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Integration of Computer Applications in Structural Engineering

Intégration de l'ordinateur dans le projet de systèmes structuraux

Integration der Computeranwendung bei der Tragwerksplanung

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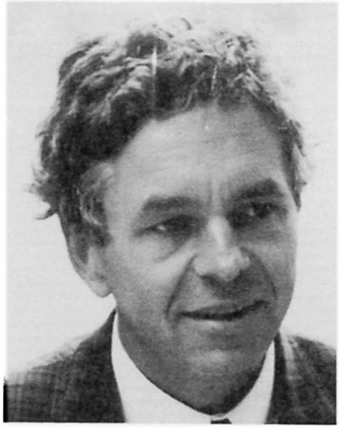

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SUMMARY

The integration of computer applications has a long tradition in structural engineering. The first attempt to achieve integrated systems was made as early as the 1960's. In contrast to this, most structural design is done today with separate programs for structural analysis and design. The paper describes the current state of the art in practical applications and trends for further development.

RÉSUMÉ

L'intégration des applications informatiques a une longue tradition dans le génie des structures. Le premier essai de réaliser des méthodes intégrées a été fait dès 1960. En opposition, la plupart des projets est couramment faite par des programmes non intégrés de projet et de calcul. Ce manuscrit explique de façon détaillée les applications pratiques de la technique actuelle ainsi que les tendances de développement.

ZUSAMMENFASSUNG

Die Integration der Computeranwendung in der Tragwerksplanung hat eine lange Tradition. Die Entwicklung der ersten integrierten Systeme begann bereits in den sechziger Jahren. Im Gegensatz dazu wird die praktische Anwendung immer noch vom Einsatz von Einzelprogrammen für den Entwurf und die Berechnung von Tragwerken geprägt. Der Bericht beschreibt den gegenwärtigen Stand der Technik der praktischen Anwendung und Tendenzen für künftige Entwicklungen.

1. INTRODUCTION:

The integration of computer applications has a long tradition in structural engineering. As early as in the sixties and seventies, the first integrated systems such as ICES (Integrated Civil Engineering System), [1], GENESYS [2] and IST (Informationssystem Technik [3] were developed.

Although these overall integrated systems were not accepted by the majority of the structural engineers, subsystems for special applications such as ICES STRUDL for structural analysis or ICES COGO for geometric computations were used to a far greater extent.

Almost parallel to these efforts towards integrated systems, a great variety of isolated programs for the analysis of structural members such as foundations, continuous beams, frames and slabs were developed. They are usually applied in a "desintegrated" manner and are the 'state of the art' software widely used for structural analysis.

The late seventies and early eighties saw the upcome of the application of graphic interactive techniques, i.e. CAD programs in structural design. They are well-established for the production of engineering drawings such as structural general arrangements, reinforcement drawings and structural steel drawings.

Today we can observe many efforts to integrate the existing landscape of disintegrated programs for structural analysis and design. First successes can be observed in the integration of CAD programs and finite element programs, for example for slab analysis or the analysis of shearing walls.

Another field of activities is to enable the exchange of CAD data between the architect, the structural engineer and building services engineers, even if they use different CAD systems.

The key to any integration is the definition of a common set of data which can be shared or exchanged between the different disintegrated programs and program systems.

2. INTEGRATED STRUCTURAL ANALYSIS:

Structural analysis by computers can be divided into the following subproblems:

- data entry of the structural system and the loads
- computation of displacements and internal forces
- superposition of load cases
- dimensioning
- presentation of the structural system and the results of the analysis.

For smaller structural problems such as continuous beam analysis, the integration of all subproblems does not represent any problem since all steps of the analysis are done within one program.

If the problems become more complicated, especially if finite element programs are used, the integration of the above-mentioned 5 subproblems is no longer self-evident. Usually, they are grouped in three programs as follows:

- the preprocessor, for graphically-oriented data entry, in many cases restricted to the generation of the finite element merits
- the structural analysis program for the computation of the displacements and internal forces
- the post-processor or the superposition of the results, the dimensioning and the graphical presentation of the results.

Typical examples are shown in figs. 1 and 2. Fig. 1 shows a computer display during the generation of an element net of reinforced concrete offshore platform.

Fig. 1 - Finite element net of 1 reinforced concrete offshore platform.

Fig. 2 - shows on the left side a graphical representation of the principal moments and on the right side a plot of the reinforcement as a result of the dimensioning postprocessing.

The graphically-orientated highly interactive preparation of input data for structural analysis programs is not restricted to the generation of finite element nets but can be applied to describe the complete structural problem including loads, supports and material properties.

In order to understand the impact of this new type of program to structural analysis, it is necessary to keep the traditional application of structural analysis programs in mind.

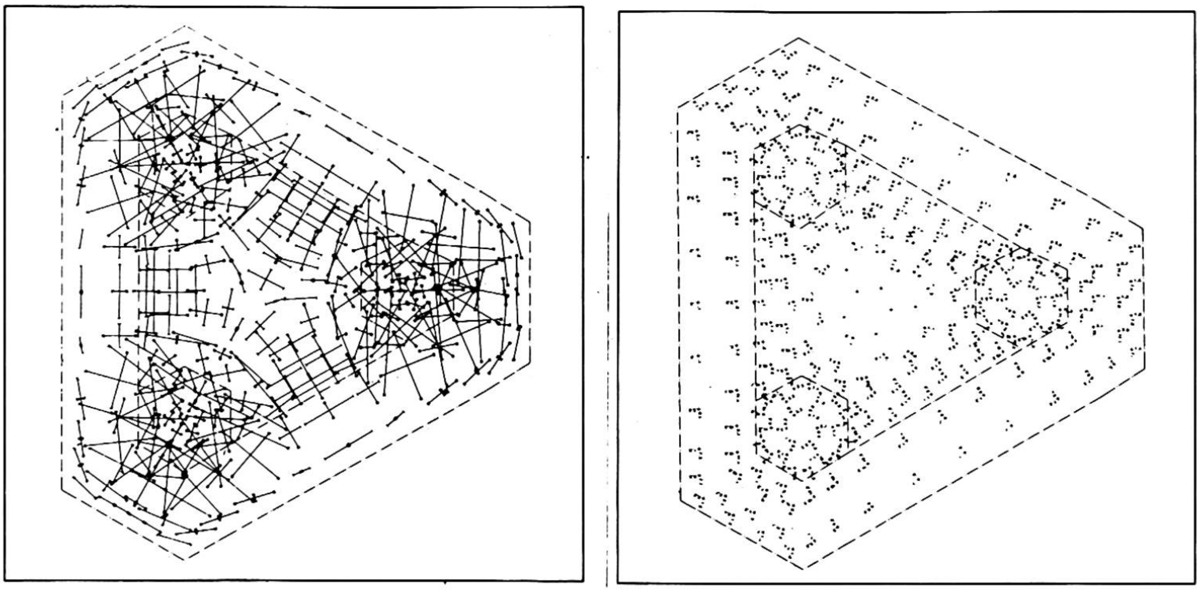

Fig. 2 - Principal moments and reinforcement dimensions for a reinforced concrete offshore platform.

The structural engineer supplies sketches of the structural system and loads. Fig. 3 shows a typical example of a plane frame.

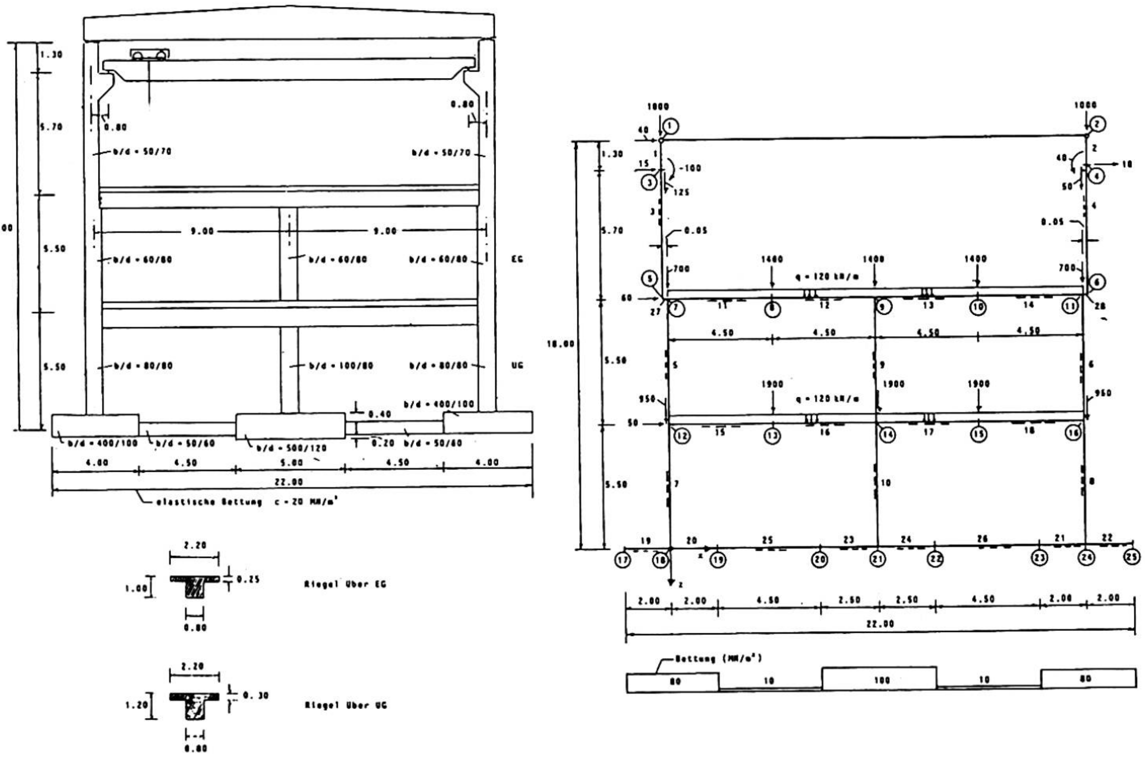

Fig. 3 - Typical sketch of a structural system with loads.

These graphically-orientated data are now translated into alphanumeric data, i.e. text and numbers. 'Graphic' is thus converted to 'alpha numeric'. With this procedure, not only has the number of data risen remarkably, but it is also susceptible to faults and very difficult to verify. In order to examine the abundance of alpha-numerical data values more effectively, so-called control plots are drawn up.

The fact that this 'historically grown' application form could be improved considerably by entering the structural system and the loads directly and graphically was first recognised at universities in the USA and transformed into prototypes for graphically-orientated structural analysis programs [4], [5]. In the meantime, such programs are commercially available.

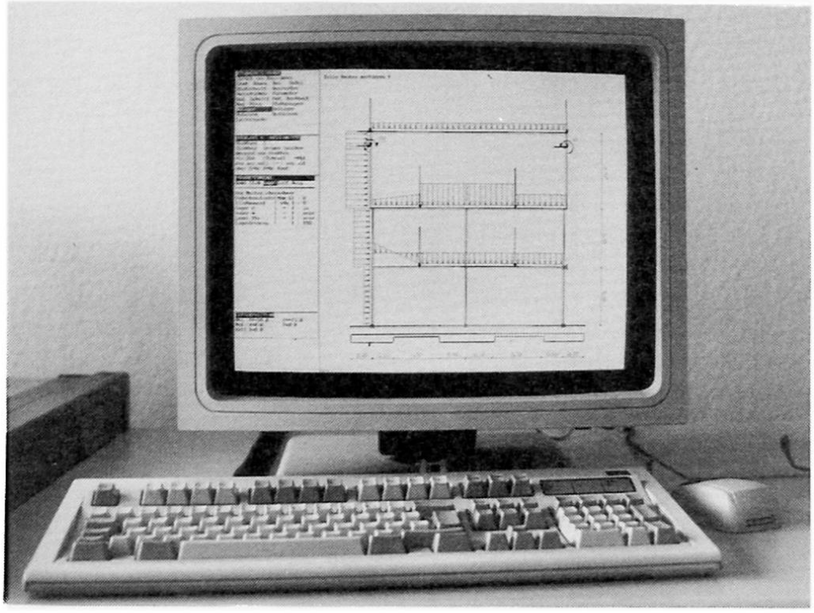

Fig. 4 - Graphic interactive preparation of input data for a structural analysis program of plane frames [6].

Fig. 4 shows a picture taken from a monitor during the preparation of input data of the presented structural system. It is evident that this manner of application is much more rational and considerably less susceptible to errors than the traditional input via alphanumeric input data.

3. INTEGRATED STRUCTURAL DESIGN:

3.1 Application of CAD programs for the production of structural general arrangements:

The CAD technology is well-accepted for the production of structural general arrangements. A reason for this good acceptance is, that this application has hardly any demands which exceed the performance of normal CAD systems for building design. With standard functions such as:

- the union of building components of the same material (i.e. walls in a floor plan),
- layer technique for the selective representation of building members and drawing items,
- the generation of regular parts of the construction,
- automated hatching of sections,
- semi-automatic dimensioning,

even complicated structural general arrangements can be created economically.

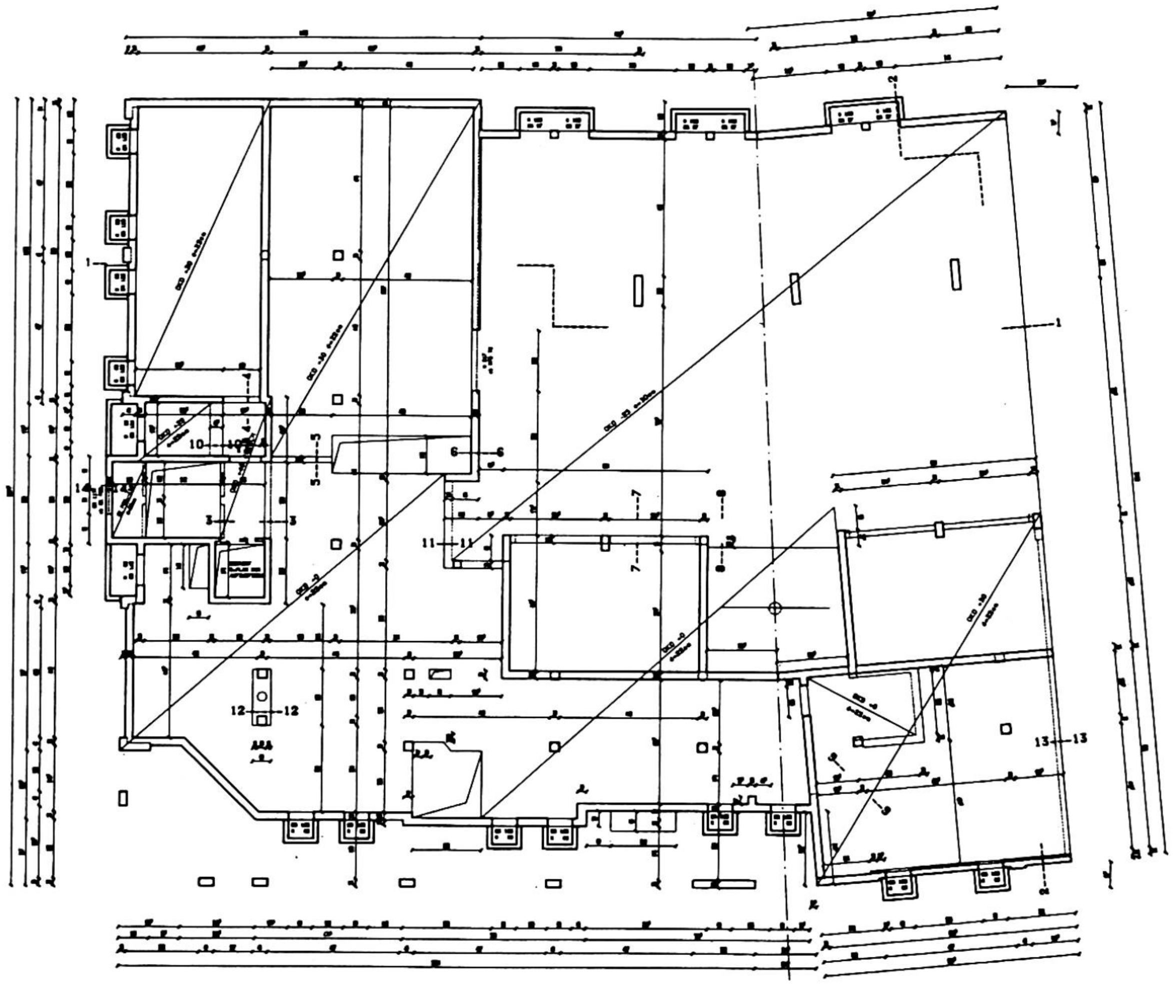

Fig. 5 - Floor plan, generated with CAD

If the structural situation is mainly prismatic, i.e. in the case of a floor plan (fig. 5), 2D systems are surely sufficient. If the structural situations become more complicated, i.e. in the case of the foundation of power plants or other engineering constructions or if several sections must be drawn in order to describe a structural situation completely, such as in stairways (fig. 6), then the application of 3D systems is more advisable. With such a 3D system, a 3D building model can be generated in the computer from which sections can be derived automatically. If the structural situation becomes very complicated, it can even be inspected in a perspective representation.

3.2 Application of CAD programs for reinforcement drawings:

Programs for reinforcement drawings were developed as early as the seventies. The starting point was the fact that for many programs for structural analysis, the geometric dimensions of the structural members are available as input data.

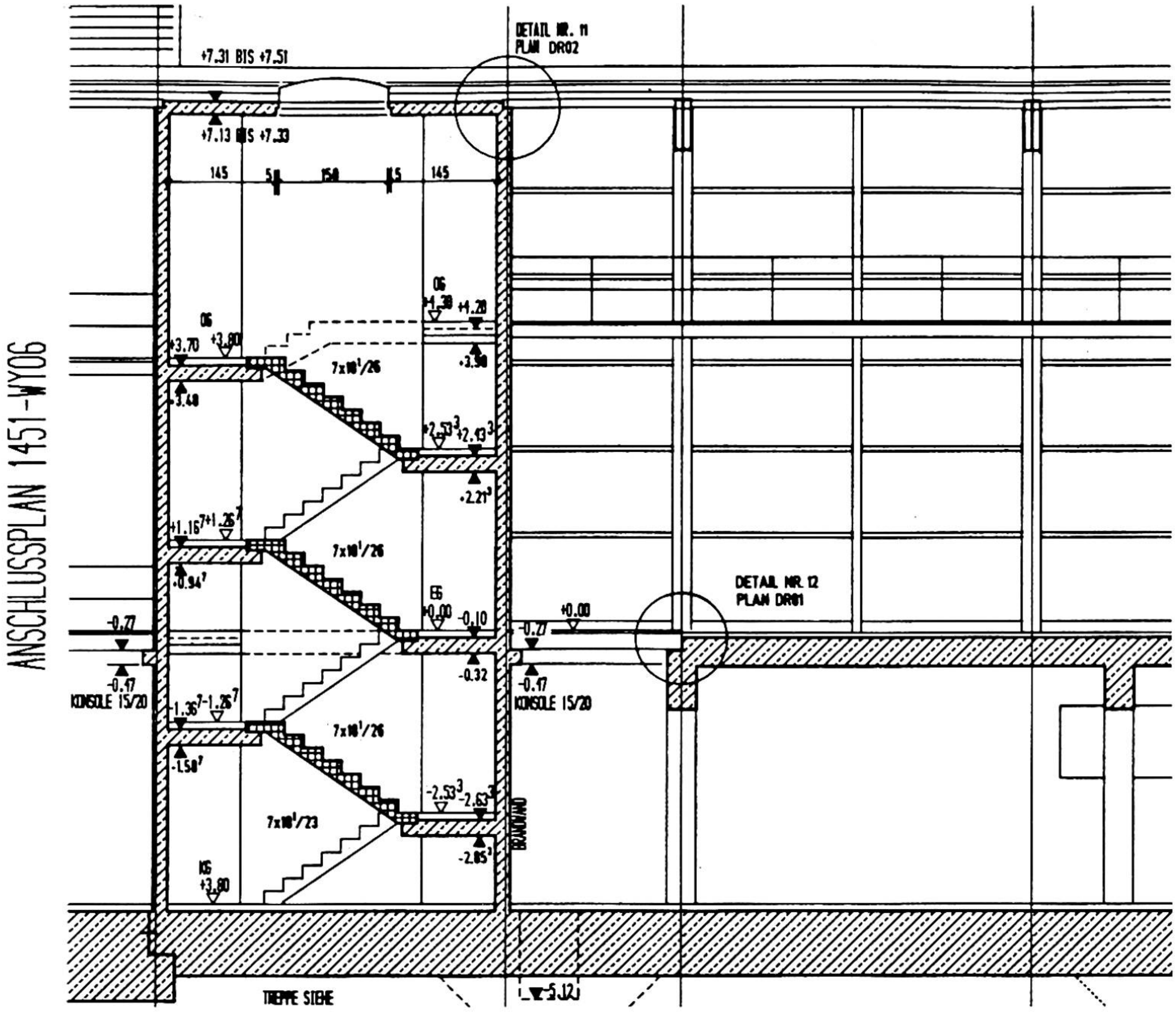

Fig. 6 - Stairway generated with CAD out of a 3D building model.

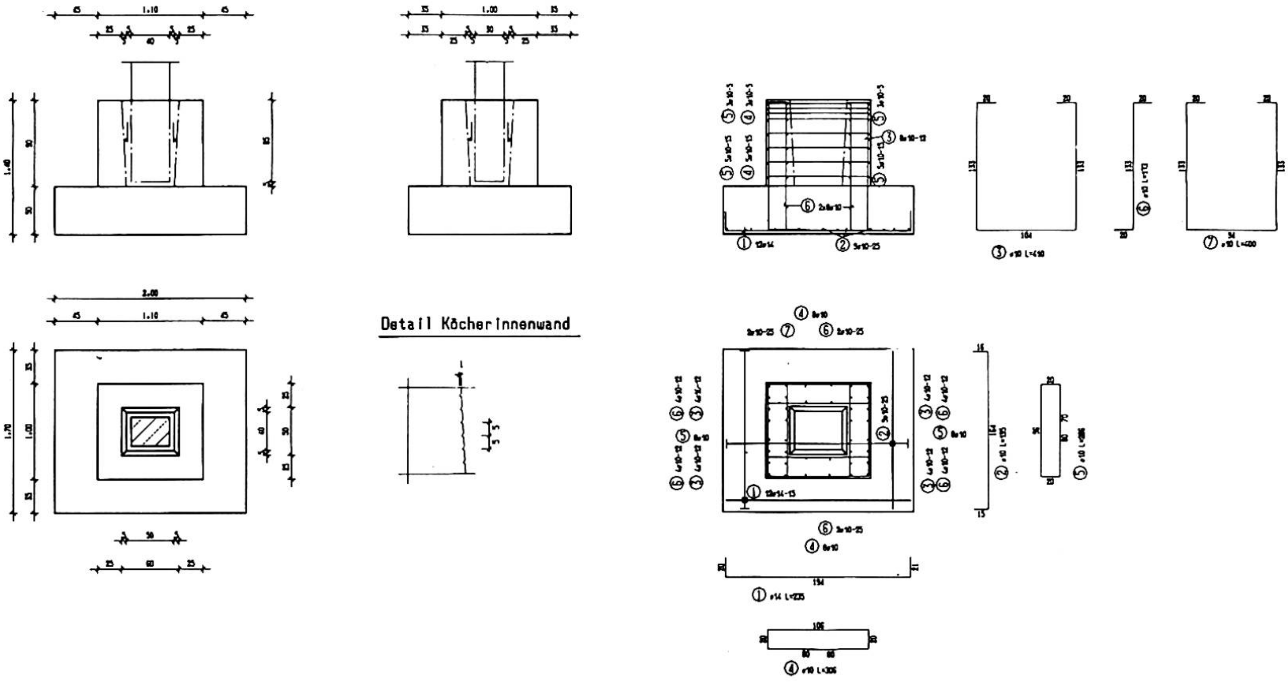

Fig. 7 - Reinforcement drawing of a foundation

The dimensioning parts of the programs calculate the cross-sections of the reinforcement. If the user provides additional data, such as preferred reinforcement diameters, reinforcement forms, etc, then reinforcement drawings can be produced automatically. The main applications of these parametric design programs are standardised building members, such as pre-fabricated, concrete members, foundations (fig. 7), columns and beams. It should be emphasized at this point, that these programs are not CAD programs as they are currently understood, since CAD techniques such as graphic interactive input are not used.

When the structural situations become more complicated, then the preparation of input data for the parametric design programs becomes a time-consuming, cumbersome task, where many errors may occur. It is here that CAD techniques, i.e. graphic interactive techniques, have definite advantages compared with the parameter controlled input techniques.

For the graphic interactive design of reinforcement with CAD programs, special input techniques have been developed. The necessity for such special input techniques will be demonstrated by means of two examples.

The first example concerns the arrangement of web reinforcement within a flat slab (fig. 8). At first glance it seems to be a generating problem which can be solved with standard CAD techniques. If one considers it more closely, then one recognises that special techniques have to be applied here in order to be cost-effective. The web reinformenent is arranged in longitudinal and transversal direction with overlap. If several strips are laid in longitudinal direction, the overlaps can be grouped alternatingly or non-alternatingly. If the web reinforcement overlap the floor strips, one should have the choice to cut the web reinforcement on the borders or to evenly distribute the overlaps.

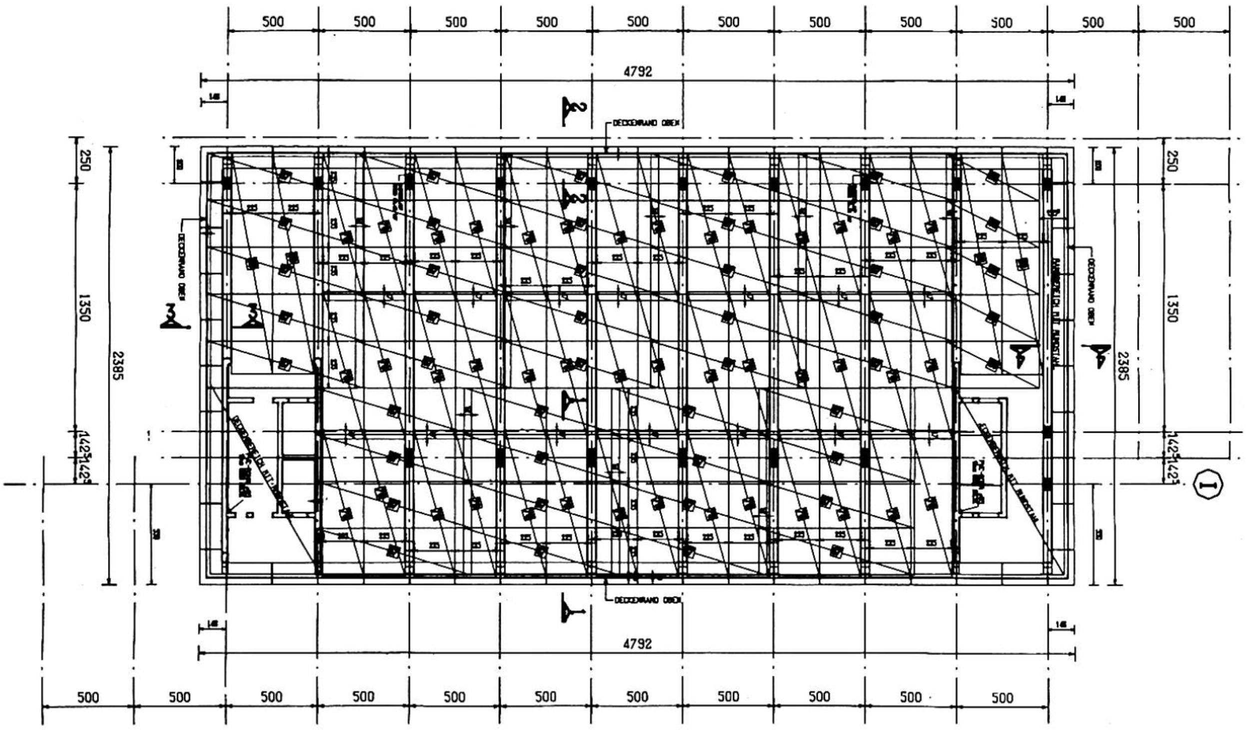

Fig. 8 - Reinforcement drawing of a flat slab

Concerning bar reinforcement, the CAD program must allow the user to describe the shape of the reinforcement bar freely or relative to the shape of the building member. For both types of reinforcements, web reinforcement and bar reinforcement, special lists must be produced automatically. These two examples only show a small number of the special problems to be solved.

Such CAD programs for the design of reinforcement are not restricted to standardised building components, but can be applied for the design of the reinforcement of arbitrary building components. Beside flat slabs (fig. 8), even special constructions such as tunnel pipes, communication towers or bridges (fig. 9) can be dealt with.

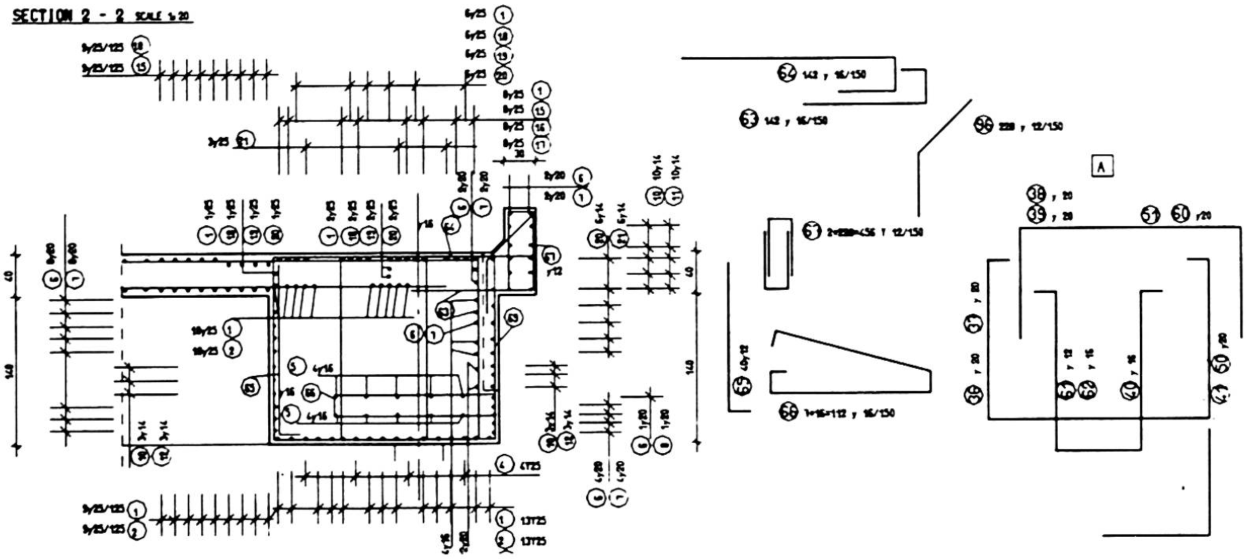

Fig. 9 - Reinforcement drawing of a detail of a bridge

3.3 Integration CAD - structural analysis:

In all applications of data processing to building design, there is a strong trend towards integration. In structural design the first integrated systems were based on the parametric design technique for reinforcement drawings. A typical example is the integrated program system for continuous beam design, described in [7].

Today, many CAD programs provide the possibility to describe finite element nets, loads and supports for structural analysis programs relative to architectural drawings or general structural arrangements.

The first application of this type of integration was the integrated analysis and design of flat slabs [8]. One prerequisite for this integrated design was that the finite element method could be established in West Germany as a standard method for the analysis of flat slabs.

Recently, a similar effective finite element program has been developed for the analysis of walls with openings. The problems of the structural analysis of walls in building design will be described on the basis of fig. 10. The wall has regularly- or irregularly-distributed openings. This structural behaviour of parts of the wall resembles beams. Slabs are connected to the wall. Obviously, this kind of structural systems cannot be analysed with programs, based on classical plane stress analysis in a cost-effective manner.

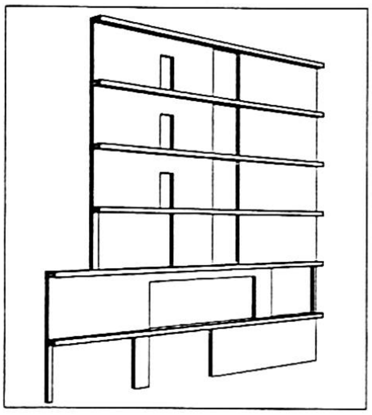

Fig. 10 Typical concrete wall

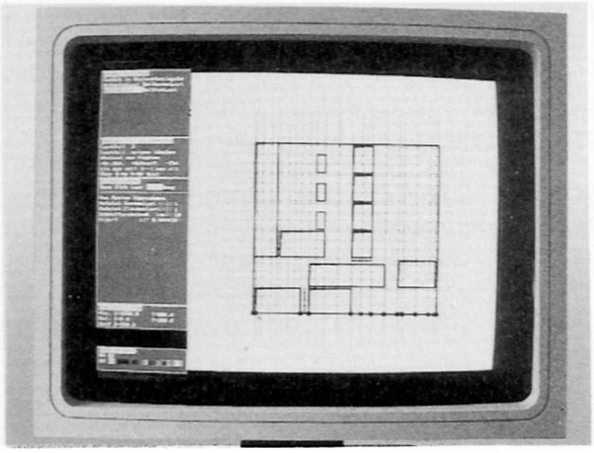

Fig. 11 - Graphic interactive input of a concrete wall

The recently-developed program for the analysis of concrete walls [9] is based on a modified hybrid plane stress finite element [10]. The parameters of this element can be determined in such a way that it has the exact stiffness of a uniaxial beam element with arbitrary cross-sectional values. This program allows one to model complex wall structures such as the one shown in fig. 10 with few elements and nonetheless obtain accurate results which can be used to directly calculate the reinforcement.

The structural design starts with the definition of the finite element net relative to the architectural drawings or a general structural lay-out. Fig. 11 shows the graphic screen during the preparation of these input data. Extensive generating possibilities are provided which allows one to define the element net economically. The support conditions, the loads and additional information for the calculation of the reinforcement can be described in a similar way.

The program for structural analysis gives the following results:

- graphical representation of the structural system;
- displacements;
- internal forces;
- dimension of the reinforcement.

These results can be shown in listings or graphically (fig. 12). These results allows one to check the analysis easily and to design a reinforcement which corresponds to the actual structural behaviour.

4. INTEGRATION OF ARCHITECTURAL AND STRUCTURAL DESIGN:

4.1 Organisational aspects:

The building design is interdisciplinary. The architect draws the lay-outs in which he first presents the rooms, their dimensions, functions and equipment. The structural engineer calculates the structure and prepares the structural general lay-out and reinforcement drawings. The Individual engineers responsible for heating, ventilation, air-conditoning, sanitary and electrical technology draw their respective installation plans on the basis of the architectural drawings or the structural general lay-out. This type of planning is presented schematically in fig. 13.

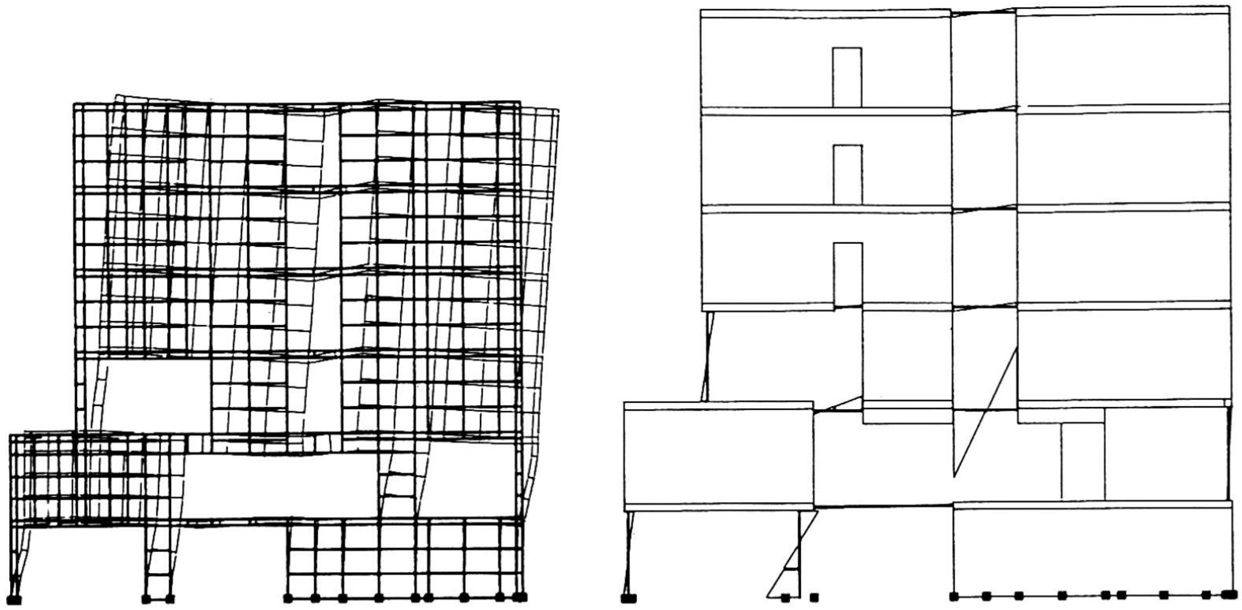

Fig. 12 - Examples of results of the concrete wall analysis
left : displaced structure
right: bending moments in "beam-like" members.

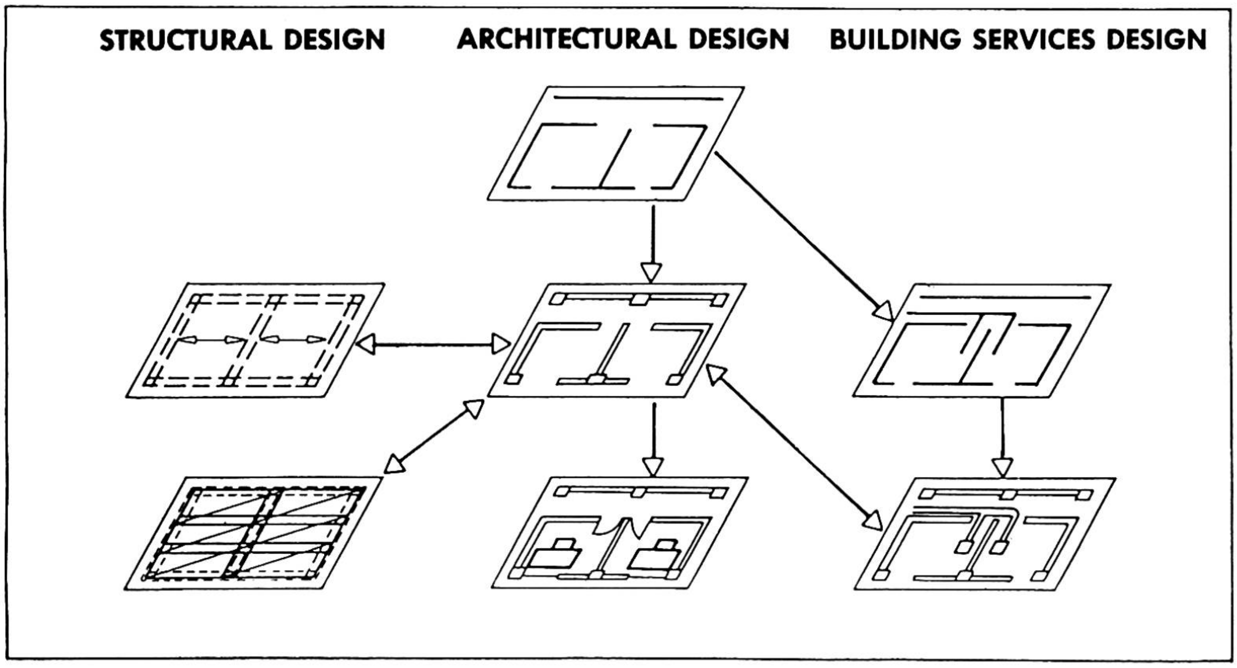

Fig. 13 - Interdisciplinary building design

In building design, particlarly for industrial buildings, the layer technique can be applied effectively to this interdisciplinary design process. With this layer technique a drawing, as presented in fig.14, can be divided into different transparent layers. These layers can be overlaid arbitrarily. Each of the architects and engineers involved in a common building project may visualise the layers of the other architects or engineers and thus coordinate the planning of his part in a better way, than with conventional methods.

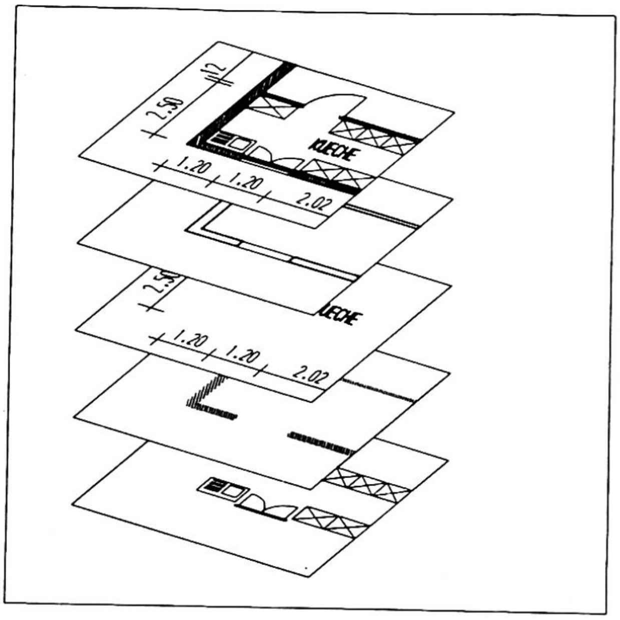

Fig. 14 - Layer technique

A good layering system and classification is decisive for a successful application of this technique and a prerequisite for an integrated building design. If this classification is carried out effectively, then the ideal that no line must be drawn twice can almost be achieved. This is explained in fig. 15.

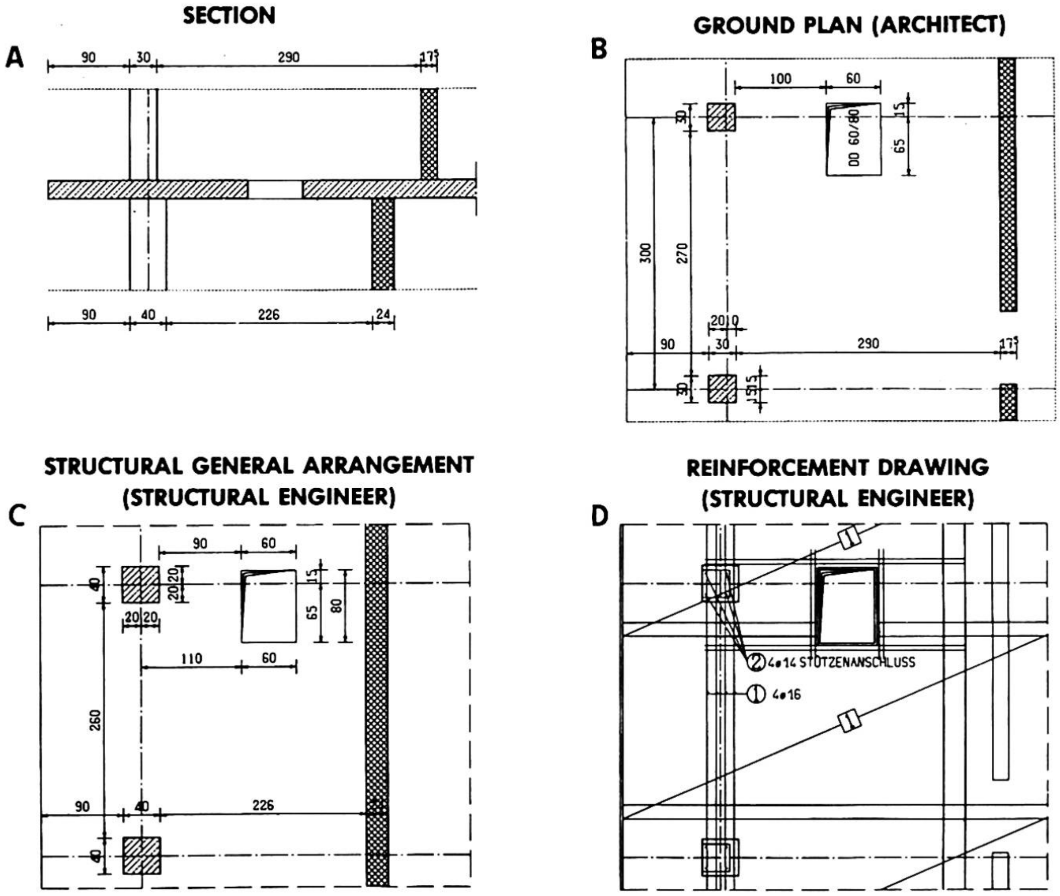

Fig. 15 - Application of the layer technique

Fig. 15A shows the vertical section of a typical building situation. The cross-section of the columns changes from storey to storey and the inner walls are shifted.

Fig. 15B shows the corresponding architectural lay-out. It also presents the slab together with its openings and walls and columns which are located above it.

Fig. 15C shows corresponding part of the general structural lay-out representing columns and walls beneath the slab together with the slab.

In the reinforcement plan, presented in fig. 15D, all building components are shown in many cases. Beside the building components below the slab, one also needs the building components above the slab for the connecting reinforcement of the columns and walls above the slab.

What can be done in order to reach the ideal case of each line having to be drawn once only in those 3 plans? One must present the building components below the slab, the slab itself and the building components beneath the slab, each in separate layer as well of course as the hatching and dimensioning. Only then does one obtain the architectural plan overlaying the layers of the slab and the layer of the building components above the slab, the general structural lay-out by overlaying the layers of the slab and the layer of the building components below the slab and the reinforcement plan by overlaying all three layers.

The effective application of the technique within one building project requires, however, an agreement between all involved architects and engineers upon a uniform naming and administration of the layers. Only then is it guaranteed that the structural engineer will actually find the requested lay-out of the architect or that the installations engineer will find the desired layer of the structural engineer or architect. Reports [11] and [12] will give an indication of the organisational problems which must be solved when the overall planning within a planning company is carried out on one CAD system within an office. Should architectural, structural and installation planning be carried out in different offices with different systems, then an additonal problem to overcome would be the transfer of CAD data between different CAD systems.

4.2 CAD Data Exchange:

Before discussing the situation in the AEC (Architecture, Engineering, Construction) industry, it is useful to look at the situation in other industries.

In Germany, several neutral exchange formats are used outside the AEC industry.

- VDA-FS [13] (Format for the exchange of surfaces for the automotive industry)

- VDA-IS [14] (IGES subset for the automotive industry).

It is interesting to note that inside the automotive industry a subset of IGES is accepted and used as an intermediate format, to exchange CAD data between different types of CAD systems.

Inside the German AEC industry IGES [15] or other neutral exchange formats [13] and [14] are not accepted. If exchange of CAD data is practised at all between different systems, then only with the help of so-called direct translators which transfer the 'sending' CAD system format directly into the 'receiving' CAD system data format. Reports on practical experience are shown in [16] - [18].

The situation abroad is similar. With regard to the exchange of CAD data in Great Britain [20] and in the USA [21], two such reports show experience in these countries. Here also the existing neutral formats are almost not accepted. Direct translators are mostly used.

In 1986 a special AEC committee was founded in Germany as a subcommittee of the German DIN committee, which contributes to the ISO standardisation concerning this topic. The goal of this AEC committee is to establish a neutral data format for the exchange between different CAD systems suitable for AEC purposes on the basis of national and international standards.

This committee consists of representatives of all types of institutions engaged in building design. The committee decided on a two-step approach in order to establish the neutral exchange format:

- rapid development of a 2D exchange format on the basis of existing standards until the end of this year;

- in 1988 beginning of a contribution to the ISO work and discussion of existing reference models.

A first version of the 2D exchange format, based on the international standard STEP with the name of STEP_2DBS (STEP 2D building subset) is currently available.

The future standard STEP was chosen as a basis, since this format will be established in the nineties. Then STEP_2DBS can be extended to exchange 3D data an alphanumeric information in order to become a comprehensive product definition exchange format for AEC purposes.

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