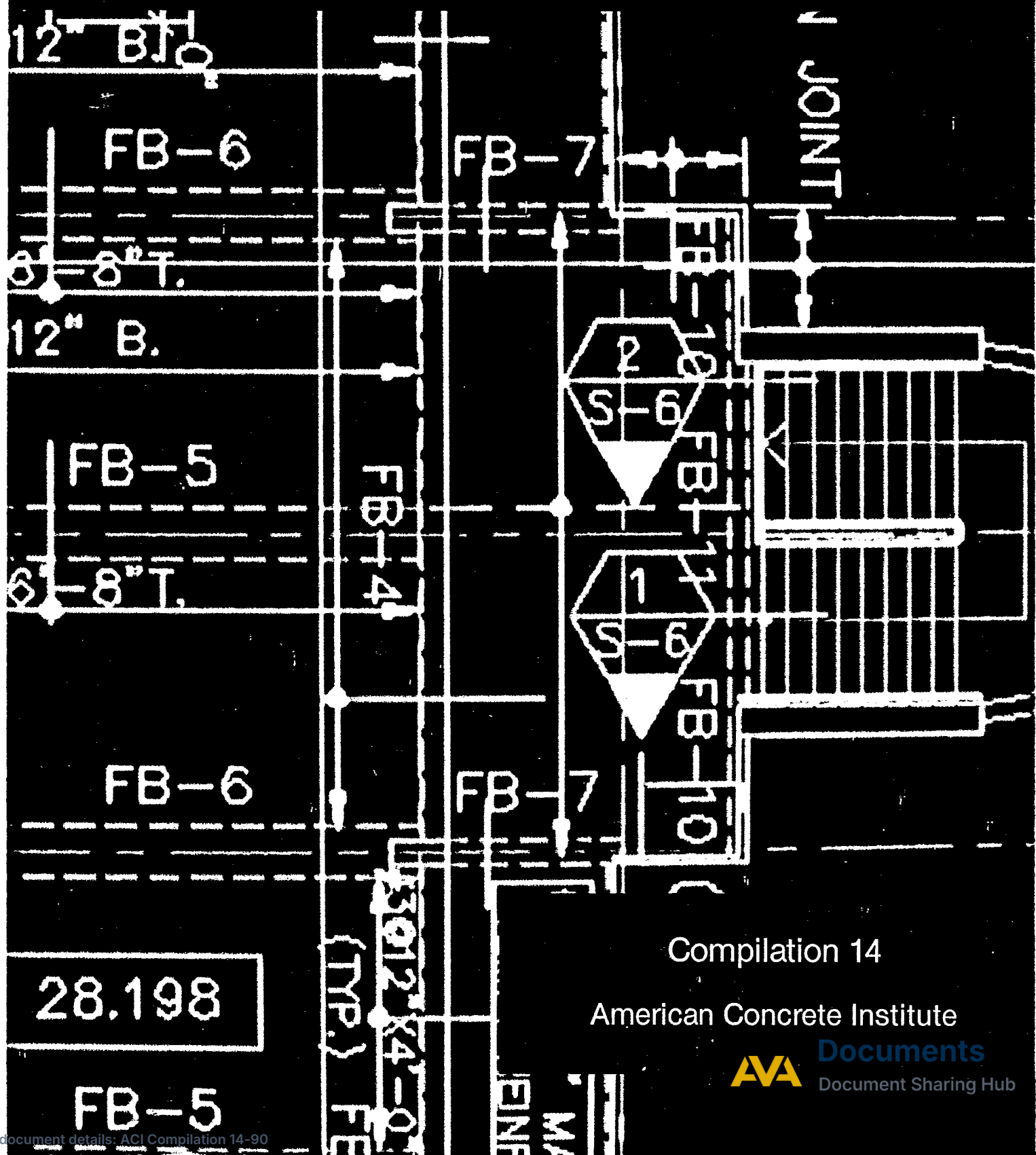


COMPUTERS IN CONCRETE DESIGN



Compilation 14

American Concrete Institute

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Computers in Concrete Design

ACI Compilation 14

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Preface

The ACI Compilation Series offers an opportunity to gather together material previously published in Institute periodicals as a compact and ready reference on a specific topic. The material in a compilation does not necessarily represent the opinion of an ACI technical committee — only the opinions of the individual authors. However, the information presented here is considered a valuable resource of readers interested in the subject.

Victor E. Saouma
Chairman, Committee 118
Use of Computers

On The Cover: There are an infinite number of ways to improve concrete detailing in Computer Aided Design (CAD) programs but considerable time is often required to develop procedures. Cover photo shows a portion of a program for detailing of reinforcing bars and hooks in a given plan. (See article on page 47.)

American Concrete Institute, Box 19150, Redford Station, Detroit, Michigan 48219



Computers in Concrete Technology

by M. A. El-Rahman and W. J. D. Shaw

During the past two decades, a dramatic change has occurred in the manner in which engineering projects are designed and managed. Long and tedious calculations have been replaced with fast, accurate, and detailed results. Complex analysis that only a few years ago was thought impossible or impractical now is conducted on a routine basis.

Computers have found their way into nearly every aspect of concrete technology; the extent of this interaction can be seen in Fig. 1. Computer technology has intertwined knowledge and applications in a manner that results in remarkable improvements in efficiency, beginning with a better understanding of material behavior and extending to the design and the construction of structures.

Computer programs have become everyday language and the mystique that surrounded their use in the sixties has been replaced today with a hands-on, do-it-yourself attitude. The complete area of materials science is expanding at a remarkable rate in the use of computer technology.^{1,2} The computing power available in desktop and laptop microcomputers of today rivals the capability of mainframe computers of a few years back. The cost of these systems has in turn decreased such that today this technology is affordable by even the smallest companies. The rate at which computer technology continues to develop points to even further involvement of computers in all aspects of engineering over the years ahead.

Some of the more common applications of computers in concrete technology are testing, material modeling, analysis and design, quality control, construction management, fatigue analysis and pre-

diction, cost estimating, and involvement in codes and specifications.

Testing

The use of computers in the laboratory is vital for testing and evaluation. They are now commonplace in structural testing and are used in several different manners.³

One major use is data acquisition, which usually involves gathering data, its subsequent storage, and sometimes displaying either the data or the current status of the test. An example is that of reading and storing strain-gage data for loaded concrete components either in the laboratory or the field. This replaces the use of data loggers, which require considerable manual handling of data for analysis at the end of the test.

Computers used for data acquisition also are suited to analyzing and reducing test data, tabulating results, and plotting engineering relationships with minimal human involvement.

Microcomputers can be used in computations for test setups as well as verifying the status and zero positions of sensors. Some programs allow for internal calibration and offset conditions prior to testing. Computers also can be interfaced for interactive control of testing machines. Fig. 2 shows a testing system controlled by a microcomputer that also acts as a data acquisition system. A microcomputer, acting as a smart terminal also can feed collected data to a mainframe computer so the data can be added to a data base or used for other analyses.

Another use is determining air-void system parameters or aggregate size and distribution in hardened concrete. These values can be determined easily using a computer-

controlled microscope stage coupled with a video recording and analysis system. These image-analysis systems now are standard items.

Computerized materials-testing systems have paid off in a number of ways. There has been an increase in experimental efficiency and precision and an improvement in the quality of both testing and the analysis of the test results. The test engineer has more information available and more time to visually observe the specimen during testing as well as to consider the significance of the results after testing is complete.

Material modeling

The stress/strain and cracking behavior of concrete and reinforced concrete structures can be described by formulating specific equations of state. These special relations are developed using power law relations or polynomial equations based upon analysis of experimental information.

For cracked concrete structures where analytical relations are not available, or when the exact analysis is tedious and time consuming, the structures' behavior can be simulated through numerical analysis procedures. The state of the art in modeling concrete structures has been basically through two distinct approaches, smeared-crack representations^{4,5} and discrete-crack representations.^{6,7}

Each method has specific advantages and disadvantages, and care must be taken in the selection of finite element size when using the smeared-crack approach.⁸ Because of this, a hybrid model using features borrowed from the two base models has been proposed.^{8,9} This area of modeling continues to evolve.

The DIANA program¹⁰ was constructed according to the smeared-

crack concept to model the nonlinear behavior of reinforced and prestressed concrete elements. Using the discrete approach, conditions for crack propagation in a porous structure have been studied analytically.¹¹

An example of the results of computer simulation analysis using discrete-crack representations for cracking in coarse and fine aggregate is shown in Fig. 3. In addition, three-dimensional elliptical voids have been used as models to study crack problems.^{12,13} Fig. 4 shows the interaction of initiation stress at voids in concrete under biaxial stress fields. These were obtained using the computer program SCATEC.¹²

Computer image analysis also can be used to help investigators assess microcrack patterns in concrete¹⁴ and trace the migration of different chemical species in hardened concrete. Once analysis is complete, complex random-path statistical models then can be constructed and used for behavior prediction in other problem configurations.

Design and structural analysis

The design of structural components always has been a repetitive and time-consuming task; similar analysis relationships are used for most types of members. The loads applied to a structure give rise to stresses, strains, and displacements in the structural elements, which are sized for limiting values of these parameters.

The optimum design of each component in a structure does not necessarily insure the best design of the structure as a whole. Rather, conceptual input from the designer always will be necessary. In statistically indeterminate structures, the interaction of stiffness in adjacent members also must be considered.¹⁵ In problems such as this where iterative analysis is required, the use of computer programs has a definite advantage.

An overall computer flow diagram for the design of engineering structures is shown in Fig. 5. Such

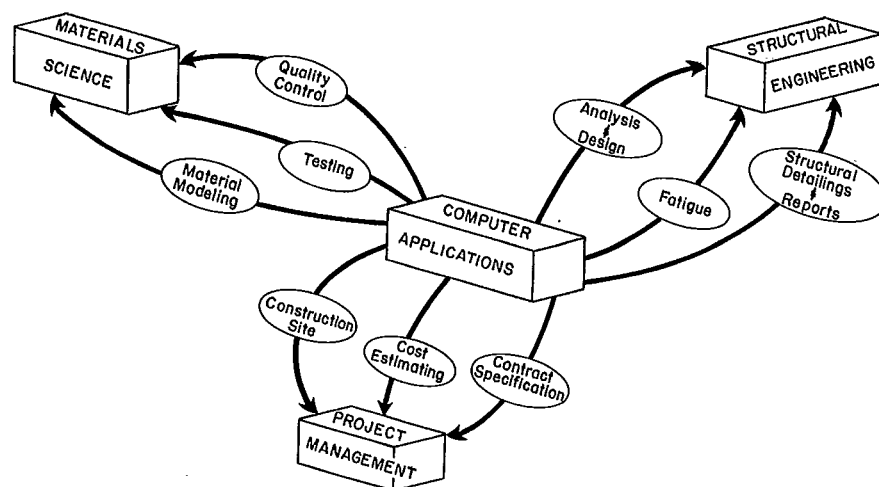


Fig. 1—Applications of computers in concrete technology.

a process always involves an interactive approach with the designer and incorporates a redesign portion. Many computer programs, classified as inhouse, university, or commercial, are available for the design of concrete structures.

Two of the most important criteria for selecting a design program are user interaction and program flexibility. These two features allow a designer to alter a design solution easily as a project progresses. For iterative programs the efficiency of convergence to a final solution is an important attribute.

Quality control

Concrete, as compared with other engineering materials, is inherently a largely variable material. When tested, two identical concrete samples can show moderate but substantial variations in mechanical properties. Variations in strength, workability, and durability of concrete are caused by many factors that should be corrected quickly by adjustments in mix proportions and close supervision at the time of mixing and placement.

Consistency in the properties of the tested concrete specimens is a prime objective at concrete batching plants, which leads to a need for a high degree of quality control during the manufacture of concrete. Computer programs can provide better control in obtaining good quality concrete and programs are able to perform virtually any operation that might be required.^{16,17}

facing page:

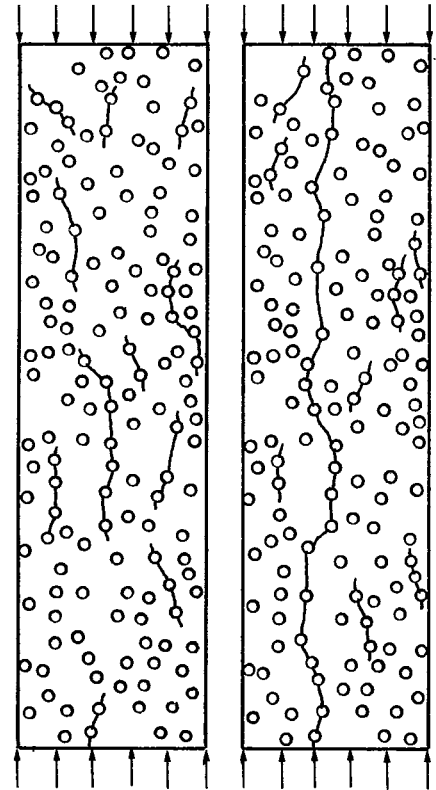
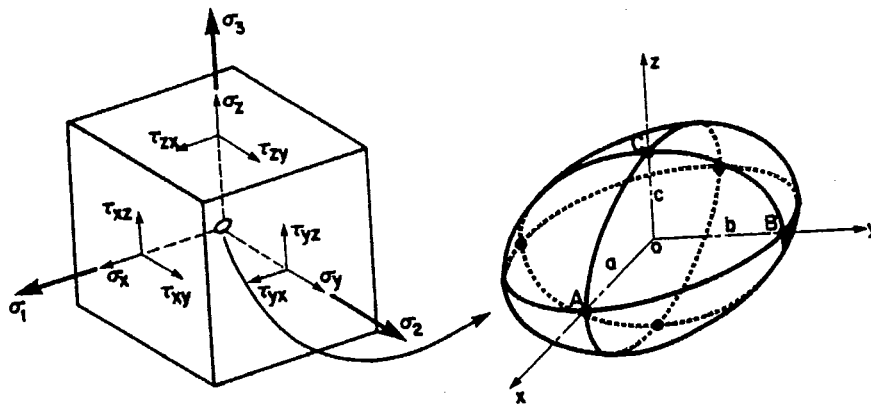
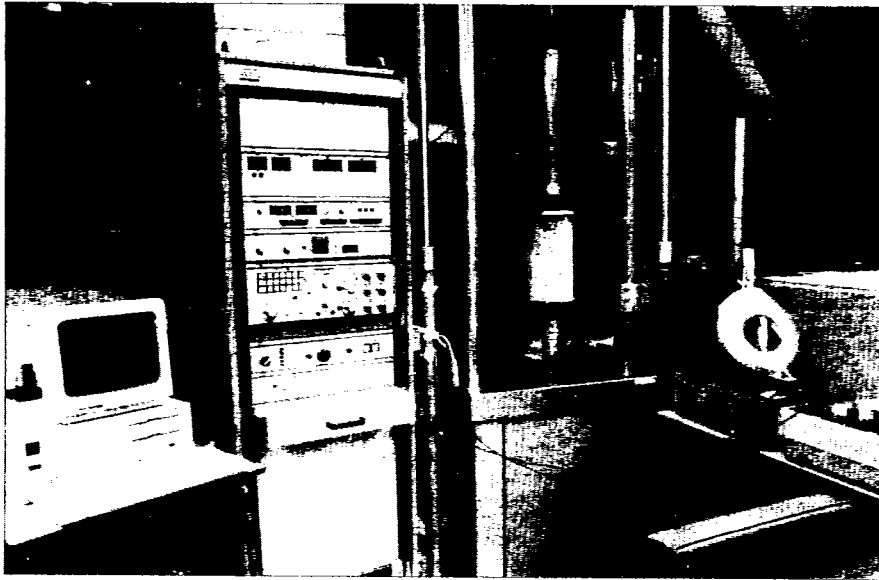
Fig. 2—(top left) Computer controlled concrete testing.

Fig. 3—(right) Compressive load crack patterns using a computer simulation technique:¹¹ a) hardened cement paste; b) concrete.

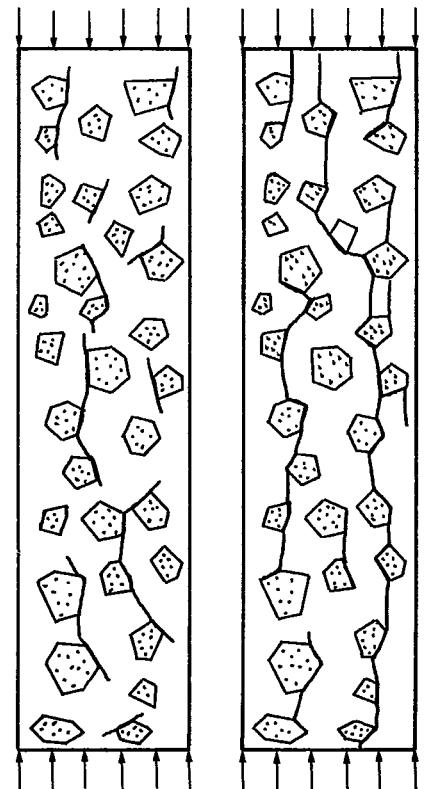
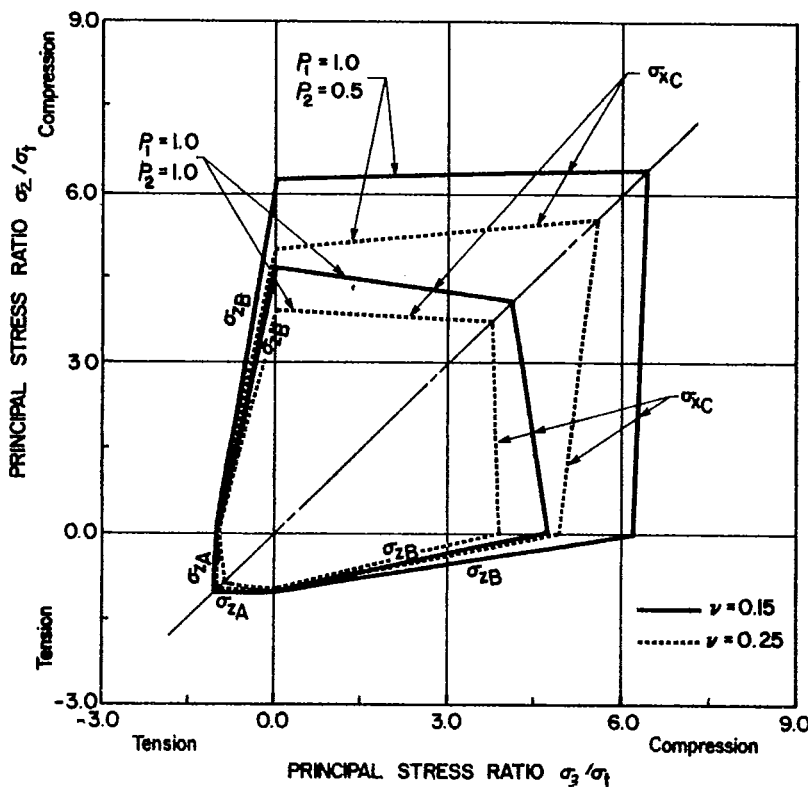
Fig. 4—(bottom left) Crack initiation stresses at voids under biaxial conditions.¹²

For example, the Project Concrete Quality Control System program,¹⁶ PCQCS, written in FORTRAN, was developed to provide information on controlling specific properties of concrete. It incorporates gradation commutations and proportions and adjustments of mix proportions for scale weight, gradation summarization, and compressive strength data. The program also can compute and store data for monthly summaries and make the necessary mix proportion adjustments for gradation and moisture. The overall structure of the program is shown in Figure 6.

Another program, COPMUMIX,¹⁷ written in BASIC, allows an automated step-by-step procedure for the design of normal weight concrete. The ACI, CSA, and British design procedures were incorporated into the program, which allows the user to design a mix according to a specific code. Once the mix is designed, it can be modified for partial replacement of cement by flyash. The program also can



(a)



Concrete Technology

continued

low the target strength to be calculated and gradation of fine aggregates to be analyzed in detail.

Integrated software is available that combines separate programs into a unified versatile program. Thus spreadsheet calculations, graphics, word processing, and communication can be used with quality-control software. The main strength in the use of computers for quality control is the ability to execute complex interactive relationships in a quick and systematic manner. Concrete mix computer programs, when combined with good inspections and workmanship, help to obtain the best end result, which is based upon a total approach to quality control.

Construction management

Computers have found their way into construction and are used in job analysis, ordering materials, and bookkeeping and also as a tool to coordinate geometry, control alignment, and control reference points.

For large-scale construction projects, planning and organization are vital and construction and materials scheduling using critical path planning is essential. This method is available in commercial programs that prevent unplanned time delays and provide the most efficient path for job progress.

Formwork design is another area that can be improved upon significantly by using computers. Formwork often has been either overdesigned or underdesigned, resulting in wasted time and money or even collapse.

The reluctance to design formwork accurately is associated with the time and effort required to perform the necessary strength analysis. The use of microcomputer programs can lead to the rapid design of more rational formwork systems, resulting in improvements in construction, safety, and cost.

Fatigue

Computers are used in a growing number of applications of concrete

technology with regards to fatigue behavior, resulting in progress in both knowledge and design. Computers often are used to gather and store fatigue information during testing of concrete, reinforced concrete, reinforcement, and post-tensioning rods.

Field loading spectrums for specific structures can be fed back into the testing machine through interactive computer control, allowing the laboratory test component to undergo the same spectrum loading conditions as those occurring in the field.

The analysis of fatigue data also is conducted easily using computer systems. Generally, empirical fitting relationships that allow life predictions can be made. Data bases are compiled for different materials and conditions that later can be incorporated directly into prediction or design programs.

Design and analysis of structures are accomplished easily with specialized computer software. Most design and analysis for fatigue conditions involves an iterative process to predict the fatigue life of the structure. This is particularly true where fatigue cracks exist in the structures as life prediction depends upon crack propagation.

In many respects, concrete is similar to such other materials as metals, ceramics, and polymers when fatigue behavior is involved. The use of computers for fatigue testing, analysis, and life prediction can be extended easily from metals to concrete structures.

Cost estimating

Estimating a price during the tender process is a difficult and time-intensive job. Accuracy is required if a low tender is to be achieved and a profit maintained. Contractors are able to derive considerable benefit when using a computer program or special computer and takeoff pen system for estimating the costs of projects. The return from using such a system can be measured in terms of success in winning contract awards, efficiency, accuracy,

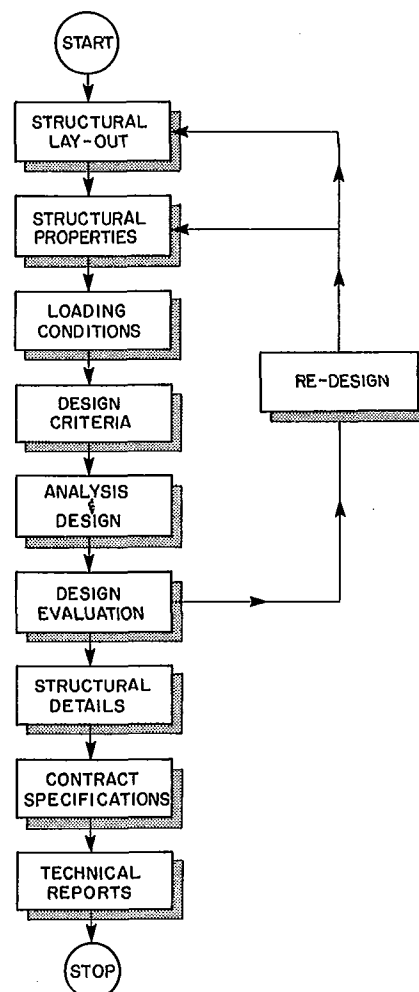


Fig. 5—Structural design process flow chart.

and time savings. In addition, estimating programs are helpful for project supervisors when placing materials orders.

Codes and specifications

In design procedure, the engineer frequently refers to building codes to insure that a structure meets the minimum requirement for safety and performance. This sometimes is a tedious job. Computer programs implementing the code requirements make it possible to search for relevant topics with considerably less effort than usually is involved. Using computer programmed codes also helps to avoid overlooking portions of the code since cross referencing is easily incorporated.

Future directions

The major advance in the use of computers in concrete technology currently is in the widespread use of

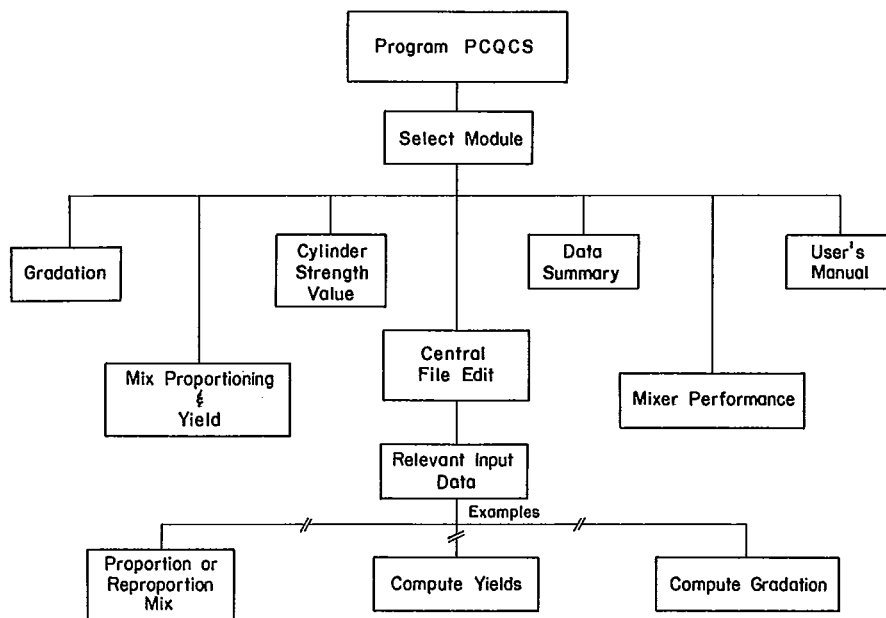


Fig. 6—Project concrete quality control system modules.

personal computer (PC) systems. The increasing capability in computing power and availability of software means that more small companies are able to afford this technology. Future applications for PC use likely will occur first in computer-aided design. Additionally, more testing laboratories will incorporate computer-controlled equipment and data acquisition in their evaluation of material properties.

Computer use can be expected to increase in the areas of fatigue and fracture mechanics. In addition, integrated quality control using feedback circuitry during the mixing of concrete also is likely to grow. Using feedback, either automatic or computer-guided, corrections can be made prior to the completion of mixing so that exacting quality control of concrete strengths and workability can be maintained.

Computer use is a powerful design aid and can be an excellent investment as long as the engineer's judgement is not sacrificed.

References

1. Harrison, R. J., and Roth, L. D., *Artificial Intelligence Applications in Materials Science*, The Metallurgical Society, Inc., Warrendale, 1987, 209 pp.
2. Ericsson, T., Editor, *Computers in Materials Technology*, Pergamon Press, Elmsford, 1981, 224 pp.
3. White, C. F., "Computer Integrated Engineering," *Proceedings*, 3rd Conference

on Computing in Civil Engineering, American Society of Civil Engineers, New York, 1984, pp.114-122.

4. Rashid, Y. R., "Ultimate Strength Analysis of Prestressed Concrete Pressure Vessels," *Nuclear Engineering Design*, V. 7, 1968, p. 334.

5. *Finite Element Analysis of Reinforced Concrete*, American Society of Civil Engineers, New York, 1982, 545 pp.

6. Loov, R. E., "The Determination of Stresses and Deformation of Reinforced Concrete After Cracking," *Proceedings*, Civil Engineering Materials Conference (Southampton, 1969), *Structure, Solid Mechanics and Engineering Design II*, Wiley-Interscience, London, 1971, pp.1257-1261.

7. Ingraffea, A. R.; Linsbauer, H.; and Rossmannith, H., "Computer-Simulation of Cracking in a Large Arch Dam—Down Stream Side Cracking," *Proceedings*, International Conference on Fracture of Concrete and Rock, Society of Experimental Mechanics, Houston, June 1987, pp. 547-555.

8. Fardis, Michael N., and Buyukozturk, Oral, "Shear Transfer Model for Reinforced Concrete," *Proceedings*, ASCE, V. 105, EM2, Apr. 1979, pp. 255-275.

9. Bažant, Zdeněk P., and Gambarova, Pietro, "Rough Cracks in Reinforced Concrete," *Proceedings*, ASCE, V. 106, ST4, Apr. 1980, pp. 819-841.

10. de Borst, R.; Kusters, G. M.; Nauta, P.; and De Witte, F. C., "DIANA—Comprehensive, but Flexible Finite Element System," *Finite Element Systems: A Handbook*, Springer Verlag, Berlin, 1985, pp. 299-311.

11. Zaitsev, Y. B., and Wittmann, F. H., "Simulation of Crack Propagation and Failure of Concrete," *Materials and Structures, Research and Testing (RILEM, Paris)*, V. 14, No. 83, Sept.-Oct. 1981, pp. 357-365.

12. El-Rahman, M., "Stress Concentration Around Ellipsoidal Flaws in Relation to the Fracture of Brittle Materials," M.Sc. thesis, University of Calgary, 1983, 228 pp.

13. Shrive, N. G., and El-Rahman, M., "Understanding the Cause of Cracking in Concrete: A Diagnostic Aid," *Concrete International: Design & Construction*, V. 7, No. 5, May 1985, pp. 39-44. Also, Discussion, V. 8, No. 3, Mar. 1986, p. 70.

14. Ohta, Toshitaka; Ohashi, Takeshi; Konagai, Nobuo; and Nemoto, Takahiro, "Measurement of Air Void Parameters in Hardened Concrete Using an Automatic Image Analyzing System," *Transactions*, Japan Concrete Institute, V. 8, 1986, pp. 183-190.

15. Cross, Hardy, "The Relation of Analysis to Structural Design," *Transactions*, American Society of Civil Engineers, V. 101, 1936, pp. 1363-1408.

16. Oliverson, James E., "Computerized Concrete Quality Control," *Concrete International: Design & Construction*, V. 4, No. 11, Nov. 1982, pp. 23-31.

17. Day, R., "Automated Concrete Mix-Design on Microcomputer," CSCE Conference (Calgary, May 1988), Canadian Society for Civil Engineering, Montreal, pp. 15-13.

Selected for reader interest by the editors.

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Spreadsheet Application for Prestressed Concrete Bridge Girder Design

by Fernando Fagundo and David Garrizo

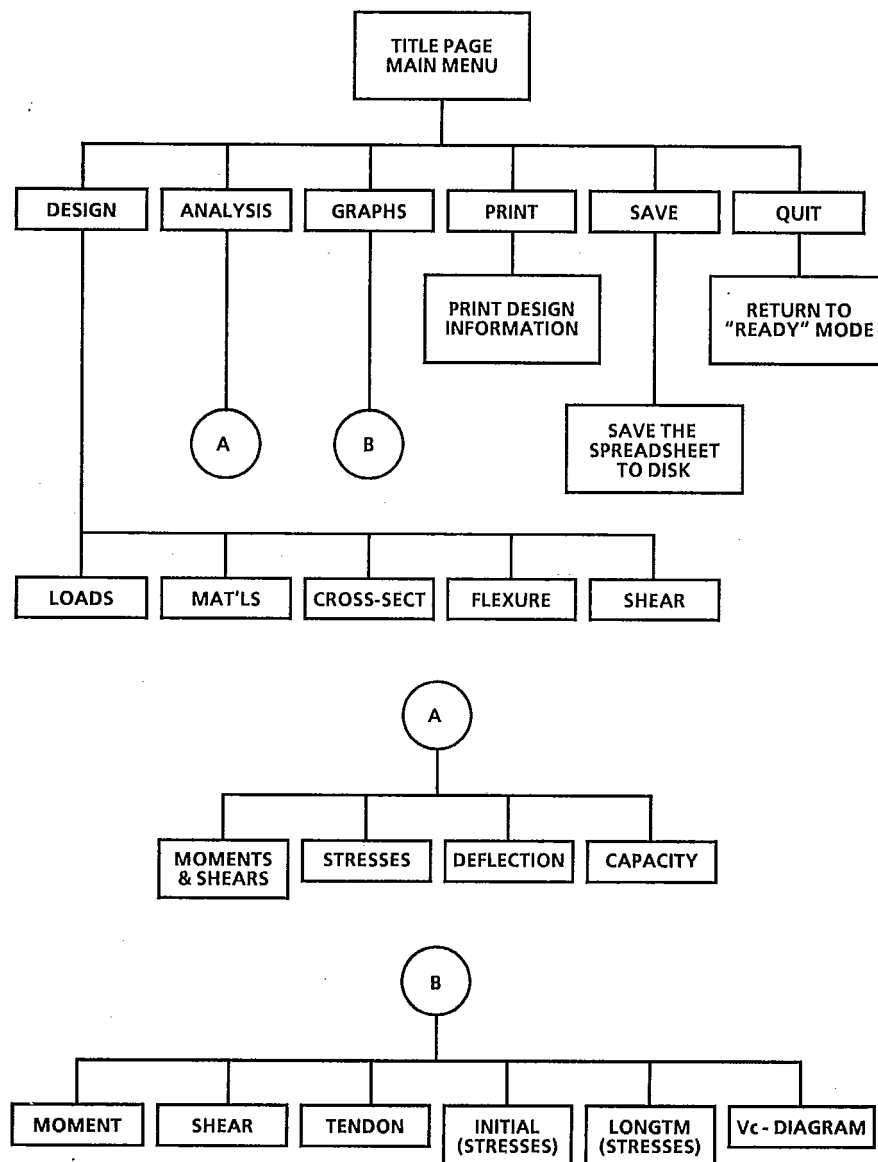


Fig. 1 — Menu tree

The electronic spreadsheet, originally conceived as a tool for business management, has found many applications in structural engineering. In recent years much focus has been placed on spreadsheets and numerous articles dealing with spreadsheet topics have been presented in professional publications.

Electronic spreadsheets possess several features that make them attractive for engineering applications:

- A change to any part of the input data is reflected in all calculations almost instantly.
- The template can be organized to follow the logical flow of the design process in the same way as an engineer would organize design computations.
- Graphic interface and database capabilities allow more options for data representation.

A spreadsheet can be customized to fit a user's needs. One of the simplest ways of doing this is to create macros that execute a series of keystrokes when a single key is pressed. If a spreadsheet contains many macros, they can be assembled into a menu system. A spreadsheet program can be made more application-specific by having all interaction controlled by a menu system.

In any bridge design problem there are many variables that affect the final design: span length, girder selection, girder spacing, and deck thickness. Other parameters related to prestressed concrete include ma-

Page 2

SECTION SELECTION			
Section: AASHTO	Type: IV	Slab Thickness=	7.50 in.
Provided Girder Properties		Provided Composite Properties	
H =	54 in.	H =	54 in.
Ag =	789 sq. in.	b.eff =	96.0 in.
St =	8908 in ³	St.c =	45067 in ³
Sb =	10543 in ³	Sb.c =	16436 in ³
I =	260730 in ⁴	I.c =	650353 in ⁴
y.b =	24.73 in.	y.cb =	39.57 in.
y.t =	29.27 in.	y.ct =	14.43 in.
r ² =	330.5 sq. in.		
b.w(eff) =	8 in.		
b.w =	8 in.		
t.flange =	2 in. (FOR T's ONLY)		

terial properties, prestress force, and tendon eccentricity. It is evident that there are many alternatives that may be considered in a bridge design.

By implementing a design procedure on a spreadsheet template, the engineer creates a design aid that will increase efficiency, allow consideration of more alternatives, and reduce design time. Spreadsheet programming makes the microcomputer a very flexible and responsive tool for the engineer.

Design procedure

The spreadsheet described here is intended as a tool for the preliminary design of prestressed concrete bridge girders. The required data includes load information, material properties, bridge geometry, and prestressing data. This information is processed to determine the required prestress force, tendon profile, initial and long-term stresses, ultimate moment capacity, required shear reinforcement, and centerline deflections. The basic organization and layout of the template is similar to that presented in reference 8.

The design procedure was adapted from references 6 and 7. The following five assumptions that were made in the development of the prestressed girder design template should be considered when using the template:

- Full prestressing
- Normal weight concrete (150 lb/ft³)
- Unshored construction
- Span length greater than 28 ft
- Precast T-sections are not composite with cast-in-place topping

When the spreadsheet is loaded, a menu appears that helps the designer move through and work with the spreadsheet. The main menu has six options: DESIGN, ANALYSIS, GRAPHS, PRINT, SAVE, and QUIT. A simplified menu tree is shown in Fig. 1.

Fig. 2 — Selection of cross section.

Page 3

SELECTION OF PRESTRESSING STEEL			
Tendon Profile: HARPED2			
Strands:		Required	Provided*
reqd # =	27.0	Pi =	781.2 kips
# =	28	R =	0.8 losses
dia. =	1/2"	Pe =	625.0 kips
Ap =	0.153 sq. in.	Asp =	4.13 sq. in.
e.end =	-10.00 in.	e.end =	-13.38 in.
e.0.3 =	-20.00 in.	e.0.3 =	-21.56 in.
e.mid =	-22.00 in.	e.mid =	-23.12 in.
			* Select quantities such that provided exceeds required !!

TENDON LIMIT ZONE (in.)	CL										
x =	0.00	8.00	16.00	24.00	32.00	40.00	48.00	56.00	64.00	72.00	80.00
h.mtcp =	29.27	29.27	29.27	29.27	29.27	29.27	29.27	29.27	29.27	29.27	29.27
e.tcp =	16.21	6.08	-4.75	-12.81	-17.50	-18.83	-17.50	-12.81	-4.75	6.08	16.21
e(x) =	-10.00	-13.33	-16.67	-20.00	-20.00	-20.00	-20.00	-20.00	-16.67	-13.33	-10.00
e.bot =	-13.38	-16.89	-19.61	-21.56	-22.73	-23.12	-22.73	-21.56	-19.61	-16.89	-13.38
h.mbot =	-24.73	-24.73	-24.73	-24.73	-24.73	-24.73	-24.73	-24.73	-24.73	-24.73	-24.73

Fig. 3— Flexural design segment.

The design procedure can be outlined as follows:

- Specification of loads and material properties
- Selection of cross section
- Flexural design
- Shear design
- Check of serviceability

Bridge design loads are different from those used for typical building designs. The loads usually consist of standard vehicles, impact factors, and distribution factors as prescribed in the AASHTO Specifications.¹ The standard vehicle can be either a truck load or an equivalent uniform lane load representing a series of vehicles. The template calculates the live load forces by using influence line envelopes with the appropriate AASHTO loading.

Dynamic effects are caused by vehicles crossing the bridge at a high velocity. The impact factor allows these dynamic effects to be included in a quasi-static analysis. The distribution factors account for the fact that the loads act on a finite width of slab that may or may not be directly above a girder.

The LOADS and the MAT'LS

choices of the DESIGN menu both bring the user to the first phase of the design segment which contains the design data. The span length, girder spacing, load information, material properties and allowable stresses, as well as prestress losses are specified in this segment. With this information, the impact factor and distribution factor are calculated. The girder self-weight and the weight of the slab are calculated assuming normal weight concrete.

The compressive strength of both the precast and the cast-in-place concrete and the grade of the prestressing and reinforcing (mild) steel must be provided by the user. The allowable stresses in the precast concrete are calculated in accordance with AASHTO Section 9.15.2. In addition, the flexural strength, stress of tendon at failure, and the allowable initial stress in the prestressing steel are calculated.

Selecting the MOMENTS & SHEARS option of the ANALYSIS menu brings the user to a window displaying the design moments and shears in tabular form. The moments and shears included are due to the girder self

weight, the weight of the slab, the dead load on the girder, the dead load carried by shear diagram can also be viewed graphically.

Section selection

The CROSS-SECT choice of the DESIGN menu brings the user to the girder selection section of the design segment, shown in Fig. 2. The user can specify either an AASHTO standard girder, a single tee, or a double tee section. When the girder has been selected, the spreadsheet finds the section properties in a data table and displays them in the girder selection window. In addition, the user can specify the dimensions for a non-standard rectangular, T, or I-section.

The deck thickness is specified and the provided composite section properties are calculated and displayed next to the girder section properties. The calculations for the composite section properties take into account any differences of materials by the use of modular ratio transformations.

Flexural design

The FLEXURE choice of the DESIGN menu brings the user to the flexural design segment of the program (Fig. 3) which consists of selecting the area of prestressing steel and the tendon profile. The designer is given the required prestress force and the area of steel required to achieve the force based on the initial allowable stress in the cable. The next step is to select the number and size of strands such that the amount of steel provided will exceed the calculated required amount. The cross-sectional area of the various diameter strands is maintained in a database within the spreadsheet.

The verification for flexural strength is based on the philosophy that the moments induced by the acting factored loads should be less than or equal to the design moment capacity of the girder.

To aid the engineer in selecting the tendon profile, the allowable tendon zone is calculated and can be displayed graphically (Fig. 4) by selecting TENDON from the GRAPHS

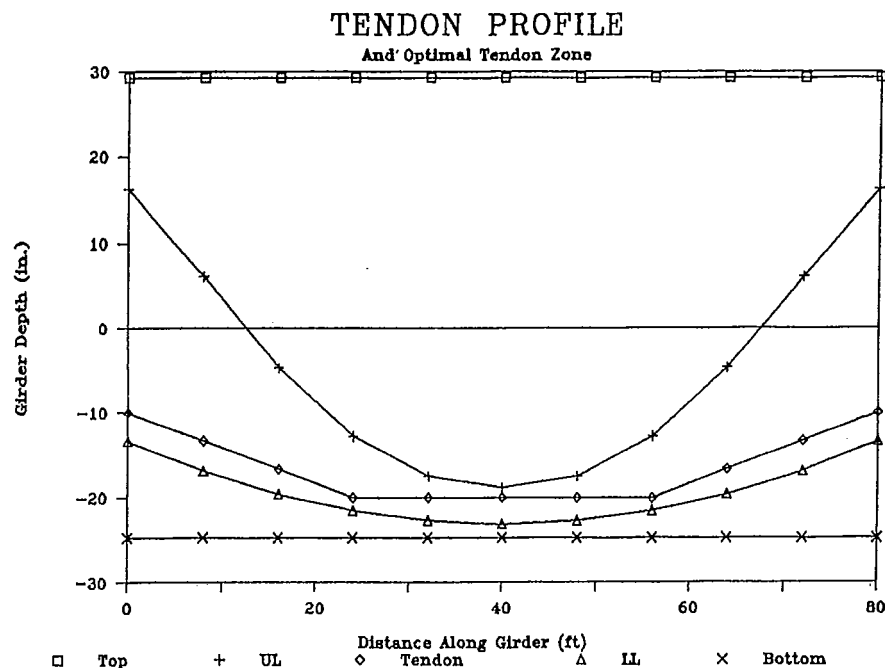


Fig. 4 — Tendon and allowable tendon region.

sub-menu. This data is also presented in tabular form in this window of the design template. The engineer has the option of selecting either a parabolic, straight, singly-harped, or doubly-harped profile. For the case of a doubly-harped profile, the cable is harped at $\frac{1}{10}$ and $\frac{9}{10}$ of the span. As a final check of the design, the ultimate moment capacity is calculated and compared to the provided moment capacity.

Shear design

Section 9.20 of the AASHTO Specifications is dedicated to the design of the shear resistance for prestressed concrete elements. The primary philosophy of the code is that the resistance provided by the concrete and steel reinforcement should be greater than or equal to the effect of the imposed factored loads.

The expressions provided in Section 9.20.2 of the specifications have been implemented to calculate the shear strength of the concrete V_c . With this value known, the shear resistance which must be provided by steel reinforcement can be determined. The user then must specify the size and spacing of the stirrup bars. To aid the engineer in selecting the stirrup spacing, the maximum allowable spacing is calculated and displayed by the worksheet.

The shear capacities and the factored shear caused by external loads can be viewed graphically for half the span (Fig. 5) by selecting the V_c -DIAGRAM option of the GRAPHS menu.

Allowable stresses

The bridge girder is designed so that at any point along the span the maximum acting stress is less than the allowable stress. The allowable stresses are set forth in the AASHTO Specifications.¹ The acting stresses are calculated at both the top and bottom face of the girder at two stages of loading. The first stage is at initial transfer of prestress force into the girder before any losses have occurred and the only loads acting are the initial prestress force and the self weight of the girder. The second stage is at the service load stage when all losses have occurred and all loads are applied. The acting stresses are calculated using the following general form of the flexure formula:

$$f = -\frac{P}{A} \pm \frac{Pe}{S} \pm \frac{M}{S}$$

where:

f = Acting stress

P = Prestress force

e = Tendon eccentricity

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For Shear Reinforcement Requirements

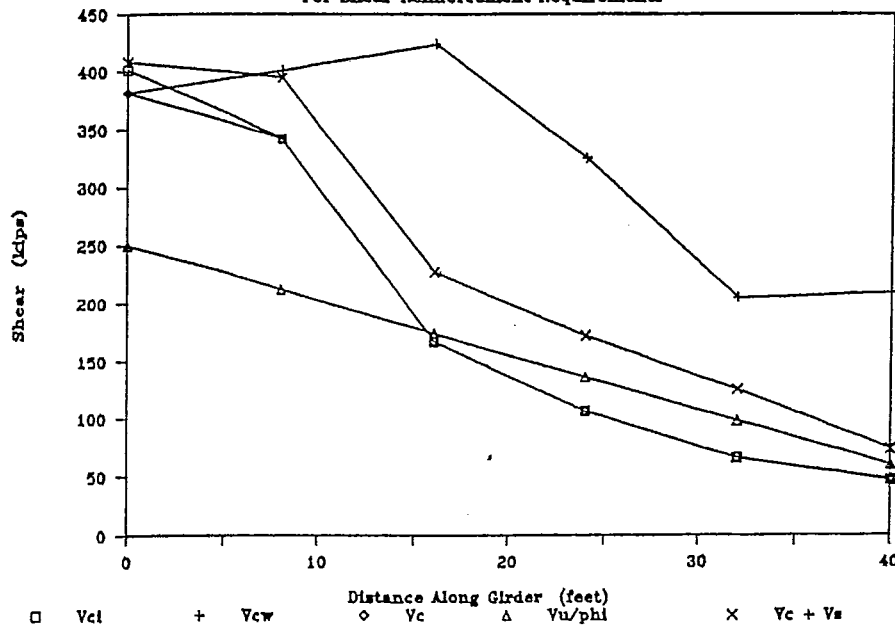


Fig. 5 — Shear capacities diagram.

M = Externally applied bending moments
 A = Cross-sectional area
 S = Section modulus

The STRESSES option of the ANALYSIS menu displays a table of the extreme fiber stresses at the tenth points of the span at the initial stage and the service or long-term stage. In addition, the initial and long-term allowable stresses are also tabulated. The concrete stresses can be viewed graphically by selecting the INITIAL and LONGTM options of the GRAPHS menu for the initial stresses and the long-term stresses, respectively. A plot of initial concrete stresses is shown in Fig. 6. By viewing the concrete stresses graphically, it becomes evident at a glance if the acting stresses exceed the allowable.

Deflection computation

Girder deflections can be displayed by selecting DEFLECTIONS from the ANALYSIS menu. The deflection of the girder is calculated at several load stages during the construction process. The first stage is at transfer when only the initial prestress force and girder self weight are acting. The deflections are calculated again after losses and most concrete creep has occurred. The next stage is after construction but before long term loading effects have occurred.

The last two stages are the long term dead load deflection and the live load deflection.

The camber caused by the prestressing force is calculated using discrete formulas which depend on the tendon profile selected. The deflections caused by dead loads are calculated using the equation for deflections on a simple span under uniformly distributed loads. The

live load deflections caused by the truck loading are calculated by placing the wheel loads such that the maximum moment is achieved, calculating the deflection due to each load, and superposing the individual deflections to get the total deflection.

Results

The design template presented is in no way a complete representation of the design procedure. It is intended rather, as a tool to aid in the preliminary sizing of prestressed concrete bridge girders and to demonstrate the use of spreadsheets in structural engineering. The spreadsheet can also be used to evaluate various alternative bridge designs, which will save time and produce a better design.

Most current computer programs for the design of highway bridges are simply analysis tools for predetermined designs. This requires a trial and error design of the entire bridge. The template presented functions as a design tool because it allows modification of the design as the analysis of each section is completed. While it is still a trial and

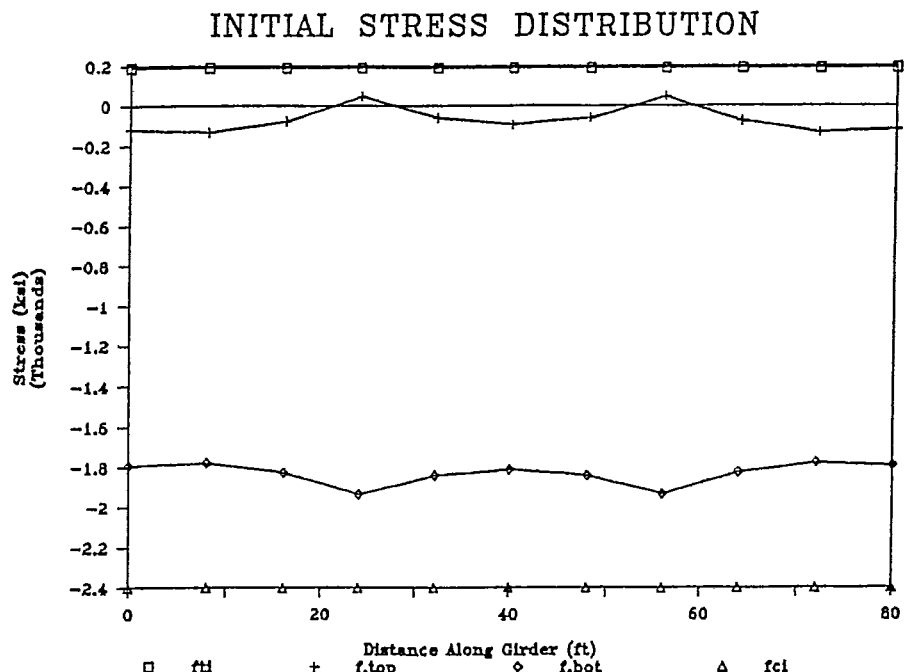


Fig. 6 — Initial extreme fiber stress distribution.



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error process, the design can be altered easily and the effects of the changes are realized immediately.

It has been shown that spreadsheets are a valuable, time-saving tool. They make it possible for the engineer to create more efficient designs due to their computational speed and interactive nature. The time and effort invested programming a spreadsheet will manifest itself later as an increase in productivity and a reduction of design time. In addition, the time put into developing a clear and understandable worksheet will result in a design tool that can change with the design codes and be employed frequently to create efficient designs with a minimum of effort. The spreadsheet brings the power of the microcomputer to the engineer in a concise, simple to use, user-friendly package.

References

1. *Standard Specifications for Highway Bridges*, 13th Edition, American Association of State Highway and Transportation Officials, Washington, D.C., 1983, 394 pp. Also, Interim Revisions, 1984-1988.

2. Casas, A., and Oppenheim, I. J., "Spreadsheet Programming for Structural Design," *Computer Applications in Concrete Technology*, SP-98, American Concrete Institute, Detroit, 1987, pp. 233-247.

3. Fagundo, F. E. and Garmizo, D. W., "The Use of Spreadsheets in the Design of Prestressed Concrete Bridge Girders," 2nd GPPE National Meeting on Prestressed Structures, Porto, Portugal, Nov. 1988.

4. Hoit, M. I.; Fagundo, F. E.; and Johnson, H., "Integrated Design Environment for Concrete Structures," *Computer Applications in Concrete Technology*, SP-98, American Concrete Institute, Detroit, 1987, pp. 139-148.

5. Kittridge, D. G., and Barnett, R. E., "Spreadsheet for Concrete Beam Design—M, V, T," *Computer Applications in Structural Engineering*, American Society of Civil Engineers, New York, 1987, pp. 403-411.

6. Nilson, A. H., *Design of Prestressed Concrete*, John Wiley & Sons, New York, 1987.

7. *PCI Design Handbook—Precast and Prestressed Concrete*, 3rd Edition, Prestressed Concrete Institute, Chicago, 1985, 531 pp.

8. Reinhorn, A. M.; Yeh, L. J.; and Snyder, J., "Prestressed Concrete Beam Design," *Computer Applications in Structural Engineering*, American Society of Civil Engineers, New York, 1987, pp. 383-394.

9. Salmon, C. G., "Concrete Beam Design Using Menus & Macros of Lotus 1-2-3," *Computer Applications in Structural Engineering*, American Society of Civil Engineers, New York, 1987, pp. 424-437.

10. *Precast Prestressed Short Span Bridges: Spans to 100 Feet*, 2nd Edition, Prestressed Concrete Institute, Chicago, 1980, 40 pp.

11. Shoemaker, W. Lee, and Williams, Steve, "Prestressed Concrete Design Using Spreadsheets," *Journal*, Prestressed Concrete Institute, V. 33, No. 2, Mar.-Apr. 1988, pp. 110-129.

Selected for reader interest by the editors.

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ACI member **David W. Garmizo** is a graduate student in the Department of Civil Engineering at the University of Florida, Gainesville.

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ACI COMPILATION

Applying PC-Based Graphics to the Display of Loads on Concrete Monolithic Structures

by Fred T. Tracy, Mary Ann Leggett, and Camille A. Issa

The U.S. Army Corps of Engineers designs and builds a wide variety of concrete monolithic structures. One common and especially tedious task involved in this work is hand computing an overturning and sliding stability analysis and the subsequent design of the structure. This is especially true for a three-dimensional analysis.

A task group of the Computer Aided Structural Engineering Project of the Office, Chief of Engineers was established to determine criteria for developing a comprehensive three-dimensional stability analysis/design program (3DSAD).¹ The program² was then developed with not only special purpose modules for dams and locks,^{3,4} but also for general geometry,⁵ general loads,⁶ general analysis,⁷ and free-body modules.⁸

Computing the geometric quantities of volume, weight, and centroid in an extremely efficient and unified manner⁹ proved essential. However, the most difficult challenge in this development was how to describe, compute, and display general loads in a user-friendly and efficient manner. The computation of loads is now well defined,^{11,12} and great progress has been made in user-friendly definition. Surprisingly useful results with the meaningful display of loads in a PC environment have also been accomplished.

Complex geometry

The geometry of the structures being analyzed can become very com-

plex. Fig. 1 shows an example of a gravity lock monolith with several parts that was modeled by solid-modeling-type capability. The primary tool used was to sweep two-dimensional cross sections in the third direction.

Another example is the tower shown in Fig. 2. Note the extensive use of curved surfaces in this example. Clearly, using color hidden-line and continuous-tone plots is essential to view of this type of geometry adequately.

Color graphics implementation

The need to produce color plots of these structures on the PC is obvious. To facilitate this, a partial frame buffer consisting of 50 lines of screen was implemented in software to run on either the EGA or EGA emulation on VGA graphics boards.

The limitation of only two shades (light blue/dark blue, light green/dark green, etc.) would seem to discount the possibility of continuous-tone shaded plots. However, consider the power houses on dam piers in Fig. 3 and its EGA continuous-tone shaded plot given in Fig 4. Using only two shades allows a clear definition of the structure. Compare this picture with the plot produced by the Matrox SM-640 Solid Modeling Engine using 32 different shades for each color (Fig. 5). This is an obvious improvement, showing a clearer definition of curvature.

Hidden-line plots may be obtained by a slight modification of

the frame buffer algorithm. Fig. 6 shows a hidden-line plot of Fig. 4.

Loads

Two ways have been developed to define loads: by pressure-volumes and by determining the loads on each face and integrating them to find the forces and moments.

Pressure-volumes are volumes with a direction. For instance, consider the overflow section with pier and curved gate given in Fig. 7. The triangular load represents horizontal water, and other nongeometry pieces represent the vertical weight of water on the structure. An isometric view of the geometry and loads is given in Fig. 8. This plot is ineffective due to the massive number of lines displayed.

Consider, however, the hidden-line plot given in Fig. 9 and the continuous-tone plot in Fig. 10. These are surprisingly effective in showing the different pieces of geometry and loads, although only two shades (light and dark) are used. Fig. 11 is another example, using different color specifications.

The advances of PC-based high-performance graphics boards can be used effectively to display loads as well. Of significant interest is using translucent shading for loads and solid shaded colors for geometry. Fig. 12 is an example of this using the translucency capability of the Matrox SM-640 Solid Modeling graphics board (translucency is implemented in the hardware), while Fig. 13 shows both geometry and loads as solid. The SM-1281 board

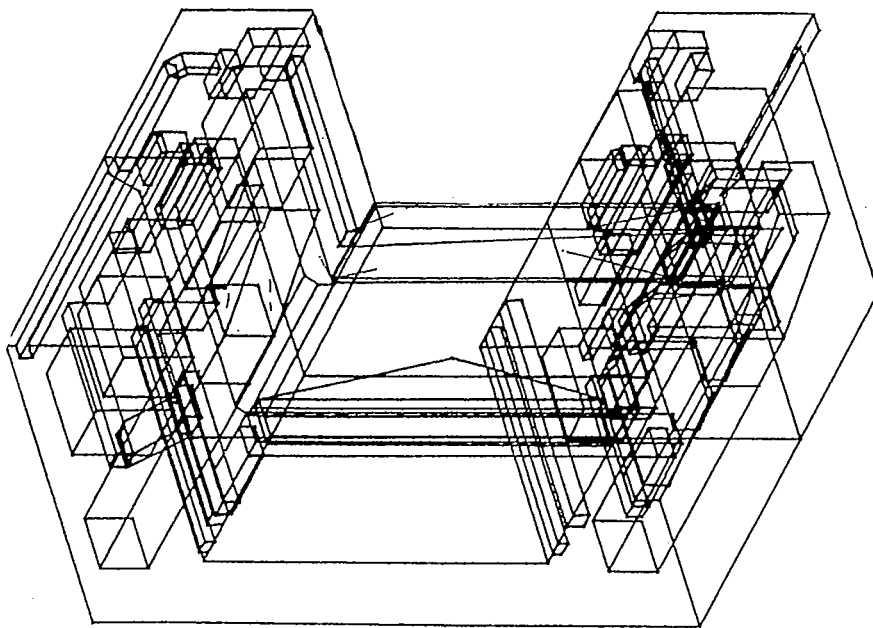


Fig. 1 — Gravity lock monolith.

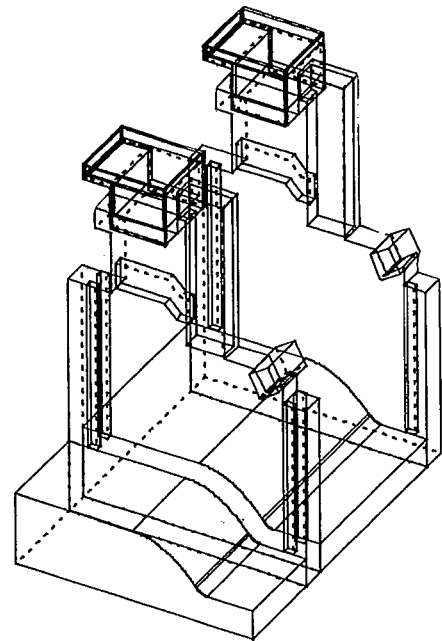


Fig. 3 — Power houses on dam piers.

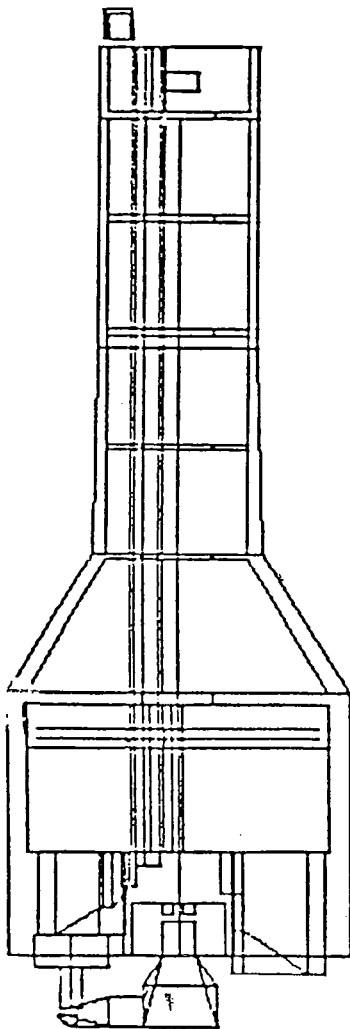


Fig. 2(a) — Tower.

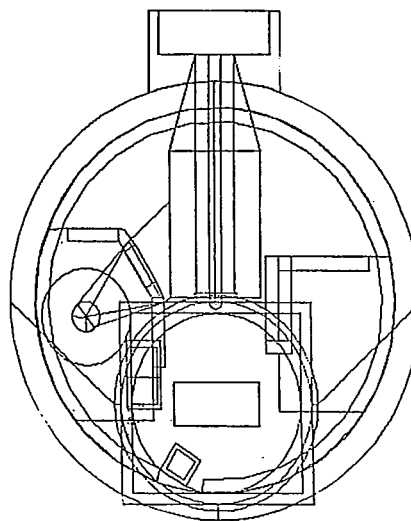


Fig. 2(b) — Tower.

would show results at an even higher resolution.

If the second way of defining loads (i.e., determining the loaded faces and integrating) has been used, the loaded faces may be displayed by painting the soil and water levels on the affected surfaces. This can also be easily accomplished by modifying the frame buffer algorithm again to paint brown soil and blue water on the proper faces, in both hidden-line and continuous-tone plots. Fig. 14 and 15 show two examples of a water load displayed in this manner,

with Fig. 14 being the hidden-line version and Fig. 15 the continuous-tone version.

Other systems and program availability

This display capability has also been implemented on the Intergraph Engineering Workstations, where added memory and other factors greatly increase the plotting speed. The entire three-dimensional stability program with its various modules is available for the PC upon request from the authors.

An application that runs on a PC automatically has a broad user base. The mainframe version of Three-Dimensional Stability Analysis/Design (3DSAD) program has been successfully converted to the PC with new and exciting enhancements. Solid modeling capability that has until fairly recently been available only on larger systems are now available in this program. Using color in both a standard PC (EGA or VGA environment) has been successfully applied to the display of geometry and loads for concrete monolithic structures.

Acknowledgments

This work was begun at the Waterways Experiment Station (WES), Dabob, Minn., under the CAS project, and the help and

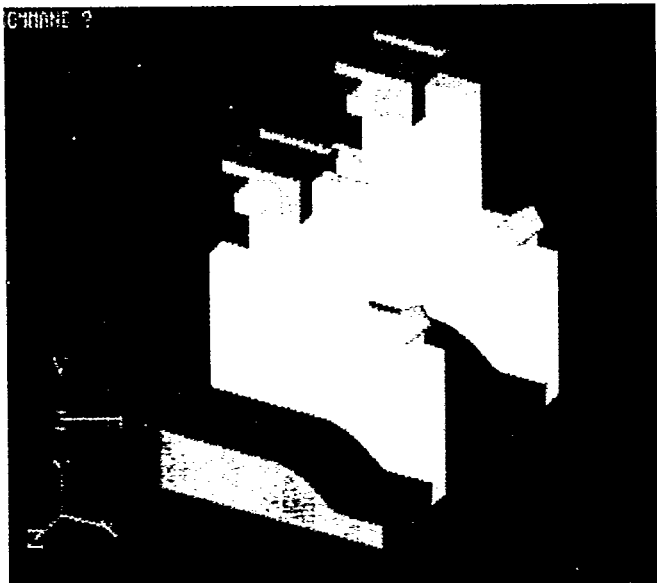


Fig. 4 — EGA continuous-tone plot.

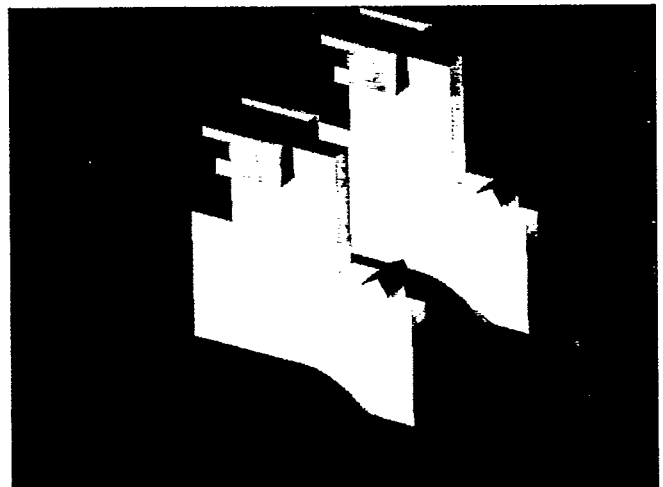


Fig. 5 — Matrox SM-640 continuous-tone plot.

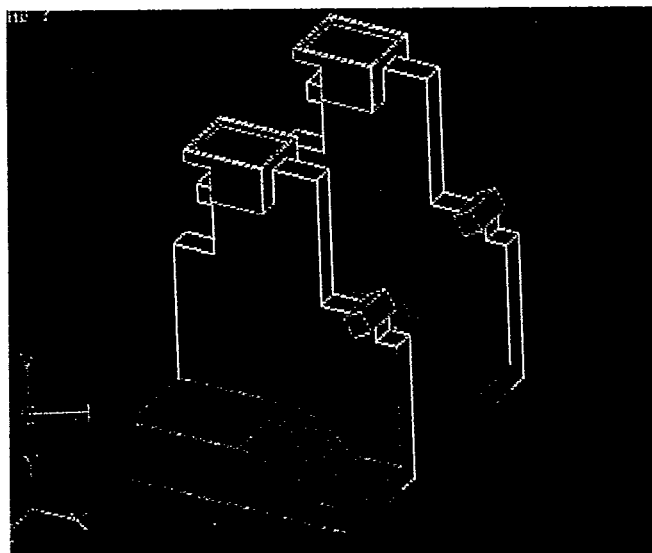


Fig. 6 — Hidden-line plot.

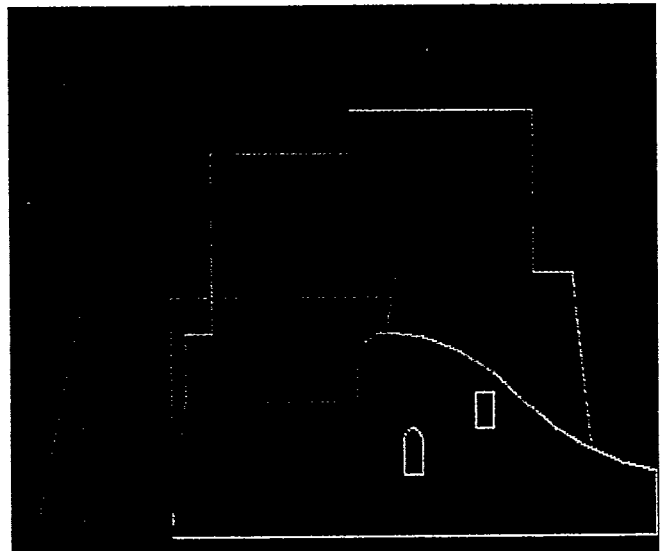


Fig. 7 — Pressure-volume example.

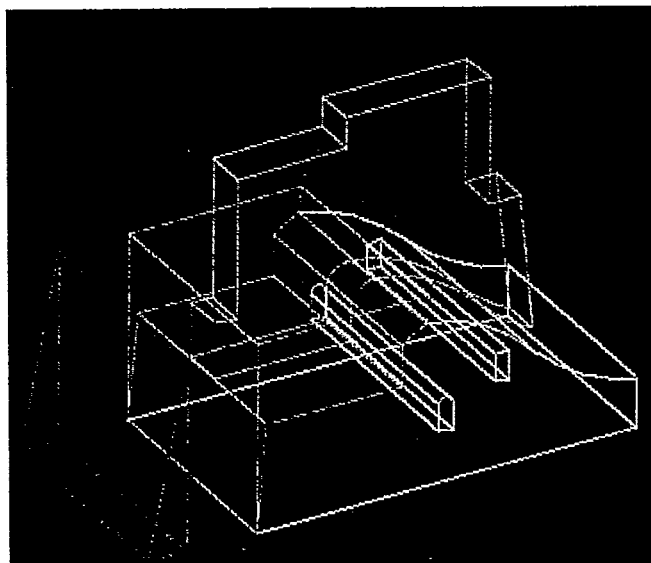


Fig. 8 — Isometric plot.

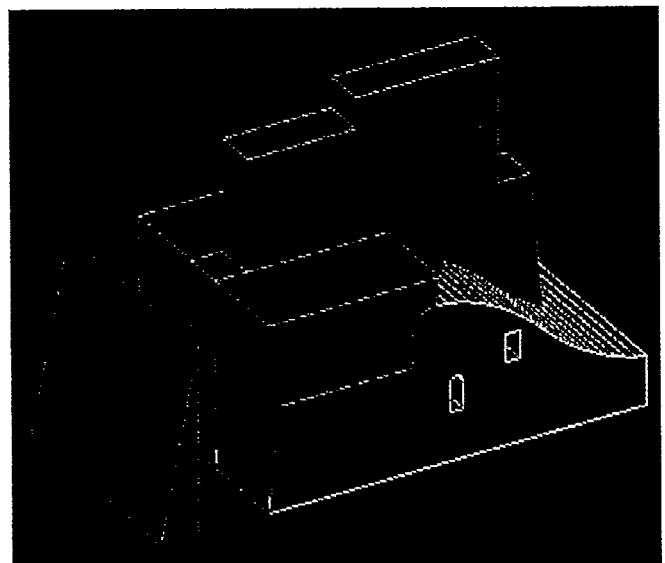


Fig. 9 — Hidden-line plot.

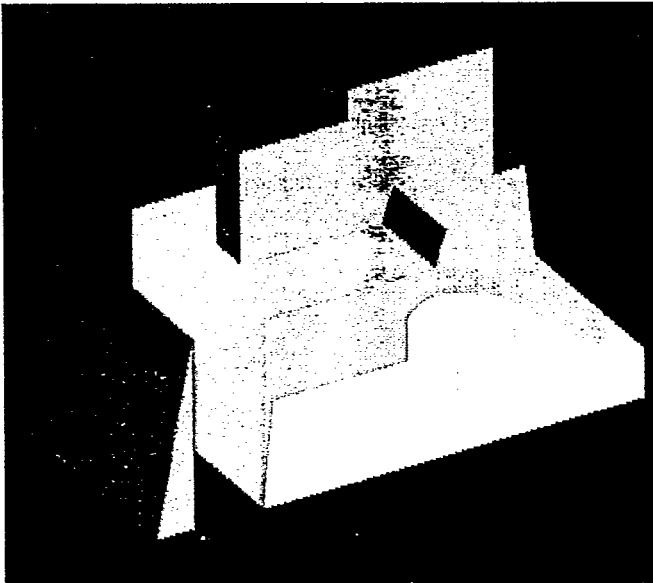


Fig. 10 — Continuous-tone plot.

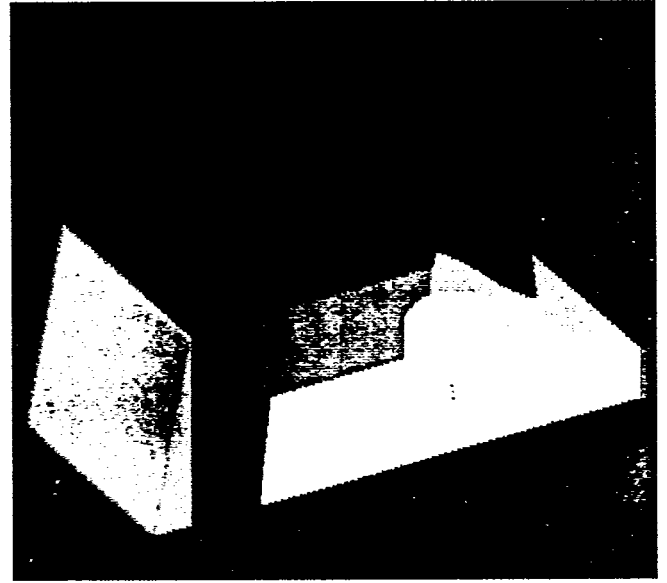


Fig. 11 — Different color combinations.

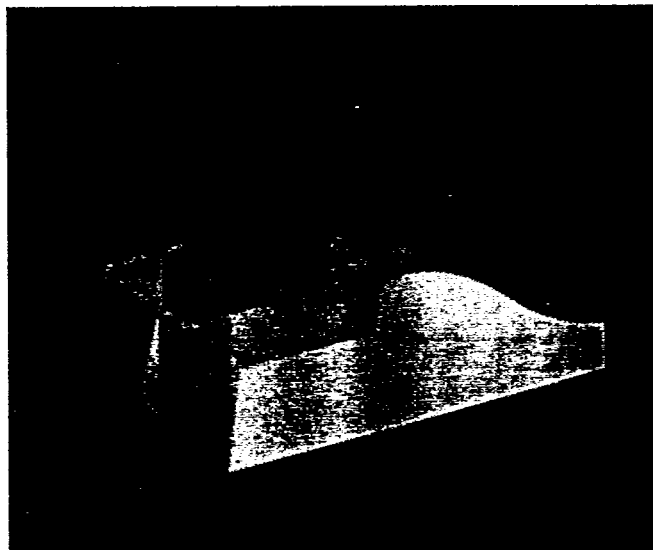


Fig. 12 — Translucent loads example.

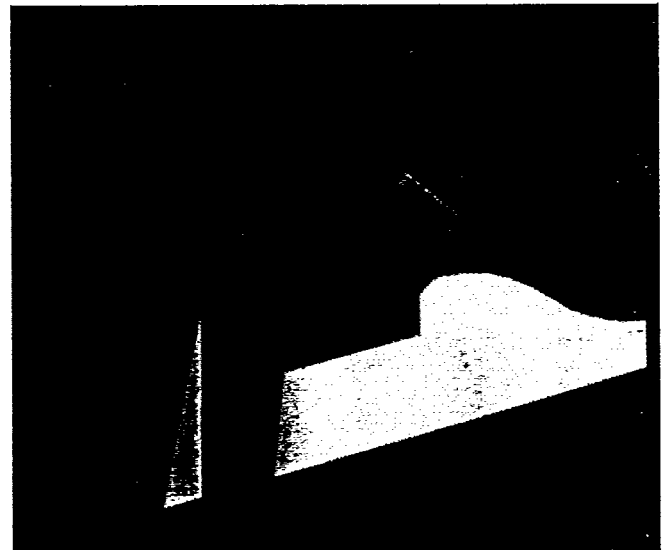


Fig. 13 — Solid loads example.

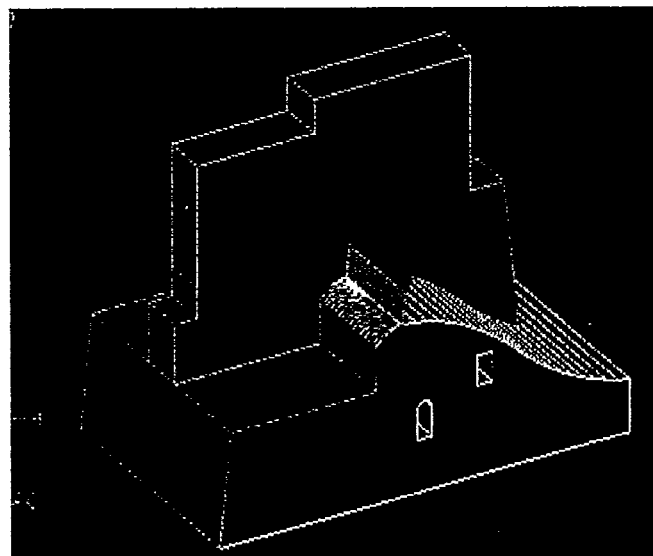


Fig. 14 — Hidden-line version.

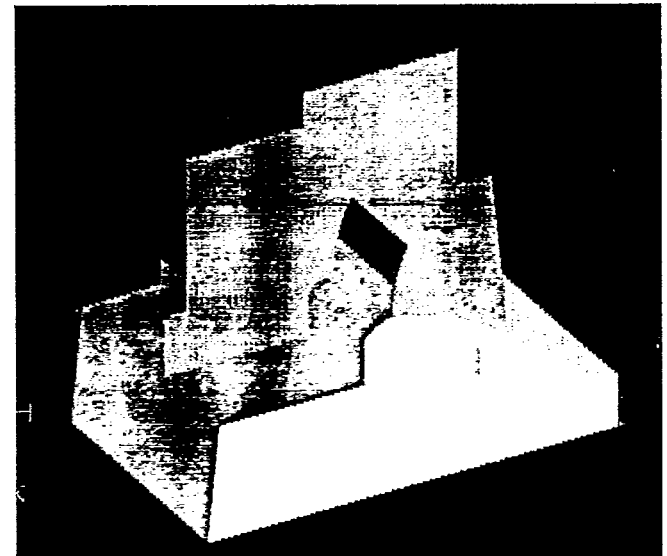


Fig. 15 — Continuous-tone version.

guidance of the 3-D Stability Task Group is greatly appreciated. Mr. Tracy's contribution was done partly at WES and partly as a special project under Dr. Camille A. Issa, Mississippi State University. The Chief of Engineers has authorized publication of this article.

References

1. CASE Task Group on 3-D Stability Analysis, "Criteria for 3DSAD, a Computer Program for Analysis and/or Design of Three-Dimensional Gravity Structures," Computer Aided Structural Engineering Project, Office, Chief of Engineers, Washington, D.C., 1978.
2. Tracy, Fred T., "A Three-Dimensional Stability Analysis/Design (3DSAD) Computer Program for Concrete Monolithic Structures," *Computer Applications in Concrete Technology*, SP-106, American Concrete Institute, Detroit, 1988, pp. 159-176.
3. Tracy, Fred T.; Kling, Charles W.; and Holtham, William J., "A Three-Dimensional Stability Analysis/Design Program (3DSAD), Special Purpose Module for Dams (CDAMS)," *Instruction Report No. K-80-4, Report 4*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, 1983.
4. Kling, C. William, "A Three-Dimensional Stability Analysis/Design Program (3DSAD), Special Purpose Module for Gravity Locks (CGLOCKS)," *Draft Report, Report 5*, U.S. Army Corps of Engineers, Mobile District, 1985.
5. Tracy, Fred T., "A Three-Dimensional Stability Analysis/Design Program (3DSAD), General Geometry Module," *Instruction Report No. ITL-87-3, Report 1, Revision 1*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, 1987.
6. Tracy, Fred T., and Leggett, Mary Ann, "A Three-Dimensional Stability Analysis/Design Program (3DSAD), General Loads Module," *Instruction Report No. ITL-87-3, Report 2*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, 1989.
7. Tracy, Fred T., and Kling, Charles W., "A Three-Dimensional Stability Analysis/Design Program (3DSAD), General Analysis Module," *Instruction Report No. K-80-4, Report 3*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, 1982.
8. Tracy, Fred T., and Leggett, Mary Ann, "A Three-Dimensional Stability Analysis/Design Program (3DSAD), Free-Body Module," *Instruction Report No. ITL-87-3, Report 6*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, 1989.
9. Tracy, Fred T., "A Unified Approach to Mass Property Computations in a Solid Modeling Environment with Application to Hydraulic Structures," *Fourth Army Conference on Mathematics and Computing*, Cornell University, Ithaca, 1986.
10. Wilson, Howard B., Jr., "Surface Loads Computation," *Draft Report*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, 1980.
11. Tracy, Fred T., "Computing Loads on Three-Dimensional Structures," *Corps-wide Structural Engineering Conference*, St. Louis, 1988.

Selected for reader interest by the editors.

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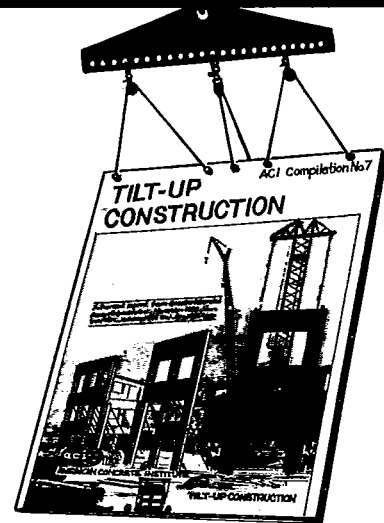
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Simplifying Concrete Mix Design with the PC

by Kurt F. Peyfuss

To simplify concrete mix design, the author has written a spreadsheet using Lotus *Symphony*. The spreadsheet, shown here in Fig. 1, was used to design pumpable concrete at the Al Wehdah tunnel project in Jordan, near Irbid, and the mix shown in the figure was one of those actually used.

The conventional method for designing concrete mixes calls for using tables and a series of simple but laborious calculations. Usually, at the outset, a water-cement ratio is selected to satisfy the given strength requirement. Other design criteria, such as durability or imperviousness, also may have to be considered at that point.

Second, based on the desired slump, the total quantity of water per cubic meter or per cubic yard is estimated, although the influence of the size of the aggregate and the degree of air entrainment also should be considered here.

The content of coarse and fine aggregate per unit volume of concrete is then conventionally estimated with the help of tables. A table in ACI 211.1 helps the designer to estimate the dry bulk volume of the coarse aggregate per volume of concrete as a function of the fineness modulus of the fine aggregate. From another table, the designer can estimate the unit weight of concrete as a function of the maximum size of aggregate. The designer is then ready to calculate the quantities of coarse and fine aggregates as the difference between the total weight of concrete and the sum of the weights of water and cement.

As long as the aggregate is dry, calculations are quite easy. If, however, the aggregate contains a significant amount of surface mois-

ture, it must be considered as part of the total free water content. Consequently, we have to deduct the weight of the surface moisture from the weight of the aggregates, and we arrive at the final weights of added mix water, cement, and aggregate by trial and error. Moreover, if we design a mix for a batch plant with several aggregate bins for materials with different unit weight and surface moisture content, calculations need to be carried out by computer.

Aggregates were purchased from nearby quarries for the Al Wehdah project. The various types of sand that were considered for use had to be transported from as far as the Jordan River valley. The original concrete specifications indicated only the grading of the coarse and fine aggregate.

However, because the contractor had a five-bin batch plant installed at the site, we modified the specifications according to the recommendations of a concrete pump manufacturer. There, the upper and lower limits of the grading of the combined aggregates was specified by two curves on a grading diagram. The batch plant did not automatically measure and adjust the quantity of mix water for the surface moisture of the aggregates.

The spreadsheet (Fig. 1) is divided into several groups of figures, or "ranges," each identified by a heading. These headings are cited in capital letters in the following description. To design a concrete mix we have only to type the usual data into the appropriate locations on the spreadsheet. Because the spreadsheet is in the "manual recalculation" mode, the user has to press the Re-calc Key after data entry is completed.

The design procedure begins by entering the screen analyses of the aggregates into the range located in the upper left-hand corner of the spreadsheet. That range contains the columns SCREEN ANALYSES and % THRU for four AGGREGATE FRACTIONS in four of the five batch-plant bins. In this example, the fifth bin remained empty because the sand that we finally used at the project satisfied the mix requirements better than the two sand fractions from another source we had tried previously.

It should be remembered: if only four aggregate fractions enter into the concrete, and one of the bins will therefore remain empty, it is not permissible to enter only zeros for the missing screen analysis. Doing so would introduce a division-by-zero error elsewhere in the calculations. To prevent this type of error, the programmer should delete the columns that correspond to the bin that is out of service. On the other hand, if a batch plant handles more than five products, the programmer can easily expand the spreadsheet with the "copy" command.

Into the second range below the upper left-hand corner, we enter the surface-dry AGGREGATE SATURATED DENSITY of the four fractions, and their respective AGGREGATE SURFACE MOISTURE in terms of percent of their dry weights. Additionally, we enter the WATER/CEMENT RATIO and the FREE WATER content of the fresh concrete in terms of liters per cubic meter. The expected AIR CONTENT should be simply typed into the spreadsheet unless the user has found a correlation between the amount of additive per sack of cement and the percentage of air.

AL WENDAH DIVERSION TUNNEL PROJECT, HARZA ENGINEERING CO.

DATE: 10-May

MIX DESIGN # C019.1 PAP

SCREEN ANALYSES, % THRU					SCREEN ANALYSES, % OVERS					SIZE DISTRIBUTION, % OVERS					
AGGREGATE FRACTION # . . .					AGGREGATE FRACTION # . . .					AGGREGATE FRACTION # . . .					
(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	
					. . WEIGHT-PROPORTIONS OF FRACTIONS . .										
					1	0.3	0.6	1.8							
2	50.08	100.0			-	-	-	-		-	-	-	-	-	
1.1/2	38.10	88.2			11.8	0.0	0.0	0.0		0.118	0.000	0.000	0.000		
1	25.00	42.6	100.0		45.6	0.0	0.0	0.0		0.456	0.000	0.000	0.000		
3/4	19.00	6.4	94.8	100.0	36.2	5.2	0.0	0.0		0.362	0.016	0.000	0.000		
3/8	9.50	0.7	7.1	96.1	5.7	87.7	3.9	1.0		0.057	0.262	0.023	0.018		
#4	4.80		0.4	3.1	0.7	6.7	93.0	9.7		0.007	0.020	0.555	0.176		
#8	2.40			0.0	0.0	0.4	3.1	17.0		0.000	0.001	0.018	0.308		
#16	1.20				0.0	0.0	0.0	14.1		0.000	0.000	0.000	0.256		
#30	0.60				0.0	0.0	0.0	15.3		0.000	0.000	0.000	0.278		
#50	0.30				0.0	0.0	0.0	22.1		0.000	0.000	0.000	0.401		
#100	0.15				0.0	0.0	0.0	14.1		0.000	0.000	0.000	0.256		
#200	0.07				0.0	0.0	0.0	3.8		0.000	0.000	0.000	0.069		
(PAN)					0.0	0.0	0.0	2.9		0.000	0.000	0.000	0.053		
										adj for equal density:	1.000	0.299	0.596	1.815	
										adj for actual density:	1.000	0.300	0.600	1.800	
											27.0%	8.1%	16.2%	48.6%	
					(1)	(2)	(3)	(4)	(5)						
AGGR SATUR DENSITY	2.579	2.569	2.563	2.6						0.3877	0.1168	0.2341	0.6923		
W/C RATIO					0.6					0.0030	0.0063	0.0276	0.1620		
FREE WATER LT/M3					190.0										
CEMENT KG/M3 CONCRETE					316.7										
AGGR SURF MOIST % WT	0.3	2.1	4.6	9.0											
PLASTICIZER	----- ML PER 50 KG CEMENT				150										
	----- ML/M3 CONCRETE				950										
AIR ENTRMT AGENT	----- ML PER 50 KG CEMENT				50				TRIAL:	0.04 M3					
	----- ML/M3 CONCRETE				317				-----						
AIR CONTENT					3.0%				FRACTION#	(1)	(2)	(3)	(4)	(5)	TOTALS:
AGGREG KG/M3 CONC	474.18	142.25	284.51	853.53		1,754.47			AGGREG	19.02	5.81	11.90	37.21		73.95 KG
SURF MOIST KG/M3 CONC	1.42	2.99	13.09	76.82		94.31									CEMENT 12.67 KG
															MIX WATER 3.83 KG
AGGREG BIN WEIGHT,KG	475.60	145.24	297.60	930.34		1,848.78									PLASTIZ 38 ML
MIX WATER LT/M3 CONCRETE						95.69									AIR ENTR 13 ML
CEMENT KG/M3 CONCRETE						316.67			BATCH VOL	1.5 M3					
AGGREG/CEMENT RATIO					5.54				=====						
CONCRETE KG/M3						2,261.14			BIN#	(1)	(2)	(3)	(4)	(5)	TOTALS:
									AGGREG	713.41	217.86	446.39	1395.51		2773.18 KG
SLUMP	-----								(CUMUL)	713.41	931.27	1377.66	2773.18		KG
STRENGTH															CEMENT 475.00 KG
	-----	-----	-----	-----											MIX WATER 143.53 KG
	13-May	17-May	24-May	07-Jun											PLASTIZ 1425 ML
	3 days	7 days	14 days	28 days											AIR ENTR 475 ML

Fig. 1 — Spreadsheet for concrete mix design.

trainment in the fresh concrete. In such a case, it should be easy to write a formula into the spreadsheet cell that shows the AIR CONTENT.

In the second range from left, the program automatically converts the % THRU to % OVERS. At the top of that group of screen analyses and under the heading WEIGHT PROPORTIONS OF FRACTIONS is a line where the designer types the proportions in which he wishes to mix the contents of the four aggregate bins. The program will then multiply these WEIGHT PROPORTIONS with the % OVERS of each of the

fractions, corrected for density.

The horizontal sums of these products, divided by their vertical total, are shown in the next column to the right. That column shows the GRADING of the resulting synthetic mix. The grading of the mix should fall between the values given in the next two columns to the right, called the GOAL, which show the upper and lower limits of the % THRU of the specified grading of all aggregates.

If the resulting grading does not fall within these given limits, other mix proportions should be tried. It is very useful if the graphics envi-

ronment of the spreadsheet is capable of producing a diagram (Fig. 2) showing the lower and upper limits of the specified grading range and the grading of the synthetic mix. With the help of this feature, and some practice, the selection of the mix proportions can be completed within minutes.

To calculate the quantities of aggregates, cement, and water in accordance with the previously entered mix specifications, the program continues in the following manner:

The spreadsheet adds up the proportions of AGGREGATE FRACTIONS,

GRADING			GOAL		FINENESS	
TOTAL	% OVERS	% THRS	% THRS		(4)	(5)
-	-	100.0%	100%	100%		
0.118	3.2%	96.8%	100%	100%		
0.456	12.3%	84.5%	80%	87%		
0.378	10.2%	74.4%	70%	80%		
0.360	9.7%	64.6%	55%	70%	1.0	0.0
0.758	20.4%	44.2%	40%	58%	10.7	0.0
0.328	8.8%	35.4%	27%	47%	27.7	0.0
0.256	6.9%	28.5%	17%	37%	41.8	0.0
0.278	7.5%	21.0%	10%	23%	57.1	0.0
0.401	10.8%	10.2%	9%	13%	79.2	0.0
0.256	6.9%	3.3%	3%	7%	93.3	0.0
0.069	1.9%	1.4%	0%	0%	-	-
0.053	1.4%	-	-	-	-	-
3.710	100.0%				3.108	0.000
3.700						
100.0%						
1.4309 AGGREGATE, M3						
0.1989 SURF MOISTURE, M3						
0.2018 MIX WATER, M3						
0.2120 CEMENT, M3						
0.0020 ADDITIVE, M3						
0.0633 AIR, M3						
2.1089 TOT M3 CONCRETE						

Fig. 1 — Spreadsheet continued.

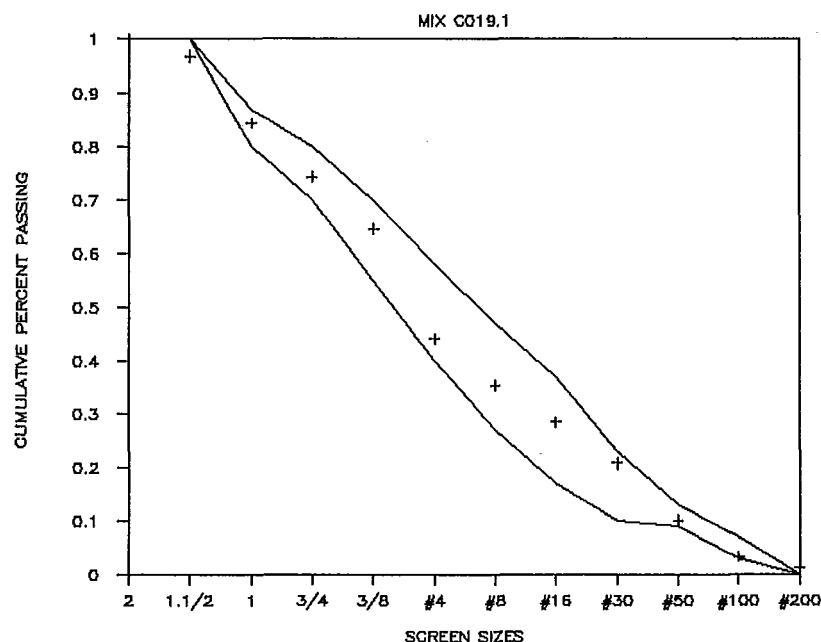


Fig. 2 — Graphic expression of grading range.

adjusted for ACTUAL DENSITIES. Purely for the convenience of calculation, the spreadsheet now assumes the totals of the fractions to be metric tons. These assumed tons of aggregates are then divided by the respective densities; this gives the solid volumes of each of the aggregate fractions. The weight of surface moisture, given on the next line below, is the product of the weight of each aggregate fraction by its respective percentage of moisture. However, the amounts of mix water and cement cannot be calculated directly because they must remain in a fixed relation to the still unknown total volume of fresh concrete, and the solution is found by the following method:

The spreadsheet adds these items:

1. AGGREGATE, m^3
2. SURFACE MOISTURE, m^3
3. MIX WATER, m^3 (= TOTAL m^3 CONCRETE $\times$ liters water/ m^3 concrete)
4. CEMENT, m^3 (= TOTAL m^3 CONCRETE $\times$ kg cement/ m^3 concrete)
5. ADDITIVE, m^3 (= TOTAL m^3 CONCRETE $\times$ ml additive/ m^3 concrete)

6. AIR, m^3 (= TOTAL m^3 CONCRETE $\times$ % air/ m^3 concrete)

The sum equals TOTAL m^3 CONCRETE.

At first sight, this addition seems not to make sense, because its total, the TOTAL m^3 CONCRETE, appears also as a factor in Items 3 through 6. However, when the spreadsheet repeatedly receives the command to "recalculate," the TOTAL m^3 CONCRETE is substituted that many times into Items 3 through 6, and the total of the summation, TOTAL m^3 CONCRETE, will rapidly converge to the correct value. These iterations are not visible on the screen because the spreadsheet is programmed to go through ten calculation loops every time the Re-calc Key is pressed. The user may, of course, write a simple algorithm to let the program loop until the desired precision of the TOTAL is reached.

In the lower part of the spreadsheet, the weights of aggregate fractions, cement, and mix water are given per cubic meter of fresh concrete. Additionally, the mix weights are shown for a laboratory mixer of a user-specified size, and for the mixer of the batch plant.

The spreadsheet dates itself, and, assuming that the trial mix will be prepared on the same day, automatically inserts the dates of the compression tests.

For a modification of the slump, the user has only to increase to the FREE WATER content by approximately six liters per inch of increase of slump, press the Re-calc Key, and the corrected mix with the originally specified water-cement ratio appears on the screen. Any other modifications of the concrete mix can be calculated with equal ease.

Selected for reader interest by the editors.

ACI member **Kurt F. Peyfuss** is currently on assignment on a tunnel construction project with DeLeuw, Cather and Company in Izmir, Turkey. Since receiving a Dipl. Ing. degree from the Montan Universitaet Leoben in Austria, he has worked for several American engineering companies on mine development, hydroelectric, and tunnel projects in the U.S., Chile, Brazil, Pakistan, Egypt, Jordan, and Peru.



Computer spreadsheets save time, money, and unnecessary frustration in concrete reinforcing steel design

Spreadsheet Topics

by Kenneth E. Wilson

Engineers, by their very nature, tend to seek efficiency, practicality, and creativity in most things that they do, both on and off the job. It is for this reason that engineers and computer spreadsheets are so wonderfully matched. Spreadsheets are efficient in that they accomplish with the push of a button what can take the engineer many hours or days to compute by hand. They are practical because they take relatively little time to create and can be used for a wide range of applications. They are creative in that the engineer has virtually unlimited potential in solving problems and can allow his or her creativity to flow freely.

As you approach an engineering project, ask yourself the following questions:

- Are there any sets of computations that must be repeated several times over the course of the project?
- Could these sets of computations be set up in the form of a table or a template, in which input values are provided based on the design parameters and output values are computed based on these input values and certain known formulas?
- Could a simple mistake or change early in the computations carry through to require a large amount of undesired recalculation?
- Do you want to minimize the amount of time, money and effort needed in performing the computations both for your own sake as well as that of your client?
- Do you want to maximize quality control, reducing both the amount of potential errors and the need for checking each computation?

If your answer to these questions is "yes", then a computer spreadsheet may provide the best method

of performing your computations and completing your project with the greatest efficiency and excellence.

The birth of a spreadsheet

On a recent bridge project, approximately 20 reinforced concrete pier footings needed to be designed, each having unique loads and dimensions. For each of these footings, flexural steel had to be designed in both directions, resulting in a total of about 40 unique sets of design computations.

For each of these sets of computations, four basic design criteria had to be satisfied:

- The factored moment at the section must not exceed the design moment strength (ACI 318 Section 10.2 or AASHTO HB-14 Section 8.16.3.2.1),
- The ratio of reinforcement provided must not exceed 0.75 of the ratio that would produce balanced strain conditions for the section (ACI 318 Section 10.3.3 or AASHTO HB-14 Section 8.16.3.1),
- The minimum reinforcement requirements for flexural members must be satisfied (ACI 318 Section 10.5 or AASHTO HB-14 Section 8.17.1), and
- The distribution of flexural reinforcement requirements to control flexural cracking of the concrete must be satisfied (ACI 318 Section 10.6 or AASHTO HB-14 Section 8.16.8.4).

Performing manual calculations for these four basic design criteria can take as much as a day for each pier section. This is particularly time consuming since several trials are often needed before all four criteria are optimally satisfied. As the design progressed, it became increasingly apparent that a computer

spreadsheet would provide the best method for solving the 40 sets of design computations.

Getting started

The first step in creating a spreadsheet is to develop a clear, orderly and systematic template to facilitate the desired computations. An easy way to accomplish this is to prepare one complete set of calculations by hand in the most logical and organized manner possible. Then go through the manual calculations and identify each of the following types of information:

- An inputted numerical value that will be used by the computer for computational purposes.
- A formula that uses either inputted numerical values or previously computed numerical values to generate additional outputted numerical values.
- A piece of text that will vary for different projects, such as a descriptive project title, the user's name and the date.
- A piece of text that will be common for each use of the spreadsheet, such as descriptive labels for input or brief explanations of output.

It may be helpful to use color pencils to identify each of the various types of information on the template.

Creating the spreadsheet

Once a systematic template has been developed and the various types of information have been identified, the next step is to sit down at the computer and begin creating the actual spreadsheet. The spreadsheet for this project was created using an IBM-compatible computer and Lotus 1-2-3 software, both of which are the most widely used.

Inputted numerical values
Computed numerical values based on given formulas
Inputted text that will vary for different projects

DESIGN OF REINFORCING STEEL FOR CONCRETE BASED ON LOAD FACTOR DESIGN

MADE BY: CHKD BY:

INPUT:

Mu, LOAD FACTOR DESIGN MOMENT = K-FT/FT
 M, SERVICE LOAD DESIGN MOMENT = K-FT/FT
 fy, YIELD STRENGTH OF REINFORCEMENT = KSI
 fc', COMPRESSIVE STRENGTH (28-DAY) OF CONCRETE = KSI
 n, MODULAR RATIO OF ELASTICITY =
 d, EXTREME FIBER TO CENTROID OF REINFORCEMENT = IN
 b, WIDTH OF MEMBER PER FOOT = IN
 h, OVERALL THICKNESS OF MEMBER = IN
 beta 1 (REFER TO AASHTO 8.16.2.7) =
 z, QUANTITY LIMITING FLEXURAL DISTRIBUTION = K/IN
 As, AREA OF REINFORCING STEEL (IN TENSION) = SQ IN/FT
 s, SPACING OF REINFORCING STEEL BARS = IN

OUTPUT:

LOAD FACTOR REINFORCING STEEL DESIGN (AASHTO 8.16.3.2):

a, DEPTH OF EQUIVALENT RECTANGULAR STRESS BLOCK = IN
 phi * Mn, NOMINAL MOMENT STRENGTH = K-FT/FT
 As (REQUIRED), AREA OF REINFORCING STEEL = SQ IN/FT

MAXIMUM REINFORCEMENT OF FLEXURAL MEMBERS (AASHTO 8.16.3.1):

rho (BALANCED) =
 rho (MAXIMUM) =
 As (MAXIMUM) = SQ IN/FT

MINIMUM REINFORCEMENT OF FLEXURAL MEMBERS (AASHTO 8.17.1):

BASED ON CRACKING MOMENT (AASHTO 8.17.1.1):

y, GROSS CENTROIDAL AXIS TO EXTREME TENSION FIBER = IN
 Ig, GROSS TRANSFORMED MOMENT OF INERTIA = IN⁴
 fr, MODULUS OF RUPTURE OF CONCRETE = KSI
 MCr, CRACKING MOMENT = K-FT/FT
 1.2 MCr = K-FT/FT

BASED ON INCREASING REQUIREMENTS FROM ANALYSIS (AASHTO 8.17.1.2):

4/3 * As (REQUIRED) = SQ IN/FT

DISTRIBUTION OF FLEXURAL REINFORCEMENT (AASHTO 8.16.8.4):

rho, TENSION REINFORCEMENT RATIO =
 k =
 j =
 fs (ACTUAL), SERVICE LOAD BENDING STRESS = KSI
 dc, THICKNESS OF CONCRETE COVER = IN
 A, EFFECTIVE TENSION AREA = SQ IN
 z/(dcA)^{1/3} = KSI
 0.6 fy = KSI
 fs (ALLOWABLE), BASED ON DISTRIBUTION REQUIREMENTS = KSI

DESIGN SUMMARY:

THE DESIGNER SHOULD CHECK THAT THE FOLLOWING FOUR STATEMENTS ARE TRUE:

1. Mu = K-FT/FT < phi * Mn
2. As = SQ IN/FT < As (MAXIMUM)
3. 1.2 MCr = K-FT/FT < phi * Mn
4. fs (ACT) = KSI < fs (ALLOW)

IF ALL FOUR OF THE ABOVE STATEMENTS ARE TRUE, THEN THE DESIGNER'S INPUTTED VALUES FOR REINFORCING STEEL AREA AND SPACING SATISFY AASHTO REQUIREMENTS. AREA OF REINFORCING STEEL EQUALS SQ IN/FT AND SPACING OF REINFORCING STEEL BARS EQUALS INCHES.

IF STATEMENTS 1, 2 AND 4 ARE TRUE, BUT STATEMENT 3 IS FALSE, THEN THE DESIGNER MAY USE A REINFORCING STEEL AREA OF SQ IN/FT AND A REINFORCING STEEL BAR SPACING OF INCHES. HOWEVER, THE DESIGNER SHOULD VERIFY THAT ALL AASHTO REQUIREMENTS ARE STILL SATISFIED BY USING SQ IN/FT AS THE NEW INPUTTED REINFORCING STEEL AREA AND CONFIRMING THAT STATEMENTS 1, 2 AND 4 ARE STILL TRUE.

IF STATEMENT 1 IS FALSE, THEN THE DESIGNER MUST INCREASE THE INPUTTED VALUE FOR AREA OF REINFORCING STEEL.

IF STATEMENT 2 IS FALSE, THEN THE DESIGNER MUST DECREASE THE INPUTTED VALUE FOR AREA OF REINFORCING STEEL.

IF STATEMENT 4 IS FALSE, THEN THE DESIGNER MUST EITHER INCREASE THE INPUTTED VALUE FOR AREA OF REINFORCING STEEL, DECREASE THE INPUTTED VALUE FOR SPACING OF REINFORCING STEEL BARS OR A COMBINATION OF THE TWO MODIFICATIONS.

DESIGN OF REINFORCING STEEL FOR CONCRETE BASED ON LOAD FACTOR DESIGN
SAMPLE RUNMADE BY: KEW
CHKD BY:

INPUT:

Mu, LOAD FACTOR DESIGN MOMENT = 116.5 K-FT/FT
 M, SERVICE LOAD DESIGN MOMENT = 66.0 K-FT/FT
 fy, YIELD STRENGTH OF REINFORCEMENT = 60.0 KSI
 fc', COMPRESSIVE STRENGTH (28-DAY) OF CONCRETE = 3.0 KSI
 n, MODULAR RATIO OF ELASTICITY = 9
 d, EXTREME FIBER TO CENTROID OF REINFORCEMENT = 37.50 IN
 b, WIDTH OF MEMBER PER FOOT = 12.0 IN
 h, OVERALL THICKNESS OF MEMBER = 42.0 IN
 beta 1 (REFER TO AASHTO 8.16.2.7) = 0.85
 z, QUANTITY LIMITING FLEXURAL DISTRIBUTION = 170 K/IN
 As, AREA OF REINFORCING STEEL (IN TENSION) = 1.05 SQ IN/FT
 s, SPACING OF REINFORCING STEEL BARS = 9.0 IN

OUTPUT:

LOAD FACTOR REINFORCING STEEL DESIGN (AASHTO 8.16.3.2):

a, DEPTH OF EQUIVALENT RECTANGULAR STRESS BLOCK = 2.06 IN
 phi * Mn, NOMINAL MOMENT STRENGTH = 172.3 K-FT/FT
 As (REQUIRED), AREA OF REINFORCING STEEL = 0.70 SQ IN/FT

MAXIMUM REINFORCEMENT OF FLEXURAL MEMBERS (AASHTO 8.16.3.1):

rho (BALANCED) = 0.0214
 rho (MAXIMUM) = 0.0160
 As (MAXIMUM) = 7.22 SQ IN/FT

MINIMUM REINFORCEMENT OF FLEXURAL MEMBERS (AASHTO 8.17.1):

BASED ON CRACKING MOMENT (AASHTO 8.17.1.1):

y, GROSS CENTROIDAL AXIS TO EXTREME TENSION FIBER = 20.73 IN
 Ig, GROSS TRANSFORMED MOMENT OF INERTIA = 76337 IN⁴
 fr, MODULUS OF RUPTURE OF CONCRETE = 0.411 KSI
 MCr, CRACKING MOMENT = 126.1 K-FT/FT
 1.2 MCr = 151.3 K-FT/FT

BASED ON INCREASING REQUIREMENTS FROM ANALYSIS (AASHTO 8.17.1.2):

4/3 * As (REQUIRED) = 0.94 SQ IN/FT

DISTRIBUTION OF FLEXURAL REINFORCEMENT (AASHTO 8.16.8.4):

rho, TENSION REINFORCEMENT RATIO = 0.00233
 k = 0.185
 j = 0.938
 fs (ACTUAL), SERVICE LOAD BENDING STRESS = 21.4 KSI
 dc, THICKNESS OF CONCRETE COVER = 4.5 IN
 A, EFFECTIVE TENSION AREA = 81.0 SQ IN
 z/(dcA)^{1/3} = 23.8 KSI
 0.6 fy = 36.0 KSI
 fs (ALLOWABLE), BASED ON DISTRIBUTION REQUIREMENTS = 23.8 KSI

DESIGN SUMMARY:

THE DESIGNER SHOULD CHECK THAT THE FOLLOWING FOUR STATEMENTS ARE TRUE:

1. Mu = 116.5 K-FT/FT < 172.3 K-FT/FT = phi * Mn
2. As = 1.05 SQ IN/FT < 7.22 SQ IN/FT = As (MAXIMUM)
3. 1.2 MCr = 151.3 K-FT/FT < 172.3 K-FT/FT = phi * Mn
4. fs (ACT) = 21.4 KSI < 23.8 KSI = fs (ALLOW)

IF ALL FOUR OF THE ABOVE STATEMENTS ARE TRUE, THEN THE DESIGNER'S INPUTTED VALUES FOR REINFORCING STEEL AREA AND SPACING SATISFY AASHTO REQUIREMENTS. AREA OF REINFORCING STEEL EQUALS 1.05 SQ IN/FT AND SPACING OF REINFORCING STEEL BARS EQUALS 9.0 INCHES.

IF STATEMENTS 1, 2 AND 4 ARE TRUE, BUT STATEMENT 3 IS FALSE, THEN THE DESIGNER MAY USE A REINFORCING STEEL AREA OF 0.94 SQ IN/FT AND A REINFORCING STEEL BAR SPACING OF 9.0 INCHES. HOWEVER, THE DESIGNER SHOULD VERIFY THAT ALL AASHTO REQUIREMENTS ARE STILL SATISFIED BY USING 0.94 SQ IN/FT AS THE NEW INPUTTED REINFORCING STEEL AREA AND CONFIRMING THAT STATEMENTS 1, 2 AND 4 ARE STILL TRUE.

IF STATEMENT 1 IS FALSE, THEN THE DESIGNER MUST INCREASE THE INPUTTED VALUE FOR AREA OF REINFORCING STEEL.

IF STATEMENT 2 IS FALSE, THEN THE DESIGNER MUST DECREASE THE INPUTTED VALUE FOR AREA OF REINFORCING STEEL.

IF STATEMENT 4 IS FALSE, THEN THE DESIGNER MUST EITHER INCREASE THE INPUTTED VALUE FOR AREA OF REINFORCING STEEL, DECREASE THE INPUTTED VALUE FOR SPACING OF REINFORCING STEEL BARS OR A COMBINATION OF THE TWO MODIFICATIONS.

Fig. 1 — Spreadsheet created for pier footing design.

Fig. 2 — Spreadsheet sample run.

DESIGN OF REINFORCING STEEL FOR CONCRETE BASED ON LOAD FACTOR DESIGN

MADE BY: CHKD BY:

INPUT:

M_u , LOAD FACTOR DESIGN MOMENT =		K-FT/FT
M , SERVICE LOAD DESIGN MOMENT =		K-FT/FT
f_y , YIELD STRENGTH OF REINFORCEMENT =		KSI
f_c' , COMPRESSIVE STRENGTH (28-DAY) OF CONCRETE =		KSI
n , MODULAR RATIO OF ELASTICITY =		
d , EXTREME FIBER TO CENTROID OF REINFORCEMENT =		IN
b , WIDTH OF MEMBER PER FOOT =		IN
h , OVERALL THICKNESS OF MEMBER =		IN
β_1 (REFER TO AASHTO 8.16.2.7) =		
z , QUANTITY LIMITING FLEXURAL DISTRIBUTION =		K/IN
A_s , AREA OF REINFORCING STEEL (IN TENSION) =		SQ IN/FT
s , SPACING OF REINFORCING STEEL BARS =		IN

Fig. 3 — Spreadsheet input form.

Fig. 1 is a copy of the spreadsheet, showing inputted numerical values, computed numerical values based on given formulas, and inputted text that will vary for different projects. All other portions of the spreadsheet are either text that will be common for each use of the spreadsheet or cells in which there is no entry and which are not being used at all. Fig. 2 is a sample run using the spreadsheet, and Fig. 3 is a spreadsheet input form.

In this spreadsheet, all inputted values are given at the beginning of the spreadsheet, with the computed output immediately following. However, it is also possible to intermix inputted values with computed output throughout the spreadsheet. Also, since there are four basic design criteria, a design summary is provided immediately following the output section to allow the user to review quickly whether each of the four criteria is satisfied.

This spreadsheet is set up so that the area of the reinforcing steel and the spacing of the reinforcing steel bars are provided in the input. The user may input different values based on trial and error until all four criteria are satisfactorily met. However, with the creative capabilities of spreadsheets, it could also have been developed so that the area and spacing of the reinforcing

steel bars were simply presented in the output without using a trial and error method.

The advantage of using a trial and error approach is that the user may investigate the status of each of the four criteria for any given area and spacing which he or she may wish to input. Such a trial and error approach usually takes about a minute of trial runs before all four criteria are optimally satisfied. The advantage of computing the required area and spacing as output is that it can be accomplished with the single push of a button and the status of the four criteria is checked by the computer instead of by the user.

Quality control

A valuable feature of computer spreadsheets is that they facilitate a high degree of quality control. A spreadsheet may be checked using any combination of the following methods:

- Check the actual formulas in the spreadsheet.
- Generate a sample run using arbitrary input values and check that the output is computed correctly.
- Generate a run based on a previous manually-computed design and compare the spreadsheet-generated output with the manually-calculated answers.

After it has been confirmed that the spreadsheet is free of computational errors and textual errors and it is in its final form, it is important that the spreadsheet be properly protected. This may be accomplished by entering:

/WGP E

This will make it impossible for any future user to change or manipulate any of the formulas or text throughout the spreadsheet.

However, since the user must be able to enter inputted numerical values and to enter pieces of text that will vary for different projects, these portions of the spreadsheet must then be unprotected. This may be accomplished by going to each of the appropriate cells and typing:

/RU [Enter]

At this point, the formulas and the permanent text are protected and may not be altered, while the cells which contain inputted numerical and textual data are unprotected and may be changed as the user sees fit.

After the spreadsheet has been thoroughly checked and the appropriate portions of it have been protected, it is then ready for use by the designer. For all subsequent design runs, the only checking that is required is for the inputted numerical and textual data.

Savings in time, money and unnecessary frustration

It took approximately one day to create this spreadsheet including both thoroughly checking it and appropriately protecting it. Since this is approximately equal to the amount of time that was spent on each set of manual calculations and since about 40 sets of computations needed to be generated, a significant savings in both time and money was realized on the project. Furthermore, the elimination of needing to check the output for each run resulted in additional significant savings.

If design parameters are changed at a future date, it will take merely a few minutes to enter the new input, arrive at an optimal design solution and print the new results. Not only does the development and use of a computer spreadsheet provide significant savings, but it also eliminates unnecessary frustration for the design engineer when initial trials do not work, when errors are encountered or when revisions are needed.

Potential for innovation

This spreadsheet has been described not so much for the reader to duplicate, but rather to illustrate the many potential benefits from the use of spreadsheets and to foster vision and creativity for additional applications. Are there any computations that you repeat on a regular basis and that could be organized into a table or into a template, as was done in this example? The potential for the use of spreadsheets is virtually endless and is waiting to be tapped.

Some potential spreadsheet applications from "Building Code Requirements for Reinforced Concrete (ACI 318-89)" include, but are certainly not limited to, the following:

- Design of concrete for shear and torsion (Chapter 11),
- Prestressed concrete design (Chapter 18),
- Special provisions for seismic design (Chapter 21), and
- Alternate design method (Appendix A).

Spreadsheets are also especially practical for:

- Monitoring cost and time budgets for project managers,
- Preparing construction quantity and cost estimates,
- Designing concrete mixtures, and
- Computing reinforced concrete section properties or composite section properties.

As you consider the projects with which you are presently involved, what are some of the applications for which a computer spreadsheet could save you significant time, money and unnecessary frustration? The potential for benefits from the use of spreadsheets is limited only by our creativity and innovation.

Kenneth E. Wilson works as a structural engineer with Baker Engineers, Beaver, Pennsylvania, a consulting engineering firm with extensive experience both in structural analysis and design and in computer software development. He is a graduate of Cornell University and the University of Illinois, and has eight years of design experience as a bridge engineer. He presently serves as computer liaison for the structural department and is cochairman of Baker's Bridge Users Group.



SP-4, FORMWORK FOR CONCRETE

The fifth edition of SP-4, *Formwork for Concrete*, will provide answers to the questions that designers, contractors, engineers and architects ask most.

In addition to dealing with fundamentals of form design and construction, *Formwork for Concrete* presents chapters devoted to specialized problems of architectural concrete, mass concrete, shell structures, underground structures and special construction techniques. The fifth edition has a completely revised section on slipforming and an entirely new section on segmental box girder bridges, plus a listing of new products and processes throughout. Design tables are all recalculated to follow the latest changes in lumber design standards.

The updated text of SP-4 reflects the latest provisions of ACI 347R-88, *Guide to Formwork for Concrete*, and the 1988 revisions in OSHA safety standards. Both 347R-88 and OSHA's 1988 regulations for concrete and masonry construction are reprinted in full in the appendix. Also in the appendix are building code provisions for formwork from the new ACI 318-89, *Building Code Requirements for Reinforced Concrete*.

Throughout *Formwork for Concrete*, the term "formwork" is employed in its broadest sense to include the total system of support for the freshly placed concrete - form lining and sheathing plus all necessary supporting members, hardware and bracing. The entire publication is dedicated to the premise that the form builders primary objectives are: quality, safety and economy.

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Knowledge-Based Expert Systems in Reinforced Concrete Design

by Alexander S. Bezzina and Sidney H. Simmonds

Knowledge-based expert systems for proportioning and detailing reinforced concrete members must incorporate both the mathematical reasoning wherein each decision step follows directly from the previous calculated information and the intuitive reasoning based on acquired knowledge that is required to arrive at a plausible design. The general requirements for such systems in the domain of structural engineering are examined and some solution strategies and heuristics used in the design of reinforced concrete columns are presented.

Most computer programs that have been written for the design of reinforced concrete members, for example programs by Halvorsen,¹ Ehsani,² Davister,³ Ross and Yen,⁴ and Balaguru,⁵ either determine the load capacity of a section selected and input by the user or check to confirm that such a section is satisfactory for a specified loading condition. While these programs are useful in performing the tedious mathematical computations involved, they lack the intuitive reasoning required to arrive at an efficient design when only minimum essential data is available.

The engineering logic and decisions inherent in the design procedures are subjective and implicit in

nature and are dependent on the acquired knowledge and experience of the structural engineer. The translation of the engineer's judgment and design concepts into computer programming is an essential component for building knowledge-based expert systems (KBES).

As the design process increases in complexity, the value of a KBES to assist the engineer becomes more apparent. A detailed description of KBES's and the techniques used in their creation is given by Frost.⁶

Knowledge-based expert systems

Feigenbaum⁷ defines an expert system as "an intelligent program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise in their solution. The knowledge necessary to perform at such a level, plus the inference procedure used can be thought of as a model of the expertise of the best practitioners in the field."

The key aspect of a KBES is the representation of a body of knowledge and the ability to use it intelligently. Thus, a computer program that, starting with the same information, proportions member sections comparable to those selected by practicing design engineers may

be classified as a KBES in the domain of structural design.

In its simplest form, an expert system consists of three main components: a knowledge base; a control module that selects, interprets, and applies the appropriate knowledge; and a blackboard in which intermediate results and observations are stored temporarily.

Although KBES's may be written in any programming language, computer programs known as KBES shells⁸ are available that have built-in data structures and inference mechanisms. Such programs are domain independent but possess a syntax that permits the user to link to the knowledge base using character strings. This facilitates building and upgrading the knowledge base since quantities may be identified using common engineering terminology.

A characteristic of structural design problems is the amount of computational work required in the solution. Hence, it is essential that existing computational programs written in, say, FORTRAN can be easily linked to the system. Many of the new KBES shells have this capability and it is expected that this feature will improve as newer versions of the shells are marketed.

Although there are several forms of knowledge representation the use of production rules is the most

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common in structural engineering. Production rules are generally based on public knowledge that includes well-defined theories and facts. Examples include such items as the principles of equilibrium and the fact that reinforcing bars are available commercially only in certain diameters. Code specifications are frequently based on experimental research. When these quasi-empirical methods are codified into standards, they become established information and form part of the public knowledge available to the engineer.

Another form of available knowledge, referred to as experiential knowledge, consists of rules of thumb, intuitive design concepts, and sound engineering judgment attained through experience in a specific field. It is the knowledge unique to the specific field that the engineer possesses that is generally unknown to others and that marks him as an expert in that field.

Production rules known as heuristics manipulate experiential knowledge by proposing a short-term plan that may not lead directly to a final solution but will give results that can be evaluated and used as a basis for invoking other production rules or subsequent heuristics.

The KBES in structural engineering

Obviously a KBES in structural engineering must produce designs that are safe, serviceable, constructible, and economical. In practice, however, it is the engineer who must take ultimate responsibility for the design. Therefore, it is essential in the planning of a KBES that provision is made for the engineer to impose, a priori, any limitations on the selection of, or prescribe specific values to, any or all of the design parameters. This means that the knowledge base must contain production rules and solution strat-

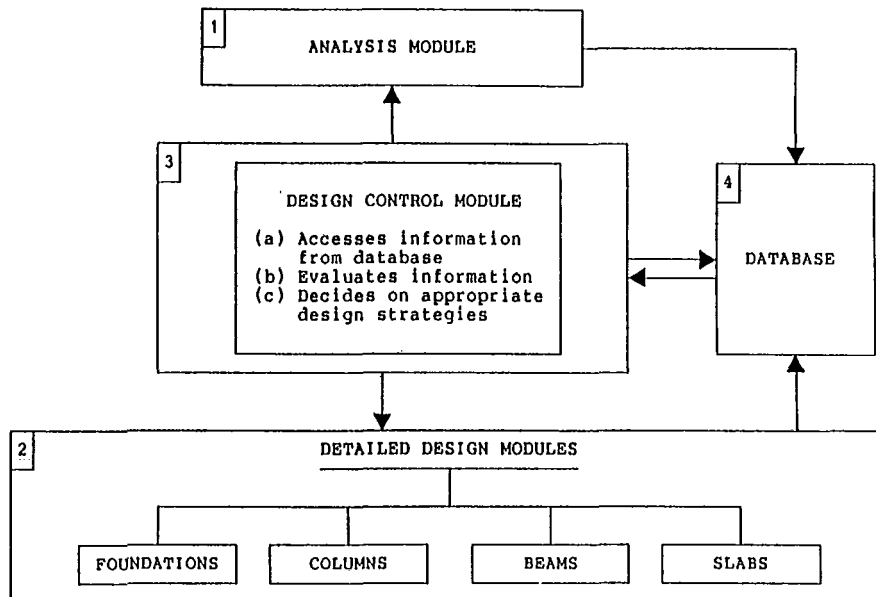


Fig. 1—Architecture of an integrated structural engineering CAD system.

egies that will accommodate any combination of these limitations when executing the design.

In most practical design situations, adherence to a particular building code is stipulated in the contract of works. These codes, in turn, require the design be performed in accordance with other design codes such as those from ACI⁹ or CSA,¹⁰ for example, in reinforced concrete. Thus, the requirements of the appropriate design codes must be incorporated in all KBES's that are intended for use by practicing engineers for proportioning structural members.

In the design of a building, a series of independent but interrelated KBES's could be developed. One, based on knowledge of the occupancy and geographic location of the structure, could determine the magnitudes and combinations of loading to be used. Another could determine the most suitable framing system to be used, while still others could select actual member sections.

These separate KBES's could be made to interact through a database to form a comprehensive CAD system as shown in Fig. 1. This integration can be done manually, thereby giving the engineer the means to monitor and control progress of the design directly, or by yet other KBES's that have the capability of evaluating the progress

of the design in accordance with objectives specified by the engineer to form an automated CAD system.

There are two approaches to organizing the solution strategy for the control module of a KBES. In the complete cycle approach, the required input parameters, including any designer limitations or requirements, are entered. The program is then run without any further external directives or user intervention until a complete design is executed. Obviously this requires the complete solution strategy and appropriate knowledge to be contained within the program.

In contrast, in the interactive or decision design approach, the program stops execution at appropriate stages and requests further information and/or decisions. The designer, therefore, intermittently interacts with the computer to control the course of the solution procedure. While the second approach may be desirable or even necessary in expert systems in some domains, it is not considered appropriate for systems intended for proportioning and detailing member sections.

KBES for member design

A KBES for the sizing of a structural member is only a part or module of a larger design process. In developing any module, our focus