Optimization of Compressive Strength of Lime-Cement Concrete using Scheffe's Regression Theory

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ABSTRACT

In this paper, a regression model is formed to make the fore-telling of the compressive strengths and their compactible mix ratios for a lime-cement concrete as effective and perfect as possible using the Scheffe's regression theory. Twenty four selected mix ratios were studied experimentally for their compressive strengths at 28 days after curing in water at room temperature. Compressive strengths obtained stretched from 15.12N/mm2 to 24.58N/mm2. Fifteen of the readings obtained were used to develop the regression model while nine mix proportions were adopted for validation of the developed model. The model was tested for reliability at 95 % level of confidence using the F-statistic test and found to be adequate as the calculated F-value (1.918) was less than the critical F-value (3.438). A MATLAB based computer program was written based on the regression model using visual basic 6.0 software to optimize the compressive strength of the lime cement concrete and also speed up the process of selecting the corresponding mix ratios. The peak value of compressive strength predictable by the model is 24.460336 N/mm2 and the corresponding mix ratio is 0.586:0.841:0.159:2.42:4.84 (water: cement: lime: sand: granite chippings). MATLAB program developed is interactive, quick and is suitable for application in optimum concrete mixture proportioning.

Keywords:

Scheffe's regression theory, Compressive strength, Lime-cement concrete, Mix ratios.

1. Introduction

In order to proffer solutions to quantitative problems, a collection of mathematical methods and principles can be adopted. This procedure is known as optimization [1]. It involves the choosing of the best solution from among the set of possible solutions. The extent of the accuracy of any chosen solution can be ascertained by an objective function. So, to carry out this operation, it is necessary to determine the system model as well as the constraints under which the model will operate. Therefore in optimization, the value of the objective function is either minimized or maximized under certain restriction [2]. Currently, the process of carrying out experimental studies in order to generate data is being taken over by the modeling approach. This is happening since the laboratory approach makes use of more time, energy and material resources [3]. Adopting developed mathematical models in system optimization has the advantage of reducing time and the quantity of materials required for conducting an investigation. One of such mathematical model in use is the Scheffe's regression model. Scheffes developed a polynomial equation that can be used for optimization in order to determine optimum content of any factor or material in a composite based on regression theory [4]. The major gain of this model is its ability to foresee the values of properties for multi-element systems with many make-ups using insignificant extent of observed results [3]. In this research, the Scheffe's mathematical optimization model was used to optimize the value of compressive strength of hydrated lime-cement concrete. The need for more and more concrete for infrastructural development of many countries is on the rise. New cities are springing up as the population of humans in the world keeps increasing. However, it is already an established fact that cement production is a very costly and environmentally unfriendly process. The high energy level needed for the calcinations process and well as the CO_2 emission that emanates from the process makes the use of more cement in concrete production a very great concern. In addition, the high energy needed for cement production always results to high production cost making the price of the finished product very expensive [5]. In Nigeria, one of the cultural heritages is for an individual to be able to at least build or buy a house to leave in. This brings great satisfaction to the family. But, presently, this heritage is under attacked by the very high cost of building materials especially cement. This is majorly due to the economic recession faced by the country. The poverty level is on the increase as well as the prices of commodities. Many more people are no longer able to afford to own their own homes [5]. This development therefore calls for the immediate need to explore into the potentials of natural cement replacement materials, in order to reduce the cost of concrete production. In this investigation, cement is incompletely replaced by lime in its hydrated form, in making concrete. The major advantages of replacing portland cement (PC) with pozzolanic or filler materials are to assist in lowering energy consumption and CO_2 emissions during cement production. Other benefits could be for better durability, workability etc. This is why hydrated lime was selected as the replacer of PC in this study. Lime in its hydrated form is equivalent to the quick lime (CaO) that water has been added to. The addition of water converts the lime from an oxide into a hydroxide. This hydroxide is then pulverized to get the final product. The strength of any hydrated lime depends to a large extent on the quick lime and catalyst applied [6]. Experimented on the splitting tensile and compressive strength of lime concrete at 28 days. They observed a 70% strength gain of cement concrete over the lime concrete. But, noted that the lime concrete had improved plasticity and workability. Awodiji et al. in 2016 in their studies on lime concrete obtained compressive strength readings of 6.12N/mm2 and 13.15N/mm2 at 28 days and 90 days

of curing respectively. This gave a strength increase of about 114% between the two ages. Therefore, the lime concrete continues to increase in strength with time [7]. Nwachukwu et al. in 2022 compared the results of using the Scheffe's second degree (5, 2) and third degree (5, 3) polynomial model in optimizing the compressive strength of glass fiber reinforced concrete. They discovered that the two models predicted results that are in close agreement. However, the (5, 3) model generated slightly higher readings than the (5, 2) model [8]. Attah et al. in 2020, adopted the Scheffe's (5, 2) model to enhance the mechanical properties of rice husk ash (RHA).They observed that the model predictions were in good fit with the data obtained experimentally. Maximum compressive strength obtained was 33.45N/mm2 at 0.6:0.65:1.3; 1.6; 0.3 (Water, cement, fine aggregate, coarse aggregates; Rice husk ash) [9]. These results confirm that the Scheffe's model is very adequate for developing concrete mix ratios and their mechanical properties. Hence, in this work, a regression model was developed using Scheffe's regression theory, to optimize the compressive strength of lime-cement concrete. Afterwards, a computer program was drafted using the visual basic environment and was employed to optimize the compressive strength of the concrete as well as select mix design parameters corresponding to desired strength values.

2. Materials and methods

2.1. Materials

The cement used as binder for this study is portland cement with properties conforming to [10]. The water used was fresh and free from any kind of impurities. The fine aggregate was obtained from Otamiri River in Imo State. It was washed and sundried for two weeks before it was used for concreting. The grading and properties of fine aggregates were carried out in accordance with the requirements of [11]. The granite used as coarse aggregate was obtained from crushed rock industry in Owerri, Imo State. It was thoroughly washed and sundried for two weeks to remove dirt. The design points for both the trial and control mixes obtained based on Scheffe's (5, 2) factor spaces are shown in Tables 1 and 2 respectively.

2.1. Methods

2.1.1. Compressive strength

The cube specimens were removed from moulds after 24 hours of casting after which they were transferred to a curing tank and allowed to cure for 28 days. After 28 days of curing, they were weighed and tested in compressive using a Universal Compression Machine. The maximum load at failure of each cube specimen was recorded. Three replicates where produced per mix ratio, giving a total of ninety concrete cylindrical specimens. The laboratory test results of compressive strength of lime-cement concrete are presented in Table 3 and Table 4. The compressive strength, (f_c) of lime-cement concrete was obtained using the formula:

$$f_c = \frac{F}{A} \tag{1}$$

Where fc= compressive strength, F=load at failure, A= area of cross section of the cube specimen.

2.1.2. Regression model development

The polynomial function that optimizes the compressive strength of a 5-component concrete mixture based on a (5, 2) factor space is given by Scheffe [12] as:

$$Y = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{14} X_1 X_4 + \alpha_{15} X_1 X_5$$
$$+ \alpha_{23} X_2 X_3 + \alpha_{24} X_2 X_4 + \alpha_{25} X_2 X_5 + \alpha_{34} X_3 X_4 + \alpha_{35} X_3 X_5 + \alpha_{45} X_4 X_5 \tag{2}$$

The model coefficients of Equation (2) are obtained according to Scheffe [12] as follows:

$$\alpha_i = Y_i \text{ and } \alpha_{ij} = 4Y_{ij} - 2Y_i - 2Y_j \tag{3}$$

Where
$$\alpha_i = \alpha_1, \alpha_3, ..., \alpha_5; \quad \alpha_{ij} = \alpha_{12}, \alpha_{13}, \alpha_{14}, ..., \alpha_{45}$$

Equation (1) is optimized subject to the constraint that:

$$X_1 + X_2 + X_3 + X_4 + X_5 = 1 \tag{4}$$

According to Scheffe [12], the number of experimental runs for a given factor space is given by:

$$N = \frac{(q + n - 1)!}{n!(q - 1)!} \tag{5}$$

Where n, q=degree of the polynomial and number of component materials respectively Let the actual and pseudo components be denoted by S_i and X_i. The relationship between X_i and S_i is given by [13] as:

$$S = AX \tag{6}$$

Where A= the transpose of the real mix ratios, Z= real mix ratio and X= pseudo mix ratio. Using Equation (6), the actual mix ratios (Z_i) are obtained and are given in matrix form as follows:

$$
\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \end{bmatrix} =
\begin{bmatrix} 0.60 & 0.57 & 0.55 & 0.53 & 0.50 \\ 0.90 & 0.85 & 0.80 & 0.70 & 0.60 \\ 0.10 & 0.15 & 0.20 & 0.30 & 0.40 \\ 3.0 & 2.0 & 2.5 & 1.5 & 1.0 \\ 6.0 & 4.0 & 5.0 & 3.0 & 2.0 \end{bmatrix} *
\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{bmatrix} \tag{7}
$$

The design mix for the trial and control points based on the Scheffe's theory (5, 2) factor space are illustrated in Table 1 and Table 2 correspondingly.

Table 1. **Design matrix for trial points based on Scheffe's (5, 2) factor space.**

X_1	X_2	X_3	X_4	X_5	Responses	S_1	S_2	S_3	S_4	S_5
1	0	0	0	0	Y_1	0.600	0.90	0.10	3.	6.
0	1	0	0	0	Y_2	0.570	0.85	0.15	2	4.
0	0	1	0	0	Y_3	0.550	0.80	0.20	2.5	5
0	0	0	1	0	Y_4	0.530	0.70	0.30	1.5	3.
0	0	0	0	1	Y_5	0.500	0.60	0.40	1.	2.
0.50	0.50	0	0	0	Y_{12}	0.585	0.875	0.125	2.5	5.
0.50	0	0.50	0	0	Y_{13}	0.575	0.85	0.15	2.75	5.5
0.50	0	0	0.50	0	Y_{14}	0.565	0.80	0.20	2.25	4.5
0.50	0	0	0	0.50	Y_{15}	0.550	0.75	0.25	2.	4.
0	0.50	0.50	0	0	Y_{23}	0.560	0.825	0.175	2.25	4.5
0	0.50	0	0.50	0	Y_{24}	0.550	0.775	0.225	1.75	3.5
0	0.50	0	0	0.50	Y_{25}	0.535	0.725	0.275	1.5	3.
0	0	0.50	0.50	0	Y_{34}	0.540	0.75	0.25	2.	4.
0	0	0.50	0	0.50	Y_{35}	0.525	0.70	0.30	1.75	3.5
0	0	0	0.50	0.50	Y_{45}	0.515	0.65	0.35	1.25	2.5

Table 2. **Design matrix for control points based on Scheffe's (5, 2) factor space.**

X_1	X_2	X_3	X_4	X_5	Responses	S_1	S_2	S_3	S_4	S_5
0.5	0.5	0	0	0	$C1$	0.585	0.875	0.125	2.5	5
0.5	0	0.5	0	0	$C2$	0.575	0.85	0.15	2.75	5.55
0	0.5	0	0.5	0	$C3$	0.55	0.775	0.225	1.75	3.55
0	0	0.5	0	0.5	$C4$	0.525	0.7	0.3	1.75	3.55
0	0	0	0.5	0.5	$C5$	0.517	0.65	0.35	1.25	2.5
0.25	0.25	0	0.25	0.25	C6	0.55	0.763	0.238	1.875	3.75
0.1	0.2	0.2	0.25	0.25	C7	0.543	0.732	0.268	1.825	3.65
0.3	0	0.3	0.2	0.2	C8	0.557	0.79	0.21	2.15	4.3
0.2	0.2	0.2	0.4	0	C9	0.56	0.79	0.21	2.1	4.2

Where

S_1 = actual proportion of water X_1 = pseudo proportion of water

S_2 = actual proportion of cement X_2 = pseudo proportion of cement

S_3 = actual proportion of lime X_3 = pseudo proportion of lime

S_4 = actual proportion of sand X_4 = pseudo proportion of sand

S_5 = actual proportion of granite X_5 = pseudo proportion of granite
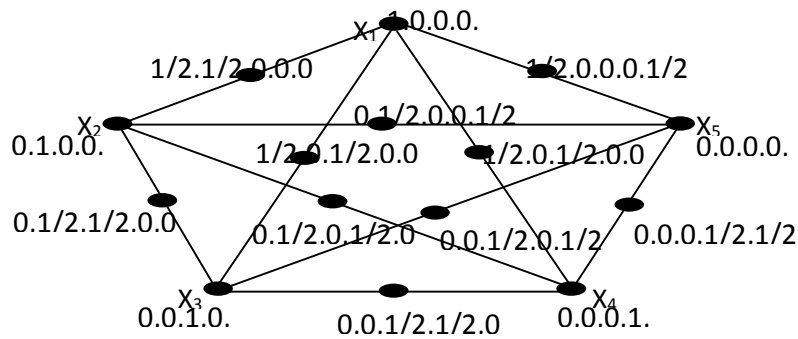
Figure 1. A simplex lattice for a 5-component mixture.

2.1.3. Program development

For ease of application of the developed regression model for optimizing the compressive strength of lime-cement concrete, a Matlab based computer program was written using the visual basic studio 6 software.

3. Results and discussion

3.1. Compressive strength results

The values for the compressive strength of lime cement concrete for the trial and control points are presented in Table 3 and Table 4 accordingly; The values of compressive strength obtained from Table 3 where used to develop the regression model for this study. While, those of Table 4 were left out but used for validating the model's ability to make accurate predictions. Results obtained varied from 15.12N/mm2 at mix label M1 to 26.68N/mm2 at mix C3.

3.2. Regression model

From Equation (2), Table 1 and Table 3, the coefficients of Equation (2) are obtained as follows:

$$\alpha_1 = 15.12, \ \alpha_2 = 18.50, \ \alpha_3 = 17.86, \ \alpha_4 = 22, \ \alpha_5 = 19.56, \ \alpha_{12} = 16.16, \ \alpha_{13} = 24.84,$$
$$\alpha_{14} = 14.44, \ \alpha_{15} = 16.88, \ \alpha_{23} = 22.52, \ \alpha_{24} = 12.36, \ \alpha_{25} = 9.20, \ \alpha_{34} = -14.84, \tag{8}$$
$$\alpha_{35} = -10.20, \ \alpha_{45} = -7.12$$

Substituting the obtained coefficients, and into Equation (2) yields;

$$y = 15.12 X_1 + 18.50 X_2 + 17.86 X_3 + 22.00 X_4 + 19.56 X_5 + 16.16 X_1 X_2 + 24.84 X_1 X_3 + 14.44 X_1 X_4$$
$$+ 16.88 X_1 X_5 + 22.52 X_2 X_3 + 12.36 X_2 X_4 + 9.20 X_2 X_5 - 14.84 X_3 X_4 - 10.20 X_3 X_5 - 7.12 X_4 X_5 \tag{9}$$

Equation (9) is the mathematical model for the optimization of the compressive strength of lime-cement concrete based on Scheffe's (5, 2) factor space.

Table 3. 28th day compressive strength results for trial points of lime cement concrete cube.

| S/No.	Mix label	Replicates	Failure Load (KN)	Compressive strength (N/mm^2)	Av. Compr. strength (N/mm^2)
1	M1	A	330.30	14.68	
		B	342.00	15.20	15.12
		C	348.30	15.48	
2	M2	A	414.45	18.42	
		B	400.50	17.80	18.50
		C	433.80	19.28	
3	M3	A	376.20	16.72	
		B	412.62	18.34	17.86
		C	416.70	18.52	
4	M4	A	499.95	22.22	
		B	468.68	20.83	22.00
		C	516.38	22.95	
5	M5	A	453.15	26.14	
		B	429.98	19.11	19.56
		C	437.18	19.43	
6	M12	A	450.45	20.02	
		B	441.45	19.62	20.85
		C	515.48	22.91	
7	M13	A	503.55	22.38	
		B	497.25	22.10	22.70
		C	531.45	23.62	
8	M14	A	466.88	20.75	
		B	491.18	21.83	22.17
		C	538.43	23.93	
9	M15	A	477.00	21.20	
		B	490.05	21.78	21.56
		C	488.25	21.70	
10	M23	A	600.08	26.67	
		B	611.78	27.19	23.81
		C	598.05	26.58	
11	M24	A	519.98	23.11	
		B	524.25	23.30	23.34
		C	531.23	23.61	
12	M25	A	445.05	19.78	
		B	514.13	22.85	21.33
		C	480.60	21.36	
13	M34	A	353.70	15.72	
		B	336.15	14.94	16.22
		C	405.00	18.00	
14	M35	A	322.20	14.32	
		B	380.70	16.92	16.16
		C	387.90	17.24	
15	M45	A	431.55	19.18	
		B	409.50	18.20	19.00
		C	441.45	19.62	

Table 4: 28th day compressive strength results for control mix of lime cement concrete cube.

S/No.	Mix label	Replicates	Failure Load (KN)	Compressive strength (N/mm²)	Av. Compr. strength (N/mm²)
1	C1	A	455.21	20.23	
		B	485.50	21.58	20.85
		C	466.65	20.74	
2	C2	A	464.21	23.63	
		B	501.30	22.28	22.45
		C	482.30	21.44	
3	C3	A	590.13	26.23	
		B	610.11	27.12	26.68
		C	600.53	26.69	
4	C4	A	362.25	16.10	
		B	367.88	16.35	16.20
		C	363.38	16.15	
5	C5	A	425.93	18.93	
		B	433.13	19.25	19.15
		C	433.58	19.27	
6	C6	A	551.00	24.49	
		B	530.78	23.59	23.87
		C	526.41	23.53	
7	C7	A	548.32	24.37	
		B	542.48	24.11	23.94
		C	525.20	23.34	
8	C8	A	558.68	24.83	
		B	542.50	24.11	24.58
		C	558.00	24.80	
9	C9	A	483.17	21.47	
		B	475.03	21.11	21.45
		C	489-83	21.77	

3.3. Testing the goodness of fit of the model

The mix proportions for the control points were feed into the formulated regression model in order to forecast the compressive strength of the concrete. Figure 2 shows a comparison between the experimental and predicted values obtained.
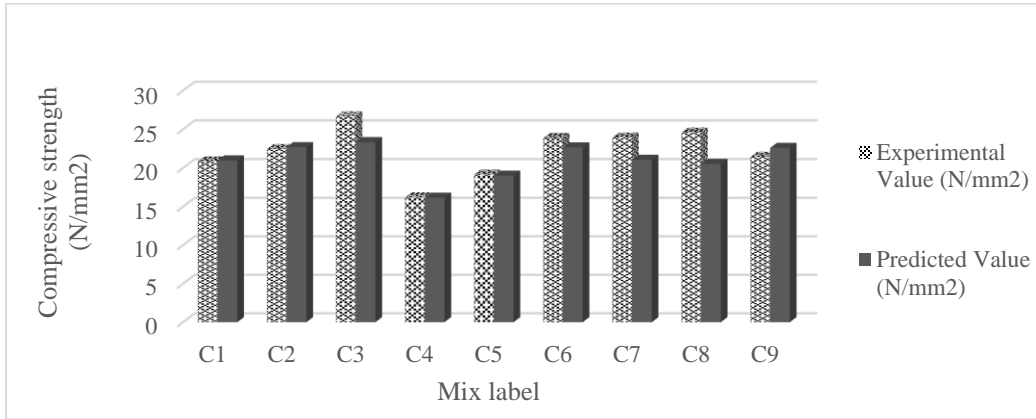
Figure 2. Experimental values vs. Predicted values of compressive strength (N/mm2).

Overview, it is seen that the experimental results had higher compressive strength values than the predicted results. Highest difference between the two values was observed at mix label C8 at 16. 48% followed by mix C3 at 12.52% and then mix C7 at 12.03%. All other mix labels had very slight differences between the two values. The higher readings at C8, C3 and C7 may be as a result of experimental errors at those points.

3.3.1. F-statics test result

To further test the goodness of fit of the model predictions, the Fisher's test was used. Results obtained are shown in Table 5.

Table 5. Results of F-statistic Test Validation.

S/N	y_o	y_p	$y_o - \bar{y}_o$	$y_p - \bar{y}_p$	$(y_o - \bar{y}_o)^2$	$(y_p - \bar{y}_p)^2$
C1	20.85	20.98	-1.28	-0.0236	1.6384	0.000555
C2	22.45	22.7	0.32	1.6964	0.1024	2.877924
C3	26.68	23.34	4.55	2.3364	20.7025	5.458973
C4	16.2	16.16	-5.93	-4.8436	35.1649	23.46003
C5	19.15	19	-2.98	-2.0036	8.8804	4.014235
C6	23.87	22.665	1.74	1.6614	3.0276	2.760398
C7	23.94	21.059	1.81	0.0554	3.2761	0.003074
C8	24.58	20.534	2.45	-0.4696	6.0025	0.220482
C9	21.45	22.594	-0.68	1.5904	0.4624	2.529514
	22.13	**21.0036**			**79.2572**	**41.3252**

Legend:

y_o , y_p = observed and predicted value of compressive strength respectively

$$\bar{y}_o = \frac{\Sigma y_o}{n} ; \quad \bar{y}_p = \frac{\Sigma y_p}{n} \tag{10}$$

From Table 5,

$$S_o{}^2 = \frac{79.2572}{8} = 9.9072 \tag{11}$$

$$S_p{}^2 = \frac{41.3252}{8} = 5.1657 \tag{12}$$

The F-statistic is given by:

$$F = \frac{9.9072}{5.1657} = 1.918 \tag{13}$$

From standard statistical table, $F_{0.95} = (8, 8) = 3.438$. This value represents the critical F-value at 0.95% confidence level and the value is greater than the calculated F-value at 95% confidence level (F= 1.918). Hence the model developed is adequate.

3.4. Program development
A Matlab based computer program was successfully written to help implement the model developed as easy and as fast as possible. The program can propose varying mix proportions when presented a target compressive strength as well as predict a compressive strength value when presented with a mix ratio. Highest compressive strength value foreseeable by the program is 24.460336N/mm^2.The program is presented in the appendix.

4. Conclusions
A mathematical model has been developed to optimize the compressive strength of lime-cement concrete based on Scheffe's regression theory. A MATLAB program was produced and used to optimize the compressive strength and to select the corresponding mix ratios of lime-cement concrete based on the formulated model. The optimum value of compressive strength predictable by the model is 24.460336N/mm2 and the corresponding mix ratio is 0.586:0.841:0.159:2.42:4.84 (Water: Cement: Lime: Sand: Granite). MATLAB program developed is interactive, quick, and take less time and effort to achieve the desired results.

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APPENDIX
COMPUTER PROGRAM

```
Private Sub STARTMNU_Click()
 Rem ONE COMPONENT
    Text1.Text = " "
    ReDim X(4)
     '  SCHEFFE'S SIMPLEX MODEL
   Print "    THE PROGRAM WAS WRITTEN "
   Print: Print "to Optimize the compressive strength of lime-cement concrete "
   Print "      "
   Print:
    WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
   Print: Print "     Optimization of Compressive Strength of Lime-Cement Concrete"
   WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
   Print "    The Program prints the corresponding Mix Ratios"
   Print "    and Vice versa"
   WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
' CIVIL ENGINEERING DEPARTMENT, FUTO
   CT = 0: OPSTRENGTH = 0
   ReDim X(10), A(5, 5), Z(5), N(15), B(5, 5), ZZ(5): QQQ = 1
   Cls
   N1 = 15.12: N2 = 18.5: N3 = 17.86: N4 = 22: N5 = 19.56
   N6 = 20.85: N7 = 22.7: N8 = 22.17: N9 = 21.56: N10 = 23.81
   N11 = 23.34: N12 = 21.33: N13 = 16.22: N14 = 16.16: N15 = 19
5  QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED
COMPRESSIVE STRENGTH OR CALCULATING COMPRESSIVE 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) = 0.6: A(1, 2) = 0.57: A(1, 3) = 0.55: A(1, 4) = 0.53: A(1, 5) = 0.5
  A(2, 1) = 0.9: A(2, 2) = 0.85: A(2, 3) = 0.8: A(2, 4) = 0.7: A(2, 5) = 0.6
  A(3, 1) = 0.1: A(3, 2) = 0.15: A(3, 3) = 0.2: A(3, 4) = 0.3: A(3, 5) = 0.4
  A(4, 1) = 3#: A(4, 2) = 2#: A(4, 3) = 2.5: A(4, 4) = 1.5: A(4, 5) = 1#
  A(5, 1) = 6#: A(5, 2) = 4#: A(5, 3) = 5#: A(5, 4) = 3#: A(5, 5) = 2#
   YY = InputBox("WHAT IS THE DESIRED Compressive STRENGTH?"): YY = YY * 1
    Rem ONE COMPONENT
    Q = -5: R = 1: E = 1
50  For I = 1 To 5: X(I) = 0: Next I
   X(E) = 1
   If Q = 0 Then GoTo 60
   GoTo 2000
55 E = E + 1: Q = Q + 1: GoTo 50
60  Rem TWO COMPONENTS
   R = R + 1: F = 1: E = 2: T = 1: J = 1: W = 1: K1 = 0.9: K2 = 0.1: V = 6
65  For I = 1 To 5: X(I) = 0: Next I
   X(F) = K1: X(E) = K2
   If T = 6 Then GoTo 70
   If J = V Then GoTo 80
   If W = 5 Then GoTo 90
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   GoTo 2000
67  T = T + 1: K1 = K1 - 0.1: K2 = K2 + 0.1: GoTo 65
70  J = J + 1: E = E + 1: K1 = 0.9: K2 = 0.1: T = 1: GoTo 65
80  J = 1: V = V - 1: F = F + 1: E = F + 1: T = 1: W = W + 1: K1 = 0.9: K2 = 0.1: GoTo 65
90  Rem THREE COMPONENTS
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.89: K2 = 0.01: K3 = 0.1
100 For I = 1 To 5: X(I) = 0: Next I
    If E = 5 Then X(2) = K3: X(1) = K1: X(E) = 0.01: GoTo 110
    X(1) = K1: X(E) = 0.01: X(E + 1) = K3
110 If T = 99 Then GoTo 120
    If J = 5 Then GoTo 130
    If W = 10 Then GoTo 140
    GoTo 2000
115 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 110
120 T = 1: J = J + 1: E = E + 1: GoTo 100
130 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K3 = K3 + 0.1: GoTo 100
140 Rem THREE COMPONENTS CONTINUED
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.69: K2 = 0.11: K3 = 0.2
150 For I = 1 To 5: X(I) = 0: Next I
    If E = 5 Then X(2) = K3: X(1) = K1: X(E) = K2: GoTo 160
    X(1) = K1: X(E) = K2: X(E + 1) = K3
160 If T = 99 Then GoTo 170
    If J = 5 Then GoTo 180
    If W = 8 Then GoTo 190
    GoTo 2000
165 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 160
170 T = 1: J = J + 1: E = E + 1: GoTo 150
180 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K3 = K3 + 0.1: GoTo 150
190 Rem FOUR COMPONENTS
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.79: K2 = 0.01: K3 = 0.1: K4 = 0.1
200 For I = 1 To 5: X(I) = 0: Next I
    If E = 4 Then X(1) = K1: X(2) = K4: X(E) = K2: X(E + 1) = K3: GoTo 210
    If E = 5 Then X(1) = K1: X(2) = K3: X(3) = K4: X(E) = K2: GoTo 210
    X(1) = K1: X(E) = K2: X(E + 1) = K3: X(E + 2) = K4
210 If T = 99 Then GoTo 220
    If J = 5 Then GoTo 230
    If W = 9 Then GoTo 240
    GoTo 2000
215 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 210
220 T = 1: J = J + 1: E = E + 1: GoTo 200
230 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K4 = K4 + 0.1: GoTo 200
240 Rem FOUR COMPONENTS CONTINUED
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.59: K2 = 0.01: K3 = 0.2: K4 = 0.2
250 For I = 1 To 5: X(I) = 0: Next I
    If E = 4 Then X(1) = K1: X(2) = K4: X(E) = K2: X(E + 1) = K3: GoTo 260
    If E = 5 Then X(1) = K1: X(2) = K3: X(3) = K4: X(E) = K2: GoTo 260
    X(1) = K1: X(E) = K2: X(E + 1) = K3: X(E + 2) = K4
260 If T = 99 Then GoTo 270
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   If J = 5 Then GoTo 280
   If W = 7 Then GoTo 290
   GoTo 2000
265 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 260
270 T = 1: J = J + 1: E = E + 1: GoTo 250
280 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K4 = K4 + 0.1: GoTo 250
290 Rem FOUR COMPONENTS CONTINUED AGAIN
   R = R + 1: E = 2: T = 1: J = 1: W = 1
   K1 = 0.29: K2 = 0.01: K3 = 0.4: K4 = 0.3
300 For I = 1 To 5: X(I) = 0: Next I
   If E = 4 Then X(1) = K1: X(2) = K4: X(E) = K2: X(E + 1) = K3: GoTo 310
   If E = 5 Then X(1) = K1: X(2) = K3: X(3) = K4: X(E) = K2: GoTo 310
   X(1) = K1: X(E) = K2: X(E + 1) = K3: X(E + 2) = K4
310 If T = 99 Then GoTo 320
   If J = 5 Then GoTo 330
   If W = 4 Then GoTo 340
   GoTo 2000
315 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 310
320 T = 1: J = J + 1: E = E + 1: GoTo 300
330 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K4 = K4 + 0.1: GoTo 300
340 Rem FOUR COMPONENTS CONTINUED AGAIN AGAIN
   R = R + 1: E = 2: T = 1
350 For I = 1 To 5: X(I) = 0.25: Next I
   X(E) = 0
360 If T = 6 Then GoTo 370
   GoTo 2000
365 T = T + 1: E = E + 1: GoTo 350
370 Rem FIVE COMPONENTS
   R = R + 1: E = 2: T = 1: J = 1: W = 1
   K1 = 0.69: K2 = 0.01: K5 = 0.1
380 For I = 1 To 5: X(I) = 0.1: Next I
   X(1) = K1: X(E) = K2: X(5) = K5
390 If T = 99 Then GoTo 400
   If J = 5 Then GoTo 410
   If W = 8 Then GoTo 420
   GoTo 2000
395 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 390
400 T = 1: J = J + 1: E = E + 1: GoTo 380
410 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K5 = K5 + 0.1: GoTo 380
420 Rem FIVE COMPONENTS CONTINUED
   R = R + 1: E = 2: T = 1: J = 1: W = 1
   K1 = 0.49: K2 = 0.01: K3 = 0.1: K4 = 0.2: K5 = 0.2
430 For I = 1 To 5: X(I) = 0.1: Next I
   If E = 2 Then X(E + 1) = K3: X(E + 2) = K4: X(E + 3) = K5: GoTo 440
   If E = 3 Then X(E + 1) = K3: X(E + 2) = K4: X(2) = K5: GoTo 440
   If E = 4 Then X(E + 1) = K3: X(2) = K4: X(3) = K5: GoTo 440
   If E = 5 Then X(2) = K3: X(3) = K4: X(4) = K5
   X(1) = K1: X(E) = K2: X(5) = K5
440 X(1) = K1: X(E) = K2
450 If T = 99 Then GoTo 460
   If J = 5 Then GoTo 470
   If W = 6 Then GoTo 480
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    GoTo 2000
455 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 450
460 T = 1: J = J + 1: E = E + 1: GoTo 430
470 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K5 = K5 + 0.1: GoTo 430
480 Rem FIVE COMPONENTS CONTINUED AGAIN
    R = R + 1: E = 2: T = 1: J = 1
    K1 = 0.29: K2 = 0.01: K3 = 0.1: K4 = 0.3: K5 = 0.3
490 For I = 1 To 5: X(I) = 0.3: Next I
    If E = 5 Then X(1) = K1: X(2) = K3: X(E) = K2: GoTo 500
    X(1) = K1: X(E) = K2: X(E + 1) = K3
500 If T = 99 Then GoTo 510
    If J = 5 Then GoTo 520
    GoTo 2000
515 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 500
510 T = 1: J = J + 1: E = E + 1: GoTo 490
520 Rem FIVE COMPONENTS CONTINUED AGAIN AGAIN
    R = R + 1
    X(1) = 0.2: X(2) = 0.2: X(3) = 0.2: X(4) = 0.2: X(5) = 0.2
    GoTo 2000
525 Rem END OF THE COMBINATIONS
    GoTo 2100
2000         Rem PRINTING OF RESULTS
    For I = 1 To 5: Z(I) = 0: Next I
    For I = 1 To 5: For JJ = 1 To 5: Z(I) = Z(I) + A(I, JJ) * X(JJ): Next JJ: Next I
    If Z(1) < 0 Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Or Z(5) < 0 Then GoTo 830
    If Z(1) < 0.52 Then GoTo 830
    If Z(2) + Z(3) <> 1 Then GoTo 830
    If X(1) < 0 Or X(2) < 0 Or X(3) < 0 Or X(4) < 0 Or X(5) < 0 Then GoTo 830
    If X(1) > 1 Or X(2) > 1 Or X(3) > 1 Or X(4) > 1 Or X(5) > 1 Then GoTo 830
    Y = X(1) * (1 - 2 * X(2) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N1 + X(2) * (1 - 2 * X(1) - 2 * X(3) - 2 * X(4) - 2 *
X(5)) * N2 + X(3) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(4) - 2 * X(5)) * N3
    Y = Y + X(4) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) - 2 * X(5)) * N4 + X(5) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) -
2 * X(4)) * N5 + 4 * N6 * X(1) * X(2) + 4 * N7 * X(1) * X(3)
    Y = Y + 4 * N8 * X(1) * X(4) + 4 * N9 * X(1) * X(5) + 4 * N10 * X(2) * X(3) + 4 * N11 * X(2) * X(4) + 4 *
N12 * X(2) * X(5) + 4 * N13 * X(3) * X(4) + 4 * N14 * X(3) * X(5) + 4 * N15 * X(4) * X(5)
    If Y > OPSTRENGTH Then For I = 1 To 5: ZZ(I) = 0: Next I
    If Y > OPSTRENGTH Then OPSTRENGTH = Y: For I = 1 To 5: For JJ = 1 To 5: ZZ(I) = ZZ(I) + A(I,
JJ) * X(JJ): Next JJ: Next I
    If Y > YY - 0.1 And Y < YY + 0.1 Then GoTo 810 Else GoTo 830
810    CT = CT + 1
    For I = 1 To 5: Z(I) = 0: Next I
    For I = 1 To 5
    For JJ = 1 To 5
    Z(I) = Z(I) + A(I, JJ) * X(JJ)
    Next JJ
    Next I
'   If QQQ = 25 Then QQQQ = InputBox("PRESS OK TO CONTINUE", , , 5500, 8500): QQQ = 1: Cls
'   QQQ = QQQ + 1
820    Text1.Text = Text1.Text + CStr("Y =" & vbTab & Format(Y, "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr(" WATER  =" & vbTab & Format(Z(1), "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr(" CEMENT  =" & vbTab & Format(Z(2), "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr(" LIME  =" & vbTab & Format(Z(3), "0.00#") & ",") & vbTab
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    Text1.Text = Text1.Text + CStr(" SAND  =" & vbTab & Format(Z(4), "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr(" GRANITE  =" & vbTab & Format(Z(5), "0.00#") & ",") & vbCrLf
830
    If R = 1 Then GoTo 55
    If R = 2 Then GoTo 67
    If R = 3 Then GoTo 115
    If R = 4 Then GoTo 165
    If R = 5 Then GoTo 215
    If R = 6 Then GoTo 265
    If R = 7 Then GoTo 315
    If R = 8 Then GoTo 365
    If R = 9 Then GoTo 395
    If R = 10 Then GoTo 455
    If R = 11 Then GoTo 515
    If R = 12 Then GoTo 525
2100
    Text1.Text = Text1.Text + (" ") & vbCrLf: Text1.Text = Text1.Text + (" ") & vbCrLf
    If CT = 0 Then Text1.Text = Text1.Text + CStr("***   SORRY THE COMPRESSIVE STRENGTH IS
OUTSIDE THE FACTOR SPACE   ***") & vbCrLf
    Text1.Text = Text1.Text + CStr("OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS
MODEL IS ") & vbCrLf
    Text1.Text = Text1.Text + CStr(OPSTRENGTH) & vbCrLf
    Text1.Text = Text1.Text + CStr(" THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:") &
vbCrLf
    Text1.Text = Text1.Text + CStr("    WATER =" & vbTab & vbTab & ZZ(1) & vbTab & vbTab & "
CEMENT =" & vbTab & ZZ(2)) & vbTab
    Text1.Text = Text1.Text + CStr("    LIME =" & vbTab & vbTab & ZZ(3) & vbTab & vbTab & "   SAND
=" & vbTab & ZZ(4) & "   GRANITE =" & vbTab & ZZ(5)) & vbCrLf
    GoTo 22222
900
    Cls
  Y = 0
  For I = 1 To 5: X(I) = 0: Next I
  Rem  *** RESPONSE AT THE CHOSEN 15 POINTS ON THE FACTOR SPACE FOR THE MODEL  ***
   N1 = 15.12: N2 = 18.5: N3 = 17.86: N4 = 22: N5 = 19.56
  N6 = 20.85: N7 = 22.7: N8 = 22.17: N9 = 21.56: N10 = 23.81
  N11 = 23.34: N12 = 21.33: N13 = 16.22: N14 = 16.16: N15 = 19
3010  Rem  *** CONVERSION MATRIX  ****
  B(1, 1) = 40.65: B(1, 2) = -25.813: B(1, 3) = -13.618: B(1, 4) = 3.658: B(1, 5) = -1.626
  B(2, 1) = -17.886: B(2, 2) = 15.857: B(2, 3) = 0.492: B(2, 4) = 9.39: B(2, 5) = -5.284
  B(3, 1) = -50.406: B(3, 2) = 28.258: B(3, 3) = 18.136: B(3, 4) = -1.037: B(3, 5) = 1.016
  B(4, 1) = 23.577: B(4, 2) = -14.722: B(4, 3) = -2.648: B(4, 4) = -32.378: B(4, 5) = 16.057
  B(5, 1) = 4.065: B(5, 2) = -2.581: B(5, 3) = -1.362: B(5, 4) = 20.366: B(5, 5) = -10.163
    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 LIME")
    Z(4) = InputBox("ENTER THE VALUE OF SAND")
    Z(5) = InputBox("ENTER THE VALUE OF GRANITE")
    Rem  *** PSEUDO MIXTURE COMPONENTS  ***
    For I = 1 To 5
    For JJ = 1 To 5
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    X(I) = X(I) + B(I, JJ) * Z(JJ)
    Next JJ
    Next I
    Rem   *** CALCULATING THE STRENGTH (RESPONSE)  ****
    Y = X(1) * (1 - 2 * X(2) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N1 + X(2) * (1 - 2 * X(1) - 2 * X(3) - 2 * X(4) - 2 *
X(5)) * N2 + X(3) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(4) - 2 * X(5)) * N3
    Y = Y + X(4) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) - 2 * X(5)) * N4 + X(5) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) -
2 * X(4)) * N5 + 4 * N6 * X(1) * X(2) + 4 * N7 * X(1) * X(3)
    Y = Y + 4 * N8 * X(1) * X(4) + 4 * N9 * X(1) * X(5) + 4 * N10 * X(2) * X(3) + 4 * N11 * X(2) * X(4) + 4 *
N12 * X(2) * X(5) + 4 * N13 * X(3) * X(4) + 4 * N14 * X(3) * X(5) + 4 * N15 * X(4) * X(5)
     Text1.Text = Text1.Text + CStr("Y =" & vbTab & Format(Y, "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr("     WATER   =" & vbTab & Format(Z(1), "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr("     CEMENT  =" & vbTab & Format(Z(2), "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr("     LIME  =" & vbTab & Format(Z(3), "0.00#") & ",") & vbTab
    Text1.Text = Text1.Text + CStr("     SAND  =" & vbTab & Format(Z(4), "0.00#") & ",") & vbCrLf
    Text1.Text = Text1.Text + CStr("     COARSE AGG.  =" & vbTab & Format(Z(5), "0.00#") & ",") &
vbCrLf
    Text1.Text = Text1.Text + (" ") & vbCrLf: Text1.Text = Text1.Text + (" ") & vbCrLf
    For I = 1 To 5
    Text1.Text = Text1.Text + (Format(X(I), "0.00#") & vbTab)
    Next I
22222
End Sub
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