

# Computer-Aided Design of Portland Cement Concrete Mixes

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## ABSTRACT

A prototype or first version of a software package being developed to assist in portland cement concrete mix design is described. This is not necessarily a research project but rather a research tool in which design information from various sources has been gathered into a single algorithm and organized into a usable and versatile form. The program consists of three sections: design of the first trial batch by any of the five commonly used methods, adjustment of an unsuccessful trial batch by a combination of empirical routines and those derived from American Concrete Institute methods, and a data file of various types of mix design information. This last section may be used independently or as an aide in blending or adjusting a mix. User friendliness is a key element of this algorithm. Computer-user interaction occurs throughout and is especially useful for the inexperienced designer. Designed and written initially for main-frame computers, the program features the addition of a translator for a problem-oriented language (SCAN), which leads to greater freedom from the structured input environment. Currently the software is being downloaded to a microcomputer (MS-DOS) system. Program output includes batch weights of the usual concrete ingredients as well as weights per cubic yard. Additional parameters provided include batch size, percent air, cement factor, unit weight, and water-cement ratio. A plot of unit weight versus air content is also offered. Like much software, this package is continually being modified and developed; however, it has already demonstrated its usefulness as a computer-aided design system.

The concrete mix design procedure, throughout its development, has been approached from various directions. Methods have been based, for example, on satisfying volume requirements, meeting specified unit weights, or matching particular weight or volume proportional relationships. Although the underlying precepts differ in each case, the goal of the designer is the same, that is, to create a blend of cement, water, sand, aggregate, and air that is of a certain strength, workability, and durability.

The designing of a successful mix can be a time-consuming process. Aggregate gradations as well as sizes and shapes differ, as do the qualities of various waters, cements, and admixtures. Therefore many material combinations must be blended and tested. In addition, a particular mix must reach a certain age (usually 7 or 28 days) before its design strength may be evaluated.

A wealth of information has been gathered by various organizations and individuals to assist the designer in shortening the time required to find a workable blend. To combine information from many sources and to enable the user to quickly retrieve and apply this information, an algorithm has been developed that attempts to codify and thus organize the portland cement concrete (PCC) mix design process. The program assembles information that has been compiled by organizations including the Portland Cement Association (PCA) (1) and the American Concrete Institute (ACI) (2,3) and from the work of Goldbeck and Gray (4), Popovics (5), and others. To assist the user in entering data and retrieving in-

formation, the SCAN subroutines developed at the University of Illinois have been employed throughout (6).

The program purpose is threefold. First, it provides a starting point for the design of a workable concrete mix by use of the various tables, mix methods, and information. Second, it provides the information and methods necessary to adjust a blend to correct certain first-batch problems, and, third, it is a repository of design information and criteria to assist in all phases of PCC design. The program should have some appeal to the entire spectrum of mix designers. It will be especially useful to those who may not have immediate access to the wide range of information necessary for successful concrete mix design. In this algorithm, the information is coordinated and is made available at those points in the design process where it is most likely to be required by the user.

## CAPABILITIES AND APPLICATIONS

The batch-design algorithm performs three main functions:

1. Designs a first trial batch by a user-designated method,
2. Adjusts batch quantities by changing particular parameters while holding others constant, and
3. Provides information files that can be used separately for general information or in conjunction with batching and adjusting.

In addition, the design algorithm provides printed output and line plots of certain data.

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### Design of First Trial Batch

First trial batches may be designed by using one of five methods: ACI volumetric, proportional by weight or volume, ACI based on consistency description, cement strength, and weight gravimetric. The consistency-description method is used for no-slump designs, whereas both the cement-strength and the weight-gravimetric methods are used to design light-weight concrete mixes. Normal-weight mixes may be designed by all of the foregoing, although the cement-strength method would not be recommended. The method used may be one of choice or of regulation, but in every case an effort has been made to provide useful assistance or information through each step of the design procedure.

Although mix designers' goals are similar in most cases, each method of obtaining a first trial batch has its own unique characteristics. A brief description of each follows.

#### ACI Volumetric (ACI 211.1-81)

The ACI volumetric method is used for normal-weight concrete mixes. The key to this method is to blend the correct amount of cement, sand, water, air, and coarse aggregate to achieve a solid volume of 27 ft<sup>3</sup> that exhibits the proper consistency and workability. The cornerstone of the method is the work of Goldbeck and Gray (4), in which a table was developed giving the necessary solid volume of coarse aggregate on the basis of maximum aggregate size and sand gradation (fineness modulus).

#### Proportional

The proportional method is the oldest in the program. In it the mix designer bases the material blend on a preselected proportional ratio of cement to fine aggregate to coarse aggregate (C:FA:CA). The ratio may be either by weight or by volume. Used for normal-weight mixes, the method probably comes from the practice of mixing a shovel of one material with two shovels of another.

#### ACI Consistency Description (ACI 211.3-75)

Similar to the ACI volumetric method, the consistency description differs in that proportional factors based on a consistency description are introduced. The goal of this method is a no-slump concrete mix.

#### Cement Strength (ACI 211.2-81)

Although the cement-strength method may be used for any type of concrete, it is especially useful for all types of lightweights. This is because it is not necessary to account for aggregate porosity, which in lightweight aggregates tends to be inconsistent. Mix is based on minimum cement content for a desired strength and the loose volume of sand and coarse aggregate.

#### Weight Gravimetric (ACI 211.2-81)

The weight-gravimetric method is useful for semi-lightweight mixes--those with normal-weight sand and lightweight coarse aggregate and for normal-weight mixes. This method requires that a preselected weight per cubic yard be established and met by the mix designer. Weights and volumes of cement, water, air,

and coarse aggregate are selected and then sand weight is adjusted to achieve the desired final weight per cubic yard of concrete.

### Adjustment

The adjustment routines may be applied to concrete batches either in conjunction with the first-trial-batch routines or as stand-alone programs. Fly-ash replacement of cement by weight or volume is possible as is the creation of per-yard batch volumes and parameters from the entry of material weights from a successful trial batch. Changes are possible to correct faults that may occur in the first batch design. Slump may be increased or decreased on the basis of a fixed amount of water or a change in water volume. Corrections for total aggregate moisture content may be made and the air-water proportional relationship can be changed by manipulating the water volume. The cost per cubic yard or batch may be computed given the unit costs of each item.

Following is a listing of the procedures available in the adjustment section and a brief synopsis of the capabilities of each.

#### Fly-Ash Replacement

Cement may be partially replaced with pozzolanic material. Options include maintenance of constant weight or constant volume of cementitious material. In addition the ratio of water to cement plus pozzolan  $[w/(c + p)]$  may also be maintained equal to the water-cement ratio either by weight or by volume.

#### Increase or Decrease in Slump

A change in slump may be accomplished in either of two ways. Water volume may be changed and compensated for by a change in sand volume, or sand volume may be changed and then balanced by an adjustment in coarse-aggregate volume. If the volume of water is changed, the user is offered the option of maintaining a constant water-cement ratio.

#### Moisture Adjustment

The algorithm will, on request, adjust the batch mix to compensate for total moisture content of the aggregate. Corrected weights for water, coarse aggregate, and sand are provided.

#### Percent Air Adjustment

Changes in percent air are compensated for by changes in water volume. This procedure is useful if slump and workability are found to be acceptable but the air content must be changed. The water-cement ratio may or may not be changed, whereas the remaining ingredients are held proportionally constant by volume.

#### Batch Costs

Determination of batch costs for the individual batch items is provided. Item costs may be supplied in unit increments of pounds, gallons, or tons.

### Information File

An information file of 18 sections is available for viewer use either as a separate reference or when

needed during trial-batch design. Tables are available, for example, that recommend water-cement ratio, amount of water, proportional ratio, air content, slump, unit weight, and coarse-aggregate volume. Listings of state regulations, various cement types, thermal coefficients, and unit weight formulas are available as well.

Two output sections will be produced each time a trial batch is completed. The first is a listing of batch parameters, including the following: water-cement ratio, cement factor, proportional ratio by weight (C:FA:CA), slump, air content, unit weight, and batch size. Section 2 consists of a listing of quantities per cubic yard and per batch. Included are water by the pound and by the gallon, cement by the pound and by the bag, fly ash by the pound, sand and coarse aggregate by the pound bulk dry and by the pound saturated surface dry. Optionally, the amount of sand, gravel, and water to be added given the total moisture content of the aggregate or a listing of the total batch costs is also available. A linear plot of air content versus unit weight is available on request in any mix design in which entrained air is specified.

Each of the output sections appears on the screen and simultaneously is placed in an external file from which hard copy is available. Similarly, the plot data are placed into an external file that may be viewed on the Tektronix screen or generated in hard copy by using the Calcomp plotter.

#### ALGORITHM

The complete software package consists of five separately stored programs or groups of subroutines:

1. The main program and the input routines;
2. The information files;
3. The computation routines, including echo and output routine;
4. The SCAN subroutines (a tool for translating problem-oriented languages stored separately but used throughout); and
5. The externally stored plotting subroutines.

FORTRAN 77 was the programming language used as source code in Sections 1, 2, and 3. Source code for the SCAN subroutines (3) and for the plotter routines (7) is FORTRAN IV. The subroutines of the first four sections have been compiled and stored in two partitioned data sets, and the plotter routines, as previously noted, are stored externally.

The main program begins with a menu display from which the user may select the mix design method to be used [ACI volumetric, proportional, ACI consistency description (no slump), cement strength, or weight gravimetric], the information files, or the adjustment routines.

If a mix design method is chosen, the user is routed to a series of input routines that ask for data describing cement, water, air, sand, and coarse-aggregate requirements or parameters. The data required for each mix design type are listed in the section entitled Using the Program. Where possible, during data entry, the user will be routed to "help" sections if this avenue is requested. Input is completely interactive; that is, all data are supplied by the user in response to specific questions asked by the program (see Using the Program for examples).

Interactive input is checked for user error on a line-by-line basis as data are entered. Error messages may indicate either syntactical errors, misused data types, or unreasonable or out-of-range data values. In each case, an error message appears on

the screen and the user is rerouted to the beginning of that input section where data may be reentered or the subprogram may be exited. On completion of input data, the user will be queried as to whether a listing of input data is needed. He may then continue to the computation section or may return to the beginning of data input to reenter data values.

When trial-batch computations have been completed, the user may proceed directly to the output routine or may select to pass through the adjustment subroutines.

The mix-adjustments section may be entered after completion of the trial-batch computations or directly when beginning the program. If entry is direct, it is necessary for the user to enter batch weights of cement, water, sand, coarse aggregate, and optionally fly-ash material. In this way, the unique parameters can be computed from a successful batch, as can any batch quantities that differ from those entered. Whether the user enters from the trial-batch routines or directly, the subsequent steps are the same. A menu board appears from which the user selects the particular process or procedure to be performed on the batch quantities. The user may select one of the following: slump increase or decrease, either with or without water volume change; fly-ash addition by weight or volume; adjustment of air percent or water volume; moisture adjustment; or calculation of batch costs.

The file section may be entered separately for information or accessed from the input routines when the user requests help. Information provided applies specifically to the various aspects of mix design. If the information files are entered via a call to help, only those tables that specifically address that area from which the call is made are available to the user. If the call for information is made from the opening menu selection board, the entire file is then available to the user. By limiting access in this manner, it was possible, through the use or multiple returns, to return the user directly to that point from which the main program was exited.

The output routines are accessible either on completion of the computation subroutines or after mix adjustment is completed. Output, as listed previously, is standard unless aggregate moisture corrections have been made, in which case the adjusted values are listed. If batch costs have been computed, the output will automatically include the results of the computations.

Significant assistance for data input is provided by the addition of the SCAN subroutines. SCAN is a translator for problem-oriented languages (POLs) developed at the University of Illinois; it provides a mechanism for entering free-format input to FORTRAN computer programs. Whether data input occurs interactively or in an unprompted environment, these routines allow the user to be free of the traditional FORTRAN-structured input environment.

The SCAN functions that appear most frequently in this algorithm are the logical functions MATCH, NUMI, and NUMR. The MATCH function compares user input to particular strings contained in programmed instructions. Where a match occurs, the program proceeds accordingly.

A useful feature of the MATCH function is its programmer-directed ability to read all or part of a word. For example, if the answer "yes" is expected in response to a question, the program, if instructed, will assume yes on receiving "y," "ye," or "yes."

The logical functions NUMI and NUMR allow the user to ignore data type when data are entered. A value entered through the NUMI function will be returned as an integer regardless of how it was entered by the user. Likewise, those values entered through

the NUMR function will be read as real values even if the user has forgotten to enter a sign or a decimal point.

#### OPERATING SYSTEM

The program in its present version is available for the system on which it was developed. All main parts of the program have been written or compiled and stored on the TUCC IBM 3081 using the ANSI FORTRAN 77 languages and compiler.

Operations on and storage of the source code for the SCAN routines, the information files, and the computation and output subroutines are through the WYLBUR operating system. The input routines and the main program are accessible through the TSO operating system and it is on this system that the program is executed.

Compiled versions of each of the four program sections are stored in two partitioned data sets (PDSCs) in the computer memory. It is the contents of these data sets that are executed when the program is used. As stated previously, the plotting subroutines are externally stored and are made available through the IBM Job Control Language (JCL) commands, which have been compiled and stored with the main program.

The microcomputer version can be used on any MS-DOS-compatible system. A newly developed system of input screens and plotter subroutines has been wedded to the original routines and a uniquely versatile system has been the result.

#### LIMITATIONS AND ACCURACY

Concrete mix design is at best a trial-and-error process. In the laboratory or in the field it is unlikely that the major concrete constituents will be weighed more accurately than to the nearest pound. For the program to provide batch weight results that are significantly more accurate than this would not be practical. Output values from any program routine, therefore, will be provided only to the nearest pound or gallon.

Input values will also vary in their accuracy. Specific gravities for concrete materials are traditionally reported to the nearest 1/100, and suggested water volume is usually provided to the nearest pound for the first trial batch. Accuracy beyond these norms would not be reasonable or necessary given that slight variations in aggregate gradation or moisture content, for example, are likely to occur.

The units system used in the program is the U.S. system (pounds). Optional unit selection will be offered to the programmer in the microcomputer version.

Limitations exist for the user when certain of the adjustment routines are implemented. Notable are the following:

1. If adjustments are made to any portion of the trial batch, changes to remaining material weights will be based on the ACI volumetric method and constant volume proportions will be maintained.

2. Adjustments to a trial batch that has been designed using the cement-strength method (light-weight aggregate structural concrete design) will be inaccurate if the user proceeds directly from trial batch design to the adjustments section. This is because of the marked difference in aggregate parameters, provided by the user, from those parameters used in the other methods. The user will be asked to provide additional information in this case.

3. Throughout the adjustments section it will be requested that the user enter values for specific factors: the amount of water required to change the slump 1 in. in a cubic yard of concrete, the amount of water required per cubic yard to provide workability equivalent to that provided by 1 percent entrained air, and the amount of sand required to reduce the slump 1 in. Suggested values for each are included in the program.

#### USING THE PROGRAM

Using the program is not complex; however, the user will be expected to provide aggregate information for proper program execution. The required information will differ slightly depending on the mix design method selected. A listing of the data required for each design method follows.

1. ACI volumetric and proportional methods:
  - a. Sand--fineness modulus (FM), specific gravity [saturated surface dry (SSD) or bulk dry (BD)], and percent absorption; and
  - b. Coarse aggregate--dry rodded unit weight, specific gravity (SSD or BD), percent absorption, and maximum size.
2. Proportional method:
  - a. Sand--specific gravity, and
  - b. Coarse aggregate--specific gravity (the program will not inquire whether it is BD or SSD; therefore the user needs to maintain consistency of type for accuracy).
3. Cement-strength method:
  - a. Sand--dry loose unit weight, percent fine aggregate to total aggregate by weight, and percent total water; and
  - b. Coarse aggregate--maximum aggregate size, dry loose unit weight, and percent total water.
4. Water method:
  - a. Coarse aggregate--dry rodded unit weight, specific gravity (SSD or BD), percent absorption, and maximum aggregate size; and
  - b. Sand--specific gravity (SSD or BD) and percent absorption.

When the user enters the adjustment routines, similar information will be requested. If cement replacement is to be performed, the specific gravity of the fly ash as well as whether the replacement is by volume or by weight will be required input. For moisture adjustment, the total percent moisture of the sand and the coarse aggregate will be necessary data. For the slump-adjustment and the air-adjustment routines, adjustment factors will be needed. Suggested values for all of the foregoing, except for the specific gravity of the fly ash, are available through the "help" requests.

Other information, including slump, air content, and water volume, will be requested of the user. As stated previously, help is available in tabular form to assist the user in arriving at a correct value. Selecting the "help" option will cause the program to provide the user with information necessary to supply the data.

Following are samples of the input required for prompted data entry. A few simple rules or guidelines should be followed when input is supplied:

1. When the requested data consist of more than one value, the information should always be entered on a single line, and a space should be skipped between values.

2. If the input is a string--for example, "yes," "help," "return," "proportional"--it is usually pos-

sible to enter only a portion of the string. A complete list of acceptable abbreviations is available.

3. Entering "return" or "r" anywhere within the program will cause the user to return either to the beginning of the program or to the beginning of that routine. In the latter case, it will be necessary to enter a second "return" or "r" to return to the beginning of the program.

4. Note that, on occasion, percentages will be requested as input. Values such as air content and absorption, which are typically reported as percentage values, will be entered as such. For example, 30 percent would be entered as 30 (not 0.30).

5. The unit weight of water is assumed to be 62.355 pcf and the specific gravity of portland cement is assumed to be 3.15.

6. If "Pause--(CR) to continue" appears on the terminal screen, the user must depress the carriage return to continue with program execution. Pauses have been inserted where it may be necessary for the user to examine the screen output but not necessarily to make a response.

A TYPICAL SESSION

Following is a typical interactive session. Strings, numbers, values, and words surrounded by quotes are input options. Capitalized portions of words are those letters required as input; T = terminal screen, U = user, \* = comments (these do not appear on the screen), (CR) = carriage return.

Follow usual log-on procedure.

```
T: Concrete--first trial batch--1985
  Select Procedure or Done
  "ACImix"          *volumetric
  "PROportional"    *mix by ratio
  "CONsistency"     *no slump - volumetric
  "CEMent"          *cement-strength
  "WEIght"
  "FILEs"
  "ADJust"
  * Only those letters that are capitalized must
  be entered when user responds.
  "DONE"           Entering "Return" at
                   any time will return
                   you to this point or to
                   calling routine.
```

```
U: ACI
T: Is prompting necessary? (Yes or No)
U: Y
T: Enter: Desired slump (inches)
      "Help" for listing of recommended slump
      for construction type
      "NC" for listing of State of North Caro-
      lina regulations
      "Return" to return to calling routine
```

```
U: H
T: Two tables are available, enter:
      "A" for slump recommended for construc-
      tion type
      "B" for consistency description at vari-
      ous slumps (used for no-slump concrete)
      "Return" to return to calling routine
```

```
U: A
T: Construction type      Max Slump      Min Slump
  Building columns        4              1
  Pavements and slabs    3              1
  Mass concrete           2              1
  (CR) to continue
```

```
U: *strike carriage return to continue execution
T: Would you like to view additional tables in this
  section? (Yes or No)
```

```
U: N
T: Enter: Desired slump (inches)
      "Help" for listing of recommended slump
      for construction type
      "NC" for listing of State of North Caro-
      lina regulations
      "Return" to return to calling routine
```

```
U: 4
T: Is concrete air entrained? (Yes or No)
U: Y
T: Enter: percent air (%)
      "Help" if air content unknown
      "Return" to return to calling routine
```

```
U: 5
T: Would you like a plot of unit weight versus air
  content? (Yes or No)
```

```
U: Y
T: Enter: water-cement ratio
      "Help" if needed
      "Return" to return to calling routine
```

```
U: 0.55
T: Enter: amount of water per cubic yard followed
  by "Gal" or "lb"
      "Help" if information necessary
      "Return" to return to calling routine
```

```
U: 35 Gal *Skip space between
T: For coarse aggregate enter: (single line-space
  after each value)
  dry rodded unit weight (lb/cy), followed
  by maximum aggregate size (inches)
  "Return" to return to calling routine
```

```
U: 98.5 0.75
T: For coarse aggregate, enter the following: (sin-
  gle line-space after each)
  percent absorption
  "BD" or "SSD"
  "Return" to return to calling routine
```

```
U: 2.65 0.6 BD
T: For fine aggregate enter the following: (single
  line-space after each)
  Fineness modulus from 2.36 to 3.04 in-
  clusive
  Specific gravity
  Percent absorption (%)
  "BD" or "SSD"
  "Return" to return to calling routine
```

```
U: 2.8 2.55 1 BD
T: Volume of coarse aggregate per unit volume of
  concrete is 0.62. Would you like to change it?
  (Yes or No)
```

```
U: N
T: The following data has been entered

  Percent air                5
  Slump                      4 in.
  Water-cement ratio         0.55
  Water (lb/cy)              291.8
  Water (gal/cy)             35
  Coarse aggregate data
  DRUW (PCF)                 98.5
  MAX aggregate              0.75
  Bulk-dry specific gravity  2.65
  Absorption (%)             0.6
  Fine aggregate data
  Fineness modulus          2.80
  Bulk-dry specific gravity  2.55
  Absorption percent        1
```

```
T: Would you like to reenter data? (Yes or No)
U: No
T: Would you like to enter adjustment section?
  (Yes or No)
U: No *For "yes" see the following example
T: Enter: desired batch size followed by "CF" or
  "CY" indicating unit to be used
  "Return" to return to calling routine
```

U: 3 CF  
 T: Batch size 3 cf  
 Water-cement ratio\* 0.55  
 Cement factor (bags/cy) 5.6  
 Percent air (%) 5  
 Fresh unit weight (lb/cf)\*\* 141.2  
 \*with fly-ash replacement w/c - w/(C+P)  
 \*\*unit weight is SSD except for mix by cement strength - or proportions

Pause  
 (CR) to continue

U: \*hit return

	Cubic Yard	Batch
Water (lb)	292.0	32.4
(gal)	35.0	3.9
Cement (lb)	531.0	58.9
(bags)	5.6	.6
Fly ash (lb)	--	---
C. Agg (lb-dry)	1649.0	183.2
(lb-SSD)	1659.0	184.3
Sand (lb-dry)	1318.0	146.4
(lb-SSD)	1331.0	147.7

(CR) to continue

U: \*hit return

T: Concrete -- First Trial Batch Design  
 Program - NCSU 1985  
 etc.

U: Done

T: Processing complete  
 To view output enter the following:  
 QED output.data  
 For hardcopy, enter the following:  
 Print output.data  
 For plot, enter the following:  
 Submit Clistlib.Clist (Plot)  
 Plot data may also be viewed on the Tektronix  
 CRT (see Tektronix manual).

#### TYPICAL ADJUSTMENT SESSION

Options exist to enter the adjustment section either from the design routines or on initial entry into the program. On entry into the adjustment section, information is requested concerning batch weights. It is not necessary to enter this information unless the entry directly follows the log-on procedure. If entry follows mix design, the batch weight information is carried forward.

The example begins at that point in the interactive example where entry into the adjustment section is offered. The user in this case answers yes.

T: terminal U: user \*: writer comments  
 T: Would you like to enter adjustment section?  
 (Yes or No)  
 U: Yes  
 T: Enter batch weights? (Yes or No)  
 (per yard parameters will be calculated automatically)  
 \*Only necessary to reenter batch weights if entry into adjustment section is direct from log-on or if batch to be adjusted differs from that already in the file.  
 U: No  
 T: Select letter or enter "Return" to return to calling routine  
 or "Done" to exit to output  
 "A" Fly-ash replacement of cement  
 "B" Increase slump  
 "C" Decrease slump  
 "D" Adjust for total moisture  
 "E" Adjust percent air  
 "F" Find batch cost

U: C

T: Enter: amount in inches by which slump is to be reduced followed by  
 "A" for reduction of water with increased sand  
 "B" for increased sand with decreased coarse aggregate  
 If "A" then follow with unit water multiplier (usually 0.75 to 1.00 gal/in./cy)  
 If "B" then follow with unit sand multiplier (approximately 5 percent/in./cy)

U: 3 A 1 \*same line - skip space between

\*T: Same water-cement ratio? (Yes or No)  
 (If "Yes," water-cement ratio is constant; if "No," cement weight is constant)

U: Yes

\*At this point adjustments are made and user decides whether further adjustments are desired.

T: Select letter or enter "Return" to return to calling routine or "Done" to exit to output

"A" Fly-ash replacement of cement

"B" Increase slump

"C" Decrease slump

"D" Adjust for total moisture

"E" Adjust percent air\*

"F" Find batch cost

U: A

T: WC constant by weight or volume? Enter "WC" or "Vol"

U: Vol

T: Enter specific gravity of fly ash

U: 2.20

T: Enter ratio of fly ash to total cementitious material

U: 0.35

T: Is that by weight "W" or Volume "V"?

U: W

At this point control transfers to calculation routines and then user is given option to continue or exit to output

T: Select letter or enter "Return" to return to calling routine or "Done" to exit to output

"A" Fly-ash replacement of cement

"B" Increase slump

"C" Decrease slump

"D" Adjust for total moisture

"E" Adjust percent air

"F" Find batch cost

U: Done \*At this point the exit to output is made and output routines, as in interactive design example, are entered.

#### CONCLUSIONS

This algorithm represents an attempt to codify what is in reality an empirical process--portland cement concrete mix design. The program assembles information that has been compiled by various individuals and organizations, including the PCA, the ACI, Goldbeck and Gray, and Popovics.

The program purpose is threefold. It provides a starting point for the design of a first-batch concrete mix based on information provided by the user and the computer. It gives the user the opportunity to adjust the various mix components for workability based on rules of thumb and local conditions, and, finally, it provides the user with a large amount of general and specific mix design information available either en masse or tailored to fit a given set of circumstances.

For the aforementioned reasons, the program should appeal especially to student users, who will find the information helpful and the ability to apply the different design methods useful.

When the recommended features have been added and

it is adapted for use on microcomputers, the program should become equally appealing to the mix designer in the industrial setting.

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