

THE USE OF STRUDL IN REINFORCED CONCRETE BUILDING DESIGN

By J. M. BIGGS, R. D. LOGCHER and HARRY N. WENKE

Describes the complete reinforced concrete capabilities in the STRUDL II (the Structural Design Language) subsystem of the ICES (Integrated Civil Engineering) computer software system. The analysis of entire building frames and the proportioning of structural members may be performed within one computer system. The problem-oriented language input, and printouts of typical beam, slab and column designs are illustrated in an example. The system is freely available for use on IBM/360 computers.

Keywords: beams (supports); buildings; columns (supports); *computer programs*; detailing; flat concrete slabs; frames; *reinforced concrete*; *structural analysis*; *structural design*; ultimate strength method; working stress method.

INTRODUCTION

□ Structural engineers were quick to recognize the value of the computer in their work and have used it extensively. However, the effectiveness of computer usage has been limited by inadequacies in programming techniques, as well as by the narrow scope of programs available. As a consequence, computers are still used in engineering primarily for their calculating capabilities. Engineering problems, however, usually involve a considerable amount of information storage, retrieval and manipulating in addition to numerical calculations. Computers can be used with considerably greater effectiveness when adapted to this, more general, view of engineering problems. The paper describes such an application of STRUDL (the Structural Design Language) to the field of reinforced concrete building design.

CRITERIA FOR AN INFORMATION SYSTEM

The process of structural design is basically one of trial-and-error. The designer makes initial decisions based on data that are currently available to him. These decisions are subject to continual revision as the data become more complete, or as conditions arise which have not yet been taken into account. The success of integrating the computer into the design process is dependent upon the ease with which the engineer can utilize the computer, the degree of flexibility it provides, and the generality or range of applications for which it may be used.

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A computer-aided design system is a collection of programs, each of which performs some particular operation for the user. The programs are of two types: those which perform the computational design tasks, and those which perform the information handling and linkage between design tasks. The flexibility of a computer-aided design system is provided primarily by the latter category, or system programs. The characteristics of the system programs are derived from the following characteristics of the design process:

1. The large size and variability of problem data.
2. The need to create, use, and modify information beyond the scope of a single problem.
3. The need for the designer to control the order in which design tasks are performed.
4. The need for updating, expanding and modifying the design system.

Utilizing the system programs, the computational design programs operate on a common data base, accepting information and storing results according to a prescribed set of conventions. In this way a computer aided design system can be expanded indefinitely, as long as the conventions (as opposed to programs) or their expansions are applicable.

SYSTEM CHARACTERISTICS

One of the basic features of STRUDL is the data structure upon which the system is based, and which facilitates interaction between the various components of the system. All data are stored in dynamic forms which are accessible from, and may be extended or modified by, any program. Preliminary design information, such as estimated member properties, are thus stored and are revised

as the design proceeds. Calculated information is stored similarly and is also available as input for subsequent operations. For example, the computed details of reinforcement in a member are available for subsequent investigations of member capacity, for display if desired by the user, and for inclusion in a quantity take off for the structure.

STRUDL is a modular system designed to operate around the information with which it deals. It appears modular both to the user and the computer. The user employs a command structured or problem-oriented language, each command initiating a specific function which is made evident by the wording of the command statement. Commands may be given in any sequence, except for obvious dependencies. The user can broaden his use of the system as his knowledge of the capabilities grows.

Similarly, new facilities and commands are continually being added by developers at MIT as well as user organizations which are tailoring STRUDL to their industry or organizational outlooks regarding structural engineering practice.

The first version was started in 1965 and was released to the engineering profession in 1967.¹ It provided a system with flexible data input, output and modification features, and some frame analysis capabilities. The user could specify an entire problem and then add, delete or modify, the problem at any time. For example; members could be added or deleted from the structural frame, member properties or loading conditions could be modified, supports could be made free, etc. If desired for study of local behavioral effects, the analysis operations could be applied to only a portion of the structure. Results from different analyses with different structure configurations could be combined to simulate a construction sequence. A SAVE feature enabled the user to store the problem, and its associated data, on disk. The problem could then be continued at a later date after the user had inspected the results up to that point.

STRUDL has undergone two kinds of major updates since this first release.² The structural analysis features have been enlarged considerably, and capabilities for the design of building components have been incorporated into the system. These expansions were achieved without sacrificing the philosophy or approach to information manipulation which characterized the initial version, even though operating on vastly more data with an order of magnitude more programs.

STRUDL now contains some of the most sophisticated analysis tools available to the structural engineer. An engineer can now solve in a realistic manner problems composed of any combination of frame members, plates, shells and solids. A broad stable of finite elements is available for modeling continuous components. Besides the static load analysis, the user may study the geometrical nonlinear, or buckling, behavior of his problem. Behavior under dynamic loads may also be studied.

These analytic facilities are coordinated with a variety of design capabilities, which include the design of members from tables subject to arbitrary design constraints and codes, and a discrete section design optimization procedure, in addition to the reinforced concrete design facilities described in this paper.

APPLICATION OF STRUDL TO RC BUILDINGS

In keeping with the general STRUDL concept, the reinforced concrete facilities are wide in scope and flexible in application so as to permit the designer to attack the total building design problem in one operation, and to do so in a manner compatible with the peculiarities of the particular problem and the designer's own personal preferences. RC STRUDL contains a set of capabilities which provide for the analysis and design of many of the components found in typical reinforced concrete buildings. The capabilities may be used in various degrees of detail and in practically any sequence desired. The general design procedures which the system permits are consistent with common practice so as to ensure usefulness, and yet are flexible so that the engineer does not have to subjugate his own ideas to the program.

The member design capabilities include rectangular or tee beams, rectangular or circular columns with ties or spirals, flat slabs with or without capitals and drop panels, and one-way solid or joist floor slabs. For the proportioning of such elements, the user may pre-specify one or more cross-section parameters or set upper and lower bounds on such parameters. He may also specify similarities (e.g., equal depth) or identities between members in advance of design. The design output consists of cross-section dimensions, all primary and secondary reinforcement, the location and length of all bars, and total material quantities. The printing of much of this information may be controlled by the user. All procedures are in accordance with ACI 318-63.

The reinforced concrete design programs utilize the member forces (moments, shears and axial loads) which have been calculated by one of a number of available STRUDL analysis procedures. Virtually any structure configuration with any variety of loading conditions can be analyzed with the general STRUDL frame analysis capability. Skewed structures may be analyzed and the members need not necessarily be normal to each other at their intersections. However, the user must realize that STRUDL "sees" only a linear element subjected to a set of forces at each end, rather than the slab or beam which the user is attempting to simulate.

The system provides certain additional analytical tools which are especially intended for use with the more common rectangular, or orthogonal, frameworks of typical reinforced concrete buildings. These not only permit greater machine efficiency, but also permit the automatic consideration of special conditions (e.g., various live load positions) which cannot be specified conveniently with the more general analysis procedure. Thus the system has great generality with regard to type of structure and loading, and yet is efficient for the typical reinforced concrete building.

The special analysis features provided for orthogonal buildings in RC STRUDL include a "segmenting" procedure which allows a unique analysis to be performed for any member of the structure. The segment consists of that member and only those members in its vicinity which have a significant influence on its design forces. When a column is proportioned with segmenting, only the horizontal members framing into the top and the bottom of the column are considered along with the accumulated gravity load acting at the top of the column. On the

other hand, the user has various options for controlling the size of segment with beam and slab proportioning. Typically, he will limit the segment to one or two spans on each side of the member being proportioned including columns which frame in from above and below. A conventional analysis by moment distribution is used to determine the moments in the segment.

The segmenting procedure is extremely useful because all potentially critical arrangements of live load can be considered automatically, whereas this is not possible in the general frame analysis procedure. Member designs are then based on the maximum moment and shear envelopes which are generated by the automatically selected loading conditions.

For wind analysis, the user has the option to: (a) make a complete three dimensional analysis of the structure, or (b) isolate vertical planes and make an analysis of such a plane independent of the rest of the structure. Shear walls and floor slabs may also be included in wind analysis and are treated as finite elements interconnected with the linear elements of the frame. For the design of columns, live load reduction and the effects of slenderness may be considered automatically.

In the common case of orthogonal buildings, live loads may be specified in terms of general floor intensities and wind loads as wall pressures. The resulting member loads are generated automatically, based on the load distribution corresponding to the type of floor system specified. Dead loads resulting from the weight of members are computed internally and, together with member properties, are updated automatically whenever a member is designed. Thus a re-cycling of analysis and design may be executed if desired. For member design, the code combinations of dead, live and wind loads are generated internally.

Although the engineer has numerous options in the use of the system, the sequence of input for a typical building design might proceed as follows. First, the user would define the geometry of the structure. The location of floors and walls would be given next together with the loading intensities on those surfaces. He might then design the floor slabs (in the case of a slab and beam system) which would provide an exact determination of most of the dead load. Next, the analysis of the frame for vertical and lateral loads would be executed by a stiffness analysis or, in the case of gravity loads, by the special segmenting procedure. Prior to the design of frame members, he would specify design information such as type of member, preferred bar sizes, constraints on cross-section dimensions, and desired similarities between members. This would be followed by the proportioning of members in any sequence desired. Member design could then be repeated, if necessary, taking into account the updated dead weights and member properties. Finally, the output of beam and column schedules, reinforcement details, and quantities would be requested.

INPUT FOR TYPICAL RC BUILDINGS

Special GRID commands are available in STRUDL to facilitate data input for typical rectangular reinforced concrete building frames. Consider the building shown in Fig. 1. It consists of one-way floor slabs supported by parallel, beam-and-column frames. The exterior walls are non-structural, except for shear walls

in two opposite bays. The loading consists of dead and live floor loads, the self-weight of the frames, and wind pressure on the exterior walls.

The geometry is specified with the single statement,

GRID DEFINITION Y 7 AT 10., Z 5 AT 15., X 3 AT 20.

which defines all lines along which members may lie. For further reference, the planes in the grid are numbered sequentially along each coordinate axis, starting with one at the origin. Thus, plane Z2 is the plane normal to the Z-axis and 15 ft from the origin.

The actual location of members, as well as preliminary estimates of sizes, are indicated by commands such as,

GRID MEMBER X 2 3, Z 2 TO 5, BOUNDS 1 3 DIMENSIONS -
RECT B 12. H 16.

which indicates the columns lying on the intersections of planes X2 and X3 with planes Z2, Z3, Z4 and Z5. The bounds indicate that the estimated dimensions (12 X 16 in. rectangular) apply to columns in the lower three stories.

The floors and vertical loadings are specified by,

FLOOR Y 2 TO 7, T 0.5, ONE WAY Z, DL 20., LL 100.

This statement covers all floors, but not the roof, and estimates a slab thickness of 0.5 ft., indicates one-way behavior in the Z-direction, and gives dead (not including slab weight) and live loads of 20 and 100 psf, respectively.

The walls along the Z-axis are defined in,

WALL X 1, BOUNDS X 1 3, 4 5, T 0., WL 1 20.
WALL X 1, BOUNDS X 3 4, T 0.67, WL 1 20.

The first statement provides for the non-structural portions (indicated by zero thickness), and the second for the shear wall section. In both, wind load condition '1' is defined as a pressure of 20 psf.

In addition, special forces can also be specified separately to be included in the dead, live or wind loadings. Such forces can be concentrated at any location or distributed in some manner along members.

The first floor slab is analyzed and designed following the command,

ANALYZE AND DESIGN ONEWAY SLAB 380 381 382 383 384/

where the series of numbers identifies the five spans which are to be designed as a continuous element. In the case of one-way floor slabs, design is based on the moment and shear coefficients given in the ACI Building Code, rather than an

elastic analysis. Unless otherwise specified, all spans will be of the same depth. The slabs on other floors could be made identical without further design.

If the wind analysis is to be based upon independent planar frame action, that for plane Z2 is executed by,

ACTIVATE PLANE Z 2
LOADING LIST '*WL/1' '*WL/2'
STIFFNESS ANALYSIS

This calls for a rigorous analysis of the plane, for wind load conditions '1' and '2', based on forces computed from the tributary wall areas. The resulting member forces are stored for later use in member design. If desired, some or all of these forces may be printed for checking purposes.

An important feature of the system is the ability to specify similarities between members, e.g., duplicating members for economy in construction, making all beams in a floor of the same depth, using the same column for two or three stories, etc. This is accomplished by statements such as the following:

GROUP 58 94 FOR DESIGN
MAKE 76 REVERSE OF 60 IDENTICAL TO 58
H 59 EQ H 58

where the numbers identify individual members. The first statement requests a composite design for the two members based on the most severe forces in either. The second indicates that member 76 and the mirror image of 60 shall be made identical to member 58, both in dimensions and reinforcement. Only member 58 is actually designed. The last statement specifies that the depth of the two members shall be equal.

RC MEMBER PROPORTIONING

Beams, flat slabs and columns are considered as primary components of a building frame. The proportioning of such members begins with the member end forces which have been computed in one of the analysis procedures described previously. The proportioning programs take into account all of the loading conditions which the user has specified, or which have been selected automatically in the segmenting procedure. One-way slabs and joists, on the other hand, are considered as secondary components. Proportioning of such members is based on moment coefficients. All member proportioning utilizes the ultimate strength method of the ACI Building Code.

The beam design routines take into account flexure, shear, bond, deflection and minimum and maximum reinforcement requirements. Bars are selected at each critical section (usually at support faces and maximum positive moment section) and are distributed in a single layer if cover, stirrups and bar clearance requirements can be satisfied. Bar lengths are calculated for all bars taking

anchorage requirements into account. If necessary, U shaped stirrups are designed. All reinforcement details are stored and may be printed out if desired by the user.

RC STRUDL will handle the proportioning of flat slab or flat plate floors in a building structure such as shown in Fig. 2. The elastic analysis method, Section 2103 of ACI 318-63, is followed and moments are distributed to column strips and middle strips as the basis for selecting bars. Column capitals and drop panels may be included in the proportioning procedure. The flat slab design programs consider flexure, beam shear, punching shear, column-slab moment transfer, minimum slab thickness, and minimum and maximum reinforcement requirements.

The column design routines utilize an iterative procedure in which column dimensions and number of bars are incremented until the capacity is slightly greater than the applied load. The column design programs utilize a rigorous method of cross-section analysis which accounts for bi-axial bending combined with axial load, and treats each bar in the cross section individually.

Slenderness effects on column capacity may be taken into account by a moment magnification procedure in which column moments are amplified by the factor $1/(1 - P_u/P_{cr})$ where P_u is the ultimate and P_{cr} is the buckling load. Determination of the buckling load is based on the elastic stability of the column, and the restraints provided by member framing into tops and bottoms of columns are computed automatically.

Beams, slabs and columns are proportioned with two comprehensive commands. The first, DESIGN DATA, is a preparatory one for specifying fixed data such as bar sizes and spacing, tie and stirrup sizes, concrete cover, etc. Most of this data is optional, and a standard value is assumed if the item is not specified by the user. For example, the following information might be given for proportioning rectangular tied columns with rectangular arrangement of bars,

```
DESIGN DATA MEMBERS 60 TO 94
TYPE COLUMN RECT, STEEL RECT, TIED
BARS COLUMN 7, 8
TIES 4
```

The last two lines, which are optional, specify that #4 ties are to be used, and that the main reinforcement shall be either #7 or #8 bars, the actual size to be determined by the program on the basis of an optimization algorithm.

The PROPORTION MEMBERS command initiates the execution of designs. For example, all beams of the structure in Fig. 1 could be designed with the following input:

```
SEGMENT TOLERANCE FRACTIONAL .03
PROPORTION MEMBERS 1 TO 114 GIVEN P .01 -
LIMITS HMAX 24.
```

The first line indicates that the design moments and shears shall be determined by the segmenting procedure previously mentioned, i.e., on the basis of a moment distribution analysis of an isolated segment of the total structure taken from the vicinity of the member being designed. The extent of that segment is determined by the tolerance .03 which refers to the maximum carry-over effect of the fixed-end moments from the member to the outer joints of the segment or from those joints into the member. The second statement calls for both the segment analysis and the proportioning of the members listed. It is also specified that the steel percentage shall be .01 but that the depths shall not exceed 24 in. If the latter instruction controls, the given steel ratio would be ignored. Utilizing alternative procedures, member thickness or width, or both, may be prespecified. When proportioning columns, the engineer also has considerable control over the relative amounts of steel in the four column faces. For all proportioned members, the details for both longitudinal steel and stirrups, and ties or spirals, including bar locations and lengths, are determined and stored automatically.

RC MEMBER INVESTIGATION

RC STRUDL also contains facilities which allow completed designs to be checked for adequacy of strength and for compliance with provisions of the ACI Building Code.

Beams may be investigated for flexure, shear, bond and deflections. Columns may be investigated for the combined effect of axial load and bending about one or two axes. Critical sections of flat slabs are checked for flexure, beam shear, minimum thickness and punching shear including the effect of column slab moment transfer. All of these investigations can be performed according to either the working stress or the ultimate strength method.

In order to perform member checks, the cross section dimensions of the members are defined with a MEMBER DIMENSIONS command. Details of the straight or bent primary reinforcement, as well as stirrups, ties or spirals are described in a MEMBER REINFORCEMENT command. The statement,

CHECK MEMBERS 'S2', 5, 24 FOR FLEXURE, SHEAR

will institute an investigation of the flexural capacity and the shear capacity of the named members at all potentially critical sections along their lengths. The potentially critical sections are selected automatically on the basis of the loading, support conditions, primary reinforcement and secondary reinforcement.

DISPLAY OF RESULTS

Examples of the output from proportioning beams and columns are shown in Fig. 3 and Fig. 4. In addition to cross-section and reinforcement information, the design moments and shears are also printed for use by the engineer in checking the reasonableness of the design.

When using RC STRUDL as a checking tool, the engineer may control the type of output with an OUTPUT FORMAT command. By this means, information ranging in completeness from short diagnostic messages regarding member capacity to the printing of complete data regarding section forces and section capacity at every critical section along the member length may be selected.

Having designed all members in the structure, and having recycled the process as necessary, the design information may be summarized by commands such as the following:

```
SCHEDULE BEAMS ALL
SCHEDULE COLUMNS ALL
PRINT ALL REINFORCEMENT ALL
QUANTITY TAKEOFF ALL
```

The first two statements cause the printing of conventional beam and column schedules in a condensed format. This may be done for the entire structure or for selected portions, e.g., only the beams in one floor are included if ALL is replaced by an identifier of that plane. Examples of such beam and column schedules are shown in Fig. 5.

The third statement above results in the printing of a detailed description of all reinforcement including the position of every bar in the cross-section, its location and length along the span, the location of hooks, etc. This output is very voluminous, but is necessary for bar detailing. The next step in system development might include some form of automatic transmission of these data to the bar fabricator. Beam and column details might also be displayed in graphical form to facilitate checking by the engineer.

The last statement above causes the computation and printing of the total quantities of concrete, reinforcement and formwork. The totals are subdivided by type of member and type of reinforcement (primary or secondary). Quantities may also be taken off for selected portions of the total structures, as illustrated in Fig. 6.

It is difficult to give accurate data regarding the operating costs involved in the use of STRUDL because of the many configurations of IBM System 360 on which the system can be run, and the flexibility of use which can be obtained with the various STRUDL capabilities. As an example, however, all floor slabs and all members in the typical interior frame, Plane Y2 shown in Fig. 1, were analyzed and proportioned on an IBM S/360 Model 65 computer in 10.2 min using 450K of core. In this particular example, the member similarities feature allowed the required number of unique member designs to be reduced to only six beams and six columns.

CONCLUSION

The primary purpose of the development reported herein was to provide a computer system with which the engineer could accomplish the structural design

of a complete building with a single facility. Therefore, the emphasis in this paper has been placed on the overall design capability of the system rather than on the details of structural analysis, member proportioning, bar selection, etc. In fact, it is not claimed that the member design facilities provided are necessarily superior to common practice, or to those included in the many available special purpose computer programs for member design. However, it is believed that the system is unique in its generality of applicability and in the extent to which it encompasses the total design process.

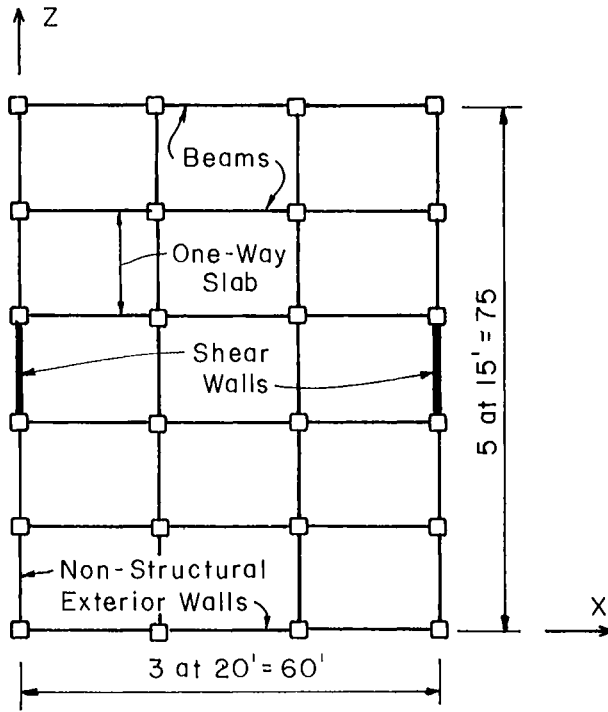
It is hoped that this development has demonstrated the enormous potential of the computer for improvement of the structural design process, and that this potential can be realized best if one considers the process in its totality rather than application of the computer to isolated portions of that process. Furthermore, it is the authors belief that efficiency of computer utilization can best be achieved through the use of systems having a wide range of application, i.e., suitable for structures of different types with different configurations, loading situations, etc.

ACKNOWLEDGMENT

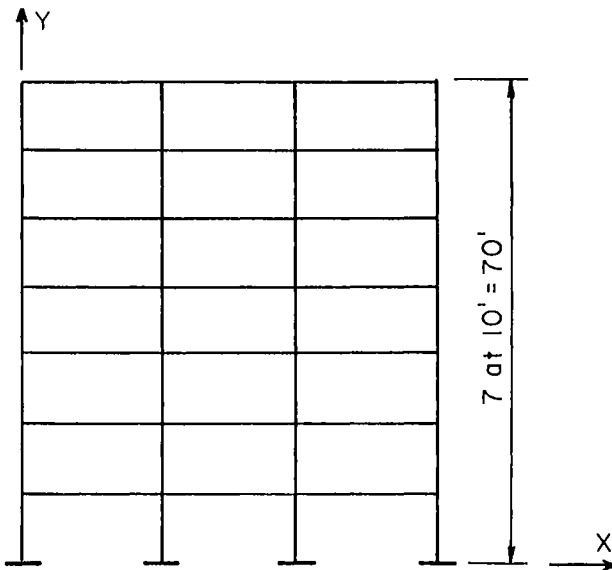
STRUDL operates on IBM 360 machines and is freely available to the profession. It has been developed at the Massachusetts Institute of Technology over a period of several years with funding provided by various government and private organizations. The reinforced concrete development within STRUDL was conducted at MIT under the sponsorship and with the cooperation of the Portland Cement Association and the Concrete Reinforcing Steel Institute. In addition to the authors, project supervision was provided by Professor P. J. Pahl, formerly of MIT and now at the Technical University of Berlin.

REFERENCES

1. Logcher, R. D., and Sturman, G. M., "STRUDL—A Computer System for Structural Design," *Proceedings*, ASCE, V. 92, ST6, Dec. 1966, pp. 191-211.
2. ICES STRUDL-II, *Engineering User's Manuals*, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge: *Report 68-91*, "Frame Analysis," Nov. 1968; *Report 68-92*, "Additional Analysis Capabilities," Nov. 1968; and *Report 70-35*, "Reinforced Concrete Structures," June 1970.



FLOOR PLAN (PLANE Z2)



ELEVATION (PLANE Y2)

Fig. 1—Multi-story reinforced concrete building



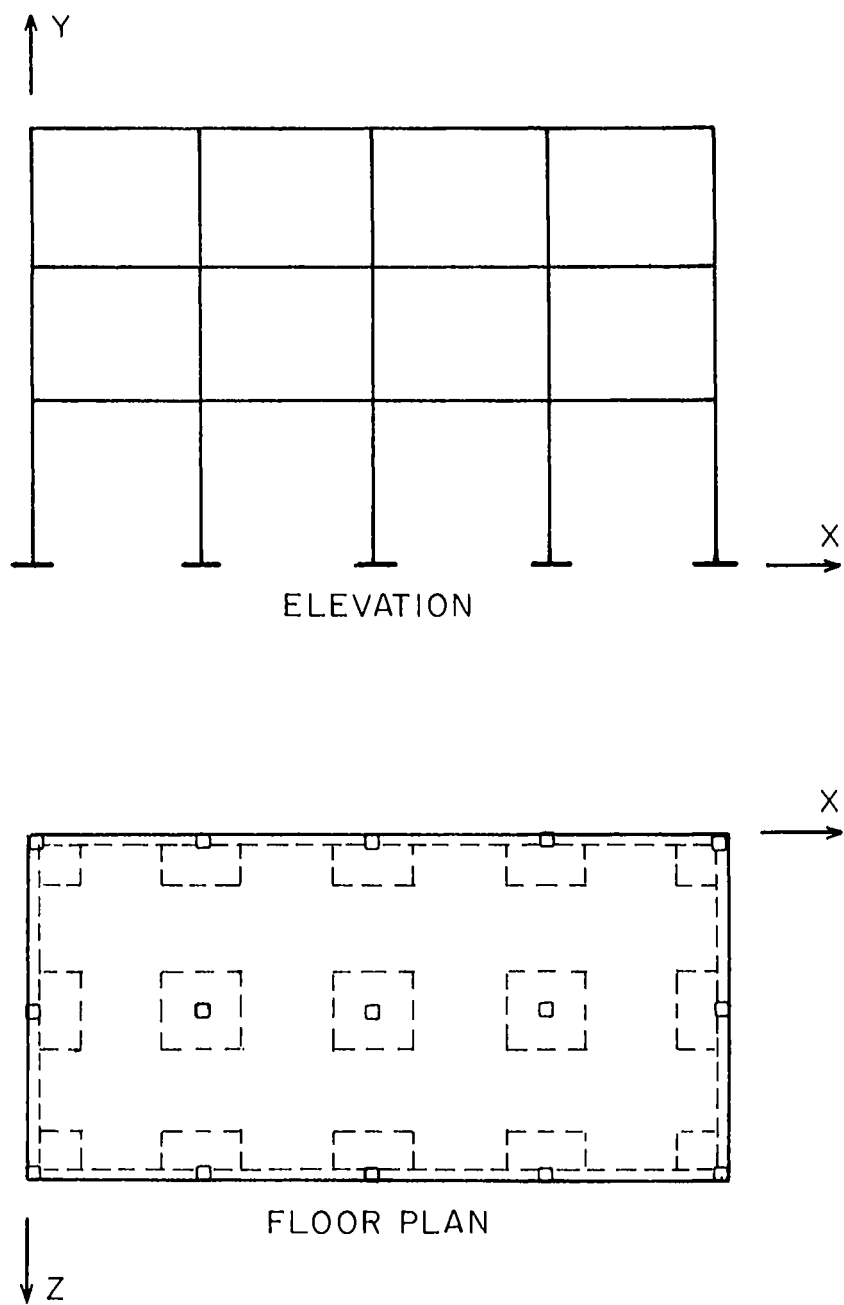


Fig. 2—Building with flat slab floors

 * RESULTS OF ULTIMATE STRENGTH BEAM DESIGN *

MEMBER	--/TYPE--/CONTR BY--/	DIMENSIONS--/INCHES	REINFORCEMENT DATA--/													
			SECT	DIST X--/FEET	SIZE	NO	TOP BARS LAYERS	AREA	YD	SIZE	NO	BOTTOM BARS LAYERS	AREA	YU		
5	TEE FLEXURE	STEM WID= 9.0	1	19.5	7	5	1	3.0	2.3	0	0	0	0.0	0.0		
		HEIGHT = 20.0	2	0.5	7	5	1	3.0	2.3	0	0	0	0.0	0.0		
		FLAN WID= 49.0	3	10.0	0	0	0	0.0	0.0	8	2	1	1.6	2.4		
		FLAN THI= 2.5														
		DESIGN MOMENT AT SECTION	1	-197666C. LB-INS												
			2	-1916122. LB-INS												
			3	1233372. LB-INS												

COMPUTATION OF BAR LENGTHS REQUESTED

STIRRUP DESIGN - NO. 3 BARS

SPACINGS FROM FACE OF SUPPORT AT MEMBER START

1 AT 3.5 INS

3 AT 7 INS

10 AT 8 INS

SPACINGS FROM FACE OF SUPPORT AT MEMBER END

1 AT 3.5 INS

3 AT 7 INS

11 AT 8 INS

DESIGN SHEAR AT FACE OF SUPPORTS

START 47707. LBS

END 48267. LBS

MEMBER 41 TAKEN IDENTICAL TO MEMBER 5

MEMBER 6 TAKEN IDENTICAL TO REVERSE OF MEMBER 4

MEMBER 22 TAKEN IDENTICAL TO MEMBER 4

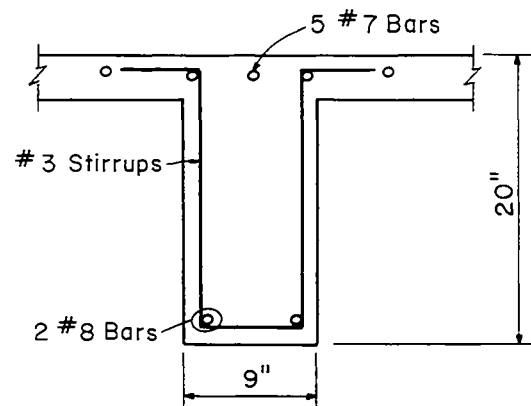


Fig. 3—Beam proportioning

 RESULTS OF ULTIMATE STRENGTH COLUMN DESIGN

MEMBER	CRIT LD	END	TYPE	DIMEN		STEEL	WID DEP	ARRANGEMENT	APPLIED	AXIAL FORCE	CAPACITY	BAR SIZE	TOT NUM	REINFORCEMENT				DATA			
														GRP A	GRP B	GRP C	GRP D				
155	*CL/9	END	RECT	14	10	RECT TIED			183547.	211726.	8	8	8	1	1	1	1	1	1	1	1
														TIES - NO. 3 AT 10 INCH SPACING							
														MOMENT IN CRITICAL LOAD CONDITION							
														MY= 0.0 LB-INS							
														MZ= 710180. LB-INS							
155	*CL/9	END	RECT	14	10	RECT TIED			183547.	191474.	7	8	8	1	1	1	1	1	1	1	1
														TIES - NO. 3 AT 10 INCH SPACING							
														MOMENT IN CRITICAL LOAD CONDITION							
														MY= 0.0 LB-INS							
														MZ= 710180. LB-INS							
155	*CL/9	END	RECT	14	10	RECT TIED			183547.	190873.	6	10	10	2	1	1	1	2	1	1	1
														TIES - NO. 3 AT 10 INCH SPACING							
														MOMENT IN CRITICAL LOAD CONDITION							
														MY= 0.0 LB-INS							
														MZ= 710180. LB-INS							

MOMENT MAGNIFICATION FACTOR IN GLOBAL YX PLANE 1.21
 ONLY THE DESIGN FOR NO. 6 BARS HAS BEEN STORED

MEMBER 177 TAKEN IDENTICAL TO MEMBER 155
 MEMBER 176 TAKEN IDENTICAL TO MEMBER 155
 MEMBER 156 TAKEN IDENTICAL TO MEMBER 155

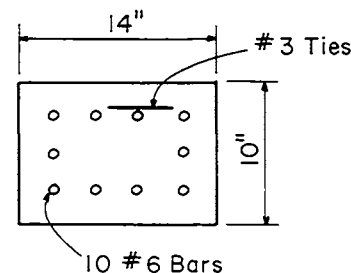


Fig. 4—Column proportioning

SCHEDULE BEAMS PLANE Z 2

SCHEDULE - PLANE Z 2

BEAMS

MEMBER	P	F	LEN	REINFORCEMENT		STIRRUPS		SPACING		
				NO	SIZE	SIZE				
4	10.0	20.0	240.0	TOP- START	3 7	3	1 AT 10.0	5 AT 8.0	11 AT 8.0	
	FLA THI	2.5		- END	4 8	3	1 AT 9.5	3 AT 7.0		
	FLA WID	50.0		BOT	3 8					
5	9.0	20.0	240.0	TOP- START	5 7	3	1 AT 9.5	3 AT 7.0	10 AT 9.0	
	FLA THI	2.5		- END	5 7	3	1 AT 9.5	3 AT 7.0	11 AT 8.0	
	FLA WID	49.0		BOT	2 8					
6	10.0	20.0	240.0	TOP- START	5 7	3	1 AT 9.5	3 AT 7.0	11 AT 8.0	
	FLA THI	2.5		- END	3 8	3	1 AT 10.0	11 AT 8.0		
	FLA WID	50.0		BOT	3 8					
22	10.0	20.0	240.0	TOP- START	3 8	3	1 AT 10.0	11 AT 8.0		
	FLA THI	2.5		- END	5 7	3	1 AT 9.5	3 AT 7.0	11 AT 8.0	
	FLA WID	50.0		BOT	3 8					
23	9.0	20.0	240.0	TOP- START	5 7	3	1 AT 9.5	3 AT 7.0	10 AT 8.0	
	FLA THI	2.5		- END	5 7	3	1 AT 9.5	3 AT 7.0	11 AT 8.0	
	FLA WID	49.0		BOT	2 8					
24	10.0	20.0	240.0	TOP- START	5 7	3	1 AT 9.5	3 AT 7.0	11 AT 8.0	
	FLA THI	2.5		- END	3 8	3	1 AT 10.0	11 AT 8.0		
	FLA WID	50.0		BOT	3 8					
40	10.0	20.0	240.0	TOP- START	3 8	3	1 AT 10.0	11 AT 8.0		
	FLA THI	2.5		- END	3 8	3	1 AT 10.0	11 AT 8.0		
	FLA WID	50.0		BOT	3 8					

SCHEDULE COLUMNS PLANE Z 2

SCHEDULE - PLANE Z 2

COLUMNS

MEMBER	H	B	LEN	REINFORCEMENT		TIES OR SPIRALS	
				NO	SIZE		
155	10.0	14.0	120.0	10	NO 6	NO 3	AT 10.0 TIES
162	14.0	14.0	120.0	10	NO 6	NO 3	AT 12.0 TIES
169	14.0	14.0	120.0	10	NO 6	NO 3	AT 12.0 TIES
176	10.0	14.0	120.0	10	NO 6	NO 3	AT 10.0 TIES
156	10.0	14.0	120.0	10	NO 6	NO 3	AT 10.0 TIES
163	10.0	14.0	120.0	10	NO 6	NO 3	AT 10.0 TIES

Fig. 5—Beam and column schedules

QUANTITY TAKEOFF PLANE Z 2

COMPUTED QUANTITIES - PLANE Z 2

	CONCRETE CUBIC YARDS	FORMWORK SQUARE FEET		
21 BEAMS	19.3	1566.7		
28 COLUMNS	7.7	877.8		
TOTAL	27.0	2444.4		
REINFORCING -			POUNDS	KIPS
21 BEAMS	- MAIN STEEL	4901.8		
	- STIRRUPS	631.5		
	- TOTAL STEEL			5.5
28 COLUMNS	- MAIN STEEL	2678.6		
	- TIES	385.6		
	- SPIRALS	0.0		
	- TOTAL STEEL			3.1
TOTALS	- MAIN STEEL	7580.4		
	- SECONDARY	1017.1		
	- TOTAL STEEL			8.6

QUANTITY TAKEOFF PLANE Y 2

COMPUTED QUANTITIES - PLANE Y 2

	CONCRETE CUBIC YARDS	FORMWORK SQUARE FEET		
18 BEAMS	24.8	1723.3		
5 FLOOR PANELS	52.7	4500.0		
TOTAL	77.5	6223.3		
REINFORCING -			POUNDS	KIPS
3 BEAMS	- MAIN STEEL	830.3		
	- STIRRUPS	112.1		
	- TOTAL STEEL			0.9
5 FLR PANELS	- MAIN STEEL	3177.0		
	- TEMPERATURE	1690.0		
	- TOTAL STEEL			4.9
TOTALS	- MAIN STEEL	4007.3		
	- SECONDARY	1802.1		
	- TOTAL STEEL			5.8

Fig. 6—Quantity takeoffs

COMMAND LANGUAGE INTERFACE FOR AUTOMATIC DESIGN OF STRUCTURES IN THREE DIMENSIONS

By ANDRE A. PALEJS

Input language conventions and associated computer printout for a large system of integrated programs, known as AMECO SYSTEM, are described. Attempt is made to demonstrate that AMECO represents the beginning of a new generation of computer programs. The simplicity and brevity of AMECO input language enables an engineer, with two or three commands, to design a multi-span girder or simple frame. With as few as 50 commands, he can implement automatic design of a structure of 1000 or more members.

Utilizing the English language, the engineer specifies only basic parameters such as concrete/steel strength, name of building code, floor loads in PSF, vehicle loads, seismic factor; he inputs only typical member lengths and their connectivity. When desired, the engineer may impose restrictions on the design process.

AMECO automatically generates the geometry of the structure in two or three dimensions, initializes member sizes, computes floor areas and member dead weights, loads on members and joints, generates critical loading patterns, applies live load reduction factors and by an iterative process selects member sizes and reinforcing steel for all members.

Principal AMECO output consists of reinforcing details and sizes for slabs, beams, columns and walls, all printed in schedule format that can be directly used for construction purposes. Material quantities, construction costs, member internal stresses, etc., are other selective printouts available.

Keywords: beams (supports); columns (supports); concrete slabs; computer programs; costs; detailing; estimates; flat concrete slabs; frames; loads (forces); multistory buildings; reinforced concrete; reinforcing steels; shear walls; stress analysis; structural analysis; structural design.

□ During the past decade, the emphasis has been on developing “analysis”-type computer programs. Utilizing these, the engineer describes geometry of the structure, loads and assumed member sizes and uses the computer to perform indeterminate frame analysis.

There are generally ten phases in the process of designing reinforced concrete superstructures. These are enumerated below. For the average project, the phase involving indeterminate frame analysis, represents about 20 percent of the total

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design process. In other words, these "analysis" programs have succeeded to computerize one fifth of the design engineer's work.

Considerably less effort has been invested to produce programs for the other phases of the design process. Apart from special purpose programs, written for the design of isolated segments of a structure, such as continuous beams, columns or plane frames, very few attempts have been made to computerize the entire design process for a 3-D structure into one continuous operation.

MANUAL PROCESS OF DESIGNING CONCRETE STRUCTURES

1. Selection of member pattern
2. Estimation of preliminary member sizes
3. Loading computations
4. Selection of loading cases
5. Indeterminate frame analysis
6. Computation of forces, moments and shears at critical sections
7. Determination of member stresses and reinforcing steel areas
8. Possible revision of member sizes, thus involving another frame analysis
9. Preparation of reinforcing steel schedules
10. Material take-off and cost estimate

A system of structural engineering programs has been developed to computerize phases 2 to 10 of the design work. This system is known by the acronym AMECO—Automatic Design in *Metals* and *Concrete*. Development work began in 1963¹ using at that time computer facilities of McGill University. Whereas AMECO became operational in the fall of 1966, many additional features and refinements have been incorporated since that date. Present design capabilities of AMECO are limited to structures having basically vertical and horizontal members, i.e., consist of beams, slabs, columns, shear walls and flat slabs, with or without drop panels and column capitals.

This paper aims to describe the AMECO system from the user's point of view. It illustrates the typical instructions an engineer can use to specify a structural problem to the machine. General characteristics of the input language are described in the following paragraphs. Detailed explanation of input data for

three example problems is presented starting on page 22. Briefly dealt with in the concluding pages is the internal logic of the program, output description and optional commands which the engineer can use to control the automatic design process.

SENTENCE STRUCTURE OF THE "AMECO" LANGUAGE

The AMECO language consists of two principal classes of input statements: commands and member data statements. All commands start with a verb and are used to specify design criteria or data common to a group of members. Commands are also entered to request selectively output printing. Member statements, on the other hand, contain information that is applicable to a particular member, such as member mark and its length. Example 1 below illustrates typical commands applicable to beams.

EXAMPLE 1 USE CONCRETE $FC' = 3000$ PSI, FLOOR LL = 100 PSF
 RESTRICT DEPTH TO MIN 18 IN., TO MAX 26.
 USE DEPTH/WIDTH RATIO = 2.4
 RESTRICT STEEL PERCENT TO MAX 3.0
 LIST REINFORCING SCHEDULES, QUANTITIES
 COMPUTE COSTS

The sentence structure of commands is the same as in everyday conversation, except that prepositions and punctuation marks may be omitted. The commands are made in an English vocabulary, with engineering terms and abbreviations well familiar to the structural engineer. If more than one command is given on one line, the command is terminated by a semi-colon.

EXAMPLE 2 COMPUTE COSTS; LIST QUANTITIES, REBAR SCHEDULES
 USE LL 100, CONC 3000, DEPTH/WIDTH 2.4
 REST DEPTH MAX 28, MIN 18, STEEL PERC MAX 3

The commands of Example 2 contain information identical to Example 1. It illustrates the following: commands can be given in any order; any number of data items can be entered within a command in any order; words can be abbreviated to first four characters, e.g. CONC; equal sign (=) and redundant words (FLOOR, RATIO, FC') can be omitted; synonyms are permitted (REINFORCING: REBAR); numerical data can be given with or without decimal point. If no units are given after numerical data, units commonly used by engineers are assumed, e.g. data related to member cross-section dimensions are presumed to be in in.; concrete or steel stresses in PSI; floor loading in PSF.

EXAMPLE 3 USE FLOOR LL .10 KSF -
 CONC FC' 3000 PSI -
 STEEL FY 40 KSI

The above demonstrates the option of continuing a command on successive lines by use of the hyphen. It also shows the choice of entering loading and

stresses in kip units. Commands can be started in any card column or keyboard position, with one or more blanks left between words and numbers. Comma and equal sign are treated as blanks.

The other class of input statements are beam and column data statements. These are used to define geometry of a structure in two or three dimensions. All beam statements begin with the word BEAM (or letter B) and column statements—with the word COLUMN (or C). Slab, flat slab and wall statements are identical to those for beams, except that these start with the words SLAB and WALL. Typical beam statements are illustrated below.

EXAMPLE 4 BEAM 101 18-6 WIDTH 12, DEPTH 18 IN.
 B301 24.33 DL L 4-0 P 10.
 B201 TO 206 24-3

In a beam statement, following the beam mark, e.g. 101, the first item entered is the span, given in ft and in. It can also be specified in ft, with a decimal fraction, e.g. beam 301. After the span, numerical data preceded by labels is entered in any order desired. For beam 101 cross section dimensions are input; for beam 301 concentrated dead load of 10 kips is specified.

Column data statements are primarily used to define connectivity between beams and columns.

EXAMPLE 5 C1 TO 7 201 TO 206, LENGTH 12-3
 C4 LENGTH 16-4, DIAMETER 18 IN.

The first line specifies a row of columns 1 to 7 supporting horizontal members 201 to 206. Length for these columns is given to be 12 ft - 3 in. On the next line, a new value for column 4 length is input, thus overriding the 12 ft - 3 in. value. Similar to beams, other known column properties can be entered in a column data statement.

EXAMPLES OF INPUT SPECIFICATION

To illustrate input specification, three structures consisting of beams, slabs, columns and shear walls will be considered. Appendix B also shows input data for a circular flat slab building. Appendix C describes a high rise curved structure. Because of the brevity of the AMECO language, it is possible to include in this paper complete input data for these structures.

Commands and member data statements are entered in a logical sequence. Commands applicable to beams precede beam data statements, while commands for columns are given ahead of column statements. Same rule is used for slabs or flat slabs. Otherwise, input data can be specified in any order—commands interspersed with member statements as required.

SAMPLE PROBLEM 1

In Fig. 1 a two bay frame, subjected to vertical loads, is shown. Input data to proportion beams and columns for this frame is reproduced in Fig. 2.

AMECO input data is initiated with the word "PROJECT." On the same line any description 48 characters long can be given. Apart from the ACI-63 building code specified on line 2, seven other code stipulations are incorporated in AMECO, with WSD and USD methods for proportioning of members. For this frame, concrete and steel strengths are entered to be the same for beams and columns. To specify higher strength steel for columns, the command "USE STEEL FY 60000 PSI" could be inserted between lines 8 and 9.

The command "DESIGN BEAMS" informs AMECO that subsequently given data pertain to beams and that proportioning of beams is desired. A command "ANALYSE BEAMS" would imply that beam sizes have been entered by the engineer.

Line 5 imposes restriction on the maximum depth of beam to be selected. No other criteria or limitations have been specified, therefore AMECO standard procedures will be used to design beams, e.g. members proportioned with balanced steel ratio; same depth chosen for both spans; also same width for both spans; "trussed" bars used to reinforce beams; stirrups selected in groups with spacing not varying more than three times per half span, etc. Typical commands to control the design process are illustrated on page 28 and 29 of this paper.

Lines 6 and 7 represent typical beam data statements for plane frames—it consists of a beam mark, span and loading. Span is entered as distance center to center of supports. Clear span, thus joint size, is computed by AMECO as function of column dimensions. As the column sizes are revised during the design process, clear span is automatically re-computed. Member dimensions or properties need not be input, since AMECO initializes all sizes and by an iterative procedure arrives at required dimensions. Since no slab data is given, the beams would be designed with rectangular cross-section shape (no flanges).

On line 6, uniform dead and live loads in kips/ft are specified. Member self-weights are computed automatically.

On line 7, after the abbreviation "LL," designating live load, two concentrated (P) loads are given in kips. No loading cases or combinations are specified by the engineer—these are all generated automatically by AMECO. Five classes of structural loads are processed by AMECO to form loading cases/combinations: dead, live, wind, earthquake and wheel loads.

The command "DESIGN COLUMNS . . ." on line 8 requests AMECO to proportion columns with square cross-section and with length of 12 ft - 0 in. Clear length is computed internally. Line 9 specifies cover to be 2 in., otherwise standard cover of 1.5 in. would have been used. Capacity reduction factors due to slenderness ratio will be computed as formulated in the code. Data on line 10 simply means that a row of columns 1 to 3 support members 101 and 102.

The last command "EXECUTE" starts execution of the design process.

SAMPLE PROBLEM 2

Fig. 3 shows a 15-story frame composed of beams, columns and a shear wall. Complete input data to design this frame for vertical and lateral loads is reproduced in Fig. 4. For multi-level frames input data is identified by level numbers. Also, a column supporting a number of levels is assigned the same mark for the full height of the frame. Otherwise, beam and column data statements and commands are identical to those for single level frames.

For the top five levels of this frame, beam/column geometry and loading per level is the same as for the frame shown in Fig. 1. Consequently, input data following the statement "LEVELS 15 TO 11" is similar to that listed in Fig. 2. The specified floor width, thickness and live load directs AMECO to compute floor loadings on the beams and to design the beams with a "T" cross-section shape. Below level 10, a shear wall is introduced and the frame widened to four bays. Data for this lower part is entered after the statement "LEVELS 10 TO 1." For input purposes, shear wall panels are treated as horizontal members supported on two columns. Thus wall input is similar to beams—only its span and thickness are input. The height of a wall is defined by column length. AMECO automatically models each wall panel into equivalent two beams and two columns.

Concrete and steel strengths for columns on the lower 10 levels is increased to 5000 psi and 75000 psi respectively. The "EQUATE . . ." command is entered to make columns 3 and 4 of equal size. During proportioning of columns, live load reduction factors are automatically applied on column axial loads.

This frame is subjected to two groups of lateral loads—wind and earthquake. After the frame identifying statement "FRAME X-1," wind is entered as load in kips acting at each level. The statement "EQ PERCENT . . ." instructs AMECO to compute mass of the frame at each level and then lateral loads, using 8 percent at levels 15 to 8 and 6 percent at levels 7 to 1.

SAMPLE PROBLEM 3

Typical floor plan of a six story building is shown in Fig. 5. The story height is 14 ft. Input data to design this structure for gravity loads and earthquake forces is listed in Fig. 6. Since column/beam arrangement and floor loading are the same on all six levels, data for one level only are provided, preceded by the statement "LEVELS 1 TO 6."

While developing AMECO routines for automatic geometry generation, advantage was taken of an elementary observation that practically all framed reinforced concrete structures are built of vertical and horizontal members. As a result, geometry input preparation for AMECO is reduced to a very nominal task.

1. All members oriented horizontally are identified by the engineer as either beams, slabs or flat slabs and vertical members as columns, walls or pilasters.
2. Typical member lengths only are entered.

3. To establish connectivity between members, the engineer specifies tributary member ends as “loads” on supporting members.

A beam mark is assigned to each span, consisting of two sets of digits. The first digit represents a beam line number, the second—span number. For example, the continuous beam 201, 202 and 203 has been assigned a beam line number of 2, and the spans are numbered consecutively in the positive direction of the X-axis. Similarly, beam spans in the Y-direction are numbered consecutively. Beam line numbers are chosen at random. Column marks are given at random, using any number 1 to 90. A column supporting a number of levels is assigned the same mark at all levels.

Information for floor dead and live loading is given in the command “DESIGN BEAMS . . . SLAB 6 IN., FLOOR LL 250 PSF.” The short, dashed lines on the floor plan show automatic floor area subdivision to establish loading on beams with trapezoidal distribution. Beam loading is computed using slab thickness of 6 in., plus live load of 250 psf. Alternate and adjacent beam spans are loaded with live load to obtain maximum forces and moments in beams and columns. To arrive at critical loading combination for any member, these gravity load effects are then automatically combined with the results of lateral load analysis.

All beams on the periphery of the floor are set by AMECO to have “L” cross-section shape, e.g. B101, while interior beams—“T” shape, e.g. B203. Beams 601 and 901 are input to have “L” shape, thus instructing AMECO that a floor opening exists. Effective flange dimensions are calculated automatically as function of slab thickness, beam span and distance to next beam, all in accordance with the specified building code—Uniform Building Code (UBC-67) in this case.

The statement “B101 25-0 12-3 801R 7-0 902R” is a typical statement for beams supporting tributary beams. It simply means that the span is 25 ft - 0 in. and at distances of 12 ft - 3 in. and 7 ft - 0 in., the right ends of beams 801 and 902 are supported on beam 101.

After the command “USE SPAN 17-0”, spans are entered for those beams only that have values other than 17 ft - 0 in. Thus input for many beams consists of their mark only. Known sizes for beams 801, 901 and 902 are input, preceded by the command “ANALYZE BEAMS.” This command instructs AMECO that size selection is not desired; however, checking of stresses, deflections and steel selection would be performed as for any other beam. To implement local opening in the floor between beams 801 and 902, negative uniform DL and LL in kips/ft are input on these beams.

The command “DESIGN COLUMNS RECTANGULAR . . .” instructs AMECO to select the two dimensions of the columns that will best resist loads and moments. On next input line, live load reduction factor of 1. is specified to override automatic reduction that would have been applied in accordance with the code.

The line “C1 to 3 101 TO 102, 502R 602R 702R” is a typical column data statement for three-dimensional structures. It designates that columns 1 to 3 support beams 101 and 102 in the X-direction and the right ends of beams 502, 602 and 702 in the Y-direction. The suffix “L” used in the other column statements designate left end of beams.

The last two statements specify that the building is to be subjected to lateral earthquake loads in X and Y-directions, equal to 10 percent of the mass. After computing mass and loads at each level, the structure is then analyzed as a frame in three dimensions, by considering the floor systems as rigid diaphragms.

To design floor beams to support wheel loads, shown in Fig. 7, one command: "MOVE WHEELS P 10. L 6-4 P 4." would have to be inserted before beam data statements. As the wheels would be "moved" over the floor area, comparison would be made between effects of wheel loads and floor load of 250 psf and the maximum used to proportion members.

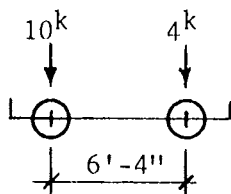


Fig. 7—Wheel loads

"AMECO" DESIGN PROCESS

In the AMECO design process frame analysis and member proportioning is integrated into a continuous, looping operation to convergence. The basic program logic is as follows:

After having initialized member sizes, the program computes loads, selects loading cases, performs frame analysis and then proceeds to proportion members. Newly obtained sizes are then used as starting values for another cycle of loading calculations, frame analysis and member proportioning. This cycling is repeated until change in cross-section dimensions inflicted by the member proportioning routines becomes insignificant. In Fig. 8 the two separate loops for gravity and lateral load analysis is also shown.

Frame analysis is performed, based on the theory of linear, elastic, large deflections. The effects of finite joint sizes with their infinite rigidity and torsional stiffness of beams are considered. However, computer time used by AMECO (with multi-cycle frame analysis) is notably less than the time required for stiffness matrix programs performing single cycle analysis. This is attributed to a number of factors: automatic segmentation of the structure is performed; relaxation method is used; analysis capabilities are limited to structures with vertical and horizontal members; axial shortening in horizontal members is ignored; all loading cases and combinations are generated internally by AMECO.

Members are designed considering the structure as a whole, i.e. cross-section dimensions and reinforcing bars are chosen to make members at joints compatible to each other. For example, for multi-span beams (slabs), top reinforcing is selected to be continuous over supports; proper bar clearances are provided at column reinforcing splices, etc. Therefore, reinforcing schedules produced by AMECO need little if any manual touch-up, prior to being issued for construction purposes.

OUTPUT DESCRIPTION

In the example problems described starting on page 22 of this paper, no output request commands were included. Therefore, only reinforcing schedules for beams and columns would be printed. These show: member dimensions; main bar sizes and arrangements; tie and stirrup sizes; spiral pitch and size. The format of these schedules and bar bending details is commensurate to the ACI-Manual 315-65, thus these can be directly used for construction purposes. Typical schedules are illustrated in Appendix A, B & C.

There are two different methods to obtain the schedules already described and additional output tabulations:

1. Results of computations may be stored on a disk by the SAVE FILE command and then selected outputs obtained on typewriter terminal and line printer by appropriate TYPE and PRINT commands, respectively.
2. Appropriate LIST commands may be entered as part of initial input data, which will then implement printouts immediately after completion of design computations.

A total of 12 different tabulations can be obtained. The syntax for the TYPE/PRINT commands is identical to the LIST commands. Consequently, some typical LIST commands will be illustrated only. When member marks are included in a command, results for those members only are output, otherwise output for all members is implemented.

LIST ENVELOPES AT 10 SECTIONS

The above command initiates printing of envelope ordinates at ten sections per span of beams or slabs. Envelopes are produced for moments, total shear and unit shear, deflection, steel areas and theoretical stirrup spacing, all for three loadings—dead load, dead + live load and critical loading (including lateral loads).

LIST COLUMN LOADS

LIST QUANTITIES, CONSTRUCTION COSTS

Column load tables show axial loads and moments about both axis, at top and bottom of a column—for dead load, live load and critical loading combination that governed a column design. A separate table is produced for each level of a

structure. Quantities and costs are produced for three items: concrete, reinforcing steel and formwork. If no unit costs are input, AMECO standard values are used. Reinforcing steel quantities are sorted by bar sizes and listed separately for beams, slabs and columns. Similar sorting is done for concrete volumes and formwork areas.

“AMECO” COMMANDS FOR CONTROLLING THE DESIGN PROCESS

The engineer is credited to make decisions based on science, art, intuition and experience. Some of the decisions made by the engineer are of major importance, such as selection of a structural system, choice of building materials and their strengths. However, most of the average design engineer's time is spent arriving at decisions of much less importance. Loading case selection, member size estimation, arranging and sizing of bars are typical design functions involving elementary decisions.

To relieve the engineer of this routine part of work, AMECO has built-in design decision routines. The principal constraints imposed on these routines, such as for stresses, for deflections and loading arrangements, is commensurate to the engineer's prescribed building code. Others, such as parameters for preferable depth/width ratio, steel percentage, size of bars, type of stirrups or ties, splice location for bars, have been programmed in these routines and field evaluated on many projects.

On the other hand, the design of structures is often controlled by the availability of materials (bar sizes, forms), headroom limitations, architectural requirements and other restrictions. Economy may also dictate that certain members should be of the same size.

In view of the above, it becomes imperative that the user of the program should be able to impose restrictions or modify the built-in procedures of the program. When he desires, the engineer should be given the opportunity to exercise his own judgement and actively participate in the design process.

In the design of concrete structures, there are great number of design parameters upon which restrictions might be imposed. Therefore a simple procedure was incorporated in AMECO to enable the engineer to convey his directives to the program. The engineer uses English language commands with practically identical syntax: all commands start with a verb and are followed by the name and then the value(s) of the parameter. Abbreviations are kept to minimum so that commands are self-explanatory and remembered easily. The four basic verbs used are: RESTRICT, USE, EQUATE & SELECT.

The RESTRICT command is used to specify a permissible range of values for a parameter(s).

RESTRICT REBAR SIZE TO MIN NO. 6, MAX NO. 9
RESTRICT DEPTH TO MAX 24, DEFLECTION TO MAX L/360,
WIDTH TO MIN 16 IN.
RESTR STEEL PERC TO MIN 1.5, MAX 6.5

The use of prepositions is optional (e.g. TO); words can be abbreviated to four characters; any number of items can be given in a single command, in any order; synonyms are permissible (e.g. REBAR = REINFORCING); values referring to member dimensions are assumed in inches, thus IN. is optional.

The words BEAM, SLAB, COLUMN are not normally included in a command. For example, when a command is inserted prior to some beam data statements, the restrictions automatically apply to all beams subsequently given in input. The command would remain in force on all beams until another command is given or SUPPRESS command entered.

RESTR XDIM TO MAX 20, MIN 14 FOR COLS 1, 5, 6, 8

Alternatively, by entering member marks in a command, the restrictions are applied to a specific group of members, such as illustrated above.

The USE command is given to specify a single value for a parameter.

USE DEPTH/WIDTH RATIO 2.2
USE TRUSSED BARS, LL REDUCTION FACTOR .80, CONC FC'—
3000 PSI

The EQUATE command is used to establish equality for a group of members with respect to their sizes and/or reinforcing.

EQUATE YDIM FOR COLS 4, 7, 24, 18
EQUATE SIZES FOR COLS 7 8 9
EQUATE SIZES, REBARS FOR COLS 22, 24 TO 31, 33

The SELECT command is used to specify the procedure for selecting member cross-section dimensions.

SELECT DEPTH IN 2 IN. INCREMENTS, CONSTANT ALL SPANS
SELECT WIDTH VARIABLE

The first command will produce depth of beams in multiples of 2 inches and the depth will be chosen the same for all spans of a continuous beam. The second command implies that beam width for each span may not necessarily have to be the same, i.e., it can be chosen variable.

CONCLUSIONS

The AMECO system exhibits numerous characteristics, highly desirable for computer programs that are to be used in design office environment:

1. Preparation and verification of input data has been reduced to a very nominal task. The amount of data to be supplied is small. Furthermore, data is entered in engineering terms and words, commonly used

by the practicing engineer in his manual design work. The engineer can converse with the computer without learning new notations or symbols and with complete disregard for card column conventions.

2. The entire structural design process, from generating geometry of the structure to production of reinforcing schedules and cost estimate, is computerized. This enables the engineer, with one set of input data and single processing on the computer, to obtain final design of a three-dimensional structure. When desired, the engineer can design only selected parts of a structure. By simple commands he can control the automatic member proportioning procedures.
3. Output interpretation is simplified. Sign conventions and units of measurement, for tabulating forces, moments and displacements, are the same as used by the design engineer. Layout of reinforcing schedules conforms to manual drafting practices.

In 30 hours, using AMECO, the engineer can prepare input, check input, process it on the computer, review output and prepare and check construction drawings for a structure that requires minimum 400 design and drafting man-hours (see appendices A to C).

Without compromise in design quality, this incredible saving in time and engineering costs opens a door to experimentation, optimization and research. Without undue involvement in routine decision making such as proportioning of individual members, the engineer can investigate multiple shapes for a structure, alternate construction methods and different building materials to minimize construction time and costs and enhance the appearance of the structure.

Whereas the accelerated pace of technology has reduced the majority of engineers to the level of technicians, the structural engineers have the opportunity to exploit the computer to their advantage, thus not only regaining their former status, but surpassing it.

ACKNOWLEDGEMENT

The AMECO system was originated in 1963 by the writer² and the principal subsystems developed over a period of three years. As of 1967, further development was undertaken by Anacor Systems Ltd., Montreal.

The structures shown in Appendix A and B were designed in the offices of Parsons-Jurden Corp., New York, N.Y., utilizing in-house IBM 360/40 computing system.

REFERENCES

1. "AMECO Design in Concrete," Ameco Computing Systems Company, Babylon, N.Y., 1970.
2. "Introduction to AMECO," A. A. Palejs, Montreal, Quebec, 1966.

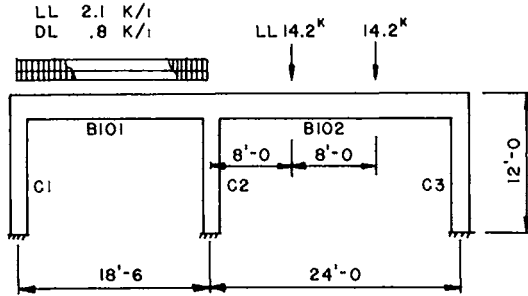


Fig. 1—Frame elevation

```

1  PROJECT- SAMPLE PROBLEM 1
2  USE CODE ACI-63 WSD, CONCRETE FC'=3000, STEEL FY= 60000
4  DESIGN BEAMS
5      RESTRICT DEPTH TO MAX 24 IN.
6  B101 18-6, DL x 0.8 KLF, LL w 2.1
7  B102 24-0 LL 2 ( L 8-0 P 14.2)
8  DESIGN COLUMNS SQUARE, LENGTH 12-0
9      USE COVER 2 IN.
10     C1 TO 3 101 TO 102
11 EXECUTE

```

Fig. 2--Input data for frame shown in Fig. 1

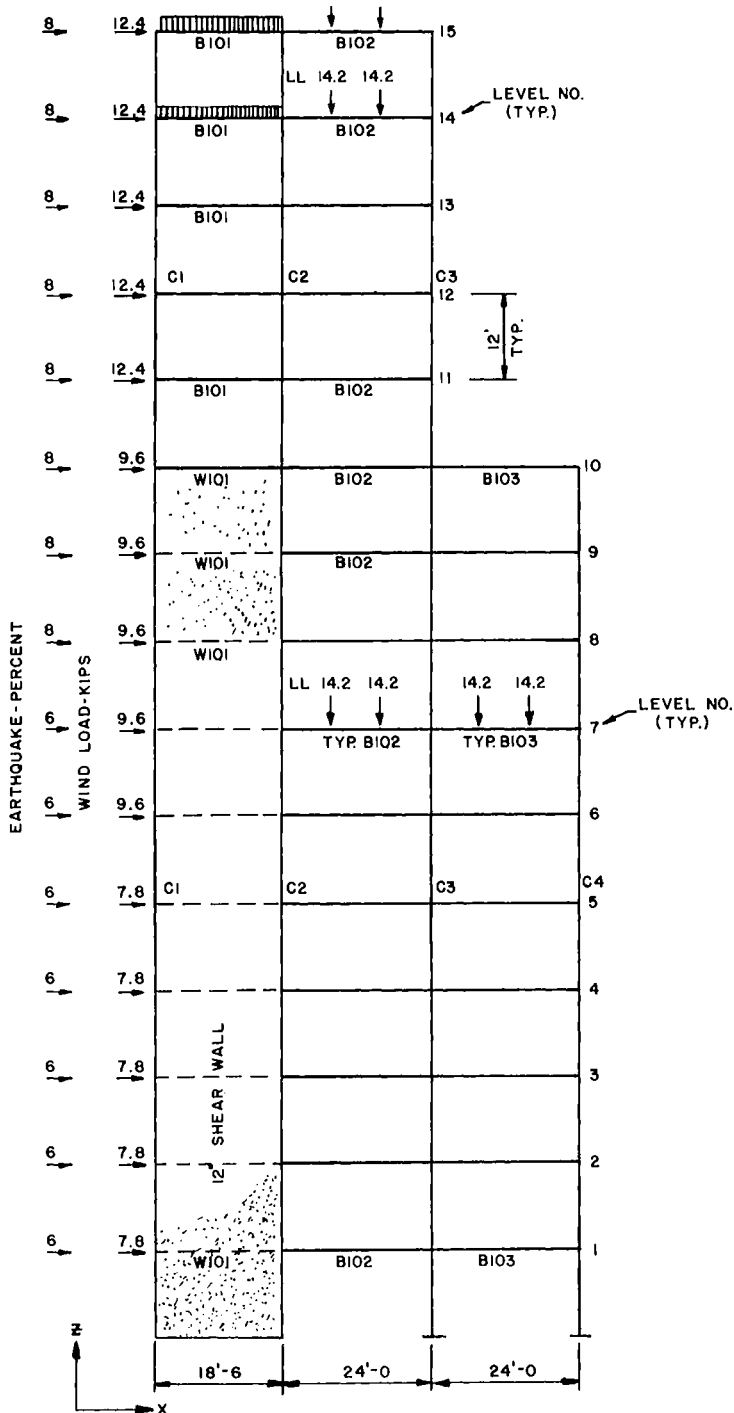


Fig. 3—Frame elevation

```

PROJECT- SAMPLE PROBLEM 2
USE CODE ACI-43, CONCRETE 3000, STEEL 60000
  LEVELS 15 TO 11
DESIGN BEAMS, FLOOR WIDTH 21-0, LL 100, SLAB 4 IN.
  RESTRICT DEPTH TO MAX 24 IN.
  B101 18-6, B102 24-0 LL 2(L 8-0 P 14.2)
DESIGN COLUMNS SQUARE, LENGTH 12-0; USE COVER 2 IN.
  C1 TO 3 101 TO 102

  LEVELS 10 TO 1
DESIGN BEAMS, SPANS 24-0
  B102 TO 103 LL 2( L 8-0 P 14.2), WALL 101 18-6 THICK 14 IN
DESIGN COLS SQUARE, L 12-0; USE CONC 5000, STEEL 75000 PSI
  EQUATE SIZE FOR COLS 3 AND 4
  C1 TO 4 101 TO 103
  FRAME X-1; EQ PCT 8. AT 15 TO 8, 6. AT 7 TO 1
  WL 12.4 AT 15 TO 11, 9.6 AT 10 TO 6, 7.8 AT 5 TO 1
EXECUTE

```

Fig. 4—Input data for frame shown in Fig. 3

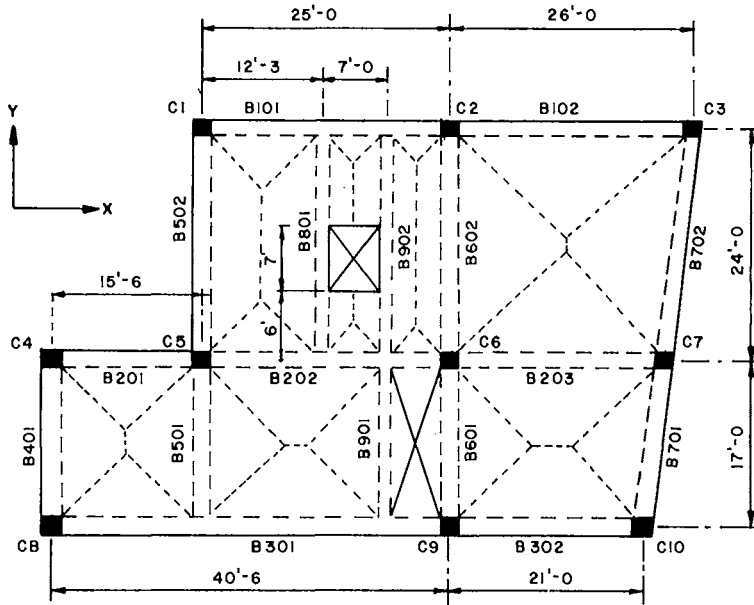


Fig. 5—Typical floor plan of a six-story building

```

PROJECT- SAMPLE PROBLEM 3
USE CODE UBC-67; LIST ALL
LEVELS 6 TO 1
DESIGN BEAMS, CONC 4000, STEEL 40000, SLAB 6 IN., LL 250 PSF
B101 25-0 12-3 301R 7-0 902R
B102 26-0 B201 15-6
B202 25-0 12-3 401L 7-0 902L
B203 23-4 B302 21-0
B301 40-6 15-6 501L 19-3 901L
USE SPAN= 17-0
B501 B502 24-0 B401
B601 'L' B602 24-0 B701 B702 24-2
ANALYSE BEAMS, WIDTH 14, DEPTH 22
B801 24-0 LL/DL L=6 L=7 W=-0.75/-0.22
B901 'L' B902 24-0 DL/LL L=6 L=7 W=-0.22/-0.75

DESIGN COLUMNS RECTANGULAR, LENGTH= 14-0
USE LL REDUCTION FACTOR = 1, STEEL 60000 PSI
C1 TO 3 101L TO 102R 502R 602R 702R
C4 TO 7 201L TO 203R 401R 502L 702L
C8 TO 10 301L TO 302R 401L 601L 701L
FRAMES X-1, X-4, X-8; EQ PERCENT 10
FRAMES Y-4 TO Y-7; EQ PCT 10
EXECUTE

```

Fig. 6—Input data for building shown in Fig. 5

Fig. 7—See page 26.

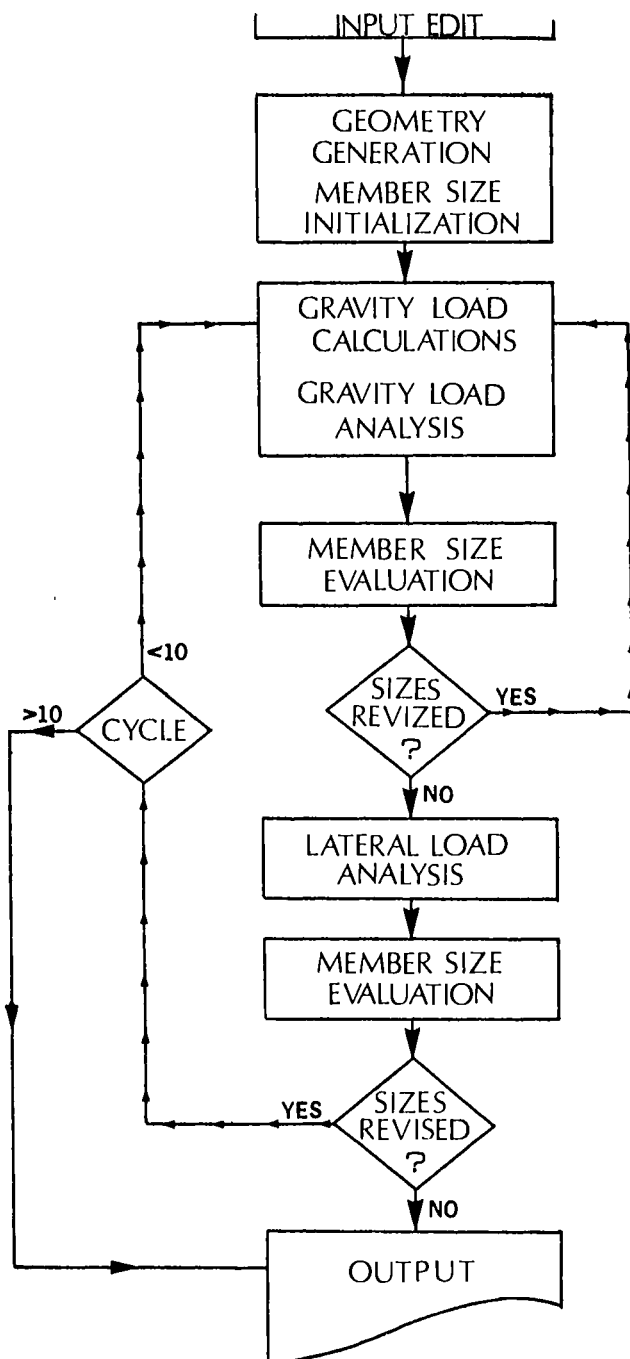


Fig. 8—Flow chart of AMECO design process

APPENDIX A

The structure illustrated in this appendix is characteristic of heavy manufacturing and process plants—irregular loading but relatively simple member pattern.

In Fig. A-1, an engineering sketch shows member layout and floor loading. It has 65 beams and 37 columns (caissons) or a total of 102 members. The floor loading varying from bay to bay is specified in PSF, while the program computes contributing floor areas and applies the loading on beams with trapezoidal distribution.

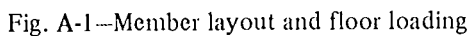
In Fig. A-2 and A-3 echo printout of input data is reproduced. The larger part of input data consists of floor load specification. For example, for beam B101, the abbreviation FL LL FS 480, means floor live load far side 480 psf. On the near side of this beam, LL = 200 psf, given in the USE . . . command, would be applied. Wall loads on periphery beams are given in kips per foot, e.g. beam B1102 DL 2.56.

Fig. A-4 depicts typical beam reinforcing schedule, produced by computer printer on transparent, adhesive backed, mylar sheets. These sheets were then attached directly on construction drawings.

All beam sizes were selected by the program within constraints imposed by the engineer. The two-way slabs were designed by separate computer run and were drawn/scheduled on drawing 100-31-09 (not included). Columns (caissons) were drawn/scheduled on drawing 100-3101 (not included).

Basic Statistics

	Man-hours
1. Determination of process tank and equipment and wall loads	2.0 hrs.
2. Input writing	2.0 hrs.
3. Key punching and verification	0.5 hrs.
4. Output review	0.5 hrs.
5. Preparation and checking of 2 drawings (beams and slabs)	25.0 hrs.
Total	30.0 hrs.
IBM-360/40 processing	
- CPU Time	12.1 min
- I/O Time	6.9 min
- Total Time	19.0 min



A-2

* A M E C O * A U T O M A T I C D E S I G N I N M E T A L S A N D

I N P U T L I S T I N G

```

PROJECT WHITEHALL PLANT
JOB 4564-02
STRUCTURE STOCK PREPARATION BLDG
INPUT P S HSUEH
LIST ALL
LIST STRUCTURAL DATA
LEVEL 1
DESIGN BEAMS
LIST ENVELOPES AT 5 SECTIONS
RESTRICT WIDTH MIN 14 MAX 20,DEPTH MIN 24 MAX 30
USE STRAIGHT BARS
SELECT DEPTH IN 6 IN INCREMENT
USE COVER 2.5 IN
USE SPAN 20-8, FLOOR LL 200 PSF, SLAB 12 IN
B101 13-6 FL LL FS 480,FL DL FS 672
B102 14-0 FL LL FS 465,FL DL FS 799
B201 20-0 FL LL FS 420,FL DL FS 559
B301 FL LL 472,FL DL 566,DL 3.84
B302 24-8 8-0 201,FL LL 420,FL DL 559,DL 3.84
B303 16-8 FL LL 420,FL DL 559,DL 3.84
B304 TO 305 FL LL 725,FL DL 171,DL 3.84
B306 FL DL 36,DL 3.84
B401 FL LL NS 472,FL DL NS 566
B402 24-0 8-0 201R FL LL NS 420,FL DL NS 559
B403 16-8 FL LL NS 420,FL DL NS 559
B404 TO 405 FL LL NS 725,FL DL NS 171
B406 FL DL NS 36
B501 24-8 8-0 101 FL LL FS 480,FL DL FS 672
B502 16-8 FL LL FS 467 FL DL FS 822
B601 FL LL FS 653 FL DL FS 842
B701 24-8 8-0 101R FL LL NS 480 FS 465,FL DL NS 672 FS 799
B702 16-8 FL LL NS 467 FS 540,FL DL NS 822 FS 809
B801
B802 FL LL FS 485 FL DL FS 544
B803 FL LL FS 322 FL DL FS 399
B901 FL LL NS 653 FL DL NS 842,DL 2.6
B902 24-8 8-0 102R 12-8 2101 FL LL NS 465,FL DL NS 799,DL 2.6
B903 16-8 FL LL NS 540 FL DL NS 809,DL 2.6
B904
B905 FL LL NS 485 FL DL NS 544 FL WIDTH FS 10
B906 6-0 FL WIDTH FS 10 FL LL NS 322,FL DL NS 399
B907 14-8 FL LL 322,FL DL 399,FL WIDTH FS 10
B1801 TO 1803
B1901 TO 1903 DL .37
USE SPAN 20-0
B1101 FL LL 472 FL DL 566,DL 2.56
B1102 DL 2.56 B1104 TO 1105 DL 2.56

```

Fig. A-2—Echo printout of input data

```
* A M E C O *   A U T O M A T I C   D E S I G N   I N   M E T A L
PROJECT - WHITEHALL PLANT
CLIENT -
STRUCTURE - STOCK PREPARATION BLOCS
```

INPUT LISTING

```
B1103 FL LL 653,FL DL 842 DL 2.56
B1201 FL LL NS 472,FL DL NS 566
B1202 20-0 12-6 501
B1203 20-0 6-0 701
B1204 TO 1205
B1301 15-0 FL LL 420,FL DL 559
B1302 17-6 5-0 402R
B1303 13-6 FL LL 473,FL DL FS 822 NS 672
B1304 14-0 FL LL FS 540 NS 465,FL DL FS 809 NS 799
B1401 FL LL FS 725 NS 420,FL DL FS 171 NS 559
B1402 20-0 12-6 502R FL LL NS 233,FL DL NS 411
B1403 20-0 6-0 702R FL LL NS 540,FL DL NS 809
B1404 TO 1405
B1501 FL LL 725,FL DL 171
B1502
B1503 FL LL FS 485,FL DL FS 544
B1601 FL LL FS 200 NS 725,FL DL FS 36 NS 171
B1602 20-0 8-0 2301
B1603 FL LL FS 322 NS 485,FL DL FS 399 NS 544
B1701 FL DL NS 36 DL 3.84
B1702 20-0 8-0 2301R DL 3.84
B1703 FL LL 322 FL DL 399 DL 3.84
B2101 TO 2102 20-0
B2301 20-8
ANALYSE COLUMNS ROUND 30 IN LENGTH 40
C1 TO 6 1101 TO 1105R 301 401 601 901 1801 1901
C7 TO 12 1201 TO 1205R 302 402 601R 902 1802 1902
C13 1301 303
C14 1302 0
C15 TO 17 1303 TO 1304R 502 702 903
C18 2101R 1803, C19 2102R 1903
C20 TO 25 1401 TO 1405R 304 404 801 904 1803R 1903R
C26 TO 29 1501 TO 1503R 305 405 802 905
C30 TO 33 1601 TO 1603R 306 406 803 906
C34 0 907
C35 TO 38 1701 TO 1703R 306R 406R 803R 907R
EXECUTE
```

DATA ACCEPTED, EXECUTION BEGINS

Fig. A-3—Echo printout of input data (concluded)

* A M E C D * AUTOMATIC DESIGN IN METALS AND CONCRETE * A M E C D *
 PROJECT - WHITEHALL PLANT JOB NO. - 4564-02
 CLIENT - INPUT BY - P S HSUEH
 STRUCTURE - STOCK PREPARATION BLDG REVISION -
 DATE - 13 OCT 70
 LEVEL NO. - 1

PAGE 1
 FOR 65 BEAM / SLAB TYPES

BEAM / SLAB REINFORCING SCHEDULE																			
LONGITUDINAL REINFORCING										STIRRUPS									
BEAM / SLAB	I	A	I	B	I	BL	I	C	I	D	I	E	I	F	I	G	LAYERS	I	STIRRUPS
I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
I NO.	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
MARK REQD	B	I	T	I	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE	SIZE
I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
B 101	1	20	24	4-7				2-7							1	1	*5	LEFT 5 D AT10, 1 D AT13, RITE 7 D AT10,	
B 102	1	20	24	4-7				2-7	2-7	3-10	1-7				1	1	*5	LEFT 7 D AT10, RITE 7 D AT10,	
B 201	1	20	24	6-10				2-7		3-10	3-10				1	1	*5	LEFT 10 D AT10, RITE 10 O AT10,	
B 301	1	24	30	5-10				2-7		1-9		3-7			1	1	*5	LEFT 7 D AT13, 1 S AT17, RITE 8 D AT13,	
B 302	1	24	30	5-10				2-7	11-10						2	1	*5	LEFT 10 D AT13, RITE 8 D AT13, 1 S AT17,	
B 303	1	24	30	4-7				2-7	7-10						1	1	*5	LEFT 7 D AT13, RITE 7 D AT13,	
B 304	1	24	30	4-10				2-7	7-9			2-7			1	1	*5	LEFT 8 D AT13, RITE 8 D AT13,	
B 305	1	24	30	4-10				2-7	8-10			2-7			2	1	*5	LEFT 8 D AT13, RITE 8 O AT13,	
B 306	1	24	30	4-10				2-7	2-7	7-10	1-7				1	1	*5	LEFT 8 D AT13, RITE 5 D AT13, 2 D AT17,	
B 401	1	24	30	4-10				2-7		1-7		3-8			1	1	*5	LEFT 7 D AT13, 1 S AT17, RITE 8 D AT13,	
B 402	1	24	30	4-10				2-7	9-10						2	1	*5	LEFT 10 D AT13, RITE 7 D AT13, 3 S AT17,	
B 403	1	24	30	4-7				2-7	3-10						1	1	*5	LEFT 2 D AT17, 3 S AT17, RITE 2 D AT17, 3 S AT17,	

Fig. A-4—Typical beam reinforcing schedule

APPENDIX B

Fig. B-1 shows engineers' floor sketch of the new Newark Airport satellite building. The periphery beam sizes were input, while the optimum slab thickness of 10 inches were determined by the program.

Fig. B-2 shows input data for the 107 members. All columns were designed with a capital having 3'-6" diameter, while columns 6 to 9 had also drop panels.

Fig. B-3 illustrates typical printout of the flat slab schedule.

APPENDIX C

Typical floor plan of a 30-story concrete structure is shown in Fig. C-1. For this curved structure, two shear walls, 602 and 1102, are introduced to participate in resisting lateral wind and seismic loads. The required fourteen input lines to design the structure for gravity and lateral loads are reproduced below the floor sketch.

Fig. C-2 illustrates a typical column reinforcing schedule.

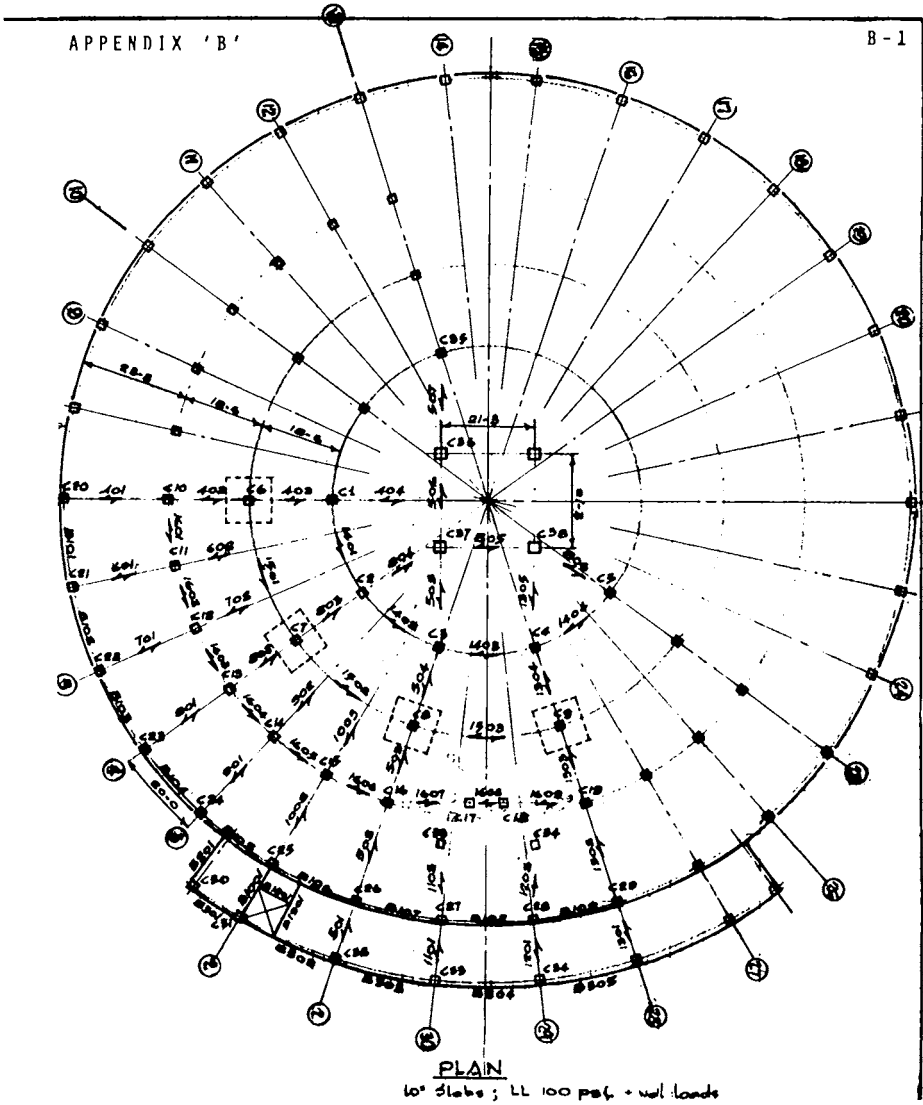


Fig. B-1—Newark airport satellite building floor plan

B-2

* A M E C O * A U T O M A T I C D E S I G N I N M E T A L S A N D
I N P U T L I S T I N G

PROJECT NEWARK AIRPORT
STRUCTURE SATELLITE BUILDING 1A - GROUND FLOOR
CLIENT PORT OF NEW YORK AUTHORITY
JOB 4515-01
INPUT T.Y. HU
LIST ALL
ANALYSE ALL

LEVEL 1
ANALYSE BEAMS
LIST ENVELOPES AT 5 SECTIONS
USE FLOOR DL 25 LL 150 PSF, SLAB 10 CONC FC' 4000
B201 13-7 WEB 22 * 27 DL 2.962
B101 L 6-0 WEB 18*24 DL 1.6
B1901 L 13-7 9-0 1801R WEB 18*24 DL 1.6
B101 TO 109 20-0 WEB 22*27 DL 2.962
B105 20-0 8-0 201R WEB 22*27 DL 2.962
B106 20-0 6-6 1901R WEB 22*27 DL .962
B107 TO 109 20-0 WEB 22*27 DL .962
B301 12-0 WEB 22 * 27 DL 2.962
B302 22-8 9-0 1901L WEB 22*27 DL 2.962
B303 23-11 WEB 22*27 DL 2.962
B304 20-0 WEB 18*30 DL .56
B305 23-11 WEB 22*27 DL 2.962
ANALYSE FLAT SLABS
USE SPAN 13-0
S401 23-2, S402, S403, S404 24-0 WIDTH 11-0
S1701 11-0 WIDTH 7-8, S1702 25-4, S1703 11-0 WIDTH 7-8
S501 13-7, S502 23-2 15-0 1701, S503, S504
S505 23-0 WIDTH 23-0 S506 21-3 10-5 404R WIDTH 23-0
S607 23-0 WIDTH 22-0
S801 23-2, S802, S803, S805 TO 806 21-0 WIDTH 22-0
S804 20-0
USE SPAN 23-2
S601, S602 21-2 WIDTH 13-0
S701, S702 21-2 WIDTH 13-0
S901, S902 21-2 WIDTH 13-0
S1001 L 13-7 3-6 1801L WEB 18*24 DL 1.6, S1002, S1003 21-2 WIDTH 13-0
USE SPAN 13-11
S1101, S1102 16-10, S1201, S1202 18-10
S1301 13-7 WIDTH 23-0
S1302 23-2 11-6 1703R, S1303 TO 1304 13-6
S1305 23-0
S1401 TO 1404 21-8
S1501 33-0 11-0 602R 11-0 702R
S1502 33-0 11-0 902R 11-0 1103R
S1503 33-0
S1601 TO 1606 15-2, S1607 17-0 WIDTH 7-8, S1608 10-8 WIDTH 7-8
S1609 17-0 WIDTH 7-8
ANALYSE COLUMNS DIAM 14 L 20-0, CAP DIAM 3-6
C1 TO 5 1401 TO 1404R 404 804 505 1305 306R
C6 TO 9 1501 TO 1503R 403 803 504 1304
C10 TO 19 1601 TO 1609R 402 602 702 802 902 1003 503 0 0 1303
C20 TO 29 101 TO 109R 401 601 701 801 901 1002 502 1102 1202 1302
C30 TO 34 301 TO 304R 201 1001 501 1101 1201
C35 0 507R, C36 0 507, C37 506 805, C38 306 1305R
C39 1701R 1102R, C40 1702R 1202R
C6 TO 9 DRIP PANEL 301R 10-0 YDIM 6-2 LEPTH 14 IN.
EXECUTE

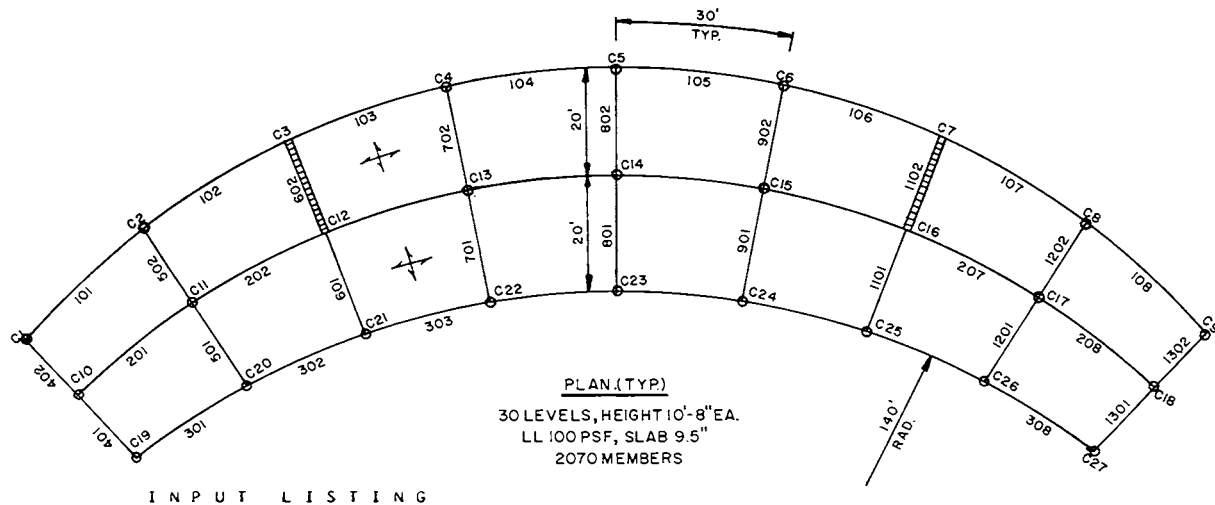
Fig. B-2—Input data for the 107 members in Fig. B-1 building

* A M E C D * AUTOMATIC DESIGN IN METALS AND CONCRETE * A M E C D *
 PROJECT NEWARK AIRPORT
 CLIENT PORT OF NEW YORK AUTHORITY
 STRUCTURE - SATELITE BUILDING 1A - GROUND FLOOR
 LEVEL NO. - 1

JOB NO. - 4515-01
 INPUT BY - T.Y. HU
 REVISION -
 DATE - 15 OCT 70

PAGE 4
 FOR 125 BEAM / SLAB TYPES

BEAM / SLAB		REINFORCING SCHEDULE													
I		LONGITUDINAL										I			
BEAM / SLAB		I										STIRRUPS			
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INPUT LISTING

PROJECT='CITY HALL'; SAVE FILE 'CITY'
LEVELS 1 TO 30

DESIGN BEAMS, FLOOR LL 100 PSF, SLAB 9.5 IN
B101 TO 108 30-1, B201 TO 208 26-3, B301 TO 308 22-9
B401 15, B402 13-6, B501 17, B502 16, B601 18-6 WALL 602 18.
USE SPAN 19-6; B701 B702 B801 B802 B901 B902
B1101 18-6 WALL 1102 18, B1201 17, B1202 16, B1301 15, B1302 13-6

DESIGN COLUMNS CIRCULAR, LENGTH 10-8
CHANGE SIZE AT LEVELS 9 AND 18
C1 TO 9, 101 TO 108, 402K 502R 602R 702R 802K 902R 1102R 1202R 1302R
C10 TO 18, 201 TO 273, 402 502 602 702 802 902 1102 1202 1302
C19 TO 27, 301 TO 308, 401 501 601 701 801 901 1101 1201 1301

FRAMES X-1, X-10, X-19; EQ PCT 9.; WL PRESS 32. PSF
FRAMES Y-19 TO 27; EQ PCT 9.; WL PRESS 36 PSF; EXECUTE

Fig. C-1—Typical floor plan of a 30-story concrete structure

* A M E C O * AUTOMATIC DESIGN IN METALS AND CONCRETE * A M E C O *

PROJECT - CITY HALL JOB NO. -
 CLIENT - INPUT BY - AAP
 STRUCTURE - REVISION -
 DATE - AUG 25 70

C O L U M N R E I N F O R C I N G S C H E D U L E

LEVEL	4	COL-9	COL-10	COL-11	COL-12	COL-13	COL-14	COL-15	COL-16
SIZE	1	180IA	240IA	340IA	12 X	360IA	360IA	360IA	12 X
VERT. STEEL	1	8-#11	10-#14	13-#13		16-#18	16-#18	16-#18	
TIES	1	*3SPR 2.50I	*3SPR 3	*3SPR 3	PILASTER	*3SPR 3	*3SPR 3	*3SPR 3	PILASTER
DWLS	1								
LEVEL	3								
SIZE	1	180IA	240IA	340IA	12 X	380IA	380IA	380IA	12 X
VERT. STEEL	1	9-#11	10-#14	14-#13		17-#18	17-#18	17-#18	
TIES	1	*3SPR 2.50I	*3SPR 3	*3SPR 3	PILASTER	*3SPR 3	*3SPR 3	*3SPR 3	PILASTER
DWLS	1								
LEVEL	2								
SIZE	1	180IA	240IA	360IA	12 X	400IA	400IA	400IA	12 X
VERT. STEEL	1	10-#11	11-#14	15-#18		17-#18	17-#18	17-#18	
TIES	1	*3SPR 2.50I	*3SPR 3	*3SPR 3	PILASTER	*3SPR 3	*3SPR 3	*3SPR 3	PILASTER
DWLS	1								
LEVEL	1								
SIZE	1	180IA	240IA	360IA	12 X	420IA	420IA	420IA	12 X
VERT. STEEL	1	11-#11	12-#14	16-#18		18-#18	18-#18	18-#18	
TIES	1	*3SPR 2.50I	*3SPR 3	*3SPR 3	PILASTER	*3SPR 3	*3SPR 3	*3SPR 3	PILASTER
DWLS	1								
FOUND'S	1								

Fig. C-2—Typical column reinforcing schedule for building shown in Fig. C-1



PROBLEM ORIENTED LANGUAGE FOR THE DESIGN OF REINFORCED CONCRETE STRUCTURES

By R. J. ALLWOOD

A machine independent data and program handling scheme entitled GENESYS (GENeral Engineering SYStem) is now being written in the United Kingdom for the Department of the Environment.

Five major subsystems for structural and highway engineers will be available initially and one will be for the design of reinforced concrete buildings. The emphasis in this subsystem is on continuing past the conventional analysis stage on through to the detailing stage printing out bar fixing and scheduling information ready for the construction site.

Keywords: beams (supports); buildings; columns (supports); *computer programs*; concrete slabs; *detailing*; frames; loads (forces); *reinforced concrete*; reinforcing steels; *structural analysis*; *structural design*.

INTRODUCTION

□ A new computer system entitled GENESYS for handling application programs and their associated data is now being developed in the United Kingdom for the Ministry of Public Building and Works. The system provides new facilities which allow practising engineers to select programs from a library, to control the calculation carried out by those programs and to select at will those parameters of a design which are to be varied during the design study. As part of the library of application programs to be issued with this system in 1971, a set of programs have been developed which enable an engineer to use a computer not only for the analysis of structures but also for the design and detailing of reinforced concrete elements. The results are printed in a form which can go straight to the construction site thus bye-passing much time-consuming and expensive drawing office work. This paper provides a brief summary of the facilities of GENESYS and the problem oriented language for reinforced concrete design.

GENESYS

GENESYS (the acronym stands for GENeral Engineering SYStem) has been extensively described by its originators Alcock and Shearing.¹ Briefly it is a computer program which consists of two parts: a master program and a library of problem solving subprograms. The master program GENESYS system is a program which by itself will solve no problems. It is concerned with the details of handling large volumes of data, transferring this data between the main memory of a computer and the backing stores and also with selecting the application

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subprograms required by a user to solve a particular problem. These problem solving subprograms form the second part of GENESYS and are conveniently grouped into subsystems relevant to a particular engineering problem field, e.g. bridge design, highway design, building design.

The principal features of GENESYS is that of allowing the user/engineer to select and control his choice of subprograms through the use of Problem Oriented Commands. These allow him to tailor the calculation sequence to fit exactly his own problem. This approach was pioneered by Miller² in the development of the ICES system. This system and a number of British systems were studied extensively after the need for such an integrating system was identified by the Ministry of Public Building and Works in 1967. At that time it was noted that although many programs were available to structural engineers their usefulness was detracted from by the varying standards to which they were written, the many different forms of input data, the machine dependent nature of the programs and the difficulty practising engineers had of identifying which, out of a formidable list, were reliable programs. It was seen to be essential to develop a system which would make this library of programs available to all, which would ensure that the programs were written to a reliable standard and with a common form of data preparation and which would allow engineers to integrate a sequence of programs so as to perform the complete design calculations they currently do by hand.

The new features of GENESYS are as follows. All data for any of the GENESYS subsystems are prepared in a standard form of table such as that illustrated in Fig. 1. Once the engineer using GENESYS has learned to prepare tables for one subsystem, he can prepare tables for any other. A table always commences with a reference title in inverted commas followed by a line of headings. These headings, which are punched together with the data, identify the items of data to be presented. These are generally numerical values or a set of letters and digits between quotation marks. A value may be an integer, a decimal number or a simple calculation expression. There are very few rules involved in writing down data, the layout across the paper can be quite flexible and there may be any number of rows to a table. This form of data table is standard to all programs in GENESYS not only for input but also for output. The tables may also be stored on magnetic tape or disc and so provide a means of communication within and between subsystems of application programs. A further feature of data tables is that the units in which the data are to be presented are identified by following the heading with a double comma and

the units symbols. Thus in Fig. 1 the units are inches. Should the engineer wish to submit data in different units then he merely substitutes the new units symbol (say FT) after the appropriate heading and GENESYS provides an automatic units conversion when the data table is read.

'FIRST LIFT COLUMNS'			
GRIDS	WIDTH,,IN	BREADTH,,IN	COVER,,IN
C/11	15	20	2
D/11	15	22	2.5

Fig. 1--A GENESYS data table

The second new feature is strictly a further facility of data tables but it is one of such importance as to warrant special reference. Any item of data presented in a data table may be substituted for by a variable. The variable can have any name. Clearly the computer must be given a numerical value for this variable before a calculation can be performed and this is given by a statement of the form:

$$X = 27.2$$

where this command is included along with the problem oriented commands required to solve the problem. This exciting feature turns any analysis program into a 'design' program. The user is able to select just those parameters which he wishes to vary while making all other values fixed numerical values. The feature is provided by the master program, GENESYS system, and is therefore available in all subsystems and requires no effort by the programmer writing each subprogram. An example of the use of data variables is shown in Fig. 2 where the length of two haunches are being varied whilst the other design values remain fixed and a calculation is made of the maximum deflection of the beam.

The third and final feature to be mentioned of GENESYS is that of machine independence of the application subprograms. These programs are written in a language called GENTRAN which is a version of FORTRAN with further facilities for dealing with the standard data tables and for providing dynamic arrays. The GENTRAN subprograms are translated by GENESYS itself into machine dependent versions in a low level version of FORTRAN. This is then compiled by

the normal compiler and loaded to the library of application subprograms. The master program which performs this translation and all the other control operations is written mainly in this same low level version of FORTRAN. Some 10 per cent of the master program is written in the machine code of the computer. The system is being made available initially on five different types of computer, namely:

ICL 1900 Series
ICL System 4
IBM System 360
CDC 6600 Series
Honeywell 200 Series

THE ADMINISTRATION OF GENESYS

Before turning to the design of reinforced concrete structures, mention will be made of the steps being taken to coordinate the development of the GENESYS project. It is the essence of GENESYS that it should lead to a channeling of the programming efforts now being made by British consulting engineers into one co-operative venture rather than the present tendency of duplicating each others efforts. The technical facilities of GENESYS encourage this but it was believed by the Ministry of Public Building and Works when originating this system that a single organisation should be set up to act as a focal point in this co-operation and to provide a stimulus through commercial pressures which would lead to co-operation. Consequently a centre entitled The GENESYS Centre has been established at Loughborough University of Technology, Leicestershire, England to act as this organization. It is already holding courses on the use of the system and in programming new application subprograms in GENTRAN. The Centre is responsible for the issue of all GENESYS programs including the master program, responsible for the documentation of these programs and also for maintaining and distributing the programs to engineers wishing to use it. The system is being offered on a commercial basis with a small annual charge payable directly to the Centre coupled with a small royalty on computer costs when an engineer uses the system through a bureau. Alternative charging methods are adopted for those engineers owning suitable computers. An incentive to practicing engineers to make their own programs available through the GENESYS Centre is provided through a marketing mechanism in which the GENESYS Centre acts as a broker for suitable programs retaining a small part of the royalty for administration costs returning, the remainder to the author.

THE BUILDING SUBSYSTEM

As one of the initial subsystems of application subprograms being developed for release in early 1971, the BUILDING subsystem will provide an entirely new computing facility for the reinforced concrete engineer. The heart of the subsystem is a set of programs which perform the detailed design of beams, columns and slabs calculating not only the size of reinforcement bars but also their lengths and disposition and printing this information out in a form which can go straight to

the construction site. In a survey conducted in the United Kingdom in 1969, 13 such programs were discovered all written by consulting engineers. The programs were tested and the most suitable selected to form the central core of the BUILDING subsystem. It was the existence of automatic detailing programs of this nature which stimulated the development of this problem oriented language and which distinguishes it from other initiatives. Biggs³ has described a problem oriented language for reinforced concrete design which selects bar sizes but does not tackle the site communication problem. Kenchington⁴ and Gifford⁵ have both developed programs which circumvent the drawing office but which do not have the benefit of a command language to provide flexibility in use. All the adopted programs start from given structural dimensions and loads, perform the appropriate analysis of the element and then determine the optimum pattern of reinforcement. The engineer is not required to provide reinforcement details in advance although certain overriding facilities such as limiting the maximum number of bars in a layer are provided. To the practicing engineer such programs represent for the first time a way in which he can use the computer to cut his own design costs. It is estimated that detailing accounts for 30 to 40 percent of design costs and furthermore, in the United Kingdom at least, competent detailers are becoming extremely difficult to find. From experience gained with the existing programs for detailing it is expected that the computer costs for this detailing work will be competitive with present manual costs and there are additional benefits to be gained by the speed with which the detailing work will be accomplished. Since the engineer can now get his detailing work done by the computer he will be more ready to consider using the computer for better structural analysis techniques or for more studies of overall building layout.

The ready acceptance of the computer output by the bar fixers on the construction site is an important part in the design of such a subsystem. By careful attention to detail such as printing the results on 10 X 8 in. paper and providing a plastic wallet to protect the site copies against adverse weather, coupled with a sympathetic site staff, it has been found that construction site gangs are entirely happy with this new form of detailing information. Indeed it may be the first step in eliminating drawings from site except for the general arrangement drawing.

The problem oriented language devised to integrate the detailing programs, reflects the conventional design procedures followed by the practicing engineer. Advanced methods of analysis have been avoided for the basic commands although options have been provided for using such methods if the engineer chooses to do so.

DATA TABLES

The building subsystem allows engineers to analyse, design or detail practical reinforced concrete buildings of beam and slab construction. The building may be irregular in elevation or plan such as that shown in Fig. 3. The slabs may be one-way or two-way with a variety of edge conditions and the beams may be supported by walls, columns or other beams.