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Integrated Design Environment for Concrete Structures

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Synopsis: This paper presents a new computer design environment that allows the designer complete freedom in choosing design options. It combines three common tools, analysis, graphics and a spreadsheet, into a completely integrated system. The environment allows the designer to take results directly from the analysis database, display them graphically, choose the values to be used for design and then insert those values automatically into the spreadsheet environment. The spreadsheet can be customized, through the use of templates, to fit any design scheme. A template for the design of singly reinforced concrete beams is presented.

Keywords: beams (supports); computer programs; reinforced concrete; stiffness methods; structural analysis; structural design.

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INTRODUCTION

The idea that the optimum structural design computer program automatically incorporates all design options based on the initial input data has lost support in recent years. Such a strategy has several problems. It is very difficult to incorporate all the options that each user would like. Thus, each user must work around the available design options to achieve the design flexibility needed for special cases. Additionally, a great deal of time is wasted by manually analyzing, revising and then re-analyzing a model until an efficient design is reached. While the fields of artificial intelligence and expert systems may reverse this trend, they are not sufficiently developed for practical use. New techniques are needed to bridge the gap between current practice and future methods.

A new approach to design, using an integrated computer program environment, has been developed. This environment consists of the integrated use of structural analysis, graphics and a spreadsheet. This combination allows the engineer-designer to follow a logical thinking process. It also allows the designer to change or include new options for design within the familiar spreadsheet format. This integration of programs creates a new environment that skillfully coordinates the best qualities of the computer with the best qualities of the individual.

Incorporating a spreadsheet into the design format is also ideal because spreadsheets are explicitly user-friendly, even for those individuals with practically no computer experience. They are highly responsive to the user, allowing complete flexibility in analysis and built-in error checking.

Considerable amounts of software have been developed and redeveloped for structural analysis and design. There is often little to be gained by continued research in the redevelopment of existing analysis or design software. A more valuable approach is to use what has already been developed and integrate it within new formats as they become available. This is what has been done for the development of the integrated system. This approach uses modular, reusable segments and incorporates them into a new environment. This makes software development a much quicker and less error-prone process.

DESCRIPTION

The integrated design environment (IDECS) is the unification of three independently developed programs: direct stiffness frame analysis, graphic display of moment diagrams and a spreadsheet program with templates (Figure 1). The result of this integrated set of programs is a new design environment allowing the designer to control the design process and try many designs in real time. The environment is presented as it applies for the design of singly reinforced concrete beams.

The process can best be demonstrated by following the design steps of a beam member in the structure shown in Figure 2. Sizes and structural loads have been previously estimated. The first step in the process is to perform the structural analysis of the assumed model. The loading magnitudes of typical dead, code and lateral loads due to earthquake forces need to be estimated for the analysis. STAN, a program based on the direct stiffness formulation, was used for this purpose. This program was originally written by Dr. E.L. Wilson for use as an educational tool (1). It is written in FORTRAN and adapted to conform to the described environment. The program can analyze general three-dimensional structures including lateral loads and uniform vertical loads. The input data necessary for STAN to execute properly consists of the standard information necessary for most structural analysis packages: geometry, connectivity, boundary conditions, properties and loading. Portions of the data file prepared for the example are shown in Figure 3. The program solves for joint displacements and member end forces and stores these in a direct access file according to the user designated member number. A printable output file is also produced containing the input and results for review and record. The designer has the option to study the structure and its response through a graphic display of the model in its deformed and undeformed modes as shown in Figure 4.

Subsequent to the analysis, execution transfers into the graphics display portion of the integrated package (MGRAPH). The raphics segment was developed specifically for interfacing be-een the analysis and design portions of the environment. This ogram allows the user to visually inspect the results of the analysis for any member of the structure. The program was written in FORTRAN using the GEOGRAF graphics development package (2).

MGRAPH first interacts with the user to determine the dimensional units (feet or inches, kips or pounds) used in the analysis portion of the program. Next, the user chooses the member (designated by number) that is to be designed. Using this information, the program reads from the direct access file of end forces and determines moment values along the beam. The program considers both combined dead plus live loads, and combined dead, live and lateral loads in accordance with ACI code requirements. The moment values for both load combinations are displayed to produce overlaid moment diagrams. Figure 5 shows the moment diagrams produced for member number 38 of the example. The user interacts with the program and chooses the location along the beam, where the moment value is taken, to be used in the design. Upon completion of this phase, the design moment is transferred into the spreadsheet program for beam design.

The spreadsheet program used is a significantly revised version of MICROCALC, written in Pascal, included as a demonstration program by Borland, Inc. for their Turbo Pascal compiler (3). Modifications to the program were made by the authors to convert the program to Microsoft Pascal so that it can be called as a subroutine from the graphics program. The contents of the template developed to design beams using the spreadsheet environment are shown in Figure 6. This template is based on ACI code requirements for strength design of singly reinforced concrete beams. The version of the template used for the design of member number 38 is shown in Figure 7. Once in the spreadsheet, the template offers the user four options. Beams can be designed specifying any one of the four parameter options: 1) beam width, 2) beam depth, 3) depth/width ratio and 4) depth and width chosen. One of the first three options should be chosen in the initial sizing of beams according to the worst case. The fourth option is then likely be used for subsequent beam sections or adjacent spans.

Included in the template are initially assumed values of design parameters. These include the yield strength of the reinforcement steel, compressive strength of concrete and reinforcement ratio limits. Checks are made on the spreadsheet to verify that the design remains within allowable steel ratio limits. If desired, the actual design strength, based on provided reinforcement area, is also computed. When the user completes his adjustments for beam design, he exits the spreadsheet and returns to MGRAPH.

The results of the beam design (beam depth, beam width, an area of steel) are stored in a printable output file. At th point, the user has the option of (1) choosing a new location the beam for design, (2) choosing a new beam to design, or exiting the design phase. On exiting the design environment th designer has the option to re-analyze the structure, if necessary, based on any design changes.

FUTURE

The integrated spreadsheet, graphics, and analysis environment has a wide variety of applications. Any process that requires analysis and subsequent user controlled iterative design decisions is likely to benefit from this environment. The current capabilities are limited to the design of singly reinforced concrete beams. New templates are currently under development for the following designs; shear reinforcement, doubly reinforced and T-beams, and column design. Eventually, the environment will be expanded to incorporate the analysis and design of one- and two-way slab systems, pan joist systems and corbels. All designs can be accomplished in a spreadsheet format provided the data can be transferred from an analysis program. Once the connection is made between the analysis program and the spreadsheet, all that is required is the development of templates. Using this environment for the design of steel structures will only require the integration of a steel section database containing the properties of the available standard steel sections. There is also the advantage that templates can be added, replaced, and adjusted to meet code revisions or user's special needs with little effort.

Having programs for a frame analysis, column design, slab design, and footing design and integrating them together with many template options, a single engineer could design a basic structure in a fraction of the time currently required. With further integration of interactive graphics and the inclusion of databases of standard structural components, the complete design could be accomplished including final construction drawings. This could be accomplished by integrating a CAD package to the database of design results.

A further extension in the process is the re-analysis of the structure as a result of the current design. This option would allow the analysis program to use the designed member sizes stored in the database as input for the re-analysis of the structure. This would include both the member properties and dead loads due to changes in sizes. This change would be relatively simple to accomplish through the use of a database management system (Figure 8).

Current work is being done to increase the size and flexibility of the spreadsheet. A new spreadsheet developed for the UNIX environment, written in C, is being completed. The program still acts as a FORTRAN subroutine. The new program allows values to be placed in any cell of the spreadsheet as well as values returned from any cell to the calling program. This is currently being incorporated into a more general, database driven analysis program.

CONCLUSION

A new integrated analysis and design environment is presented. It incorporates the use of direct stiffness analysis, graphics and a spreadsheet. It demonstrates a new method for designing concrete beams that can be extended to any type of design process. This combination of different programs into an integrated environment is the key to complete efficient designs using the computer. It allows the use of general analysis tools to design structures and gives the designer the freedom to iterate over different solutions to a particular engineering problem. By developing a template, any designer can customize the design process. The environment can be extended to allow total access to a database that will allow more complicated and complete designs to be accomplished. The complete design, estimating and billing of a project using an integrated environment is possible with a few new developments. Such a system allows for a wide latitude in design flexibility by ease in execution, encouraging creativity in design and by its ability to incorporate new software and design recommendations.

REFERENCES

(1) Correspondence with Dr. E.L. Wilson, University of California, Berkeley, California, 94720.

(2) Geograf Graphics Package, Geocomp Corporation, Concord, Massachusetts, 01742.

(3) Turbo Pascal, Borland International, Scotts Valley, California, 95066.

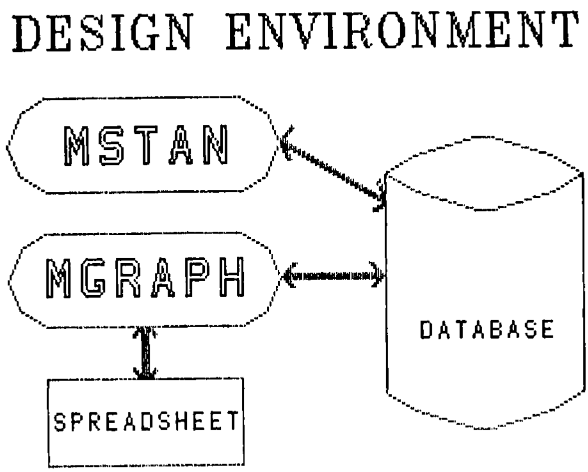

FIGURE 1

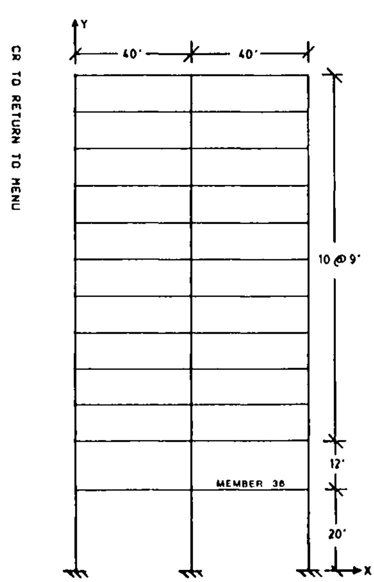

FIGURE 2

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ACI EXAMPLE FOR SAN FRANCISCO: STAN INPUT FILE
39,1,3                         : # nodes, # elem types, # load cases
1  D=1,1,1,1,1,1 C=0,0,0       : Nodal Coordinates and Boundary Conditions
2  D=1,1,1,1,1,1 C=480
3  D=0,0,1,1,1,0 C=0,240
          *
          *
39 D=0,0,1,1,1,0 C=960,1464
C*** Beam and Column Data
3,60,8,2 D=4,1                            :Elem Type,# elem.,# Properties,Memb.
1 I=27648,27648    A=576  E=3605000       :24 X 24 COLUMN
2 I=111360,111360 A=1156 E=3605000        :34 X 34 COLUMN
3 I=49150,49150    A=576  E=3605000       :18 X 32 GIRDER
M=200,150                     : Member Loading
1,1,4,39     M=1              : Connectivity
2,2,5,39     M=2
      *
      *
37,4,5,39    M=3 L=1,2        : Include Member Loading L=
38,5,6,39
39,7,8,39
C*** Concentrated Loads
4  L=3 F=700
7      F=1200
10     F=1500
25     F=3100
:
```

FIGURE 3

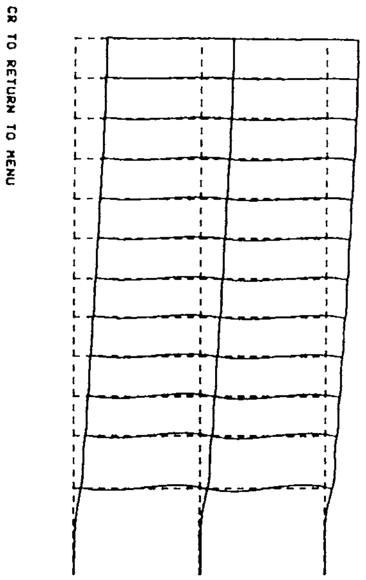
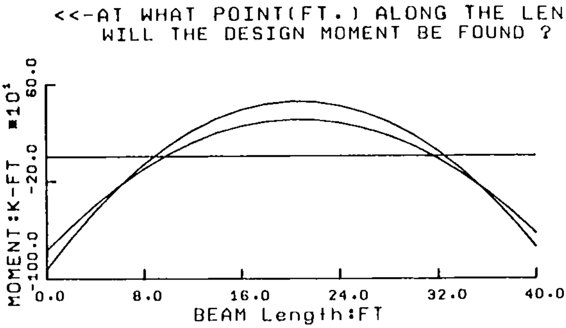


FIGURE 4



MOMENT DIAGRAMS FOR COMBINED ULTIMATE DESIGN
DEAD+LIVE LOADS D+L+WIND LOADS

FIGURE 5

	A	B	C	D	E	F	G
1							
2			Member No. 38		Sec. Dist. Left 0 ft.		
3							
4		Mu k-ft. 925.00		β_1 from A20 0.85		d in. from A21 31.00	
5		Des.% of ρb 0.3750		ρbal from C20 0.0285		b in. from C21 24.00	
6		f'_c ksi 4.00		Ru psi from E20 534.74		As req. in² from D21, 7.26	
7		fy ksi 60.00		Mn k-ft from F20 1027.78		Md k-ft from G12, 1010.12	
8		Option 4					
9							
10							Option=4 ∴ d in 31.00
11							Option=4 ∴ b in 24.00
12							As prov. in² 8.00
13							
14							
15		Pmin from E21 0.0033	If Option=4 $\rho=\frac{1}{m}(1-\sqrt{1-\frac{2mRu}{fy}})$ ρ=.3750 ρbal 0.0098	ρprov. = $\frac{As\ prov.}{b*d}$ 0.0108	ρmax=0.75 ρbal 0.0214		
16							
17							
18							
19							
20	If f'_c<4 β_1=.85 If not then B20 0.85	If f'_c > 8 β_1=.65 If not then β_1=.85-.05(f'_c-4) .85	ρbal= $.85\beta_1 \frac{f'_c}{fy} \frac{87}{87+fy}$ 0.0285	$m=\frac{fy}{.85f'_c}$ 17.65	$Ru=\rho fy(1-\frac{\rho m}{2})$ 534.74	$M_n=\frac{Mu}{.9}$ 1027.78	If option=3 then $d=\sqrt[3]{\frac{Mn*12000}{Ru\ b}}$ If not then d=G10 31.00

21	If option=2 then
	$d=\sqrt{\frac{Mn*12000}{Ru\ b}}$
	If not then
	d=G10
	31.00
		If option=1 then
		$Ru=\frac{Mn*12000}{bd^2}$
		If not then
		b from F21
		24.00
			If option=1 then
			d from G10
			If not then
			b from B21
			24.00
				As=ρ*b*d
				7.26
					$\rho min=\frac{200}{fy}$
					0.0033
						If option=3 then
						b=d/(d/b)
						If not then
						b=G11
						24.00	

FIGURE 6

```
  A          B          C          D          E          F          G
 1 INTERACTIVE DESIGN OF SINGLY REINFORCED CONCRETE BEAMS IAW ACI 318-83
 2          Member No. 38          Section @          0 Ft. from left
 3_____PARAMETERS______ _______TERMS_________ ______RESULTS_______
 4 (K-Ft):Mu=     925.00  Beta 1     =      0.85 (in):Depth=     31.00
 5 % Rho Bal=     0.3750  Rho Bal. =      0.0285 (in):Width=     24.00
 6 (Ksi):f'c=       4.00  (Psi):Ru =      534.74 (in^2):As =      7.26 (Required)
 7 (Ksi):fy =      60.00 (K-Ft):Mn =     1027.78 (K-Ft):Md =   1010.12
 8 OPTION    =       4
 9  ENTER PARAMETERS BELOW CORRESPONDING TO DESIGN OPTION CHOSEN   _INPUT (in)_
10 For option 1) or 4) ENTER Depth, 2) Width or 3) D/W Ratio ----->     31.00
11 For option 4) also  ENTER Width                            ----->     24.00
12 Enter area of steel (in^2) provided for design check      ----->      8.00
13----------------------------------------------------------------------------
14     CHECK :    Rho Min <= Rho Des.   Rho Prov. <= Rho Max.
15                0.0033      0.0098      0.0108      0.0214
16
17 Design may be revised as follows: 1) Move cursor to cell and enter
18 new value, 2) Return, 3) Repeat Command (/R) several times until the
19 values in "RESULTS" column no longer change.
20      0.85       0.85      0.0285      17.65      534.74     1027.78      31.00
21     31.00      24.00      24.00       7.26      0.0033      24.00
C 2 Text                              Type / for Commands      AutoCalc: ON
```

FIGURE 7

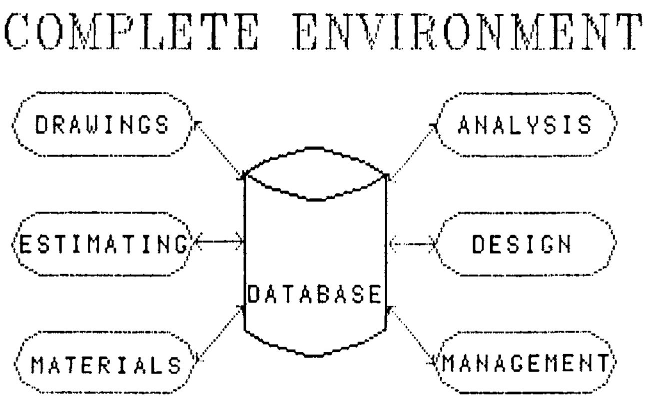


FIGURE 8