Computers & Structures Vol. 40, No. 5, pp. 1213–1221, 1991
Printed in Great Britain.

0045-7949/91 $3.00 + 0.00
Pergamon Press plc

COMPUTER ASSISTED STRUCTURAL CONCRETE EDUCATION

R. A. CHANDANSING, H. SLIEDRECHT, W. A. DE BRUIJN and CH. J. VOS
Faculty of Civil Engineering, Delft University of Technology, 2628 CN Delft, The Netherlands

Abstract—A CAD system, called the CAD Structural Concrete Exercise, has been developed by the Concrete Structures section of Delft University of Technology to improve the learning effect of a structural concrete design exercise. AUTOCAD was selected as the basic software. Much work has been carried out to tailor AUTOCAD for this specific exercise, by writing subroutines in AUTOLISP and PASCAL. The main feature of the CAD system is the ability to check the design, the accessory calculations and the drawing by using information which is gathered by the system during the drawing activities of the students. Another feature is the possibility of performing parameter studies to investigate the influence of the different parameters on the design. The CAD system, of which development started in 1987, has recently been used for the first time by 187 students. It was evaluated as quite successful. Apart from educational purposes, the CAD system has the potency to be used as a tool for research activities on CAD applications in the concrete construction industry. The CAD system is running on Apollo DN 3000 workstations under AEGIS. A demonstration version is available for PCs running under MS-DOS.

INTRODUCTION

Structural design of concrete structures is taught in the beginning of the third year of the curriculum for civil engineering by the section for Concrete Structures of the Faculty of Civil Engineering at Delft University of Technology (DUT). The basic theory of structural concrete design is taught in the course G20, and is examined by tests and a design exercise.

The tests are meant to examine the students' understanding of the basic theory of the subjects of the course. Since 1985 the students have been examined by means of computer tests. These tests were judged very positively after an evaluation carried out in 1986.

The structural concrete design exercise is meant to develop and train the students' design and drawing skills. It became clear, however, that the original exercise did not meet its educational aims sufficiently; Shortage of staff to guide the students through the exercise and to correct their errors was the main reason. Apart from this, the time students can spend on exercises such as this became more and more limited.

The insufficient learing effect of the exercise, the possibilities of modern computer aids and the good experience the section for Concrete Structures had with computer testing, led to the development of the CAD Structural Concrete Design Exercise. The heart of this new exercise is a CAD system to produce reinforcement drawings interactively, to check the design, the calculations and the drawings of the students, and to enable the students to do parameter studies.

The main objective of the development of the CAD system for the CAD Structural Concrete Design Exercise were:

1. To improve the learning effect of the exercise by means of CAD in terms of the students' understanding of the subject and the development of design and drawing skills.
2. To guide the students adequately through the exercise, in spite of limited time and assistance by staff.
3. To familiarize the students with the use of an integrated CAD application.
4. To increase the students' understanding of the subject by means of parameter studies.

THE CAD STRUCTURAL CONCRETE DESIGN EXERCISE

General description of the exercise

In the CAD Structural Concrete Design Exercise some structural members of a multi-storey office building, made of cast *in situ* reinforced concrete, have to be designed and detailed (Fig. 1). The exercise is subdivided into four parts:

1. Dimensioning of the concrete members.
2. Detailing of a T-beam.
3. Detailing of a slab.
4. Detailing of a column and performing of a parameter study.

Each part of the exercise consists of two stages. Firstly the students make the calculations required for dimensioning and detailing without the use of the CAD system. Secondly the students enter the results of their calculations into the CAD system. These are either simple numbers or complex geometry, shape and position of reinforcement bars.

After the students have entered their results and activated the control module, the results are analysed by the CAD system. A list of errors and remarks is produced on the screen. With this feedback the students can change and improve the design interactively until it is approved by the CAD system. The students can also obtain a hard copy of their errors

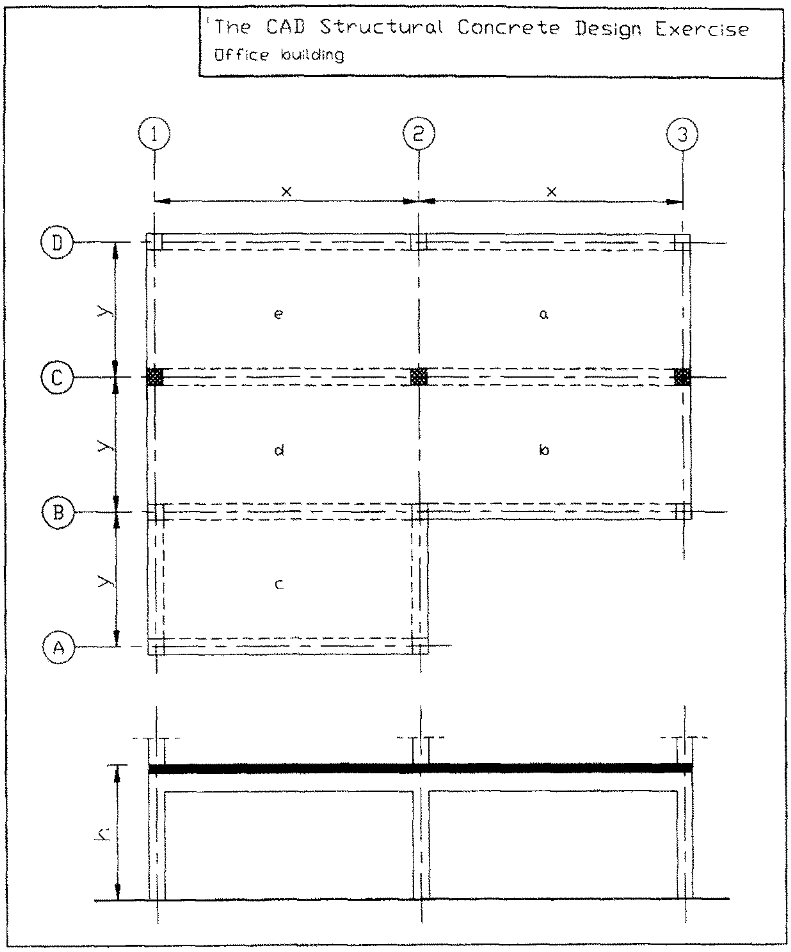

Fig. 1. The CAD Structural Concrete Design Exercise.

and remarks to study and improve the design carefully later. During the sessions at the CAD station, it is also possible to get some assistance from a staff member.

The exercise has a sequential character. The students are allowed to move to the next part only if the previous part is approved by the CAD system. The students are not allowed to make changes in previous parts which have already been approved by the CAD system.

Part 1

Basic data, such as spans, material properties, loads, safety factors, etc., are derived by the computer from the student identification number, being exclusive for every student.

With these basic data the dimensions of the structural members, such as beams, slabs and columns, are calculated by hand by the students. Behind a CAD station the basic data and the dimensions of the structural members are put into the CAD system (Fig. 2). This input is then analysed and checked by the CAD system, resulting in a list of errors and remarks on the screen.

Part 2

The reinforcement of a T-beam is calculated and designed by the students. The reinforcement is assembled, with the aid of the CAD system, in drawings of the concrete shapes, presented by the system. The CAD system uses data from part 1 to present drawings of the concrete shapes. The reinforcement is presented in a front view and in three cross-sections. The CAD system automatically checks if the reinforcement in the cross-sections is in accordance with the reinforcement in the front view (Fig. 3). When the total drawing has been made, the design, the calculations and the drawing are checked by the CAD system (Fig. 4).

Part 3

The reinforcement of a slab is calculated and designed by the students. With the aid of the CAD system the reinforcement is assembled in a drawing of the plan of the concrete shape of the slab (Fig. 5). The reinforcement of the slab is assembled in several fields of similar reinforcement. The reinforcement drawings of the cross-sections are automatically generated from the reinforcement drawings in the plan.

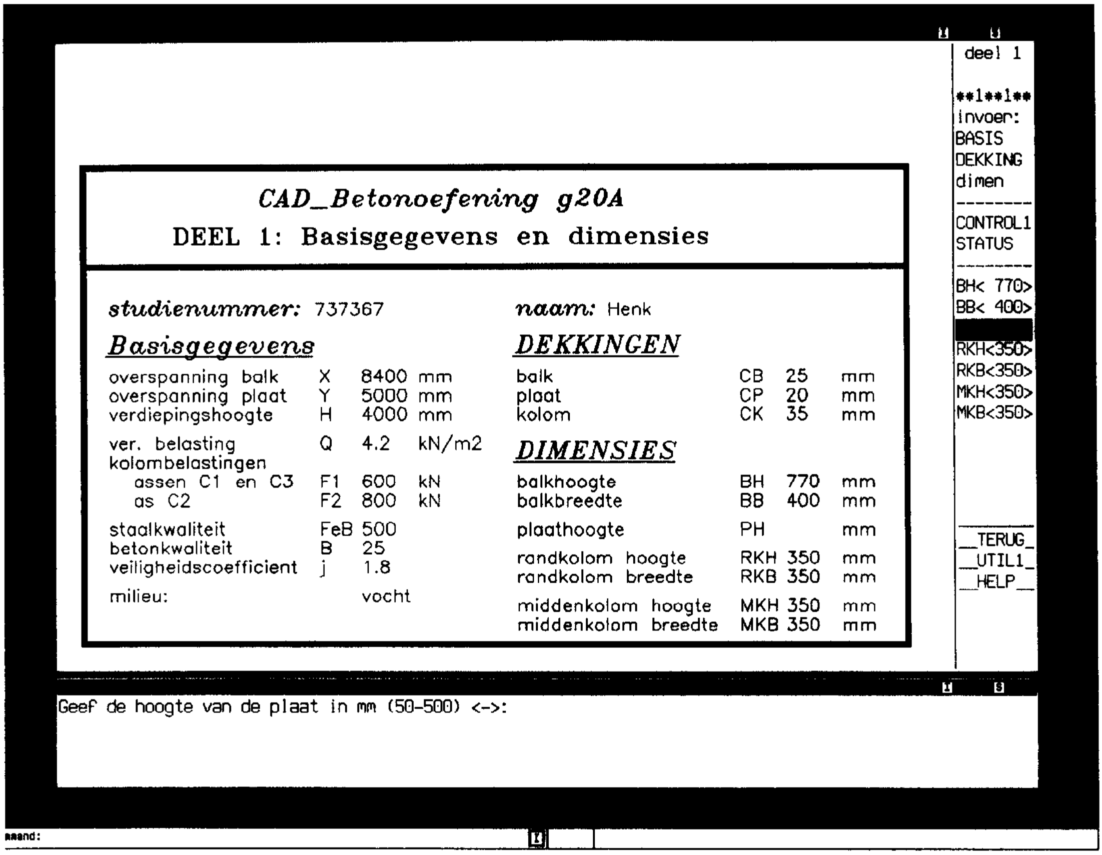

Fig. 2. Part 1: basic data and concrete dimensions.

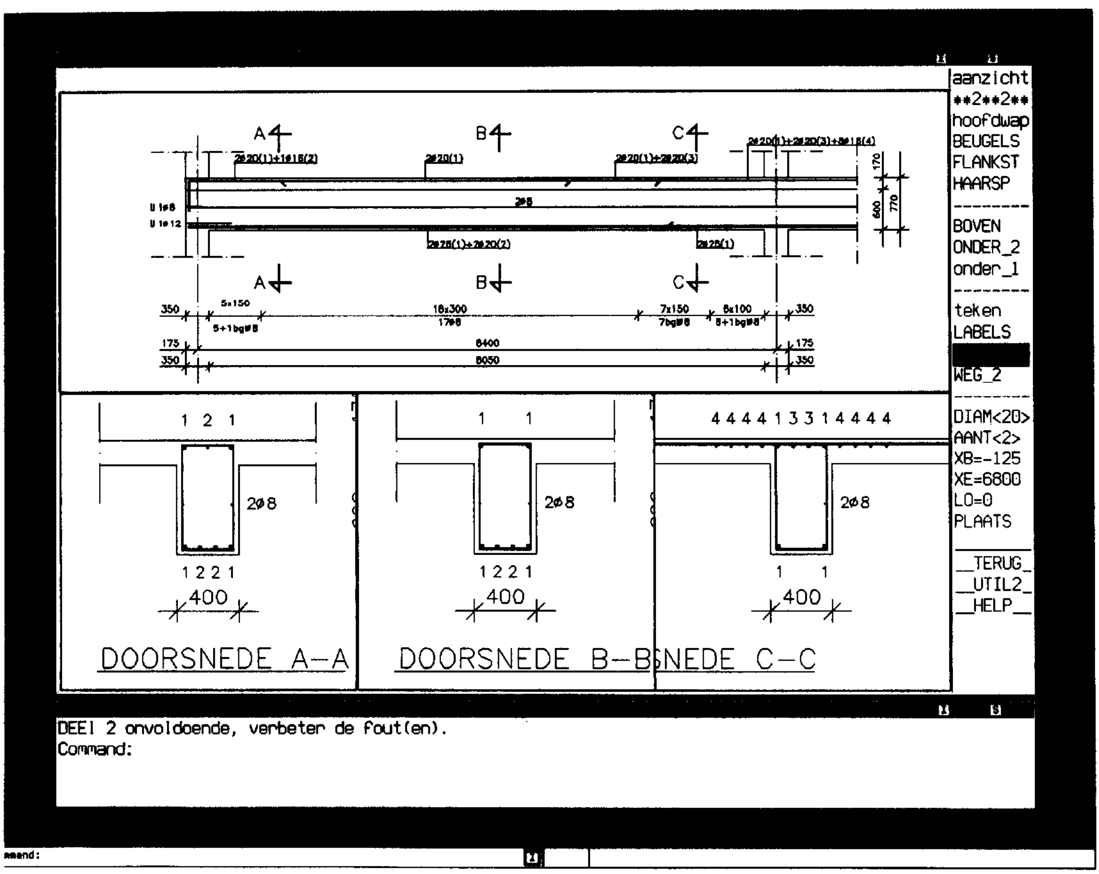

Fig. 3. Part 2: assembling reinforcement drawing.

-1- 69-29-19

CAD-BETONOEFENING G20A

Deel 2 : dimensionering T-balk

naam : *Henk*
studienummer : *737367*
datum : *06-02-1991*
onderwerp : *DEEL 2*

ALGEMEEN
Fouten : geen
Opmerkingen : geen
Fouten : geen
Opmerkingen : geen

Aantal fouten : 0
Toegestaan : 0
Resultaat : voldoende
Je kunt verder gaan met DEEL 3

GEGEVENS BALK :

Maatgevende doorsneden : ω_{min} = 0.00222 ω_{max} = 0.01400

belasting				sterkte				scheurwijdte							
dsn	x mm	M kNm	γ*M kNm	As mm²	ω %	Mu kNm	γop	Act mm²	ωt %	σs N/mm²	σscr2 N/mm²	w_cr mm	lst mm	δw mm	w_x mm
1	0	-110	-198	829	0.269	-291	2.64	221765	0.37	-211	719	0.121	143	0.030	0.151
2	3390	330	595	1963	0.637	697	2.11	77429	2.54	258	120	0.057	119	0.025	0.223
3	8400	-507	-913	2865	0.930	-935	1.84	221765	1.29	-281	220	0.123	140	0.029	0.226

Las- en verankeringslengten :

Verankering onderwapening tpv randkolom : Ru = 394 kN, Ru_max = 394 kN, γ*R = 374 kN

staafgroepgeg				gegevens beeindiging staafgroep							resultaat analyse
stgr	x mm			typ	lst_u mm	a	d mm	lst mm	lst_th mm	Δ mm	
eerste laag onderwapening											
1	-125	b	2Ø25	VER	747	-	-	300	-	-	bezwijkkracht Ru=197 kN
2	-125	b	2Ø25	VER	747	-	-	300	-	-	bezwijkkracht Ru=197 kN
2	6800	e	2Ø25	RED	747	0.50	720	1240	1096	145	goed
bovenwapening											
1	-115	b	2Ø20	VER	657	0.68	722	565	447	118	goed
2	-117	b	1Ø16	VER	481	0.68	722	567	328	239	goed
2	1300	e	1Ø16	RED	481	0.76	722	1300	1264	36	goed
3	5300	b	2Ø20	RED	657	0.51	722	1312	1233	79	goed
4	5900	b	8Ø16	RED	481	0.46	723	1529	1122	408	goed, kan eerder worden beeindigd

Dwarskrachtwapening :

randkolom : γ*R = 374 kN middenkolom : γ*R = 543 kN aantal beugels = 39
Vcu = 176 kN Vcu = 265 kN theoretisch = 38

beugelgegevens						toegepast	theoretisch		resultaat analyse
plts -	n -	hoh mm	Øks mm	xb mm	xe mm	Ass/t mm²/mm	xb_th mm	Ass/t mm²/mm	
rklm	7	150	8	50	1100	0.67	0	0.63	goed
veld	17	300	8	1100	-->	0.34	928	0.28	goed, kan eerder beginnen
veld	17	300	8	1900	-->	0.34	1691	0.26	goed, kan eerder beginnen
mklm	7	150	8	850	1900	0.67	696	0.62	goed
mklm	8	100	8	50	850	1.01	0	0.89	goed

Afstanden Hoofdwapeningsstaven :

laag	dsn A		dsn B		dsn C		
	hoh	tussen	hoh	tussen	hoh	tussen	
eerste laag onderwapening	100	75	100	75	299	274	
bovenwapening	152	134	304	284	101	81	

Hoeveelheden en kosten : per halve balk				per m³		
kostenposten	hoeveel-heid	eenh. prijs	totale prijs	totaal/m³		
hoofdwapening (inclusief flankstaven)	219.8 kg	1289,-	283,-			
opbouw : diam fl/ton meter kg fl						
8 2200. 17.05 6.73 15,-						
16 1400. 21.87 34.51 48,-						
20 1300. 24.13 59.51 77,-						
25 1200. 30.90 119.07 143,-						
beugels en haarspelden	50.7 kg	2383,-	121,-	wapening	102.4 kg	153,-
opbouw : diam fl/ton meter kg fl						
8 2400. 124.96 49.31 118,-						
12 1800. 1.61 1.43 3,-						
beton (balk)	2.6 m³	170,-	449,-	beton	1	170,-
bekisting						
onderzijde (horizontaal)	3.4 m²	60,-	206,-			
zijkanten (vertikaal)	10.6 m²	80,-	848,-	bekisting	5.3 m²	399,-
kosten per balk (1 overspanning = halve balk) :			1907,-	per m³ :		722,-

Fig. 4. Part 2: list of errors, remarks, bill of quantities and cost.

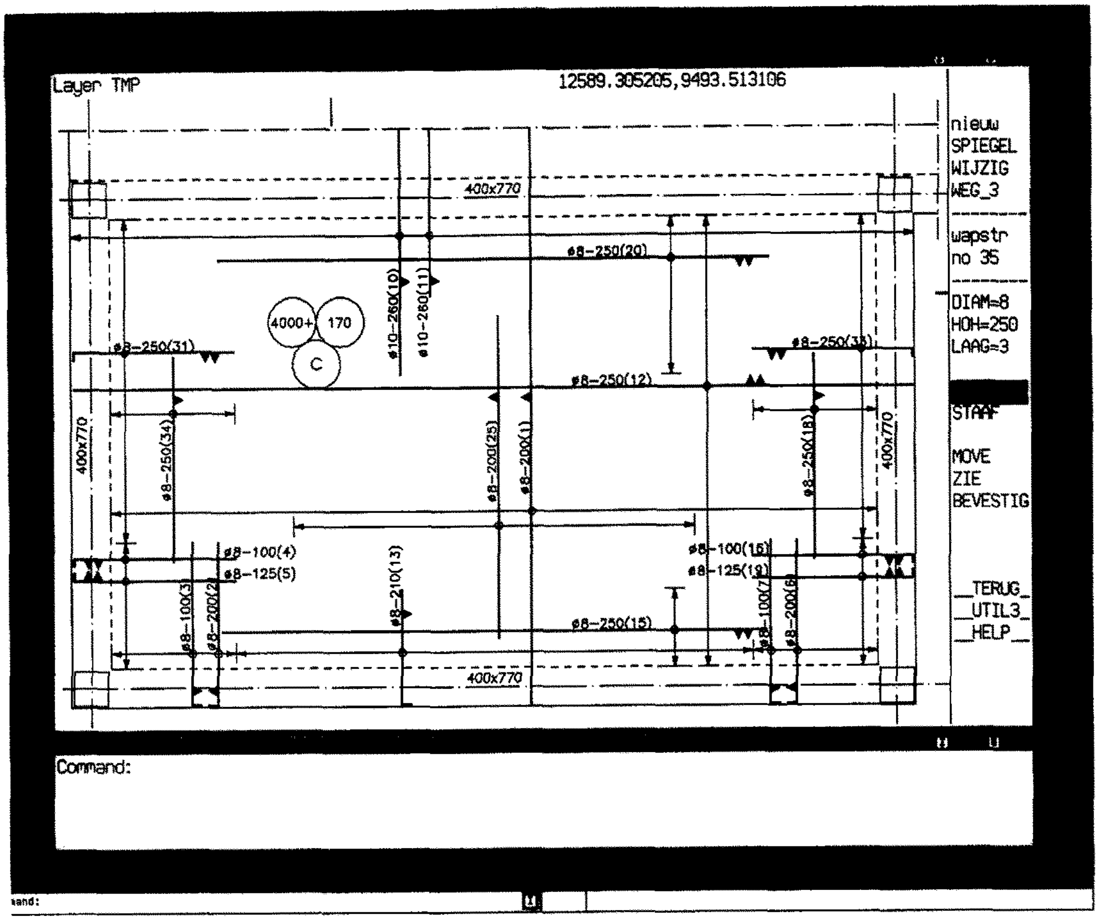

Fig. 5. Part 3: assembling reinforcement drawing.

Part 4

The reinforcement of two columns is calculated and designed by the students. With the aid of the CAD system the reinforcement is assembled in a front view of the concrete shape of the columns and in a cross-section. The CAD system automatically checks if the reinforcement in the cross-sections is in accordance with the reinforcement in the front view. When the columns have been finished with good results the students are allowed to start with a parameter study to investigate the influence of several parameters, such as the concrete geometry, etc. on the design of the reinforcement, the total quantities and the costs of the structure. The influence of the magnitude of the loads on the cost of the design will, for instance, be evaluated in such a parameter study.

THE CAD SYSTEM

Hardware

The hardware facilities of the CAD training centre (CAD-TC) of DUT were selected to be used for the CAD system in an early development stage. The CAD-TC is an independent section of the Faculty of Mathematics and Informatics of the DUT, which offers CAD training facilities for all the faculties.

Thirty Apollo DN 3000 stations (screen resolution 1280 × 1024), two A4 laser-printers, one A3 HP-plotter and other facilities to support the use of the hardware are available in the CAD-TC.

The CAD exercise runs under AEGIS, which is supported by Apollo. This is because of the decision to use the hardware available at the CAD-TC. A PC version, running under MS-DOS, is also made available for demonstration purposes.

Software

The actual process of the original Structural Concrete Design Exercise was analysed and completed with data analysis in order to develop an appropriate CAD system [1]. 'IDEF-modelling' techniques were used and compared with the experience of the staff members of the section involved in the conventional exercise. This resulted in the design of the CAD system in three stages:

1. An input and drafting stage to specify geometry and to establish reinforcement drawings.
2. A review stage to check the design, the calculations and the drawings.
3. A parameter study stage to investigate the influence of several parameters on the design.

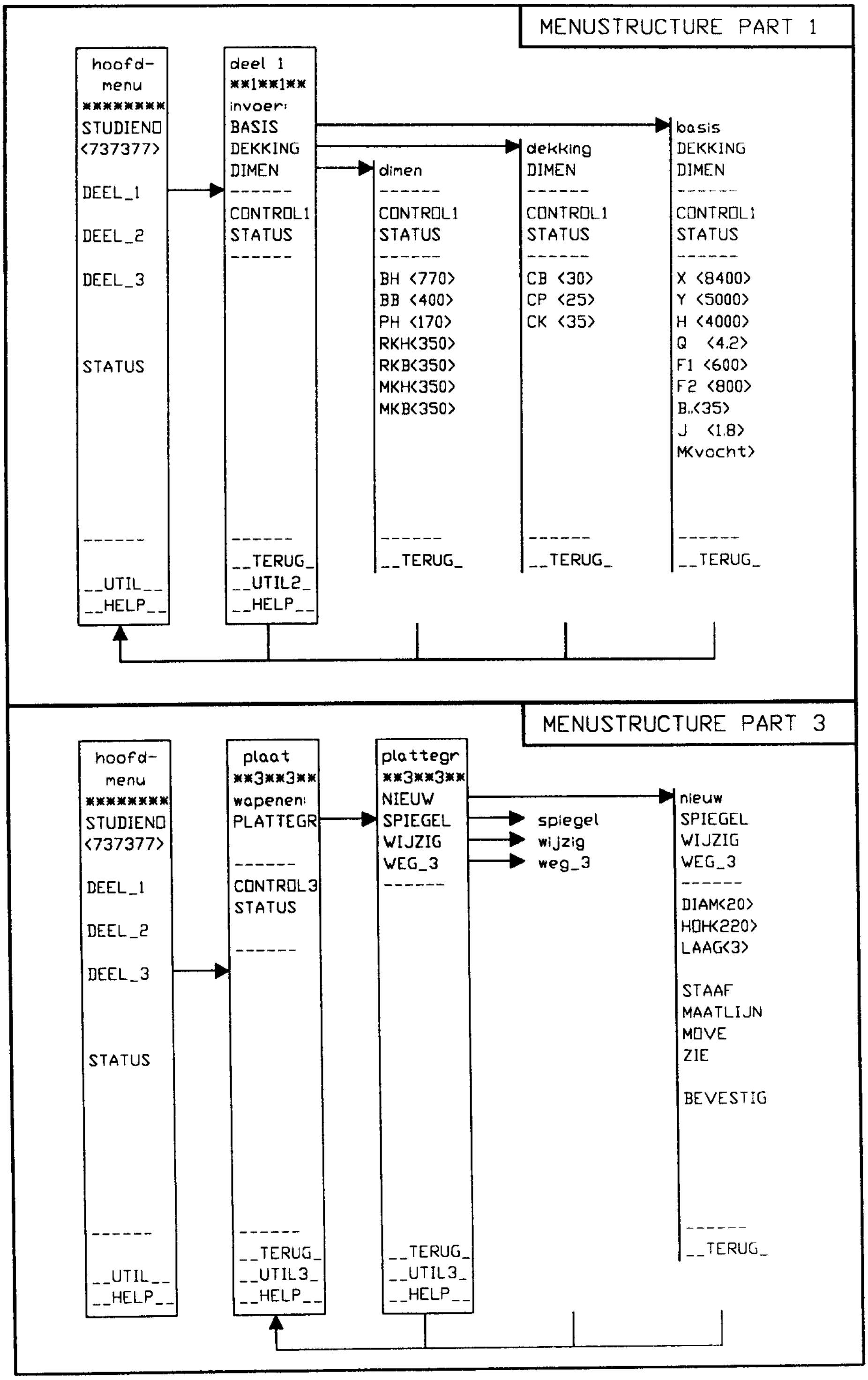

Fig. 6. Menu structure of parts 1 and 3.

The basic design of the CAD system required some facilities from the software to be used. Such facilities involved the ability to change the menus, to program, to use both geometrical and non-geometrical information and to use external programs. After a careful evaluation, AUTOCAD was chosen as the most suited for this system. Available know-how, the impact of the hardware to be used and the prospects for multi-lateral development were the main factors for this decision. It was realized that this decision meant that more powerful software, enabling less costly dedicated programming, was ruled out in favour of presently commonly used hardware and software.

Input and drafting

The input and drafting stage enables one to enter data and assembling drawings interactively. For this reason the standard AUTOCAD menu was replaced by a new specially designed menu (Fig. 6) which enables the students to control the whole CAD system. Menu selections are used to activate sub-menus or commands. In the latter case a question appears on the screen which can be addressed by activating a menu selection, by cursor pointing in the drawing or by typing in a numerical value.

Modification of AUTOCAD to this particular CAD system made it inevitable that several routines were needed to be written in AUTOLISP, the programming language available within AUTOCAD. Input routines were required in order for the students to specify the required data. Drafting routines were written to manipulate the drafting of concrete shapes and reinforcement, and the placing of text on the drawings. Supporting routines were written to manipulate the AUTOCAD database and to perform input checks.

On-line help texts were made available on every menu item, explaining what the item means and how it can be used. They are needed to improve the user-friendliness of the system and to minimize use of the user manual. This feature required modification of the CAD system's standard help facility within AUTOCAD.

Review

Every part of the exercise is checked by a control program which is written in Pascal. The input for these control programs are ASCII input files, containing data, which are retrieved from the AUTOCAD database. The checking programs are based on Dutch codes (NEN 3870 and VB 1974/84) and the lecture material from the course [3, 4]. In the future this part will be modified in accordance with new codes, possibly the Eurocode, and any new lecture material [4].

In the checking stages three steps can be distinguished. Firstly the data in the ASCII file are checked. Secondly calculations are made to get the theoretical values and the actual values, related to a student's specific exercise. Finally, the theoretical and the actual values are compared, resulting in a listing of errors and consequential remarks. This listing is presented, together with a bill of quantities and the costs of the structural member, in an ASCII output file.

The ASCII output file with errors, remarks, bill of quantities and the cost of the structural member are handled by two drivers; a screen-driver, to present the results of the control procedure on the screen, and a printer driver, to make a postscript file of the ASCII output file. With this postscript file it is possible to get a hard copy of the ASCII output file, with the aid of a postscript printer (Fig. 4).

Parameter study

The possibilities for the performance of parameter studies are present in the actual version of the CAD system. This part has, however, not yet been programmed in a way that the students who have finished the exercise can do this without producing many calculations and re-doing the exercise. Such a trial-and-error method would also be too time-consuming, which is not in accordance with the target.

The Concrete Structures section is now looking at the possibility to structure this part in such a way that the design is automatically modified after variation of parameters. This enables the students to observe simply the impact of changed dimensions, loads and other parameters on the design, quantities and costs of a concrete structure. This part of the program is still under development.

TUTORIAL STRATEGY

The learning effect of an exercise depends on the quantity and the quality of instruction. However, the quantity of instruction is, in most cases, restricted in time [5]. For the quality of an exercise it is important to activate the students to perform the exercise, to guide them through the exercise and to control their progress.

The aim of the CAD Structural Concrete Exercise has been achieved by improving the quality of the instruction and hence the learning effect of the exercise. Using this exercise, it has not only been more attractive for the students to participate, but the possibilities to guide them through the exercise have been improved, together with the control of their progress.

The attractiveness of the CAD Structural Concrete Design Exercise relates to the user-friendliness of the CAD system. By offering the students a high level of freedom, a clear and easily understandable menu and on-line help facilities throughout the exercise, a high level of user-friendliness has been achieved. To improve this user-friendliness, a brief introduction manual of only four pages is provided, with a one hour demonstration of the CAD system during lecture hours. The need for this became obvious during a test with a limited number of students in early 1990.

Guiding the students and controlling their progress means a constant checking of input activities. Therefore, students are obliged to specify all input values in a certain sequence before entering them. All input values can be checked by the system in this way. Before writing these values into the database the CAD system will always show the values again and ask for a reconfirmation. In this way an extra check of the input has been granted.

Guidance of the students and control of their progress also means that the system provides feedback with instructions on how to correct errors (Fig. 4). This feedback can also be consulted during input activities. In this way a good opportunity has been offered to the students to finish the exercise successfully, either interactively or with a hard copy to study later. For problems that the students cannot solve alone there is the possibility of getting help from a staff member during the interactive sessions.

TUTORIAL EXPERIENCE

An interim evaluation was carried out on the CAD Structural Concrete Design Exercise in January 1990, with the aid of 18 students who went through parts 1 and 2 of the exercise [2]. This evaluation had to check, in the first place, if the exercise met its educational purpose. Secondly it had to prove if the exercise was sufficiently 'student friendly', also meaning that the students felt that it was better than the traditional exercise. Finally the evaluation had to determine the time required by the students to perform the exercise.

Several useful recommendations for improvement resulted from the evaluation. It became clear that better and more consistent documentation, an explanation of how to deal with feedback and a demonstration of the CAD system were required in order to prepare the students sufficiently for the interactive CAD sessions. It also became evident that the CAD system had to be screened on inconsistent terminology and some other minor features. It was concluded that four sessions of two hours each would be sufficient for the students to finish the exercise. All of these recommendations have been incorporated into the final version.

The first group of 187 students have performed this updated exercise, completed with part 3 in December 1990 and January 1991. The students were observed during the sessions and were asked to complete an evaluation sheet at the end of the exercise. These results will be used to evaluate the present version of the exercise.

The final results of this evaluation were not available by the time this paper was written. However, based on the observations it can be concluded that the students reacted positively. They concluded that it was student friendly, educational and an interesting exercise with an integral CAD application.

From an educational point of view, it can be concluded that the students are guided well enough through the exercise and the progress of the students can be watched carefully (Fig. 7). Only a few students exceeded the envisaged average time-limit of eight hours substantially.

FUTURE POSSIBILITIES

The main objective of the developed CAD system was to assist the Concrete Structures section in its educational tasks. However, the CAD system has potential for other uses. Purposes other than just educational ones are being considered by the Concrete Structures section.

Two possibilities for other uses of the CAD system seem attractive. The first is an update version of the

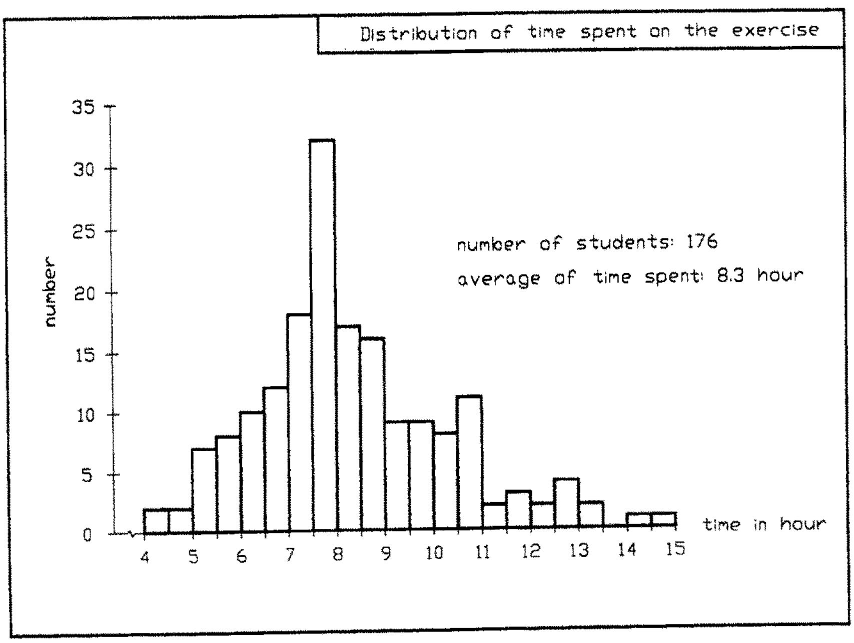

Fig. 7. Distribution of computer time spent on the exercise.

CAD system in cooperation with other European universities. This would involve a general structural concrete design exercise based on widely accepted design rules and codes, preferably the Eurocode. The second attractive possibility is a follow-up which will explore the use of this CAD system for research activities. As the CAD system has the potential to optimize concrete structural members by means of parameter studies, it can also be used as a research tool for the investigation of several aspects of the use of computer aids in the concrete construction industry. Cooperation with either European universities or the European concrete construction industry will be quite useful for such an option.

Hopefully, the presentation of this paper may contribute to the establishment of cooperation for further developments.

REFERENCES

1. H. W. Sliedrecht, CAD-betonoefening (CAD structural concrete design exercise). DUT, afstudeerverslag (1988).
2. R. A. Chandansing and S. Kunst, Een formatieve evaluatie van de CAD-betonoefening g20 (An interim-evaluation of the CAD Structural Concrete Design Exercise). DUT, Sectie Betonconstructies (1990).
3. A. S. G. Bruggeling and W. A. de Bruijn, Theorie en praktijk van het gewapend beton: deel 1 en 2 (Theory and practice of reinforced concrete: parts 1 and 2). PBF.
4. J. C. Walraven, Kollege g20: Gewapend beton (Course g20: reinforced concrete). DUT, Sectie Betonconstructies (1990).
5. W. Jochems, Productiever onderwijs (More productive education). DUT, Delft Universitaire Pers (1990).