A NEW APPROACH TO CONCRETE MIX DESIGN USING COMPUTER TECHNIQUES

Okoloekwe, R.C. (MNSE)
Department of Civil Engineering,
Enugu State University of Science and Technology.
Enugu - Nigeria

Okafor, F.O. (MNSE)
Department of Civil Engineering
University of Nigeria, Nsukka.
Nsukka – Nigeria.

ABSTRACT

Concrete is an essential part of most civil engineering works. Mix design of concrete is usually specified in terms of prescription or performance. The purpose of this work is to develop a model that is capable of reproducing any expected concrete strength within a specified range of cement content. In addition such a model can be used to generate data on mix proportions and their corresponding compressive strength, thereby furnishing useful information for general purpose, safe-ready-to-use mix design. Such data were generated and checked against values obtainable from standard mix design practice and found to agree very well within the limits of experimental error. A test of the statistical significance of the developed model using F-statistic shows that the regression as a whole is highly significant.

The work culminated in the development of a concrete mix design chart which presents mix proportions for various grades of concrete ranging from compressive strength values of 10N/mm^2 to 50N/mm^2. This chart is expected to be of immense help to site supervisors involved in concrete production since the use of the chart as a guide to batching the ingredients of concrete, will eliminate the need for tedious mix design procedures and at the same time ensure that correct quantities of the required materials are used for concrete production.

INTRODUCTION

Concrete production over the years has been done either by using prescribed mixes or designed mixes. These methods involve the use of some design tables and graphs followed by a series of calculations. The result of the design process is the stipulation of the required proportions of cement, aggregates and water required to produce concrete of a specified compressive strength.

Concrete production can result in either good quality or poor quality concrete. To obtain good quality concrete the constituent materials must be properly proportioned. Concrete mix design is the process of ascertaining the appropriate quantities of the ingredients of concrete required for a specified grade of concrete.

Over the years a number of standards have been stipulated for concrete mix design. These include:

- The Department of the Environment's Design of Normal Concrete Mixes (DoE method published in 1975 which originated from the long-established Road Note 4 of the Road Research Laboratory [1, 2].
- American Concrete institute (ACI) method which is similar to the DoE method but differs from it in the method of estimating the relative proportions of fine and coarse aggregate [1, 2].
- The British Ready Mixed Concrete Association (BRMCA) method developed over many years provides base data on the ideal proportioning for all mix constituents to achieve specified concrete properties enabling preparation of correct batching instructions for the production of all mixes [1, 2].
- BS5328 also caters for safe designs for instant use for site mixing by the provision of standard mixes [1, 2]
- CP114 gives three well known nominal mixes and the amounts of fine and coarse aggregate usually required per bag (50 kg) of cement [2].

The problem usually encountered in practice is the batching of the required proportions specified, either as prescribed mixes or designed mixes [1]. In the case of prescribed mixes, the specifications are in terms of volumes and weights of the constituent materials of concrete while in designed mixes, the specifications are in terms of the grade of the concrete required, its durability and workability requirements, etc. In all cases it is the duty of the concrete producer to ensure the production of concrete of the desired quality by estimating the appropriate quantities of the ingredients required and ensuring that they are correctly measured out. At large sites, where technical skill and facilities for weighing are available concrete production become just a routine estimation and measurements of the weights of the batch quantities of cement, sand, gravel, and water. In small sites, however, correct batching becomes difficult due to the absence of weighing instruments and skilled personnel. The supervisors at such sites have always resorted to rule of the thumb or trial and error approach. This often times leads to the production of poor quality concrete. This problem of guessing what quantities of materials of concrete are to be used can be avoided if a sort of design chart is made available to the supervisors to guide them in the batching operation. Such a chart presented in a tabular form and specifying various mix proportions based on local measuring apparatus for various grades of concrete will no doubt be of great assistance to concrete producers .The chart will become a sort of guideline for production of good quality concrete of various grades.

In recent times however, that the trend is towards the use of the computer for most computations, a computer-aided approach to the design of concrete mixes is becoming a welcome practice. An example of such effort is the computerized method developed by Ghaly and Almstead [3].

This method involved an algorithm that contains virtually all the steps used in the American Concrete Institute (ACI) Mix Design Method. The software package for this process can be accessed from the Internet [3].

METHODOLOGY

Modeling requires substantial data for a truly representative model to be developed. The approach adopted in this work for the accumulation of data is a combination of literature survey [2, 4], and experimental investigations. This is to ensure that sufficient data is used for modeling of concrete strength involved in this research. From literature survey, available data on mix proportions and concrete strength were extracted and analyzed.

The experimental investigation aspect dealt with actual concrete production and testing. The experiments were designed to ensure maximum yield of required information with minimum number of experiments, hence, the method of statistical design of experiments was used [5].

The method of statistical design of experiments involves the use of a planned approach to experimental investigation. In this work, the response surface designs were used to determine the empirical functional relation between the factors (cement, water, fine and coarse aggregates) and the response (compressive strength of concrete). In particular, the central composite design was applied as the data used in modeling were generated for the mixes where the compressive strength of concrete falls within the range of values used in normal concrete works i.e. $10N/mm^2$ to $50N/mm^2$ Investigations were therefore carried out in the regions expected to have the required responses, i.e. with normal mixes that are expected to produce the range of compressive strength values that are required for normal concrete works. This involved mixes made with cement content in the range of 100 to $500kg/m^3$and well graded and adequately proportioned aggregates.

Mathematical modeling using the data obtained from literature, computational analysis and experimental investigations, was done with the aid of MATLAB and SPSS softwares [6].

THE COMPUTERIZED MIX PROCESS DESIGN

In recent times efforts have been directed towards computerizing the concrete mix design process. The computerized method developed by Ghaly et al [3] involved an algorithm that contains virtually all the steps used in the American Concrete Institute (ACI) Mix Design Method. The Soft ware package for this process can be accessed from the internet.

The computerized approach to concrete mix design developed in this work is based on modeling and approximation techniques. A model for the mix design was first developed; subsequently, a computer programme [7], which is based on the application of approximation techniques, was developed for computing the mix proportions and their corresponding compressive strength. The computerized method comprised the following techniques:

1. **Approximation Technique**: “The Art of Nearly” which is an approximation technique proposed by Beaven, was applied [8]. This approximation theory emphasizes the futility of rigorous calculations aimed at obtaining accurate values for parameters that cannot easily be measured with a high degree of accuracy. Applying this theory to the batching of coarse and fine aggregates, it can be seen that an appropriate approximation can be made for the ratio of coarse to fine aggregate required to make good concrete. The coarse to fine aggregate ratio affects concrete strength and workability. However, a well-proportioned mixture of coarse and fine aggregate will result in the production of concrete with good workability, while the compressive

strength will then depend mainly on the cement content. An approximation for a well proportioned aggregate was made from an overview of available data on concrete production [2, 4]. From such an overview, a fine to coarse aggregate ratio of 1:1.75 by weight was adopted as an acceptable approximation.

2. **Modelling Technique**: Modelling of data on mix proportions was done by regression analysis with the aid of a computer. The working data for modeling the strength of concrete mixes were obtained from three sources namely Literature, Computational Analysis and Experimental Investigations [7].

RESULTS AND DISCUSSION

Modelling of Concrete Strength

The data obtained were used to develop different models. A validation of the models developed from the different groups of data was made by using the different models to evaluate compressive strength values for different mix proportions and comparing the evaluated values with the expected values of compressive strength for the different mixes. A comparison of the compressive strength values from the different models with the expected compressive strength values is shown graphically in fig.1.

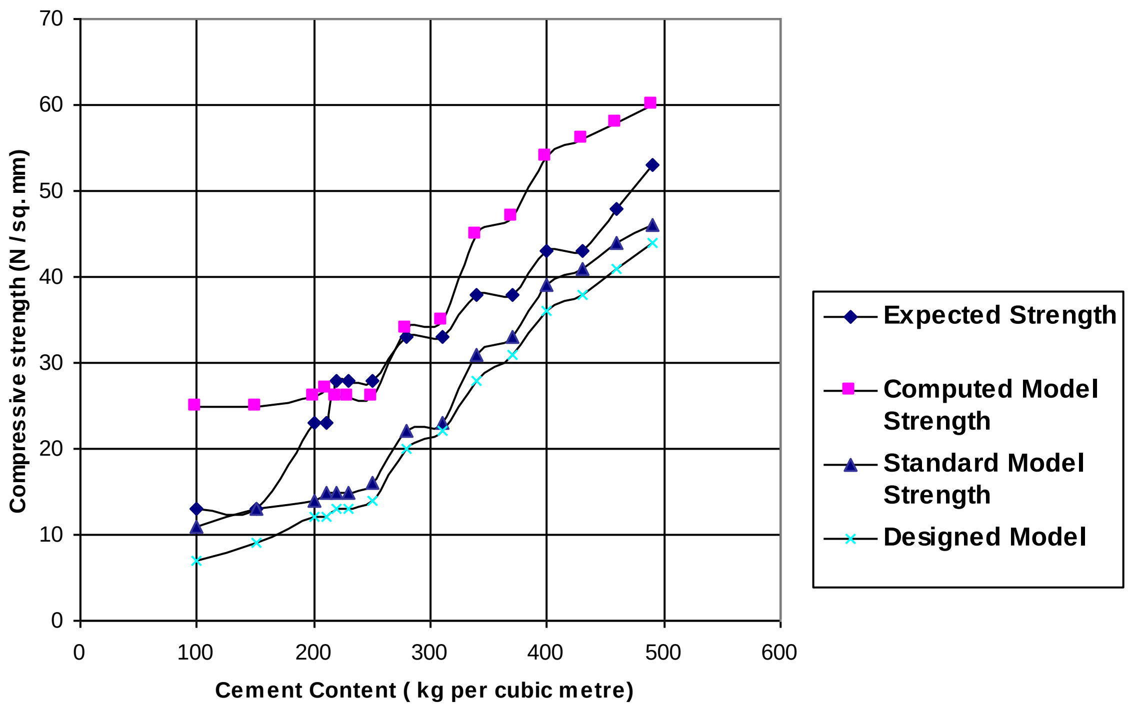

Fig.1: Comparison of Compressive Strength Values from differnt Models with the Expected Compressive Strength Values.

TESTING THE DIFFERENT MODELS ON CONCRETE MIXES.

The four different models obtained were analyzed with a view to identifying the model that most aptly defines the relationship between concrete mix proportions and the corresponding compressive strength. The four models developed using the MATLAB software are:

- **Standard –mix model**: $-33.6016 + 0.1778X_1 – 1.2029X_2 + 0.7153X_3 - 0.1669X_4$
- **Computed–mix model**: $-275.2523 + 0.3227X_1 + 0.1638X_2 + 0.01067X_3 – 0.1442X_4$
- **Experimental–mix model**: $277.0131 – 0.1298X_1 – 0.1203X_2 – 0.0831X_3 – 0.0734X_4$
- **Designed–mix model**: $-251.5854 + 0.2576X_1 + 0.1290X_2 + 0.0959X_3 – 0.0366X_4$

The corresponding four models developed using the SPSS software include:

- **Standard – mix model**: $-33.602 +0.178X_1 – 1.203X_2+ 0.715X_3 – 0.167X_4$
- **Computed mix model**: $-113.595 + 0.254X_11 + 0.162X_2 – 0.211X_4$
- **Experimental- mix model**: $276.443 – 0.130X_1 – 0.121X_2 – 0.083X_3 − 0.069X_4$
- **Designed – mix model**: $-84.770 + 0.118X_1+ 0.052X_2 + 0.026X_3 + 0.071X_4$

Where X_1, X_2, X_3, X_4 represent cement content, sand content, gravel content and water content in kg/m^3 respectively.

Of the eight models developed from the different sources of data, the two models developed from data from computed mix were chosen because they produced values of compressive strength that are close to the expected values.

DEVELOPMENT OF A COMPUTER PROGRAM FOR COMPUTING CONCRETE MIX PROPORTIONS AND CONCRETE STRENGTH VALUES

Firstly, the model to be used in the program was developed from regression analysis of data on concrete production.

The developed model chosen was the Computed–mix model which is represented as:

$$Y = -275.2523 + 0.3227X_1 + 0.1638X_2 +0.1067X_3 – 0.1442X_4$$

$$\text{Or, } Y = -113.5\,95 + 0.2541 X_1 + 0.162 X_2 – 0.211X_4$$

Where Y = compressive strength of concrete (N/mm^2)

X_1 = Cement content in kg/m^3
X_2 = Sand Content in kg/m^3
X_3 = Gravel content in kg/m^3
X_4 = Water content in kg/m^3

The program for the computed mix proportions was written by using the concept of “approximation” or “guesstimation” to obtain some average values for certain quantities involved in the mix design, such as the ratio of fine to coarse aggregate. This ratio was given an approximate value of 1:1.75.This approximation technique is then combined with the traditional mix- design process which uses the mass balance method to evaluate the values of the total aggregate content for a specified cement content, water/cement ratio and density. The developed computer program for evaluating mix proportions and resulting compressive strength values for specified cement content, water/cement ratio and plastic density is presented elsewhere [7].

The input data required to run the computer program are:

i. The required cement content.
ii. The required water-cement ratio
iii. The average wet density of concrete.

With this information the computer evaluates and presents data on the fine and coarse aggregate proportion, the water content and the expected concrete compressive strength.

GENERATION OF DATA ON MIX PROPORTIONS AND COMPRESSIVE STRENGTH OF CONCRETE

A working data bank was generated by computing various mix proportions and their corresponding compressive strength for various cement contents at varying water/cement ratios using the developed computer program .A sample of the resulting information on concrete mixes and compressive strength with cement content and water content ratio are also presented as output data elsewhere [7].

DEVELOPMENT OF CONCRETE MIX DESIGN CHART

A concrete mix design chart was developed from the data generated from the computer program for computing mix proportions and compressive strength values .The chart was made in two forms, one showing concrete mix proportions in kilograms while the other is in units of locally available measuring containers namely, head-pans, bags and cans. In the later case the cement was measured in number of 50 kilogram bags of cement, while fine and coarse aggregates were measured in number of head pans of standard size and water was measured in litres or in cans of known volumes. These units of measurements were chosen because most local construction sites do not have weighing machines, measurements being usually done with local measures or locally fabricated containers.

The chart was further reproduced in the form of portable design charts or pamphlets, which can be very handy for supervisors in charge of concrete production at construction sites. This portable design chart or pamphlet was named “CONCRETE MIX DESIGN CHART, CMD 2001” and is partly presented in table1. The comprehensive chart can be found in the full text of this work [7]. The chart covers mix proportions for $1m^3$ or less of concrete for the normal range of cement content usually used in practice .To obtain mix proportions for multiples of $1m^3$ of concrete, the specified proportions for $1m^3$ in the chart should be multiplied by the required multiples. Furthermore, where the aggregates are wet or extremely dry, the usual adjustments for moisture content of the aggregates should be made. The mix proportions in this chart were compared with the stipulated mix proportions for the commonly used standard or nominal mixes of (BS8110)[2] and they were found to be very close for the grades of concrete considered. Cube tests were performed with samples of concrete prepared using the mix proportions specified in the CMD – 2001 mix design chart. A comparison of the experimentally determined compressive strength values of the CMD chart mixes and the corresponding model and expected values is presented graphically in fig. 2.

Table 1: Concrete Mix Design Chart (CMD 2001)

S/N	Specification	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	Cubic metre Concrete.
1	100 – 180kg/m^3 σ_{100}=10 – 15N/mm^2 w/c = 0.8 Use: Kerb bedding and backing, mass concrete fill, back filling of trenches, blinding, etc.	12.5 25 37.5 50 75 100	100 200 300 400 600 800	175 350 525 700 1050 1400	10 20 30 40 60 80	1/8 1/4 3/8 1/2 3/4 1
2	200 – 220kg/m^3 σ_{200} = 15 - 25N/mm^2 w/c = 0.7 Use: Strip footings, mass concrete foundations, house and garage ground floor slabs (unreinforced or reinforced structural or non-structural concrete).	12.5 25 50 75 100 200	46 92 184 277 369 739	80 160 320 480 640 1285	9 18 36 54 72 144	1/16 1/8 1/4 3/8 1/2 1
3	230 – 250kg/m^3 σ_{230} = 25 – 30N/mm^2 w/c = 0.7 Use: Strip footings, mass concrete foundations, house and garage ground floor slabs (unreinforced or reinforced structural or non-structural concrete). Nominal mix;1:3:6	25 50 75 100 112.5 225	81 162 243 324 365 730	142 283 425 566 637 1275	18 35 53 70 80 161	1/9 1/4 1/3 1/2 1/2 1
4	250 – 280kg/m^3 σ_{250} = 25 – 30N/mm^2 w/c = 0.7 Use: Structural protection of buried pipelines, structural plain concrete for drainage works, foundations to manholes. Nominal mix;1:2 1/2:5	25 50 75 100 125 250	72 144 216 288 360 718	125 250 376 502 628 1256	18 36 53 70 88 175	1/10 1/5 3/10 2/5 1/2 1
5	280 – 310kg/m3 σ300=30 – 35N/mm2 w/c = 0.6 Use: Same as for σ250. Unreinforced and reinforced structural and non-structural concrete, prestressed concrete. Nominal mix;1:2:4	25 50 75 100 150 300	57 114 171 228 342 685	100 200 300 400 600 1200	15 30 45 60 90 180	1/14 1/7 1/5 1/3 1/2 1
6	320 – 350kg/m3 σ350=35 – 40N/mm2 w/c = 0.6 Use: Concrete surfaces exposed to rain, alternate wetting and drying or occasional freezing or continuously under water or in contact with non-aggressive sand. Nominal mix;1:2:4	25 50 75 100 175 350	48 96 144 192 336 670	84 167 250 334 585 1170	15 30 45 60 105 210	1/14 1/7 1/5 1/3 1/2 1
7	360 – 400kg/m3 σ400 = 40 – 45N/mm2 w/c = 0.5 Use: All types of concrete surfaces exposed to very severe conditions such as seawater, de-icing salts, corrosive fumes or severe freezing whilst wet. Nominal mix; 1:1 1/2:3	25 50 75 100 200 400	40 80 120 160 320 636	70 140 210 280 560 1114	12 25 37 50 100 200	1/16 1/8 1/5 1/4 1/2 1
8	410 – 450kg/m3 σ450 = 45 – 50N/mm2 w/c = 0.5 Use: All types of concrete surfaces exposed to extreme conditions of abrasive action such as seawater carrying solids or with pH ⊆4.5 or machinery or vehicles. Nominal mix; 1:1:2	25 50 75 100 225 450	34 67 100 134 301 604	58 117 176 234 527 1056	12 25 37 50 112 225	1/20 1/10 1/6 1/5 1/2 1

Table 2: Concrete Mix Design Chart (CMD 2001)

S/N	Specifications	No of bags (50kg/per bag of cement)	No of head-pans of sand	No of head-pans of gravel	No of litres of water.(or 12 litre- bucket)	Cubic metre Concrete.
1	100 - 180kg/m^3 σ_{100}=10 - 15N/mm^2 W/C=0.8 Use: Kerb bedding and backing, mass concrete fill, back filling of trenches, blinding, etc.	¼ ½ ¾ 1 1½ 2	3 $5^{2}/_{3}$ $8^{2}/_{3}$ $11^{1}/_{3}$ 17 23	6½ 13 $19^{1}/_{3}$ 26 $38^{3}/_{4}$ 52	10 ($^{3}/_{4}$) 20 ($1^{2}/_{3}$) 30 ($2^{1}/_{2}$) 40 ($3^{1}/_{3}$) 60 (5) 80 ($6^{2}/_{3}$)	$^{1}/_{8}$ ¼ $^{3}/_{8}$ ½ ¾ 1
2	200 –220 kg/m^3 σ_{200}=15 – 25N/mm^2 w/c = 0.7 Use: Strip footings, mass concrete foundations, house and garage ground floor slabs (unreinforced or reinforced structural or non-structural concrete).	¼ ½ 1 1½ 2 4	$1^{1}/_{4}$ $2^{1}/_{2}$ $5^{1}/_{4}$ 8 $10^{1}/_{2}$ 21	3 $5^{3}/_{4}$ $11^{1}/_{2}$ 17 23 46	10 ($^{3}/_{4}$) 20 ($1^{3}/_{4}$) 40 ($3^{1}/_{2}$) 60 (5) 80 ($6^{1}/_{2}$) 160($13^{1}/_{3}$)	$^{1}/_{16}$ $^{1}/_{8}$ ¼ $^{3}/_{8}$ ½ 1
3	230 – 250kg/m^3 σ_{230}=25 – 30N/mm^2 w/c = 0.7 Use: Strip footings, mass concrete foundations, house and garage ground floor slabs (unreinforced or reinforced structural or non-structural concrete). Nominal mix;1:3:6	½ 1 1½ 2 2¼ 4½	$2^{1}/_{4}$ $4^{2}/_{3}$ 7 $9^{1}/_{4}$ $10^{1}/_{3}$ $20^{2}/_{3}$	5 10 15 20 $22^{3}/_{4}$ $45^{1}/_{2}$	18 ($1^{1}/_{2}$) 35 (3) 53 ($4^{1}/_{2}$) 70 ($5^{3}/_{4}$) 80 ($6^{2}/_{3}$) 161($13^{1}/_{3}$)	$^{1}/_{9}$ ¼ $^{1}/_{3}$ ½ ½ 1
4	250 –280kg/m^3 σ_{250} = 25 – 30N/mm^2 w/c = 0.7 Use: Structural protection of buried pipelines, structural plain concrete for drainage works, foundations to manholes. Nominal mix; 1:$2^{1}/_{2}$:5	½ 1 1½ 2 2½ 5	2 4 6¼ 8¼ 10¼ 20½	$4^{2}/_{3}$ $9^{1}/_{3}$ 14 $18^{2}/_{3}$ $23^{1}/_{4}$ 45	18 ($1^{1}/_{2}$) 36 (3) 53 ($4^{1}/_{2}$) 70 ($5^{3}/_{4}$) 88 ($7^{1}/_{3}$) 175($14^{1}/_{2}$)	$^{1}/_{10}$ $^{1}/_{5}$ $^{3}/_{10}$ $^{2}/_{5}$ ½ 1
5	280 – 310kg/m3 σ_{300} = 30 -35N/mm2 w/c = 0.6 Use: Same as for σ250 . Unreinforced and reinforced structural and non-structural concrete, prestressed concrete. Nominal mix;1:2:4	½ 1 1½ 2 3 6	$1^{1}/_{2}$ 3¼ 5 6½ 9¾ $19^{2}/_{3}$	$3^{2}/_{3}$ 7 $10^{2}/_{3}$ $14^{1}/_{3}$ $21^{1}/_{3}$ 43	15 ($1^{1}/_{4}$) 30 ($2^{1}/_{2}$) 45 ($3^{3}/_{4}$) 60 (5) 90 ($7^{1}/_{2}$) 180 (15)	$^{1}/_{12}$ $^{1}/_{6}$ ¼ $^{1}/_{3}$ ½ 1
6	320 – 350kg/m3 σ_{350} = 35-40N/mm2 w/c = 0.6 Use: Concrete surfaces exposed to rain, alternate wetting and drying or occasional freezing or continuously under water or in contact with non-aggressive sand. Nominal mix;1:2:4	½ 1 1½ 2 3½ 7	$1^{1}/_{3}$ $2^{2}/_{3}$ 4 5½ $9^{2}/_{3}$ 19	3 6 9 12 21 42	15 ($1^{1}/_{4}$) 30 ($2^{1}/_{2}$) 45 ($3^{3}/_{4}$) 60 (5) 105 ($8^{3}/_{4}$) 210($17^{1}/_{2}$)	$^{1}/_{14}$ $^{1}/_{7}$ $^{1}/_{5}$ $^{1}/_{3}$ ½ 1
7	360 – 400kg/m σ_{400} = 40-45N/mm2 w/c = 0.5 Use: All types of concrete surfaces exposed to very severe conditions such as seawater, de-icing salts, corrosive fumes or severe freezing whilst wet. Nominal mix; 1:$1^{1}/_{2}$:3	½ 1 1½ 2 4 8	1 $2^{1}/_{4}$ $3^{1}/_{3}$ $4^{2}/_{3}$ 9 18	$2^{1}/_{2}$ 5 $7^{1}/_{2}$ 10 20 40	12 (1) 25 (2) 38 (3) 50 (4) 100 ($8^{1}/_{3}$) 200($16^{2}/_{3}$)	$^{1}/_{16}$ $^{1}/_{8}$ $^{1}/_{5}$ ¼ ½ 1
8	410 – 450kg/m3 σ_{450} = 45 – 50N/mm2 w/c = 0.5 Use: All types of concrete surfaces exposed to extreme conditions of abrasive action such as seawater carrying solids or with pH $\leq$4.5 or machinery or vehicles. Nominal mix; 1:1:2	½ 1 1½ 2 4½ 9	1 2 3 3¾ $8^{2}/_{3}$ $17^{1}/_{3}$	2 4 $6^{1}/_{4}$ $8^{1}/_{3}$ 19 38	12 (1) 25 (2) 38 (3) 50 (4) 112 ($9^{1}/_{3}$) 225($18^{2}/_{3}$)	$^{1}/_{20}$ $^{1}/_{10}$ $^{1}/_{6}$ $^{1}/_{5}$ ½ 1

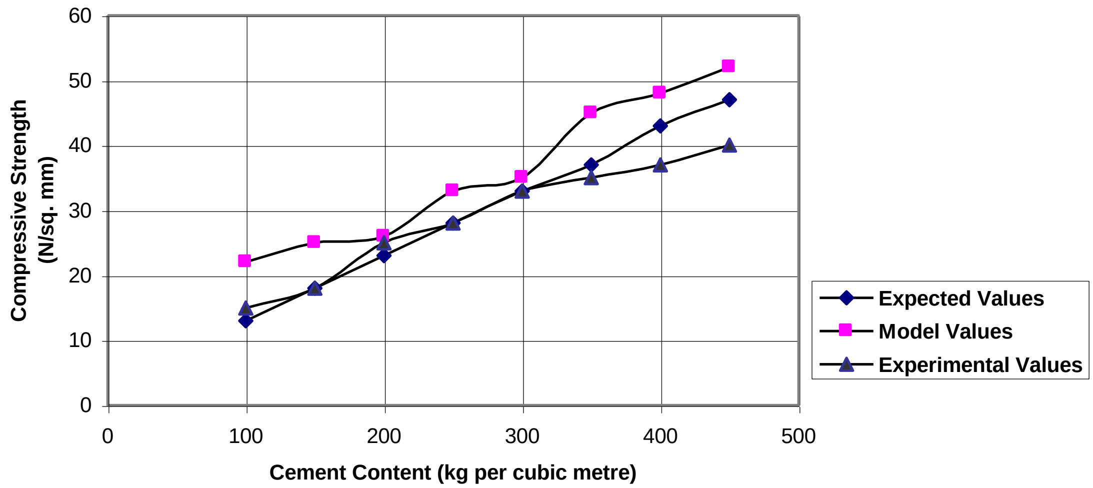

Fig. 2 Comparison of Compressive Strength Values computed from Model with the corresponding Experimentally determined and Expected Compressive Strength Values

GENERAL OBSERVATIONS/DEDUCTIONS

The quantities of cement, sand and gravel specified in the chart were found to closely approximate the quantities specified by the age long nominal or standard mixes. This confirms the validity of the model used in the evaluation of the mix proportions specified in the CMD – 2001 chart. In addition, compressive strength tests carried out on cubes prepared using the proportions specified in the chart showed that the values of the compressive strength obtained from the tests closely approximate the expected values for such grades of concrete as depicted by the curves in fig. 2. This indicates that the developed model truly depicts the concrete mix design process. The model can therefore be used for evaluation of concrete strength for various mix proportions or grades of concrete especially those which fall within the region in which the model was developed i.e. within a range of cement content, 220- 360 kg/m^3.

TESTING THE STATISTICAL SIGNIFICANCE OF THE DEVELOPED MODEL

The statistical significance of each of the partial regression coefficients, bi, may be tested using a t-statistic, while the statistical significance of the regression model as a whole i.e. it's overall explanatory power is measured by the multiple coefficient of Determination, R^2 [9]. For this work, the regression analysis was done using the MATLAB and SPSS soft wares.

The results of the statistical analysis for the data from computed mix proportions indicate that these data produced a model which has a high value of explanatory power, R^2 = 0.995 and a value of F-statistic of 485.112 which is much greater than the critical F-value of 4.07 at 0.05 level of significance or 7.59 at 0.01 level of significance. This shows that the regression is highly statistically significant, hence this model was chosen as the model that most aptly describes the concrete mix design process being modelled.

Other observations that can be made from the results of the statistical analysis include:

- The overall regression is highly significant since not only is the F-statistic above the critical F-value but it has a probability value of 0.0000 indicating that the probability of this result being obtained by chance is very small. Hence, almost 100 percent of the variation in concrete strength is explained by the regression
- Although the F- statistic indicate that the overall regression is statistically significant, the t-test for the partial coefficients of regression indicate that all the individual coefficients are not statistically significant. This is so since the values of the t-tests for all the coefficients fall below the critical value of 1.82($t_{a,10}$ = 1.82 from t-test table) [9]. This can be explained by the fact that the relationship between the dependent and independent variables is quite complex depending on other factors such as:
  - Aggregate size and grading
  - Degree of compaction of fresh concrete
  - Curing conditions
  - Temperature, etc.

Hence, any or a combination of these factors can become quite significant in some of the tests hence masking or reducing the effect of some of the independent variables thereby making it difficult for statistical significance of the variables to be established. Such results therefore when analysed statistically tend to indicate that the effect of the independent variables is not statistically significant resulting in the partial coefficients tending to zero and their t-test values being less than the critical t-test value. On account of the complexity and known non-linear behaviour of the concrete matrix, it is suggested that future studies on modeling be focused on non-linear relationships.

CONCLUSION

The project surveyed in details the existing methods of concrete mix design with the aim of finding a computer aided technique for the concrete mix design process. An applicable model was developed and consequently a computer program that can be used to evaluate mix proportions and the corresponding compressive strength of concrete for various cement content and varying water/cement ratios was developed. The following conclusions can be drawn from the work:

1. With the developed computer program, a data bank on concrete production can be generated whenever required.
2. The concrete mix design chart, CMD 2001, developed in this work may actually represent a solution to the problems that local site supervisors usually face with evaluation of the required proportions of the ingredients of concrete for various grades of concrete .The use of the chart as a guide in the batching of the ingredients of concrete will drastically reduce the trial and error approach which often lead to production of low quality concrete.
3. This work opens up a wide range of areas in concrete research that could lead to the development of specific models for the different grades of concrete.

Computational analysis using the computer technique developed in this work can also be used to carry out investigations on the various factors that affect the strength of concrete.

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