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# Computerized Proportioning and Adjustment of Concrete Mixes

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The procedure of concrete mix proportioning adopted by the ACI Standard 211.1-77 uses a set of tables relating the different ingredients. Regression analysis was used to convert these tables into regression equations which in turn allowed the design procedure to be easily computerized.

## Introduction

During the last few years, the introduction of microcomputers has helped in many of the tasks connected with different civil engineering practices: structural analysis and design, project management, etc. However, microcomputers have not commonly been used for the proportioning of concrete mixes, probably because mix design is more empirical, involving many trials, than analytical.

In big projects where a number of mixes with different requirements are needed and where frequent adjustments of the mixes are necessary, design of such mixes, without the aid of a computer, becomes a tedious and laborious task.

A computer program for concrete mix design and adjustment has been developed, based on the method proposed by the American Concrete Institute in the ACI Standard 211.1-77 [1]. The program is written in Fortran IV. The flow chart of the program is shown in Fig. 1.

### *ACI Method for Mix Proportioning*

The procedure for selection of mix proportions proposed by the ACI is applicable for both normal and heavy-weight concrete. Estimating the required batch weights for concrete involves a sequence of logical, straightforward steps which, in effect, fit the characteristics of the available materials into a mixture suitable for

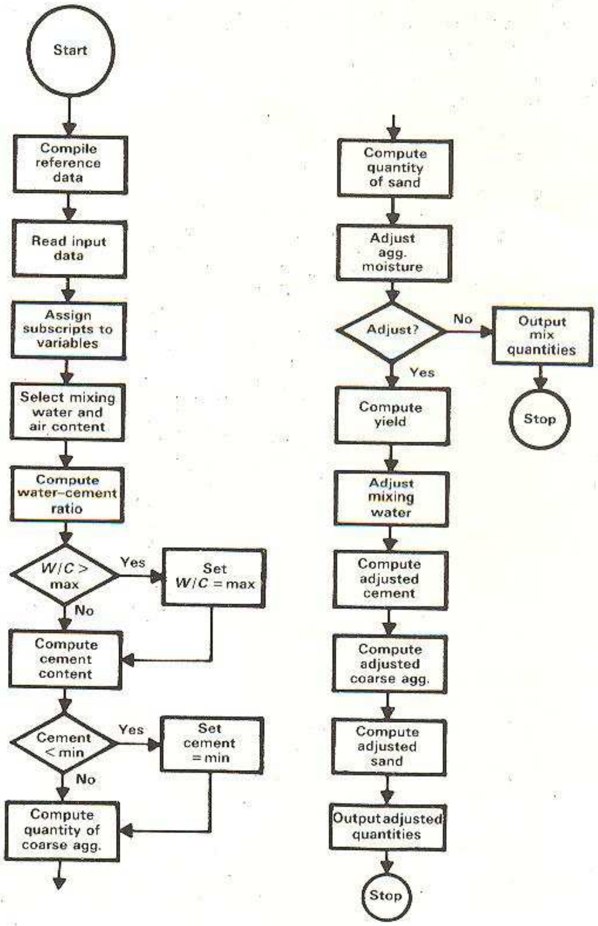

**Fig. 1**

the work. The job specifications may dictate some or all of the following: maximum water–cement ratio, minimum cement content, air content, slump, maximum size of aggregate, strength, admixtures, and special type of cement or aggregate. Using a number of different tables, the mix design procedures are carried out in nine stages as follows:

> Choice of slump: choice of maximum size of aggregate; estimation of mixing water; selection of water–cement ratio; calculation of cement content; estimation of coarse and fine aggregate content; adjustment for aggregate moisture;

and finally trial batch adjustment. In the program all the tables have been expressed by mathematical expressions using regression analysis.

### *Regression Analysis*

Regression analysis is one of the most widely used statistical techniques for exploring relationships between two or more variables, often by a linear equation

$$y = b_0 + b_1 x \tag{1}$$

but sometimes by other algebraic expressions. The dependent variable $y$ is sometimes related to more than one independent variable, $x_1, x_2, \ldots$, etc.

The constant coefficients in the regression equation are called the regression coefficients. In the simple linear equation the regression coefficient is the slope of the line and $b_0$ is its intercept with the $Y$-axis. For finding the relation between the variables it is usually recommended to try to fit a straight-line linear equation. If the data do not fall on a straight line, some transformation of the $x$ variable might be called for. Equation (1) can thus be written in the form

$$y = C_0 + C_1 \cdot F(x) \tag{2}$$

where $F(x)$ is some function of $x$.

$F(x)$ may be chosen upon plotting of the data. If the $y$ values increase as $x$ increases and the data appear to be concave downward, the functions $1/x$, $\log x$, or $\sqrt{x}$ may fit the data. However, if the data are concave upward, $e^x$, $x^2$ or $x$ to some power greater than one may be used. If $y$ values decrease as $x$ increases, the reverse is true. Curves of $1/x$, $\log x$ or $\sqrt{x}$ are concave upward, and the others are concave downward. The equation fitted to the data is the least squares fit. The measure of goodness of fit is the correlation coefficient designated by $r$, and $r^2$ is the fraction of the sum of squares of deviations of the variable from its mean that is accounted for by the regression line. The larger the value of $r$, the better the correlation. An $r$ value of unity indicates perfect correlation, whereas an $r$ value of zero indicates no correlation [2].

### *Derived Regression Equations*

The computer program used for regression analysis was the Statistical Analysis System (SAS) [3].

Table A1.5.2.3 of Ref. [1] gives the required mixing water for given ranges of slump and different maximum sizes of aggregate. The regression equations relating these variables are found to be as follows:

For non-air-entrained concrete

$$\text{Water (kg/m}^3) = 241.3 - 69.1 \log(\text{max. size of agg. mm}) + 51.4 \log(\text{slump cm}) \quad r^2 = 0.90 \tag{3}$$

For air-entrained concrete

$$\text{Water (kg/m}^3) = 209.0 - 57.4 \log(\text{max. size of agg. mm}) + 48.5 \log(\text{slump cm}) \quad r^2 = 0.86 \tag{4}$$

Values of water–cement ratios required to develop the required strength are given in Table A1.5.2.6 of Ref. [1]. The regression equations are:

For non-air-entrained concrete

$$f'_c = 57 - 932 \log(W/C) \quad r^2 = 0.99 \tag{5}$$

For air-entrained concrete

$$f'_c = 23 - 825 \log(W/C) \quad r^2 = 0.99 \tag{6}$$

where

$f'_c$ = 28-day compressive strength of concrete in kgf/cm$^2$

$W/C$ = water–cement ratio by weight.

The required volume of coarse aggregate per unit volume of concrete is expressed in terms of the maximum size of aggregate and the fineness modulus of sand by the following regression equation:

$$\text{Vol. of coarse agg.} = 0.39 + 0.40 \log(\text{max. size of agg. mm}) - 0.116(\text{fineness mod.}) \quad r^2 = 0.86 \tag{7}$$

The percentage of air content is related to the maximum size of aggregate (Table A2.5.2.3 of Ref. [1]) and is given by the following regression equations:

For non-air-entrained concrete

$$\text{Max. size of agg. (mm)} = 45.11 - 94.57 \log \text{air} \quad r^2 = 0.82 \tag{8}$$

For air-entrained concrete

$$\text{Max. size of agg. (mm)} = 221.76 - 261.10 \log \text{air} \quad r^2 = 0.73 \tag{9}$$

## Discussion of Results

Tables 1, 2 and 3 have been prepared using equations (3)-(7) for comparison with data of the ACI Standard [1] together with data obtained by Jerath and Kabbani [4].

Table 1 shows the mixing water requirements for different ranges of slump and maximum sizes of aggregates. Equations (3) and (4) were derived based on average slumps.

Table 2 shows the relationship between water-cement ratio and the compressive strength of concrete. It can be noted that both regression equations (5) and (6) give

**Table 1. Approximate Mixing Water Requirements For Different Slumps and Maximum Size of Aggregates (Metric)**

| Slump (cm) | | Water kg/m$^3$ of Concrete for Indicated Maximum Size of Aggregate in mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 10 | 12.5 | 20 | 25 | 40 | 50 | 70 | 150 |
| | | **Non-Air-Entrained Concrete** | | | | | | | |
| 3 to 5 | ACI | 205 | 200 | 185 | 180 | 160 | 155 | 145 | 125 |
| | Equation (3) | 203 | 196 | 182 | 176 | 162 | 155 | 145 | 122 |
| | Jerath and Kabban | 209 | 201 | 185 | 177 | 163 | 156 | 147 | 128 |
| 8 to 10 | | 225 | 215 | 200 | 195 | 175 | 170 | 160 | 140 |
| | | 221 | 214 | 200 | 194 | 180 | 173 | 163 | 140 |
| | | 227 | 218 | 200 | 192 | 177 | 170 | 160 | 139 |
| 15 to 18 | | 240 | 230 | 210 | 205 | 185 | 180 | 170 | — |
| | | 235 | 228 | 214 | 207 | 193 | 186 | 176 | — |
| | | 241 | 231 | 213 | 204 | 188 | 180 | 170 | — |
| Entrapped Air per cent | ACI | 3 | 2.5 | 2 | 1.5 | 1 | 0.5 | 0.3 | 0.2 |
| | Equation (8) | 2.4 | 2.2 | 1.8 | 1.6 | 1.0 | 0.9 | 0.6 | 0.1 |
| | | **Air-Entrained Concrete** | | | | | | | |
| 3 to 5 | ACI | 180 | 175 | 165 | 160 | 145 | 140 | 135 | 120 |
| | Equation (4) | 181 | 175 | 163 | 158 | 146 | 141 | 132 | 112 |
| | Jerath and Kabban | 184 | 178 | 166 | 161 | 150 | 145 | 138 | 123 |
| 8 to 10 | | 200 | 190 | 180 | 175 | 160 | 155 | 150 | 135 |
| | | 198 | 192 | 181 | 175 | 163 | 158 | 149 | 130 |
| | | 201 | 194 | 181 | 175 | 164 | 158 | 151 | 135 |
| 15 to 18 | | 215 | 205 | 190 | 185 | 170 | 165 | 161 | — |
| | | 211 | 205 | 193 | 188 | 176 | 170 | 162 | — |
| | | 215 | 208 | 194 | 188 | 175 | 169 | 161 | — |
| Air content per cent | ACI | 8 | 7 | 6 | 5 | 4.5 | 4 | 3.5 | 3 |
| | Equation (9) | 6.5 | 6.3 | 5.9 | 5.7 | 5.0 | 4.6 | 3.5 | 1.9 |

**Table 2. Relationship between Water–Cement Ratio and Compressive Strength of Concrete (Metric)**

| Compressive Strength at 28 Days kgf/cm$^{2}$* | Water–Cement Ratio, by Weight | | | | | |
|---|---|---|---|---|---|---|
| | Non-Air-Entrained Concrete | | | Air-Entrained Concrete | | |
| | ACI* | Equation (5) | Jerath and Kabbani | ACI* | Equation (6) | Jerath and Kabbani |
| 450 | 0.38 | 0.38 | 0.40 | — | — | — |
| 400 | 0.43 | 0.43 | 0.43 | — | — | — |
| 350 | 0.48 | 0.48 | 0.47 | 0.40 | 0.40 | 0.40 |
| 300 | 0.55 | 0.55 | 0.52 | 0.46 | 0.46 | 0.45 |
| 250 | 0.62 | 0.62 | 0.58 | 0.53 | 0.53 | 0.51 |
| 200 | 0.70 | 0.70 | 0.67 | 0.61 | 0.61 | 0.59 |
| 150 | 0.80 | 0.79 | 0.81 | 0.71 | 0.70 | 0.71 |

* Table A1.5.2.4(a), Ref. [1].

almost identical values to those given by the ACI Standard. This is also indicated by the higher correlation coefficients. The results obtained by Jerath and Kabbani, however, seem to be slightly lower. The regression equations derived by them were in exponential form [4].

The volume of coarse aggregate per unit volume of concrete is tabulated in Table 3. Equation (7) indicates very good correlation with the ACI data and compares favourably with the results given by the exponential equation of Jerath and Kabbani.

## Conclusions

*The regression equations derived indicated very good correlation with the ACI* data. Their chief advantage lies in the possibility of computerizing the mix design procedure. They also have advantage over tables in particular when interpolation is called for. Moreover, they indicate the real variables more clearly than when they are in tabular form.

## References

1. **ACI Standard 211.1–77**, *Recommended Practice for Selecting Proportions for Normal and Heavyweight Concrete*, American Concrete Institute, Detroit (1977).
2. **Volk, W.**, *Engineering Statistics with a Programmable Calculator*, McGraw-Hill Book Company.
3. **Statistical Analysis System (SAS) User's Guide**, SAS Institute, Inc., North Carolina (1979).
4. **Jerath, S.** and **Kabbani, I.A.**, Computer-aided concrete mix proportioning, *Journal of the American Concrete Institute*, Vol. **80** (4), pp. 312–317 July–August (1983).

Table 3. Volume of Coarse Aggregate Per Unit Volume of Concrete (Metric)

| Maximum Size of Aggregate mm | Volume of Dry-Rodded Coarse Aggregate per Unit Volume of Concrete for Different Fineness Modulus of Sand | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.40 | | | 2.60 | | | 2.80 | | | 3.00 | | |
| | ACI | Equation (7) | Jerath and Kabbani | ACI | Equation (7) | Jerath and Kabbani | ACI | Equation (7) | Jerath and Kabbani | ACI | Equation (7) | Jerath and Kabbani |
| 10 | 0.50 | 0.51 | 0.55 | 0.48 | 0.49 | 0.53 | 0.46 | 0.47 | 0.51 | 0.44 | 0.44 | 0.50 |
| 12.5 | 0.59 | 0.55 | 0.59 | 0.57 | 0.53 | 0.57 | 0.55 | 0.50 | 0.55 | 0.53 | 0.48 | 0.53 |
| 20 | 0.66 | 0.63 | 0.64 | 0.64 | 0.61 | 0.62 | 0.62 | 0.59 | 0.60 | 0.60 | 0.56 | 0.59 |
| 25 | 0.71 | 0.67 | 0.67 | 0.69 | 0.65 | 0.65 | 0.67 | 0.62 | 0.63 | 0.65 | 0.60 | 0.61 |
| 40 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.72 | 0.72 | 0.71 | 0.69 | 0.68 | 0.68 | 0.67 |
| 50 | 0.78 | 0.79 | 0.77 | 0.76 | 0.77 | 0.75 | 0.74 | 0.74 | 0.73 | 0.72 | 0.72 | 0.71 |
| 70 | 0.81 | 0.85 | 0.83 | 0.79 | 0.83 | 0.80 | 0.77 | 0.80 | 0.78 | 0.75 | 0.78 | 0.76 |
| 150 | 0.87 | 0.98 | 0.95 | 0.85 | 0.96 | 0.92 | 0.83 | 0.94 | 0.90 | 0.81 | 0.91 | 0.87 |