Computer-aided design of precast reinforced concrete building frame structures

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ABSTRACT

In several countries a great number of industrial and public buildings are constructed by the use of precast rc frame systems.At the Technical University of Budapest program systems have been developed for the computer-aided design of such building structures. These programs contain all the specific features of the building system in question, which allow to reduce significantly the amount of input data. One of the programs has been elaborated for a fully precast building system which allows the design of single-storey buildings /with or without craneways/, as well as that of multi-storey buildings, with the possibility of various plan layouts. By the use of the program the whole analysis and design process passes off automatically. Loads and internal forces of all structural members are calculated, appropriate system components are selected from database, schedule of structural elements is made, and floor plans are drawn on plotter. Another program has been worked out for a special building system where the structural elements /columns, floor slabs/ are joined by prestressing. The most important part of this program is the design of the prestressing strands and the plotting of the prestressing plan.

Conception assistée par ordinateur d'ossatures des batiments en béton armé préfabriqué

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SOMMAIRE

En plusieurs pays un grand nombre des bâtiments publiques et industriels sont construits en utilisant des systèmes d'ossatures en béton armé préfabriqué. A l'Université Technique de Budapest des systèmes de programmes ont été élaborés pour la conception assistée par ordinateur de telles structures. Ces programmes tiennent compte des traits distinctifs du système en question, en ce qui permet de réduire des données initiales en faisant marcher le programme. Un de ces programmes a été conçu pour un système de construction composé d'éléments préfabriqués, permettant l'étude des batiments d'un niveau /sans ou avec des ponts roulants/, et aussi de plusieurs niveaux, ayant des arrangements de plan les plus variés. En utilisant le programme, le procédé complet de l'étude se déroule automatiquement. Les charges et les forces intérieures des membres structuraux sont calculées, les composants du système appropriés sont choisis de la base des données, le relevé des éléments est établi, et les plans des planchers sont dessinés par des plotters. Un autre programme est élaboré pour un système de construction spécial, ou les éléments structuraux /poteaux, panneaux de plancher/ sont reliés par précontraint. La partie la plus importante de ce programme est l'étude des cables de précontraint et le dessin du plan des cables.

1. INTRODUCTION

In several countries a great number of industrial and public buildings are constructed by the use of precast rc frame systems. At the Technical University of Budapest, Department of Strength of Materials and Structures, program systems have been developed for the computer-aided design of such building structures. These programs contain all the specific features of the building system in question, and this solution allows to reduce significantly the amount of input data.

2. PROGRAM SYSTEM FOR STRUCTURAL DESIGN OF BUILDINGS "BVM-TIP"

Between 1977 and 1984 - based on the know-how of the swedish "STRANG-BETONG" company - a fully precast rc open building system has been developed in Hungary under the name of "BVM-TIP". The system allows the design of single-storey and multi-storey buildings, with the possibility of the most various orthogonal plan layouts. The structural system consists of precast multi-storey columns and precast, prestressed beams. For the floor structure three kinds of prestressed slab elements are available. Façades are made of vertical /standing or suspended/, or horizontal wall panels. The single-storey frames can be built with or without craneways, with short longitudinal or large-span transversal girders; the structural model consists of columns fixed at their lower ends and simple beams, joined to them by pins /Fig.1/. There are two variants of the multi-storey frames: the beams are supported on the columns by rc cantilevers or hidden steel plate cantilevers; the structural model is a chain of pinned bars; spatial stiffness of the building is provided by shear walls /Fig.2/.

As elaborating a computer-aided structural design method for the described building system, our aim was to develop a program which furnishes a maximum of computer aid for the design of "BVM-TIP" frame structures of optional plan and optional number of storeys, based on the simplest possible designer input.

To achieve the described aim, the program system accomplishes the following tasks:
- Based on data given by the designer it produces the internal image of the structure, i.e. it numbers the columns, distributes the floor slabs, disposes and numbers the floor beams.
- Traces on the plotter preliminary floor plans on which the designer can check the correctness of the input data and of the internal image.
- Calculates the loads of the structural members /floor slabs, beams, columns, shear walls/ and the design values of internal forces; produces combinations of design values of internal forces significant for checking the load-bearing capacity.
- Selects precast structural units /floor slabs, beams, columns/ from the data base of system components according to the designer's wishes so as to meet geometry, strength and deformation conditions.
- Prepares the schedule of system components.
- Traces on the plotter the floor plans for each storey, in two phases /the column/beam plan and the floor slab layout plan/.

The structural design of any building which can be constructed in the BVM-TIP system can be carried out with the structural design program system /with a few exceptions/. In the case of single-storey buildings, the building may be with or without a craneway, the ground plan can be of rectangular, L, T or I shape. In case of multi-storey buildings, they should fit a rectangular grid with optional ground plan and contour. The building may have interior courtyards, floor holes and set-back parts, and cantilevers as well. The higher storeys can be set back as compared to the lower ones. Also the storey heights may be different.

Any load occurring in practice may be defined on the structures. Beside the uniformly distributed floor loads, the loads due to façade cladding and crane loads, also loads distributed over any rectangular surface and linear or concentrated loads may be specified. The wind load has not to be specified in the input as the computer takes it automatically into account, according to standard specifications. The effects due to temperature changes, shrinkage and placing inaccuracies are also automatically involved in the program.

Limits of application of the program system are irrevelant in general to the design of a building in practice. Some limitations: the number of storeys cannot exceed 10, and a maximum of 200 columns can be designed.

In developing the input system it has been endeavoured to enable the designer to specify the building and its loads with the smallest amount of input data and paper work possible. On the nine different data sheets the data to be specified are divided into three principal groups: some general data concerning the building - principal geometric data of the structural system /storey heights, column layout/ - loads acting on the building. Specification of the column system takes repetition of column spacings into account. The system permits some columns to be omitted from the column grid and allows also application of columns outside the regular grid. In specifying the floor system only the load-bearing direction of each floor field has to be specified; slabs and beams are automatically distributed by the computer. Identification and numbering of each structural element are also automated. To check the input data, the program system presents several facilities /reprint of data, check of data syntax; plotting of preliminary floor plans/.

The output results supplied by the program system appear partly on the line printer, partly as drawings provided by the plotter. In filling out the data sheets, the designer may make a choice among options, defining which kinds of output results - enumerated below - he wants to be printed out or to be traced.

Outputs on the line printer are:
- input data reprinting;
- design values of internal forces of the system components and combination of internal forces for each storey and member;
- results of member selection and schedules. Member selection means that the program checks the load-bearing capacity of the structural

members, with the dimensions specified by the designer /using the load-bearing capacity data stored in the data base/. If the catalogue of the "BVM-TIP" system provides the possibility, among members of identical geometry the computer choses the most economical reinforcement variant granting the member a safe load-bearing capacity, and prints out the system catalogue code of the member complying with the given geometry and strength requirements. The output indicates if there is no member meeting the given geometry and strength conditions in the data base of the system, and possibly tries again the design with another member, with larger dimensions. Member selection is carried out member-type-wise /floor slab, beam, column/ and storey by storey. Also schedule is made member-type-wise, at first storey by storey, then summing up each member type for the entire building.

As for the plotter-traced plans, beside the mentioned preliminary floor plan /Fig.3/, the program system produces also phase floor plans, separately for the columns and beams /Fig.4/, and separately for the floor slabs /Fig.5/. The phase floor plans contain layout of the structural members, their codes according to the catalogue and the member schedule for the given storey.

Remind that the graphical output is carried out parallel to the calculations, based on input data and on calculation outputs; thus no separate data specification is needed for the drawings.

Further some features of the algorithms used in the program system will be mentioned. Determining the loads, the calculation of the wind load may be of interest: they are more precisely calculated than in the usual methods, the possible oblique wind directions being also considered, because these directions will give the most dangereous loads for the columns. All possible load combinations are considered and from these the range of loading for each cross-section is produced automatically.

Condition for selecting members fulfilling geometrical, ultimate limit state and serviceability limit state conditions is a data base containing all necessary data. In our data base, limit values of load-bearing, crack width and deformation of the elements are stored. In the case of rc structures, setting up the data base requires special considerations, as the ultimate limit values are not independent from each other. In the case of beams we must take bending moment and torque, and shear force and torque together into account; in the case of columns the axial force and the biaxial bending moments must be considered together. Thus, the mentioned limit values cannot be stored separately; they must be stored in mutual relation, in the form of ranges of load-bearing capacity.

Check of the load-bearing capacity and member selection is based on the comparison of the range of loading with that of load-bearing capacity.

The program system containing about 15000 FORTRAN statements has been developed for a Hungarian-made mini-computer, having a core store capacity of 64 kbytes; two discs of 2,5 Mbytes are attached. The computer

is off-line connected with a CALCOMP plotter. Modification of the program permitting interactive work is under way.

3. PROGRAM SYSTEM FOR STRUCTURAL DESIGN OF BUILDINGS "IMS"

In the last 15 years a special building system, based on a Yougoslavian licence and having the name IMS, has been developed in Hungary. The frame system consists of precast multi-storey columns and precast floor slabs. The members are joined by a two-direction prestressing system; the prestressing strands pass through holes of the columns. After post-tensioning, the strands are pulled down at one third of the spans; the vertical force components arising from this operation increase the load-bearing capacity of the floor. Having finished the construction, we get a multiple redundant space frame structure. In the case of multi-storey buildings, the space stiffness is assured by shear walls. The dimensions of the concrete structures are constant; variables are: the prestressing system, and the reinforcement of columns and shear walls.

Elaboration of an integrated computer program for the above mentioned frame system is under way. Some parts of the "BVM-TIP" program /e.g.input system, pre-processing programs/ could have been adopted also for this work. The whole system, however, is much more complicated, because of the complexity of the structural model and the great number of free parameters in prestressing. As preparing this program, our aim was again to automatize the entire structural analysis and design process: calculation of the loads and the internal forces, determination of the necessary prestressing forces, design of the necessary cross-sections of the prestressing strands, design of the system of pulling down the strands, design of the necessary reinforcement of columns and shear walls, and drawing the prestressing plans on plotter. Analysis is carried out by matrix-displacement method; as applying this method, in a first step a real floor slab element or a floor field, and in a second step the entire floors, the columns and the shear walls are considered as finite calculation elements. As checking the load-bearing capacity of the structure, its non-linear behaviour is also taken into account. As determining the prestressing system, the degree of automatization of the design process may vary according to the desire of the user or according to the complexity of the prestressing system; choice between options is possible due to input data.
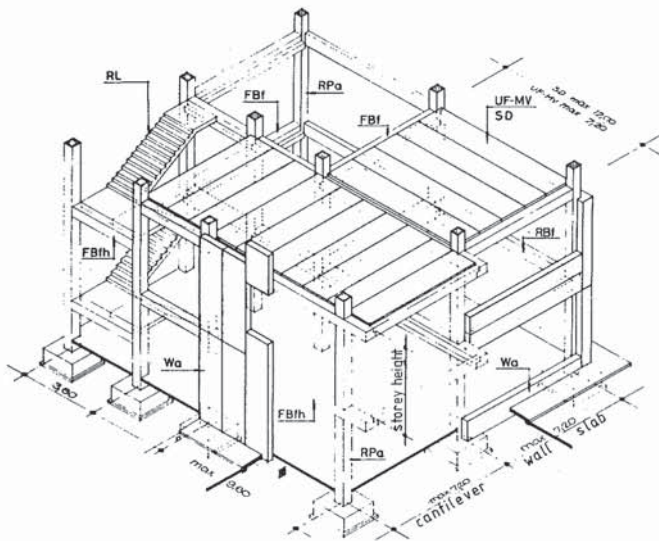
Fig.6. shows a plotter-made prestressing plan of an IMS system building.
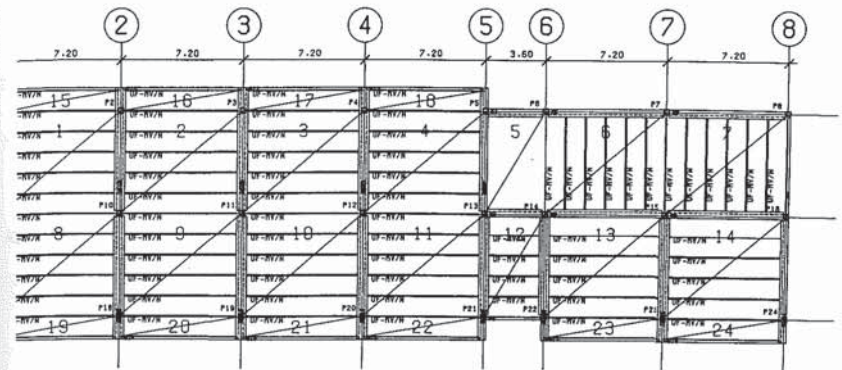
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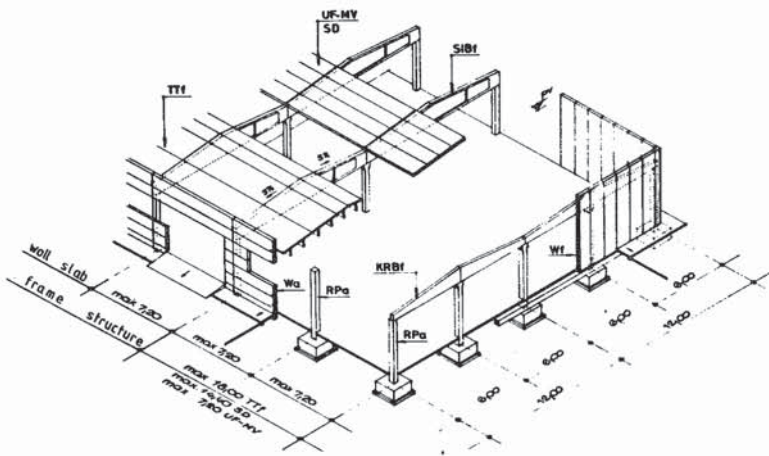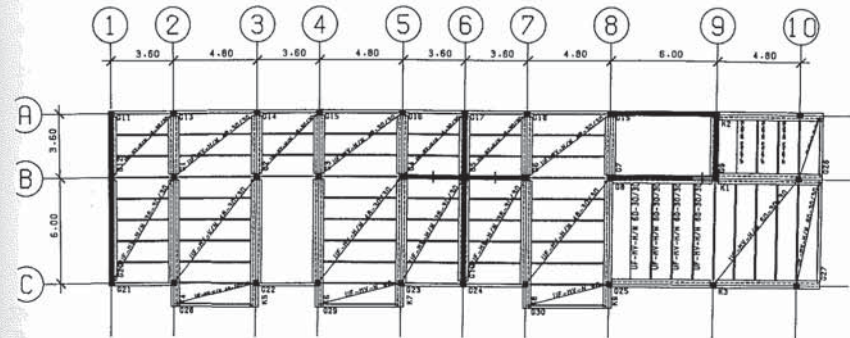
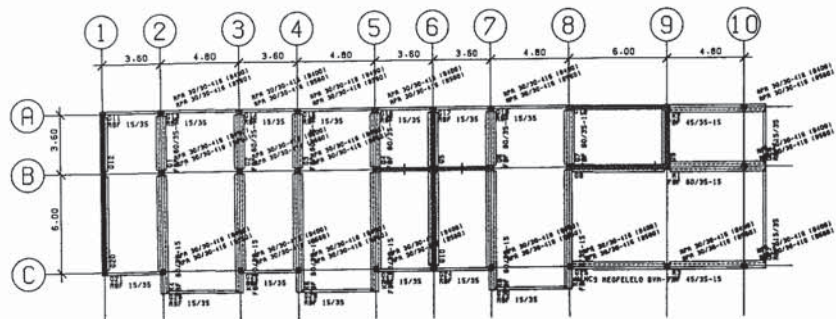1 Single-storey frame system "BVM-TIP"

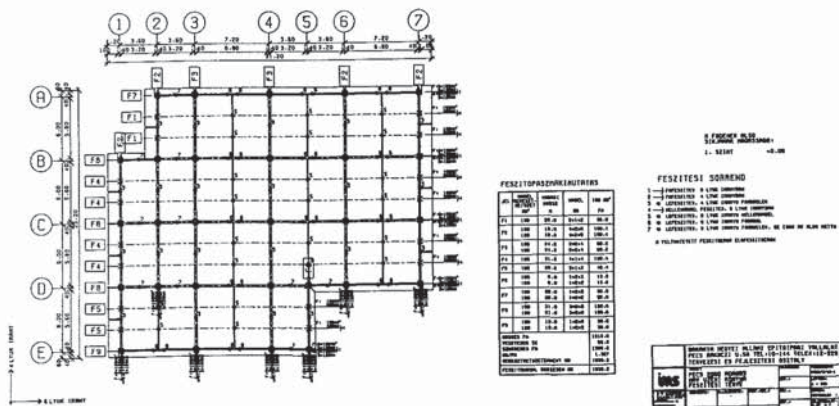2 Multi-storey frame system "BVM-TIP"

3 Plotter-traced preliminary floor plan of a "BVM-TIP" building

4 Plotter-traced column/beam plan of a "BVM-TIP" building

5 Plotter-traced floor slab plan of a "BVM-TIP" building

6 Plotter-traced prestressing plan of an "IMS" building

Development of CADS and their Interactions
with Other Automated Systems

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KEYWORDS

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ABSTRACT

Design technology, design procedures and data sets providing
synthesis, analysis, estimation, and choice of installation
design were investigated to develop the computer-aided design
systems (CADS) of structure and item catalogues and also
catalogues of industrial and civil buildings. A new com-
puter technology of design was worked out on the basis of
this information and the previous design automation experi-
ence. This technology provided 2-5 times labour and time
expenditure decrease, and 7-10 percent economy of material
resources. Examples of information transmission from the
CADS to information processing systems for construction
preparing show the possibility of an important economy of
time and engineer work during this work as well.