting engineering quantity.

All basical data and intermediate data are stored in a database by form of database file, the function modules link each other by these database files. The blocks and data flow chart are shown in Fig.4.

5. PROBLEMS CONCERNED WITH DEVELOPING

5.1. Database management

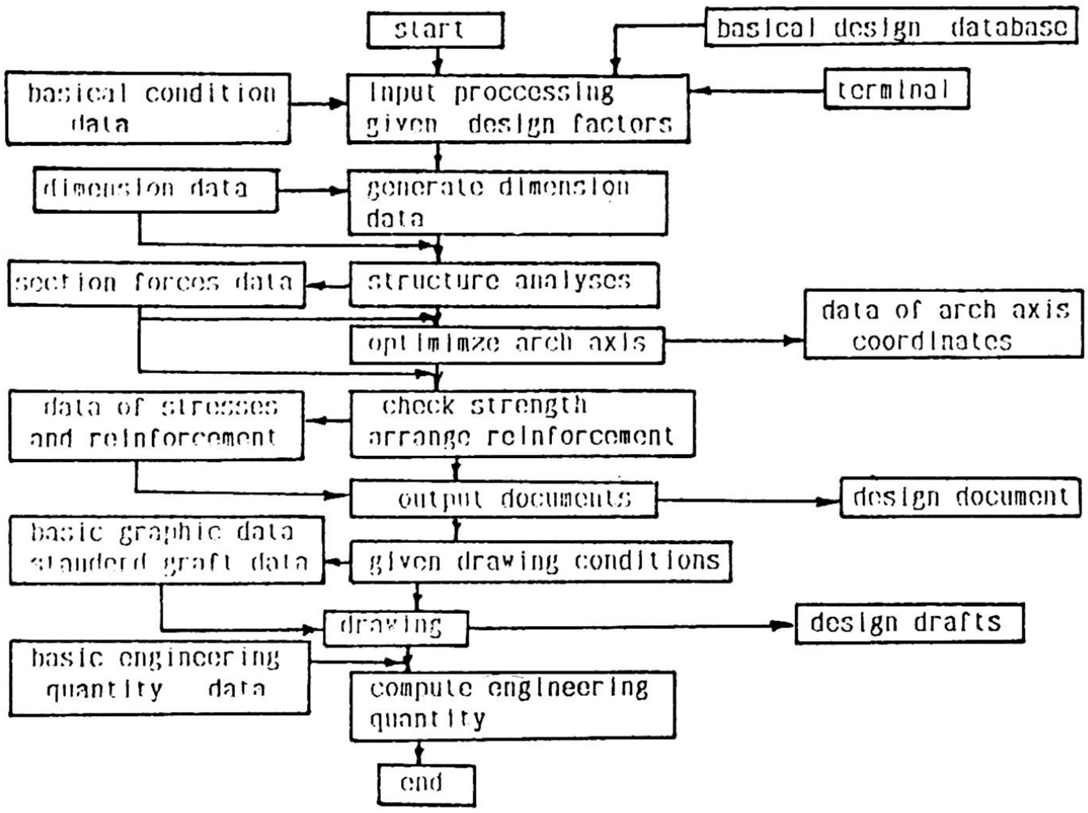

Fig. 3 Flow chart of data and modules

Because the procedure of bridge design is a repeatedly modified progressive approach, dealing with a wide range of factors and a large quantity of information, the data of bridge CAD system have the following distinctive features:

1) The design information is varied basically in types of numeric, geometric and characters.
2) When the design work intensifies, the quantity of information will increase rapidly.
3) The data information has transmissibility and share together.
4) There is a great amount of input and output.

It is apparent that the data of the integreted CAD system must be managed by a united common database management system to enhance data independence, lower superfluousness and ensure correctness of data. At present, the technique of application database in CAD systems is not in a ripe condition. There is no available specialized engineering database management system (EDMS) for bridge CAD system, as a result EDMS has to be developed first. In comparision with current database management systems (DBMS) EDMS have a lot of different characteristics in some respects, for example:

* Data model and structure, which mirror engineering prototypes and their relationships.
* Given power of defining and processing the complicated engineering data structure.
* Propagation of revising the engineering data.

Considering that to develop an EDMS by oneself needs large expenditure of time and labour, to develop ABCAD System using current DBMS (e.g. RMS, etc.) is the most realistic way at the moment. The DBMS has matured relatively, is provided with a rather great capability of describing complex data structures and operating language of rather unified format, having a whole set of perfect service programs to guarantee the reliability of data [1].

The fuctions of DBMS are able to satisfy the greater part of requirements for the AB-CAD System. Therefore, before the EDMS is accomplished the DBMS is used in an initial developing stage.

2. Data structure

The data concerned with arch bridge design is rather miscellanendous and varied, included geometric, physical, design factors and rules of Code etc. In the ABCAD System the structure of common data identifies with the whole integrated system. The more complex data in that for modelling dimension and shape of arch bridge. To differentiate the data with respect to levels the tree shape structure is used. The data structure tree of the dimension data of arch bridge is shown as bellow in Fig. 4.

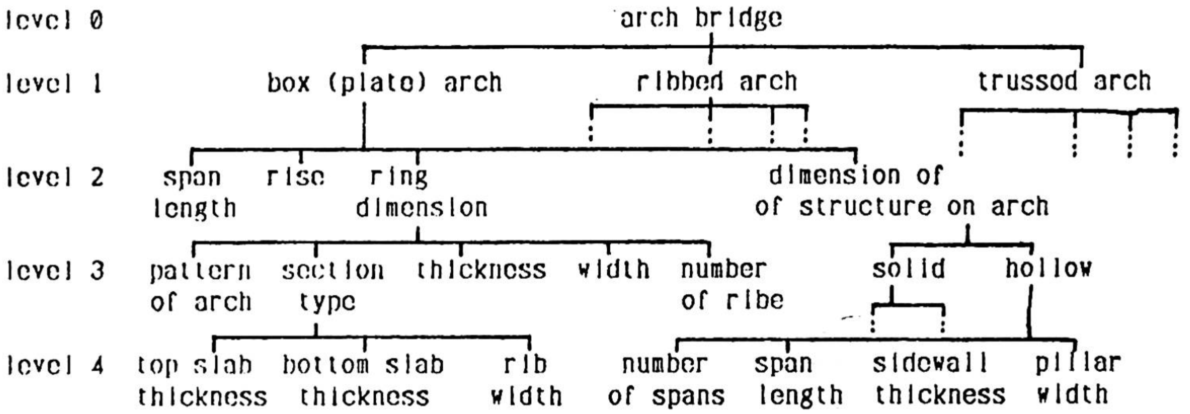

Fig. 4 Dimension data tree of arch bridge

5.3. Main algorithms

1) The thickness of arch ring is determined by designer-computer interaction using empirical equations and experience data stored in database.

2) Fundamentals of structure analysis are plane beam finite elememt solution, while the conventional methods for arched bridges in common practice of China are given. Temperature stresses, elastic stability, concrete shrinkage and additional calculations are computed by the traditional simplified methods.

3) The pressure line under dead load is regarded as the datum line when optimizing the pattern of arch axis, using cubic spline fitting through linear programming.

4) The section strength is determined in accordance to the rules of Codes JTJ 022-85 [2] and JTT 023-85 [3].

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Integrated Bridge Design and Analysis System

Programme intégré pour la conception et l'analyse de ponts

Integriertes Brückenplanungs- und Berechnungssystem

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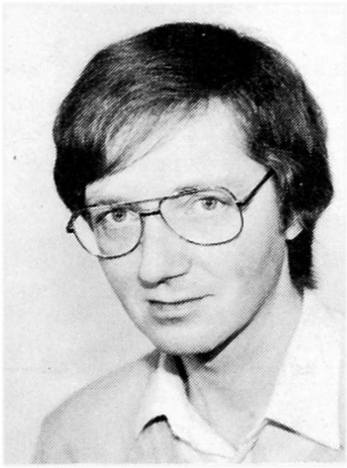

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SUMMARY
This paper briefly describes the structure, function and capabilities of a newly developed, fully integrated bridge design and analysis system based on three dimensional parametric solid modelling.

RÉSUMÉ
Cet article donne un apercu sommaire de la composition, du fonctionnement et de la capacité d'un programme intégré et nouvellement développé, basé sur la modélisation paramétrique tridimentionnelle et utilisé pour la conception et l'analyse de ponts.

ZUSAMMENFASSUNG
Der vorliegende Artikel beschreibt in kurzer Form Aufbau, Funktion und Kapazität von einem neuentwickelten, integrierten Brückenplanungs- und Berechnungssystem, das auf dreidimensionaler parametrischer Modellierung basiert.

1. INTRODUCTION

IBDAS is a fully integrated bridge design and analysis system based on three dimensional parametric solid modelling.

It has been developed by the authors of this paper and financed jointly by Cowiconsult and the Development Foundation under the Danish Ministry of Industry.

IBDAS has been developed primarily for the integrated design of reinforced and prestressed concrete bridges and the calculation of permissible loads on existing reinforced and prestressed concrete bridges with regard to the bridges' current condition.

At the same time the system can also be used for the design of steel and composite bridges and for the design of structures in general.

IBDAS has been programmed in standard FORTRAN 77 and has been implemented on the VAX/VMS operating system. The program comprises approximately 170.000 lines of code of which 75.000 lines are executable and consists of a database module and application modules for statical analyses, geometrical analyses, optimization, drawing generation and report generation.

The simplified system diagram in Fig. 1 shows the component parts of the program whose function and capabilities are briefly described in this paper.

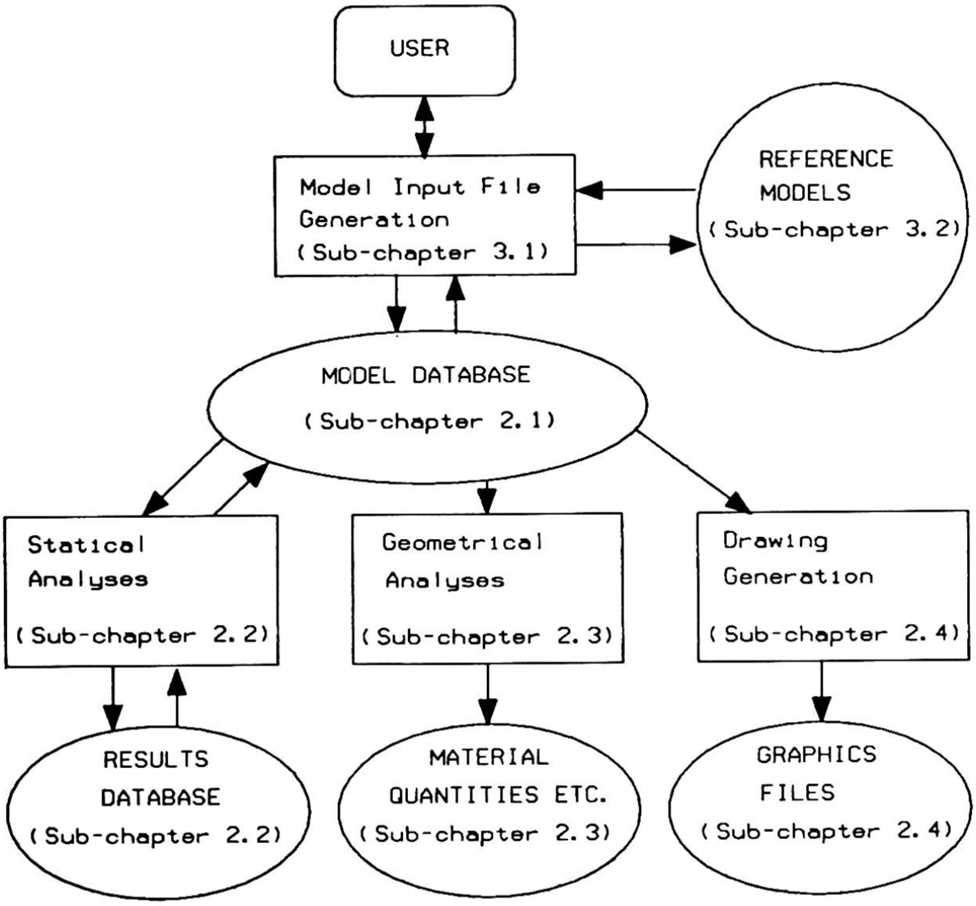

Fig. 1 Simplified system diagram

2. INTEGRATED LOGICAL DESIGN WITH IBDAS

2.1 Model Database

A user defined model database constitutes, in an actual design situation, the common integrated basis for the production of drawings and written documentation as well as statical and geometrical analyses.

The model database is built up as a sequential system of data entity definitions (points, curves, surfaces, volumes, etc.). The definition of each data entity in the sequence of definitions can logically refer to previously defined entities. This enables an automatic update of secondary data entities after any user defined changes to primary data entities.

For example, the model database for a bridge design task will normally first of all contain definitions of the overpassing and underpassing roads (alternatively railways or waterways).

Fig. 2 shows a simple example of such a defined road system.

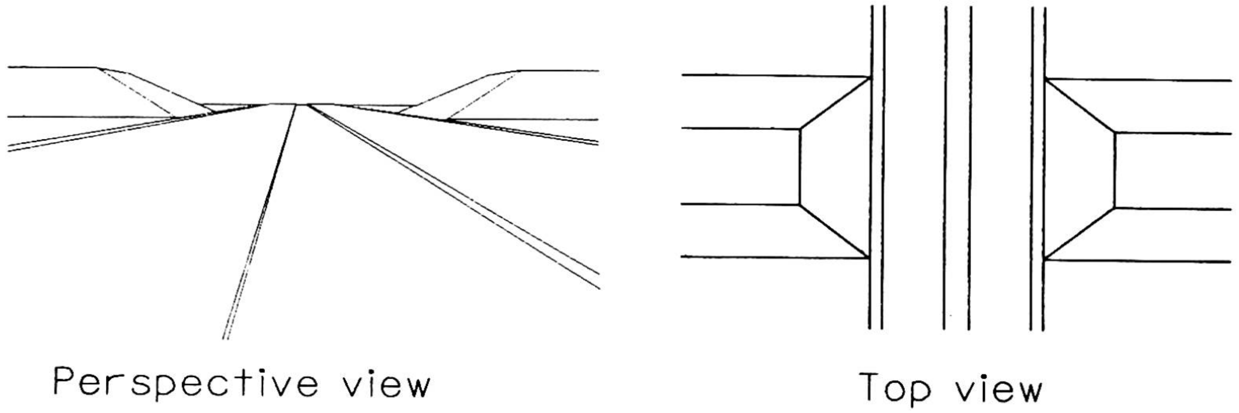

Fig. 2 Road system

Secondly, the model database will contain geometrical and material definitions of the actual bridge type, where geometrical definitions logically refer to the previously defined road systems.

Fig. 3 shows a simple bridge defined logically in relation to the previously defined road system.

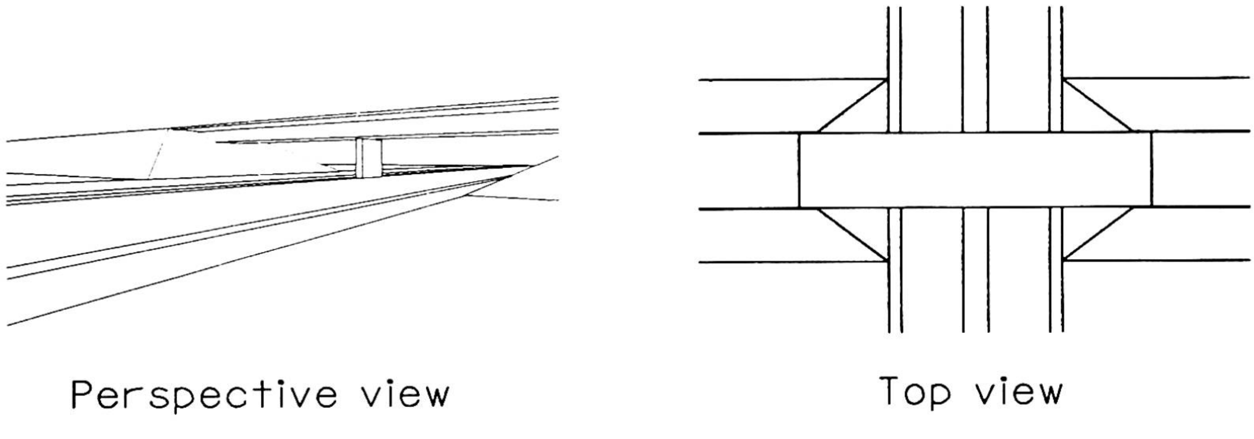

Fig. 3 Simple bridge defined in relation to road system

Fig. 4 shows the result of the automatic consequence update of the bridge definition after changing the road system.

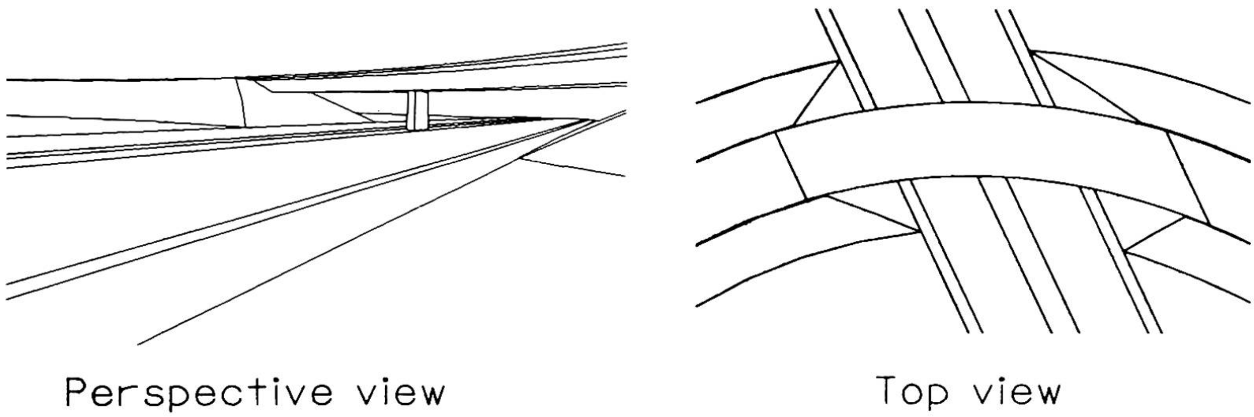

Fig. 4 Automatic update of bridge after changing the road system

The rest of the model database's component parts, i.e. definitions of reinforcement, statical analysis models, loads, construction processes, drawings, written documentation, etc., will similarly update automatically when defined logically in relation to previously defined data entities.

2.2 Statical Analyses

Statical analyses are carried out by the statical analysis module, which operates directly on the model database where actual analysis models, building processes, loads and load combinations, and design criteria are defined.

Fig. 5 shows an example of a finite element model, which has been logically defined in relation to the bridge definition illustrated in Figs. 3 and 4.

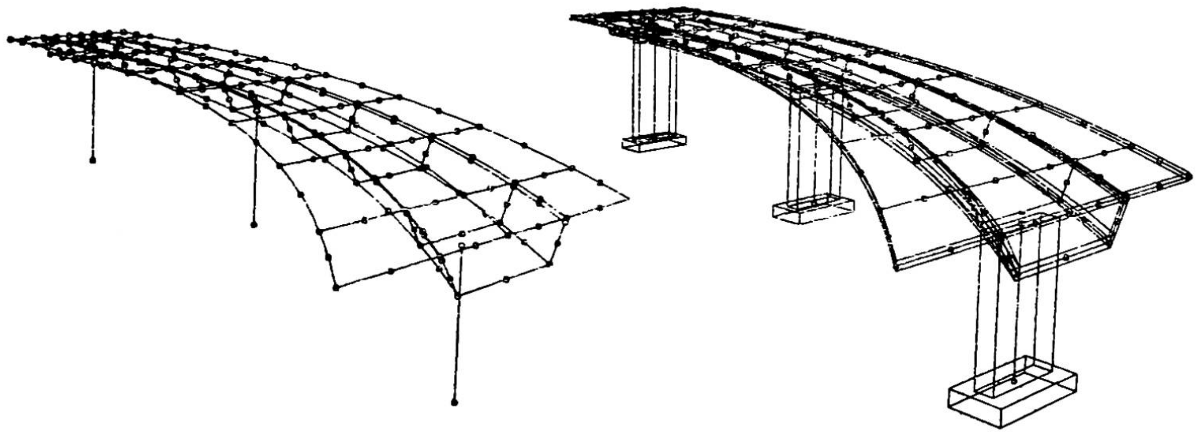

Fig. 5 Finite element model

The analyses may comprise load effect analyses, statical verification and dimensioning.

The load effect analyses may be construction process analyses, where the accumulated effects of dead loads, temporary supports, pre-stressing, shrinkage, creep and relaxation etc. are calculated, or service load analyses where extreme effects of traffic, wind and temperature loads are calculated.

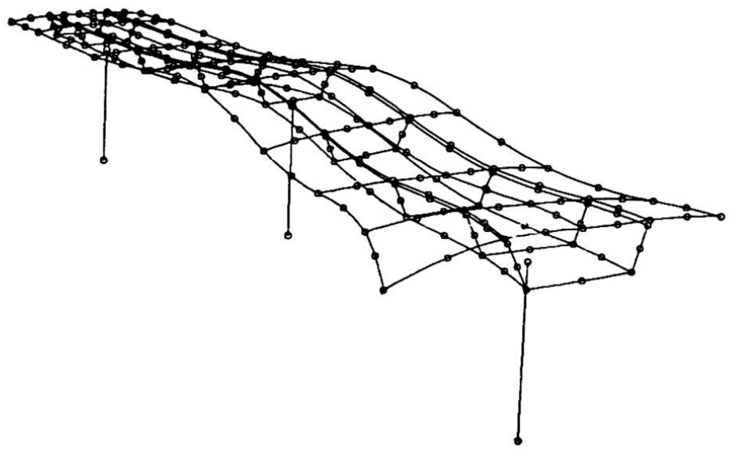

Fig. 6 shows a result (deflection corresponding to uniform distributed load) from a simple load effect analysis carried out with the analysis model shown in Fig. 5.

The calculated load effects are stored in a results database. The verification analysis and dimensioning programs subsequently operate on this database in combination with the model database.

Fig. 6 Deflection corresponding to uniform distributed load

2.3 Geometrical Analysis

Written geometrically based project documentation as, for instance, material quantities, bending schedules and setting out data tables, are generated by the geometrical analysis module, which operates directly on the model database where the required geometrical project documentation is defined logically in relation to the geometrical and material definitions of the actual bridge type.

2.4 Drawing Generation

The drawings are built up as organized collections of 3-D pictures, fully dimensioned 2-D pictures, and text blocks.

They are generated as graphics files by the drawing module which operates directly on the model database where the required drawings are defined in relation to the geometrical and material definitions of the actual bridge type.

All the figures in this paper are examples of drawings produced by the drawing module.

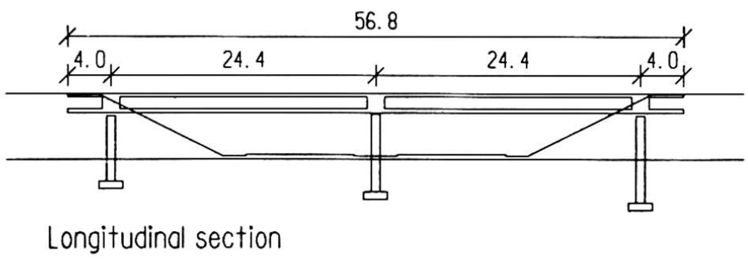

Fig. 7 shows a simple example of a drawing, which has been defined logically in relation to the bridge definition illustrated in Figs. 3 and 4 and the road system shown in Fig. 2.

The drawing module consists og a general part and special interfaces to external graphics systems. In the first version of IBDAS an interface to the Intergraph IGDS graphics system has been implemented.

Fig. 7 Drawing

3. DEFINITION OF IBDAS MODEL DATABASES

3.1 Model Input Files

A model database is generated by the database module by compiling and linking a model input file.

The model input file is a readable text file which constitutes the user's task definition.

It is built up interactively with the help of a text editor and written in the IBDAS model definition language.

This language has been developed on the basis of a comprehensive analysis of the work processes and data which structural design entails. It is a high level language which enables logical and parametric descriptions of design objects, statical and geometrical analyses as well as drawings and written design documentation.

Creating a model input file may be done stepwise and recursively with a degree of detail which at each step corresponds to the user's actual requirements. Defined coordinate systems, geometrical elements, design objects, etc. can be visualized in their entirety or selectively at any stage during the creation of model input files.

3.2 Reference Models

The user may use previously defined models as parametric or fixed reference models during the creation of an actual model input file.

These models are then included logically as part definition in the actual task definition.

When a previously defined model is used as a fixed reference model, it is maintained as an individual model database and operates as the same fixed part definition wherever it is used in the task definition.

On the other hand, when a previously defined model is used as a parametric reference model, data entities in the reference model may be substituted by corresponding data entities defined in the actual, higher-level, model input file. In this way parametric reference models are able to adapt to the specific requirements of the actual task. Parametric reference models are linked together with the actual, higher-level, model input file and are then included as integral parts of the corresponding model database.

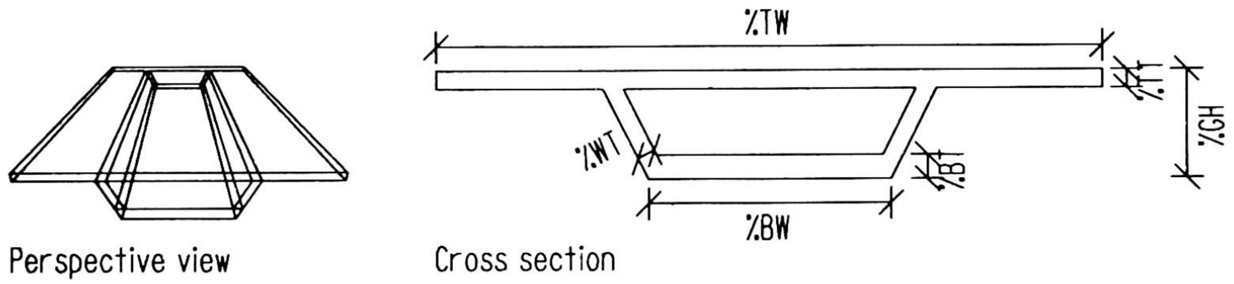

Fig. 8 Simple parametric girder model

Fig. 8 shows a graphical representation of the model which has been used as parametric reference model for the superstructure in the model of the simple bridges shown in Figs. 3 to 7.

Models which are used as reference models are themselves able to use reference models. This means that different kinds of tasks may be defined individually as a multi-level structure of reference models with optimum use of standard models, which have been defined once and for all.

Production of Drawings with a Three-Dimensional Volume Based CAD-System

Production de dessins à l'aide d'un logiciel tridimensionnel

Erstellung von Zeichnungen mit einem dreidimensionalen CAD-System

Ragnar WESSMAN
M.Sc. Struct. Eng.
Tekla Oy
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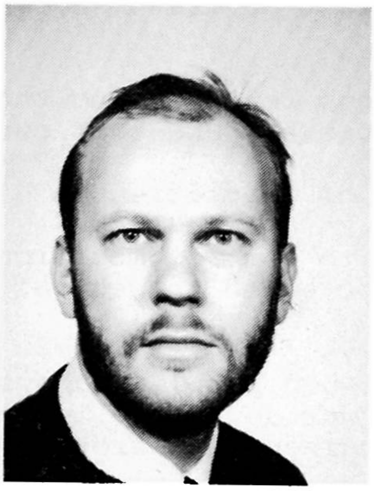

Ragnar Wessman, born 1956, received his engineering degree at the Technical University of Helsinki. For nine years he has been involved in steel structure design and CAD-development. Now he is responsible for the development of CAD/CAM tools for steel structure design and production in the leading Finnish engineering software house, Tekla Oy.

SUMMARY
A new revolutionary approach towards steel structure design will be presented. By building up a full three-dimensional model into a database, the entire building can be described. By this approach all design outputs, drawings, bills of material and input for NC-machines can be produced fully automatically and buildings can be designed essentially faster and more accurately than with traditional systems.

RÉSUMÉ
L'auteur présente une nouvelle approche dans la conception de structures métalliques. Par la constitution d'un modèle entièrement tridimensionnel au sein d'une banque de données, une construction entière peut être décrite. Grâce à cette technique, tous les résultats de la conception: plans, listes des matières et input pour les machines à commande numérique peuvent être obtenus de manière entièrement automatique. Ainsi, les projets sont conçus d'une manière nettement plus rapide et plus sûre qu'avec les logiciels traditionnels.

ZUSAMMENFASSUNG
Eine neue, fast revolutionäre Lösung für das Konstruieren im Stahlbau wird vorgestellt. Durch den Aufbau eines dreidimensionalen Volumenmodells in einer Datenbank kann ein Bauwerk vollständig dargestellt werden. Dadurch können automatisch alle Konstruktionsunterlagen, Zeichnungen, Stücklisten und Steuerinformationen für NC-Maschinen erzeugt werden. So wird das Konstruieren und Detaillieren wesentlich schneller und fehlerfreier als bei konventionellen Systemen.

1. GENERAL

When applying traditional CAD systems in building design an increase of productivity has been gained mainly in the field of automatic drafting. The traditional systems have not been able to facilitate the design work itself. Among others, the following problems have occurred:

- Only drawing - not design - has been facilitated by automation.
- The same parts must be drawn several times in several drawings.
- Different drawings representing the same structure are not connected together and thus can be contradictory.
- Producing bills of quantities is difficult.
- It is difficult to control modifications. One change in a structure must be added in several drawings.

To solve the above mentioned problems a system called BOCAD-3D (Building Oriented CAD) was developed in Germany. The special requirements of civil engineering were paid attention to in creating this system.

The system is based on a very advanced integration. A full three-dimensional model of the whole building is created and stored into a data base. The data base has been designed to effectively handle typical constructions consisting of thousands of different parts. All drawings can be produced automatically on the basis of the information fed into the data base.

The advantages of such a CAD system based on a three-dimensional volume model are as follows:

- Every part needs to be fed to the system only once. This reduces the need of input work.
- The whole building is described in the data base. In this way the compatibleness of the parts can be guaranteed.
- All production drawings can be produced automatically. The designer will not be tied to the screen to draw drawings.
- True bills of quantities can be listed and information for CAM can be produced.

The BOCAD-3D system has been used in Finland for three years mainly in design of steel structures. Many objects have been designed by using it. On the so far largest design object - a recovery boiler house delivered to USA - approximately 1500 drawings were automatically produced. The steel structure of this building consisted of about 1500 metric tons of steel. The BOCAD-3D system is used in Europe in more than 80 steel structural engineering companies, f.ex. BBC and KWU.

Tekla Oy is the representative of the BOCAD-3D system in Finland, Sweden, Norway and the Soviet Union.

2. CREATING THE MODEL

A model of the whole building is constructed interactively. The model is described by placing beams and columns (frames, parts) and defining joints between them. The designer does not have to do any drawing work using lines and arcs (as in a traditional system). The items he uses are beams and joints.

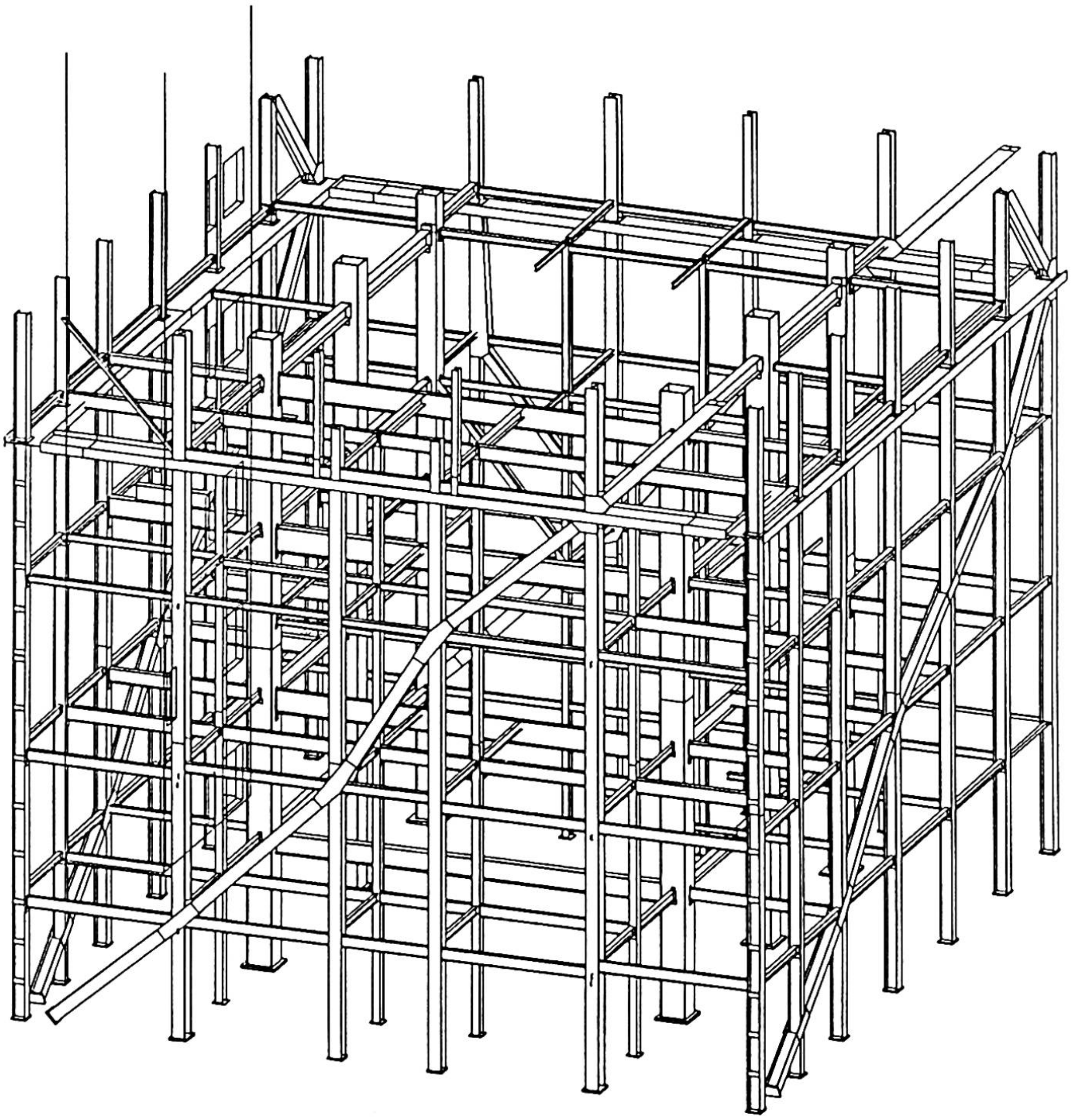

Fig. 1
The steel framework of the first assembly stage of a recovery boiler building.

The joint library of the system consists of 40-50 different types of joints. The user can modify existing joints and add own joint types in a simple manner.

The joints take care of cutting the beams to the appropriate length and also cut out parts of the flanges if necessary. They also check that all parts fit in their places and that minimum distances between screws and edges are not violated.

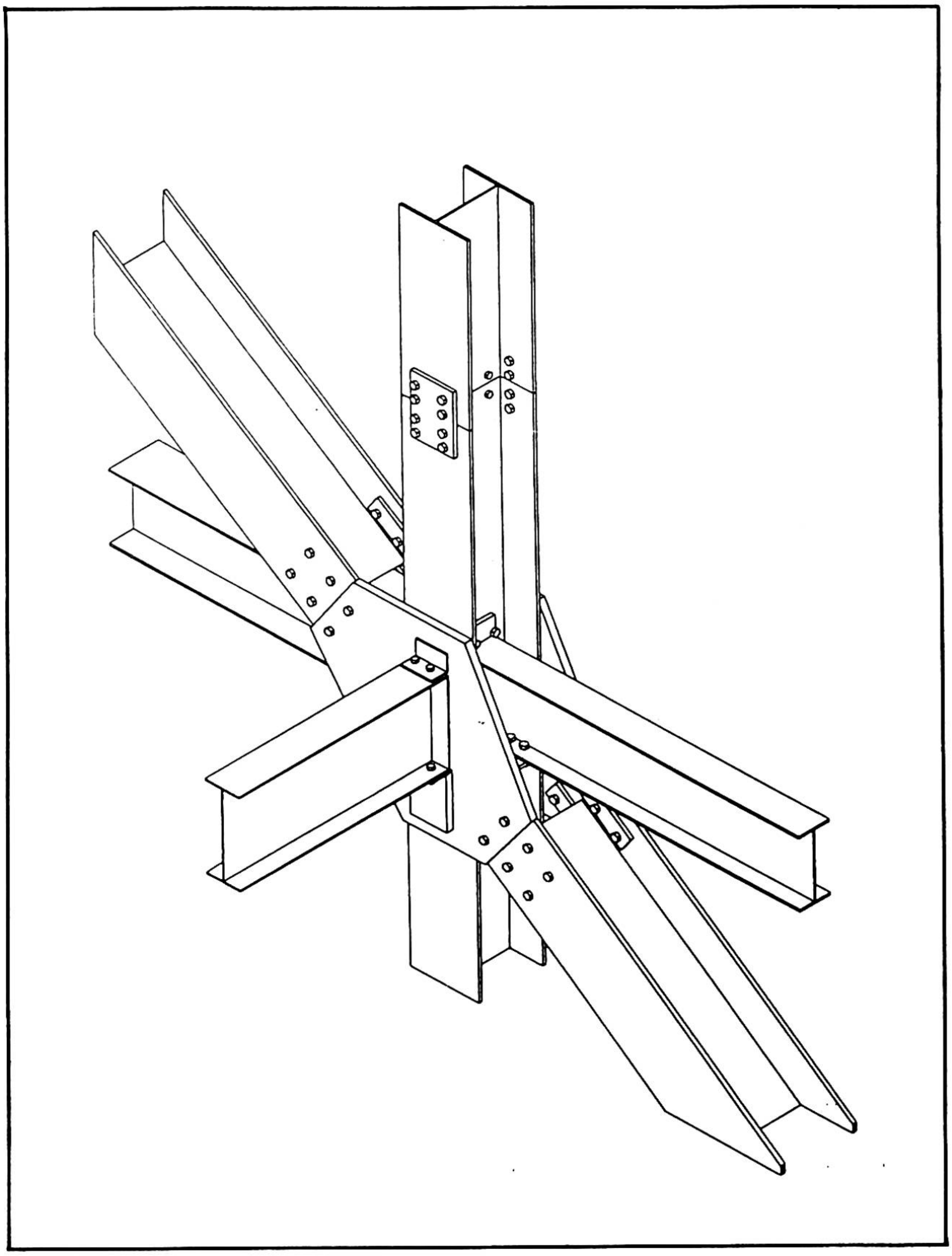

Fig. 2 An example of a complicated joint.

3. PRODUCING DRAWINGS

When the whole building or a certain part of it has been modelled, the user can produce all necessary drawings by just defining what drawings he wants.

3.1 Assembly drawings

All assembly drawings are produced as 3D-windows of the structure. All plan views, line drawings, perspective views, explosion drawings, sections and details can thus be produced. All necessary texts are added to the drawings automatically. In this way part numbers, profile names, assembly screws, component lists including weights, title blocks, frames, distribution and modification labels can be added automatically.

Sections and details from different parts of the structure can be added.

3.2 Workshop drawings

The greatest advantage of using this 3D system is that all workshop drawings and component drawings can be produced automatically. Workshop drawings constitute the main part of all drawings. By automatizing this routine work notable increase of productivity is achieved.

With the BOCAD-3D system a complete workshop drawing can be produced of every different assembly part and component. The drawing contains all the information needed in manufacturing.

The user need not input any measure lines nor tell where sections must be drawn from. All this is done automatically.

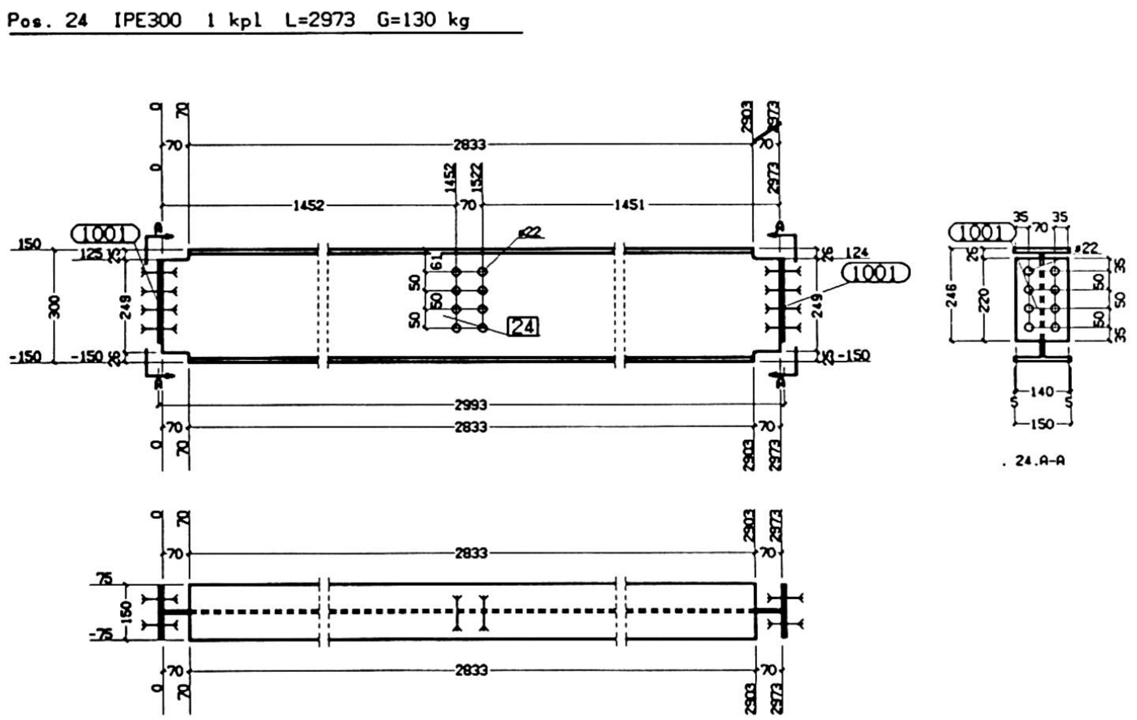

Fig. 3 An automatically produced workshop drawing of a typical beam.

4. INFORMATION FOR AUTOMATIC PRODUCTION

Besides workshop drawings, many different kinds of input data for NC-machines can easily be produced from the 3D data base. Several companies use the BOCAD-3D-system in computer-aided manufacturing on a very advanced level - only the welding work is done manually.

5. CONCLUSIONS

The traditional CAD systems - drawing systems - can not make the design process itself any more effective. By using modern data bases the whole geometry of a building can be modelled into a data base. A designer using a system based on a three-dimensional volume model need not waste time on drawing the drafts on the screen. He only creates a model of the structure and after that all drawings are produced automatically. After creating the model all the workshop drawings can be produced overnight. This may mean hundreds of drawings of one plane of a building.

A data base which contains all the data of a building facilitates revisioning and reduces mistakes. Every part needs to be fed to the data base and revisioned only once. When a part has been revisioned, the change is automatically shown in all drawings drawn out after the revision. Producing the workshop drawings from a common data base assures that all parts fit together and no measurement faults occur. With the help of BOCAD-3D complicated steel structure objects can be designed in a time remarkably shorter than manually. At the same time the quality of plans have improved considerably.

Computer Aided Bridges Design

Conception assistée d'ouvrages d'art

Computerunterstützter Brückenentwurf

J.P. CHANARD
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J.P. Chanard, born in 1958, graduated from Ecole Centrale de Paris. After one year of computer research in the Tokyo Institute of Technology, he entered Campenon Bernard as structural engineer. He is now managing the CAD services in the design office since its creation in 1984.

RÉSUMÉ
Un programme complet de CAO pour la modélisation de ponts permet à l'utilisateur de construire une maquette réaliste, à partir de laquelle seront extraits des données de calcul et permettant de même la génération partielle ou totale de plans nécessaires à la construction de l'ouvrage.

SUMMARY
An extensive CAD software for bridge design enables the user to produce a realistic model of the structure from which structural software data files and drawings are partly or totally generated automatically.

ZUSAMMENFASSUNG
Das vollständig computerunterstützte Programm ermöglicht dem Anwender ein realistisches Modell zu entwickeln, aus welchem Bemessungsdaten sowie Konstruktionspläne der Brücke automatisch produziert werden können.

INTRODUCTION

For **CAMPENON BERNARD**, a major French civil engineering contractor, the use of a CAD system was at first an answer to a drafting problem. Meanwhile the choice of a powerfull system was brought about by the wish to perform a smooth evolution to computer-aided design.
Drawings are nevertheless the main production from the design office. CAD system beeing mainly devoted to draftmen, the aim of the first developpement was to process data exchanges between drafting and design. Drawings, as a main data base for design, are transformed to a computer data base, easily and errorfree processed by structural analysis software. But there is some differences between a computing model and a drafting model. Many precise details must be drafted, while they are unnecessary for structural analysis.Sometimes inconsistant with software simplification, they are of no mechanical consequence.
The aim of our developpements was to have the design draftman responsible for the preparation of a common model, under the control of the design engineer.

I STRUCTURE LAY-OUT (Fig. 1)

The structure is positioned in space with the help of two plannar definitions, the site view and the profile line.
Site plan view is a projection of the reference axis of the structure upon an horizontal plane. Computations are very precised, the results are often to the millimeter even for radii of more than 1 kilometer.
The profile line gives the level of every point of the plan reference line. It usualy consists of straight lines and conics.
Construction lines are drafted in a 3D file, on two perpendicular planes. On each curve, particular points are defined as indications of the major geometrical changes of the deck.
A 3D curve is automatically generated. More than a curve, points are placed in space. Every point is the location of piers or represents changes of the structure which leads to section modification. These points often mark a discontinuity in the construction process or precast element fabrication.

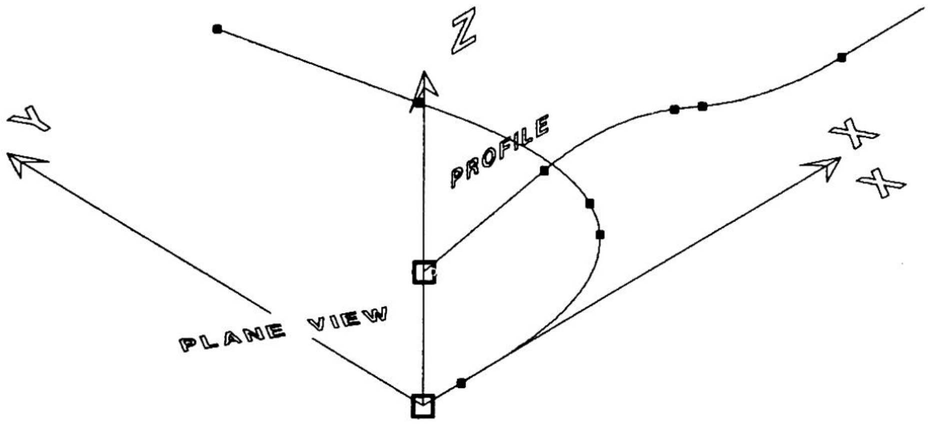
II SECTIONS DRAFTING

Bridge sections while varying a lot, always still have some common characteristics between them.
A bridge section consists of slabs and webs. It can be open or closed with one or more openings. Symetrical or not, its shape is directly linked to its behavioural properties. It is one of the variables in the calculations, and cannot be fixed at the beginning.
For these reasons, we had to imagine an evolutionary process, free enough to allow any particularity while offering practical tools for drafting usual shapes.
Before they are recorded, different mechanical properties are computed and listed. Modifications are easy and quick, especially if these modifications are the usual geometrical changes applied to sections to improve their behavourial properties such as thickening of slabs and webs. These sections are named and stored in a library. They can be recalled at any moment for any project.

III PLACING THE SECTIONS (fig. 2)

In addition to the mechanical and geometrical parameters, some more data linked to layout process are defined for each section. Attachment point to reference curve, superelevation points and theoretical mechanical axis for computation are defined. Some reference points can be added too, in order to identify, after the completion of the structural design process, the final coordinates of the different parts, which is usefull for

Fig. 1 - Layout curves



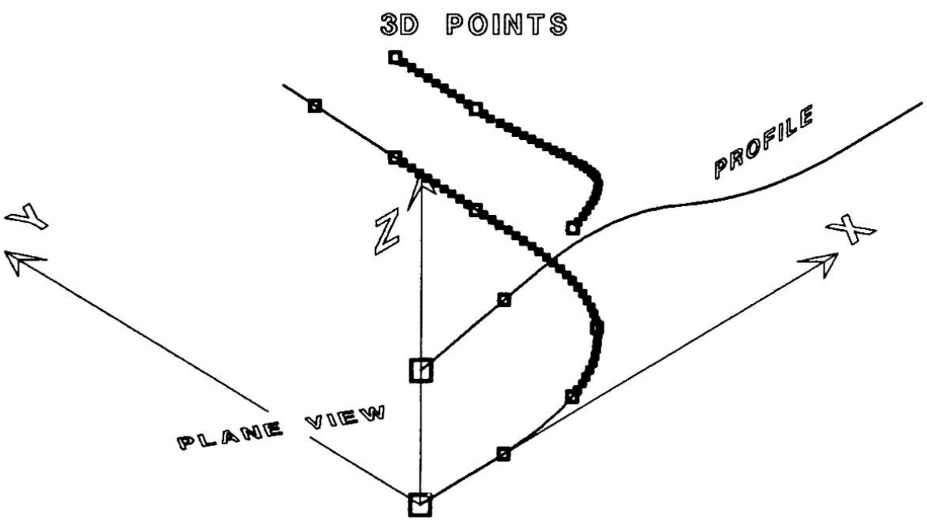
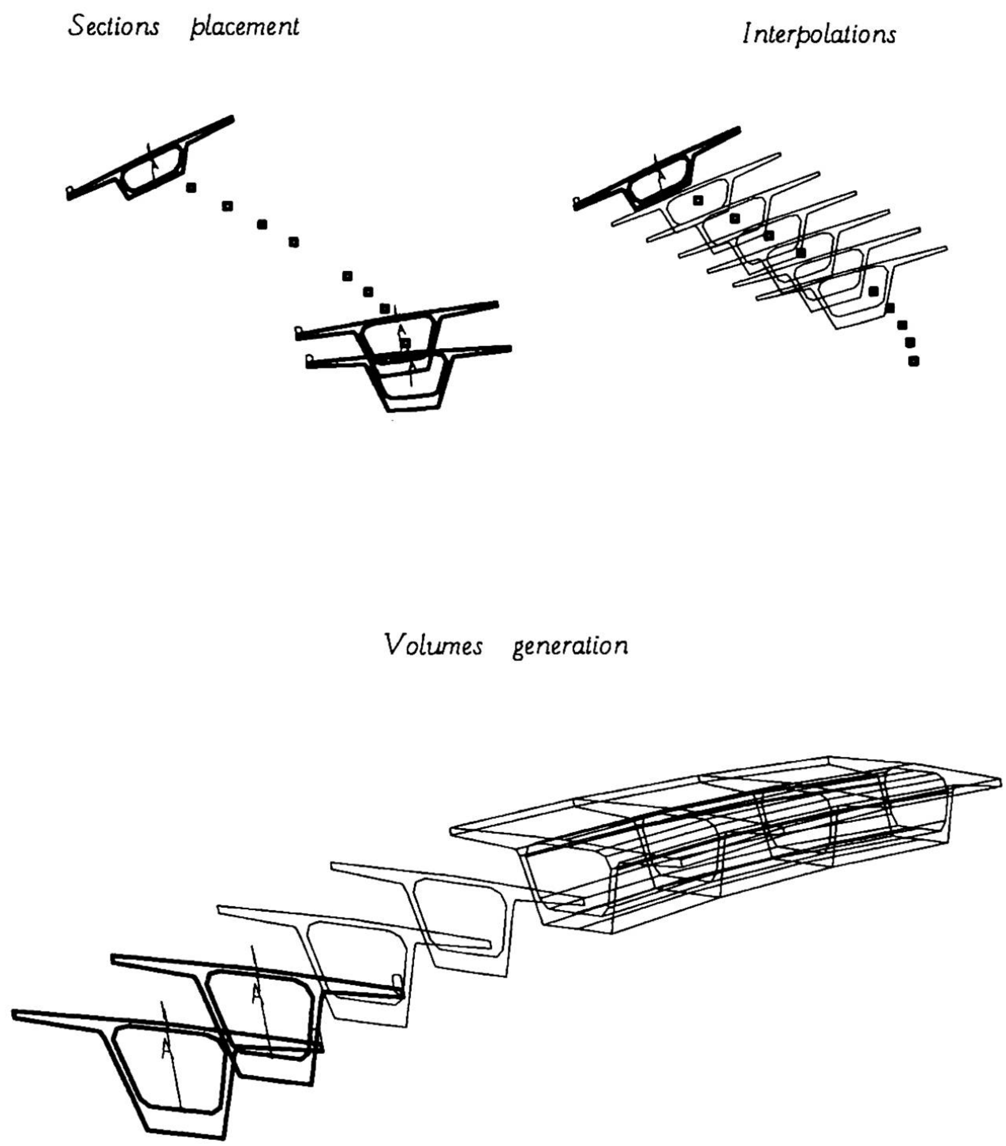


Fig. 2 - Sections and volumes



construction.

IV VOLUME GENERATION (fig. 2)

From the positioned sections, volumes are automatically generated from one section to another. The usual variation is linear but it can also be parabolic or user defined. One restriction is that sections must be defined with the same number of points all along the project, even if some points are geometrically at the same place.
Erection of piers is done in the same manner. They are in fact very similar to the deck, in their design process.

V PRESTRESS CABLES

Two types of prestressing techniques are used wich need totally different processes to be generated.
Cables placed externally to the structure are the easiest to design. Tendons are linked to concrete at some particular points, such as a deflacting block, wich modify their direction. The constitution of such a cable is made of lines linked by circular arcs at attachement points. It is often defined by theoretical points where lines cross, wich are also the points where loads concentrate. Circular arcs are determined as fillets between lines, with a given radius. The direction of the cable model is left to the draftman. Once the model is defined, all the different parts are linked together, and software is called upon to transform all this information into a coherent system. A facility is provided to the operator to perform difficult connections such as for non coplanar lines.
For internal cables, definition is totaly different. Some leading points are imposed. In sections, positions are often the same from cable to cable in the different sections. Geometrical interpolation between these points have to follow given rules. Ends near the anchorages are often the same too, in order to make design and construction easier and to reduce cost. For that reason, the user is helped as much as possible to easily define that kind of cable.
Tendons are then generated by a batch job. They are aproximated by cubic parabolae. Imposed points between sections or new ones can be defined, some can be suppressed or moved to another place.
For both types, additional parameters are defined for each cable. The type of the cable, the different mechanical properties and the initial stressing load are input in order to get the final tension and expected loss. After modification, these results can be obtained interactively allowing the best definition to be found.
Cables are modelled by their central axis only. For spare economy and minimized response time, it is useless to model the sheath. But in particular points, for interference checking, an overall dimension tube can be automatically generated giving two points on the cable.

VI ANCHOR BLOCK DEFINITION

Anchor block design has always been the most difficult part in bridge drafting, due to the complicated geometrical definition of these parts. If we try to simply define an anchor block, it is made of a dimension imposed face on wich rests the metal anchor plate, perpendicular to the axis of the cable. Pyramidal facets are the drawn to obtain the jonction with the surrounded concrete base. In order to simplify design and construction, shapes are often the sames for every anchor, even if the concrete base is different, leading to some simple geometrical modifications and adjustments. Variable facets are automatically adjusted to be linked to the existing concrete surface.

VII COMPUTING INPUT FILES GENERATION

Until then, the work performed by draftsmen has been identical to the one they should have done before, but much easier and quicker. As he is processing, much of the information is recorded for later use. With the help of the engineer, some parameters, directly linked to computation software as nodes and bars definition, sub-cutting and connections, internal as well as external, are defined.
The software will automatically generate input data files for structural analysis software.
The engineer will have only to define external loads and get the results of the computation.

VIII GRAPHICAL EXTENSION

All the informations collected can also be used for the graphics. First, form plans are drafted from different parts of the model, automatic references and titles are added. No more difficult geometrical calculation is needed for complex shapes, software simply uses coordinates data from the real sized model. Hidden lines removal and automatic perspective generation is often used to add detailed views wich make the plan more easily readable and understandable by everybody.
The drafting activity most aided by this facility is the preparation of prestress cables plans. On the longitudinal profile, for each point of the cable much information can be automatically written as name, local radius or slope. A set of section plans can be automatically generated to, giving for each defined section the position of the cables going through it with exact local coordinates.
Bench marks set on each sections can also be collected on setting plans in order to help the making and placement of segments.
The Model is also used as a reference for reinforcement placement. No 2D interpretation of the model is required. Bars are directly defined inside the concrete model using the INTERGRAPH CDP software. The aim of this software is to provide an automatic check of the major rules of rebars placement in accordance with several major standards (ACI,CP100,BAEL). Freed from this, the draftsman can design better reinforcement. At the end of the work, sections and detail views are automatically generated, for assisting quantity takeoffs.

Report and bending schedules are drawn automatically too .With the help of interference checking, the draftman is able to draw more realistic plan of reinforcement.(fig. 6 & 7)

CONCLUSION

This major development needed more than one and a half year-man of programming. However, that important work has been done in understanding the basic softwares.
The first use of that software showed an important saving of time and more consistency in design.
We had given consideration wether we have to go further in automation of modelling process, eg. prestress optimisation. In fact, the bridges studied at the design office are too different from each other to find a common calculation method for geometrical optimisation and get the best results.
As of now, this software with the help and speed it provides, allows the engeneer to design a greater number variant models to select the best one.

CAD Anwendung im Konstruktiven Ingenieurbau und Expertensystem

Use of CAD in Construction Engineering Design and Expert Systems

Conception assistée par ordinateur et systèmes experts en génie civil

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Wolfgang Ehlert, geboren 1951, Studium und Promotion an der Ruhr-Universität Bochum. Seit 1981 bei der Strabag Bau-AG, seit 1982 Leiter der Technischen EDV, seit 1987 auch Geschäftsführer der DICAD Software GmbH Köln.

ZUSAMMENFASSUNG
Erfahrungen aus dem CAD-Einsatz im Konstruktiven Ingenieurbau zeigen, daß die Vorteile für das technische Büro und die Baustelle überwiegen und nicht durch die entstehenden Kosten oder die auch vorhandenen Nachteile aufgewogen werden. Aus dem täglichen CAD-Einsatz lassen sich realistische Vorstellungen über die Möglichkeiten von Expertensystemen ableiten, speziell auf dem Gebiet des Datentausches zwischen verschiedenen CAD-Systemen.

SUMMARY
Experience gained from the use of CAD in construction engineering design clearly demonstrates that the advantages for both, engineering offices and construction sites, are overwhelming, and far outweigh the resulting costs or present disadvantages. A realistic idea of the possibilities of expert systems, particularly in the sector of data-exchange between differing CAD systems, can be deduced from the practical, everyday use of CAD programs.

RÉSUMÉ
Des expériences dans l'utilisation de la conception assistée par ordinateur dans le domaine du génie civil montrent que les avantages pour le bureau technique et le chantier sont prédominants et supérieurs aux coûts résultants ou aux désavantages aussi existants. Un concept réaliste concernant les possibilités des systèmes experts, en particulier dans le domaine de l'échange des données, peut découler de l'utilisation quotidienne de la conception aidée par ordinateur.

1. EINLEITUNG

Die überwiegende Anzahl der in Deutschland mit Konstruktivem Ingenieurbau befaßten Technischen Büros, beschäftigt immer noch mehr Bauzeichner und Konstrukteure als Statiker. Während für die Statiker der Rechnereinsatz heute selbstverständlich ist, gilt dies noch nicht für die Konstrukteure.
Es gibt aber CAD (Computer aided detailing)-Systeme, die die Konstruktionstätigkeit so unterstützen, daß ein Rechnereinsatz wirtschaftliche Vorteile bringt.
Diese Vorteile ergeben sich zum Teil aus Zeitersparnissen im Konstruktionsbüro und zu einem ebenso wichtigen Teil durch die hohe Qualität der mit CAD-Unterstützung erstellten Pläne, die sich direkt positiv auf die Bauausführung auswirkt.
Neben diesen Vorteilen ergibt eine Abhängigkeit von Technik immer auch Nachteile, die aber den CAD-Einsatz nicht grundsätzlich in Frage stellen.
Daneben sind heute Expertensysteme im Gespräch, die z.B. in engen Bereichen der Medizin oder des Automobilbaus Beachtung finden.
Gerade aus den Problemen mit einem alltäglichen CAD-Einsatz,lassen sich für den Bereich des Konstruktiven Ingenieurbaus realistische Vorstellungen über die Möglichkeiten eines Expertensystemes ableiten.

2. CAD - ANWENDUNG IM KONSTRUKTIVEN INGENIEURBAU

2.1 Vorteile für das Technische Büro

2.1.1 Erforderliche Wirtschaftlichkeit

Die Aufwendungen für den CAD-Einsatz ergeben sich aus den Kosten für Programme und Hardware, sowie für die Schulung und aus der verminderten Leistungsfähigkeit des Anwenders während der Einführungsphase. Daneben ergeben sich Kosten aus der Abschreibung, Wartung, Verzinsung, ...

Die Frage nach der Wirtschaftlichkeit des CAD-Einsatzes läßt sich nicht aus einem möglichen Beschleunigungsfaktor beantworten. Stattdessen ist die Ermittlung eines erforderlichen Faktors wesentlich hilfreicher zur Abwägung des CAD-Einsatzes.
Durch Auswahl für CAD geeigneten oder ungeeigneten Projekten kann dann der Einsatz und die Wirtschaftlichkeit vom Anwender gesteuert werden.
Die Preise für zwei Arbeitsplätze auf PC-Basis stellen sich wie folgt dar :

2 x PC-Rechner (80386 CPU, 20" Farbbildschirm Eingabetablett : 2 x DM 30.000,--	DM 60.000,--
1 DIN A0-Plotter	DM 30.000,--
2 x Programme und Schulung	DM 77.000,--
<u>Investition :</u>	<u>DM 167.000,--</u>
Laufende Kosten :	
Abschreibung auf 5 Jahre ca.	DM 33.400,--
Verzinsung ca.	DM 8.400,--
Wartung, Verbrauchsmaterial	DM 21.200,--
<u>Jahreskosten für 2 Arbeitsplätze :</u>	<u>DM 63.000,--</u>
<u>Monatl. Kosten je CAD-Arbeitsplatz (starker PC)</u>	DM 2.625,--

Die Kosten beim Einsatz einer Anlage der mittleren Datentechnik wie z.B. einer Micro-VAX II, liegen in den Investitionen um ca.
DM 20.000,-- höher. Auf den Monat bezogen ergibt sich dabei:

<u>Monatl. Kosten je CAD-Arbeitsplatz (Micro-VAX II Basis)</u>	DM 2.850,--

Setzt man für die Konstrukteurstunde einschließlich Lohnnebenkosten und sonstiger Umlagen 70,-- DM/Std an, so ergeben sich bei 175 produktiven Tagen im Jahr monatliche Kosten von :

70 x 175 x 8/12 = DM 8.167,--

Aus diesen Zahlen ergibt sich ein erforderlicher Beschleunigungsfaktor von

1 + 2625/8167 = 1,32

Erfahrungsgemäß reicht ein schneller DIN A0-Plotter für 4 CAD-Arbeitsplätze aus, so daß sich bei 4 Arbeitsplätzen ein erforderlicher Faktor von ca. 1,23 ergibt.

2.2.1 Erreichbare und erreichte Wirtschaftlichkeit

Die vorgenannten Faktoren können bei der Bearbeitung eines einzelnen A0-Planes nicht ohne weiteres erreicht werden. Sobald der einzelne Plan aber Teil einer Plankette ist, sind die Faktoren leicht zu erhalten. Der Effekt der Plankette ist im Konstruktiven Ingenieurbau fast immer allein dadurch gegeben, daß Schalung und Bewehrung bei mittleren und allen größeren Bauvorhaben auf mehreren Plänen dargestellt werden müssen. Wenn zusätzlich weitere Gewerke wie z.B. die Haustechnik oder als Vorlauf sogar die Planer mit CAD gearbeitet haben, sind immer erhebliche wirtschaftliche Vorteile der Konstruktionstätigkeit gegeben.
Als typisches Beispiel für Pläne, bei dem die Einzelbearbeitung mit CAD nicht den erforderlichen Faktor liefern kann, dient Bild 1.

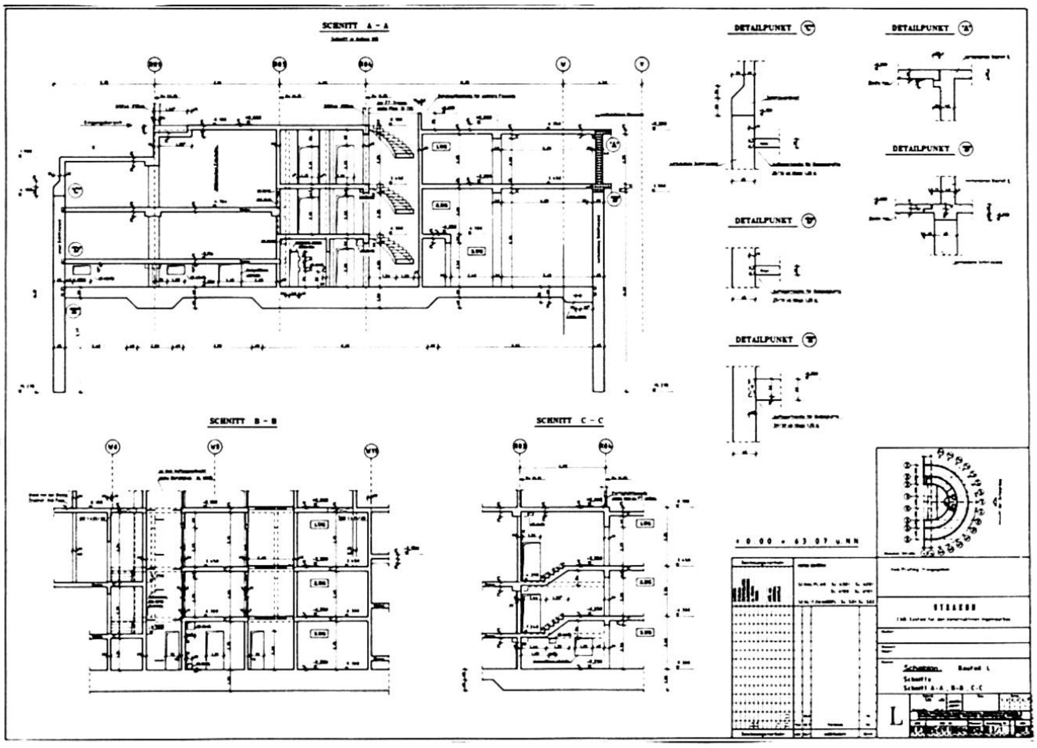

Bild 1
Beispiel für Plan der mit CAD-Bearbeitung keinen ausreichenden Beschleunigungsfaktor liefert.

Im Vergleich dazu erreicht man bei der Ausarbeitung des einzelnen Grundrissplanes des gleichen Bauvorhabens, der als Übersicht in der rechten unteren Ecke von Bild 1 sichtbar ist, durch die vorhandene Geometrie, Faktoren größer 2.

Neben dem Effekt der Plankette ergeben sich bei geeignetem CAD-System immer auch Einsparungen bei Bewehrungsplänen (s.Bild 2)

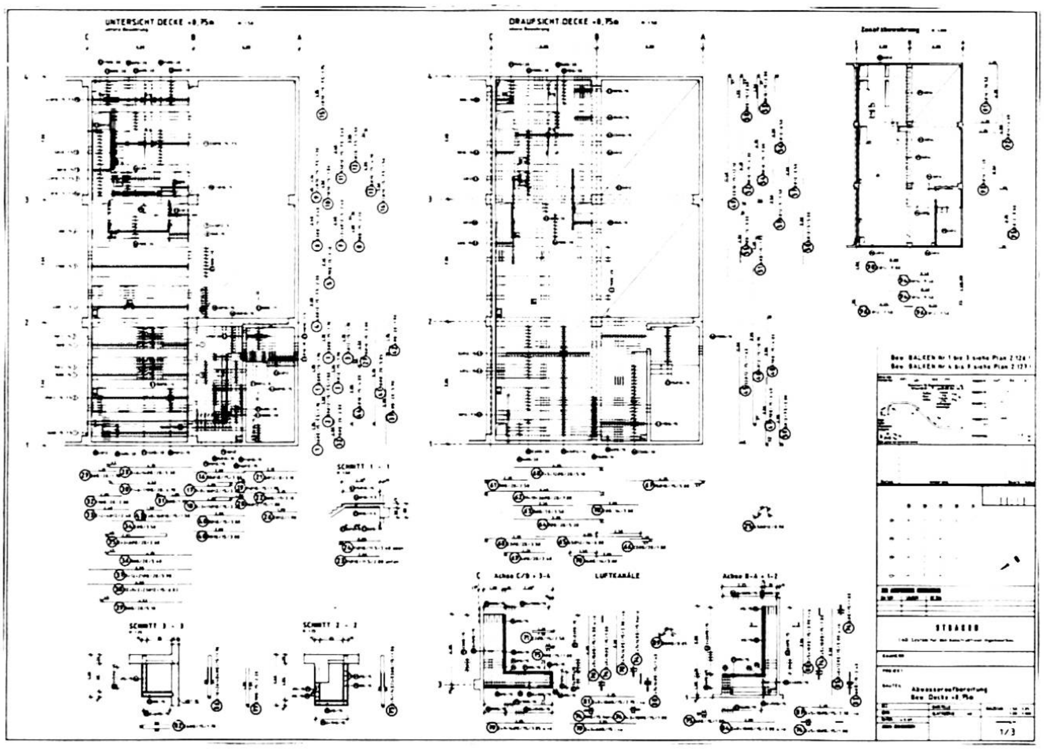

Bild 2
Bewehrungsplan bei dem der erforderliche Faktor erreicht wurde.

Da sich die Länge und die Anzahl der Bewehrungsstäbe aus der Anbindung an die Schalungsgeometrie ergeben, wird auch im schweren Industriebau (Bild 2) ohne den Effekt der Plankette immer mindestens der Faktor 1,2 erreicht.
Die Faktoren liegen bei Fertigteilen, z.B. Fassadenfertigteilen, Fertigteilstützen und -balken, ... immer über den erforderlichen.

2.2 Nachteile aus dem CAD-Einsatz für das Technische Büro

Die in Deutschland vielfach übliche baubegleitende Planung, ist ein wesentlicher Störfaktor für eine ordnungsgemäße Abwicklung der konstruktiven Bearbeitung und der Bauausführung.
Häufig werden noch Änderungen nach dem Betonieren vorgenommen. Diese z.T. chaotische Planung verschwindet leider nicht, wenn im Bereich des Konstruktiven Ingenieurbaus CAD eingesetzt wird. Es ist viel zu zeitaufwendig, für jede kleine Änderung CAD einzusetzen, auch wenn der Plan mit CAD erstellt wurde.
Stattdessen ist eine ordentliche Dokumentation der "per Hand" aufgelaufenen Änderungen erforderlich, die, soweit notwendig, bei passender Gelegenheit in den CAD-Datenbestand übernommen werden. Diesem erhöhten Aufwand steht eine erhöhte Sicherheit bei Änderungen mit einem CAD-System gegenüber. Z.B. ändern sich bei Verschiebung einer Schalkante automatisch die Vermaßung, die Flächen-, Umfangs- und Gewichtsberechnungen sowie die entsprechenden Bewehrungspositionen bzw. -formen. Hier ist der mündige Anwender aufgerufen, einen gesunden Kompromiß zu finden.

Beim Einsatz von Technik entstehen Abhängigkeiten.
Während in den vergangenen Jahrzehnten nur die Pausmaschine eine kritische Stelle für unvorhergesehene Probleme mit dem Planversand bildete, ist beim CAD-Einsatz die Abhängigkeit vervielfacht.

Nachfolgende Liste von Stoßgebeten der CAD-Anwender gibt einen kleinen Einblick in die Problematik :

- hoffentlich stürzt das Programm jetzt nicht ab,
- hoffentlich streikt mein Monitor, bzw. mein Rechner nicht,

- hoffentlich sind meine Dateien noch alle vorhanden,
- hoffentlich speichert mein Rechner meine Tagesarbeit problemlos,
- hoffentlich läuft der Plotter,
- hoffentlich schreiben alle Tuschestifte während mein Plan gezeichnet wird,
- usw.

Natürlich gab und gibt es in allen vorgenannten Bereichen Störungen, die sich mehr oder weniger negativ bis katastrophal auf die Tagesarbeit auswirken. Nur der Einsatz von bewährter Soft- und Hardware minimiert diese Risiken.

Für den CAD-Einsatz haben sich fast als Standard, 20" Farbmonitore durchgesetzt. Größere Monitore sind zur Zeit gar nicht oder nur zu unverhältnismäßigen hohen Preisen verfügbar. Die eingesetzten Monitore sind zu klein.
Durch die Verwendung eines zweiten Schirmes oder eines Graphiksystems, in dem sich Planausschnitt und gleichzeitig der Gesamtplan speichern lassen und auf Knopfdruck ohne Zeitverlust schaltbar sind, kann man eine ausreichende Akzeptanz beim Anwender erreichen.
Die Kontrolle des Planes durch den Ingenieur während der Bearbeitung durch den Konstrukteur wird aber sehr stark behindert. Hier bot das Zeichenbrett wesentlich mehr Möglichkeiten. Dieser Mangel kann nur durch einen erhöhten Aufwand, z.B. durch das Plotten von Zwischenzuständen der Bearbeitung, gemildert werden.

Keiner der aufgelisteten Nachteile hat bisher die Vorteile des CAD-Einsatzes im Konstruktiven Ingenieurbau aufgewogen.

3. VOR- UND NACHTEILE FÜR DIE BAUAUSFÜHRUNG

Die Vorteile für die Bauausführung ergeben sich aus der Qualität der Pläne samt den zugehörigen Listen (z.B. Stahl- und Einbauteillisten). Richtige Maße und richtige Stücklisten, sowie ein mehr an Informationen auf den Plänen (z.B. die Fläche eines komplizierten Brückenquerschnitts), führen zu weniger Rückfragen im Technischen Büro und zu einem ungestörten Bauablauf.

Wir wissen aus einem wirtschaftlich erfolgreich abgewickelten U-Bahn Bauvorhaben (Bausumme 100 Mio. DM), daß alleine aus fehlendem bzw. falschem Bewehrungsstahl, der kurzfristig teuer beschafft werden mußte, Mehrkosten entstanden sind, die die Anschaffung von 2 CAD-Arbeitsplätzen ermöglicht hätten.
Nachteile aus dem CAD-Einsatz gibt es bei einem geeigneten System nicht. Bei geeigneten Systemen sehen Bauzeichnungen so aus, wie sie vom besten Konstrukteur unter Berücksichtigung aller Baustellenbelange erstellt werden.

4. EXPERTENSYSTEM UND CAD

Expertensysteme [1] [2] können die 3. Stufe der Rechneranwendung im Konstruktiven Ingenieurbau bilden. (Stufe 1: Berechnung - Statik, Stufe 2: Interaktive rechnergestützte Zeichnungserstellung-CAD).

Die Grundlage vorhandener Expertensysteme beruhen auf neuen Softwaretechnologien, überwiegend auf Basis der Programmiersprachen PROLOG, bzw. LISP.
Expertensysteme erscheinen geeignet, um z.B. den Datenaustausch zwischen beliebigen CAD-Systemen durchzuführen.

Erfolgt heute ein Datenaustausch zwischen zwei verschiedenen CAD- Systemen, so sind folgende programminterne Möglichkeiten vorhanden :

a) beide Systeme beherrschen die Datenausgabe bzw. -eingabe eines Standard - Datenaustauschformates (z.B. IGES im Maschinenbau).
b) in einem der CAD-Systeme ist die möglichst vollständige Umsetzung der Daten in das andere CAD-System realisiert.

Im Fall a) ist der Datenaustausch für den Bereich des Konstruktiven Ingenieurbaus infolge der Mängel der existierenden, genormten Schnittstellen immer mit dem Verlust von Dateninhalten verbunden. Im Fall b) ist im günstigsten Fall eine sehr ähnliche Datenstruktur der CAD-Informationen vorhanden, die einen Datentausch mit geringem Programmieraufwand ermöglichen; im ungünstigsten Fall ist ein immenser Aufwand zur Umsetzung der unterschiedlichen Verwaltung der Dateninhalte erforderlich.

Aus der Struktur der realisierten Expertensysteme [3] [4] [5] läßt sich ableiten, daß die Nachteile in a) und b) vermieden werden können.

Ein Expertensytem mit den nachfolgenden Fähigkeiten :

-Phase I 1) Lerne : Was ist ein Baukörper, Einbauteil, Bewehrungskörper.... im CAD-System A,B,C....,

2) Speichere dieses Wissen,

-Phase II 3) Lies die Daten eines beliebigen CAD-Systemes,

4) Gib die Daten an ein beliebiges CAD-System weiter,

schließt die Nachteile von a) und b) aus.

Der Anwender eines CAD-Systemes wäre nicht mehr von den Programmierfähigkeiten bzw. -kapazitäten der betroffenen Softwarehäuser abhängig, um Daten zwischen den etwa 30 bauwesengeeigneten CAD-Systemen auszutauschen. Die betroffenen Softwarehäuser wären vom Zwang befreit, sich auf einen gemeinsamen Standard (in der Regel der kleinste gemeinsame Nenner) zu verständigen. Falls die Realisierung eines Expertensystems für den Datentausch zwischen beliebigen CAD-Systemen des Baubereiches gelingt, darf man auch hoffen, daß z.B. die automatische, optimale Bewehrungsführung eines geometrisch komplizierten Tragwerksknoten durch ein anderes Expertensystem gelöst werden kann.

5. SCHLUSSBEMERKUNG

CAD-Einsatz im Konstruktiven Ingenieurbau ist heute für jedes Technische Büro wirtschaftlich sinnvoll. Ohne Menschen, die diese Technik wollen, ist aber kein Erfolg erreichbar.

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Personal Computer Systems in Nonlinear Analysis of Structures

Micro-ordinateurs dans l'analyse nonlineaire des structures

Anwendung von Personalcomputern zur Analyse nichtlinearer Strukturen

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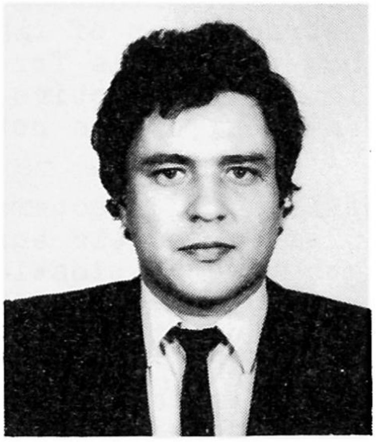

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SUMMARY
This paper presents a software package for the analysis of non-linear behaviour of bar structures modelled by means of non-dimensionalised Ramberg-Osgood curves. The incremental rigidity matrices are determined directly correcting the corresponding elastic matrices. The authors also present the results and conclusions arrived at on the basis of a numerical example.

RÉSUMÉ
Un ensemble de programmes pour l'analyse non-linéaire de structures en barres est présenté. Le comportement non-linéaire est modelé par des courbes sans dimension de type Ramberg-Osgood. Les matrices de rigidité incrémentales sont déterminées directement par correction de matrices d'élasticité. Les resultats et conclusions de l'étude sont présentés à l'aide d'un exemple numérique.

ZUSAMMENFASSUNG
Die Arbeit befasst sich mit Programmen für nichtlineare Substrukturen, modelliert durch dimensionslose Kurven des Ramberg-Osgood Typs. Die Steifigkeitmatrizen werden direkt durch Anpassung der elastischen Matrizen formuliert. Ergebnisse und Schlussfolgerungen werden anhand eines Berechnungsbeispiels verdeutlicht.

1. INTRODUCTION

Nowadays, in most countries - Romania included - structure calculation norms used in civil engineering resort to limit state design, which is considered to be more rational than permissible resistance design or fracture design. The limit state taken into consideration (serviciability limit state, elastic limit state, or plastic limit state) depends on the nature and the function of the building being designed. As far as frame structures are concerned, plastic limit state calculations ensure a rational and efficient design, regardless of whther the frames are made of reinforced concrete or steel. The introduction of limit state design in current design processes, however, calls for a nonlinear analysis procedure which is sufficiently effective from the technical point of view, but whose implementation does not pose great complications to the designer.

For instance, TWG 8.2 of ECCS [5] recommends the following calculation methods for the elastic-plastic analysis of steel structures: (1) ultimate strength theory (plastic zone theory); (2) second-order plastic hinge theory; (3) first-order plastic hinge theory. The first method is much too complicated to be used in current design processes, so that only the other two may be considered, keeping in mind their limitations as specified in the literature [5], [6]. As far as their implementation on microcomputers - equipment suited to design processes - is concerned, these methods have the drawback that they do not allow the direct determination of the incremental rigidity matrix; this is why the DISNABS (Dynamic and Static Nonlinear Analysis of Bar Structures) software package described in this paper implements a numerical method which allows the direct determination of the incremental rigidity matrix on the basis of Ramberg-Osgood nonlinear models of material (reinforced concrete or steel) behaviour [3]. This method considerably simplifies the computational algorithm, lowering memory requirements and increasing execution speed.

2. THE ASSUMPTIONS UNDERLYING THE COMPUTATIONAL ALGORITHM

The following assumptions underlie the nonlinear computational algorithm implemented in the DISNABS package:
- 1. Structures are made up of constant cross section straight bars.
- 2. The characteristic action-response diagram employed is of the same type for all the bars in a given structure.
- 3. Structure loading increases in direct proportion to the loading parameter .
- 4. Nonlinear analysis is based on first-order plastic theory, which gives up the plastic hinges hypothesis and takes into account the variable bending rigidity of cross sections along bars, which depends on loading and the real characteristics of the material the structures are made of. The nonlinear material-behaviour model is represented by means of the adimensional version of the Ramberg-Osgood M-ϕ diagram adapted to the type of material used in the given structure (Fig. 1, (a), (b), and (c)). This model enables the designer to take into consideration various material-behaviour laws formulated by means of the parameters μ and ρ (Fig. 1, (d) through (h)). If the sign of the bending moment changes in time - in the case of dynamic actions -, branching curves are used (Fig. 1, (i)).

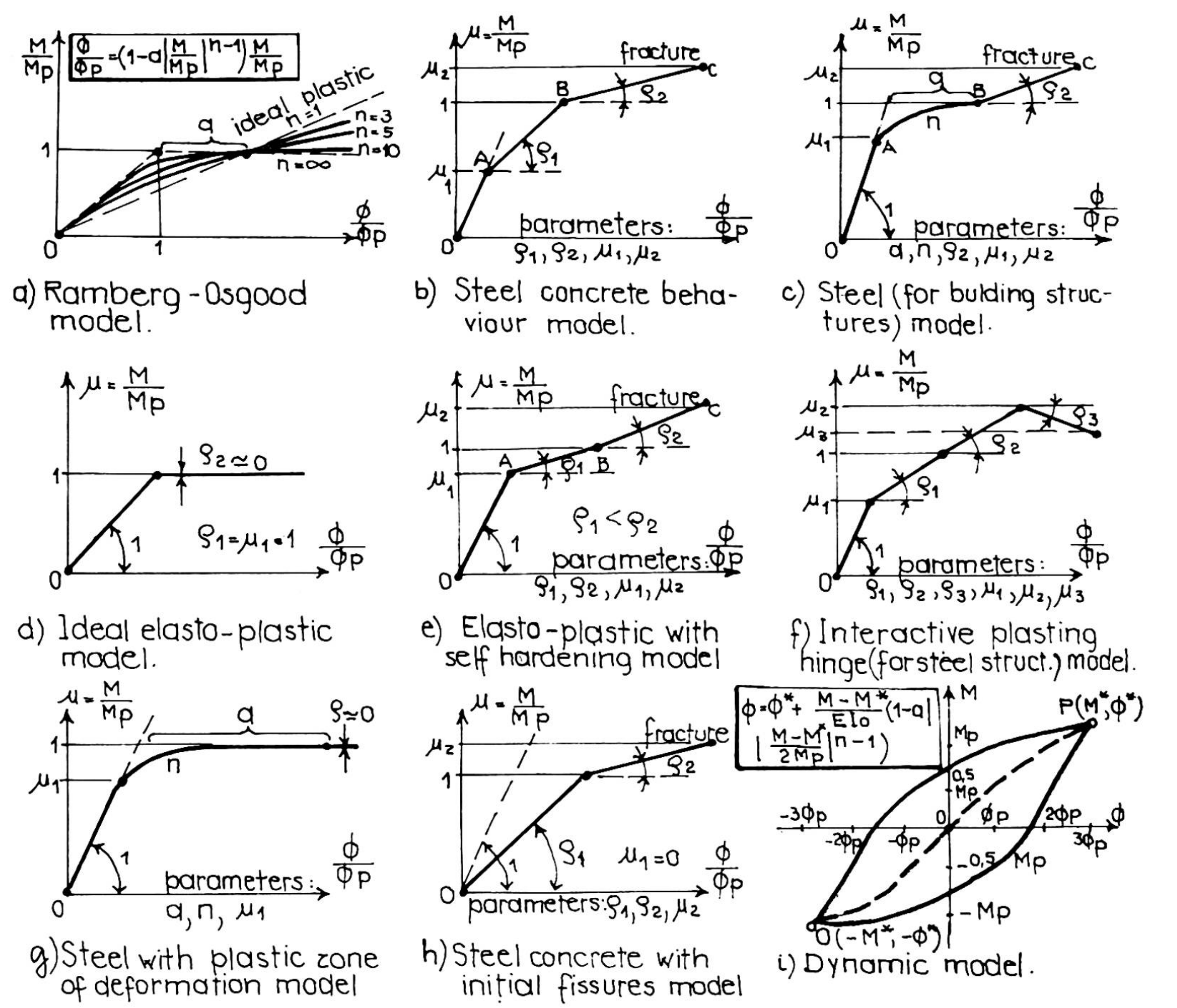

Fig. 1 Characteristic curves

- 5. The incremental rigidity matrices of the bars are obtained via the succesive-stage linearization of the M-Ø characteristic diagrams. The form of these matrices is similar to that of the rigidity matrices in elastic calculations; the former differ from the latter in that they display elements affected by nonelastic correction coefficients which take into account decreases in bending, axial, and torsional (for spatial structures) rigidity in each loading step. The way in which these correction coefficients are established is similar to that in which rigidity correction coefficients are determined for bars with variable cross sections in elastic calculations; for this purpose, each bar is divided into a number m of sections ($m \geqslant 30$).

- 6. Geometrical imperfections are considered to be related to the real deformation of the structure and are modelled by equivalent distributed loadings.

- 7. Residual tensions are taken into account via the initial decrease in the rigidity of the bars.

- 8. In dynamic analysis, the masses of the structures are assumed to be concentrated in the nodes, displaying translation inertia only. Under these circumstances, the dynamic rigidity matrix is obtained by condensing the D.O.F. corresponding to the rotations of the nodes.

- 9. In seismic analysis, vertical vibrations are ignored and the floors are assumed to be perfectly rigid in their plane.

- 10. The action-response hysteretic curves determined statistically do not change under low-speed dynamic loading.

- 11. Seismic movement acceleration varies linearly over incremental discrete time intervals Δt.

- 12. Nonstructural elements do not work together with the basic structure.

3. THE DISNABS SOFTWARE PACKAGE

The DISNABS software package, which is designed to be used on personal computers, performs the static and dynamic analysis of bar structures with nonlinear behaviour. The main functional characteristic of the DISNABS package consists in the fact that it allows the use of various M-Ø nonlinear curves, so that it can be used in the analysis of both steel structures and reinforced concrete structures. The characteristic curve is specified by the user via the input data, the package including an independent module, COEFC, by means of which one can determine the rigidity correction coefficients using the transfer matrices procedure, the parameters of the characteristic M-Ø curves being stored in a special-purpose file.

At present, DISNABS performs the static and dynamic analysis of three types of structures: plane frames, girder networks, and spatial frames. In order to deal with static problems, DISNABS includes a module for solving nonlinear equation systems that is based on a Newton-Raphson algorithm and offers the user three options when tackling a static problem: (1) the Newton-Raphson approach; (2) the modified Newton-Raphson approach; (3) incrementation with Newton-Raphson approach [2]. Dynamic (time-dependent) problems are solved by means of a Newmark-Wilson algorithm. The modular structure of the package makes it possible to create independent programs, one for each type of problems, a feature which ensures efficient memory management. Maximum program length is 64K.

Starting from the input data, which describe the topology of the structure, the type of M-Ø nonlinear characteristic curves, and loading, DISNABS presents the entire evolution of the stresses and displacements, throughout the successive calculation stages, until the carrying capacity of the structure is exceeded, either by fracturing or by exaggerated deformation.

The overall structure and organisation of the DISNABS package observe the same principles and the same functional diagram as the DISTAS package, presented in extenso in [4].

4. RESULTS

Figure 2 (c) shows the results obtained using the DISNABS package to analyze a frame (Fig. 2, (a)) for which eight M-Ø characteristic diagrams were given (Fig. 2, (b)). It was assumed that ΔP = 10 KN and $\underline{m}$ = 30. It is noted that in certain situations the ultimate state is reached via exaggerated deformation (relative limit gradient = 1/1,000), whereas in others via material fracture (elastic failure), at the base of the column on the right. In the case of the characteristic diagram no. 8, the results are close to those obtained applying first-order plastic hinge theory, P_{lim} = 260 KN.

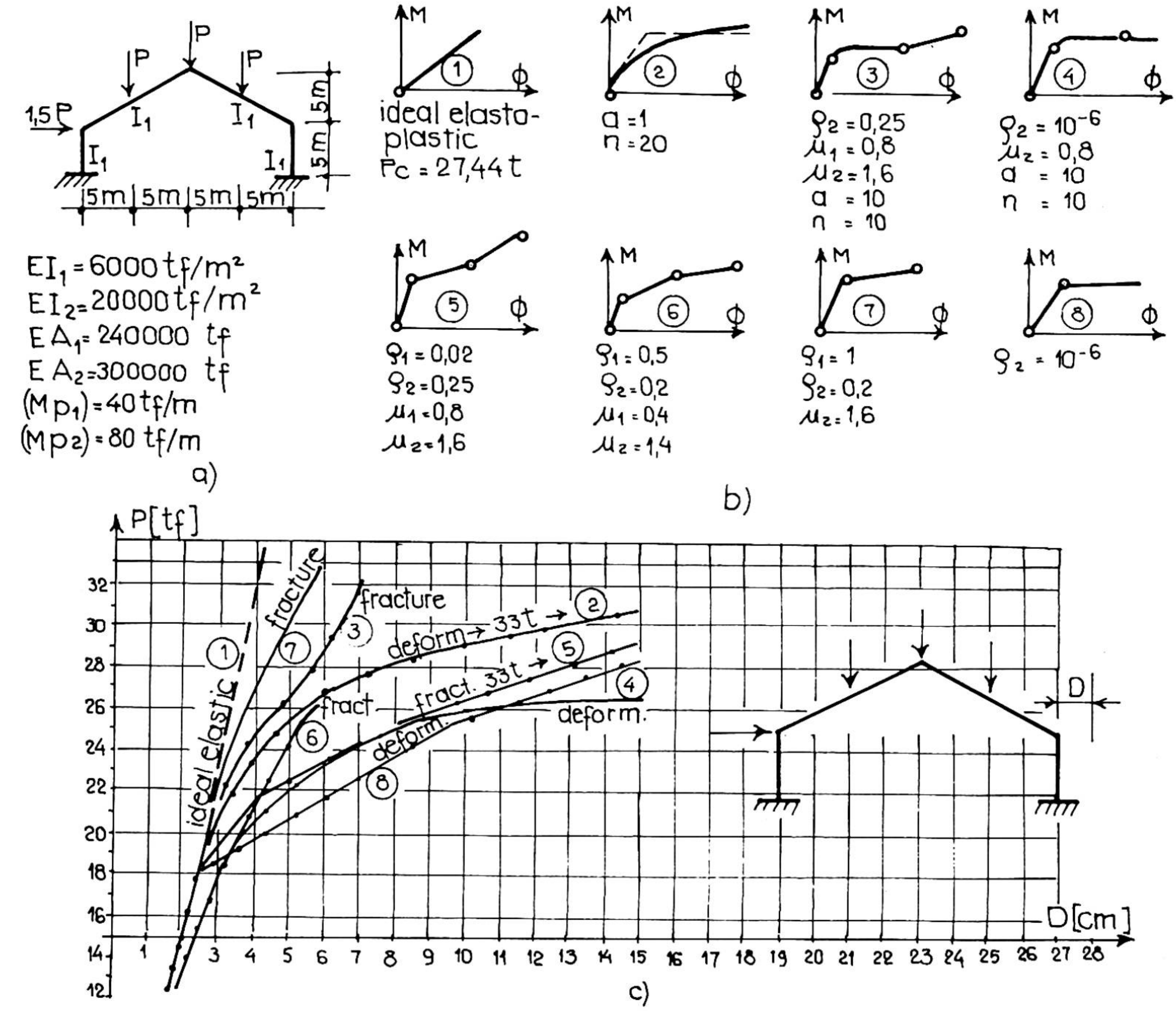

Fig. 2 Numerical example

The program was run on a SINCLAIR QL personal computer with 640K RAM (128K + 512K) and two 100K microdrives.

5. CONCLUSIONS

For reasons of space, it has not been possible to present at length the computational algorithm used and the performance characteristics of the DISNABS software package. The following general conclusions can nevertheless be drawn from the presentation above:

- 1. The DISNABS package performs the first-order plastic theory nonlinear analysis of bar structures, under both static and dynamic conditions, employing an algorithm that directly determines the incremental rigidity matrix.

- 2. The incremental rigidity matrices are determined by correcting the corresponding linear rigidity matrices.

- 3. DISNABS makes possible the differentiated analysis of structures by taking into account the materials they are made of.

- 4. The results obtained applying first-order plastic hinge theory are also yielded by an ideal elastic-plastic M-Ø model.

- 5. The DISNABS package is, according to its creators, a highly efficient calculation instrument when designing structures with elastic-plastic behaviour by means of the limit state method.

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Automatisierung der Berechnungen von räumlichen Konstruktionen

Computer-Aided Design of Three-Dimensional Structures

Automatisation du calcul de constructions spatiales

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ZUSAMMENFASSUNG
Dieser Bericht gibt allgemeine Informationen über einen Programmkomplex, der es ermöglicht, die Probleme der geometrischen Berechnung und Formbildung zu lösen.

SUMMARY
In the report general information on some software to solve problems of geometric analysis and three-dimensional form-developing of metal structures in given.

RÉSUMÉ
Le rapport présente des données sommaires sur le complexe des programmes qui permet de résoudre les problèmes du calcul et de la conception de la forme des constructions métalliques tridimensionnelles.

1. EINFÜHRUNG

Bei der Projektierung räumlicher Metallkonstruktionen, wie Kuppeln, Hängedächer und Kühltürme ist die geometrische Berechnung relativ kompliziert und aufwendig. Bis in neuere Zeit wurden die geometrischen Parameter solcher Bauwerke manuell oder manchmal mit individuellen Computerprogrammen ermittelt.

2. DER PROGRAMMKOMPLEX "GERA"

Für die Lösung eines breiten Aufgabenbereichs der geometrischen Berechnung und Darstellung räumlicher Metallkonstruktionen wurde ein Programmkomplex "GERA" erfolgreich entwickelt.

Die Hauptteile des Programmkomplexes sind:

- Einführung der Bezugsdaten
- Geometrische Darstellungen
- Umwandlungen
- Berechnungen
- Tabellieren
- Bildung des topologischen Schemas
- Projizierung
- Anordnung der Darstellung
- Zeichnungsausgabe

Jeder Teil besteht gewöhnlich aus einigen unabhängigen Teilen oder Berechnungsprozeduren. Bei einer konkreten Prozedur fragt das Programm alle notwendigen Bezugsdaten ab, wobei es auf Punkte, Längen, Winkel usw. hinweist. Die Nummer der Programmteile und genutzten Prozeduren zusammen mit wirklichen Parametern als Punkt-, Längen- und Winkelnummer werden als zweidimensionales ganzzahliges Feld C aufbewahrt. Das Feld C bestimmt die Reihenfolge der Berechnungsprozeduren und ist im Grunde genommen das Lösungsprogramm der konkreten Aufgabe, die nicht in der Programmsprache, sondern in einer relativen, problemorientierten Sprache geschrieben ist, welche mit weiteren Berechnungsprozeduren operiert. Die gemeinsame Invariante ist das Nummerierungsschema der Knoten, Längen und Winkel sowie anderer geometrischer Elemente. Die konkreten Berechnungszahlen dieser Elemente können jedoch verschieden sein. Das Feld C, das im Regime Mensch-Computer gebildet ist, erlaubt die Berechnung mit neuen Bezugsdaten ganz oder teilweise bei einer beliebigen Zahl von Wiederholungen und Umadressierungen automatisch zu wiederholen.

2.1. Einführung der Bezugsdaten

Jede geometrische Berechnung benötigt numerische Anfangsinformationen als konkrete Punkt-, Längen- und Winkelkoordinaten. Der erste Teil dieses Programmkomplexes ist gerade für die Einführung dieser Information vorgesehen. Im Verlaufe der Berechnung werden in der Regel zusätzliche Eingaben numerischer Information verlangt, aber in diesem Fall ist es zweckmässiger, sie mit entsprechenden Programmblöcken zu realisieren. Bei einigen Aufgaben, wo z.B. wirkliche Messergebnisse der Parameter eines geometrischen Objekts mit rechnerischen Werten verglichen werden, kann der Umfang eingegebener Anfangsinformation ziemlich gross sein, aber dieser Fall ist nicht kennzeichnend.

2.2. Geometrische Darstellungen

Dieser Teil ist der Hauptteil des Komplexes. Das Ergebnis jeder berechneten Prozedur sind Punkte im Raum, die als Schnitte dreier Flächen bestimmt werden. Die produktivsten Berechnungsprozeduren sind: Kreuzung dreier Kugeloberflächen, zweier Kugeloberflächen und einer Ebene, einer Kugeloberfläche und zweier Ebenen. Die Lösung dieser Aufgaben sind Koordinaten zweier Raumpunkte. Zwischen zwei Lösungen wird eine Lösung gewählt. In vielen Fällen sind die Punkte einander nahe, und die Auswahl einer Lösung fordert eine ausführliche Analyse. Dafür eignet sich ein Dialogprogramm, wobei die Darstellung des nötigen Fragments in grossem Massstab erfolgt. Die weiteren Berechnungsprozeduren sind: Kreuzung dreier Ebenen, einer Geraden und einer Ebene, einer Geraden und einer Kugeloberfläche, einer Geraden und eines Zylinders, einer Geraden und eines Kegels usw. Die einzelnen Flächen können analytisch oder numerisch angegeben werden.

2.3. Umwandlungen

Die neuen Punkte können aus den bekannten mit Hilfe einer linearen Umwandlung des Raums bekommen werden, wie Rotation, Versetzung, Spiegelung, lineare Verformung, Verschiebung. Der allgemeine Fall einer Umwandlung ist der Übergang zu einem neuen Koordinatensystem. Alle Transformationen können sowohl mit einem einzelnen Punkt als auch mit einer Punktgruppe durchgeführt und mehrfach wiederholt werden.

2.4. Berechnungen

Die Hauptinformation über die Geometrie eines Objekts sind kartesische Koordinaten charakteristischer Punkte. Aber in vielen Fällen reicht diese Information nicht aus. Die Prozeduren des Teils "Berechnungen" erlauben Punktabstände, Winkel zwischen Geraden, Winkel zwischen Ebenen und die Ebenen dreieckiger Zellen zu bestimmen. Die Prozedurliste kann leicht um weitere Berechnungen für Schwerpunkte, axiale und zentrifugale Trägheitsmomente usw. erweitert werden.

2.5. Tabellieren

Die Operatoren dieses Teils des Programmkomplexes erlauben die Ausgabe kartesischer, zylindrischer oder sphärischer Koordinaten und anderer obgenannter geometrischer Parameter in Tabellenform auf den Displayschirm oder den Printer.

2.6. Bildung des topologischen Schemas

Die numerische Information über ein geometrisches Objekt ist notwendig, aber nicht ausreichend. In vielen Fällen wäre auch eine graphische Darstellung erwünscht. Um eine Darstellung zu bekommen, werden Punktverbindungen mit Geraden eingeführt. Man kann ein beliebiges Schema mit verschiedenen Methoden in gebrochene Linien aufteilen und als Liste der Punktnummern, welche die Knoten dieser gebrochenen Linien bezeichnen, anschreiben. Die Anfangsnummer dieser Liste bekommt ein negatives Vorzeichen.

Der Programmkomplex GERA ist hauptsächlich auf die Benutzung bei der Projektierung von Metallbaukonstruktionen ausgelegt, deshalb stellt jede Gerade in der Darstellung entweder eine Stabachse oder die Schnittgerade zweier Ebenen dar. Die Flächen im Gegensatz zu Stabelementen werden als gebrochene Linien beschrieben. Das Zusammenfallen der Nummer des Anfangs- und Endpunktes bedeutet, dass die durch die gebrochene Linie begrenzte Fläche eine undurchsichtige Platte ist.

Bei der Bildung eines topologischen Schemas regulärer Konstruktionen können verschiedenartige Wiederholungen effektiv genutzt werden. Dies erlaubt den Pultarbeitsaufwand um ein Vielfaches zu vermindern. Wie das Programmfeld C, ist auch das topologische Schema in Bezug auf Punktkoordinaten invariant. Das einmal entwickelte Schema kann mehrmals genutzt werden, um die optimale geometrische Form des projektierten Objekts zu finden.

2.7. Projizierung

Das topologische Schema und das Koordinatenfeld sind die ausreichende Information für die Bildung der zentralen Projektion eines Raumobjekts von einem beliebigen angegebenen Punkt aus. Die orthogonalen Projektionen sind ein spezieller Fall perspektiver Darstellung, für deren Bildung der Zentralpunkt nur weit vom Objekt entfernt werden muss. Die erhaltene Darstellung kann am Displayschirm ganz oder teilweise dargestellt und anschliessend auf Magnetplatte aufgezeichnet werden.

2.8. Anordnung der Darstellung, Umformung und Redigieren der Darstellung

Dieser Programmblock erlaubt die Zeichnung des gewünschten Formates aus vorgegebenen, auf der Magnetplatte gespeicherten ebenen Darstellungen. Die Darstellungen können im entsprechenden Massstab gezeichnet, gedreht und beschriftet werden.

2.9. Zeichnungsausgabe

Die mit den zwei obgenannten Programmblöcken gebildeten Darstellungen werden mit Hilfe eines Plotters oder Printers auf Papier ausgegeben.

3. ZUSAMMENFASSUNG

Mit Hilfe des Programmkomplexes GERA wurden einige geometrische Aufgaben zur Projektierung räumlicher Stahlkonstruktionen gelöst. Dabei ist es gelungen, den Freivorbau weitgespannter Kuppeldächer zu modellieren und den Einfluss der Herstellungsgenauigkeit einzelner Elemente auf die Montierbarkeit und das Abweichungsmass der Konstruktionsknoten gegenüber der projektierten Lage zu untersuchen, geometrische Kennwerte zu berechnen und perspektive Knotendarstellungen komplizierter Raumkonstruktionen zu erstellen.

Design Code for Concrete Structures as an Expert System

Règlements techniques pour les constructions en béton et systèmes experts

Technische Vorschriften für Betonkonstruktionen als Expertensystem

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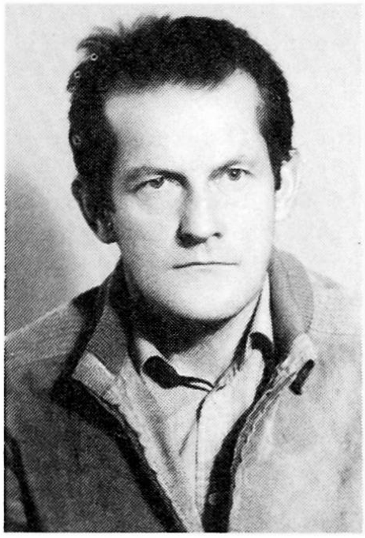

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SUMMARY
The reasons which stimulate the development of expert systems in the field of civil engineering and, particularly, in the field of technical provisions and design codes are discussed. The process of the creation of the knowledge base, using the Yugoslavian Code for Concrete Structures as a specific field of experience is described.

RÉSUMÉ
Les raisons expliquant le développement des systèmes experts dans le domaine de la construction, et particulièrement des règlements techniques, sont présentées. L'etablissement de la base des données, à l'aide des règlements techniques yugoslaves pour les constructions en béton, est mentionné à titre d'exemple.

ZUSAMMENFASSUNG
Es werden die Gründe, die die Entwicklung von Experten-Systeme in der Bautechnik und besonders im Bereich von technischen Vorschriften stimulieren, diskutiert. Der Prozess der Vorbereitung einer Datenbasis mit den jugoslawischen Vorschriften für Betonkonstruktionen als ein spezifischer Bereich von Erfahrungen ist beschrieben.

1. INTRODUCTION

As in other technical fields, expert systems are one of the possibilities for the more intensive use of the computers in the everyday work of civil engineers.

At present, the majority of the programs used in civil engineering practice are algorithmic programs, designed and applicable to "crunch" the numbers and to produce numerical and/or graphical results. The quality of the results is strongly dependent on the experience and knowledge of the user. He has to select different methods, prepare input data and last, but not least he has to review the results.

Many algorithmic programs comprise the knowledge about a defined problem. This knowledge is usually built into the particular statements of the program code and only rare people are able to change it. In contrast to these algorithmic programs, expert systems involve knowledge in a systematic and easily accessible form, called the knowledge base [1].

Regarding the fact that a greater part of the professional knowledge in civil engineering originates from experience and only a smaller part of the knowledge is of such a kind that it can be translated into different algorithms, it is possible to conclude that the use of the computers in civil engineering will be much more intensive and also more effective, if suitable expert systems are developed.

2. DESIGN CODES IN CIVIL ENGINEERING

Design codes are a very important resource and guidance in the work of civil engineers. The essential property of the design codes is that they involve a lot of knowledge, which is based on long term experiences. This knowledge is incorporated into many determinations and requirements in the codes. Rosenman and Gero [2] state that this knowledge is usually widespread and ill-structured. Consequently, finding and interpreting the necessary information is often difficult and time-consuming. This is not valid only for designers but also for other participants in the process from the idea to the construction of a building, its maintenance and demolition. It may be concluded that any systematic process should result in the reduction of errors or inconsistent decisions with resultant general benefits.

The number of codes which a civil engineer has to take into account in his work is very great. Therefore, a tool for the determination of all the relevant provisions to any given situation can solve one of the main problems facing the user. After the selection of the appropriate provisions, the civil engineer has to use them in different ways. Sometimes, he can use them directly but mostly he uses them as the data in his further work.

At present, this work is often carried out with different algorithmic programs and the problem of interfacing the codes and these programs is the second task which has to be resolved.

This article deals with the problem of the selection of those articles from the Yugoslavian Design Code for Concrete Structures, which are needed for a defined user in a given situation.

3. CHOICE OF TOOL FOR BUILDING EXPERT SYSTEM

There are two extreme possibilities for the development of an expert system. The first one is the application of an artificial intelligence language and the other is the use of an expert system shell. Although the expert systems which are developed using an artificial intelligence language are very effective, the development of such expert systems is time consumming.

This is the reason that many expert systems have been developed using the expert system shells available on the market. Particularly the expert system shells, which are installed on microcomputers, are very usable. The best property of these expert system shells is a low price, which make these shells accessible to everybody.

Because of the mentioned facts it was decided that the treated problem will be solved through the transformation of the contents of the code to the knowledge base of the expert system shell which must have the following properties:
- the knowledge is represented by the rules,
- the inference mechanism uses backward and forward chaining,
- the user interface, explanation facility, and knowledge acquisition facility are available,
- the possibility of calling other DOS programs is available,
- the use of DBASE files and worksheets is possible,
- "the chaining" of many knowledge bases is possible,
- the expert system shell runs on microcomputers (IBM PC or XT/AT compatible).

4. YUGOSLAVIAN DESIGN CODE FOR CONCRETE STRUCTURES AS THE KNOWLEDGE BASE

The Yugoslavian Design Code for Concrete Structures is based on the Model Code for Concrete Structures CEB-FIP [3]. The code comprises twelve sections. The first section involves general determinations and explanations of symbols. The second section involves the regulations on materials for concrete and the third section the regulations on steel for the reinforcement. The fourth section deals with the rudiments of the calculation of internal forces, stresses and displacements, using different methods. The fifth section involves the rules for the reinforcing. The sixth section deals with the design of the concrete elements and structures. The seventh section involves the process of constructing a concrete structure. The eight section involves the estimation of the quality of the concrete in a structure. The ninth section involves the test loading. The tenth section deals with the complementary proof of the quality of the built-in concrete. The eleventh section involves the maintenance of the buildings. The twelfth section involves final provisions.

The code is composed of 291 articles, 57 figures, and 29 tables. The code is written on 112 typed A4 pages. Up till now, the text and tables have been included in the knowledge base, however the figures are only mentioned.

The code is used by different users. The most important are: producers of concrete, producers of reinforcement, contractors, designers, and supervisors.

Some of them use only a part of the code, the others use many parts of the code. Some parts of the code are used by only one user, the others are used by many users (Fig. 1).

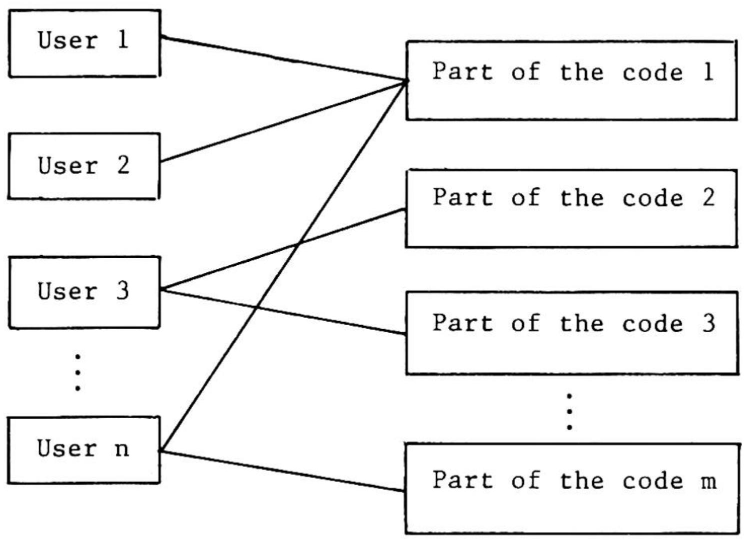

Figure 1. The interests of the users for the different parts of the code

Because of the extension of the code, many knowledge bases are used. These knowledge bases are formed accordingly to their users. As a consequence of the different interests shown in Figure 1, some parts of the code are included in many knowledge bases.

The first knowledge base (named CHAIN) involves the rules which define "the chaining" of the knowledge base used by a defined user. A part of the contents of this knowledge base, written for the expert system shell VP-Expert [4] is shown in Figure 2.

```
          .
          .
          .
          FIND way;

     RULE 1
          IF user = producer_of_concrete
          THEN CHAIN procon
               way = known;

     RULE 2
          IF user = producer_of_reinforcement
          THEN CHAIN proste
               way = known;
          .
          .
          .

     RULE 5
          IF user = designer
          THEN CHAIN design
               way = known;

   ASK user; "Who is the user of this expert system?"
   CHOICES user: producer_of_concrete, producer_of_reinforcement ...
                 designer;
```

Figure 2. The contents of the knowledge base CHAIN

The statement FIND causes forward chaining in the inference mechanism of the expert system shell, the statement ASK puts the question to the user and the statement CHOICES generates the menus, where the user can select the answer.

The contents of the knowledge base CHAIN is metaknowledge: knowledge about where it is possible to find the knowledge which is of interest for a defined user.

As mentioned before, the code is composed of many articles. The articles have different contents:

- the complete contents can be transformed into the rules,
- only a part of the contents can be transformed into rules,
- no part of the contents can be transformed into rules.

The final result of the expert system is the printout of the articles, which are needed by a user in a given situation. In the first case, the article is not printed out. In the second case, only the parts of the article, which are not able to be transformed into rules, are printed out. In the third case, the article is completely printed out.

The complete contents of the code is separated in five main knowledge bases: PROCON for the producers of concrete, PROSTE for the producers of reinforcement, CONTRA for the contractors, SUPER for supervisors and DESIGN for the designer. Some of them are composed of many sub-knowledge bases.

Typical rules in these knowledge bases are shown in Figure 3.

```
RULE 7
     IF concrete = B_II
     THEN WHILEKNOWN have
               RECEIVE art_0\art 7,have
               DISPLAY "{have}"
          END
          WHILEKNOWN have
               RECEIVE art 0\art 8,have
               DISPLAY "{have}"
          END
          WHILEKNOWN have
               RECEIVE art 0\art 10,have
               DISPLAY "{have}"
          END
     end = here;

RULE 8
     IF sections = materials AND
          material = cement AND
          cmt = have
     THEN WHILEKNOWN have
               RECEIVE art 0\art 11,have
               DISPLAY "{have}"
          END
     printout = ok;
```

Figure 3. Typical rules in knowledge base PROCON

5. CONCLUSIONS

The expert system described in this article can be used in different ways. It is possible to use it in the education process, in the practical work of inexperienced civil engineers, and for the documentation of the work of experienced users. The preparation of the knowledge base for the other national codes can be carried out in a similar way, if the structure of the codes is alike. The possibility of the processing of the figures will influenced strongly the effectiveness of the system.

If the code changes, changing the knowledge base is easy.

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Computers and Building Codes – Enemies Forever?

Informatique et codes de construction – ennemis pour toujours?

Computer und Normen – Feinde für immer?

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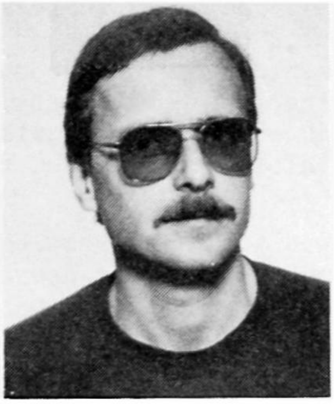

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SUMMARY
The traditional formulation and representation of codes and standards constitute serious obstacles for incorporation in a computer integrated engineering environment. New models and methods for formulation of standards has been proposed and prototyped, but practical applications are lagging far behind the needs. An intermediate approach based on a functional specification for computer implementation of an existing standard for snow loading is proposed and discussed, and some pertinent problems are illustrated. Alternative approaches for computerized representation and processing of standards are briefly discussed.

RÉSUMÉ
La formulation traditionelle des codes et des normes crée des obstacles à leur incorporation dans un environnement d'ingéniérie informatisé. De nouveaux modèles et méthodes de procédures d'homologation ont été développés mais leurs applications pratiques sont inexistantes. Une approche intermédiaire d'une formulation fonctionelle pour le développement informatisé de normes actuelles sur les charges de neige est proposée et quelques problèmes concrets sont donnés en exemple. Différentes approches pour le développement informatisé des codes sont rapidement discutées.

ZUSAMMENFASSUNG
Die traditionelle Gestaltung der Normen bildet ein ernsthaftes Hindernis bei der Berücksichtigung in computerintegrierten Ingenieursystemen. Neue Modelle und Methoden für die Normentwicklung werden vorgeschlagen und erprobt, aber die praktischen Anwendungen entsprechen noch in keiner Weise den Bedürfnissen. Eine vorläufige Formulierung, die auf einer funktionellen Formulierung für die Computerentwicklung einer bereits existierenden Norm der Schneebelastung basiert, wird vorgeschlagen und diskutiert. Einige aktuelle Problemstellungen sind als Beispiele angeführt. Alternative Verfahren für die Computerverarbeitung und die Entwicklung von Normen werden kurz diskutiert.

1. COMPUTER INTEGRATED ENGINEERING AND BUILDING CODES

We are facing a new computer revolution. In the next decade, computers "will grow more powerfull by at least an order of magnitude and become a ubiquitous intellectual utility" [1]. The introduction of the personal computer made the accessibility and convenience of computers increase even faster, and Apple's Macintosh exhibits how the computer can be designed to fit human behaviour. Adding databases, networking and communications, the technological foundation is laid for a computer integrated engineering environment, where the engineer from her workstation will have access to a variety of tools, functions and services for creation and manipulation of information related to the structural system and objects under work.

Building codes are immense repositories of knowledge and experience which ought to be incorporated in the computer-based engineering information environment. Research in the area of representation and processing of standards has been in progress for two decades [2], and general models, methods, and techniques for computerized formulation and treatment of standards have been proposed and prototyped [3,4,5]. The practical effect on the formulation of standards is unfortunately moderate; revised and even new standards are still old-fashioned, and poorly suited for use with computers. In order to keep up with the increasing demands for efficient programming of standards, an approach based on a functional specification could be feasible.

2. A PRAGMATIC APPROACH: REQUIREMENT SPECIFICATION

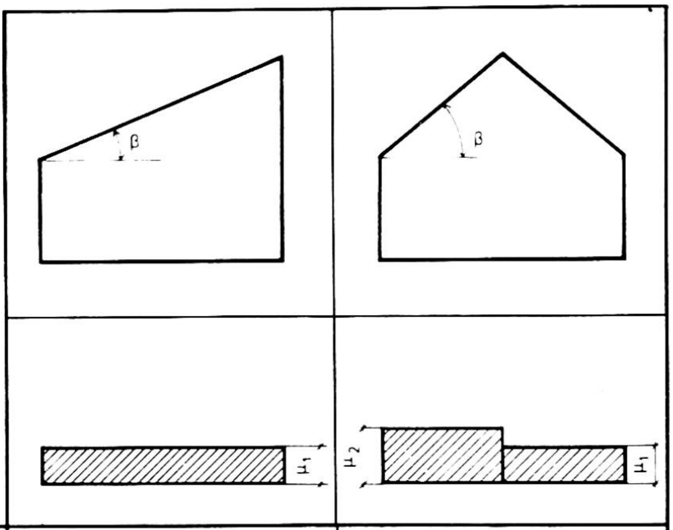
2.1 Design of Building Structures - Snow Loads

The Norwegian Standard NS 3479 "Design of Building Structures - Design Loads" [6] is well suited for manual use, but requires both engineering judgement and adjustments when applied to a particular structure, and is hence a poor candidate for automated computations. A commitee appointed by the Norwegian Council for Building Standardization (NBR) has worked out a recommendation for development of software for computation of snow loading on roofs [7]. The aim of this work has been to provide software developers with an efficient and sound basis for implementation of the requirements of the standard. The target readership of the recommendation is programmers, which differs from the users of the standard.

2.2 A general numerical formulation

NS 3479 identifies seven typical roof profiles, mono-pitch, duo-pitch, arch, and so on. For each roof profile, the form factors for snow loading are defined and referenced to the geometry of the profile, but the profile types have individual reference frames. Fig. 1 illustrates the manner of form factor definition. A computer implementation based on this definition would require entirely different data representations for each profile type, and individual or manual mechanisms for linking of snow load to the structural model. A common reference model for geometry and form factors is necessary, preferably with a rather simple link to the structural system.

The proposed, common geometric model for different roof profiles is illustrated in Fig. 2. The roof points are referenced to a global coordinate system, and the roof segments are connected to neighbouring points. The monotonically increasing numbering sequence of points and segments provides an implicit topology of the system (segment numbers are encircled in the figure). Segments may be furnished with outward ends, to model eaves (not shown on figure). Wall segments may be included, to allow the same model be used for wind loading. To each segment is attached a local coordinate system for definition of form functions. A form function is assumed to vary linearly between the form points, which are always located at the ends of a segment and optionally in between (Fig. 2).



$0° \leqslant \beta \leqslant 15°$	$\mu_1 = 0,8$	$\mu_2 = \mu_1 = 0,8$
$15° < \beta \leqslant 30°$		$\mu_2 = 0,8 + 0,4 \frac{\beta - 15}{15}$ $\mu_1 = 0,8$
$30° < \beta < 60°$	$\mu_1 = 0,8 \frac{60 - \beta}{30}$	$\mu_2 = 1,2 \frac{60 - \beta}{30}$ $\mu_1 = 0,8 \frac{60 - \beta}{30}$
$\beta \geqslant 60°$	$\mu_1 = 0$	$\mu_2 = \mu_1 = 0$

Fig. 1 Form factors (μ) for mono-pitch and duo-pitch roofs [6].

2.3 Basic load case and derived load case

A basic load case for a roof profile consists of the corresponding maximum loads for all roof segments. A particular roof profile has a prescribed number of basic load cases. The form functions for a particular roof segment is defined by the same number of form points in all the basic load cases.

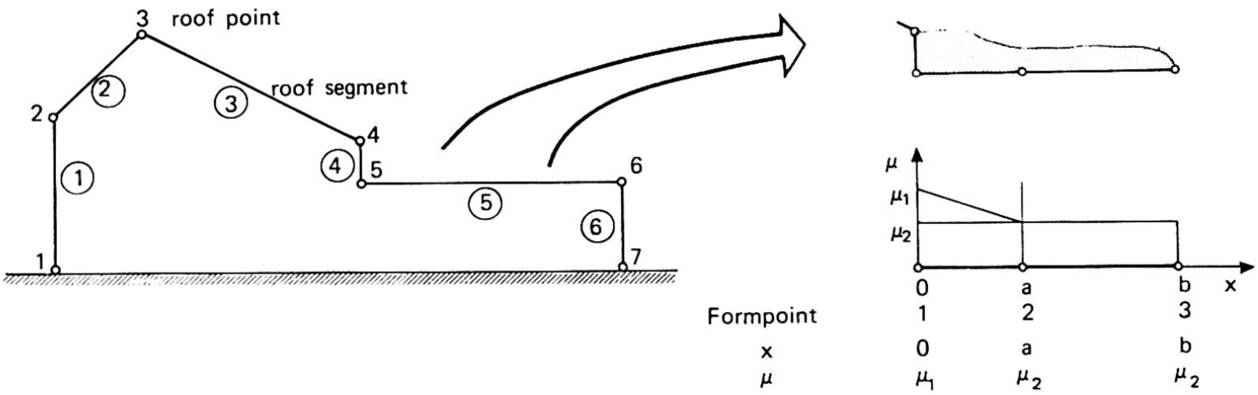
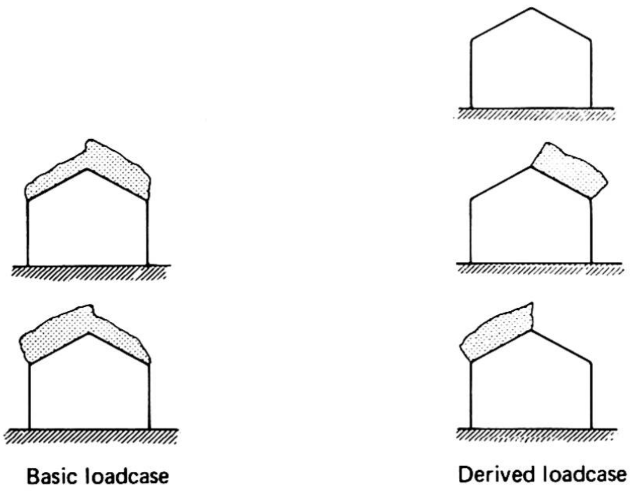


Fig. 2 Geometric model for roof profile and form function for roof segment



A derived load case represent a reduction of load on one or more segments or segment parts (Fig. 3). The concept of derived load case provides a mechanism for generating any number of load cases, as prescribed by NS 3479, cf section 3.2. This mechanism is, however, not included in the general numerical formulation.

Fig. 3 Basic and derived load cases

2.5 Functional specification

Based on the general numerical formulation for profile geometry, form factors and load cases, a software package for computation of snow loads is specified. The specification comprises a modular structure (Fig. 4), a data structure, and interfaces for the individual modules.

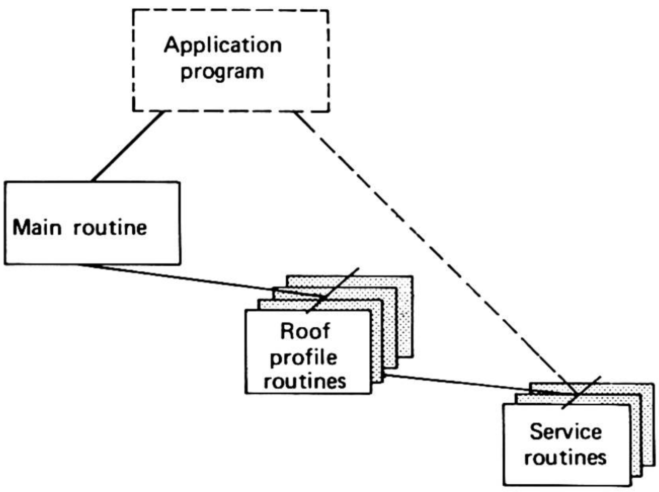


Fig. 4 Module structure for software package

The package is linked to an application program by a single, main routine which administrates the different roof profile routines. Input data to the main routine is geometric data description, profile type identifier, characteristic snow load and some control parameters. Output is form point coordinates, form factors for all for points and all basic load cases, and a status variable (error flag). The main routine is called once for each roof segment. The specification does not define how the application program provides or exploites data.

The interface specification for each module defines purpose, input data, output data and error handling. The specification is independent of programming language, and may easily be converted to e.g. Pascal or FORTRAN.

The service routines offer computation of some control variables, form function value in an arbitrary position along a roof segment, error messages, etc. These routines may optionally be invoked from the application program.

The functional specification provides a common basis for programming of the standard's provisions, and the single-routine interface will make application programs far less sensitive to changes in the standard than when "hard-coded" into the program.

2.6 Algorithmic description

The programming of a routine package according to the requirement specification implies the interpretation and translation of the verbal, formulae and graphical information of the standard (Fig. 1) into detailed instructions for the computer. This is a tedious and error-prone task, and in order to relieve the implementators of much distress and reduce the risk of misinterpretation, an algorithmic description was worked out and presented as pseudo-code based on the principles of structured programming.

3. SOME PERTINENT PROBLEMS

The draft recommendation for computer implementation of the snow load part of NS 3479 comprises some 40 pages. The provisions of NS 3479 occupies 7 pages, and the work with detailing of the contents revealed a lot of principal and practical problems related to the formulation of the standard. Some examples may illustrate the incompatibilities between traditional standards and computers.

3.1 Completeness

NS 3479 recognizes seven distinct roof profiles or types. Other types are not covered, nor are combinations of the basic profiles. The problem space of the real world is infinite and continous, while the solution space defined by the standard is finite and discrete. Hence a mapping is needed, but no mapping function or procedure is prescribed.

A basic feature of computers is the generality; a single program may be applied to any problem within its scope by defining the problem in terms of appropriate data describing the problem. With NS 3479 it is difficult to utilize this property. The problem must be manually mapped onto one of the recognized profiles, which in most cases is significantly different from the structural model used for analysis where the load is to be applied.

3.2 Uniqueness

NS 3479 prescribes that under certain circumstances, the roof shall be checked for snow load on any part whatsoever of the roof with no snow load anywhere else on the roof. In principle, this clause gives rise to an infinite number of load cases. For a particular roof, the application of this rule depends on factors as covering material, heat penetration, snow catchers, snow clearance, sub-structure, etc. The solution space prescribed by the standard is in principle infinite and continous, even if the standard's problem space is finite and discrete. Again, the mapping function is missing, and left to the user.

3.3 Correctness

It is evident that when the properties of completeness and uniqueness are missing in a standard, correctness is hard to obtain. Correctness is closely related to the meaning, the result intended by the standard writers. When this meaning is not completely and uniquely expressed, the result is hard to predict and incorrect use is probable.

When converting the provisions of a standard into computer code, another source of error is introduced, namely software errors. Quality assurance and validation of software becomes an important area, which standard writers could consider. providing not only methods and procedures, but also solutions to a standard set of problems.

4. THE CHALLENGES

The hostile relations between building codes and computers will inevitably lead to severe problems. Developers of engineering software are torn between the vast potential of information technology and the old-fashioned standards. If not bridged, this gap will undermine the authority and reliance of established codes and practises.

There are two major problem areas; first, the formal representation of standards and next, the computer implementation of a standard in a vast number of computer programs. Models of design standards exist, but are not perceived by code writers. One such model proposed by Fenves et al [3] consisting of four components (data items, decision tables, information network, organizational system) provides a framework for the representation of certain standards. Lacking expertise among code writers may be supplied by computer-based tools for analysis and synthesis of a code with regards to the formal requisites, like the support system for the Australian Model Uniform Building Code [4].

The solution to the implementation problem might be a generic standards processor [2,5], which treats the standard as data instead of coded instructions, and can be used to link a structural design program with any specific standard. This approach is well suited for expert system technology, which unfortunelately is still unmature and lacks standardisation like good, old FORTRAN!

The functional specification approach for algorithmic programming as described in this paper, is easily followed if the standard is formulated with computer implementation in mind.

Remoulding of existing standards into a fairly computer-compatible form seems to be feasible to day by employment of knowledge which is available to the engineering society. In some areas like the generic standards processing, links between knowledge-based systems and databases or algorithmic software, a lot of research is still necessary to establish models and methods which are convenient for use in standards.

The major challenge of today should be to apply what we already know. The major challenge for the future should be to upgrade the education (and reeducation) of structural engineers to also be masters of the information technology.

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Use of Computer Simulation in Structural Design Education

Enseignement de la conception des structures par simulation à l'aide de l'ordinateur

Das Lernen des Tragwerkentwurfes durch Computersimulation

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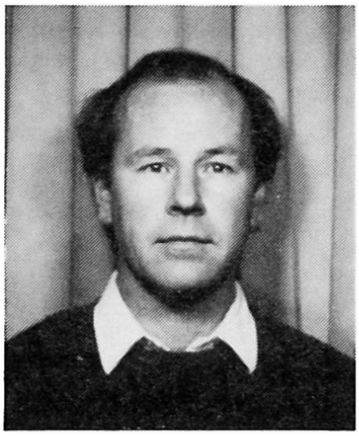

Bill Addis studied engineering and philosophy at Cambridge University. Following some years as a designer he has been researching into structural design and lecturing at Reading for 9 years.

SUMMARY
The paper proposes an alternative view of engineering design to the idea that it comprises "putting theory into practice". The notion of the design procedure is introduced and used as the basis for the simulation of the process of structural design. The author's educational use of simulation is summarized and related to the needs of professional structural designers.

RÉSUMÉ
L'exposé propose une optique différente de la conception classique des structures à "mettre la théorie en pratique". L'idée d'une méthode de projet est introduite et utilisée comme base de la simulation du processus de la conception des structures. L'utilisation pédagogique de cette simulation est résumée et mise en rapport avec les besoins des ingénieurs de la pratique.

ZUSAMMENFASSUNG
Zur Auffassung, daß der Entwurf "das Umsetzen der Theorie in die Praxis" sei, schlägt dieser Aufsatz eine alternative Ansicht vor. Der Begriff "Design Procedure" wird vorgestellt und als Basis für eine Simulation des Entwurfsprozesses angewandt. Die pädagogische Anwendung der Simulation wird zusammengefaßt und in Beziehung zur den Bedürfnissen der Fachleute in der Praxis gestellt.

1. THE NATURE OF STRUCTURAL DESIGN

1.1 Putting Theory into Practice

It is a commonly perceived notion that the art of designing structures is a matter of "putting into practice" certain bodies of knowledge known as "theory". This attitude has its roots very firmly established in our culture which has, for several centuries, categorized knowledge as either of a "theoretical" or of a "practical" nature.

In the last century or so there has also developed the notion that "theoretical" knowledge is somehow primary and an antecedent to "practical" knowledge. It has also long been perceived that there is a gap betwen these two types of knowledge.

And yet, there has been no successful intellectual bridging of the gap: there have been no successful explanations as to precisely what "putting theory into practice" actually entails.

Meanwhile, engineers continue to design structures making use of certain "theory", but not taking it as a starting point; and engineering students are taught the "theory" which, they are told, they will later be "putting into practice".

1.2 The Role of Theory

"Theory" is a term which, in recent historical times, is linked to the idea of "a theory" (or hypothesis) and hence to the activities of the natural sciences. However, the natural sciences and engineering design are distinguished sharply in having utterly different aims - the one seeking a deeper understanding of the universe; the other striving towards the manufacture or construction of an artefact. A theory occupies a central role in the pursuit of science, but is only peripheral to the process of engineering design. Engineering design can proceed without theory. Indeed, it did so for many thousands of years and it still does for many structures, such as houses. Science, on the other hand, cannot proceed without theory or hypotheses [1], [2].

The author has elsewhere proposed a resolution to the above epistemological problem in which engineering knowledge is categorized differently from scientific knowledge [3]. Rather than "theory" being of central interest, attention is focussed upon the "design procedure".

2. THE DESIGN PROCEDURE

The design procedure is a statement, or often, since designers seldom write such things down, a potential statement, of how a designer could proceed to arrive at a design for a proposed structure.

A design procedure is not an attempt to indicate how to design creatively and with originality; nor is it a set of rules to be followed blindly. As such, a design procedure has something in common with certain Codes of Practice which guide the designers of, for example, steel structures [4]. A design procedure is, however, conceived at a more general and philosophical level than a particular Code of Practice.

A design procedure has an input and an output, and its function is modulated or regulated by a number of influencing factors (Fig 1). The output is the specification and the justification of the design of a proposed structure. The specification comprises sufficient details of the design to meet the needs of the client, architect or builder, as appropriate. The justification consists in the argument that is, or could be, used to defend the adequacy or suitability of the proposed design to whoever may require it.

INPUT	PROCESS	OUTPUT
Engineering and other knowledge	Design Procedure	Specification Justification

REGULATION	client, finance, time, construction method etc.

Figure 1. The Design Procedure

The input to a design procedure is, potentially, the whole of engineering and other relevant knowledge - not just engineering "theory" but also empirical data, well-established empirical rules (rules-of-thumb) and also certain intuitive knowledge about the behaviour of structures which is often difficult to express or communicate.

Finally, a design procedure is regulated by a variety of influences such as the constraints of construction method, time, finance, availability of materials and components, Codes of Practice, building regulations, fashion, current safety standards and so on - what Pugsley has succinctly called the "engineering climatology" [5].

Thus, a design procedure will vary almost infinitely, according to the precise circumstances of a particular design goal. In general terms, it can be seen as a summary of the knowledge which must be taken into account, and what to do with that knowledge, in order to design a structure; and as such, it is an expression of the skill and know-how which a designer of structures possesses over and above a bare knowledge of facts and "theory".

3. STRUCTURAL DESIGN AS A PRACTICAL SKILL

3.1 Learning the Skill of Structural Design

To approach the task of structural design in the above manner is to recognize that it is a practical skill, much in the way that the ability to fly an aeroplane or to manage construction project can be seen as practical skills. This view has important consequences for the manner in which the skill of structural design might be learnt and taught - if it is a skill, then it can only be learnt by doing.

Several writers have conluded that design both can and should be taught to structural engineering sudents [6], [7]. However the comparison of the complex skill of structural design with the skills of flying and managing suggests that similar learning techniques might also be appropriate - particularly the use of techniques analagous to the flight simulator and the management game. Simulation gaming of the role playing variety has already met with some success within the context of a civil engineering department [8].

It is a familiar criticism of young or student structural engineers that, while they might be familiar with many modern techniques of structural analysis and even with the Codes of Practice, they do not have a real feel for the process of designing a structure - indeed the ultimate goal can become lost amid a forest of equations and computer programs. Even more seriously, a young designer can come to believe the results of mathematical equations and computer programs with scant regard to their real significance. Many engineers can relate stories of young designers finding, to their surprise, and yet believing, that the sum of the vertical foundation reactions could exceed the total weight of the building; or that, in certain circumstances, a particular high-rise building could lean into the wind.

3.2 The Teaching of Structural Design

3.2.1 Manual Simulation

At the University of Reading the author has implemented the above ideas in the teaching of structural design to students destined to work in the construction industry, but not as structural designers. So far the design of two types of structure have been selected - a typical steel or concrete framed commercial building, and the load bearing falsework for a reinforced concrete bridge.

Initially students undertook the structural design "manually" using an outline design procedure at a level appropriate to their technical and mathematical knowledge. For a desired building plan and elevation different groups of students investigated different designs for the structural frame in steel or concrete using one of several different types of floor structure - composite (Holorib), precast concrete slabs, flat slab, one-way slab, ribbed slab, waffle slab and so on. They were able to do some of this using genuine structural calculations and the rest using the simple rules often used by professionals, such as deriving the slab thickness as a fraction of the span.

The above approach has had greater success than previous approaches based only upon the conventional teaching of the theory of structures and the relevant Codes of Practice. The students were able to complete more of the total design, albeit approximately. They ended up with a deeper understanding of the whole process of structural design and were also able to see the context into which more advanced techniques of structural analysis and design would fit.

3.2.2 Computer Simulation

Following these successes, a computer program has been written to avoid the need to do some of the tedious mathematics and hence to speed up the process. The program allows someone effectively to "experience" the process of structural design by means of a simulation of the real process. By "experience" is meant the production of a specification and a justification of a proposed design, making use of certain bodies of engineering knowledge under the influence of a particular "engineering climatology", and being faced with real choices as to how to proceed and what knowledge to use. These are similar to the choices which face a "real" structural designers designing a ral building. In the educational environment the whole process is, of course, much simplified compared to the real world; but the differences are of degree of complexity and sophistication, not of type.

4. CONCLUSIONS

4.1 Progress in Structural Engineering Design

In order to detect and to evaluate progress in any field, it is essential to identify suitable criteria by which change can be assessed [3]. By focussing upon the central activity of engineering design, the design procedure can help to identify such criteria.

While some major developments in structural design do indeed result from new theories of engineering science and new data, other developments come about through making new use of old knowledge and theories. These latter developments are not recorded in new methods of modelling the behaviour of structures and thus progress is not necessarily perceived.

The design procedure can be viewed rather as a sort of model of the behaviour of structural designers. This can enable developments in design method to be perceived both in their very first use by students learning their art through simulation, and by professionals who come to perceive their activity in terms of the design procedure.

4.2 Comparison with Other Uses of Computing in Structural Design.

Current developments in the use of computing in structural design are along five main paths:

- techniques of structural analysis and modelling structural behaviour;
- computer aided drafting;
- detail design and specification of structural members;
- computerizing the Codes of Practice;
- expert systems.

The work described in the present parper is believed to be different from all of these. It seeks directly to reflect the needs of structural designers, be they students of professionals; it takes direct account of how designers design - identifying problems, proposing solutions and evaluating the consequences of these proposed solutions. It aims to help them to do this more effectively while not seeking to replace the skills of the designer, as complex structural analysis programs and expert systems often seek to do [9].

4.3 Future Developments

The result of the above work is believed to have great potential. In the educational context, the program is being further developed to suit different types of student with different aims and levels of technical mathematical and structural design skills. And in the professional environment, the program is already helping designers in their early-stage investigations of different proposed designs for a building.

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Informatics in Civil Engineering Education

Informatique dans l'enseignement du génie civil

Informatik in der Ausbildung von Bauingenieuren

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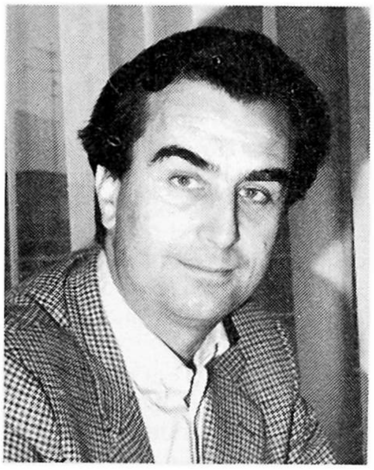

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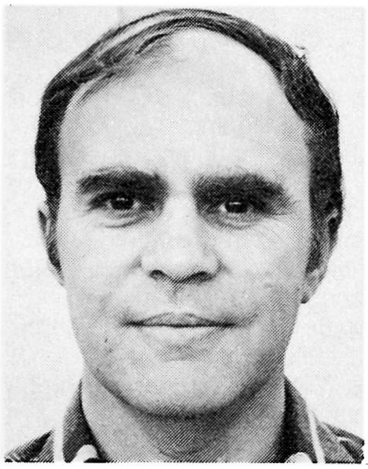

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SUMMARY
The authors trace briefly the developments in informatics at the Federal Institute of Technology, Zurich, over the past 30 years. In particular, the aims, necessity and contents of introductory courses in informatics for civil engineering students are discussed, together with the rôle of computer programs and CAD in teaching structural analysis.

RÉSUMÉ
L'article résume les principaux développements de l'informatique à l'Ecole Polytechnique Fédérale de Zurich au cours des 30 dernières années. Il discute ensuite les problèmes concernant l'enseignement de l'informatique aux étudiants du génie civil soit au niveau de base, soit en relation avec la statique des constructions.

ZUSAMMENFASSUNG
Die Autoren zeigen kurz die Entwicklung der Informatik während der letzten 30 Jahre an der Eidgenössischen Technischen Hochschule, Zürich. Insbesondere werden die Ziele, die Notwendigkeit und der Inhalt eines Einführungskurses in der Informatik für Studenten der Bauingenieurabteilung, sowie der Stellenwert von Computer- bzw. CAD-Programmen in der Baustatiklehre diskutiert.

1. INTRODUCTION

There is little doubt today that the developments in computer hardware and software over the last 30 years have given birth to a new epoch in the history of our civilisation. With a computer anyone can "build his own machine" [1]. In fact, simply by writing a program, which is essentially a text, one is able to transform a general-purpose computer into a special-purpose machine capable of solving a specific problem. All that is needed is logical thinking and a knowledge of an easy-to-learn formal programming language. The computer itself takes care of the rest. This new way of building machines has proved to be extremely well suited to man's basic natural abilities and, in many fields, much more flexible and efficient than any other problem solving procedures previously devised. As we all know, this basic capability has led to the spectacular development of countless computer applications which directly influence many aspects of our professional and private life.

It is obvious that technical education at the university level must take into account these developments. The point to be stressed, however, is that because of the fundamental significance of informatics - whose historical importance one dares to compare with that of the differential and integral calculus developed in the 17th and 18th centuries - students at university level must understand not only *what* a computer can do, but also *why* it can do it. This is certainly also true in civil engineering: it is not enough to demonstrate all the new possibilities offered by today's computers and assess their impact on the way specific civil engineering problems are solved. Because of the broader scope of higher education, civil engineering students must understand at least the most fundamental aspect of informatics, namely that computers are programmable. Therefore, although students are not intended to work as professional programmers, they must understand what programming involves independent of any practical application.

With these general thoughts in mind a "case study" is discussed in the present paper. It concerns the development of informatics at the Swiss Federal Institute of Technology (ETH) in Zurich and the way informatics is taught in the department of civil engineering. Some questions concerning the teaching of computer-based methods in structural engineering will also be discussed.

2. INFORMATICS AT THE SWISS FEDERAL INSTITUTE OF TECHNOLOGY, ZURICH

In the field of informatics our university can look back on a rather illustrious past. Without going into detail some historical highlights might be worth mentioning:

- already in 1953 an electrical relais computer manufactured during the war by the German civil engineer K. Zuse was installed at the ETH.
- the ERMETH computer (with vacuum tube hardware, drum-storage, no operating system or compilers, etc.) was built at our university and operated from 1955 to 1964
- the professors of applied mathematics E. Stiefel and H. Rütishauser greatly contributed to the development of the programmimg language ALGOL60
- in 1971 a large computing centre with hardware costing some 30 Mio. Swiss Francs (in 1971) was installed in a new, specially designed building.
- in the years 1970-73 Professor N. Wirth developed the highly successful programming language PASCAL, to be followed more recently by MODULA-2.
- in the early seventies introductory courses on computer applications and programming were introduced in most engineering departments, including civil engineering.
- in autumn 1981 a separate department of informatics was established. After four and half years of study the first students of our university graduated in informatics in early 1986 (i.e. some 10 years later than in many other European and American universities)
- in spring 1984 the Swiss parliament approved a special funding for providing the Federal Institutes of Technology in Zurich and Lausanne with some 3000 personal computers for students (approximately 1 personal computer for 5 students in all disciplines) in the next 5 years. Today approximately 450 personal computers for students (or about 1/4 of the planned number) have already been installed at the ETH in Zurich.
- of course, many more large and small computers are installed in the institutes where they are used for research purposes.

These few remarks show that a great interest in computers and informatics has always existed both within our university and outside of it. However, the establishment of a new department of informatics still met with opposition and was long delayed. This was due not only to bureaucratic reasons or to the fact that a new department obviously meant cutbacks in other departments. But even as recent as 5 or 6 years ago, a considerable number of people could not understand why a nation like Switzerland with no computer industry of its own needed a new breed of specially educated professional computer experts. It was argued that civil or mechanical engineers, who are the only ones who know how to build structures or machines, should also be the ones to write the programs needed in their professions. There was little appreciation of the fact that the skills required for devising computer based solutions are not only quite difficult to acquire but also very different from the skills required of a civil or mechanical engineer. The differences between operating software and application software were not always clear to everyone. There was even some confusion between numerical mathematics and informatics. Six years after the very successful establishment of the new department of informatics (which today has twice as many students as civil engineering) this kind of discussion is no longer encountered. Informatics is now well established as an independent field of applied science and the general appreciation of some of the problems mentioned above has certainly improved. There is also a broad consensus of opinion that students in all fields of engineering should take some introductory courses in informatics. However, there is still room for improvement in the syllabus of these courses for engineers, including the civil engineering department, in which the authors have direct involvement.

3. BASIC EDUCATION IN INFORMATICS FOR CIVIL ENGINEERING STUDENTS

At the ETH in Zurich today's first semester civil engineering students are given an introductory course in informatics comprising 2 hours of lectures and 2 hours of exercises each week over a period of 16 weeks. For these exercises (and also for word processing and other applications, including playing games) the students have free access to a number of Apple Macintosh personal computers (about 1 PC to 5 students). The exercises consist of small Pascal programs or parts of programs to be written and tested by the students using the MacPascal interpreter.

The fundamental concepts of the programming language Pascal are discussed in the lecture and a number of typical algorithms and data structures are explained and demonstrated. Some additional topics concerning hardware, operating systems, different programming languages, networks, etc. are also briefly discussed. It should be stressed, however, that the aim of this lecture is not really to teach programming. In fact, it is realised that the great majority of civil engineers do not need to know how to program. The basic aim of this lecture was explained above: like mathematics or physics, informatics is a fundamental science, which has to be taught to all students of all technical disciplines at a preparatory level and independent of specific applications. Because programming is certainly the most important aspect of informatics, students must understand what it really involves. Later, in professional life, this basic knowledge will be essential for assessing the feasibility of computer based procedures, which in civil engineering, like in most technical disciplines, are bound to have a profound impact on our day-to-day professional work.

This also explains why the programming language Pascal was chosen for this course: because we do not want to teach programming at a professional level, it does not matter if the language students learn is not the language they are most likely to encounter in practice. What really matters is that they learn the basic concepts of programming and Pascal is certainly ideally suited for this purpose. In some other departments of the ETH and also at the University of Zurich the programming language Modula-2 has been used in similar lectures instead of Pascal over the past 2 years. The reason for this is that, although Modula-2 is little used in practice, it represents a natural evolution of Pascal and is considered to be better for understanding modular programming techniques and state-of-the-art software engineering procedures. Again what matters are the fundamentals of informatics and not the practical ability to write professional programs. Other popular programming languages are considered to be inadequate for this purpose: Basic is too simplistic; Fortran, which suffers from an uncoordinated development over a 30 year period, has too many artificial conventions and insufficient built-in checks; the Unix language C is too cryptic for non-professional programmers, etc.

In many fields of civil engineering computers may be regarded as basic professional tools. Therefore, the question arises whether, in addition to the more fundamental aspects of informatics mentioned above, a general introduction to the practical use of computers should also be offered to our students in their first year of study. The answer to this question is not so obvious because such an introduction would have to be, to a large extent, application independent. Furthermore, computers are certainly difficult to program in a proper way, but very easy to use as soon as one understands the problem to be solved and a well-written application program is available. Of course, understanding the specific civil engineering problems to be solved by computer-based methods as well as the choice of the corresponding software cannot be part of an introductory course. Nevertheless, there are a number of important applications which are not specific to any of the classical civil engineering disciplines, but should at least be briefly explained and demonstrated to our students. These include word and document processing, use of spreadsheets, computer-aided drawing, setup and use of databases, mail and data transmission via local and wide area networks, etc. In fact, all these applications may actually turn out to be important working tools and also serve as an excellent introduction to more specific computer applications encountered in later years of study.

Our civil engineering students have to take the mandatory course mentioned above and solve the corresponding exercises. However, they do not have to pass a corresponding examination. We consider this to be a serious deficiency of our curriculum. Like mathematics or physics, informatics is a fundamental discipline made up of a number of relatively difficult concepts, which can only be understood and assimilated by hard work on the part of the individual. Experience shows (and common sense tells) that students will not be willing to invest the necessary effort in a field which, though it looks interesting and is certainly recognised as important, yet is not treated as such within the curriculum leading to their diploma.

4. COMPUTERS IN STRUCTURAL ENGINEERING EDUCATION

After the introductory courses in the early stage of their studies students have to learn the specifics of their future profession. It would be far beyond the scope of this paper to list and comment on all computer applications in civil engineering. Therefore, as an example, only some thoughts concerning structural engineering will be briefly discussed.

Structural analysis is the field of civil engineering in which computer based methods (above all the finite element method) had the earliest and probably greatest impact. The way displacements, forces, moments and stresses are computed today bears, in most circumstances, no resemblance to the procedures used 20 or 30 years ago. Of course, these developments, and above all the finite element method, should be taken into due account when teaching structural analysis. Old fashioned hand methods such as the Hardy-Cross method or the use of Fourier series for plate bending analysis definitely no longer belong in the structural engineering syllabus. There is, however, a more important point to be made.

The spectacular advances we have witnessed in structural analysis also have some important drawbacks. In the (good) old days the engineer who had the responsibility of designing a structure generally also defined the mathematical model needed for the analysis and did the corresponding numerical calculations himself (or at least he always knew exactly how to do them). Today structural analysis is often done by "black-box" programs whose internal workings and the sophisticated mathematical models used for simulating reality are not always completely understood by their users. In fact, due to the sophistication of today's structural analysis programs, it has become quite difficult to be at the same time a good designer and a good numerical analyst. This, of course, leads to problems. In some cases designers lose all confidence in the programs they use, and sometimes they even go back to hand calculations. Therefore, when teaching structural engineering the problem of combining modern analysis methods with sound design concepts deserves (at least at undergraduate level) much attention. It is certainly necessary that students gain direct experience in the use of analysis programs when solving practical design problems. These programs should preferably run on user-friendly personal computers and be as simple as possible (i.e. as less general as possible) in order to demonstrate the essentials of the algorithms they use with a minimun of unnecessary overheads. Programs specially written for teaching purposes, although they might not be those one would use in practice, can certainly be very useful.

With this goal in mind a number of programs have been written either strictly for teaching purposes or expressly so as to optimise the understanding of their internal workings (which is also a very welcome feature among practicing engineers). The following programs are used today at the ETH for teaching structural analysis:

SMIS : an iteractive MS-DOS Pascal program for simple matrix manipulations, based an old batch program developed at the University of California, Berkeley. This program is used for teaching the fundamentals of static, dynamic and stability analysis by the finite element method.

MacBeams : A highly interactive Modula-2 program for the MacIntosh with mouse input and graphic output illustrating displacement and moment distribution of plane frame structures (see Fig. 1)

STATIK: a simple yet very general linear frame analysis program including calculation of cross-sectional properties and prestressing. This program is now widely used both in practice and at our university for solving relatively simple day-to-day design problems.

FLOWERS : a large, very general finite element program for static and dynamic, linear and nonlinear analysis of many kinds of structures. This program was also written with teaching in mind (see [2]) and is regularly used for teaching purposes.

Finally, it must be clearly stated that computers have certainly had a great impact on analysis but, so far, very little on conceptional design, which, of course, is what structural engineering students are really supposed to learn. CAD-systems (where "CAD" in most cases stands for "Computer Aided Drawing" possibly with automatic storage and retrievial of graphical and other design data) just like other procedures known under the label of "office automation" will no doubt improve the working efficiency of structural engineering offices considerably. Few people believe, however, that CAD-systems lead or will lead in the near future to conceptually better structures. Therefore, the question of how (or if) to teach CAD as an additionai subject (i.e. in addition to computer-oriented analysis and conceptual design) is still debatable. Probably, as suggested above, it might make sense to explain and demonstrate some well established, simple CAD procedures as a typical example of computer applications in a general, application-oriented basic informatics course in the first year of study.

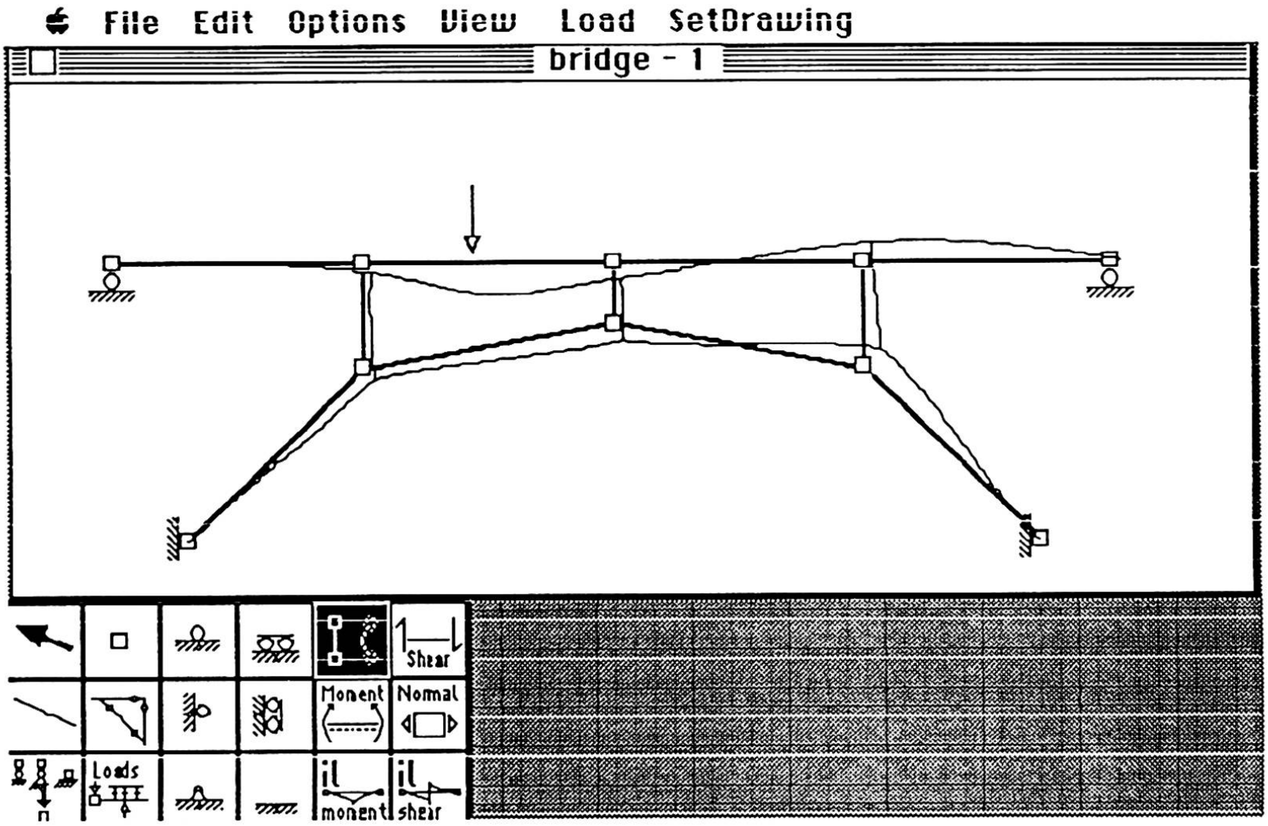

Fig.1 Screen dump of MacBeams Program showing menus, structure and deformed shape

5. CONCLUSIONS

This paper outlines some thoughts concerning the teaching of informatics-oriented subjects in our civil engineering department, firstly at preparatory level and then in the field of structural engineering. Obviously, the ideas presented reflect both personal experiences and the special situation of our university. Nevertheless, while computers are rapidly changing our lifes, universities have to be somewhat conservative in order to provide their students first and foremost with the well-established fundamentals of their chosen profession. Because of these conflicting aims it is felt that some of the problems discussed above must also arise, in similar forms, in other universities. It is the scope of the paper to provide a contribution to the discussion of education related problems, which certainly also ought to be of concern to practicing civil engineers.

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Electronic Spreadsheets in Concrete Design

Calcul électronique en tableaux pour le béton armé et précontraint

Elektronische Tabellenkalkulation im Stahl- und Spannbetonbau

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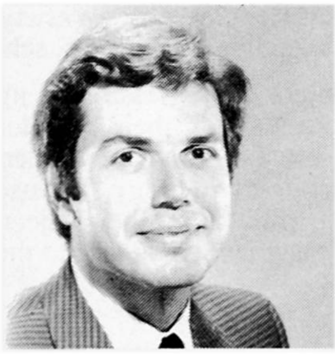

Filip C. Filippou, born in 1955, received a Dipl. Ing. degree from the Technical University of Munich in 1978 and a Ph.D. degree from the University of California at Berkeley in 1983. His research interests lie in the areas of reinforced and prestressed concrete and computer-aided design.

SUMMARY
This paper shows the tremendous potential of electronic spreadsheets as a teaching tool in graduate and undergraduate courses of structural design. To demonstrate the possibilities of this tool a few advanced applications encountered in graduate level courses on behavior and design of structural elements are presented.

RÉSUMÉ
La contribution montre le grand potentiel du calcul électronique en tableaux dans les cours de projet et de dimensionnement des constructions. Les possibilités de cet outil sont présentées à l'aide de quelques exemples, présentés dans les cours avancés sur le comportement et le projet des éléments de structure.

ZUSAMMENFASSUNG
Diese Arbeit zeigt wie leistungsfähig die elektronische Tabellenkalkulation als Lehrwerkzeug sein kann. Die Möglichkeiten dieses Hilfsmittels werden anhand von einigen Beispielen vorgestellt, die in Vertiefungskursen über das Last-Verformungs-Verhalten von Bauteilen behandelt werden.

1. INTRODUCTION

The last ten years have seen a dramatic change in the way engineers perform their work. The most important factor contributing to this change was the introduction of microcomputers into the market in the late 70's. A number of related factors led to the rapid spread of microcomputers in engineering offices of any size:

- the low cost of microcomputers afforded small engineering offices access to the new technology;
- the development of powerful software packages which are easy to learn encouraged non-specialists to use the new technology;
- microcomputers help the average engineer in a variety of tasks; these include proposal and report preparation, calculations, budget preparation, scheduling, drafting, presentation etc.

The widespread use of microcomputers by professional engineers and their appearance in large numbers on university campuses necessitates their introduction in graduate and undergraduate courses. This fact presents the instructor with the challenge of adjusting course content and presentation to take advantage of the new technology. The use of microcomputers as a learning tool is, however, not an easy task. The pitfalls of the project have led many educators to reject microcomputers as a learning tool altogether and adhere to the old and established ways of teaching engineering principles.

2. ADVANTAGES OF ELECTRONIC SPREADSHEETS

Electronic spreadsheets can find many applications in the area of structural engineering [6]. The integration of a very powerful electronic calculator with database functions and easy-to-use graphics appears to be especially appealing in structural design. Engineering calculations are often organized in tabular fashion which is precisely the structure that lies at the heart of electronic spreadsheets. The power of these software packages is combined with great flexibility of use allowing the designer to readily develop procedures to fit his special needs. Modification of existing spreadsheets is extremely easy, since the spreadsheet structure is transparent to the user.

These characteristics make electronic spreadsheets an ideal tool in the instruction of structural design. While teaching tools are available in structural analysis [1], no such tools have been developed to date for structural design.

To be successful as a teaching tool a program should satisfy the following requirements:

- the amount of time the student spends learning the details of the program should be kept to a minimum; this amount of time should enable the student to actively interact with the program by modifying portions of it or developing new features and solution schemes;
- the program should be based on a language that is easy to learn and use; most engineering tasks are based on simple functions and solution schemes;
- the program organization should resemble that of the engineering notepad; this facilitates going back and forth between hand and computer calculations

Electronic spreadsheets satisfy all these requirements. Some of the most striking features are:

- ease of programming of complex formulas which include scientific functions and logical operators
- integration of calculation of complex formulas with easy-to-use graphics and basic database concepts; this corresponds to the manual "calculate and look-up" activity of design engineers; the integration of graphics into the spreadsheet allows the student to quickly check his calculations and at the same time enhances his understanding of the interrelationship between key variables of the particular design problem
- the spreadsheet is transparent to the user and can be modified with great ease; this satisfies the need for flexibility in the solution of design problems; at the same time it allows the student to follow the logical flow of the solution process in a spreadsheet that he did not develop himself

- the program does not have to be compiled and linked before it can be executed; execution rather takes place immediately; any syntax errors are flagged as they occur reducing the frustrations associated with debugging the program
- electronic spreadsheets are geared towards resources that all engineers will possess in the very near future; this fact makes their impact immediate; they illustrate to students the power of computers in a very direct way, since the organization and internal structure of electronic spreadsheets very closely resembles that of manual calculations
- electronic spreadsheets allow the user to investigate the effect of variation of key parameters on the solution of the problem under study; this can be done with a few keystrokes; this should be an important ingredient of instruction tools for structural design
- most electronic spreadsheets are very user-friendly with extensive on-line help facilities; this helps allay the fear of inexperienced users towards microcomputers.

3. APPLICATIONS IN REINFORCED CONCRETE DESIGN

3.1 Moment-curvature of rectangular sections

3.1.1 Problem statement

An understanding of the nonlinear behavior of reinforced concrete (RC) sections loaded to failure under a combination of bending moment and axial load forms an important part of a course on advanced reinforced concrete design.

The formulation of the problem is relatively straighforward: given is a rectangular concrete section reinforced with longitudinal and transverse steel. The section is subjected to a constant axial load *P* and a moment *M* which is increased until failure occurs (Fig. 1). The student is asked to develop a procedure for determining the moment-curvature relation of the section up to failure. This procedure should take into account the nonlinear behavior of the materials, the effect of confinement provided by the transverse steel and the possibility of buckling of the compression steel. It is based on the well known assumptions of the simple bending theory of RC sections [2].

Electronic spreadsheets offer an excellent set of tools for developing the procedure described above. The nonlinear material models can be described by a sequence of nested IF statements. The integration of concrete stresses is accomplished by subviding the compression zone into a number of layers (Fig. 2). Each layer corresponds to a different row in the spreadsheet with different columns displaying information on the location, the stress, the axial force and bending moment contribution of each concrete layer.

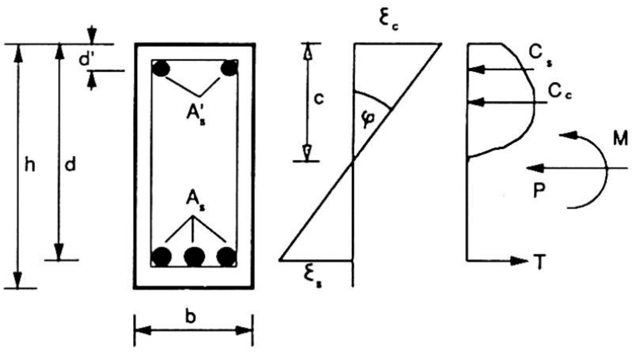

Fig. 1 Distribution of stresses and strains in a rectangular R/C section subjected to bending moment *M* and axial load *P*

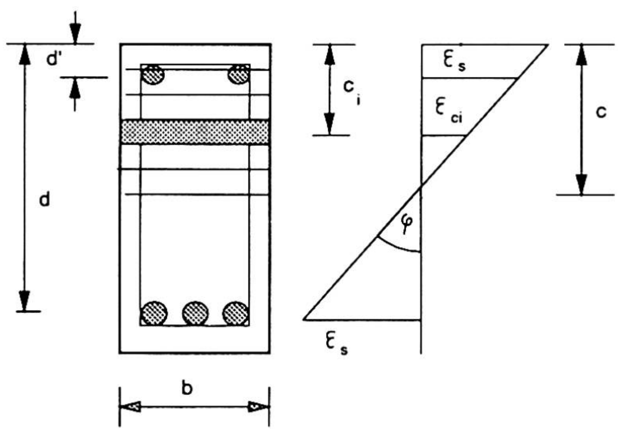

Fig. 2 Subdivision of compression zone in concrete layers

At each moment increment the location of the neutral axis needs to be established by trial and error. It is instructive to ask the students to adopt this approach for a few steps of the moment-curvature relation in order to gain a better understanding of the behavior of the section. The iterative process can, however, be automated rather easily using the macro command language that many spreadsheets support. The possibility of using the same spreadsheet in a trial and error mode and an automatic mode is an important aspect of the use of this tool in the classroom.

3.1.2 Examples

Parametric studies of the effect of various parameters on the monotonic moment-curvature relation of reinforced concrete sections can be conducted using the spreadsheet program described in the previous paragraph. A small sample of such studies are presented in Figs. 3-5.

A rectangular reinforced concrete section with top and bottom reinforcement, an effective depth of 25" and a width of 15" is used in these examples. Longitudinal and transverse reinforcement consists of Grade 60 steel. Fig. 3 shows the effect of tensile reinforcement ratio ρ on strength and curvature ductility of the section. Fig. 4 shows the effect of concrete compressive strength on strength and curvature ductility. In both cases transverse reinforcement consists of #3 bars spaced at 4" o.c. and no compression reinforcement is used.

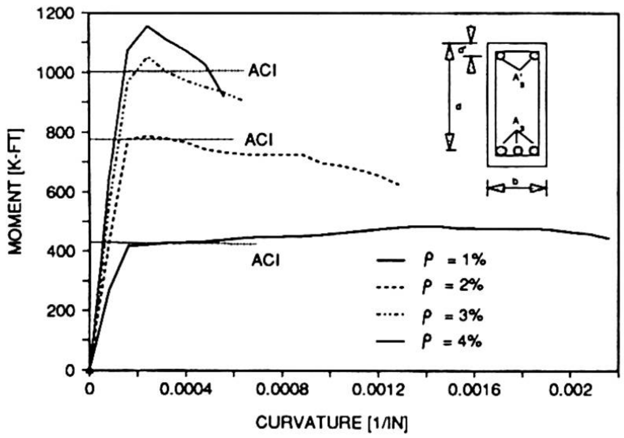

Fig. 3 **Effect of tensile reinforcement ratio ρ on moment-curvature relation. ρ'=0, f'_c = 4 ksi**

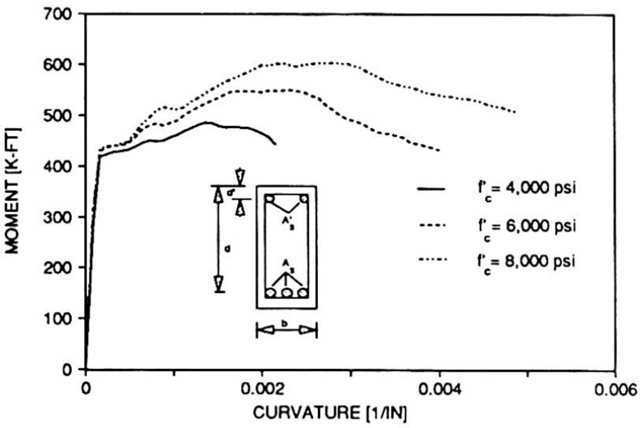

Fig. 4 **Effect of concrete compressive strength f'_c on moment-curvature relation.**
ρ = 1%, ρ'=0

Fig. 5 shows the effect of axial load on the moment-curvature relation of the section. Fig. 5 can be used as a starting point when studying the buckling behavior of reinforced concrete columns.

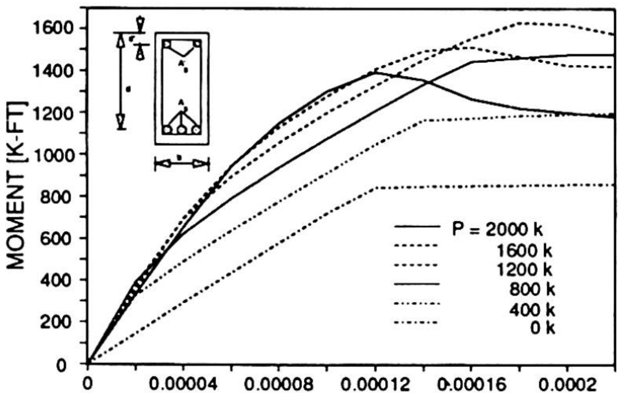

Fig. 5 **Effect of axial load *P* on moment-curvature relation. ρ = 2%, ρ'=2%, f'_c = 4 ksi**

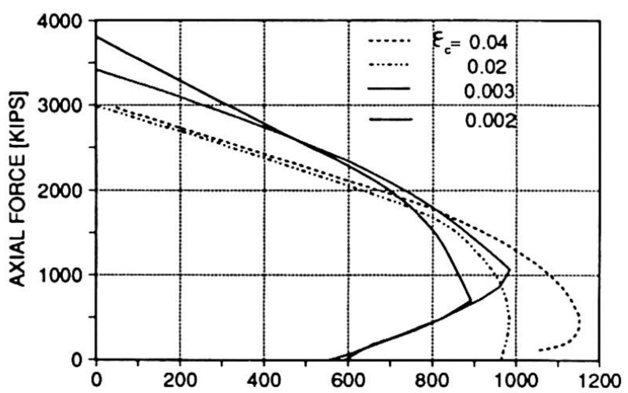

Fig. 6 **Axial load-bending moment interaction diagram for a 20" square R/C column with ρ = ρ' = 2% and transverse reinforcement of #4 bars at 2" o.c., f'_c = 8 ksi**

3.2 Interaction diagram for axial load and uniaxial bending

A slight modification of the **MOMCURV** spreadsheet can be used to derive the axial load-bending moment interaction diagrams for rectangular reinforced concrete section. An example of such an investigation is shown in Fig. 6. In this case the strain at the outermost compression fiber is kept constant and the program calculates the axial load and the bending moment of the section for a range of strains in the tensile reinforcement layer. It is interesting to note the effect of the maximum concrete strain on the shape of the interaction diagram. The actual interaction diagram is the envelope of the curves in Fig. 6.

3.3 Interaction diagram for axial load and biaxial bending

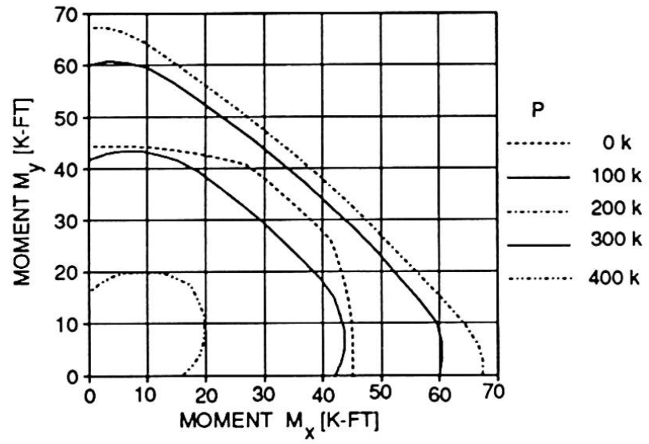

Fig. 7 **Axial load-Biaxial bending moment interaction diagram for a 10" square R/C column reinforced with 4 #9 bars, f'_c = 4 ksi**

Finally, it is possible to let the neutral axis of the section rotate with respect to a fixed coordinate system which is parallel to the edges of the rectangular section. In this case one can obtain the interaction diagram for biaxial bending and axial load. Such a diagram is shown in Fig. 7. Each curve represents the ultimate strength of the section for combinations of bending moments M_x and M_y and a constant value of axial load P.

4. APPLICATIONS IN PRESTRESSED CONCRETE DESIGN

4.1 Moment-curvature of rectangular sections

4.2 Design and tendon layout of simply supported beams

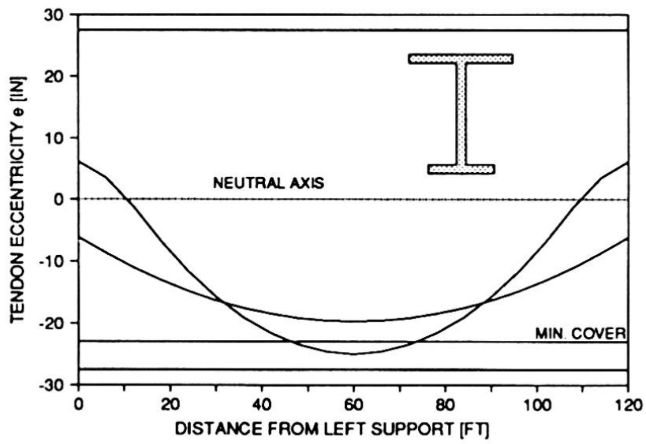

Fig. 8 **Tendon limit zone for an unsuccessful trial section**

Figs. 8-10 show a typical application from prestressed concrete design. The students are asked to develop a spreadsheet which will help establish the tendon layout for a simply supported beam subjected to uniform loads and prestressed with straight or draped tendons. The only given information is the type of materials used, the span of the beam and the magnitude of the superimposed dead and live loads that the beam carries.

The student can go through a trial and error procedure to determine the cross section dimensions. After he has selected a trial section he can ask for a graphic representation of the tendon limit zone. An unsuccessful trial is shown in Fig. 8 and the final section selection is shown in Fig. 9. It takes about two to three minutes to find an optimum cross section characterized by a limit zone which has shrunk to a minimum. Upon selection of the section dimensions the student can plot the Magnel diagram of the section shown in Fig. 10 which enables him to select the minimum prestressing force and the corresponding eccentricity at the critical section of the girder.

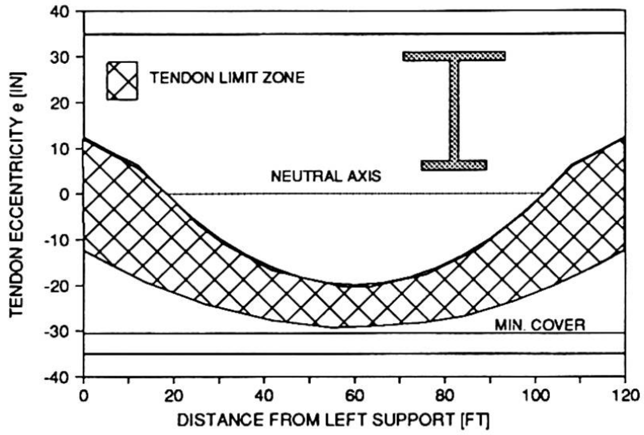

Fig. 9 **Tendon limit zone for a successful trial section**

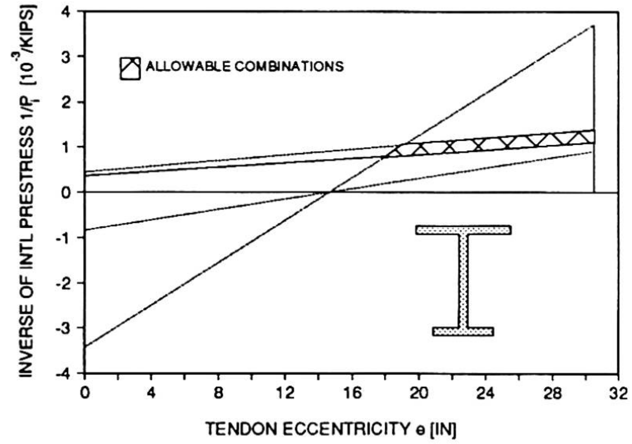

Fig. 10 **Magnel diagram of the inverse of the prestressing force vs. the tendon eccentricity at the critical section of the girder of Fig. 9**

5. CONCLUSIONS

This paper demonstrates the possibility of innovative use of electronic spreadsheets in advanced graduate courses on reinforced and prestressed concrete design. In addition, it hopes to advocate the exposure of undergraduate and graduate students to the power offered by electronic spreadsheets in connection with desktop microcomputers in solving various design problems. These problems range from the simplest case of shear design to highly involved nonlinear moment-curvature relations of reinforced and prestressed concrete sections. Familiarity of students with electronic spreadsheets is all the more important, since these can be used to great advantage in many other engineering tasks such as construction scheduling, budget preparation, etc.

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Educational System for Structural Engineering Using Personal Computers

Système d'enseignement dans le génie des structures à l'aide de micro-ordinateurs

Ausbildungssystem mit Minicomputern für das Bauingenieurwesen

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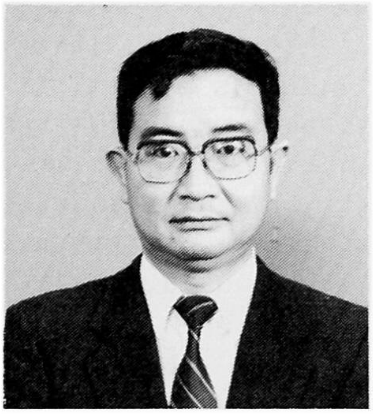

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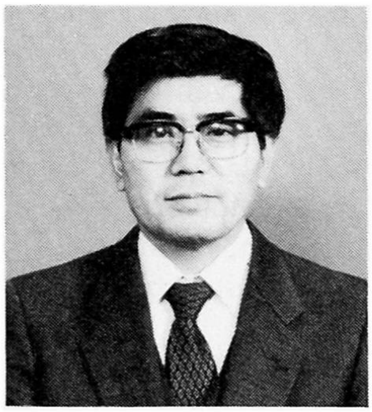

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SUMMARY
There are many subjects that students must learn in the short time available for structural mechanics and engineering. By using animation techniques, color display functions, etc. on mini-computer systems, it will be easier for students to understand the relationships among many concepts, theories and equations in the structural engineering field.

RÉSUMÉ
Il y a un bon nombre de sujets que les étudiants doivent apprendre en peu de temps. Par l'utilisation des techniques d'animation, les possibilités de l'écran en couleur, etc. du système de micro-ordinateur, les étudiants pourront comprende aisément les relations parmi un bon nombre de concepts, de théories et d'équations dans le domaine du génie des structures.

ZUSAMMENFASSUNG
Bautechnikstudenten müssen sich in kurzer Zeit Wissen in vielen verschiedenen Fachbereichen aneignen. Bisher mußte der Student sein Wissen mit Lehrbüchern, Tafelbildern und Uebungsvorlagen erarbeiten. Unter Verwendung eines Minicomputersystems, mit Animationstechnik, Farbdisplayfunktion u. dergl. kann der Student auf einfache Weise die Zusammenhänge zwischen verschiedenen Konzepten, Theorien und Gleichungen im Rahmen des Faches Bautechnik begreifen.

1. INTRODUCTION

Students must learn and study many subjects and terms in the structural engineering field. There are fundamental subjects such as mechanical properties from pure physics, and strength of materials. Combining these subjects, students must also understand the more complex subjects of structural engineering. They must learn about the materials of which buildings are made. There are the more linear elastic materials such as steels and also the nonlinear materials such as soils and concrete. The teachers will also explain the difference between static and dynamic problems. At the same time, engineers in this field need to understand the relationship between these subjects and real structural designs. As a result, both teachers and students waste much energy in coming to understand these complex subjects.

In conventional structural engineering education, many subjects and terms are studied step by step from the fundamental theories and axioms, using only blackboard, paper, and simple exercises to reinforce them using abacuses and calculators. This process requires much time to build up understanding of complex structural designs through many simplified exercises and experiments. This would be logical, if the student learns to understand and manage complex designs in the end, but most do not.

On the other hand, the development of computer systems, both hardware and software, has been remarkable since 1950. Many application programs for structural analysis and design have been developed. It has been quite convenient for users of this software to get their results simply by preparing the input data and putting it into the computer systems. However, these application programs are not the ones used as educational systems for structural engineering. It is quite easy to use application software for structural analysis and design. It does not mean that users end up with an understanding of the essence of structural engineering, though it is quite difficult to produce the structural analysis and design software without understanding the essence of structural engineering.

It has recently become possible to run this software on personal computers. Such a machine, equipped with a large amount of memory (1 Megabyte or more) and a hard disk with a capacity of 40MB or more is no longer difficult to find, or afford.`Hardware makers supply the colour display with high resolution and performance. The users can see the behavior of the structures under different loading cases like the real ones, utilizing animation techniques of the systems. Using these excellent computer systems, it is possible to understand the true essence of huge structural engineering projects, not only as the theories, but also through the behaviors that computer systems show. It is easy to demonstrate some of the more complex behaviors, that cannot be seen even in the actual experiments, by using this display equipment.

In this paper, several of the functions in the system that is now being developed are reported.

2. CONVENTIONAL EDUCATION

Generally speaking, the curriculums for conventional education in the structural engineering field are planned for 4 years of universities study and 3 years in the technical high schools. All the content of the education is divided into many lectures. Some teachers take charge of each part in their lectures from preliminary stages. Students start to learn the primitive axioms, and theories from the first step. After they perfectly understand each theory and term, the teachers progress to the next step. With this method, students learn the strength of materials from linear to nonlinear problems, structural mechanics from static to dynamic problems, etc. For this reason, they can understand the theories and terms loosely in each course of lectures. It is difficult for students to understand theories and terms while recognizing the logical connections among them in the whole structural engineering.

When students go out into the world of practice, corporations and laboratories must reeducate them. Because the structural engineering field is quite large, teachers and students must recognize the fundamentals of it in their lectures. Recently, students are able to use many computer systems. According to these environments, the lectures on the use of computer systems have been started in the universities and many technical high schools. It is easy for students to perform some numerical analysis, statistics and graphic presentstion of experimental data.

3. COMPUTER–AIDED EDUCATION

It is true that the computer faculties are more powerful in the structural engineering field. Especially, it is quite efficient for us to get good results for numerical analysis, simulations, etc. The developments of numerical techniques have been done for many differential equations in the structural engineering field. Many computer programs for numerical analysis have been produced with this development. These programs could not be made without understanding the essence of structural engineering. In the process of production of these programs, it is necessary to know the fundamentals in order to check the results.

It is not useful for students to use only computers and see results output. Once many programs in development are finished , it will be difficult to understand all of the programs due to their complexity. As the excellent environments of the computer systems were described before in this paper, the educational systems will be changed by using modern computer facilities. Using these computers, it will be easier to study structural engineering. Students will be able to see the behaviors of structures under dynamic loadings that could not be inspected even in experiments. It is necessary to combine basic theories and axioms with the high numerical methods and technologies for making the convenient systems. The total concept has been working by considering the database of the system for functions and terms. It will result in a bigger system. However, the functions of the systems should be divided into compact sizes. Some prototype functions have been built. They are shown in this paper.

4. HARDWARE CONFIGURATION

We show the hardware system in Fig. 1 that has one central processing unit, 1 mega byte main memory, 2 floppy disks which users will select the size 5 inch or 8 inch, as the external memory, one lineprinter, one keyboard typewriter, one mouse and one colour display.

Students always use the keyboard by seeing the colour display to understand the lectures. It will be necessary to set the lineprinter for a hardcopy of the lecture. It will be better to select the command and the data for students to use the mouse. We estimate the cost for this system less than 5 hundred thousand yen. It will also be necessary to have the animation function with th display cathode ray tube in this hardware configuration.

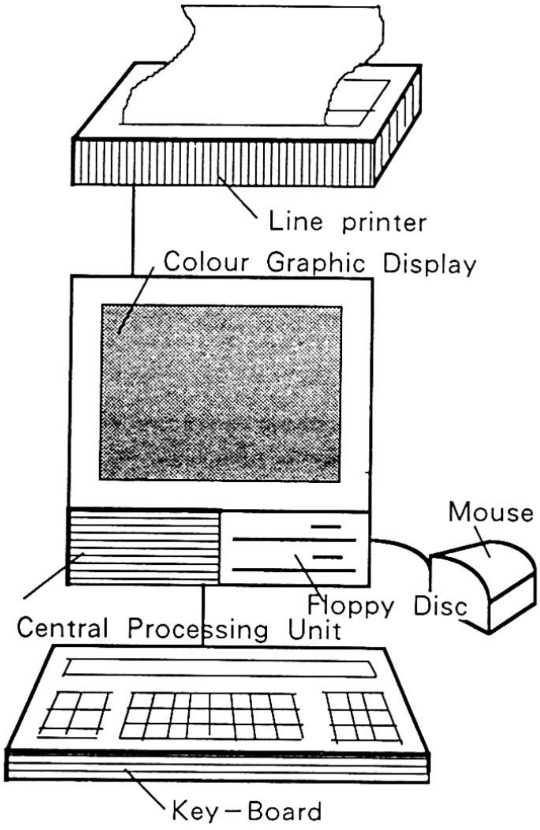


Fig.1 Hardware Configration

5. SOFTWARE FUNCTIONS

We list up the software functions as followings.

(1) Students can see the relations between all subjects by using the indices on the terminals. This system has the database system which connects with all subjects.

(2) By using the database system, students can select all suppositions, all theorems, and all knowledges. It will be quite easy to study them in accordance with their selected levels.

(3) There is the HELP function to give instructions to the userswhat they need to perform.

(4) Users can see the explanations with beautiful and understandable display, for example, aminations.

(5) Teachers can know the students' capabilities, and also can advise the students.

(6) Teachers can select the exercise problem on the terminal arbitrarily.

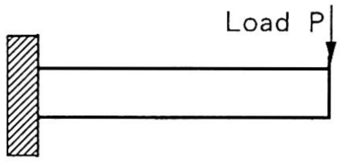
(7) There is the calculator function in this system. With this facility, students

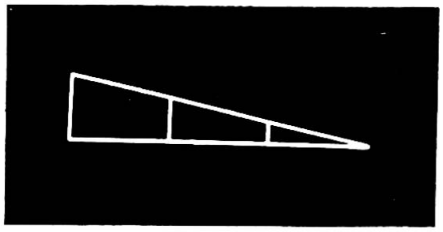
can perform calculations for the exercise problems. With a mouse, students can calculate.
(8) Students can handle the fomulas. And also check them.
(9) Students can use the display as the memorandum paper.

First of all, you will be able to see the displacement diagrams of the canti–lever beam for the concentrated load in Fig 2. Students would be able to understand if the bending moment is considered. Probably, students will better understand if they have the basic concept for the bending moment from the teachers exactly. Students can see the dynamic behaviors with the animation function,e.g. for experiments. It is easy to change the sectional sizes of beams, and on the colour display all of the forces can be seen as if forces were propagating.

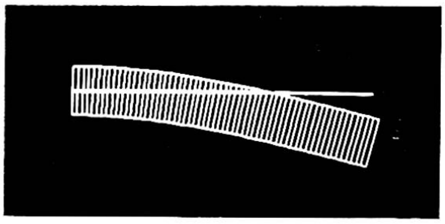
In Fig 3, students will be able to see the shear deformation that the bending moment will be ignored by considering only shear deformation. After that, students will learn Navier assumption for the stress and strain distribution in the beam by showing them on the colour display. At last, students will be able to understand the assumptions. In other words, it will be clear for students to understand the difference between two assumptions. We show the diagrams in the final stages. Actually, students will be able to see the displacement diagrams by using the animation technique. Students know the essence of the deformations for bending moment case and shear deformation case, because we will show the deformations gradually corresponding to the static load scales.

Next, we will show another deformation diagram for the frames in Fig 4. At the same time, students will understand the bending moment diagram in Fig 5. In Fig 6, we will show the space structure. Seismic ground motion from many directions will





Bending Moment



Deformation

Fig. 2 Cantilever beam

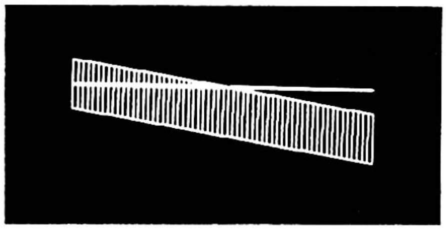


Fig. 3 Shear Deformation

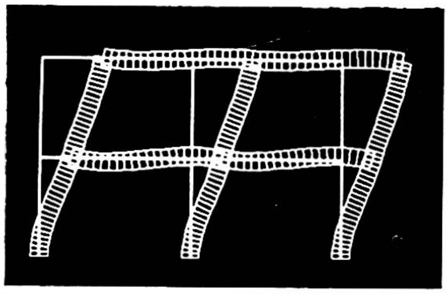


Fig. 4 Deformation

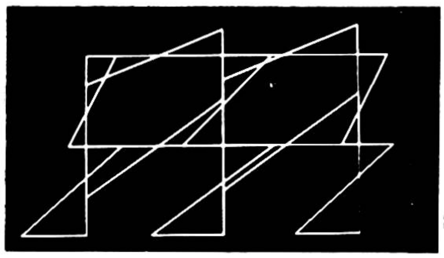


Fig. 5 Bending Moment

come to the structures with reinforced concrete columns' properties as shown in Fig 7. In Fig 8, and in Fig 9, we can see loci of column shear forces in X and Y directions. Of course it will be possible to understand the dynamic behavior of the structure. It will be very easy to understand the dynamic response for the seismic ground motion. It should be very good to understand the behavior of the structures as students can actually see the behaviors of structures for the earthquakes on the colour display. At the next stage, students will perform the exercise problem on the display terminal. If students make errors, this system will suggest and advise with some comment.

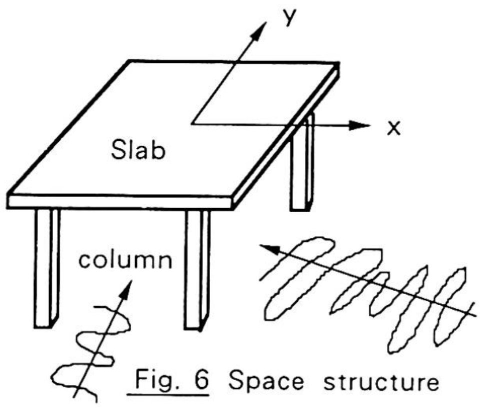


Fig. 6 Space structure

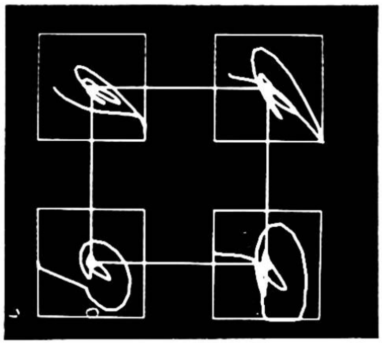


Fig. 8 Loci of column shear force X and Y

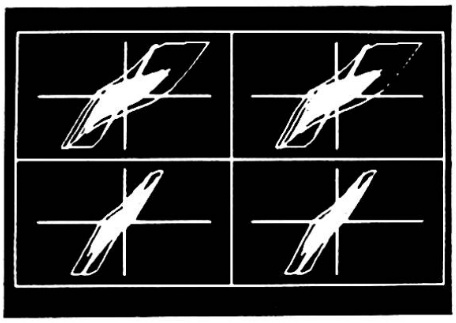


Fig. 7 Hysteresis loop of column shear force and story deflection

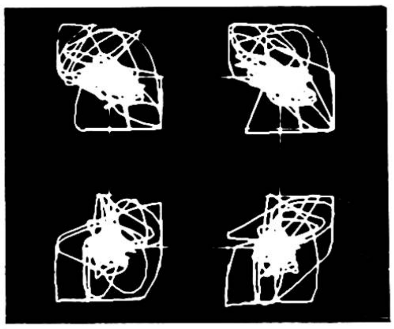


Fig. 9 Loci of column shear force X and Y after Some time in Fig. 8

6. CONCLUSION

Now we are on the way to develop good education systems using personal computers. Gradually, we will study the essence of the education system by investigating real education. From now on, it will be necessary to get many opinions from the people who will use the education systems. In the near future, we will consider combining the artificial intelligence systems with education systems. However, it is necessary to make the small systems with micro—computers. From these each small systems, we will develop systems adequate for students and teachers alike. We intend to connect this system with large network systems.

Micro-Computer Based System for Management of Bridges

Système de surveillance et entretien des ponts à l'aide de micro-ordinateurs

Ein Micro Computer System für die Verwaltung von Brücken

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Lone Davidsen, born 1958, received her Bachelor's Degree in Civil engineering at the Technical University of Denmark in 1984. She has worked with Cowiconsult since 1986 and has been responsible for the database design and programming of the Bridge Management and Maintenance System.

SUMMARY
The Bridge Management and Maintenance System is implemented for PC-computers as a menu driven, user friendly system to be used by bridge authorities. The manuals of the system include standardized inspection routines and methods for evaluation of damages. A priority list is produced which forms the basis of maintenance detailing and final scheduling and budgeting of maintenance works.

RÉSUMÉ
Les programmes d'ordinateur pour l'entretien des ponts sont présentés sous forme d'un menu, facilement compréhensible pour l'utilisateur, la Direction des Ponts et Chaussées. Les modes d'emploi comprennent les inspections de routine et les méthodes d'évaluation des dommages. Une liste de priorités est fournie par l'ordinateur et elle est la base de la planification financière et dans le temps des opérations d'entretien.

ZUSAMMENFASSUNG
Das Programm für die Verwaltung und Unterhalt von Brücken wurde für PC-Computer aufgestellt, und zwar als ein benutzerfreundliches System, das von Brückenbehörden benutzt werden kann. Die Handbücher des Systems enthalten standardisierte Inspektionsabläufe und Methoden für die Bewertung von Schäden. Eine Prioritätsliste wird erstellt, die die Grundlage für detaillierte Unterhaltsmassnahmen und für die Planung und Finanzierung der Unterhaltsarbeiten bildet.

1. INTRODUCTION

COWIconsult has developed a Bridge Management and Maintnance System for - and in cooperation with - the Danish Railway Organization (DSB). The system is implemented on Personal Computers and can be used on single units or in a network. It is operated from menus with clear descriptions of the possible activities to be chosen, and the user is aided by prompts and helpscreens.

The system is divided into three modules:

- o Inventory
- o Inspection and Bearing Capacity
- o Ranking and Budgeting of Maintenance Works

A set of manuals explain the system activities and further define standards for inspection of bridges and evaluation of deterioration of the bridge elements.

The system can be used initially with just few data. Detailed data are registered when required, but always minimized by the hierarchical element description of the bridges.

The system has since December 1986 been used in the State Railway Organization for management and budgeting of maintenance for the 2200 bridges owned by the organization.

2. SYSTEM PLANNING

2.1 Background

During the last 25 years activities for the operation, maintenance and repair of the approx. 10,000 Danish bridges have increased in accordance with the rate of deterioration of especially the concrete bridges.

Regular inspection routines have been followed by the Danish Road Directorate and the State Railways as well as by other authorities in order to follow this deterioration and register current conditions.

A rating procedure for the determination of the load bearing capacity of existing bridges has also been instituted.

Budgeting and scheduling of the repair works for deteriorated bridges has been carried out centrally in the organizations mainly based on inspectors' recommendations.

In 1984 the time had come to strengthen the overall coordination of the inspections, rating and budgeting activities. Further, revisions were needed for the inspection routines, as major parts of the continuously collected inspection data were never used.

An objective procedure for evaluation and ranking of the bridges in need of repair was also required.

2.2 Objectives

A Bridge Management System deals with all activities related to the bridges after construction. The System must therefore comprise features to assist the administration in order to:

- o Keep the bridges well functioning
- o Ensure optimal lifetime of each bridge

in consideration of:

- o Safety
- o Current construction technology
- o Economical restraints
- o Aesthetics
- o Political aspects

2.3 Outlines of the System

The requirements of the system and methods to be followed were discussed in a working group comprising:

- o Representations of the future users:
  - inspectors and technical assistants
  - planners of maintenance works
  - budget authorities
- o System planners and engineers with long-term experience in bridge design and rehabilitation works
- o Specialists in database structuring and programming

In close and interactive cooperation the system was developed through pilot stages to a fully implemented system, that has been functioning to the client's full satisfaction for the past 1½ year.

The development of the system has been based upon the database system DATAFLEX, which has its own compiled programming language.

The following diagram shows the main activities in the system:

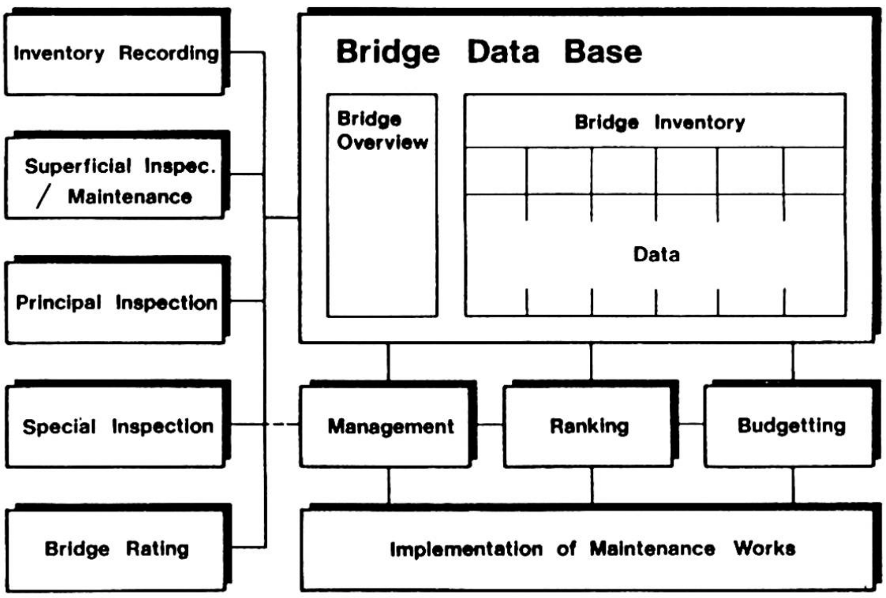

Fig. 1: Main activities covered by the system.

Administrative information and description of condition is referred to an element, which can be the bridge as a whole or a specific part (element) of the bridge. By using this method, the amount of data can be kept at a minimum corresponding to the detailing required. An extract of the total element list for a bridge is shown below.

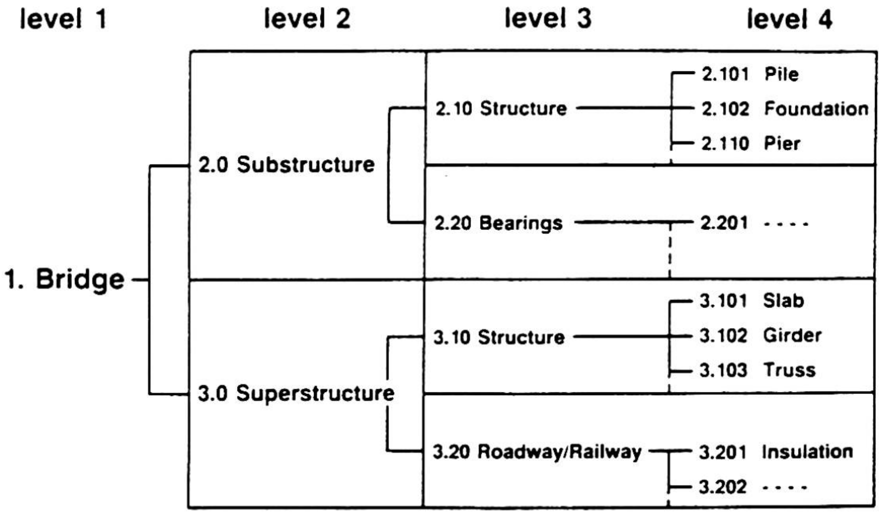

Fig. 2: Hierarchical structure of elements

Detailed data for deteriorated elements at level 4 can be abandoned after repair, and the condition can be described by a single element at level 3, 2 or 1.

The data describing an element at any level can be categorized in the following subjects:

- Administrative data
- Geometry
- Statics (bearing capacity and safety)
- Materials
- Condition and remaining life
- Maintenance requirements

2.4 Data Base Structure

The system is based on a relational data base in which the individual bridge is the basic unit.

The data base consists of 50 registers, which can be divided into the following logic groups:

- System registers
- Basic registers
- Bridge data registers
- Maintenance alternative registers
- Budget registers
- Index and intermediate registers

o The system registers contain the principal catalogues of information used in the system. Data in these catalogues are constant in the daily use, but can be modified when required.
System registers:
- Element register
- Catalogue of the responsible for bearing capacity
- Catalogue of partners in cooperation

- Catalogue of consultants and their principal staff
- Catalogue of contractors an their principal staff

o The basic registers contain data on the individual bridges. These data are in principle constant for each single bridge after it has been registered. Bridge data can at any time be added, changed or deleted according to the actual number of bridges in the system.
Basic registers:
- Section No./bridge No. register
- Section register
- District register

o Bridge data registers contain administrative, geometric and condition data. The administrative and geometric data are in principle constant in daily use, whereas the condition data reflect the actual condition of each bridge as reported by the inspections. Furthermore, there is a register containing the ranking points as last calculated.
Bridge data registers:
- Administrative/geometric data
- Span lengths
- Maintenance contracts
- Archive register for inspection and repair data
- Material deterioration data
- Element rating data
- Remarks by inspectors
- Ranking points as last calculated

o Maintenance alternative registers contain one or more repair schedules for each bridge. Elements and specific repair works may be listed in any number for the various years. The system calculates the net present value of each maintenance alternative and keeps a list of which alternative is the most economical for each bridge.
Maintenance alternatives registers:
- Maintenance alternatives general data
- Routine maintenance
- Specific repair cost for individual elements
- Cost of delayed traffic for rail and road

o Budget registers contain expenses for the maintenance alternatives.
Budget rgisters:
- Intermediate register used during preliminary budget calculations
- Accepted budget figures for each bridge, which may be overlayed by new budget figures in case budgets are re-calculated

3. CONCEPT AND PERFORMANCE

3.1 The Inventory Module

The user can choose predefined output forms or create individual outputs comprising selected data. A typical predefined form - "Bridge Overview in General" - includes:

- o Bridge number
- o Stationing
- o Bridge name
- o Bridge type (railway, highway or other)
- o Year of construction or major repair works
- o Superstructure type and materials

Querry facilities for selected information are also available. An example could be: All bridges belonging to a certain authority - constructed in the period 1950 to 1960 - with information on:

- o Bridge number
- o Bridge name
- o Superstructure type and materials
- o Current condition marks

Such facilities may be required for the general administration work or for the planning of maintenance and allocation of resources.

3.2 The Inspection and Bearing Capacity Module

The system facilitates inspections to predetermined standards at optimum intervals. Reference data can be printed out for the inspectors and a forecast of conditions as well as remaining life is automatically prepared.

The inspectors may receive data from or report directly to the central database through portable computers.

3.3 The Ranking and Budgeting Module

Ranking points are calculated for each bridge on the basis of data from the Inspector's observations. All bridges are sorted according to their condition and bearing capacity in relation to current loads.

Overall budget requirements are calculated and adjusted to budget restraints. Maintenance strategies for the individual bridges are optimized on the basis of net present value calculations.

4. EDUCATIONAL PROGRAMMES

Educational programmes have been carried out to ensure the succesfull introduction of this new tool into a long established tradition for manual work with data kept in ordinary files.

The educational programmes also covered the standardization of inspection routines.

5. FUTURE TRENDS

The basic concept for the Bridge Management System has been successfully used during the development of similar Management Systems. A Road Management System has been implemented and other subjects for maintenance management is under way.

PC networks for the management of de-centralised systems have already been established.

Currently, we are working on a graphic support to the menus.

Graphic representation of information is under preparation and digital storage of colour pictures (of damages) will be supported when the technology is suitable.

Expert Systems for Quality Prediction in Structural Engineering

Systèmes experts pour la prédiction de la qualité dans le génie civil

Expertensysteme für die Qualitätsvorhersage im Bauingenieurwesen

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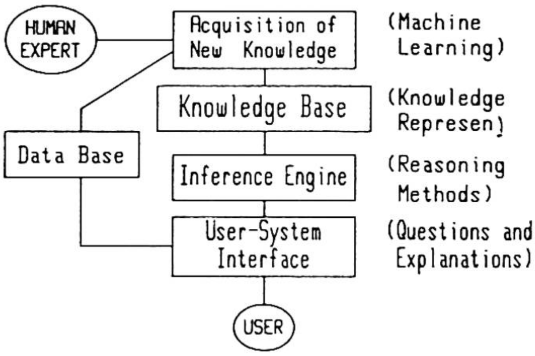
SUMMARY
This work deals with quality level prediction in concrete structures through the helpful assistance of an expert system which is able to apply reasoning to this field of structural engineering. Evidences, hypotheses and factors related to this human knowledge field have been codified into a Knowledge Base in terms of probabilities for the presence of either hypotheses or evidences and conditional presence of both. Human experts in structural engineering and safety of structures gave their invaluable knowledge and assistance, necessary when constructing the ''computer knowledge body''.

RÉSUMÉ
On étude la possibilité de prédire la qualité des bâtiments en béton à l'aide d'un système expert. Les évidences, les hypothèses et les facteurs en relation avec cette technique ont été introduites dans la base des connaissances avec une définition des probabilités correspondantes en relation avec les hypothèses et les évidences. L'ensemble des connaissances pratiques nécessaires pour prendre les décisions a été fournie par des ingénieurs experts dans les techniques du bâtiment.

ZUSAMMENFASSUNG
Diese Arbeit befasst sich über die Vorhersage des Qualitätsniveaus in Betonstrukturen, mit Hilfe eines Expertensystems für das Bauingenieurwesen. Die Grundannahmen und Einflussfaktoren in diesem Feld der Wissenschaften sind als Wahrscheinlichkeitrelationen in einer Datenbasis kodifiziert worden. Fachleute in der Strukturingenieurwissenschaft und in der Struktursicherheit haben ihre unschätzbaren Kenntnisse gegeben, die notwendig sind, um eine Computer-Datenbasis zu schaffen.

1. INTRODUCTION

In recent years, an ever-increasing effort has been devoted to the research, development and marketing of Expert Systems in a great number of specific fields - within human knowledge although only some of them have reached a truly "production" status. Likewise, Knowledge Engineering will have a really important impact in those areas of human activities where knowledge provides a powerful tool for solving relevant problems. Thus, it is possible to predict two beneficial effects [1]: an increase in knowledge based systems development for reproducing and applying human knowledge and, in second place, "... as an inevitable side effect, knowledge engineering will acelerate the development, clarification and expansion of human knowledge itself." Figure 1 illustrates a typical expert system with its basic modules. In some fields of human knowledge (medicine, law, mathematics) a considerable - number of expert systems have been developed [1,2,9,11]. In what follows, we briefly review some Expert Systems developed for structural engineering, in order to give an appraisal of the existing possibilities. SPERIL-II [6] evaluates the general safety and damageability of existing structures by analizing inspection data and instrumental records of the structural response as a consequence of earthquake loading. The system has a predicated logic rules KB and uses both forward and backward chaining combined with certainty factors. It was written in a dialect of Prolog. SACON [7], determines particular ways and strategies for analizing structural engineering problems. The system works coupled with program MARC (FEM code) using knowledge about stresses and displacements. It is a rule based system with backward chaining for the inference process. PROSPECTOR [8] is another expert system which helps geologists in their exploration and search for mineral deposits. The system works by using rule based knowledge and certainty factors, together with Bayesian inference. It was written in Interlisp and has reached the stage of production prototype.



This work is devoted to the generation of a Knowledge Base for quality Level prediction in concrete structures and its implementation on a Bayesian expert system, called "QL_CONST1" (Quality Level prediction in CONcrete STructures).

2. THE BAYESIAN APPROACH FOR PROBABILISTIC PHENOMENA

The well known Bayes' Theorem has singular importance in processes normally involving probabilistic knowledge, such as engineering design, damage assessment, etc. In these cases, information which must be included into the inference process is available from various sources: engineer's experience, visual inspection, experimental test, etc. We will briefly review the basic ideas and formulae inherent to Bayes' Theorem, as follows. Let U be the universe comprising a set of a mutually exclusive events Hi and Ej another event belonging to U. The conditional probability for the presence of event Ej assumed that event Hi has occurred is:

$$P(Hi : Ej) = P(Hi \& Ej)/P(Ej) \quad (1)$$

where

P(Hi & Ej) = probability for the occurrence of both events simultaneously

From (1) we can write

$$P(Hi : Ej) . P(Ej) = P(Ej : Hi) . P(Hi) \quad (2)$$

Now, Bayes' theorem could be written as:

$$P(Hi : Ej) = P(Ej : Hi) . P(Hi)/P(Ej) \quad (3)$$

In our case, Hi should be interpreted as a "Hypothesis", whereas Ej is an "evidence". Thus,

P(Hi) = probability "a priori" for the occurrence of hypothesis Hi.

$P(Hi : Ej)$ = probability "a posteriori" for the occurrence of Hi, updated by - knowing the evidence Ej.

$P(Ej : \bar{H}i)$ = conditional probability for the presence of Ej, assumed that Hi has occurred.

3. PROBABILITY KNOWLEDGE BASE FOR "QL_CONST1"

The knowledge base (KB from now on) is generated upon "a priori" and conditional probabilities with the asistance of human experts in structural engineering and safety of structures. The degree of dependence in Ej (in this case, a small one) will affect all information for all hypotheses considered. Therefore, the overall conclusions reached by the system are quite reasonable, as expected. In QL_CONST1 (version I) three basic hypotheses are included up-to-date: GOOD, MEDIUM and POOR Quality Level (QL from now on). The hypotheses and evidences are codified into - the KB in natural language. Each one has a considerable number of evidences Ej - and a set of probabilites associated: P(Hi) for the hypothesis itself and $P(Ej : Hi)$ and $P(Ej : \bar{H}i)$ for each one of the evidences related to the hypothesis. Evidences were classified into several groups, depending upon their source, which are: Visual inspection, Control of materials, Inspection "on site" and Project - and building planes.

Human experts could provide, with relative easyness and clarity, the "a priori" probability for each hypothesis, P(Hi), and conditional probability for - the presence of Ej given that Hi has occurred, i.e. $P(Ej : Hi)$. However, the values of $P(Ej : \bar{H}i)$ were - much more difficult to give by experts than the previous ones. Nevertheless, it can be avoided by calculating them as described below. Let Ej be the new evidence introduced and Hi the hypothesis under consideration. The Universe U of hypotheses considered is show in figure 2, where we state:

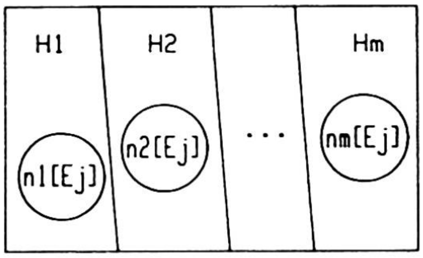


Fig. 2. Universe of Hi

$ni|Ej|$ = number of specimens (in hypothesis Hi) which presents evidence Ej (4)
ni = number of specimens in Hi
$N|Ej|$ = total number of specimens in U which presents Ej (5)
$\bar{N}|Ej|$ = total number of specimens in U which do not presents Ej
$N=N|Ej|+\bar{N}|Ej|$ = total number of specimens in U (6)

The probability for the presence of Ej in specimens belonging to Hi is:

$$P(Ej : Hi) = ni|Ej|/ni \; ; \quad i = 1,2,...,m \tag{7}$$

The "a priori" probability for each hypothesis Hi could be written as:

$$P(Hi) = ni/N \; ; \quad i = 1,2,...,m \tag{8}$$

In view of (4) and (5), we can write:

$$P(Ej : \bar{H}i) = \sum_{k\neq i}^{m} nk|Ej| \; / \sum_{k\neq i}^{m} nk \tag{9}$$

By substituting (6) into (9) yields

$$P(Ej : \bar{H}i) = \sum_{k\neq i}^{m} nk|Ej| \; / \; (N-ni) \tag{10}$$

By substituting (7) and (8) into (10) we obtain

$$P(Ej : \bar{H}i) = N \; . \sum_{k\neq i}^{m} P(Hk) \; . \; P(Ej : Hk) \; / \; (N-ni) \tag{11}$$

By dividing (11) by N and remembering that $1-P(Hi = P(\bar{H}i)$, we finally arrive at:

$$P(Ej : \bar{H}i) = 1/P(\bar{H}i) \; . \sum_{k\neq i}^{m} P(Hk) \; . \; P(Ej : Hk) \tag{12}$$

4. DESCRIPTION OF EXPERT SYSTEM "QL_CONST1"

The final goal is to obtain the probability of occurrence for the likely hypothesis Hi by including all the required evidences. The probability values are updated, by asking about the new evidences (let's, for instance, presence or not of shear cracks), until the system reaches a reliable conclusion. The way how the User answers the system's questions is a topic of interest. In classic logic, events either occur or do not occur, which implies that answers would be either true (1) or false (0). Nevertheless, in probabilistic processes (also in those governed by Fuzzy Logic Theory [10]) knowledge is no longer either true or false, but has an associated degree of uncertainly.

Thus, when the system requests information about a certain evidence, it becomes necessary to allow the User to reply with phrases such as: "I don't know" (absolute uncertainty) or "more or less" (may be 'yes' but not really sure). So, "QL_CONST1" accepts the user's answer in the form of a numerically graded scale, with values comprised between a negative integer (-5) and a positive one (+5). The zero value represents absolute uncertainty.

5. EXPERT SYSTEM BEHAVIOUR ASSESSING AND RELIABILITY

The KB developed here was extensively tested and modified taking into consideration the suggestions from many human experts. Also, some critical situations were considered, giving satisfactory results, one of them will be shown and discussed further. In order to improve the sequence of computer questions, the Rule Value [4] was optimized together with a selective refinement of the probability values. This combined approach allows to obtain a questions' sequence more efficient and closer to human behaviour. This example assumes an hypothetical structure whose build-up process was made following high quality guidelines. A visual inspection was made giving excellent results, i.e., neither cracks, nor reinforce without cover, etc. were observed. The following text reproduces exactly the messages and dialog between the user and the computer:

```
Please, answer questions with integer numbers as indicated in the scale below...
                   -5            0            +5
                   |-------------|-------------|
                   NO       UNCERTAINTY       YES
```

QL_CONST1 : What about control of CONCRETE QUALITY?. Were there enough compression strength tests on cylinders?.

User : 5

QL_CONST1 : Were there COLUMNS outside its vertical line observed?

User : -5

QL_CONST1 : Were there FLEXURE CRACKS observed?

User : -5

QL_CONST1 : Were there SHEAR CRACKS in beams observed?

User : -5

(As the dialog progress, the system incorporates more and more "a posteriori" information and, after a few more questions, it announces its most likely conclusion.)

QL_CONST1 : Were there qualified PERSONNEL to build-up the FORMS and to retire them?.

User : 5

QL_CONST1 : Were there qualified PERSONNEL to handle and place the reinforcement?

User : 5

```
QL_CONST1 : Were there any previous studies on SOIL BEHAVIOUR?
User      : 5
===============================================================================
My PREDICTION is: The structure has GOOD quality level with a probability of 99%
===============================================================================
```

Now, it is necessary to demonstrate that expert system responses do not "jump" - around local intermediate situations. The set of evidences was divided into two main groups, namely: a) evidences related to knowledge about build-up process - (KDC group) including plans, details, materials control, etc., and b) evidences related to visual inspections, which will be identified as VIR from now on. Thus, for instance, figure 3 illustrates the system responses when KDC = -5, i.e., all

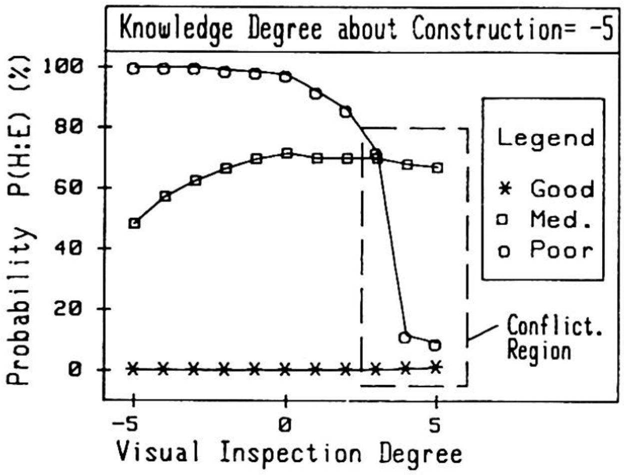


Figure 3. ES Responses (KDC = -5)

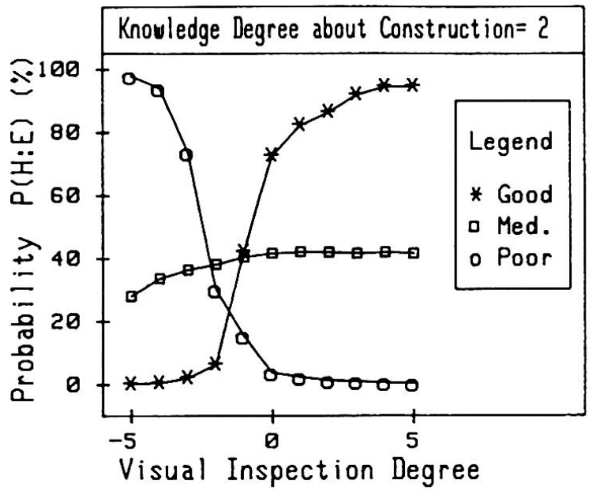


Figure 4. ES Responses (KDC = 2)

questions related to evidences comprised into the KDC group were answered with -5 (NO) in the case they were formulated towards GOOD quality structures and with +5 (YES) for questions formulated in the opposite direction. The vertical scale of - figures reflects the final conditional probability values for the hypotheses considered herein, whereas horizontal scale contains the VIR values given for all - questions related with evidences belonging to VIR group. Figure 3 represents a - subset of structures with KDC = -5, i.e. structures built following wretched guidelines with an "absolute certainty". As expected, the QL for such structures could never be GOOD and the system recognizes this fact. Also observe that, even in the presence of "more or less" satisfactory VIR values (say, until VIR=2) the system assigns the POOR grade, which could be seen as a conservative criterion. - For VIR values larger than 2, the system recognizes a real-world piece of - non-sense identified as a "conflictive region" in the figure: it is normally improbable that badly build-up processes could give acceptable QL structures. Figure 4 (KDC=2) shows the QL results - for a "moderate confidence" in a suitable build-up process. As expected, VIR parameter is again decisive to assign whatever qualification. Finally, figure 5 (KDC=5) constains the QL results for an "absolute certainty" in a suitable build-up process. Once again, the sys-

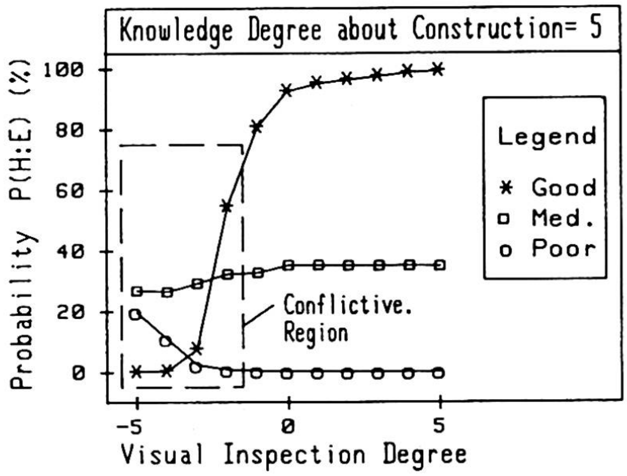


Figure 5. ES Responses (KDC = 5)

tems recognizes a real-world contradiction: it is not normally probable that - well-built specimens could exhibit either bad or calamitous final aspect.

As it can be observed, the system's performance follows a not "jitter" way, going assimptotically towards numerical limits expected. From another point of - view, when comparing the system judgement to human experts ones, satisfactory - results were obtained. In most cases, human experts did not hesitate to claim - that they agree with the system answers inside a reasonable range.

6. CONCLUSIONS

A knowledge-based system prototype for Quality Level prediction in concrete structures has been presented. The KB developed here for structural quality assessing was extensively tested. It has show a satisfactory performance, even in the presence of limit situations, and it is actually being increased by adding more probability based rules and by refining the set of hypotheses.

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Expert Systems for the Concrete Industry

Systèmes experts dans l'industrie du béton

Expertensysteme für die Betonindustrie

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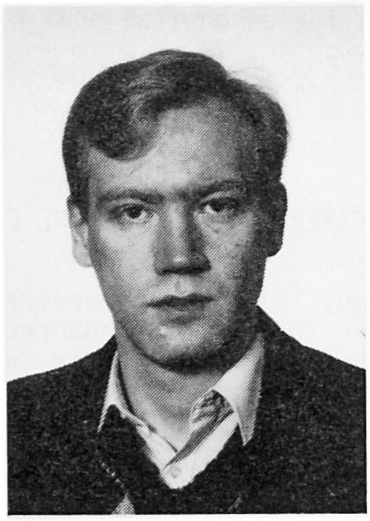

Karl-Johan Serén, born 1958, received his MScTech degree in mechanical engineering at Helsinki University of Technology. For three years he has been involved in research projects concerning automation in the concrete industry, with special interest in application of advanced electronic data processing techniques, such as knowledge engineering.

SUMMARY
In this paper, potential applications of knowledge based expert systems in the concrete industry are discussed. Moreover, two expert system applications for building sites concerning concrete and concrete structures are presented. The first expert system assists in choosing ready-mix concrete. The second system is an expert system for the repair of concrete balconies. Both systems are prototypes and they run on microcomputers.

RÉSUMÉ
L'article présente les réalisations possibles des systèmes experts dans l'industrie du béton, dont deux se rapportent particulièrement aux chantiers de construction en béton. Le premier système facilite le choix du béton prêt à emploi, et le second à la réparation des balcons en béton. Les deux systèmes sont des prototypes fonctionnant sur des micro-ordinateurs.

ZUSAMMENFASSUNG
Dieser Vortrag behandelt potentielle Anwendungsbereiche von Expertensystemen in der Betonindustrie. Ferner werden zwei für Baustellen mit Betonverarbeitung konzipierte Expertensysteme vorgestellt. Das erste Expertensystem dient der Wahl von Transportbeton. Das zweite Expertensystem ist bei den Reparaturen von Betonbalkons behilflich. Beide Systeme sind Prototypen und funktionieren auf Mikrocomputern.

1. INTRODUCTION

Knowledge based expert systems offer a new way of solving various problems related to concrete. A wide variety of potential knowledge engineering applications can be found in the precast concrete industry as well as on site in concrete construction. In Finland the research activities in the field of artificial intelligence in building construction have mainly focused on the practical aspects, i.e. what expert system techniques offer in the way of problem solving and decision support; what knowledge engineering applications from other branches of industry can be used; the state of art of software tools; building small expert system prototypes for demonstrational purposes to prove the feasibility of the technique etc.

2. POTENTIAL APPLICATIONS OF EXPERT SYSTEMS IN THE CONCRETE INDUSTRY

The conclusion of a brief study [6] was that several potential applications for knowledge based systems can be found in the concrete industry. One aspect to consider are the differences between the concrete industry branches, especially in view of automation level and type of production. The concrete industry branches can be divided into three categories [1]: 1) ready mix concrete plants, 2) concrete product factories and some of the precast element factories with large production lot sizes and 3) precast element factories with small production lot sizes consisting of individually shaped concrete elements.

2.1 Design and its impact on the manufacturing process

Several expert systems assisting the design process have been reported. As an example one could mention the work done in Sheffield Polytechnic in conjunction with Ove Arup and Partners to develop an expert system written in Prolog which relates to reinforced concrete beams design [7]. The expert systems relating to architectural and structural design do not usually deal with the constraints of the manufacturing process and the need for such systems is obvious. An expert system of this kind should be able to consider the constraints set by the mould and casting equipment, make the selection of materials and check the dimensions of the elements (depending on the precast concrete factory manufacturing the elements) as well as check the design in relation to the national building codes and structural aspects.

2.2 The manufacturing operations

The use of expert systems for the control of manufacturing equipment and machinery obviously requires a high level of automation. The implication of this is that, in the short term, application areas for manufacturing operations expert systems can be found mainly in ready mix concrete plants and in concrete product factories manufacturing mass-produced articles. In ready mix concrete plants expert systems can be used to automatically choose the appropriate mix proportion according to the structure to be cast. Another application would be monitoring the mixing process and interpreting the signals from various probes and sensors. In the future knowledge based systems can be used in various robotic applications, for instance in the control systems of autonomous mobile robots [8].

2.3 Production planning and control

Production planning and control seems to offer the highest application potential in the short-term for expert systems in the manufacturing process of precast concrete factories. The optimization of production is difficult due to the great amount of information. It is often difficult to form production lots from different orders even though these may contain similar elements. The detailed scheduling is also difficult because of the great amount of possible control parameters. An additional difficulty is that the element factory does not have the final manufacturing drawings, the order in which the elements will be erected or the erection schedule at its disposal when the production planning is done. For a human being, such a dynamic environment is hard to master, and conventional computerized production planning systems are too inflexible. Expert systems could be used for the production management in cases such as the one described above, for instance, to generate acquisition proposals, production schedules and work descriptions. In other branches of industry expert systems have been developed for this purpose. One example of such a system is Isis [3].

2.4 Quality control

Automated quality control is a potential application area for knowledge based systems. Advanced sensors, such as machine vision systems, laser gauges [5] and ultrasonic pulse systems [4], are being developed to perform repetitive inspection tasks (for instance dimensional measurements and defect detection) more economically and more accurately. Knowledge based systems can be used to interpret the signals and to make a statistical analysis of the production output to minimize product error and downtime with automatic correction control of the manufacturing machinery.

2.5 Maintenance

The maintenance of a complex item of machinery involves a diagnostic procedure incorporating many rules as well as judgment decisions by the maintenance mechanic. Expert systems can be utilized to assist maintenance personnel by presenting menu-driven instruction guides for the diagnostic task. Many examples of such systems have been reported [5].

3. EXPERT SYSTEMS FOR CONCRETE CONSTRUCTION

3.1 An expert system for choosing the type of ready mix concrete

This expert system is intended to be utilized as a decision support system for the building site personnel in choosing the type of fresh concrete to be ordered from the ready mix concrete plant. At present the system is a demonstration prototype and it can't be used in production as such due to its somewhat limited knowledge base (the knowledge base does not contain any information about special cases). It can be used for educational purposes though. The system runs on IBM PC/XT/AT and compatible microcomputers. The software tool used for developing the system is a commercially available expert system shell called Insight 2+. The knowledge is presented in the form of productions (IF-THEN-ELSE -

rules), which are formed of statements or facts bound together by logical operators (AND, OR and NOT). The inference system is mainly goal-driven (backward-chaining). The knowledge bases are developed by writing the source code in the knowledge representation language and by thereafter compiling the knowledge bases into an inner representation form, which the inference system can use during a consultation. The inference system automatically generates menu-type queries when it finds a statement with an unknown value during the search through the rules. Textual information can be attached to the facts to give a more finished appearance to the user interface.

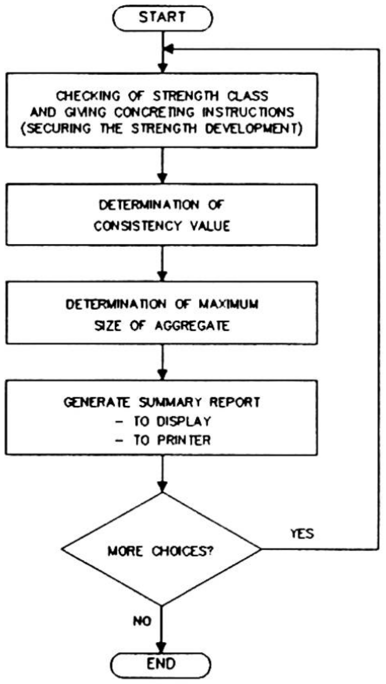

Fig. 1 The general outline of the expert system for choosing ready-mix concrete.

In Finland the building site personnel has to inform the ready mix plant about the following properties when ordering fresh concrete:

1. The compressive strength class (defined by the designer), taking into consideration appropriate concreting techniques.
2. The consistency value of the fresh concrete (usually defined as VeBe-time or sVB).
3. The maximum size of aggregate.

The domain is therefore divided into three sub-problems or contexts, each of which is a typical classification problem, i.e. the system has to choose from a number of pre-defined solutions. Weiss & Kulikowski [9] have stated that a production system is a natural way of solving problems like this. The production systems have one major drawback [2]: the search space easily grows very large and the system becomes inefficient. The general outline of the knowledge base and the course of inference is shown in fig. 1.

The first context contains knowledge about the compressive strength class and about appropriate concreting techniques. First the system checks the required minimum value for the strength class and compares it to the strength class defined by the designer. If the strength class given by the designer is too low the system gives a warning about this. The system queries following fact values from the user for this purpose:

- environment class,
- water impermeability requirements,
- frost proof requirements,
- corrosion proof requirements and type of corrosive environment and
- the compressive strength class given by the designer.

Secondly the system gives recommendations about appropriate concreting techniques, such as curing, heating and heat treatment; increasing the strength class for the ordered fresh concrete in some cases; some general information about the use of admixtures. The fact values queried from the user for this purpose are

- the outdoor temperature at the building site and
- the desired production cycle time (form stripping time).

The second context contains knowledge about the consistency value of the fresh concrete. The system deduces the suitable consistency value using following fact values queried from the user:

- structure: the type of structure, the thickness of the structure and the spacing between the reinforcement bars,
- production equipment: the compaction method and the transport method for fresh concrete used on the building site.

The third context contains knowledge about the maximum size of aggregate. The facts influencing the choice of maximum aggregate size are

- structure: the type of structure, the thickness of the structure, the spacing between the reinforcement bars and the desired quality of the concrete surface
- environmental requirements: water impermeability requirements
- production equipment: the compaction method and the type of form (number of joints in the formwork and the sealing of the joints).

It may be noticed that some of the facts mentioned above have been queried in the previous contexts. The results from each context are shown on the display as the inference proceeds. The results from the strength class checking and concreting recommendations are shown as textual displays and the results of the determination of the consistency value and maximum size of aggregate are shown as bar-charts, where the suitability of each alternative is given by the length of the bar.

3.2 An expert system for the repair of concrete structures

The expert system for the repair of concrete structures is intended to be used as aid in preparing the repair planning documents, but it may also be used by the contractor to aid in preparing the working plans. At present only a small subset of the final knowledge base is implemented. The implemented part of the knowledge base contains knowledge about repairing concrete balconies. The software tool used to develop this system is an expert system shell called Xi Plus. The system runs on IBM PC/XT/AT and compatible microcomputers. Like Insight 2+, Xi Plus is a rule-based shell.

The knowledge base contains information about the repair of concrete balconies. The domain consists of two main damage types: surface damages and cracking. The knowledge base is divided into three separate knowledge bases: a small main knowledge base, from which one of the two sub-knowledge bases for the different damage types are loaded. This divided knowledge base structure is chosen to maintain the efficiency of the system and to make it easier to add new parts to the knowledge base.

Each sub-knowledge base has two contexts. First the system makes a diagnosis of the damage. It queries from the user a number of properties related to the damaged concrete and concludes from these the possible causes of the damage. Secondly the system determines the level of damage based on some facts queried from the user, after which it gives recommendations about repair methods.

4. CONCLUSIONS

The experiences show that it is quite possible to build feasible microcomputer based expert systems with the software tools available at present. There are some restrictions: the problem domain should be very small and clearly defined. If possible, the knowledge bases should be divided into separate smaller knowledge bases to maintain a reasonable performance of the systems. The first of the described expert systems is presently being modified for educational purposes. It will, however, take some time before systems like these will be taken into production use on building sites.

At present a major project for developing an automated real time manufacturing process control system for precast concrete factories is under planning at The Technical Research Centre of Finland. This system will consist of modules for measurement and control of various manufacturing parameters, such as moisture of the concrete aggregate, workability of the fresh concrete, compaction parameters, curing and heat treatment and control of the strength development. The system is planned to include knowledge based expert system modules for the handling of uncertain and incomplete feed-back information.

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Computer-Aided Fatigue Design of Steel Structures

Conception assistée par ordinateur de structures soumises à la fatigue

Computergestützter Entwurf bei ermüdungsbeanspruchten Stahlbauten

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SUMMARY
A pilot expert system for the fatigue design of steel structures is presented. This system was developed for use with the ECCS Recommendations for the Fatigue Design of Steel Structures (1985). The system helps designers identify appropriate detail categories and also, alternative designs are proposed if a detail is not satisfactory.

RÉSUMÉ
Un système expert pilote pour la conception assistée par ordinateur de structures métalliques soumises à la fatigue est présenté. Le système a été développé pour être utilisé avec les recommandations de la CECM pour la vérification à la fatigue des structures en acier (1985). Il permet aux ingénieurs de classifier de façon appropriée un détail de construction, et propose des solutions de rechange au cas où un détail n'était pas satisfaisant.

ZUSAMMENFASSUNG
Ein Prototyp eines Experten-Systems zum Entwurf von ermüdungsbeanspruchten Stahlbauten wird vorgestellt. Das System wurde entwickelt zur Anwendung der EKS Empfehlungen für die Bemessung und Konstruktion von ermüdungsbeanspruchten Stahlbauten (1985). Es dient dazu, Konstruktionsdetails in die richtigen Kerbgruppen einzuordnen und, falls nötig, Alternativen zu einem gegebenen Konstruktionsdetail vorzuschlagen.

1. INTRODUCTION

Good fatigue design requires an understanding of many factors. Although fatigue-design guidelines are numerous, many are not appropriate for assessment of large steel structures. During a fatigue assessment, designers can become confused by the complexity of the problem and the variety of available solutions.

Recently, parameters which are most important to large steel structures were identified and as a result, many countries simplified code provisions. International harmonization was achieved in 1985 when the European Convention for Constructional Steelwork (ECCS) published "Recommendations for the fatigue design of steel structures" [1]. This publication is beinq used as a basis for revising many national design guidelines.

Although the ECCS document represents an important contribution toward simplifying the designer's task, some problems remain. Work associated with implementing the Recommendations revealed that when using the document, designers may not always make the same judgements as would experts.

This paper begins with a summary of the ECCS Recommendations and a discussion of areas where expert judgement is needed. Next, expert systems are described and evaluated within the context of civil engineering. Finally, a pilot expert system, developed for use with the ECCS Recommendations, is introduced.

2. ECCS RECOMMENDATIONS FOR THE FATIGUE DESIGN OF STEEL STRUCTURES

These Recommendations are the result of six years work by members and guests of ECCS Committee TC6 under the chairmanship of Prof. Hirt, the Swiss Federal Institute of Technology, Lausanne. The fatigue assessment employs the following four fundamental parameters : number of stress cycles, detail category, fatigue strength (in terms of stress range), and applied stress range. The first three parameters can be related to each other by means of the following relationship :

$$\Delta\sigma_R = DC \left(\frac{2 \cdot 10^6}{N}\right)^{1/3} \qquad (1)$$

where DC is the detail category, $\Delta\sigma_R$ is the fatigue strength and N is the number of stress cycles.

The Recommendations propose that the designer compares the fatigue strength of a given detail, $\Delta\sigma_R$, at a given number of stress cycles with the fourth parameter, applied stress range, $\Delta\sigma_e$, using partial safety factors.

$$\gamma_s \, \Delta\sigma_e < \frac{\Delta\sigma_R}{\gamma_m} \qquad (2)$$

where γ_s and γ_m are partial safety factors determined from a reliability analysis, or from the authority having jurisdiction.

Therefore, a procedure for details requiring a fatigue assessment could be carried out according to the following (simplified) steps :

STEP 1. Classify a given detail according to its detail category through reference to diagrams and descriptions in the Recommendations.

2. Taking the required fatigue life (number of stress cycles) and the detail category, determine the fatigue strength in terms of stress range according to Equation (1).

3. Calculate the applied stress range using loading information.

4. Using appropriate safety factors, test the requirement described by Equation (2).

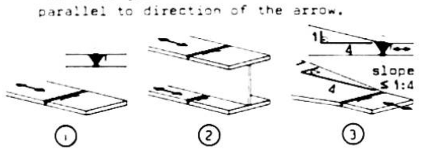
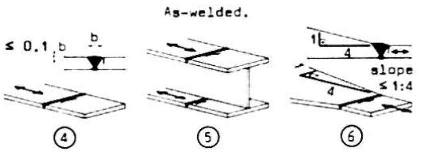
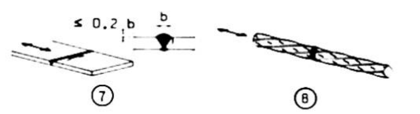
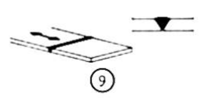
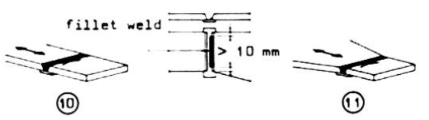
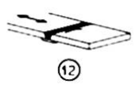
5. If the requirement described by Equation (2) is met, select next detail for assessment and return to Step 1.
6. Select an alternative detail design. This involves measures such as revising the design in order to change the detail category, increasing plate thickness, employing fatigue strength improvement methods (which should be verified through laboratory testing), or any combination of these measures. Repeat assessment from Step 1.

After discussions with design engineers who use these Recommendations, two problems were identified. The first problem is associated with detail classification, Step 1. Some designers have difficulty identifying the most appropriate category for the detail being assessed. The diagram, for example see Figure 1, corresponding to the correct detail category in the Recommendations may not resemble the detail. Occasionally, a non-expert may decide erroneously that another detail category is more appropriate. Errors due to this problem can have very serious consequences.

The second problem occurs at Step 6. If a fatigue assessment reveals that the detail is unsatisfactory, the most appropriate alternative detail design may not be chosen. Errors due to this problem are caused by a lack of practical experience in detail design when fatigue assessments are necessary. A design engineer may not be capable of good fatigue design. Such difficulties result in unnecessarily costly structures.

TABLE B2.3 : TRANSVERSE BUTT WELDS

Classification of typical constructional details. The arrow indicates the location and the direction of the stresses for which the stress range is calculated.

DETAIL CATEGORY	CONSTRUCTIONAL DETAILS	DESCRIPTION
112	All welds ground flush to plate surface parallel to direction of the arrow. 	Without backing bar ① Transverse splices in plates, flats and rolled sections. ② Flange splices in plate girders before assembly. Details ① and ② may be increased to Category 125 when high quality welds, proven free of detectable discontinuities are used, see Appendix B3. ③ Transverse splices in plates or flats tapered in width or in thickness where the slope is not greater than 1:4. ④ Transverse splices of plates or flats. ⑤ Transverse splices of rolled sections or welded plate girders. ⑥ Transverse splices in plates or flats tapered in width or in thickness where the slope is not greater than 1:4. Requirements for details ④, ⑤ and ⑥ : - The height of the weld reinforcement to be not greater than 10 % of the weld width with smooth transitions to the plate surface. - Welds made in flat position. ⑦ Transverse splices of plates, flats, rolled sections or plate girders. The height of the weld reinforcement smaller than 20 % of weld width. Requirements for details ① to ⑦ : - Weld run-off pieces to be used, subsequently removed and plate edges ground flush in direction of stress. - Welds made from two sides. ⑧ Butt welds in concrete reinforcing bars. ⑨ Butt welds made from one side only.
90	As-welded. 	
80		
36*		
71		With backing bar ⑩ Transverse splices. ⑪ Transverse butt welds tapered in width or in thickness where the slope is not greater than 1:4. Requirements for details ⑩ and ⑪ : - The fillet weld which attaches the backing bar to terminate more than 10 mm from the edges of the stressed plate.
50		⑫ Transverse butt welds when a good fit cannot be guaranteed or when backing bar fillet welds are terminated closer than 10 mm to the plate edge.

* : see Clause B1.07

FIGURE 1 : Example of tables of constructional details contained in [1].

3. EXPERT SYSTEMS FOR ENGINEERING DESIGN

3.1 Characteristics of expert systems

Expert system development involves placing all information pertaining to a domain in knowledge bases. Knowledge bases contain both facts and logical relationships between data groups. In addition, knowledge bases may have rules formulated using an expert's experience in the domain. Some of this experience-developed knowledge is termed heuristic knowledge, and it is used principally to identify a group of good solutions from a large number of possible solutions. Therefore, expert systems are most useful when a detailed analysis of all solutions is not justified.

Expert systems control their knowledge bases by means of inference engines. Inference engines are programs which contain procedural information on how knowledge bases are used to find solutions to given problems. No facts or logical relationships concerning any domain are held in inference engines. If not enough information exists in the knowledge base, the user is consulted automatically. Most inference engines have explanation facilities which backtrack through the knowledge base in order to explain to the user the reasoning behind a particular question or conclusion.

Most inference engines are independent of the knowledge base and consequently, they can be applied to many problems. However, the inverse is not true; knowledge bases, including their heuristic information, are constructed for specific inference engines. Typically, inference engines are enclosed in environments which facilitate user interface during problem solving. Also, editors for creating and changing knowledge bases are included. Such environments are called shells or expert-system development tools.

The results provided by an expert system normally take the form of conclusions which are based on deductions made while the inference engine was processing the knowledge base. More than one conclusion may be offered; concepts of likelihood can be employed to indicate the most probable. More sophisticated tools provide indications of the sensitivity between facts supplied and conclusions drawn.

In civil engineering, expert systems are particularly applicable because a large proportion of civil engineering tasks require the use of knowledge gained through experience. Expert systems synthesize facts and heuristic knowledge, thereby providing useful design aids for civil engineers.

3.2 A pilot expert system for fatigue design

A pilot expert system has been developed in order to improve the quality of fatigue design using the assessment procedure described in Section 2. Development of this system involved the following phases :

PHASE 1. Creation of a paper model for detail classification using information given in the ECCS Recommendations.

2. Generation of case studies; alternatives have been priorized for situations where details, classified in Phase 1, fail the fatigue assessment.
3. Analysis of case studies; formulation of general rules for the selection of alternative designs.
4. Transfer of the paper model and rules for alternative designs to a computer model using an expert-system development tool called EXSYS [2].
5. Testing and verification of the computer model.

PHASE 1 - A paper model of approximately one fifth of the details, or half of Figure 1, is shown in Figure 2. Detailed criteria determining the finest divi-

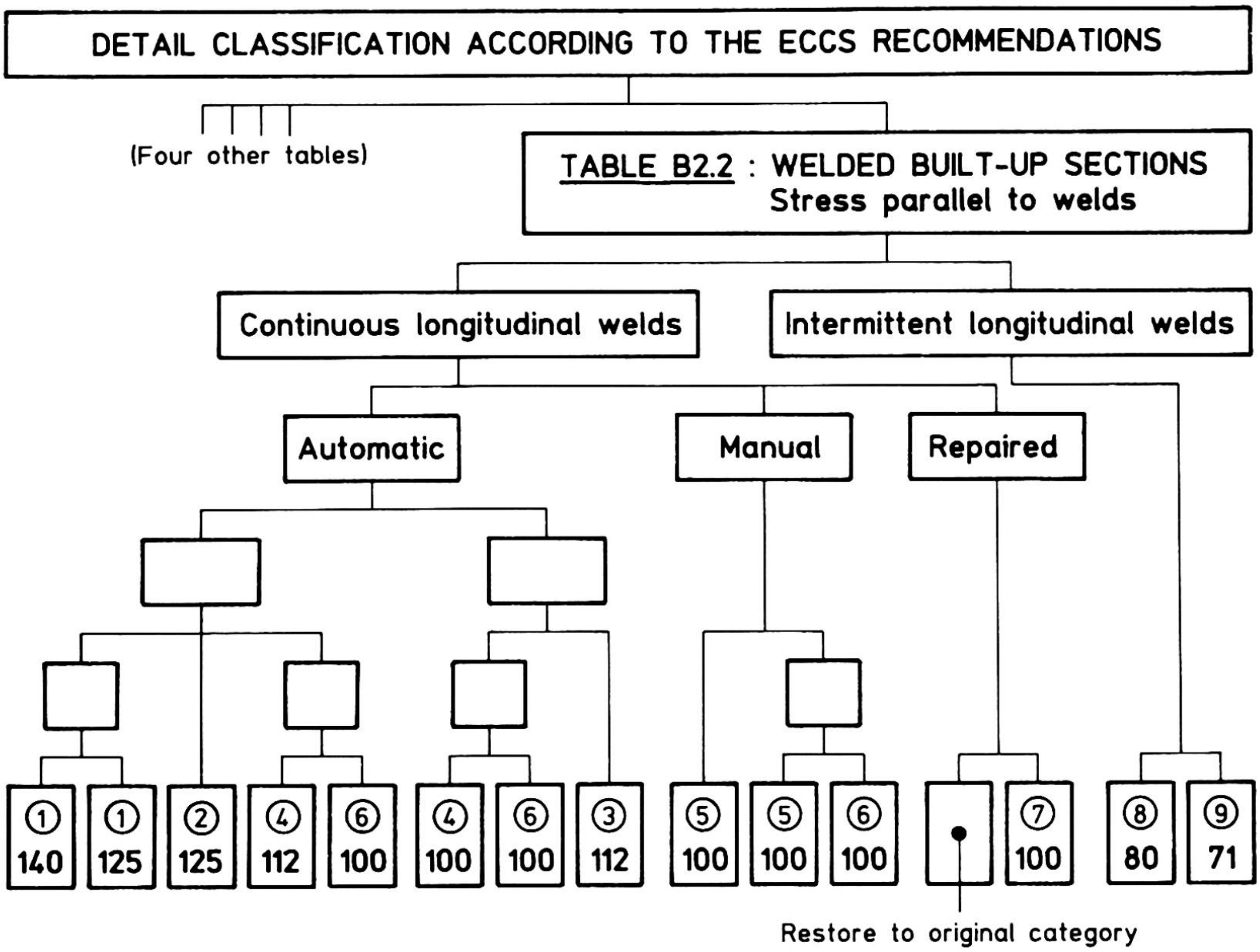


FIGURE 2 : Part of the paper model of the ECCS detail classifications [1].

sions, such as the presence of stop-start conditions, inspection criteria and weld type, are not shown. Each box at the bottom of Figure 2 represents a particular detail. The circled number in the box refers to the detail number defined in the Recommendations and the other number gives the detail category used during the assessment, see Equation (1). The structure of Figure 2 is analogous to an inheritance tree whereby the boxes in the bottom portion of the figure inherit the characteristics of their so-called parents higher up in the tree.

PHASE 2 - Generation of case studies was performed using an expert who selected and priorized alternatives for every detail in the paper model. The first author served as the expert. A description of this exercise is shown on Figure 3 for one detail in the tree. The detail which is presumed to fail the fatigue assessment is shown by the symbol, x, and alternative detail designs are numbered from highest to lowest priority.

PHASE 3 - The most obvious characteristic of the choice of alternatives is that, for a given case, whole sections of the paper model are not considered. This is due partly to detail compatibility. For example, a welded beam cannot be replaced by a longitudinal attachment, or a shear stud.

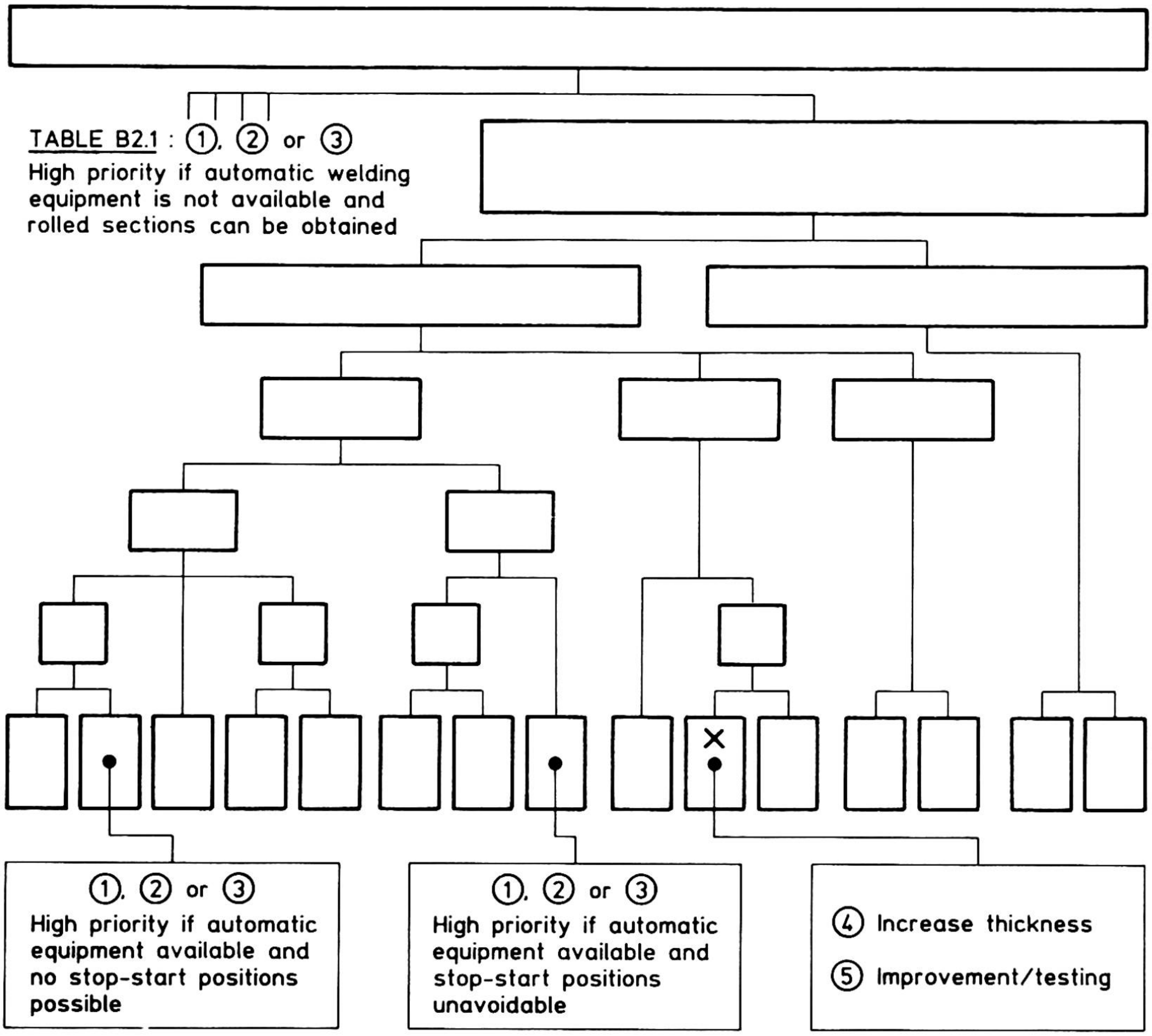


FIGURE 3 : Generation of alternative detail designs, numbered according to their priority given that a detail, shown by an x, fails the fatigue assessment.

Additional criteria were used to eliminate compatible designs. For example, if quality assurance cannot be guaranteed during fabrication, then all details which require high quality welding are not considered. Other criteria such as access for two-sided welding and the availability of automatic equipment often determine the number, type and priority of alternatives.

Details were priorized using criteria which are not described explicitly in the Recommendations, and which non-expert designers may not employ. Two alternatives, increasing thickness and fatigue-strength improvement including testing are not included in the classification model, Figure 2. Since these alternatives are possible for the large majority of details, the alternative-solution space is really three dimensional and therefore, the problem becomes more difficult.

However, some simplifications are possible. The improvement/testing alternative was always the lowest priority and increasing thickness was usually second lowest. Generally if a detail fails a fatigue assessment, it is best to investigate another detail before an attempt is made to keep the original detail through increasing plate thickness or through prototype testing and fatigue-strength improvement. This type of knowledge was used to assign values to alternatives. These values help to rank the alternatives from highest to lowest priority.

Thus heuristic knowledge was used for two purposes. The first helped to reduce the number of possible solutions, and the second helped to priorize the remaining alternatives. In most cases, eleven rules were being employed repeatedly during the selection of alternatives. These rules formed the basis of the heuristic portion of the knowledge base.

PHASE 4 - Transfer of the paper model and selection criteria to a rule-based expert system was achieved using a development tool called EXSYS [2]. Rules were constructed for classifying details, for generating alternative designs, for enabling user intervention and for providing control. A total of 154 rules (IF...THEN...ELSE...) make up the knowledge base. The inference engine employed backward chaining [2] for examining the rules and for interrogating the user. The system can be run in two modes - detail classification and alternative search. Figure 4 summarizes the principal components of the system.

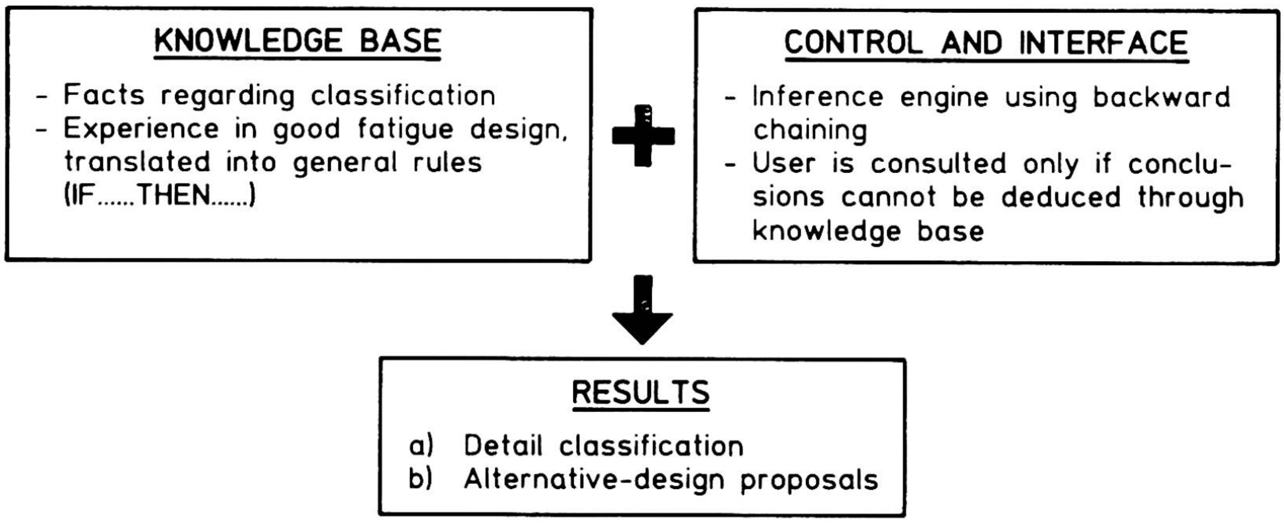


FIGURE 4 : Components of an expert system for fatigue design.

During detail classification some information, such as the ability to ensure adequate quality control, are stored for use during the generation of alternatives. This information helps to avoid situations where the user is asked needless questions. For example, if the original detail is one which requires special quality-control measures, the user will not be asked about quality during the generation of alternatives. It is assumed that if special quality-control measures are possible for one detail, they are also possible for another.

Before generating alternatives, the user is asked whether the original detail failed the fatigue assessment by a great deal, little, or half way between these extremes. If the fatigue assessment fails by a great deal, possible alternatives having high fatigue strengths are favoured. Conversely if the assessment fails by a little, the alternative detail design which increases the thickness of the original detail may be given a higher value.

Occasionally, alternatives do not include retaining the original detail under any circumstances. This is the case where the original detail has a low fatigue strength and there is another detail which is always a better design. In such cases, alternatives involving increasing thickness and testing/improvement are provided for the stronger detail.

During the search for alternatives, the user is given the opportunity to diverge from the opinion of the expert who helped develop the model. This is achieved by changing coefficients which govern the viability and priority of some alternatives. The user is asked if a personal opinion regarding a certain factor differs from the expert's opinion. If so, a new coefficient is requested.

PHASE 5 - Testing and verification is in progress. The information provided by the system compare well with the choices of the expert. Several fatigue experts are evaluating the recommendations provided by the system. This stage will be followed by non-expert evaluations in order to provide stimulus for creation of a clear and simple user interface.

Throughout the testing stages, some work will concentrate on the coefficients which are employed to select and to priorize alternatives. More work is needed to determine a physical meaning for their values in order to give the user an indication of the influence of certain factors on recommendations.

4. CONCLUSIONS

1. Even when modern codes are used, a certain amount of expert knowledge may be needed to create good fatigue designs.
2. Expert-system knowledge bases provide an effective way of formalising expert capabilities in civil engineering through synthesizing facts and design strategies.
3. A pilot expert system which aids good detail design was developed successfully using the ECCS fatigue-design document.
4. Further work, such as testing the system using several fatigue experts, is needed before the system can be offered for general use.

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[2] EXSYS, Expert system development package, Exsys Inc., Albuquerque NM, 1985.

Advances in Communication between CAE-Systems

Progrès dans la communication entre les systèmes informatiques

Fortschritte in der Kommunikation zwischen CAD-Systemen

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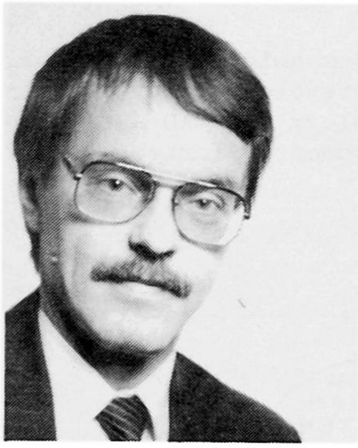

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SUMMARY
The paper presents a standard for bi-dimensional intelligent CAD data exchange created within a national development effort 1984–87 in Finland. Communication between various CAD-systems in based on an extremely compact transfer file format which is especially feasible for electronic data interchange. Interfaces to various CAD systems have been prepared by CAD-vendors, software houses and users. For the end users of of CAD-data a receiving system software package is provided with functions like graphical viewing and editing, plotting, extracting alphanumeric attributes and interfacing to computer integrated manufacturing. Application program developers are provided with software tools that allow them to interface in-house application software with various CAD systems.

RÉSUMÉ
Le document présente un standard pour l'échange de données bidimensionnelles de CAO créé dans le cadre d'un effort national de la Finlande entre 1984 et 1987. La communication entre les divers systèmes de CAO repose sur un format de fichier de transfert extrêmement compact, qui est spécialement favorable à l'échange électronique de données. Des interfaces pour divers systèmes de CAO ont été préparés par les vendeurs de CAO, les sociétés de logiciel et les utilisateurs. Pour les utilisaterus finaux de données de CAO, un progiciel système de réception est fourni avec des fonctions comme: vue et édition graphiques, tracé, extraction d'attributs alphanumériques et interface pour fabrication intégrée avec ordinateur. Des programmes d'application permettent l'interface des logiciels d'application maison avec divers systèmes de CAO.

ZUSAMMENFASSUNG
Dieses Referat stellt einen Standard für den zweidimensionalen, intelligenten CAD-Datenaustausch vor, der in den Jahren 1984–87 in Finnland entwickelt worden ist. Die Kommunikation zwischen verschiedenen CAD-Systemen basiert auf einem höchstkompakten Übertragungsdateiformat, das für den elektronischen Datenaustausch besonders geeignet ist. Schnittstellen mit unterschiedlichen CAD-Systemen sind von CAD-Lieferanten, Software-Häusern und Anwendern vorbereitet worden. Den Endbenutzern von CAD-Daten steht eine Empfangssystem-Software zur Verfügung, und zwar mit u.a. folgenden Funktionen: grafische Abbildung und Aufbereitung, grafische Darstellung, Abfrage alphanumerischer Attribute und Schnittstelle mit computerintegrierter Fertigung. Die Entwickler der Applikationsprogramme werden mit Software-Werkzeugen ausgestattet, die ihnen den Anschluß der betriebseigenen Anwendersoftware an verschiedene CAD-Systeme erlaubt.

1. BACKGROUND

By late 1984 integrated computer aided design had been applied in several building projects in Finland. In most cases the involved parties had different CAD-systems and various ad-hoc methods were used to solve communication between various systems. Interfaces based on the well known IGES standard for CAD-data interchange were generally found unusable because of:

- large file size practically prevents electronic data transfer,
- loss of information due to incompatible implementations,
- high translation cost due to heavy processing load,
- lack of well defined subsets leads to high cost of developing new compatible interfaces.

At the same time various companies in the construction industry were accelerating their efforts in the development of computer integrated design and manufacturing. The missing technology for CAD-data interchange was setting limits to the integration and development efforts.

2. BEC-PROJECT

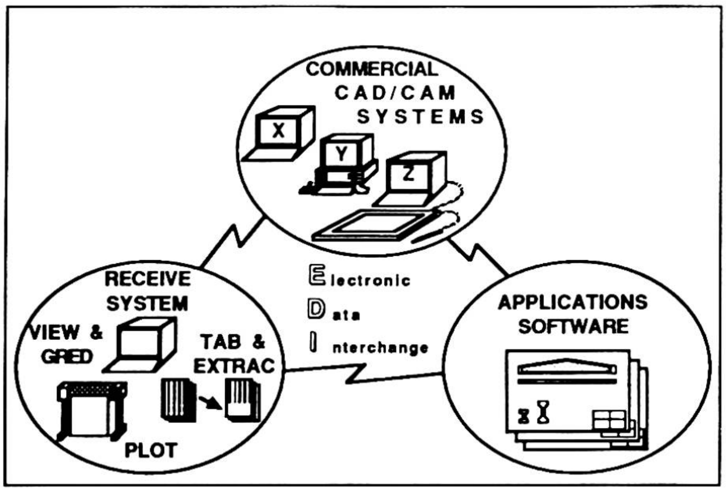

Fig. 1. Scope of BEC transfer system

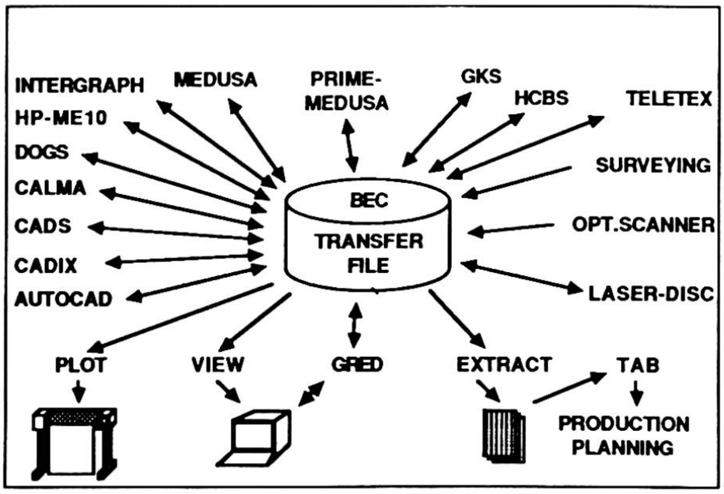

Fig. 2. CAD-systems and various applications supporting BEC data interchange format

In late 1984 the Association of Concrete Industry of Finland initiated a national development project on computer aided design and manufacturing of precast concrete components. Again, it was recognized that the major obstacle to development was the poor communication between various CAE-systems of the numerous companies participating in the design-manufacturing process Although this problem was evidently common to the whole (building) industry a decision was made in early 1985 to solve this problem between the most commonly used CAD-systems (in Finland). During 1985 a neutral transfer file format was specified. Also a common software library was developed to be used in writing all the various system dependent interface programs In January 1986 agreements were made with several CAD-vendors on cooperation to develope interface programs between their systems and the BEC transfer file format. During 1986-7 several interface programs were developed. As the last phase of the project a number of companies developed interfaces to their existing application software. The project was terminated in november 1987. The BEC format remains accepted as a de facto standard and is widely supported by CAD-vendors and users.

It was only natural that the initial development project called "BEC" (Betoni Elementti Cad) became to lend its name to the CAD data interchange system, which was an important but not the only part of the overall BEC-project. Other results of the BEC-project were:
- handbook on computer aided design of precast concrete,
- standardized product definition of precast concrete structures and components.

The purpose of these efforts was to create unified common practices that would allow more automated information processing and data exchange between organizations.

However, it should be noted that the BEC file transfer system described in this paper is based on general purpose computer graphics only and is independent of the technical application area.

3. TRANSFER FILE CHARACTERISTICS

The BEC transfer file format has been mainly affected by:
- Limitation to 2D-graphics only with associated alphanumeric information.
- ISO/GKS-standard on computer graphics programming.
- Data compression algorithms used to control some graphical devices.
- Common entities and data structures of modern CAD-systems.

The transfer file contains logical entities of the ISO/GKS-standard enhanced with several commonly used entities of interactive CAD-systems: line, arc, text, dimensioning, fill area, segment, symbol, layer, transformation matrix, alphanumeric attribute etc.

Data values are stored in packed ASCII format. The transfer file is unreadable to a human and "looks" similar to control code of e.g. a graphical terminal. The data is coded into a continuous sequence of ASCII-characters using a binary packing algorithm. As a result, the transfer file size is extremely compressed. Generally a BEC-file is less than 10 % of the corresponding IGES-file. A BEC-file is also typically about 50 % smaller than the original system dependent binary file of a CAD-system.

It should be noted that a BEC-transfer file can be treated as any ordinary text file. Any technology for text file transfer can be directly applied to transfer intelligent CAD-files as well.

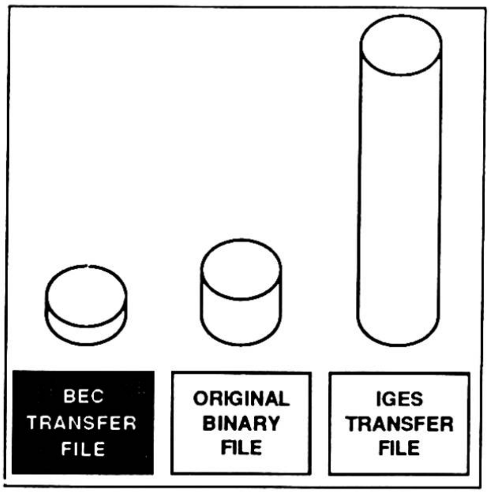

Fig. 3. File size in different formats

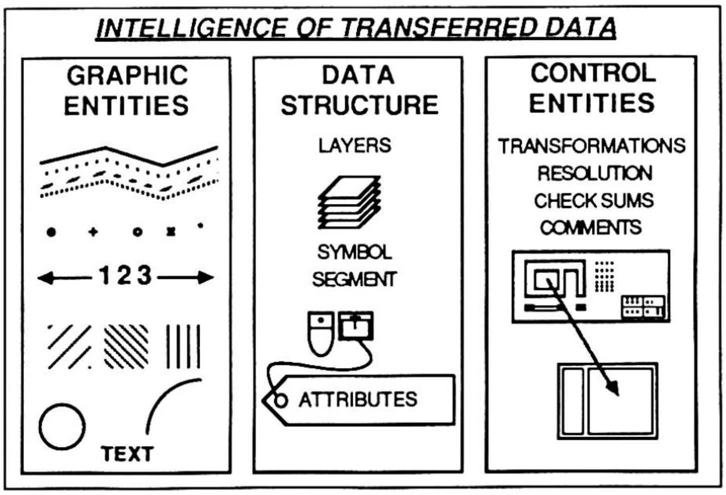

Fig. 4. Logical data structure of BEC transfer file

The core of the system is a common subroutine library which complies with the Fortran77-binding of the ISO/GKS-standard with some enhancements. The purpose of this software library is to assure compatibility of the various programs and to reduce the required development effort. As an internationally accepted computer graphics standard, GKS was a natural choice for the programming interface.

4. COMPATIBILITY

Development of compatible data communication software is an extremely sensitive process where the possibilities of something to go wrong are numerous. For this reason several precautions were taken in order to assure compatibility of various interface programs:

Instead of only releasing a written file format definition the authors of interface programs were provided with tested program modules and assistance during development. The common software modules are maintained as one original source code only for all supported different computers.

All interface programs are subjected to a formal validation test. Without approval any delivery of an interface program is prohibited. The vendors are obliged to inform their customers about the approved level.

It is also extremely essential to clearly define the implementation levels at which various conversion programs should operate. Otherwise various subset-implementations automatically lead to incompatibility and corrosion of the whole concept.

Three implementation levels of BEC were defined:

Level 0: All graphics must be transferred but no requirements are imposed on the logical data structure. Various user-developed application programs are allowed to operate at this level.

Level 1. In addition to visual graphics also the logical data structure is concerned (primarily layers, segments, symbols). This is the minimum accepted level for commercial CAD/CAM-systems.

Level 2. Alphanumeric attributes associated with graphical entities must be transferred. This is a voluntary capability.

Graphics can be transferred across implementations at all levels without loss of information.

5. RECEIVING SYSTEM

A receiving system was developed for the end-users of CAD-files. Such organizations may be passive users of data and may not need a "real" CAD-system. The included modules are:

- Previewing program VIEW allows viewing of BEC transfer files on a graphics screen with zoom, pan and level selection.
- Interactive modification of BEC-files is provided by the graphical editing program GRED.
- Program PLOT outputs transfer files on a plotter.
- Program EXTRAC separates alphanumeric attributes from the transferred file into formatted text file.
- Program TAB manipulates e.g. quantity information in array formed text files in various ways: sort, sum, re-order etc. Resulting data would typically be further transferred to a production planning or CIM system.

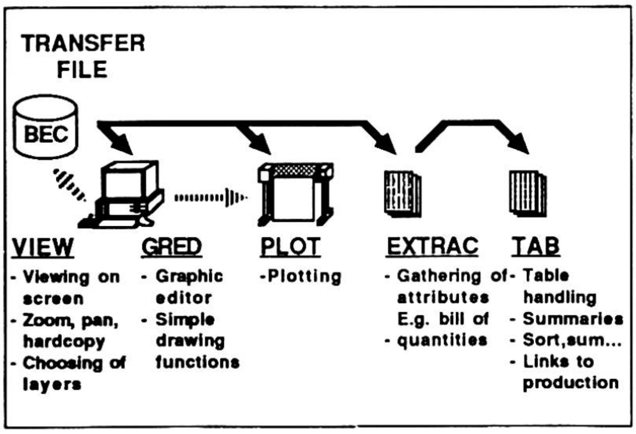

Fig. 5. Receive system modules

For electonic data transfer the public-domain terminal emulation program KERMIT is most commonly used to transmit files between various computers over public telephone network. Resently teletex emulation software like TELETEX-EMU has become available and adopted for BEC file transfer with a high automation level of data communication. Also other means for electronic data exchange are becoming available. If large amounts of information are to be transferred then physical media like magnetic tapes or PC-diskettes may be more appropriate.

6. INTERFACES TO APPLICATION SOFTWARE

Inspired by the removal of communication barriers between CAE-systems some innovative software has emerged within related applications.

Existing application software of a number of companies has been interfaced through the GKS/BEC-subroutine library which has been delivered to application developers. An alternative interface based on the well known HCBS subroutine library has also been used. These "conversionware" tools reduce the development effort of new interfaces.

Data transfer and conversion software converts recorded field surveying measurement data from data acquisition terminal connected to a theodolite and distance measurement equipment into CAD-files. Typical applications are: topographic surveying, measurement of old buildings for renovation design etc.

Interface program to an optical scanner transfers manually prepared drawings into various CAD-systems.

The VIEW-program of the BEC-receiving system has been enhanced for menu-controlled viewing and retrieval of CAD-archives stored on optical laser disks. Other spin-offs of VIEW are a graphical user interface to data base management systems and a PC-based maintenance system using CAD-graphics.

7. TOWARDS HIGHER LEVEL TRANSFER OF PRODUCT DATA

The focus of the BEC data transfer development was on 2D graphics exchange. However, as part of the overall BEC-project a higher level product model data transfer format was defined. Basically the definition is based on hierarchical assembly of buildings, components and details. The model also supports connections between objects. Experiments were made to define a whole building in this manner. Experimental software was developed to extract from a product model transfer file various kinds of lists and drawings.

Similar concepts of product modelling have been adopted in the development of vertical applications and have already resulted in commercial CAE-systems for the design of concrete and steel structures.

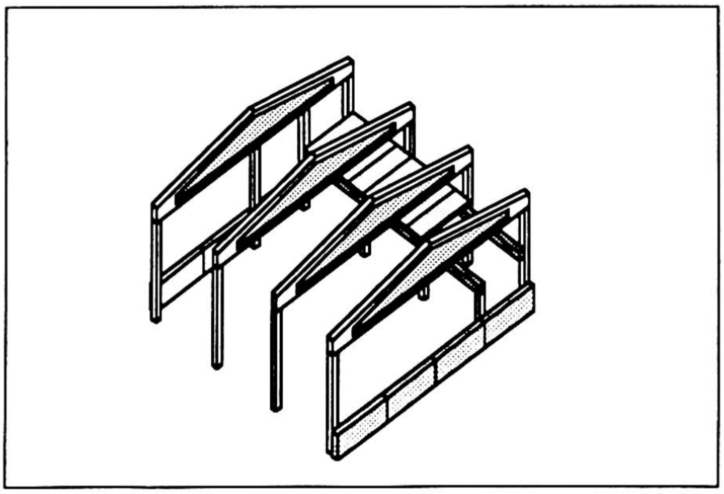

Fig. 6. Product modelling

In a national research and development project called RATAS more general product modelling concepts of building design are developed. As practical results standardized data transfer formats are being defined for various types of data and combinations of them: text, array, vector graphics (=BEC), raster graphics, product model (of buildings) and knowledge (rules and facts). The aim is to provide guidelines for further development of more integrated utilization of CAE-technology from public data bases to design, construction, maintenance etc.

8. CONCLUSIONS

Electronic data interchange (EDI) is emerging as a key technology in the way that organizations operate in the near future. After the initial years of learning to use computers also construction industry and building consultants are entering the era of computer integrated design and manufacturing. In this process electronic CAD-data interchange is a crucial element.

In about three years since the start of first development efforts the BEC file format has been accepted as a de facto standard for 2D-CAD data exchange method in the Finnish building industry and consulting. To some extent BEC has also been adopted in other application areas like mechanical engineering. In the near future electronic data interchange based on the BEC format is expected to be an essential element in the development of computer integrated design and manufacturing of buildings.

The majority of CAD-systems that are used in Finland provide a BEC-interface and new interfaces are continuously developed.

For the (small) CAD-community in Finland it was more important to get the day-to-day problems solved than continue the unsure waiting for something useful to appear from the CAD-vendors as a result of international standardization efforts. With limited resources but realistic goals it has been possible to develope a feasible solution for intelligent 2D-CAD interchange.

Encouraged by the results so far more ambitious developments have been initiated on a higher abstraction level of product modelling.

9. ACKNOWLEDGEMENTS

The initial development of the CAD-data transfer system described in this paper was funded by the Association of Concrete Industry in Finland (SBK) and the Technology Development Centre (TEKES). The work has been supported by leading organizations of the Finnish AEC-community, CAD/CAM-vendors and numerous individuals.

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Improvements in Data Communication in Switzerland

Amélioration dans l'échange des données en Suisse

Verbesserungen des Datenverbunds in der Schweiz

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SUMMARY
With the increasing use of computers, data communication is needed in practically all phases of the design and construction process. Incompatibilities in hardware and software, however, often make the exchange of data difficult or even impossible. In Switzerland efforts were made by the Swiss Society of Engineers and Architects during the past two years to improve this situation. These efforts and the resulting Recommendation are discussed in the paper. The impact of this Recommendation on the Engineering community is discussed.

RÉSUMÉ
Avec l'utilisation toujours plus grande d'ordinateurs apparait la nécessité d'échanger des données à chaque stade de la conception et de la construction d'un ouvrage. Cependant, les incompatibilités des matériels et des logiciels rendent cette communication souvent difficile sinon impossible. Au cours des deux années écoulées, la Société Suisse des Ingénieurs et Architectes a travaillé pour remédier à cette situation. Cet exposé décrit ces efforts ainsi que la recommandation qui en résulte. Il montre l'impact de cette recommandation sur le secteur du génie civil.

ZUSAMMENFASSUNG
Mit dem zunehmenden Einsatz von Computern wird der Datenaustausch in praktisch allen Phasen der Planung und der Ausführung benötigt. Inkompatibilitäten der Hardware und Software machen aber den Datenaustausch oft sehr schwierig oder verhindern ihn gänzlich. In der Schweiz wurden während der letzten zwei Jahre vom Schweizerischen Ingenieur- und Architektenverein Anstrengungen unternommen, um diese Situation zu verbessern. Diese Arbeit sowie die daraus resultierende Empfehlung werden in der vorliegenden Veröffentlichung diskutiert. Die Auswirkungen dieser Empfehlung auf die Bauindustrie werden besprochen.

1. INTRODUCTION

When the first electronic computers became available on the market about 40 years ago, the Civil and Structural Engineers were among the first to use these new facilities. It was realized, that by the use of computers problems which could not be solved till now suddenly could be attacked with new numerical procedures. Among these problems were numerous tasks of structural analysis such as the analysis of plates and shells, nonlinear problems and dynamic problems. In addition to these technical problems many administrative tasks could be handled more effectively by means of computers.

With the rapid increase of the power and the availability of computers and software a new industrial revolution has started. Today we are in the middle of a complete reshaping of our working and social environment. It was soon realized, that inspite of sophisticated software in many cases the exchange of data between different programs was necessary or desirable. The incompatibilities of the software- or hardware-interfaces, however, prevented data communication in many instances. These difficulties in data communication still prevail. This situation was recognized by the Swiss Society of Engineers and Architects (SIA) and efforts were made to improve the data communication situation for the construction industry. A Committee headed by the author was formed to define the rules for the exchange of data.

2. DEFINITION OF TASKS

A first study of the situation of Data Communication in the construction industry showed, that the problem was very complex indeed. Practically all parties in a construction project such as the contractor, the architect, the engineer, the owner, the banks etc. have needs for data exchange. The data comprise the whole range from accounting data to structural analysis data and CAD. The hardware and software used by the different parties is usually not compatible. A comprehensive definition of interface formats for all the different tasks seemed to be above the means of the Committee. A study of existing exchange formats such as used in the systems SWIFT or TELETEX indicated, that these formats were only partially suited for the needs of the construction industry. It was also realized that the upcoming new data communication facilities by the PTTs on the basis of fibreglass optics (ISDN etc.) will open up new ways for the exchange of data.

It was soon clear, that an improvement of the data communication situation could be done only in a coordinated step by step approach. Therefore the tasks were defined and restricted as follows:

a) As a first step the exchange of data should be done by means of traditional data carriers such as magnetic tapes, diskettes a.s.o. The use of telephone networks for data exchange was considered to be a second step.

b) The area of application was limited to the exchange of tenders. As a basis for the exchange, the use of Catalogues of Standard

Building Descriptions was considered to be mandatory.

c) The resulting Recommendation on exchange formats should define easy to implement formats for the software developers.

3. PILOT PROJECTS

In order to check the feasibility of this approach, two pilot projects were run. The first project used a tender generated by the engineer on an 8"- Diskette on IBM format 1D, 128 bytes/sector. This diskette was sent to a contractor who could read it and filled in the corresponding prices. The tender then was sent back to the engineer for evaluation and comparisons.

A second pilot project was set up to exchange a tender by means of a Diskette from an Olivetti- PC to an IBM- PC. The exchange of data was difficult because the format on the Diskette on Olivetti was different from the format on IBM. Furthermore, it turned out that the data had been encyphered by the software developer. Both difficulties are typical for the present situation in data communication. They could be overcome with some additional efforts.

The two pilot projects showed, that the exchange of data between architect, engineer and contractor is technically quite possible. They also confirmed that substantial savings of time and effort were possible by exchanging data rather than retyping the information. Furthermore, typing errors etc. are eliminated completely by this approach. It is necessary, however, to define the exchange formats hardwarewise and softwarewise. In addition procedures have to be defined to make tenders on data carriers legally binding and to ensure data security.

4. SIA RECOMMENDATION V451

The Recommendation V451 contains the rules for Data Communication and defines the exchange formats for tenders. The Recommendation is based on formats for Catalogues of Standard Building Descriptions and references these standard descriptions by codes. The exchange formats were open to discussion until the end of the year 1987. A fixed format was chosen on purpose in order to keep high transparency. It was proposed, that menue- driven interactive programs form the user interface. The fixed format data can later be run through a compacting/ decompacting program to remove unnecessary blanks. Presently pilot interface programs are developed based on that Recommendation which will be available to the engineering community in early 1988. The V451 is planned to be given the character of a code in 1988.

A number of recommendations for improvements were made during the discussion period. They essentially concerned the availability of a free format representation of the data in addition to the fixed format, the representation of Codes (ASCII,EBCDIC), the proposed standard data carriers and the arrangement of some data fields. All these recommendations are presently evaluated and will reflect in the final version of V451.

Several meetings were held with the city and the canton of Zurich as well as with other owners in the public domain in order to get the cooperation of the owners for the new data exchange facilities. In addition a meeting was held with software developing companies to encourage them to implement the recommended formats into their codes. From their response it can be expected, that a number of engineers, architects and contractors will start exchanging tenders by data carriers rather than by paper in 1988.

5. CONCLUSIONS AND RECOMMENDATIONS

The improvement of Data Communication in the area of exchange of tenders will undoubtedly increase the efficiency of the construction industry. The quality of tenders will probably increase and the rate of errors will decrease. The task of comparing different tenders will be greatly simplified by the exchange of data carriers.

There are several steps to follow up. One is to use public or private networks for Data Communication in the near future. For this the use of compacted data formats for the data exchange would be mandatory. Other areas such CAD, structural analysis etc. should be looked at to define standard exchange formats and such to improve further the facilities for data exchange in the construction industry.

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Der rechnerunterstützte Ingenieurarbeitsplatz – Anforderungen und Lösungen

The CAE – Workstation – Requirements and Approaches

La place de travail informatisée: besoins et propositions

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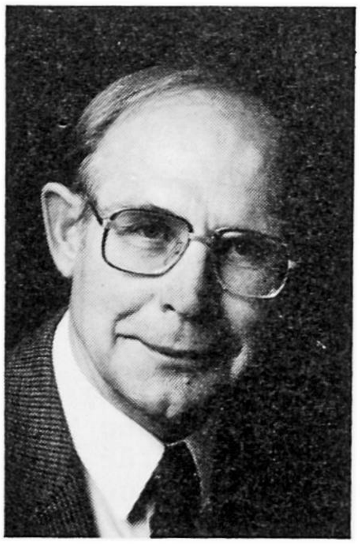

Heinrich Werner, geboren 1931, promovierte 1965 als Bauingenieur an der Universität Hannover. In den nachfolgenden fünf Jahren war er in der Bauindustrie besonders mit dem Rechnereinsatz im konstruktiven Ingenieurbau befaßt. 1969 habilitierte er sich für das Fach Elektronisches Rechnen im konstruktiven Ingenieurbau. Seit 1971 ist er Universitätsdozent und seit 1977 Universitätsprofessor an der Technischen Universität München.

ZUSAMMENFASSUNG
Der multifunktionale Ingenieurarbeitsplatz wird zur Standardausrüstung in den nächsten Jahren. Über ihn steht der Ingenieur in interaktiver Verbindung sowohl mit den Bearbeitungsprogrammen als auch mit anderen, am Planungs- oder Entwurfsprozeß beteiligten Personen. Die Kommunikation in lokalen und überörtlichen Netzen erhält eine Schlüsselrolle. In dem Beitrag werden Anforderungen an die Softwarequalität und an die Dialoggestaltung aufgestellt und Lösungen beschrieben.

SUMMARY
The multifunctional engineerung workstation is supposed to become general equipment within the next years. By means of this equipment the engineer is interactively connected to engineering software and to other people involved in the design process. Communication in local area networks and in remote networks are becoming a key object. In the paper some requirements of software quality and user interfaces are given and current approaches are indicated.

RÉSUMÉ
Dans un proche avenir, la place de travail de l'ingénieur sera multifonctionelle et informatisée. Grâce à celle-ci, l'ingénieur sera en liaison interactive aussi bien avec les programmes de calcul de structures qu'avec d'autres personnes concernées dans le processus du projet. La communication joue un rôle déterminant dans les réseaux locaux et à grande distance. La contribution mentionne les qualités requises du logiciel ainsi que les interfaces nécessaires aux utilisateurs; les solutions actuelles sont indiquées.

1. EINFÜHRUNG

In den kommenden Jahren werden rechnerunterstützte,multifunktionale Arbeitsplätze zur Standardausrüstung der Ingenieure gehören. Ihre Vernetzung ermöglicht eine weitreichende Kommunikation zwischen den am Planungs- oder Bauprozeß Beteiligten und zur Außenwelt.
Diese technischen Entwicklungen haben tiefgreifende Konsequenzen auf das Ingenieurgeschehen: War bisher die Datenverarbeitung ein Mittel zur Herstellung besserer Entwürfe mit geringerem Aufwand, so ist jetzt die Bauinformatik dabei, Entwurfs-, Planungs- und Bauprozesse selbst zu analysieren und zu modellieren.
Der Einsatz moderner Informations- und Kommunikationstechniken wird zur Schlüsselaufgabe in einem sich verschärfenden Wettbewerb.

2. HARDWARE /2/

Seit dem Beginn der Vermarktung von Mikroprozessoren 1974 haben die Prozessorleistung und die Speicherkapazität pro Chip sich aller drei Jahre vervierfacht.
Seit drei Jahren werden 32-Bit-parallel verarbeitende Mikroprozessoren angeboten, deren Rechnerleistung bei 4 Mips (= 4 Millionen Instruktionen pro Sekunde) liegen; für die nächste Zukunft könen wir davon ausgehen, daß alle Ingenieurarbeitsplätze mit 'persönlichen' Rechnern der 32-Bit-Klasse ausgestattet sind.
Die Arbeitsumgebung des Ingenieurs bilden der Bildschirm mit Tastatur und Stift oder Maus, die Ausgabegeräte Drucker und Plotter, Plattenspeicher und der Anschluß an lokale und öffentliche Netze.
Der Trend, diese peripheren Geräte mit separaten Prozessoren zu betreiben, führt zu einer Steigerung der Gesamtleistung der Systeme.
Insbesondere setzen bei den graphischen Bildschirmen eigene Bildprozessoren vektorielle und flächenhafte Informationen schnell in Bildpunkte um.
Farbbildschirme verbessern die Übersicht des konstruktiv tätigen Bearbeiters so entscheidend, daß dieser darauf nicht mehr verzichten wird. Hochauflösende Laserdrucker kommen in akzeptable Preisbereiche, insbesondere wenn sie von mehreren Arbeitsplätzen aus angesteuert werden.

3. SOFTWARE

3.1 Betriebssysteme und fachübergreifende Software

Mit der Entwicklung weitverbreiteter Mikroprozessoren haben sich Betriebssysteme auf dem Markt durchgesetzt, die zum Quasi-Standard wurden; so z.B. MS-DOS oder sein Nachfolger OS/2 für PCs.
Zur Erhöhung des Bedienungskomforts tragen stift- oder mausgesteuerte graphische Benutzeroberflächen bei, wie z.B. GEM von Digital Research. Die volle Leistungsfähigkeit der heutigen 32-Bit-Prozessoren wird durch das Betriebssystem UNIX ausgenutzt, das dabei ist, zum verbreiteten Qasi-Standard für Workstation-Computer und für alle Computer der höheren Leistungsklasse zu werden.
Insbesondere ist UNIX durch seine Mehrprozeß-, seine Mehrbenutzer- und durch seine Netzfähigkeit ausgezeichnet.

Mit verbreiteten Betriebssystemen konnte sich fachübergreifende Software entwickeln, die wegen ihrer hohen Verkaufszahlen durch
- eine hohe Zuverlässigkeit, durch
- bemerkenswerten Handhabungskomfort und durch
- ein sehr günstiges Preis-/Leistungs-Verhältnis

gekennzeichnet ist.
Zu ihr zählen z.B. Textbearbeitungssysteme, Desktop-Publishing-Systeme, Datenverwaltungssysteme, Tabellenkalkulationsprogramme (Spreadsheets) sowie graphische Zeichnungssysteme.

3.2 Benutzeroberflächen

Die Bedienung der Arbeitsplätze erfolgt im Dialog über die 'Benutzeroberfläche'. Ihre Ergonomie beeinflußt entscheidend die Akzeptanz und die Effektivität rechnerunterstützten Arbeitens /1/.

Der Ingenieurdialog umfaßt im Bauwesen etwa die Funktionen:
1. Interaktive Dateneingabe über Tastatur, Stift oder Maus,
2. Darstellung und Interpretation von Ergebnissen in Tabellen, Zeichnungen oder Schaubildern,
3. Steuerung der Aufruffolge von Bearbeitungsprogrammen und
4. Informationsgewinnung und -weitergabe auf Kommunikationswegen.

An die Gestaltung des Dialogs sind hohe Anforderungen zu stellen:
1. Einheitlichkeit auch bei unterschiedlichsten Aufgaben:
   - Gleichartige Aktionen sind mit gleichartigen Interaktionen auszulösen (z.B. Kopieren eines Briefes oder einer Zeichnung),
   - die Dialogform darf nicht mit jeder Aufgabe wechseln,
   - die manuellen Arbeitsmittel (z.B. Aktenordner, Papierkorb, Lineal) sollten auf dem Bildschirm symbolisch beibehalten werden.
2. Selbsterklärungsfähigkeit der Benutzeroberfläche (eine zusätzliche Handbuchbenutzung widerspricht dem Dialogcharakter):
   - statische Auskunftssysteme, deren Auskünfte auf Anfrage unabhängig vom Bearbeitungszustand erfolgen und
   - Beratungssysteme, die als Expertensysteme die Bearbeitungsgeschichte mitverfolgen und die sich bei Fehlern melden.
3. Steuerbarkeit und individuelle Gestaltbarkeit:
   - ständiger Zugang zum Arbeitsplatz, stete Zugriffsmöglichkeit auf alle benötigten Daten und Programme und jederzeitige Auskunft über den aktuellen Bearbeitungszustand,
   - Steuerung der Aktionenfolge, der Datenverwaltung und des Geräteeinsatzes durch den Bearbeiter,
   - UNDO- und REDO-Fähigkeiten sowie
   - Anpassung des Dialogs an den Erfahrungs- und Wissensstand des Benutzers sowie an seine Fähigkeiten und seine Eigenheiten. Eine Überforderung des Benutzers führt zur Ablehnung, eine Unterforderung zur Eintönigkeit.

Es ist erkennbar, daß in der Gestaltung von Bedieneroberflächen Multifenstertechniken mit Maus- oder Stiftsteuerung die kommende Entwicklung bestimmen.
Graphische Darstellungen eingegebener Objekte, Manipulationen an diesen Objekten durch Anpicken von zu verändernden Objektteilen und von Menüfeldern sowie die geometrische Eingabe mittels eines Digitalisierstiftes greifen ingenieurmäßige Arbeitstechniken wieder auf. Fig. 1 zeigt einen Vorschlag für die interaktive Generierung finiter Elemente /5/.

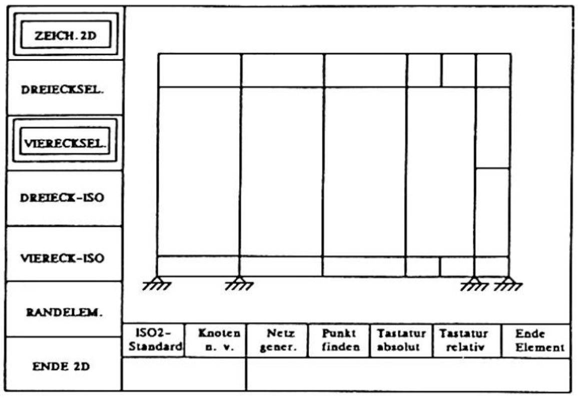

Fig.1 Erzeugung eines Finite-Element-Netzes

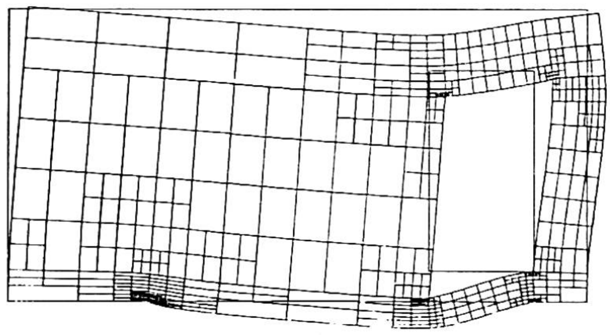

Fig.2 Adaptiv verfeinertes Finite-Element-Netz

3.4 Fachspezifische Software

Mit dem Fortschritt der Informationstechnik wachsen die Anforderungen an die Leistung und die Qualität fachspezifischer Software:

1. Zwingend notwendig erscheint die Einbindung vorhandener Einzellösungen in Konzepte der vernetzten Bearbeitungen. Das erfordert eine umfangreiche Analyse der Prozeßabläufe in Entwurf, Konstruktion, Planung und Bauausführung. Ihr folgt eine Feststellung der Informationsflüsse und die Formulierung von Schnittstellen.
2. Es empfiehlt sich, fachspezifische Aufgaben so zu modellieren, daß bei der Realisierung in möglichst hohem Maße fachübergreifende Software als Werkzeuge mit eingestzt werden kann. Dazu gehören z.B. der Rückgriff auf Datenverwaltungssysteme, auf Graphiksysteme oder der verstärkte Einsatz von Tabellenkalkulationsprogrammen, aus denen heraus fachspezifische Berechnungen aufgerufen werden.
3. Bei der Handhabung von Programmen ist es einem Ingenieur nicht zuzumuten, daß er gedanklich laufend von einer zur anderen Eingabevorschrift umwechselt. Heutige Fenstertechniken wie z.B. X-WINDOWS ermöglichen standardisierte Dialogformen in unterschiedlichsten Programmumgebungen.
4. Ein wichtiges Merkmal qualitativ hochwertiger Software ist ihre Zuverlässigkeit. Sie umfaßt
   - richtige Problemlösungen in abgegrenzten Einsatzbereichen,
   - Minimierung von Abstürzen durch Programmierfehler und
   - Plausibilitätskontrollen der Eingabedaten.

   Dem ersten Punkt kann man sich durch die Erarbeitung von Patchtests, die freizugebende Programme mindestens erfüllen müssen, nähern. Bemerkenswert sind hier die Patchtests der britischen Organisation NAFEMS für Finite-Element-Programme.
   Der zweite Punkt wird durch modernes Softwareengineering mit erprobten Testmethoden sowie durch vermehrten Einsatz ausgereifter Softwarebausteine erreicht.
5. Programme des rechnerunterstützten Ingenieurwesens (CAE) stützen sich auf Ingenieurmodelle. Diese Modelle erhalten im Laufe eines

Entwurfs- oder Planungsprozesses zunehmenden Verfeinerungsgrad. Eine Effizienzsteigerung wird erreicht, wenn durch automatische Abschätzung der Güte eines Ergebnisses das verwendete Modell adaptiv verfeinert werden kann.
Bekannte Beispiele in dieser Richtung sind die adaptiven Finite-Element-Modelle, in denen auf Grund lokaler Fehlerschätzungen /6/ entweder die Elementeinteilung (Fig. 2) oder die Elementwertigkeit oder beides zusammen /7/ verändert wird.

4. KOMMUNIKATION

4.1 Überblick

Über den Arbeitsplatzrechner ist der Ingenieur als Sachbearbeiter in vernetzte Planungs-, Konstruktions- oder Herstellungsprozesse eingebunden. Der Bildschirm wird zum wichtigen Kommunikationsmittel
- zwischen den an den Prozessen beteiligten Bearbeitern und Gewerken (horizontaler Informationsaustausch),
- zwischen den nacheinander ablaufenden Phasen der Projektentwicklung (vertikaler Informationsfluß),
- zwischen den Bearbeitern und der 'Außenwelt' (Bauherr, Behörde, Informationsdienste) sowie
- zwischen den Arbeitsplätzen und gemeinsam genutzten Geräten (Laserdrucker, Plotter oder Massenspeicher).

4.2 Lokale Netze

Lokale Netze (LANs) dienen dem Informationstransfer zwischen gleichberechtigten Rechnern in einem räumlich begrenzten Gebiet. Angebotene Basisdienste der lokalen Netze /3/ sind z.B.
- der Zugriff auf Dateien anderer Rechner (remote file acces),
- der Zugriff auf Geräte, die durch andere Rechner betrieben werden (remote device acces),
- die Nutzung fremder Rechenkapazität (remote execution) und
- die Kommunikation zwischen auf unterschiedlichen Rechnern aktiven Prozessen (intertask communication)

Die Ausnutzung der genannten Fähigkeiten vergrößert den Leistungsbereich eines einzelnen Arbeitsplatzes beträchtlich durch
- parallele Nutzung mehrerer Prozessoren, durch
- gemeinsame Nutzung teurer Peripheriegeräte oder durch
- dezentral verwaltete, aber gemeinsam benutzte Datenbestände.

4.3 Öffentliche Netze

Über öffentliche Wählnetze (Telefonnetze, Datex-Netze) wird der Arbeitsplatzrechner mit der gesamten Außenwelt, z.B. mit Informationsdatenbanken oder mit Projektpartnern an anderen Orten verbunden. Im Bereich der Universitäten wird seit einigen Jahren erfolgreich das EARN ('European Academic Research Network') der IBM für den elektronische Briefverkehr und für Dateiübermittlungen eingesetzt. EARN ist über 'Gateways' mit dem Nachbarnetz BITNET in den USA verbunden; eine Einrichtung, die einen raschen wissenschaftlichen Austausch innerhalb und zwischen beiden Kontinenten ermöglicht hat. In der Bundesrepublik Deutschland wird zur Zeit das Deutsche Forschungsnetz 'DFN' aufgebaut und in Pilotprojekten erprobt. In ihm können Arbeitsplatzrechner und Großrechner unterschiedlicher Bauart

über Standardprotokolle miteinander kommunizieren.
Eines der DFN-Pilotprojekte ist die 'Softwarebörse Bauwesen', in dem an verschiedenen Orten Aufgaben der Tragwerksplanung im Verbund bearbeitet werden. Ziel ist es, die dezentrale Projektplanung modellhaft zu erproben.

5. AUSBILDUNGSFRAGEN

Einen Hauptkostenfaktor bei der Einführung von CAE in einem Ingenieurbüro bildet die Ausbildung und die Schulung der Mitarbeiter.
Die CAE-Ausbildung an den Universitäten hat mit der technologischen Entwicklung nicht Schritt gehalten.
Verstand man seither unter Technik die Beherrschung von Materialien, von Kräften und von Energien, so tritt heute die Beherrschung und Verarbeitung von Informationen in den Vordergrund. Dieser Veränderung hat die Ingenieurausbildung Rechnung zu tragen.
Im Bereich des Bauingenieurwesens formiert sich als neues Querschnittsfach die Bauinformatik. Die Schwerpunkte in Lehre und Forschung der Bauinformatik liegen in der Analyse und der Modellierung von Prozessen des Bauwesens sowie in der Entwicklung von Methoden zu ihrer Realisierung.
An der Fakultät für Bauingenieur- und Vermessungswesen der Technischen Universität München wurden im Rahmen des Computerinvestitionsprogrammes der Bundesregierung (CIP) 20 untereinander vernetzte UNIX-Arbeitsplätze für die rechnerunterstützte Lehre bereitgestellt.
Auf ihnen erhalten die Studenten eine, auf einem vorangehenden Programmierkurs aufbauende, Querschnittsausbildung im Fach Bauinformatik mit den Themenbereichen
- Betriebssysteme und Datenverwaltung,
- geometrische Modellierung und interaktive Computergraphik,
- bauspezifische Prozesse, Modelle, Algorithmen und Software.

Im Vertiefungsstudium bauen fachspezifische Lehrangebote, wie z.B. Finite Elemente in der Tragwerksberechnung, darauf auf.

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