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Use of CAD in Finite Element Analysis

Utilisation de la CAO pour le calcul avec des éléments finis

Einsatz von CAD bei Berechnungen mit finiten Elementen

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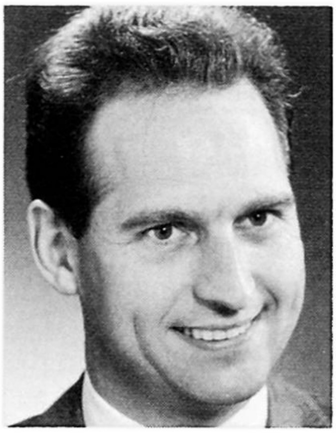

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SUMMARY
The increasing use of CAD-systems makes it feasible to incorporate in a much better way the FE-analysis in the design process. In addition to the graphic-display facilities of modern FE-programs, the geometric data base of CAD-systems offers many new additional possibilities, some of which are discussed in the paper.

RESUME
L'utilisation croissante des systèmes CAO rend plus facile l'intégration de l'analyse avec les éléments finis dans le projet. Outre les représentations graphiques du programme des éléments finis, la banque de données géométriques des systèmes CAO offre beaucoup de possibilités nouvelles, qui sont présentées dans l'article.

ZUSAMMENFASSUNG
Der zunehmende Einsatz von CAD-Systemen ermöglicht es, FE-Berechnungen viel besser in den gesamten Entwurfsprozess zu integrieren. Neben den graphischen Darstellungen der FE-Programme bietet vor allem die geometrische Datenbank von CAD-Systemen viele neue Möglichkeiten, von denen einige diskutiert werden.

1. INTRODUCTION

Modern finite-element programs offer numerous facilities for graphical displays. By means of these, the analysis model can be completely verified before large and costly calculations are performed. This verification is of great importance, because errors in the model can make comprehensive calculations useless or, if they are not detected, can have consequences on the safety of the structure. For the evaluation of the results, graphic displays are also indispensible for furnishing a quick overview of the structural quantities. Thus the engineer can judge the behavior of the structure immediately and may modify his construction accordingly. Through close interaction between man and computer by means of graphics, the most suitable structure for the required specifications can usually be found rather quickly.

During recent years, the use of CAD-systems has become increasingly popular in the construction industry. In such systems, all geometric data of the structure to be designed are stored in a geometric database. It is feasible to use these data for the structural analysis as well. By this approach, errors in the idealization can be drastically reduced, and the efficiency in preparing the FE-mesh can be greatly improved. In addition, selected results of the subsequent structural analysis can be interfaced with the CAD-system for further processing. As an example, the use of the calculated reinforcements of a reinforced-concrete structure in the CAD-system permits the interactive definition of the reinforcing steel. Many CAD-systems also contain information on prices of materials and parts of the structure. By using this information, it is also possible to determine the economic consequences of structural changes readily. On this background the FE-analysis appears as a subtask within the integrated computer-aided design of structures.

In the following, some of the possibilities of graphical representations of FE-programs will be shown which can support the user very effectively. In addition, it will be demonstrated on the basis of the CAD-system CAD-B "Computer-Aided Design of Buildings" of IEZ and the program FLASH, how the structural analysis with finite elements can be integrated into the design process.

2. THE USE OF GRAPHICS FOR THE VERIFICATION OF THE MODEL

One of the standard graphical means for verifying a model is the plot of the mesh. Of particular use are options to shrink the elements around their centers of gravity. By this it can be verified that all elements in the model exist. For larger structures, it is advisable to remove the hidden lines. The resulting plots generally give a very clear picture of the structure. For shell structures, it is useful to verify the angle between elements by plotting the edges of element junctures which exceed a certain given angle. By means of such plots, the user can make sure that the curvatures of the shell are sufficiently well idealized. As an illustration, Figure 1 shows the mesh of an arch dam with selected angles for the elements. This structure is presently under study at the Institute of Structural Engineering of the Swiss Federal Institute of Technology.

In some cases, it is useful to plot the local as well as the global coordinate systems of a structure. This is especially useful for the beam elements because the orientation of the local axes is usually not immediately clear from the plot of the mesh. Figure 2 shows as an example the plot of the element coordinate systems as well as of the system used for the modeling of a part of a stell construction. By means of such plots, errors in the orientation of element loads can easily be avoided.

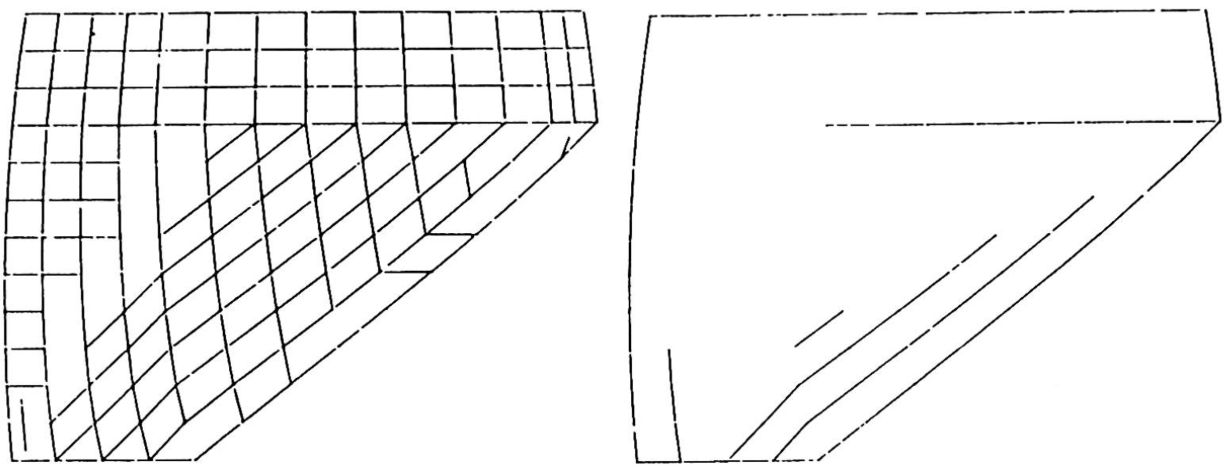

Figure 1: Meshes of the model of an arch dam showing the edges of element junctures exceeding 2° and 5°, respectively

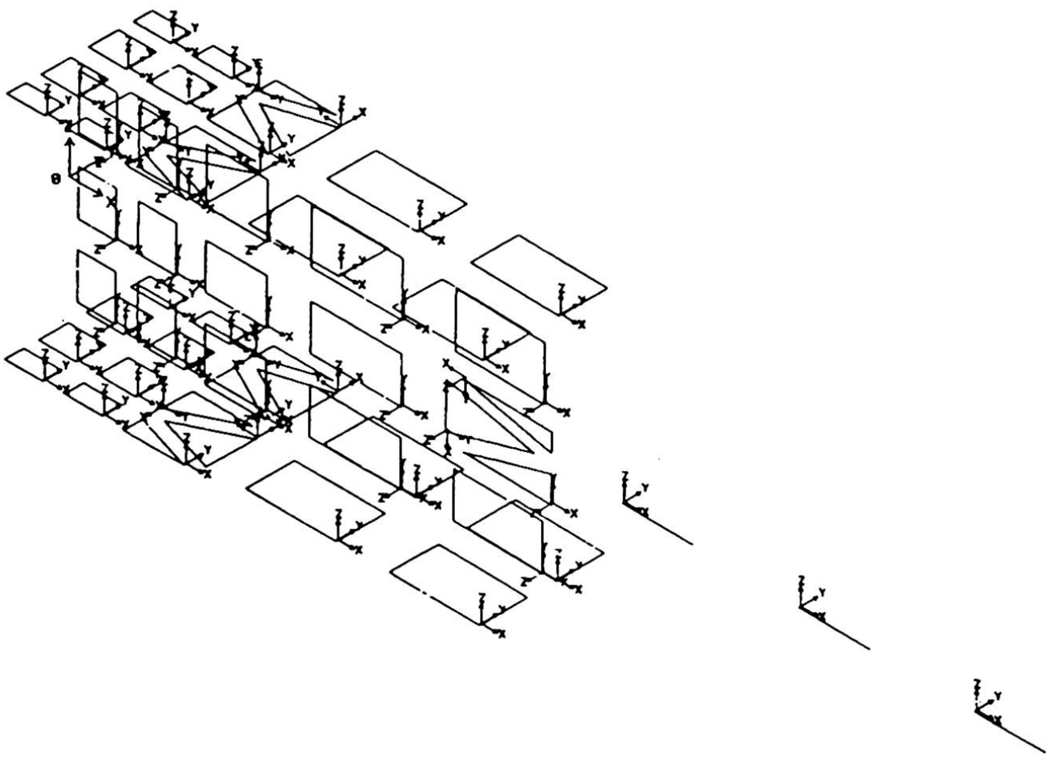

Figure 2: Local coordinate systems

A chronic source of errors is the formulation of the boundary conditions. Therefore the graphic representation of the boundary conditions with respect to the degrees of freedom and of the coordinate system are of great importance. The same is true for linear constraint equations.

Figure 3 shows a shell structure for which the outline and the boundary conditions have been plotted. At each boundary node, the node number and the boundary condition with respect to the constrained degrees of freedom and also the coordinate systems used are displayed.

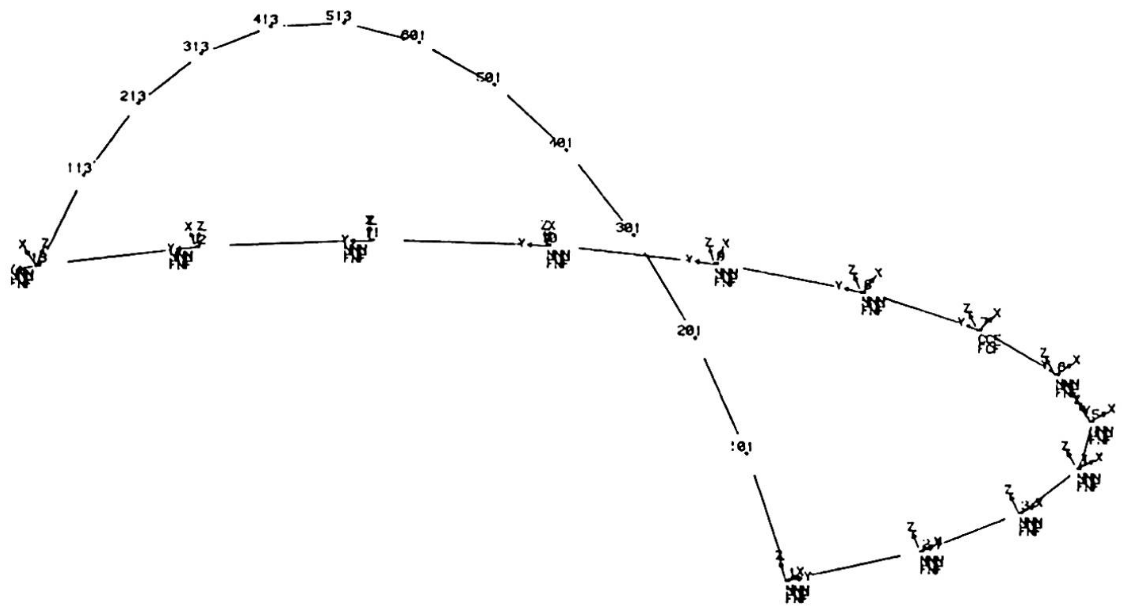

Figure 3: Outline of shell with boundary conditions

3. DISPLAY OF RESULTS

After the analysis, the deformed shape of the structure under the action of the static or dynamic loads is plotted first of all. If the deformed shape is properly scaled, errors in the stiffness properties, the boundary conditions or the loads can frequently be detected right away. Of special interest is the representation of the forces and stresses. For this, either plots along sections or contour-plots can be used. The deformed shape is a means for verifying the kinematic boundary conditions. As a corollary, the stress field permits checking the quality of approximation of the static boundary conditions.

As static boundary conditions are automatically satisfied in pure-displacement models, the quality of the stress field along the boundaries is a measure for the quality of the discretization (Figure 4).

In addition to the above-mentioned structural quantities, the support reactions, strain energies, contents of reinforcement etc. for specific load cases as well as their envelopes can also be plotted. To illustrate this point, Figure 5 shows the extreme values (envelopes) of the support reactions in a flat slab.

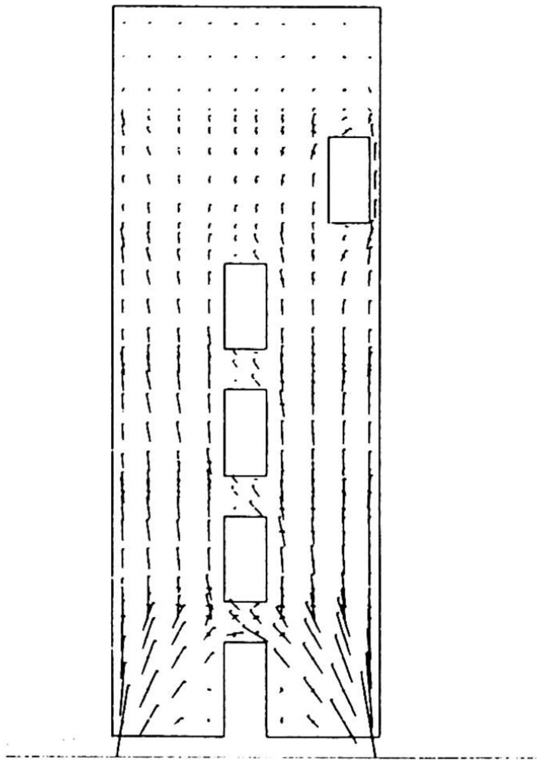

Figure 4: Principal stresses in a shear wall

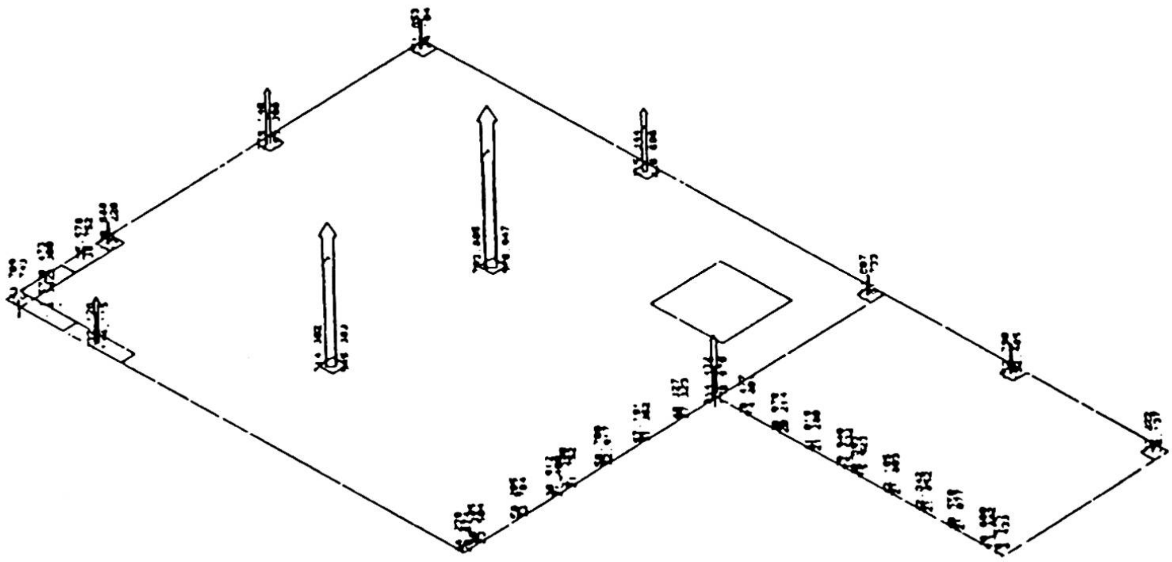

Figure 5: Extreme values of support reactions in a flat slab

4. COMPUTER-AIDED DESIGN AND FE-ANALYSIS

The support given to the engineer by interactive mesh-generators as well as by the graphic display facilities has contributed much to the wide distribution of FE-methods. In recent years, however, the use of CAD-systems in the design process has become more and more popular. Once the structure is designed by such a system, all geometric data are defined. By using the geometric data base, it is possible to support the engineer very effectively in his work in setting up the FE-model. To do so, it is necessary that interfaces be developed between the CAD-system and the FE-system, and that the FE-system be capable of analyzing the structures encountered. In the building-construction industry, for instance, the analysis of slabs, flat slabs, and of slabs with stiffeners and holes has to be dealt with.

Modern CAD-systems also provide the user with a method data base. This method data base has been used in the CAD-system CAD-B to interface the system with FLASH. By means of simple user-oriented commands, the engineer can extract the geometric data and request the automated mesh generation. The system supports the user in many respects. For instance, supporting walls are introduced automatically as support lines. He can also select the appropriate code requirements. The results of the automated mesh generation immediately appear on the screen and can be modified interactively. The data are completed by describing the material properties, the load cases and the output requests.

After the analysis, the results will be displayed on the screen. These results can now be interfaced with the CAD-system. For example by using for the contour lines of the reinforcements, the reinforcement bars or meshes of reinforcement can be designed interactively. As a by-product, the lists for the reinforcement steel and the cutting drawings for the steel meshes are automatically generated.

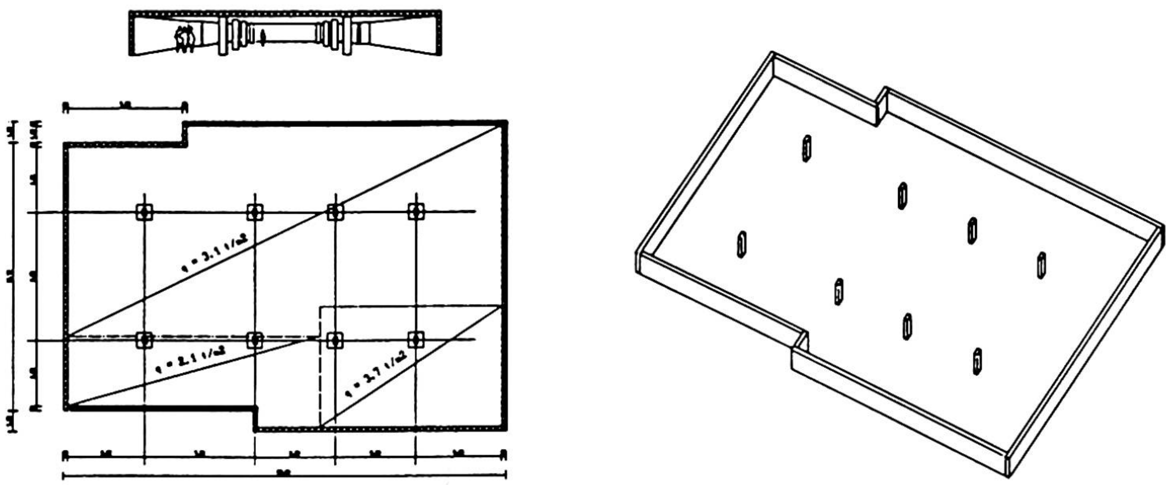

Figure 6: Pedestrian underpass designed with the CAD-system CAD-B

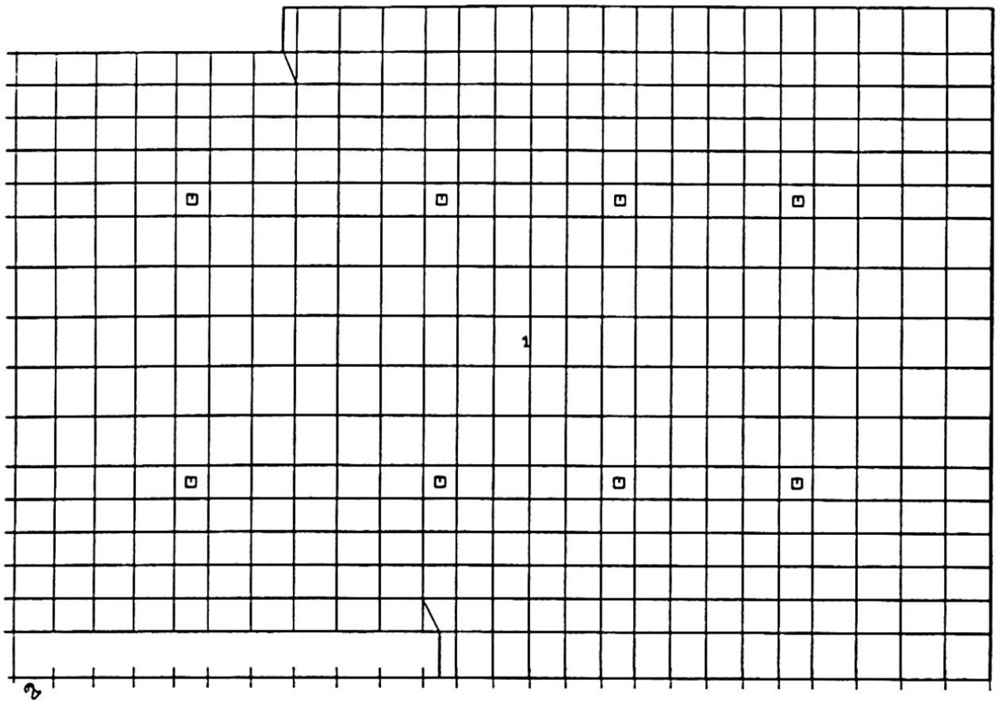

Figure 7: Automatically generated finite-element mesh on the basis of given boundary modes

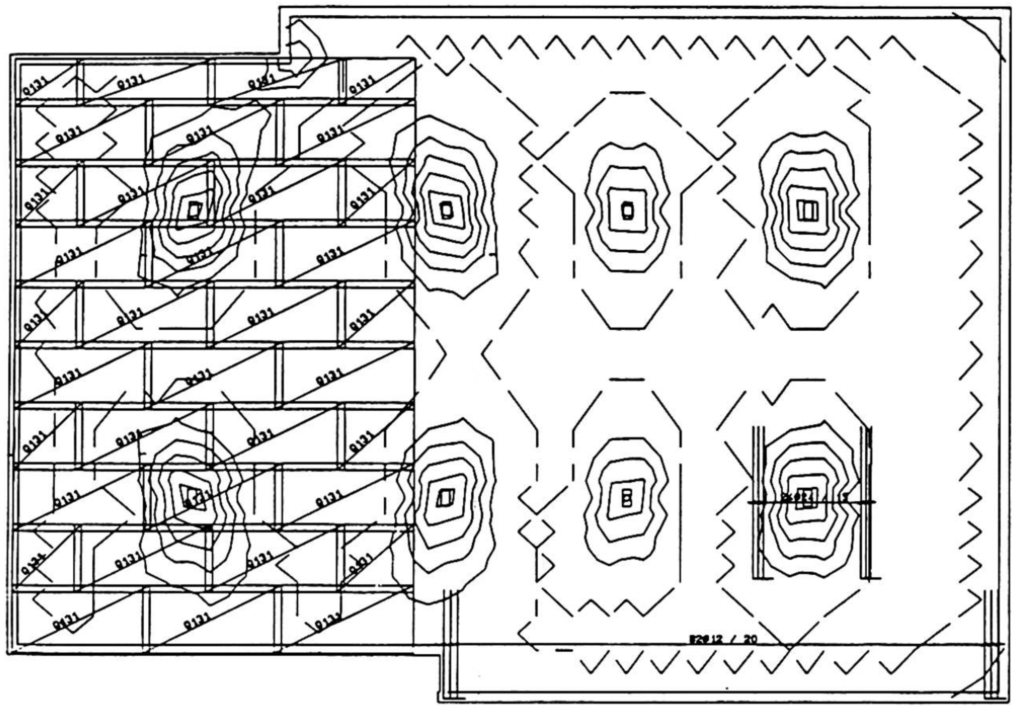

Figure 8: Interactive design of the reinforcement based on the contour lines of required steel as calculated by FLASH

Figures 6 - 8 show the different phases of an integrated CAD-design and the analysis process for a slab.

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