CONCRETE MIX DESIGN SOFTWARE

The software incorporates the information set forth in ACI 211, ACI 214 and ACI 613 Standards for the production of all types of concrete for structures of various load-carrying capacities and degrees of exposure. It determines the concrete batch quantities in Imperial and in International units for air-entrained and non-air-entrained concretes. The program output includes the determination of the required average design strength, the probabilities of tests falling below the characteristic strength, the required water/cement ratio, the percentage of voids in the mix, and the quantities of the concrete ingredients.

CONCRETE software is a users' friendly program that would guide the users to make correct decisions and reject illogical data input. The design procedure was used to design concrete mixes for many projects totalling in volume to about 2 million cubic meters with excellent results.

The following literature explains the theory of concrete mix design. It contains excerpts from ACI Standards that were incorporated in CONCRETE software

INTRODUCTION

Proportions for concrete should be selected to make the most economical use of available materials to produce concrete of the required placeability, durability and strength. The properties of both aggregates and cement have a marked effect on strength and durability of concrete and on the amount of mixing water required for its placement.

Concrete should be placed with the minimum quantity of mixing water consistent with proper handling, since this will tend to greatly improve its strength, durability and other desirable properties. Proportions should be selected to produce concrete that conform to the following requirements

1. of the stiffest consistency (lowest slump) which can be placed efficiently to provide a homogeneous mass
2. with the maximum size of aggregate economically available and consistent with satisfactory placement
3. of adequate durability to withstand satisfactorily the weather and other destructive agents to which it may be exposed
4. of the strength required to withstand the loads to be imposed without danger of failure.

CONCRETE PRODUCTION CONTROL

The primary function of compression tests of field concrete is to ensure the production of uniform concrete of desired strength and quality. Concrete being a hardened mass of heterogeneous materials is subject to the influence of numerous variables. The magnitude of variations in the strength of concrete depends upon how well the materials, concrete manufacture, and tests are controlled. Difference in strength can be traced to two fundamentally different sources (a) differences in strength-producing properties of the concrete mixture, and (b) apparent difference in strength caused by discrepancies in tests.

STATISTICAL FUNCTIONS

If the theory of the weakest link is applied to concrete, the number of tests lower than the desired strength is more important in computing the load-carrying capacity of

concrete structures than the average strength. It is impractical, to specify minimum strength since the law of normal probability indicates that we can expect one strength out of every six tests to be lower than the standard deviation, σ below average strength X, one out of every 44 will be lower than 2σ below X and one out of 741 will be lower than 3σ below X.
The strength of concrete test specimens on controlled projects can be assumed to fall into some pattern of normal frequency distribution curve. Where there is good control, the strength values will be bunched close to the average, and the curve will be tall and narrow. As the variations in strength increase, the values spread and the curve becomes low and elongated.
CONCRETE software incorporates the following functions of the normal frequency curve in evaluating strength data.
The average strength of all specimens, X is calculated as follows

$$X = \frac{X_1 + X_2 + X_3 + \ldots X_n}{n} \qquad (1)$$

Where X_1, X_2, X_3 . . . . X_n are the strength results of individual specimens and n is the total number of specimens tested.
The measure of dispersion, the standard deviation, is the root-mean-square deviation of the strengths from their average. The standard deviation is the radius of gyration of the area under the theoretical probability curve about the centre. The standard deviation, σ is found by extracting the square root of the average of the squares of deviations of individual strengths from their average.

$$\sigma = \sqrt{\frac{(X_1 - X)^2 + (X_2 - X)^2 + (X_3 - X)^2 . \quad . \quad . \quad (X_n - X)^2}{n}} \qquad (2)$$

Coefficient of variation, V is the standard deviation expressed as a percentage of the average strength, as follows

$$V = \frac{\sigma}{X} * 100 \qquad (3)$$

This function makes it possible to express the degree of dispersion on percentage basis rather than the absolute. The ratings of control are based on experience from a large number of projects and are presented in Table 1 here below as a general guide in evaluation of concrete control

Table 1

Class of operation	Coefficients of variation for different control standards			
	Excellent	Good	Fair	Poor
Overall variations:				
General construction	below 10	10 to 15	15 to 20	above 20
Laboratory control	below 5.0	5.0 to 7.0	7.0 to 10	above 10

To satisfy strength performance requirements expressed in this fashion the average strength of concrete must obviously be in excess of the design strength specified, f'_c, the degree of excess strength depending on the expected uniformity of concrete production and the allowable proportions of low tests. The required average strength, f_{cr} for any design can be expressed as

$$f_{cr} = \frac{f_c^{'}}{\left(1 - t\frac{V}{100}\right)} \tag{4}$$

Where
t = a constant depending upon the proportion of tests that may fall below f'_c and the number of samples used to establish V. Its values are obtained from Table 4, ACI 214.
V = forecasted value of the coefficient of variation expressed in percent

EXAMPLE OF COMPUTATIONS
In this example, concrete is required for a pre-cast pre-stressed girder for a bridge which will be exposed to severe weather with frequent alterations of freezing and thawing. Structural considerations require it to have a design characteristic compressive strength of 26 N/mm^2 (4000 psi) at 28 days. From previous experience in the plant production, the degree of control may be assumed to be excellent with a coefficient of variation, $V \leq 10$ %. It is further required that no more than one test in 20 may fall below the design strength of 26 N/mm^2 (4000 psi) at 28 days.
The size of the section and spacing of pre-stressing tendons are such that a maximum size aggregate of 3.81 cm (1 ½ in) is indicated and a properly graded coarse aggregate is locally available. Heavy internal and external vibration is available to achieve compaction, enabling the use of concrete with stiff consistency.

General design criteria
1. Cement is assumed to have a specific gravity of 3.15
2. The coarse aggregate has a specific gravity of 2.68, absorption of 0.5 % and dry-rodded unit weight of 1.6 kg/lit
3. The fine aggregate has a specific gravity, bulk dry, of 2.65, an absorption of 0.7 %, and fineness modulus of 2.80

Running the program
After running the program, users may select either Imperial or International Units of measurements and display the results in both units. In this particular example, the following parameters have been selected
1. International Units of Measurements
2. The category of this job is assumed to fall under General Construction
3. The degree of control is assumed to be excellent. Hence, a coefficient of variation, V shall be taken as ≤ 10 %
4. About 33 specimens shall be made for the trial mix of this concrete.
5. The structure is not thin
6. Since the exposure is severe, air-entrained concrete shall be used as advised by the program. The program would adopt a water/cement ratio not exceeding 0.44.
7. A characteristic 28 day compressive strength of 26 N/mm^2 is specified
8. A slump of 2.54 cm (1 in) is specified

9. A maximum size of coarse aggregate of 3.81 cm (1 ½ in) is selected
10. Fine aggregate fineness modulus is taken as 2.8
11. Coarse aggregate specific gravity is taken as 2.68
12. Fine aggregate specific gravity is taken as 2.65
13. Coarse aggregate dry-rodded unit weight is 1.6 kg/lit

Program output

1. Average strength

The required average design compressive strength at 28 days is 31 N/mm^2.
The coefficient of variation is ≤ 10 %.
Probability of strength ≥ than the characteristic strength is 96.09 %.

2. Batch quantities per cubic meter of concrete shall be as follows:

Cement	331 kg
Water	143 kg
Void in mix	4.5 %
Sand (dry bases)	749 kg
Coarse aggregate (dry bases)	1136 kg
Water/cement ratio	0.433
Total weight per cubic meter of wet concrete	2360 kg

3. Batch quantities per cubic yard of concrete shall be as follows:

Cement	558 lb
Water	242 lb
Voids in mix	4.5 %
Sand (dry bases)	1262 lb
Coarse aggregate (dry bases)	1915 lb
Water/cement ratio	0.433
Total weight per cubic yard	2976 lb