AN AUTOMATED CONCRETE MIX DESIGNER

Abdullah M. Y. Sirajuddin, Wajahat H. Mirza
King Abdulaziz University, Jeddah, Saudi Arabia

ABSTRACT. This paper discusses the development of a computer program that has the capabilities of designing mixes for normal weight, no-slump or light weight concrete. Designs based on American Concrete Institute (ACI) is adopted. The step-by-step approach and user friendly statements incorporated by the computer program help the designer in making the spot decisions according to factors as quality of constituent materials to be used in making concrete, level of technical supervision at the construction site, and the type of exposure environment for the built-up structure. The tables and figures, as given in the afore-mentioned method, has been converted into low variance equations developed by extensive regression analyses.

1. INTRODUCTION

The concrete mix design is a procedure that requires a wealth of information on the mix ingredients (water, cement, sand, coarse aggregate, and admixtures if any) as well as the mix environments, methods and techniques. Using this information to design a successful mix can be a time-consuming process both for educational and professional purposes. The rapid development of computers presented a good tool that can make the mix design process easy and quick.

Several computer programs have been developed based on various designing techniques. One of these programs is based on the surface area of aggregate which affects the water requirements and the segregation resistance of the mix [1]. In this program, a new developed factor named the Modified Specific Surface (MSS) is considered more significant than the Fineness Modulus. The latest development of this system is named CONAD. The system is quite sophisticated and complex in its calculation (180 numbers are displayed on the screen at one stage). A version of the program is designed for a batch plant operation [2]. Another concrete mix design program has been developed using the mix information of the Portland Cement Association (PCA), and the American Concrete Institute (ACI). Several adjustment routines for Fly-Ash replacement, increase or decrease in slump, moisture content change, percent air and batch cost are included [3].

A spreadsheet has been used to develop a concrete mix template that simplifies the mix design in tunnel project in Jordan [4]. With the development of the Knowledge Based programming techniques, expert systems based on concrete mix programs are increasingly published in the literature (ESCON and EXMIX are example of such programs) [5,6].

A Concrete Mix (CMIX) program is developed in this paper. The program is designed for both field professionals, students and researchers to understand the process of the design and to apply quick changes to the mix input variables in order to come up with a mix suitable for
individual requirements. The program uses the PASCAL programming language and is developed on 486 IBM compatible machines.

2. PROGRAM DEVELOPMENT

The program is developed in four phases. These phases are the user interface phase, the ACI Normal concrete mix design phase, the ACI No-Slump concrete mix design phase and the ACI Light Weight concrete mix design phase [7]. Figure 1 shows the general outline of the CMLX program. The following sections give detailed contents of each phase.

2.1. The User Interface Phase

In this phase, the overall structure of the program is designed and the following parts of the program are developed:

I. The user interactive data input procedure in which the user inputs the program data through the keyboard.

II. The file data input procedure in which the program reads the input data from a text file.

III. An input data editing procedure in which the user can change one or more input data for another run without leaving the program.

IV. The output displaying procedure in which the design result can be displayed on the screen or sent to the printer.

Figure 2 shows the flowchart of the common data needed in the three ACI concrete design types. Data needed for each particular design type is shown in Table 1 and the flowcharts of the mix calculations for each method are shown in Figures 3, 4 and 5. Details of these figures are discussed in sections 2.3, 2.4 and 2.5 respectively.

2.2. Regression Equations

The Tables in the appendix A list the reference number and the title of the tables of the ACI code that are used in the Normal, the Light Weight and the No-Slump manual mix procedure. The Water/Cement Ratio vs Compressive Strength table in each method is replaced with a regression equation. Also, the Volume of Coarse Aggregate vs Finesness Modulus of Sand and Maximum Aggregate Size table in each method is replaced with regression equations.

The original upper and lower limit of the Finesness Modulus in each table are from 2.4 to 3.0. This range has been expanded from 1.5 to 3.5 by using the regression equations replacing thereby the tedious manual procedure of extrapolation.

2.3. The ACI Normal Concrete Mix Design Phase

The ACI Normal concrete mix design procedure is detailed in the Flowchart of Figure 3. The type and range of each data needed is displayed in Table 1. These data variables are used to develop other design parameters. The design calculation steps are displayed in the last part of the flowchart of Figure 3.

2.4. The ACI Light Weight Concrete Mix Design Phase

Figure 4 shows the flowchart of the ACI light weight concrete mix. The range of the data used in the design is displayed in Table 1. This method uses the same data used in the ACI Normal design in addition to the Freshly-mixed concrete density entry as shown in Table 1. A different mix calculation is followed in this method as shown in the last part of the flowchart of Figure 4.
Table 1: Lower/Upper Parameter Limits for the ACI Normal, ACI Light Weight and ACI No Slump Concrete Mix.

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Design Mix For Concrete Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal</td>
<td>Light Weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower Limit</td>
<td>Upper Limit</td>
</tr>
<tr>
<td>1</td>
<td>Minimum Strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Air entrained (N/sq.mm)</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>- Non-air entrained (N/sq.mm)</td>
<td>5</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>Design Strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Air entrained (N/sq.mm)</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>- Non-air entrained (N/sq.mm)</td>
<td>14</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>Maximum aggregate size* (mm)</td>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Slump</td>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>5</td>
<td>Consistency</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Unit weight of coarse aggregate (Kg/cu.m)</td>
<td>1,400</td>
<td>1,300</td>
</tr>
<tr>
<td>7</td>
<td>Specific gravity of coarse aggregate</td>
<td>2.4</td>
<td>2.85</td>
</tr>
<tr>
<td>8</td>
<td>Specific gravity of fine aggregate</td>
<td>2.4</td>
<td>2.85</td>
</tr>
<tr>
<td>9</td>
<td>State of moisture of coarse aggregate</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Effective water absorption of coarse aggregate</td>
<td>0</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>State of moisture of fine aggregate</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Effective water absorption of fine aggregate</td>
<td>0</td>
<td>2%</td>
</tr>
<tr>
<td>13</td>
<td>Fineness modulus of fine aggregate</td>
<td>1.5</td>
<td>3.5</td>
</tr>
<tr>
<td>14</td>
<td>Specific gravity of cement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Freshly-mixed concrete density (Kg/cu.m)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* In program generated aggregate size: 1) For Unreinforced concrete column and walls use Aggregate Size = 0.2 x Minimum Thickness. 2) For Unreinforced concrete pavement use Aggregate Size = 0.33 x Minimum Depth. 3) For Reinforced concrete use Aggregate Size = 0.75 x Minimum Clear Space.
Figure 1: Concrete MIX Design Program Outline (CMIX)

Figure 2: Detailed Steps of the CMIX Program
2.5. The ACI No Slump Concrete Mix Design Phase

The data needed in this method is almost the same as the ACI Normal method. The only difference is that this method uses the consistency data entry (instead of slump) as shown in Table 1. The mix calculation procedure followed in this method is shown in the last part of the flowchart of Figure 5.

3. DEMONSTRATION RUN

CMIX is a user-friendly program in which there is continuous interaction between the user and the computer. The program starts with a question about the type of mix the user needs and the means of data input (keyboard or data file) as shown in Appendix B. If the user chooses to enter the data through the keyboard, several questions on the mix parameters will be asked and the user must provide the answer. The limits of the parameters are displayed in the lower part of the screen for each question. The user will then be asked whether he wants to display the data on the screen or the printer. If the user wants to edit the data before the next run, he will choose this option at this stage. The data entered and the result of the mix calculation can then be displayed.
4. RESEARCH SIGNIFICANCE AND UTILIZATION

The concrete mix design is a well defined sequential task that has been defined in the ACI code. This fact made the process easy to be implemented in a computer program. The program gives the user the ease of changing the input of the design to see the effect on the output. Changing the value of one or several parameters of the design can be seen in a few seconds. This program can be utilized by concrete manufacturers in the construction industry as well as students and researchers in the academic institutions.

5. RECOMMENDATIONS FOR FUTURE WORK

The vast capabilities of personal computers, both in terms of memory storage and the speed of calculations, presents a big opportunity to expand the work on concrete mix design on a much larger scale. This expansion should encompass addition of new additives and pozzolaine materials, influence of exposure condition on the fresh and hardened state of concrete and the quality control aspects. Experts systems may be developed to monitor the concrete mix design at each step from start to finish.
Figure 5: Steps in ACI No Slump Concrete Mix Design Calculations

REFERENCES

[7] American Concrete Institute, Committee 318, Building Code Requirements for Reinforced Concrete (318-89), Detroit, Michigan, American Concrete Institute, 1989.
## APPENDIX A

Reference of the ACI tables used in the CMIX program

<table>
<thead>
<tr>
<th>Table reference in the paper</th>
<th>Table number in the ACI code</th>
<th>Corresponding table title in the ACI Normal Mix design</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>A1.5.2.3</td>
<td>Approximate requirements for mixing water and air content for different workability and nominal maximum sizes of aggregate according to ACI 211.1-81.</td>
</tr>
<tr>
<td>A2</td>
<td>A1.5.2.4(a)</td>
<td>Relation between water/cement ratio and average compressive strength of concrete, according to ACI 211.1-81.</td>
</tr>
<tr>
<td>A3</td>
<td>A1.5.2.4(b)</td>
<td>Maximum permissible water/cement ratio for concrete in severe exposures.</td>
</tr>
<tr>
<td>A4</td>
<td>A1.5.2.6</td>
<td>Volume of coarse aggregate per unit volume of concrete as given by ACI 211.1-81.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table reference in the paper</th>
<th>Table number in the ACI code</th>
<th>Corresponding table title in the ACI Light Weight Mix design</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>3.6.2.3(b)</td>
<td>Approximate mixing water and air content requirements for different slumps and maximum sizes of aggregate.</td>
</tr>
<tr>
<td>B2</td>
<td>3.6.2.4(a)</td>
<td>Relationships between water/cement ratio and compressive strength of concrete.</td>
</tr>
<tr>
<td>B3</td>
<td>3.6.2.4(b)</td>
<td>Maximum permissible water/cement ratio for concrete in severe exposures.</td>
</tr>
<tr>
<td>B4</td>
<td>3.6.2.6</td>
<td>Volume of coarse aggregate per unit of volume of concrete.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table reference in the paper</th>
<th>Table number in the ACI code</th>
<th>Corresponding table title in the ACI No Slump design</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>A2.2.3.1(c)</td>
<td>Approximate mixing water requirements for different consistencies and maximum sizes of aggregate.</td>
</tr>
<tr>
<td>C2</td>
<td>A2.3.4.1</td>
<td>Maximum permissible water/cement ratio for concrete in severe exposures.</td>
</tr>
<tr>
<td>C3</td>
<td>A2.3.4.3</td>
<td>Relationships between water/cement ratio and compressive strength of concrete.</td>
</tr>
<tr>
<td>C4</td>
<td>A2.3.5.1(a)</td>
<td>Volume of coarse aggregate per unit of volume of concrete (metric) of plastic consistency (8-13 cm slump).</td>
</tr>
<tr>
<td>C5</td>
<td>A2.3.5.1(b)</td>
<td>Volume of coarse aggregate per unit volume of concrete for different consistencies.</td>
</tr>
</tbody>
</table>
APPENDIX B

Sample run of the CMIX program

YOUR INPUT WILL BE:
1. KEYBOARD INPUT
2. FILE INPUT
TYPE YOUR CHOICE (1 OR 2): 1

Type of Concrete Mix Design:
1 = ACI - NORMAL CONCRETE PROCEDURE
2 = ACI - NO SLUMP CONCRETE PROCEDURE
3 = ACI - LIGHT WEIGHT CONCRETE PROCEDURE
4 = EXIT

TYPE YOUR CHOICE: 1

GIVEN DATA (Part 1)

1. CONCRETE IS: Not-Air Entrained
2. STRUCTURE WET CONTINUOUSLY OR FREQUENTLY AND EXPOSED TO FREEZING AND THAWING:
3. STRUCTURE HAS TRANSITIONS (Railings, Curbs, Sills, Ledges, Ornamental Work) AND SECTIONS WITH LESS THAN 25 (mm) COVER OVER STEEL: YES
4. STRUCTURE IS EXPOSED TO SEA WATER OR SULFAT: YES
5. TYPE OF CEMENT: TYPE V

Press any Key to Continue...

GIVEN DATA (Part 2)

1. Not Applicable
2. MINIMUM DESIRED STRENGTH: 25 N/mm²
3. DESIGN STRENGTH: 25 N/mm²
4. CONSTRUCTION TYPE:...
5. MINIMUM DEPTH:...
6. MAXIMUM AGGREGATE SIZE: 12.5
7. SUMP: 40 mm
8. COARSE AGGREGATE UNIT WEIGHT: 1500 Kg/Cu m
9. SPECIFIC GRAVITY OF COARSE AGGREGATE: 2.58
10. SPECIFIC GRAVITY OF FINE AGGREGATE: 2.60
11. COARSE AGGREGATE MOISTURE STATUS: SATURATED SURFACE DRY
12. EFFECTIVE WATER ABSORB OF COARSE AGG: 0.0 %
13. FINE AGGREGATE MOISTURE STATUS: SATURATED SURFACE DRY
14. EFFECTIVE WATER ABSORB OF FINE AGG: 0.0 %
15. FLEXIBILITY MODULUS OF FINE AGGREGATE: 2.40
16. SPECIFIC GRAVITY OF CEMENT: 3.15

Press any Key to Continue...

DO YOU WANT THE OUTPUT:
1. DISPLAYED ON THE SCREEN
2. SENT TO THE PRINT...)
3. SAVED ON A FILE
4. EDIT THE DATA FOR NEXT RUN
5. RUN THE PROGRAM AGAIN
6. EXIT

TYPE YOUR CHOICE (1, 2, 3, 4, 5 OR 6): 1

INPUT PARAMETERS:

*** STANDARD USED IS: ACI - NORMAL CONCRETE COMMAND
*** THE CONCRETE IS NOT AIR ENTRAINE
*** THE STRUCTURE HAS THIN SECTIONS OR SECTIONS WITH LESS THAN 1 in COVER OVER STEEL
*** STRUCTURE IS EXPOSED TO SEA WATER OR SULFATE

CEMENT USED = TYPE V
DESIGN STRENGTH = 25 N/mm²
SLUMP = 40 mm
MAX. AGG. SIZE = 12.5 mm
UNIT WT OF COARSE AGG. = 1650 Kg/Cu m
SPECIFIC GRAVITY OF COARSE AGG. = 2.58
SPECIFIC GRAVITY OF FINE AGG. = 2.60
STATE OF MOISTURE OF COARSE AGG. = SATURATED SURFACE DRY
STATE OF MOISTURE OF FINE AGG. = SATURATED SURFACE DRY
EFFECTIVE WATER ABSORPTION OF COARSE AGG. = 0.0 %
EFFECTIVE WATER ABSORPTION OF FINE AGG. = 0.0 %
FM OF FINE AGG. = 2.40
SPECIFIC GRAVITY OF CEMENT = 3.15

PRESS ANY KEY...

THE DESIGN:

W/C RATIO (CONSIDERING SEVERE EXPOSURE) = 0.450
W/C RATIO (NOT CONSIDERING SEVERE EXPOSURE) = 0.620
FINAL W/C RATIO USED = 0.450
AIR UNTRAPPED = 2.5 %
HULK VOLUME OF COARSE AGG. = 0.59

ABSOLUTE VOLUME OF WATER = 0.200 Cu m
ABSOLUTE VOLUME OF CEMENT = 0.141 Cu m
ABSOLUTE VOLUME OF COARSE AGG. = 0.378 Cu m
ABSOLUTE VOLUME OF FINE AGG. = 0.925 Cu m
ABSOLUTE VOLUME OF FINE AGG. = 0.257 Cu m

QUANTITY PER Cu m OF CONCRETE:
WATER = 200 Kg
CEMENT = 444 Kg
COARSE AGG. = 974 Kg
FINE AGG. = 667 Kg

WET DENSITY OF CONCRETE = 2285 Kg/Cu m
MIX PROPORTION = 1 : 1.50 : 2.19 : W/C = 0.45
WATER TO BE ADDED TO THE CONCRETE MIX DUE TO AGGREGATE ABSORPTION = 0.000 Liter/Cu m

CONCRETE

PRESS ANY KEY...