

**Zeitschrift:** IABSE congress report = Rapport du congrès AIPC = IVBH  
Kongressbericht

**Band:** 11 (1980)

**Artikel:** Computer design of complex building structures

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**DOI:** <https://doi.org/10.5169/seals-11323>

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## VII

### Computer Design of Complex Building Structures

Projet de structures complexes de bâtiments à l'aide de l'ordinateur

Planung komplexer Baukonstruktionen mit Hilfe des Computers

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### SUMMARY

This paper deals with the use of computers in the design of complex building structures such as structures in sport centres and industrial buildings. Rather than use large integrated computer systems it is preferred to develop chains of programmes for each of the different building components: beams, columns, frames, etc. Such a chain of programmes for reinforced concrete columns is described with special emphasis on the analytical aspects.

### RESUME

Ce rapport décrit l'utilisation de l'ordinateur dans l'étude de structures complexes telles que les structures de centres sportifs et de bâtiments industriels. Au lieu d'utiliser des systèmes de calculs très intégrés il est préférable de développer une chaîne de programmes pour chaque élément de construction: poutres, poteaux, portiques, etc. Une telle chaîne de programmes pour poteaux en béton armé est décrite en mettant l'accent sur les aspects analytiques.

### ZUSAMMENFASSUNG

Der Artikel behandelt den Einsatz von Computern bei der Projektierung komplexer Baukonstruktionen wie Sportzentren oder Industriebauten. Es wird vorgeschlagen, anstelle komplizierter Computerprogramme eine Reihe von Teilprogrammen für die einzelnen Bauelemente wie Stützen, Balken, Rahmen etc. zu benutzen. Ein solches Teilprogramm für Stahlbetonstützen wird beschrieben.



## 1. INTRODUCTION

Large integrated computer systems for calculation and drawing of building structures become extensive, elaborate and overwhelming if they shall cover the complexity and the variety of structures facing the designer of buildings.

Buildings for sports and industrial production have to be designed to meet individual needs. The variation from project to project is so great that systematic computerized design of the total structural system is meaningless.

However these individual projects often contain problems which can only be solved properly with computer aid. In our building department we have therefore put emphasis on the development of advanced programmes for calculation of individual structural members as columns, beams, frames, foundations and slabs.

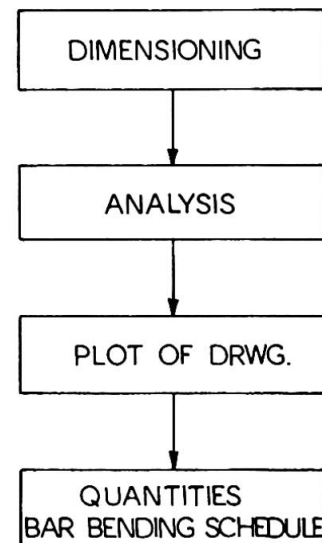
## 2. BASIC CONCEPT

As the programme library grows in width - covering more and more structural elements - and in depth - covering all phases of design from dimensioning to prepairing of bill of quantities - the need for a framework, a common basic concept, is strongly felt.

The system under development consists of chains of programmes for the individual structural members consisting of programmes for dimensioning, analysis, plotting of drawings, measuring and storing of quantities and, for reinforced concrete, extracting bar bending schedules.

From these chains of programmes information may be collected and used in programmes to produce the synthesis in the form of layout drawings, joint details, bill of quantities etc.

To illustrate the structure of these chains the programmes for calculation and drafting of reinforced concrete columns are described in the following.



## 3. PROGRAMME CHAIN FOR REINFORCED CONCRETE COLUMNS

Traditional simplified analysis of reinforced concrete columns disregarding such effect as the variation of stiffness with the extent of cracking, the non-linear stress/strain diagramme, the true shape of the moment curve etc. are in many cases not satisfactory.

One of our first programmes was therefore a column programme which took these effects into account (2), (3). This first generation programme, which was limited to statical determinate columns with rectangular or circular cross section and subject to mono-axial bending, has now been replaced by a second generation programme. This programme analysis statically indeterminate reinforced concrete columns with arbitrary polygonal, solid or hollow, section and subject to variable normal forces and biaxial bending.

### 3.1 Dimensioning

The possibility of developing a programme for dimensioning has been considered and given up for two reasons: It would be complicated and the geometrical properties depend to a great extent on irrational considerations e.g. aesthetics which is not well suited for computers.

### 3.2 Analysis

The programme uses a finite element method to calculate stresses and strains in a reinforced concrete column subject to biaxial bending and normal force with due regard to the physical and geometrical non-linearities.

A space beam element with an inner joint is used in the finite element formulation. This element has 11 degrees of freedom as torsion is neglected. The solution to the non-linear problem is arrived at by an iterative process divided into a physical and a geometrical iteration.

The purpose of the physical iteration is to determine the stiffness constants corresponding to the actual stress/strain distribution. The stiffness constants are calculated as the area integral over the cross section of the product of the geometrical properties and the secant modulus of elasticity based on the elastoplastic stress/strain diagrams for concrete and steel. It can be shown (1) that this procedure leads to the exact correlation between generalized strains and stresses.

In the integration the reinforcement is considered placed in points and the surface integral over the compressed concrete area is transformed to a line integral using Gauss' integral law i.e. the integration is performed along the periphery of the compressed concrete area.

The purpose of the geometrical iteration is to determine the deflection curve corresponding to the stresses and strains in the sections in a state where the column is in equilibrium subject to moment and normal force and taking into account second order effects i.e. the moments from the normal force due to the deflection. It is the second order phenomena which necessitate the iterative process to solve the system equations.

In the development of the element matrices, it is taken into account that the centerline of the system not necessarily coincide with a line through the gravity centers of the elements. The use of elements with an inner joint is necessitated by this fact. The system matrix is composed of the traditional stiffness matrix,  $\bar{K}_O$ , the geometric matrix,  $\bar{K}_G$ , the geometric matrix for large deformations,  $\bar{K}_L$ , and a new matrix called the load dependent geometric matrix,  $\bar{K}_F$ . Thus the system matrix has the following form:

$$\bar{K}_O = \bar{K}_O + \bar{K}_G + \bar{K}_L + \bar{K}_F$$

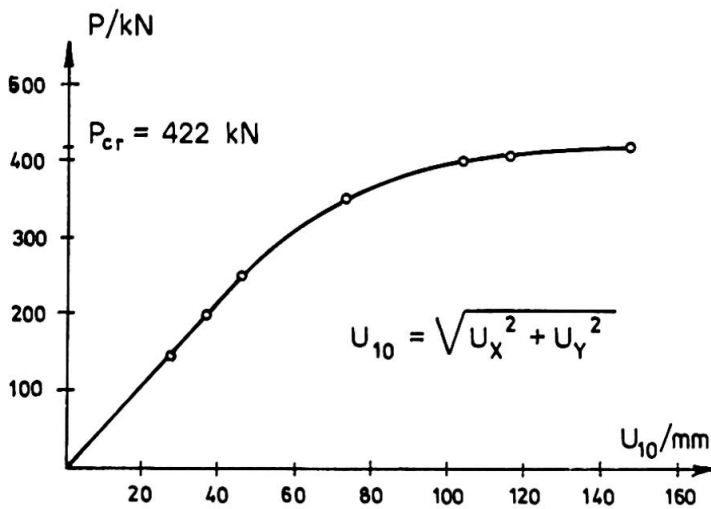
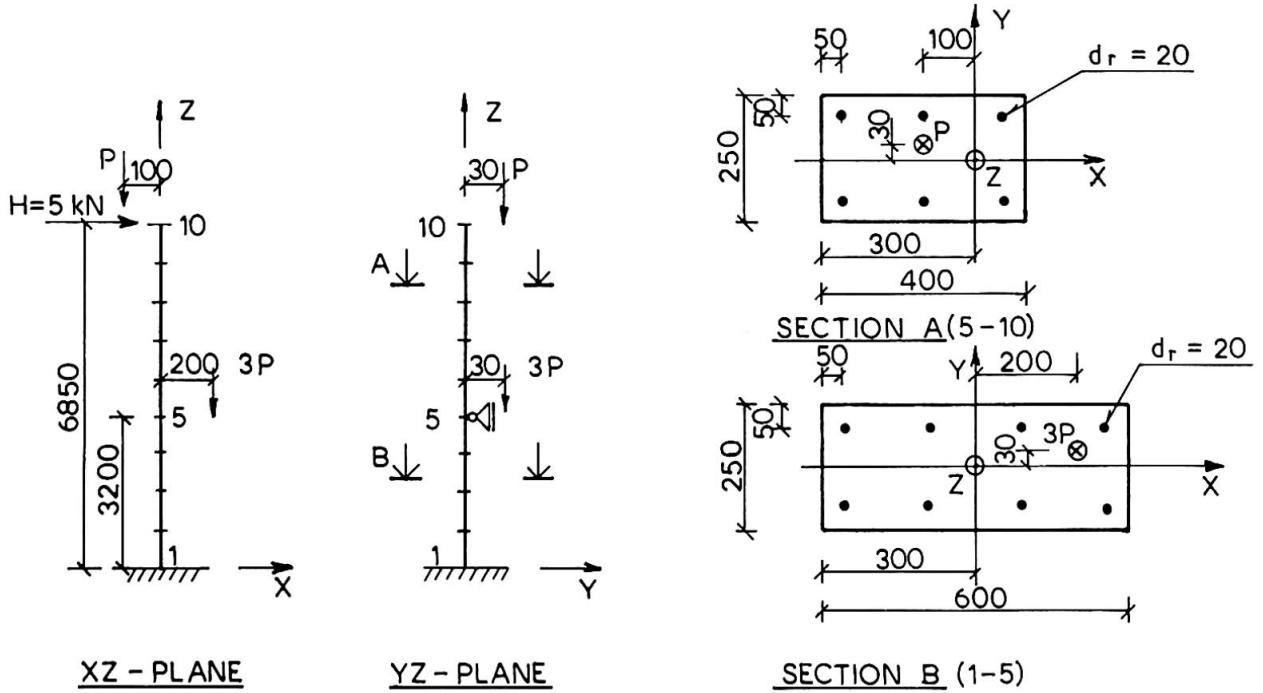
The geometrical iteration process is accelerated by means of a Newton-Raphson method.



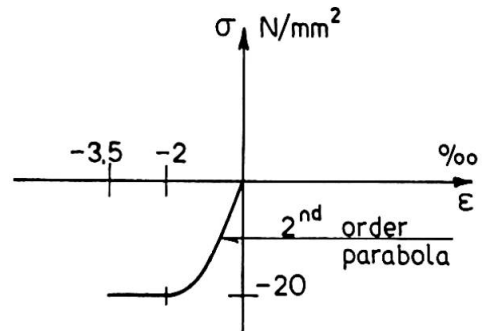
The core of the programme is the general finite element part, which provides the means for dealing with the support conditions in a general way. One of the advantages is the possibility of analysing multispans columns.

The programme is an analysis programme that calculates stresses and strains in a columns with given geometry, reinforcement and load.

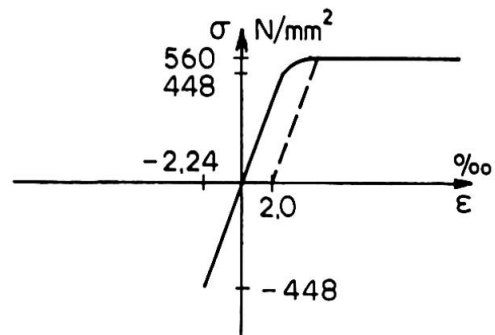
By stepwise increase of the load on the columns it is possible to determine the critical load. The positive definiteness of the system matrix is used as criterion for stopping. This procedure is illustrated below.



**LOAD/DEFLECTION CURVE**  
(Deflektion in point 10)



**STRESS-STRAIN CURVE: CONCRETE**



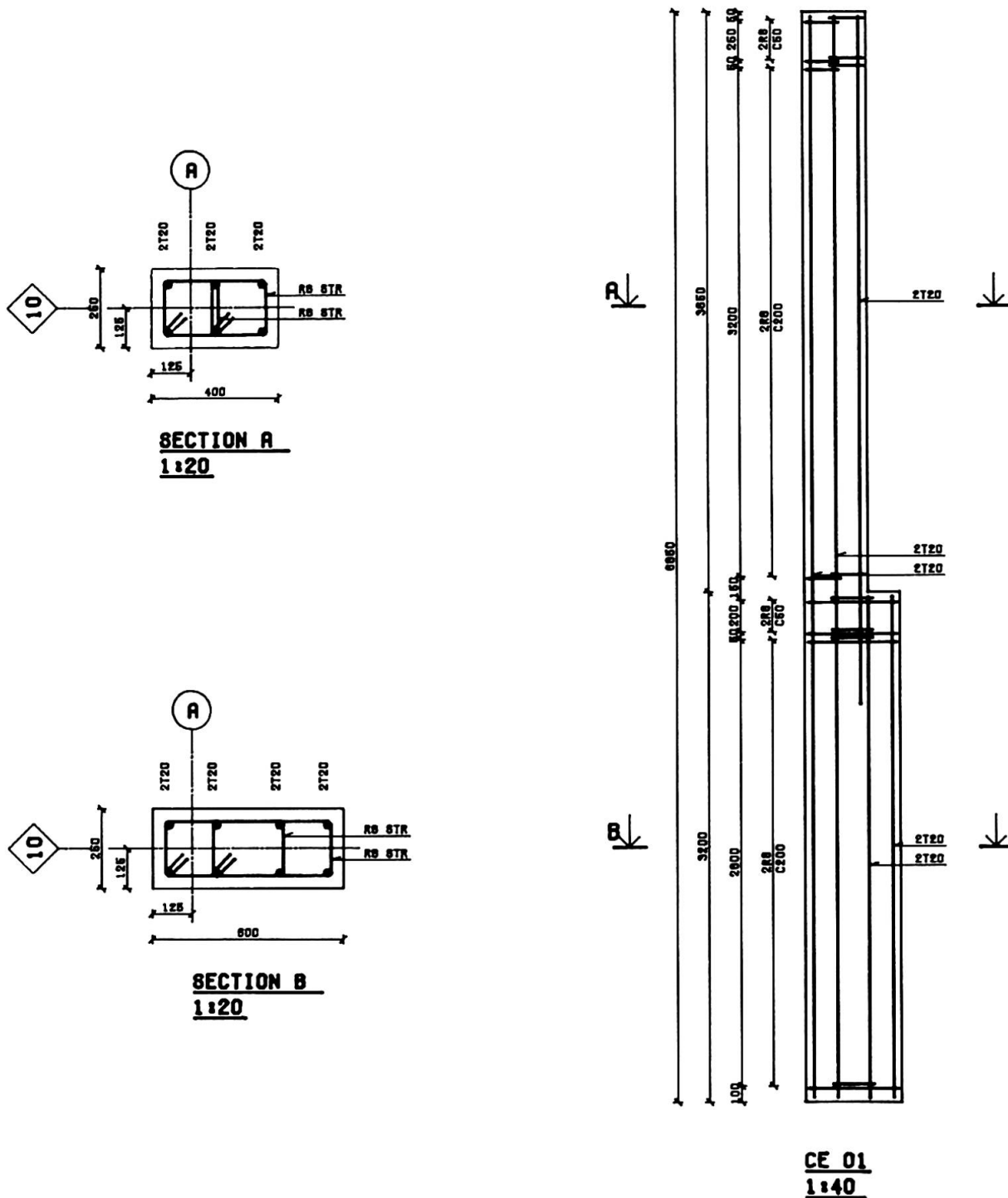
**STRESS STRAIN CURVE: REINFORCEM.**



### 3.3 Drawing programme

The next link in the chain is the plotter programme which draws up the complete reinforcement drawing based on the data used in the analysis programme and a supplement of drafting instructions. The drawing is produced on a computer controlled plotter.

An example is shown on the figure.





### 3.4 Calculation of quantities and working out of bending schedules

Using the same data as used in the plotter programme the quantities of concrete, formwork, and reinforcement can be measured and stored for use in the bill of quantities.

Furthermore data may be drawn from the plotter programme and used to produce the corresponding bar bending schedule.

## 4. CONCLUSION

The programmes, the analysis programme as well as the plotter programme, have build in check of the structural rules given in the Danish Code of Practice for Reinforced Concrete. This facility can naturally be extended to any kind of Code of Practice.

The output of the analysis programme can be displayed on a printer or on a graphic computer terminal, where the results are shown as curves for moment, stresses and deflections.

The latter facility provides a simple and efficient check of the calculation. Commonplace errors and misunderstandings will normally be revealed.

It has furthermore proved to be of utmost importance for the safe use of the programme that it has been developed by engineers in the same department where it shall be used and in close collaboration with the users. This means that the daily use of the programmes takes place in close contact with engineers who have a thorough knowledge of the way the programmes operate. This close collaboration between programmers and designers also secures that the programmes are adjusted, updated and supplemented according to the needs of the users.

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