Computer-Aided Design of Concrete Mixes

[1,]D.O. Onwuka, [2,]C.E. Okere, [3,]O.M. Ibearugbulem, [4,]S.U. Onwuka
[1,2,3,4,]Civil Engineering, Federal University of Technology, Owerri, Nigeria

Abstract

The determination of mix components and their proportions is referred to as mix design. Traditional methods of designing concrete mixes are based on laid down rules, design standards and codes of practice. These methods are arbitrary and require several trial mixes. Consequently, it is not possible to select at once, the exact mix proportions required to produce concrete of specified or desired property. Thus this work focuses on the development of computer programmes (code in VISUAL BASIC Language) based on simplex and modified regression theories for the designing of concrete mixes. The computer programs can predict all possible combinations of concrete mix proportions if given a desired compressive strength of concrete. Conversely, they can predict the compressive strength of concrete if the mix proportion is specified as well as the optimum value (for the case of the Scheffe's based program). The programs developed are user friendly, easy and inexpensive to use and yield quick and accurate results. The results obtained from the programs agreed with the experimental results and with each other.

Keywords: computer programs; computer-aided design; concrete mixes; compressive strength; simplex method; modified regression method; visual basic language.

1. Introduction

Concrete is an inevitable material in construction industry. It is the backbone of infrastructural development of every country. It is made by mixing cement, water, fine and coarse aggregates and sometimes admixtures in their right proportions to obtain the specified property. The proportions of these constituent materials control the properties of concrete. Majid [1] stated that the compressive strength of hardened concrete is the most convenient property to measure among many properties of concrete. Two main objectives of hardened concrete tests are control of quality and compliance with specifications [2]. Concrete cube strength test is one of the major tests carried out on concrete before it can be used effectively. In addition, concrete grades are usually specified in standard construction work. Various methods have been developed in order to achieve the desired property of concrete cube strength. However, the methods require trial mixes [3]. In this work, statistical theories by Scheffe [4] and Osadebe [5] and experimental results were used to develop model programs for designing of concrete mixes. For example, if the concrete strength is specified as input, the computer prints out all mix proportions that match the concrete strength. On the other hand, if the concrete mix proportion is specified as input, the computer prints out the compressive strength obtainable from that concrete mix proportion.

2. Numerical Analysis

The model programs are based on numerical functions derived from simplex and modified regression statistical theories.

2.1 Simplex Function

The simplex theory of statistics by Scheffe [4] and some experimental results were used for the derivation of the simplex function on which the model programs are based. In his work, Scheffe considered experiment with mixtures in which the desired property depends on the proportions of the constituent materials present as atoms of the mixture. He assumed that n+1 mixture components acting as atoms will interact within n-dimensional space, provided the sum of all the proportions of the constituent components, X_i, is equal to unity. That is

$$\sum X_i = 1 \quad (1)$$

and

$$X_i \geq 0 \quad (2)$$

For normal concrete, the components are four in number and so it was analysed using a three dimensional factor space (i.e. a tetrahedron).

In the simplex theory, the response function (i.e. property of the mixture sought) with the following equation

$$Y = b_0 + \sum b_i X_i + \sum b_{ij} X_i X_j \quad (3)$$

where b_i and b_{ij} are constants

X_i and X_{ij} are pseudo components

For a four-component mixture, i and j which represent points on the 3-dimensional space is given as follows

$$0 \leq i \leq j \leq 4 \quad (4)$$

The application of the Scheffe's equation (i.e. Eqn 3) to a four –component mixture, normal concrete yielded the following simplex function derived by Okere et. al. [6].

$$Y = 26.22X_1 + 30.22X_2 + 24X_3 + 27.55X_4 + 2.68X_1X_2 – 2.68X_1X_3 + 20.46X_1X_4 + 16X_2X_3$$

$$– 25.78X_2X_4 + 0.9X_3X_4 \quad (5)$$

where Y is the response (concrete cube strength).
X_1, X_2, X_3 and X_4 are the pseudo components which represent the proportion of the ith component in the mixture.
In order to satisfy the condition given by Eqn (1), normal mixes such as 1:2:4 and 1:3:6 must be transformed using Eqn (6).

$$[Z] = [A] [X] \quad (6)$$

where [Z] = matrix of actual component proportions
[X] = matrix of pseudo components proportions
[A] = matrix of coefficients
Generally, the final simplex function for the response of a four- pseudo component mixture, is given by Eqn (7)

$$Y = \sum \alpha_i X_i + \sum \alpha_{ij} X_i X_j \quad (7)$$

where $1 \le i \le j \le 4$
Y is the response
α_i = coefficient corresponding to the response to pure component i
α_{ij}= coefficient corresponding to the response of binary mixture of components i and j.

2.2 Modified Regression Function

The second model program is based on a modified regression function derived from modified regression theory of statistics by Osadebe [5] and some experimental results. In his work, Osadebe [5] assumed the following continuous response function which is differentiable with respect to its predictors, Zi

$$F(Z) = \sum F''(Z^{(0)}) * (Zi – Z^{(0)})/m! \quad (8)$$

where
Z_i = fractional portions or predictors
=ratio of the actual proportions components to the quantity of concrete, S
$0 \le m \le \infty$
m = degree of the response function
Using Taylor's series, the response function was expanded up to the second order in the neighbourhood of a chosen point, $Z^{(0)} = Z_1^{(0)}, Z_2^{(0)}, Z_3^{(0)}, Z_4^{(0)}, Z_5^{(0)}$ to obtain the Eqn (9)

$$F(z) = F(z^{(0)}) + \sum [\partial F(z^{(0)}) / \partial z_i](z_i – z_i^{(0)}) + ½! \sum\sum [\partial^2 F(z^{(0)}) / \partial z_i \partial z_j](z_i - z_i^{(0)})(z_j – z_j^{(0)}) + ½! \sum\sum [\partial^2 F(z^{(0)}) / \partial z_i^2] (z_i – z_i^{(0)})^2 + \ldots \quad (9)$$

where $1 \le i \le 4$, $1 \le i \le 4$, $1 \le j \le 4$,and $1 \le i \le 4$ respectively.

This function was used to derive the following modified regression function, *F*(*z*) for the response of a normal concrete, which is a four-component mixture [7].

$$Y = -394790933.1Z_1 – 220057975.6Z_2 - 4093499.945Z_3\ 1283.021096Z_4 + 1204352313Z_1Z_2 + 318501118.4Z_1Z_3 + 395949693.6Z_1Z_4 + 284162641.2Z_2Z_3 + 219194875.1Z_2Z_4 + 4214942.072Z_3Z_4 \quad (10)$$

where Y is the response symbol (concrete cube strength).
Z_1, Z_2, Z_3 and Z_4 are the fractional portion i.e. the ratio of the actual portions, S_i to the quantity of concrete, S.
At nth observation point, the response $Y^{(n)}$ corresponding with the predictor $Zi^{(n)}$, is given by Eqn (11).

$$Y^{(n)} = \sum \alpha_i Z_i^{(n)} + \sum \alpha_{ij} Z_i^{(n)} Z_j^{(n)} \quad (11)$$

where $1 \le i \le j \le 4$ and n = 1,2,3, …………. 10
In general, Eqn (11) is given as follows:

$$[Y^{(n)}] = [Z_i^{(n)}] \{\alpha\} \quad (12)$$

where $[Y^{(n)}]$ = matrix of response function
$[Z_i^{(n)}]$ = matrix of predictors
$\{\alpha\}$ = matrix of coefficients of the regression

3. Model Programs

Two distinct computer programs were developed in VISUAL BASIC Language and presented in Appendices 2 and 3. The first model program based on the simplex function is given in Appendix 2 while the second model program based on modified regression function is given in Appendix 3. For both programs, the concrete compressive strength can be obtained by imputing into the computer the mix proportions of the concrete components. On the other hand, the input of mix proportions of the constituent concrete materials into the computer gives the compressive strength as output

The outputs of the model programs based on the simplex functions and modified regression models are given below Part 1: Output of model programs for computation of concrete mix ratios corresponding to desired concrete cube strength.

The executed program segment shown in Table 1 used desired concrete cube strength of 28N/mm^2

TABLE 1. SIMPLEX MODEL OUTPUT

STRENGTH	WATER	CEMENT	SAND	GRANITE
27.932	0.536	1	2.145	4.58
27.983	0.535	1	2.15	4.6
28.033	0.535	1	2.155	4.62
28.083	0.534	1	2.16	4.64
27.961	0.461	1	2.895	5.605
27.933	0.526	1	2.245	4.73
28	0.525	1	2.25	4.75
28.066	0.525	1	2.255	4.77
27.913	0.586	1	1.645	3.725
27.938	0.514	1	2.365	5.36
27.978	0.513	1	2.37	5.38
28.019	0.513	1	2.375	5.4
28.058	0.512	1	2.38	5.42
28.097	0.512	1	2.385	5.44
27.907	0.489	1	2.61	5.315
27.957	0.488	1	2.62	5.33
28.008	0.487	1	2.63	5.345
28.06	0.486	1	2.64	5.36
27.903	0.504	1	2.46	5.215
27.959	0.503	1	2.47	5.23
28.015	0.502	1	2.48	5.245
28.072	0.501	1	2.49	5.26
28.061	0.522	1	2.285	4.935

MAXIMUM CUBE STRENGTH OF CONCRETE PREDICTABLE BY THIS MODEL IS

31.71N/mm^2

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER	CEMENT	SAND	GRANITE
0.4845	1	2.655	5.845

The executed program segment shown in Table 2 used desired concrete cube strength of 21.7N/mm^2.

TABLE 2. MODIFIED REGRESSION MODEL OUTPUT

STRENGTH	WATER	CEMENT	SAND	GRANITE
21.764	0.484	1	2.69	7.889
21.778	0.437	1	3.115	6.341
21.768	0.48	1	2.742	7.598
21.779	0.439	1	3.128	6.22
21.768	0.488	1	2.642	7.663
21.78	0.451	1	3.018	6.389
21.768	0.451	1	2.977	6.359
21.762	0.478	1	2.721	7.138
21.768	0.488	1	2.635	7.332
21.779	0.444	1	3.047	5.873

21.765	0.469	1	2.797	6.451
21.776	0.454	1	2.968	5.813
21.773	0.478	1	2.75	6.513
21.77	0.501	1	2.514	7.209
21.764	0.476	1	2.77	6.326
21.775	0.486	1	2.64	6.65
21.77	0.457	1	2.944	5.68
21.762	0.447	1	3.025	5.38
21.773	0.47	1	2.82	6.04
21.78	0.494	1	2.597	6.732
21.761	0.45	1	2.987	5.357
21.776	0.451	1	2.983	5.219
21.761	0.471	1	2.805	5.635
21.78	0.46	1	2.895	5.232
21.772	0.461	1	2.869	5.202
21.773	0.487	1	2.62	5.933
21.766	0.513	1	2.397	6.649
21.776	0.513	1	2.397	6.605
21.766	0.466	1	2.844	5.233
21.774	0.512	1	2.409	6.507
21.772	0.465	1	2.838	5.158
21.766	0.502	1	2.505	6.135
21.778	0.468	1	2.808	5.115
21.778	0.505	1	2.475	6.121
21.76	0.496	1	2.559	5.787

Part 2: A computer model output for the computation of concrete cube strength corresponding to a specified mix ratio. Tables 3 and 4 show the simplex model output and modified regression model output respectively for specified mix ratios.

TABLE 3. SIMPLEX MODEL OUTPUT

STRENGTH	WATER	CEMENT	SAND	GRANITE
27.57367	0.55	1	2	4

TABLE 4. MODIFIED REGRESSION MODEL OUTPUT

STRENGTH	WATER	CEMENT	SAND	GRANITE
28.89249609	0.525	1	2.25	5

4. Discussion Of Results

Each program is in two parts. The computer print-out shows all possible mix ratios for the desired concrete cube strength. The computer model programs can also predict the concrete cube strength if the mix ratios are given. The simplex model program can also predict the maximum concrete cube strength which in the above case is 31.71N/mm^2. The computer results were obtained within seconds.

4.1 Comparison With Existing Codes And Implications

Mathematical modelling for optimisation of concrete mix design is quite different from the conventional method of concrete mix design and as such codes from both methods cannot be effectively compared numerically.

However, the following comments can be made. Concrete mix design is still very much a problem of trial and error and any calculation based on design data are really only a means of providing at best a starting point so that the first test can be conducted. Simon et. al.,[8] stated that the general approach to concrete mixture proportioning can be described by the following steps:

(1) Identifying a starting set of mixture proportions
(2) Performing one or more trial batches, starting with the mixture identified in step (1) above, and adjusting the proportions in subsequent trial batches until all criteria are satisfied.

Various methods are available. These include American Concrete Institute (ACI) mix design method, the British Method of mix deign, DOE method, USBR method, to mention but a few. All these methods basically follow the same approach stated above. Apparently, time and energy used in order to get the appropriate mix proportions may be enormous. The method applied may not be cost effective. This shows that the various mix design methods have limitations. To minimize some of these limitations, an optimisation procedure has been proposed. A process that seeks for a maximum or minimum value for a function of several variables while at the same time satisfying a number of other imposed requirements is called an optimisation process [1]. As the cost of materials increases, optimising concrete mixture proportions for cost becomes more desirable. Furthermore, as the number of constituent materials increases, the problem of identifying optimal mixtures becomes increasingly complex [8]. With the model equations and the corresponding computer programs developed, several analyses are possible. For instance, a user could determine which mixture proportions would yield one or more desired properties. The mixture proportion that has the highest or most desired property is the optimum mixture. A user also could optimise any property subject to constraints (specified requirements) on other properties. Simultaneous optimisation to meet several constraints is also possible. For example one could determine the lowest cost mixture with strength greater than a specified value. These are some of the advantages of computer –aided optimisation of concrete mixture design. In addition, the computer output results are obtained instantaneously. The user needs only to specify the strength of concrete desired and almost immediately, the computer provides all the possible mix ratios that can yield the desired concrete cube strength. The model computer program can also produce the concrete cube strength if mix proportions are given. The simplex model program is able to predict the maximum concrete cube strength. With these computer model programs, the arbitrary choice of constituent mix and the use of trial mix have been reduced. The effort used in traditional system of design mixes is also reduced. In addition, the use of these models will make concrete production less expensive.

5. Conclusion

It is worthy of note here that concrete cube strength has been characterised by equations (models) which were formulated in previous works [6-7]. The strength is expressed as an algebraic function of factors (individual component proportions) such as water-cement ratio, cement content and aggregate content. Without the programs developed, the models cannot be used effectively. An attempt to use the models without the computer programs will be a waste of precious time. Two computer programs, each in two parts, for optimisation of concrete cube strength were developed i.e. simplex model and modified regression model. The programs were written in visual basic language. With the models, the user needs only to specify the concrete cube strength and almost immediately the computer provides all the possible mix ratios that can yield the desired cube strength. The model can also produce the concrete cube strength if the mix ratios are given as well as the optimum cube strength. With these models, the arbitrary choice of constituent mix and the use of trial mix have been reduced. The effort used in traditional system of design mixes is also reduced. In addition, the use of these models will make concrete production less expensive.

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APPENDIX 1

List of some of the Arrays and Variables used in the programme.

Arrays

A = matrix whose elements are obtained from arbitrary mix proportions prescribed.
B = inverse of matrix A
z = fractional portions or predictors
α = coefficients of regression.

Variables

Z = matrix of actual components
X = matrix of pseudo components
Desired concrete cube strength
Mix ratios.

APPENDIX 2

```
Private Sub ENDMNU_Click()
End
End Sub
Private Sub STARTMNU_Click()
Dim oExcel As Object
Dim oBook As Object
Dim oSheet1 As Object
Dim oSheet2 As Object
 'Start a new workbook in Excel
Set oExcel = CreateObject("Excel.Application")
Set oBook = oExcel.Workbooks.Add
Rem ONE COMPONENT
Cls
ReDim X(4)

 SCHEFFE'S SIMPLEX MODEL FOR COMPRESSIVE STRENGTH
Print "    THE PROGRAM WAS WRITTEN BY"
Print: Print
Print "    DR. DAVIES ONWUKA"
Print:
WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls

CIVIL ENGINEERING DEPARTMENT, FUTO
 ReDim MIX(300, 4), STRGTH(300, 1), MIXX(1, 4)
Dim NP As Variant
KK = 0: MM = 1: CT = 0: OPSTRENGTH = 0: OPT1 = 0: OPT = 0: KKK = 0
ReDim X(10), A(4, 4), Z(4), N(15), M(15), B(4, 4), XX(4), ZZ(4): QQQ = 1
XX(1) = 0: XX(2) = 0: XX(3) = 0: XX(4) = 0
Cls
E1 = 1: E2 = 2: E3 = 3: E4 = 4:  J1 = 1: J2 = 0: J3 = 0: J4 = 0:  TT = 1
5  QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED
STRENGTH OR CALCULATING STRENGTH GIVEN MIX RATIO?", "IF THE STRENGTH IS KNOWN TYPE 1
ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")
If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK and do so"): GoTo
5
If QQ = 0 Then GoTo 900
Rem   ***   CONVERSION MATRIX    ***
A(1, 1) = 0.55: A(1, 2) = 0.5: A(1, 3) = 0.45: A(1, 4) = 0.6
A(2, 1) = 1: A(2, 2) = 1: A(2, 3) = 1: A(2, 4) = 1
A(3, 1) = 2: A(3, 2) = 2.5: A(3, 3) = 3: A(3, 4) = 1.5
A(4, 1) = 4: A(4, 2) = 6: A(4, 3) = 5.5: A(4, 4) = 3.5
YY = InputBox("WHAT IS THE DESIRED STRENGTH?"): YY = YY * 1
Q = -4
10     X(1) = 1: X(2) = 0: X(3) = 0: X(4) = 0: Q = Q + 1: GoTo 2000:
11     X(1) = 0: X(2) = 1: X(3) = 0: X(4) = 0: Q = Q + 1: GoTo 2000:
12     X(1) = 0: X(2) = 0: X(3) = 1: X(4) = 0: Q = Q + 1: GoTo 2000:
13     X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 1: Q = Q + 1: GoTo 2000:
```

```
Rem TWO COMPONENTS
14     E = 1: R = 1: F = R: Y1 = 1: Y2 = 0: Y3 = 0: Y4 = 0: T = 1: U = 1: V = 1: Q = 1: QQ = 1
       X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
20     Y1 = Y1 - 0.01: Y2 = Y2 + 0.01
       If F + 1 > 4 Then GoTo 30
25     X(E) = Y1: X(F + 1) = Y2
       If T = 100 Then T = 1: GoTo 30
       T = T + 1
       GoTo 2000
28     GoTo 20
30     If U = 3 Then U = 1: GoTo 40
       X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
       U = U + 1: F = F + 1: Y1 = 1: Y2 = 0: GoTo 20

40     If V = 3 Then GoTo 50
       V = V + 1: E = E + 1: F = R + 1: R = F: Y1 = 1: Y2 = 0
       X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0: GoTo 20

50     Rem THREE COMPONENTS
       Rem FIRST ROUND
       Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
       E = 1: R = 1: F = R: Y1 = 0.89: Y2 = 0.01: Y3 = 0.1: Y4 = 0: T = 1
60     Rem
70     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3
       If T = 99 Then GoTo 80
       T = T + 1:
       GoTo 2000
75     Y1 = Y1 - 0.01: Y2 = Y2 + 0.01: GoTo 70

80     Rem SECOND ROUND
       Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
       E = 1: R = 1: F = R: Y1 = 0.89: Y2 = 0.1: Y3 = 0.01: Y4 = 0: T = 1
90     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
       Rem

       If T = 99 Then GoTo 120
       T = T + 1
       GoTo 2000
115    Y1 = Y1 - 0.01: Y3 = Y3 + 0.01: GoTo 90

120    Rem THIRD ROUND
       Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
       E = 1: R = 1: F = R: Y1 = 0.89: Y2 = 0.01: Y3 = 0: Y4 = 0.1: T = 1
130    X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4

       If T = 99 Then GoTo 160
       T = T + 1
       GoTo 2000
155    Y1 = Y1 - 0.01: Y2 = Y2 + 0.01: GoTo 130

160    Rem FOURTH ROUND
       Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
       E = 1: R = 1: F = R: Y1 = 0.89: Y2 = 0.1: Y3 = 0: Y4 = 0.01: T = 1
170    X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4

       If T = 99 Then GoTo 200
       T = T + 1
       GoTo 2000
195    Y1 = Y1 - 0.01: Y4 = Y4 + 0.01: GoTo 170

200    Rem FIFTH ROUND
       Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
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```
      E = 1: R = 1: F = R: Y1 = 0.89: Y2 = 0: Y3 = 0.01: Y4 = 0.1: T = 1
210   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4

      If T = 99 Then GoTo 240
      T = T + 1
      GoTo 2000
235   Y1 = Y1 - 0.01: Y3 = Y3 + 0.01: GoTo 210
      Rem SIXTH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.89: Y2 = 0: Y3 = 0.1: Y4 = 0.01: T = 1
240   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
      If T = 99 Then GoTo 270
      T = T + 1
      GoTo 2000
265   Y1 = Y1 - 0.01: Y4 = Y4 + 0.01: GoTo 240

270   Rem FOUR COMPONENTS

      Rem FIRST ROUND
 '     Print " THIS IS OWUS"
       Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
       E = 1: R = 1: F = R: Y1 = 0.79: Y2 = 0.01: Y3 = 0.1: Y4 = 0.1: T = 1
280    X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
290    Y1 = Y1 - 0.01: Y2 = Y2 + 0.01
       If T = 79 Then GoTo 300
       T = T + 1
       GoTo 2000
295    GoTo 280
300   Rem SECOND ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.79: Y2 = 0.1: Y3 = 0.01: Y4 = 0.1: T = 1
310   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
320   Y1 = Y1 - 0.01: Y3 = Y3 + 0.01
      If T = 79 Then GoTo 330
      T = T + 1
      GoTo 2000
325   GoTo 310

330   Rem THIRD ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.79: Y2 = 0.1: Y3 = 0.1: Y4 = 0.01: T = 1
340   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
350   Y1 = Y1 - 0.01: Y4 = Y4 + 0.01
      If T = 79 Then GoTo 360
      T = T + 1
      GoTo 2000
355   GoTo 340

360   Rem FOURTH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.69: Y2 = 0.2: Y3 = 0.01: Y4 = 0.1: T = 1
370   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
380   Y1 = Y1 - 0.01: Y3 = Y3 + 0.01
      If T = 69 Then GoTo 390
      T = T + 1
      GoTo 2000
385   GoTo 370

390   Rem FIFTH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.69: Y2 = 0.2: Y3 = 0.1: Y4 = 0.01: T = 1
400   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
410   Y1 = Y1 - 0.01: Y4 = Y4 + 0.01
      If T = 69 Then GoTo 420
```

```
        T = T + 1
        GoTo 2000
415     GoTo 410

420     Rem SIXTH ROUND
        Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
        E = 1: R = 1: F = R: Y1 = 0.59: Y2 = 0.3: Y3 = 0.01: Y4 = 0.1: T = 1
430     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
440     Y1 = Y1 - 0.01: Y3 = Y3 + 0.01
        If T = 59 Then GoTo 450
        T = T + 1
        GoTo 2000
445     GoTo 430

450     Rem SEVENTH ROUND
        Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
        E = 1: R = 1: F = R: Y1 = 0.59: Y2 = 0.3: Y3 = 0.1: Y4 = 0.01: T = 1
460     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
470     Y1 = Y1 - 0.01: Y4 = Y4 + 0.01
        If T = 59 Then GoTo 480
        T = T + 1
        GoTo 2000
475     GoTo 460

480     Rem EIGTHTH ROUND
        Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
        E = 1: R = 1: F = R: Y1 = 0.49: Y2 = 0.4: Y3 = 0.01: Y4 = 0.1: T = 1
490     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
500     Y1 = Y1 - 0.01: Y3 = Y3 + 0.01
        If T = 49 Then GoTo 510
        T = T + 1
        GoTo 2000
505     GoTo 490

510     Rem NINETH ROUND
        Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
        E = 1: R = 1: F = R: Y1 = 0.49: Y2 = 0.4: Y3 = 0.1: Y4 = 0.01: T = 1
520     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
530     Y1 = Y1 - 0.01: Y4 = Y4 + 0.01
        If T = 49 Then GoTo 540
        T = T + 1
        GoTo 2000
535     GoTo 520

540     Rem TENTH ROUND
        Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
        E = 1: R = 1: F = R: Y1 = 0.39: Y2 = 0.5: Y3 = 0.01: Y4 = 0.1: T = 1
550     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
560     Y1 = Y1 - 0.01: Y3 = Y3 + 0.01
        If T = 39 Then GoTo 570
        T = T + 1
        GoTo 2000
565     GoTo 550

570     Rem TENTH ROUND
        Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
        E = 1: R = 1: F = R: Y1 = 0.39: Y2 = 0.5: Y3 = 0.1: Y4 = 0.01: T = 1
580     X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
590     Y1 = Y1 - 0.01: Y4 = Y4 + 0.01
        If T = 39 Then GoTo 600
        T = T + 1
        GoTo 2000
595     GoTo 580

600     Rem ELEVENTH ROUND
```

```
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.29: Y2 = 0.6: Y3 = 0.01: Y4 = 0.1: T = 1
610   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
620   Y1 = Y1 - 0.01: Y3 = Y3 + 0.01
      If T = 29 Then GoTo 630
      T = T + 1
      GoTo 2000
625   GoTo 610

630   Rem TWELVETH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.29: Y2 = 0.6: Y3 = 0.1: Y4 = 0.01: T = 1
640   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
650   Y1 = Y1 - 0.01: Y4 = Y4 + 0.01
      If T = 29 Then GoTo 660
      T = T + 1
      GoTo 2000
655   GoTo 640

660   Rem THIRTEENTH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.19: Y2 = 0.7: Y3 = 0.01: Y4 = 0.1: T = 1
670   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
680   Y1 = Y1 - 0.01: Y3 = Y3 + 0.01
      'GoTo 2000
      If T = 19 Then GoTo 690
      T = T + 1
      GoTo 2000
685   GoTo 670

690   Rem FOURTEENTH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0.19: Y2 = 0.7: Y3 = 0.1: Y4 = 0.01: T = 1
700   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
710   Y1 = Y1 - 0.01: Y4 = Y4 + 0.01
     ' GoTo 2000
      If T = 19 Then GoTo 720
      T = T + 1
       GoTo 2000
715    GoTo 700

720   Rem THREE COMPONENTS CONTIUES
      Rem SEVENTH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0
      E = 1: R = 1: F = R: Y1 = 0: Y2 = 0.89: Y3 = 0.01: Y4 = 0.1: T = 1

750  X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
      If T = 99 Then GoTo 760
      T = T + 1
      GoTo 2000
755   Y2 = Y2 - 0.01: Y3 = Y3 + 0.01: GoTo 750

760   Rem EIGHTH ROUND
      Q = Q + 1: X(1) = 0: X(2) = 0: X(3) = 0: X(4) = 0: P = 1
      E = 1: R = 1: F = R: Y1 = 0: Y2 = 0.89: Y3 = 0.1: Y4 = 0.01: T = 1

790   X(E) = Y1: X(F + 1) = Y2: X(F + 2) = Y3: X(F + 3) = Y4
      If T = 99 Then GoTo 800
      T = T + 1
      GoTo 2000
795   Y2 = Y2 - 0.01: Y4 = Y4 + 0.01: GoTo 790
800
2000       Rem PRINTING OF RESULTS

 '    Y = 26.22 * X(1) + 30.22 * X(2) + 24 * X(3) + 27.55 * X(4) + 2.68 * X(1) * X(2)
  '   Y = Y - 2.68 * X(1) * X(3) - 20.46 * X(1) * X(4) + 16 * X(2) * X(3) - 25.78 * X(2) * X(4) + 0.9 * X(3) * X(4)
```

```
Y = 26.22 * X(1) + 30.22 * X(2) + 24 * X(3) + 27.55 * X(4) + 2.68 * X(1) * X(2) - 2.68 * X(1) * X(3) - 20.46 * X(1) * X(4) + 16 * X(2) * X(3) - 25.78 * X(2) * X(4) + 0.9 * X(3) * X(4)

 If Y > OPSTRENGTH Then For I = 1 To 4: ZZ(I) = 0: Next I
 If Y > OPSTRENGTH Then YOP = 26.22 * X(1) + 30.22 * X(2) + 24 * X(3) + 27.55 * X(4) + 2.68 * X(1) * X(2) - 2.68 * X(1) * X(3) - 20.46 * X(1) * X(4) + 16 * X(2) * X(3) - 25.78 * X(2) * X(4) + 0.9 * X(3) * X(4)
 If Y > OPSTRENGTH Then OPSTRENGTH = Y: For I = 1 To 4: For J = 1 To 4: ZZ(I) = ZZ(I) + A(I, J) * X(J): Next J: Next I

If Y > YY - 0.1 And Y < YY + 0.1 Then GoTo 810 Else GoTo 830

810   NP = NP + 1
      CT = CT + 1
      For I = 1 To 4: Z(I) = 0: Next I
      For I = 1 To 4
      For J = 1 To 4
      Z(I) = Z(I) + A(I, J) * X(J)
      Next J
      Next I
      If Z(2) > 1.01 Or Z(2) < 0.9998 Then GoTo 830
      If Z(1) < 0 Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Then GoTo 830
     ' If QQQ = 15 Then QQQQ = InputBox("PRESS OK TO CONTINUE", , , 5500, 6000): QQQ = 1: Cls
      QQQ = QQQ + 1

      STRGTH(NP, 1) = Format(Y, "0.00#")
      MIX(NP, 1) = Format(Z(1), "0.00#")
      MIX(NP, 2) = Format(Z(2), "0.00#")
      MIX(NP, 3) = Format(Z(3), "0.00#")
      MIX(NP, 4) = Format(Z(4), "0.00#")

'      Print "  STRENGTH  =   N"; Format(Y, "0.00"),
 '     Print "    WATER "; Format(Z(1), "0.00#");
  '    Print "    CEMENT  "; Format(Z(2), "#");
   '   Print "    SAND  "; Format(Z(3), "0.00#");
    '  Print "    GRANITE   "; Format(Z(4), "0.00#")

830   If Q = -3 Then GoTo 11
      If Q = -2 Then GoTo 12
      If Q = -1 Then GoTo 13
      If Q = 0 Then GoTo 14
      If Q = 1 Then GoTo 28
      If Q = 2 Then GoTo 75
      If Q = 3 Then GoTo 115
      If Q = 4 Then GoTo 155
      If Q = 5 Then GoTo 195
      If Q = 6 Then GoTo 235
      If Q = 7 Then GoTo 265
      If Q = 8 Then GoTo 295
      If Q = 9 Then GoTo 325
      If Q = 10 Then GoTo 355
      If Q = 11 Then GoTo 385
      If Q = 12 Then GoTo 415
      If Q = 13 Then GoTo 445
      If Q = 14 Then GoTo 475
      If Q = 15 Then GoTo 505
      If Q = 16 Then GoTo 535
      If Q = 17 Then GoTo 565
      If Q = 18 Then GoTo 595
      If Q = 19 Then GoTo 625
      If Q = 20 Then GoTo 655
      If Q = 21 Then GoTo 685
      If Q = 22 Then GoTo 715
      If Q = 23 Then GoTo 755
```

```
       If PP = 7 Then GoTo 2100
       PP = PP + 1
       If Q = 24 Then GoTo 795

2100   'Add headers to the worksheet on row 1
   Set oSheet1 = oBook.Worksheets(1)
   Set oSheet2 = oBook.Worksheets(2)
   'oSheet.Range("A3").Resize(1, NN + 1).Value = MF
   oSheet1.Range("A2").Resize(NP + 1, 2).Value = STRGTH
   'oSheet.Range("A1").Resize(NP + 1, 2).Value = YYY

   oSheet1.Range("C2:F2").Resize(NP + 1, 5).Value = MIX
'   oSheet.Range("C2").Resize(NP + 1, 2).Value = CM
 '  oSheet.Range("D2").Resize(NP + 1, 2).Value = LT
  ' oSheet.Range("E2").Resize(NP + 1, 2).Value = GT
   oSheet1.Range("B1:G1").Value = Array("STRENGHT", " ", "WATER", "CEMENT", "SAND", "GRANITE")
'   If CT = 0 Then oSheet.Range("J2").Resize(2).Value = "***   SORRY THE COMPRESSIVE STRENGTH IS
OUTSIDE THE FACTOR SPACE    ***"
oSheet1.Range("J3").Resize(2).Value = "MAXIMUM CUBE STRENGTH OF CONCRETE PREDICTABLE BY
THIS MODEL IS"
 oSheet1.Range("J4").Resize(2).Value = Format(OPSTRENGTH, "0.##")
    oSheet1.Range("J5").Resize(2).Value = "THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:"
    oSheet1.Range("I7:L7").Resize(1, 5).Value = ZZ
    oSheet1.Range("J6:M6").Value = Array("WATER", "CEMENT", "SAND", "GRANITE")

    'oSheet.Range("B2:I2").Value = Array("MF1", "MF2", "MF3", "MF4", "MF5", "MF6", "MF7", "MF8")
   'Save the Workbook and Quit Excel
   oBook.SaveAs "C:\Book1.xls"

   oExcel.Quit

 '      QQQQ = InputBox("PRESS OK TO CONTINUE", , , 5500, 6000)
  '     Print: Print
   '    If CT = 0 Then Print "   ***   SORRY THE STRENGTH IS OUTSIDE THE FACTOR SPACE   ***"
    '   Print: Print
     '  Print "    MAXIMUM CUBE STRENGTH OF CONCRETE PREDICTABLE BY THIS MODEL IS "
      ' Print "    N"; Format(OPSTRENGTH, "0.00"): Print
       "Print Format(YOP, "0.00#"): Print
'      Print "     THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:"
 '     Print "     WATER ="; Format(ZZ(1), "0.00#"); "    CEMENT ="; Format(ZZ(2), "0.00#");
  '    Print "     SAND ="; Format(ZZ(3), "0.00#"); "    GRANITE ="; Format(ZZ(4), "0.00#")
       GoTo 22222
 900
       Cls
    Y = 0
    For I = 1 To 5: X(I) = 0: Next I
    Rem   ***  RESPONSE AT THE CHOSEN 10 POINTS ON THE FACTOR SPACE FOR THE MODEL  ***
       GoTo 3010
3010   Rem    ***  CONVERSION MATRIX    ****

       B(1, 1) = 10000: B(1, 2) = -7500: B(1, 3) = 1000: B(1, 4) = -1.58595E-13
       B(2, 1) = 1440:  B(2, 2) = -1081.285714: B(2, 3) = 142.8571429: B(2, 4) = 0.857142857
       B(3, 1) = -4300: B(3, 2) = 3224.857143: B(3, 3) = -428.5714286: B(3, 4) = -0.571428571
       B(4, 1) = -7140: B(4, 2) = 5357.428571: B(4, 3) = -714.2857143: B(4, 4) = -0.285714286

       Rem   ***   ACTUAL MIXTURE COMPONENTS    ****
       Z(1) = InputBox("ENTER THE VALUE OF WATER")
       Z(2) = InputBox("ENTER THE VALUE OF CEMENT")
       Z(3) = InputBox("ENTER THE VALUE OF SAND")
       Z(4) = InputBox("ENTER THE VALUE OF GRANITE")
                   Rem   ***   PSEUDO MIXTURE COMPONENTS    ***
       For I = 1 To 4
       For J = 1 To 4
```

```
X(I) = X(I) + B(I, J) * Z(J)
    Next J
    Next I
          Rem   ***  CALCULATING THE STRENGTH (RESPONSE)  ****

    YM = 26.22 * X(1) + 30.22 * X(2) + 24 * X(3) + 27.55 * X(4) + 2.68 * X(1) * X(2) - 2.68 * X(1) * X(3) - 20.46 *
X(1) * X(4) + 16 * X(2) * X(3) - 25.78 * X(2) * X(4) + 0.9 * X(3) * X(4)

     'Add headers to the worksheet on row 1
  Set oSheet1 = oBook.Worksheets(1)
  Set oSheet2 = oBook.Worksheets(2)

    MIXX(1, 1) = Format(Z(1), "0.00#")
    MIXX(1, 2) = Format(Z(2), "0.00#")
    MIXX(1, 3) = Format(Z(3), "0.00#")
    MIXX(1, 4) = Format(Z(4), "0.00#")

   oSheet1.Range("B2").Value = YM
   oSheet1.Range("C1:F1").Resize(2, 5).Value = MIXX
   oSheet1.Range("B1:G1").Value = Array("STRENGTH", " ", "WATER", "CEMENT", "SAND", "GRANITE")
     oBook.SaveAs "D:\Book1.xls"

  oExcel.Quit

'      Print "  STRENGTH = "; Format(Y, "0.0#");
 '     Print "  WATER "; Format(Z(1), "0.0#");
  '    Print "  CEMENT "; Format(Z(2), "0.0#");
   '   Print "  SAND "; Format(Z(3), "0.0#");
    '  Print "  GRANITE    "; Format(Z(4), "0.0#")

   22222
 End Sub
```

APPENDIX 3

```
Private Sub STARTMNU_Click()
   Dim oExcel As Object
  Dim oBook As Object
  Dim oSheet1 As Object
  Dim oSheet2 As Object
  'Start a new workbook in Excel
  Set oExcel = CreateObject("Excel.Application")
  Set oBook = oExcel.Workbooks.Add
   Set oSheet1 = oBook.Worksheets(1)
   Cls
   Print "     THE PROGRAM WAS WRITTEN BY"
   Print: Print
   Print "     DR. DAVIS ONWUKA"
   Print:
     WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
'   CIVIL ENGINEERING DEPARTMENT, FUTO
   ' IT IS STRENGTH OPTIMIZATION PROGRAM BASED ON OSADEBE'S MODEL
    ReDim MIX(300, 4), STRGTH(300, 1), MIXX(1, 4)
   Dim NP As Variant
   CT = 0: YMAX = 0: KK = 0
   ReDim X(10), A(5, 5), Z(5), N(15), B(5, 5)
   Rem        ***     COEFFICIENTS OF REGRESSION     ***
   A1 = -394790933.1: A2 = -220057975.6: A3 = -4093499.945: A4 = -1283.021096: A5 = 1204352313
   A6 = 318501118.4: A7 = 395949693.6: A8 = 284162641.2: A9 = 219194875.1: A10 = 4214942.072
   Rem  ***   DECISION FOR CALCULATING MIX RATIOS GIVEN DESIRED STRENGTH OR OTHER WISE
***
```

```
10  QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED
STRENGTH OR CALCULATING STRENGTH GIVEN MIX RATIO?", " IF THE STRENGHT IS KNOWN TYPE 1
ELSE TYPE 0", "Type 1 or 0  and CLICK OK.")
    If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK  and do so"):
GoTo 10
    If QQ = 0 Then GoTo 100
    Rem PUT IN THE VALUE OF STRENGTH DESIRED HERE
    YY = InputBox("WHAT IS THE DESIRED STRENGHT?"): YY = 1 * YY
    Rem    *** Here is where the Actual Strength is calculated    ***
    For Z1 = 0.04 To 0.09 Step 0.0001
    For Z2 = 0.08 To 0.16 Step 0.0001
    For Z3 = 0.2 To 0.31 Step 0.001
    Z4 = 1 - Z1 - Z2 - Z3
    Rem    ***    The Binary Predictors will be calculated here    ***
    Z5 = Z1 * Z2: Z6 = Z1 * Z3: Z7 = Z1 * Z4
    Z8 = Z2 * Z3:    Z9 = Z2 * Z4: Z10 = Z3 * Z4
    Rem CACCULATING ACTUAL STRENGTH
    YACT = A1 * Z1 + A2 * Z2 + A3 * Z3 + A4 * Z4 + A5 * Z5 + A6 * Z6
    YACT = YACT + A7 * Z7 + A8 * Z8 + A9 * Z9 + A10 * Z10
    If Z1 / Z2 >= 0.7 Then GoTo 30
    If Z1 + Z2 + Z3 + Z4 > 1 Or Z1 + Z2 + Z3 + Z4 < 1 Then GoTo 30
    If YACT > YY - 0.01 And YACT < YY + 0.01 Then NP = NP + 1: GoTo 20
    GoTo 30
20  ' If KK = 23 Then KK = 0: VV = InputBox("CLICK O.K. TO CLEAR SCREEN AND continue", "PRINT
COUNTER", , 1500, 5200): Cls
    KK = KK + 1
     STRGTH(NP, 1) = Format(YACT, "0.00#")
       MIX(NP, 1) = Format(Z1 / Z2, "0.00#")
       MIX(NP, 2) = Format(Z2 / Z2, "0.00#")
       MIX(NP, 3) = Format(Z3 / Z2, "0.00#")
       MIX(NP, 4) = Format(Z4 / Z2, "0.00#")
30
    Next Z3
    Next Z2
    Next Z1
   'Add headers to the worksheet on row 1
      Set oSheet1 = oBook.Worksheets(1)
   oSheet1.Range("A2").Resize(NP + 1, 2).Value = STRGTH
   oSheet1.Range("C2:F2").Resize(NP + 1, 5).Value = MIX
   oSheet1.Range("B1:G1").Value = Array("STRENGTH", " ", "WATER", "CEMENT", "SAND", "GRANITE")
   'Save the Workbook and Quit Excel
   oBook.SaveAs "C:\Book1.xls"
   oExcel.Quit
70  'Print "Sorry! Desired strength is outside the range of the model"
111  GoTo 222
100 Rem *** Here is where the INPUT of the Principal Predictors will be made    ***
    Cls
    Z1 = InputBox("What is Water/Cement ratio"): Z1 = Z1 * 1
    Z2 = InputBox("What is Cement value"): Z2 = Z2 * 1
    Z3 = InputBox("What is Sand value"): Z3 = Z3 * 1
    Z4 = InputBox("What is Periwinkle value"): Z4 = Z4 * 1
    TZT = Z1 + Z2 + Z3 + Z4 + Z5
    Z1 = Z1 / TZT: Z2 = Z2 / TZT: Z3 = Z3 / TZT
    Z4 = Z4 / TZT
    Rem    ***    The Binary Predictors will be calculated here    ***
    Z5 = Z1 * Z2: Z6 = Z1 * Z3: Z7 = Z1 * Z4
    Z8 = Z2 * Z3:    Z9 = Z2 * Z4: Z10 = Z3 * Z4
    Rem CACCULATING ACTUAL STRENGTH
    YACT = A1 * Z1 + A2 * Z2 + A3 * Z3 + A4 * Z4 + A5 * Z5 + A6 * Z6
    YACT = YACT + A7 * Z7 + A8 * Z8 + A9 * Z9 + A10 * Z10
     'Add headers to the worksheet on row 1
   Set oSheet1 = oBook.Worksheets(1)
```

```
   Set oSheet2 = oBook.Worksheets(2)
       MIXX(1, 1) = Format(Z1 / Z2, "0.00#")
       MIXX(1, 2) = Format(Z2 / Z2, "0.00#")
       MIXX(1, 3) = Format(Z3 / Z2, "0.00#")
       MIXX(1, 4) = Format(Z4 / Z2, "0.00#")
     oSheet1.Range("B2").Value = YACT
     oSheet1.Range("C1:F1").Resize(2, 5).Value = MIXX
     oSheet1.Range("B1:G1").Value = Array("STRENGTH", " ", "WATER", "CEMENT", "SAND", "GRANITE")
    oBook.SaveAs "C:\Book1.xls"
  oExcel.Quit
222

End Sub
```

```
Private Sub STOPMNU_Click()
End
End Sub
```