



## OPTIMIZATION OF FLEXURAL STRENGTH OF CHIKOKO BLENDED CONCRETE USING SCHEFFE'S REGRESSION THEORY

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### ABSTRACT

In this paper, a regression model is developed to optimize the flexural strength and the corresponding mix ratios of chikoko blended concrete using Scheffe's statistical theory. The regression model is a multivariate function of the proportion of the component materials. The regression model was coded in a Visual basic 6.0 environment to predict the mix corresponding to any desired value of the flexural strength and vice versa. The observed and the predicted values of flexural strength were found to coincide at every observation point. The model was tested for reliability at 5% level of significance using F-statistic and was found to be adequate. The optimum value of the flexural strength predictable by the model is  $4.933\text{N/mm}^2$  corresponding to mix ratio of 0.526:0.947:0.053:2.10:4.20 (Water:Cement:Chikoko:Sand:Granite).

**Keywords:** Regression model, Flexural strength, Statistical theory, Multivariate function, Reinforced concrete

### Introduction

In recent times, Nigeria has experienced an unprecedented increase in price of cement which is the most expensive component of concrete. This scenario has contributed in no small measure to the problem of inadequate housing in Nigeria (Anyaoagu and Ezech, 2013; Onwuka et al, 2013; Osadebe, and Obam, 2006; Okere et al., 2013). Thousands of buildings and other civil engineering projects

are abandoned due to the recent increase in price of cement. The absolute dependence on portland cement for construction works in Nigeria is worrisome. The supply of

cement for building and other construction works in Nigeria is grossly inadequate. Major projects in Nigeria are sometimes, not furthered due to scarcity of cement. Also, bringing cements to Nigeria may be difficult due to the high cost involved in foreign exchange. The building of new cement factories at every nook and corner of Nigeria still proffers no solution to non-availability of cement. Consequently, concrete structures and houses which are needed to accommodate the growing population of Nigeria are difficult and expensive to construct. Chikoko has been used as cement replacement material in concrete production without any adverse effects on the strength properties of concrete (Onwuka and Sule, 2016; Onwuka and Sule, 2017). In this paper, a mathematical model is developed based on Scheffe's regression theory to predict the flexural strength of chikoko blended cement concrete. Computer programs are also developed to predict the flexural strength and the corresponding mix ratios for any desired value of flexural strength of the flexural strength of chikoko blended cement concrete.

## **Materials and Methods**

The cement used as binder was Ordinary Portland cement with properties meeting the requirements BS EN 197, Part 1, 2000. The water used was clean, fresh and drinkable. 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 aggregate were carried out to the requirements of BS 882 Part 2, 1992. The granite used as coarse aggregate was obtained from a Crushed Rock Industry in Rivers State. The aggregate was properly washed and exposed to sun for two weeks to remove dirt. The chikoko was obtained in bags from the chikoko deposit at Eagle's Island, Port Harcourt, Rivers State. It was exposed to sun for three weeks after which it was ground and sieved to obtain fine particles close to those of cement. The oxide composition test of chikoko was carried out to investigate its suitability for use as pozzolan in concrete production (Table 4). The trial and control mixes obtained based on Scheffe's (5, 2) factor space are shown in Tables 2 and 3 respectively. Additional fifteen experimental runs were carried out to serve as test points for model validation.

## **Flexural Strength Test**

The flexural strength test was performed on chikoko blended cement concrete to obtain the tensile load at which the concrete would crack. The concrete was filled in the mould of size 150 x 150 x 500mm and compacted with a tamping rod 400mm long. The specimen to be tested was placed in the testing machine on two 38mm diameter rollers.

The load was applied through two similar rollers mounted at the third points. The specimen were cured in water and tested at 28 days. The flexural strength determined obtained using:

$$\sigma = PL / bd^2 \quad (1)$$

Where  $\sigma$  = the flexural strength

$P$  = Load at failure

$L$  = Length of the beam specimen

$b, d$  = width and depth of the beam specimen respectively.

### Development of regression Model

According to Okere et al. (2013), the response function for a 5- component concrete mixture based on a (5, 2) factor space is given by:

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

The coefficients of equation (2) are obtained as follows:

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

Where

$$\alpha_i = \alpha_1, \alpha_3, \dots, \alpha_5$$

$$\alpha_{ij} = \alpha_{12}, \alpha_{13}, \alpha_{14}, \dots, \alpha_{45}$$

Equation (1) is subject to the constraint that:

$$\sum_{i=1}^5 X_i = 1 \quad (4)$$

Where  $X_i \geq 0$  = the components proportion,  $q$  = number of components in the mixture.

According to Scheffe (1958), the number of experimental runs corresponding to a given factor space is given by:

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

Where:  $n, q$  = Degree of the polynomial and number of concrete components respectively

Let the actual and pseudo components be denoted by  $Z_i$  and  $X_i$ . The relationship between  $Z_i$  and  $X_i$  is given by:

$$X = BZ \quad (6)$$

Where  $B$  is the inverse of  $Z$  matrix

Also, the equation that transforms the pseudo to actual components ( $Z_i$ ) according to Osadebe and Obam (2006) is given by:

$$Z = AX \quad (7)$$

Where  $A$  = the transpose of the real mix ratios,  $Z$  = actual mix ratio,  $X$  = pseudo mix ratio

Using Equation (7), the actual mix ratios ( $Z_i$ ) are obtained and are given in matrix form as follows:

$$A = \begin{pmatrix} 0.526 & 0.566 & 0.589 & 0.611 & 0.596 \\ 0.947 & 0.919 & 0.823 & 0.889 & 0.846 \\ 0.053 & 0.081 & 0.177 & 0.111 & 0.154 \\ 2.100 & 2.020 & 1.910 & 2.160 & 2.150 \\ 4.200 & 4.040 & 3.820 & 4.320 & 4.300 \end{pmatrix} \quad (8)$$

$Z_1, Z_2, Z_3, Z_4, Z_5$  = Actual proportion of water, cement, chikoko, sand and coarse aggregate respectively

The design matrices for the trial and control mix ratios are presented in Tables 2 and 3 respectively.

Table 2. Design Matrix for Trial Points based on Scheffe's (5, 2) Factor Space

$Z_1$	$Z_2$	$Z_3$	$Z_4$	$Z_5$	Response	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$
0.52601	0.947	0.053	2.1	4.2	$Y_1$	1	0	0	0	0
0.566	0.91901	0.081	2.02	4.04	$Y_2$	0	1	0	0	0
0.589	0.823	0.17701	1.91	3.82	$Y_3$	0	0	1	0	0
0.611	0.889	0.111	2.1601	4.32	$Y_4$	0	0	0	1	0
0.596	0.846	0.154	2.15	4.301	$Y_5$	0	0	0	0	1
0.546005	0.933005	0.067	2.06	4.12	$Y_{12}$	0.50	0.50	0	0	0
0.557505	0.885	0.115005	2.005	4.01	$Y_{13}$	0.50	0	0.50	0	0
0.568505	0.918	0.082	2.13005	4.26	$Y_{14}$	0.50	0	0	0.50	0
0.561005	0.8965	0.1035	2.125	4.2505	$Y_{15}$	0.50	0	0	0	0.50
0.5775	0.871005	0.129005	1.965	3.93	$Y_{23}$	0	0.50	0.50	0	0
0.5885	0.904005	0.096	2.09005	4.18	$Y_{24}$	0	0.50	0	0.50	0
0.581	0.882505	0.1175	2.085	4.1705	$Y_{25}$	0	0.50	0	0	0.50
0.6	0.856	0.144005	2.03505	4.07	$Y_{34}$	0	0	0.50	0.50	0
0.5925	0.8345	0.165505	2.03	4.0605	$Y_{35}$	0	0	0.50	0	0.50
0.6035	0.8675	0.1325	2.15505	4.3105	$Y_{45}$	0	0	0	0.50	0.50

Table 3. Design Matrix for Control Points based on Scheffe's (5, 2) Factor Space

$Z_1$	$Z_2$	$Z_3$	$Z_4$	$Z_5$	Response	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$
0.560337	0.896337	0.10367	2.01	4.02	$Y C_1$	0.333333	0.333333	0.333333	0	0
0.575337	0.886333	0.11367	2.0567	4.113333333	$Y C_2$	0.333333	0	0.333333	0.333333	0
0.57767	0.894	0.106	2.1367	4.273666667	$Y C_3$	0.333333	0	0	0.333333	0.333333
0.573003	0.894503	0.105503	2.047525	4.095	$Y C_4$	0.25	0.25	0.25	0.25	0
0.580503	0.87625	0.123753	2.080025	4.16025	$Y C_5$	0.25	0	0.25	0.25	0.25
0.569253	0.883753	0.116253	2.045	4.09025	$Y C_{12}$	0.25	0.25	0.25	0	0.25
0.551755	0.909003	0.091003	2.0325	4.065	$Y C_{13}$	0.5	0.25	0.25	0	0
0.576753	0.8655	0.134503	2.0775	4.1555	$Y C_{14}$	0.25	0	0.25	0	0.5
0.563604	0.905002	0.095002	2.05802	4.116	$Y C_{15}$	0.4	0.2	0.2	0.2	0
0.577602	0.884802	0.115202	2.06802	4.1362	$Y C_{23}$	0.2	0.2	0.2	0.2	0.2
0.573603	0.887601	0.112402	2.07602	4.1522	$Y C_{24}$	0.3	0.1	0.2	0.2	0.2
0.586101	0.879002	0.121002	2.07403	4.1482	$Y C_{25}$	0.1	0.2	0.2	0.3	0.2
0.565254	0.886552	0.113453	2.053	4.10625	$Y C_{34}$	0.35	0.15	0.25	0	0.25
0.574453	0.891002	0.109002	2.07752	4.1552	$Y C_{35}$	0.25	0.2	0.15	0.2	0.2
0.566005	0.903701	0.0963	2.12302	4.2463	$Y C_{45}$	0.45	0.05	0	0.2	0.3

Where

$Z_1$  = actual proportion of water  
 $Z_2$  = actual proportion of cement  
 $Z_3$  = actual proportion of chikoko  
 $Z_4$  = actual proportion of sand  
 $Z_5$  = actual proportion of granite

$X_1$  = pseudo proportion of water  
 $X_2$  = pseudo proportion of cement  
 $X_3$  = pseudo proportion of chikoko  
 $X_4$  = pseudo proportion of sand  
 $X_5$  = pseudo proportion of granite

The simplex lattice for a 5-component mixture used in this study is shown in Figure 1.

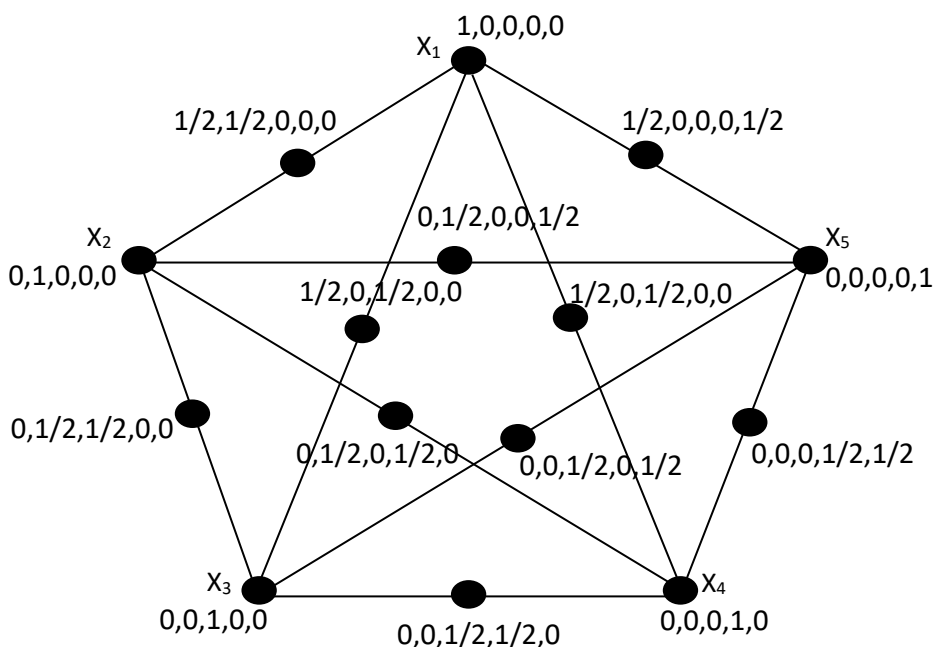


Figure 1: A simplex lattice for a 5-component mixture used in this study

Table 5: Results of flexural strength test after 28 days of curing in water

Exp. No	Replicates	Mass(Kg)	Density (Kg/m <sup>3</sup> )	Average Density $\rho$ (kg/m <sup>3</sup> )	Load at Failure (KN)	Flexural Strength	Average Flexural Strength
1	A	27.8	2471.111		39	5.200	
	B	26.9	2391.111	2432.593	36	4.800	4.933
	C	27.4	2435.556		36	4.800	
2	A	28.2	2506.667		30	4.000	
	B	27	2400.000	2447.407	22	2.933	3.644
	C	27.4	2435.556		30	4.000	
3	A	27.1	2408.889		28	3.733	
	B	27.1	2408.889	2388.148	20	2.667	3.467
	C	26.4	2346.667		30	4.000	
4	A	26.8	2382.222		21	2.800	
	B	27.1	2408.889	2429.630	22	2.933	2.711
	C	28.1	2497.778		18	2.400	
5	A	27.8	2471.111		26	3.467	
	B	28	2488.889	2477.037	21	2.800	3.422
	C	27.8	2471.111		30	4.000	

6	A	28.2	2506.667		32	4.267	
	B	27.9	2480.000	2450.370	40	5.333	4.267
	C	26.6	2364.444		24	3.200	
7	A	28.4	2524.444		36	4.800	
	B	26.2	2328.889	2447.407	30	4.000	4.533
	C	28	2488.889		36	4.800	
8	A	28.2	2506.667		36	4.800	
	B	28	2488.889	2465.185	24	3.200	3.733
	C	27	2400.000		24	3.200	
9	A	28.1	2497.778		37	4.933	
	B	27	2400.000	2432.593	20.5	2.733	4.022
	C	27	2400.000		33	4.400	
10	A	27.1	2408.889		35	4.667	
	B	27.2	2417.778	2420.741	19.5	2.600	3.844
	C	27.4	2435.556		32	4.267	
11	A	28.2	2506.667		24	3.200	
	B	27.2	2417.778	2435.556	18.5	2.467	3.356
	C	26.8	2382.222		33	4.400	
12	A	28	2488.889		28	3.733	
	B	28	2488.889	2459.259	22.7	3.027	3.542
	C	27	2400.000		29	3.867	
13	A	27	2400.000		30	4.000	
	B	26.9	2391.111	2420.741	22.5	3.000	3.311
	C	27.8	2471.111		22	2.933	
14	A	27.9	2480.000		34.5	4.600	
	B	27.4	2435.556	2438.519	25	3.333	3.756
	C	27	2400.000		25	3.333	
15	A	28.2	2506.667		29	3.867	
	B	27	2400.000	2435.556	19	2.533	2.978
	C	27	2400.000		19	2.533	
<b>Control points</b>							
C1	A	27.6	2453.333		28	3.733	
	B	27.2	2417.778	2438.519	40	5.333	4.267
	C	27.5	2444.444		28	3.733	
C2	A	28	2488.889		30	4.000	
	B	27	2400.000	2432.593	26	3.467	3.867
	C	27.1	2408.889		31	4.133	
C3	A	27	2400.000		32	4.267	
	B	26.8	2382.222	2402.963	21	2.800	3.689
	C	27.3	2426.667		30	4.000	
C4	A	28	2488.889		30	4.000	
	B	26.4	2346.667	2411.852	29	3.867	3.867
	C	27	2400.000		28	3.733	

C5	A	27.4	2435.556		32	4.267	
	B	28	2488.889	2447.407	21	2.800	3.689
	C	27.2	2417.778		30	4.000	
C6	A	28.1	2497.778		28	3.733	
	B	26.6	2364.444	2429.630	28	3.733	4.178
	C	27.3	2426.667		38	5.067	
C7	A	26.4	2346.667		33	4.400	
	B	27.5	2444.444	2426.667	32	4.267	4.489
	C	28	2488.889		36	4.800	
C8	A	27.2	2417.778		30	4.000	
	B	28	2488.889	2438.519	34	4.533	4.178
	C	27.1	2408.889		30	4.000	
C9	A	26.3	2337.778		30	4.000	
	B	28	2488.889	2414.815	28	3.733	3.911
	C	27.2	2417.778		30	4.000	
C10	A	27.3	2426.667		30	4.000	
	B	27	2400.000	2420.741	27	3.600	3.822
	C	27.4	2435.556		29	3.867	
C11	A	28	2488.889		29	3.867	
	B	27	2400.000	2417.778	25	3.333	3.911
	C	26.6	2364.444		34	4.533	
C12	A	26.7	2373.333		24	3.200	
	B	27.5	2444.444	2408.889	31	4.133	3.600
	C	27.1	2408.889		26	3.467	
C13	A	27.1	2408.889		25	3.333	
	B	26.9	2391.111	2414.815	34	4.533	4.133
	C	27.5	2444.444		34	4.533	
C14	A	27.8	2471.111		31	4.133	
	B	27.1	2408.889	2426.667	23	3.067	3.911
	C	27	2400.000		34	4.533	
C15	A	26.5	2355.556		28	3.733	
	B	27.2	2417.778	2400.000	30	4.000	3.867
	C	27.3	2426.667		29	3.867	

### Optimization Model Development

Using Equations (3) and Table 5, the coefficients of equation (2) are obtained as follows:

$$\alpha_1 = 0.186 \quad \alpha_2 = 0.223, \quad \alpha_3 = 0.225, \quad \alpha_4 = 0.245, \quad \alpha_5 = 0.243$$

$$\alpha_{12} = 4(0.199) - 2(0.186) - 2(0.223) = -0.022$$

$$\alpha_{13} = 4(0.209) - 2(0.186) - 2(0.225) = -0.014$$

$$\alpha_{14} = 4(0.208) - 2(0.186) - 2(0.245) = -0.03$$

$$\alpha_{15} = 4(16.415) - 2(17.511) - 2(14.489) = 1.66$$

$$\alpha_{23} = 4(0.214) - 2(0.223) - 2(0.225) = -0.04$$

$$\alpha_{24} = 4(0.237) - 2(0.223) - 2(0.245) = 0.012$$

$$\alpha_{25} = 4(0.224) - 2(0.223) - 2(0.243) = -0.036$$

$$\alpha_{34} = 4(0.244) - 2(0.225) - 2(0.245) = 0.036$$

$$\alpha_{35} = 4(0.236) - 2(0.225) - 2(0.243) = 0.008$$

$$\alpha_{45} = 4(0.243) - 2(0.245) - 2(0.243) = -0.004$$

Substituting the obtained coefficients,  $\alpha_i$  and  $\alpha_{ij}$  into equation (1) yields:

$$y = 0.186 X_1 + 0.223 X_2 + 0.225 X_3 + 0.245 X_4 + 0.243 X_5 - 0.022 X_1 X_2 - 0.014 X_1 X_3 - 0.03 X_1 X_4 + 1.66 X_1 X_5 - 0.04 X_2 X_3 + 0.012 X_2 X_4 - 0.036 X_2 X_5 + 0.036 X_3 X_4 + 0.008 X_3 X_5 - 0.004 X_4 X_5 \quad (9)$$

Equation (10) is the mathematical model for the prediction of poisson's ratio of chikoko blended cement concrete.

### Test of adequacy of the model

The model was tested for adequacy against the control points using F-Statistic. The results are as shown in Table 6.

Table 6: F-Statistic to test the adequacy of control points using Excel sheet

Two-Sample for Variances		
	<i>Experiment</i>	<i>Predicted</i>
Mean	15.322	15.189
Variance	0.504	0.488
Observations	15	15
df	14	14
F	1.032	
P(F<=f) one-tail	1.534	
F Critical one-tail	2.484	

## 4. Discussion of Results

The results of an experimental determination of the flexural strength of chikoko blended cement concrete are presented. A regression model is developed to predict the mix ratios and optimize the

Poisson's ratio. The prediction of the flexural strength was carried out using a computer program written in Visual basic 6.0. The model was tested for adequacy at 5% level of significance using F-statistic and the results are shown in Table 6. From Table 6, it can be seen that the F-value obtained at 5% level of significance is 2.484. This value is greater than the calculated value of F which is 1.534 showing that the model is adequate and therefore can be used to predict the flexural strength of chikoko blended cement concrete. The maximum value of the flexural strength predictable by the model is 4.933Mpa corresponding to mix ratio of 0.526:0.947:0.053:2.10:4.20 (Water:Cement:Chikoko:Sand:Granite). This value of the flexural strength falls within the value recommended for concrete (Neville and Brook, 2000) showing that chikoko blended cement concrete is adequate for construction of structural members such as beams, columns and walls.

## 5. Conclusion

A regression model has been formulated to predict and optimize the poisson's ratio of chikoko blended cement concrete and has been tested for adequacy against the control points using F-statistic in Microsoft Excel. The results of the F-statistic showed that the regression model can be used to predict the poisson's ratio of chikoko blended concrete. The predicted values of flexural strength were found to coincide with the experimental values. The computer program developed using Visual Basic 6.0 based on the formulated model can be used to select the mix ratios of chikoko blended cement concrete corresponding to a desired value of poisson's ratio and vice-versa. The optimum value of the flexural strength predictable by the model is 4.933Mpa corresponding to mix ratio of 0.526:0.947:0.053:2.10:4.20 (Water:Cement:Chikoko:Sand:Granite).

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Private Sub ENDMNU\_Click ()  
End  
End Sub



```
Private Sub STARTMNU_Click ()  
Rem ONE COMPONENT  
Text1.Text = ""  
ReDim X (4)  
  
' SCHEFFE'S SIMPLEX MODEL  
WWWWW = InputBox ("CLICK OK. TO CONTINUE"): Cls  
  
' CIVIL ENGINEERING DEPARTMENT, FUT0  
  
CT = 0: OPSTRENGTH = 0  
ReDim X (10), A(5, 5), Z(5), N(15), B(5, 5), ZZ(5): QQQ = 1  
  
Cls  
  
N1 = 4.933: N2 = 3.644: N3 = 3.467: N4 = 2.711: N5 = 3.422  
N6 = 4.267: N7 = 4.533: N8 = 3.733: N9 = 4.022: N10 = 3.844
```

N11 = 3.356: N12 = 3.542: N13 = 3.311: N14 = 3.756: N15 = 2.978

5 QQ = InputBox ("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED COMPRESSIVE STRENGTH OR CALCULATING FLEXURAL 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) = 0.52601: A (1, 2) = 0.566: A (1, 3) = 0.589: A (1, 4) = 0.611: A (1, 5) = 0.596

A (2, 1) = 0.947: A (2, 2) = 0.91901: A (2, 3) = 0.823: A (2, 4) = 0.889: A (2, 5) = 0.846

A (3, 1) = 0.053: A (3, 2) = 0.081: A (3, 3) = 0.17701: A (3, 4) = 0.111: A (3, 5) = 0.154

A (4, 1) = 2.1: A (4, 2) = 2.02: A (4, 3) = 1.91: A (4, 4) = 2.1601: A (4, 5) = 2.15

A (5, 1) = 4.2: A (5, 2) = 4.04: A (5, 3) = 3.82: A (5, 4) = 4.32: A (5, 5) = 4.301

YY = InputBox ("WHAT IS THE DESIRED Flexural 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

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

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
  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 (" ASH =" & vbTab & Format (Z (3), "0.00#") & ",") & vbTab
Text1.Text = Text1.Text + CStr (" SAND =" & vbTab & Format (Z(4), "0.00#") & ",") & vbTab
Text1.Text = Text1.Text + CStr (" COARSE AGG. =" & 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 (" ASH =" & vbTab & vbTab & ZZ(3) & vbTab & vbTab & " SAND =" & vbTab & ZZ(4) & " COARSE AGG. =" & 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 = 4.933: N2 = 3.644: N3 = 3.467: N4 = 2.711: N5 = 3.422

N6 = 4.267: N7 = 4.533: N8 = 3.733: N9 = 4.022: N10 = 3.844

N11 = 3.356: N12 = 3.542: N13 = 3.311: N14 = 3.756: N15 = 2.978

3010 Rem \*\*\* CONVERSION MATRIX \*\*\*\*

B(1, 1) = -23.71018046: B(1, 2) = 3.660972017: B(1, 3) = 14.38346512: B(1, 4) = 1291.514125: B(1, 5) = -643.5564605

B(2, 1) = 26.77605909: B(2, 2) = 4.862402729: B(2, 3) = -21.54113443: B(2, 4) = -2429.352469: B(2, 5) = 1210.498261

B(3, 1) = -9.345425143: B(3, 2) = 5.117619174: B(3, 3) = 17.30932952: B(3, 4) = 1113.768466: B(3, 5) = -557.0861363

B(4, 1) = 5.232810175: B(4, 2) = -10.53424477: B(4, 3) = -7.626348251: B(4, 4) = 1686.735861: B(4, 5) = -841.5518316

B(5, 1) = 1.046562035: B(5, 2) = -2.106848953: B(5, 3) = -1.52526965: B(5, 4) = -1662.652828: B(5, 5) = 831.6896337

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 ASH")
Z (4) = InputBox ("ENTER THE VALUE OF SAND")
Z (5) = InputBox ("ENTER THE VALUE OF COARSE AGG.")
Rem *** PSEUDO MIXTURE COMPONENTS ***
For I = 1 To 5
For JJ = 1 To 5
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 (" ASH =" & 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