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Optimization of Concrete Cost Based On Its Elastic Modulus

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Abstract: *In order to obtain concrete with a desired elastic modulus, E, at minimum cost, it is necessary to carry out optimization of concrete mixtures. Effectively and efficiently optimized concrete mixtures, usually have better properties, satisfy intended use and minimize costs. In this work, the cost of concrete mixtures based on its elastic modulus, E, is optimized using Osadebe's optimization Method. The resulting optimization model can be used to estimate the cost of concrete when the elastic modulus, E, is specified. Conversely, the model can be used to determine the elastic modulus, E, obtainable from concrete mixture of a given cost. In addition, it can be used to determine the optimum concrete mix and cost when given the desired elastic modulus, E. Fluctuations in market prices can be accommodated by multiplying the base prices of constituent materials with a price fluctuation factor (PFF). The predicted costs compare favourable with the values obtained from the market survey. The optimization model was tested for adequacy using statistical tools and found to be adequate.*

Keywords: *Optimization, Costs, Concrete Mixtures, Elastic Modulus, Osadebe'sTheory, Optimization Method.*

I. Introduction

Today, concrete is the most widely used construction material. Some of its notable properties are workability of the fresh concrete are compressive strength, elastic modulus, durability and thermal characteristics of hardened concrete. A knowledge of its modulus of elasticity, E, is necessary in the analysis and design of structural concrete members. The production of concrete using conventional mix design methods, are well known and documented. These conventional methods of concrete mix design used to obtain concrete of desired modulus of elasticity, MOE, involve several trial mixes with their attendant waste of time, materials and labour.

However concrete can be optimized to meet a number of performance criteria simultaneously at minimum cost. Majid (1974) defined optimization as a process that seeks for a maximum value for a function of severable variables while at the same time satisfying a number of imposed requirements. Although, optimization methods require commitment of time and money upfront, they have the potential to save money during production (Simon et al, 1997). In this article, an optimization approach by Osadebe (2003) is adopted and used for the formulation of an optimization model for predicting the cost of concrete on the basis of its modulus of elasticity. To achieve this, experiments were carried out and the results used to develop the final optimization model based on the Osadebe's optimization method.

II. Methods

2.1Osadebe Optimization Method

Osadebe (2003) assumed that a regression function, $F_{(Z)}$, is continuous and differentiable with respect to its variables, Z_i . By making use of Taylor's series, the response function, could be expanded in the neighbourhood of a chosen point, $Z^{(o)}$

$$F(z) = \sum_{m=0}^{\infty} \frac{f^{(m)}_{(z\ )^{(0)}}}{m!}(z_i - z^{(0)})^m \qquad \text{.......... (1)}$$

Expanding Eqn (1) up to the second order gives:

$$F(z) = f(z)^{(0)} + \sum_{m=0}^{\infty} \frac{f^{(1)}_{(z)^{(0)}}}{1!}(z_i - z^{(0)})^1 + \sum_{m=0}^{\infty} \frac{f^{(2)}_{(z)^{(0)}}}{2!}(z_i - z^{(0)})^2 + \sum_{m=0}^{\infty} \frac{f^{(2)}_{(z)^{(0)}}}{2!}(z_i - z^{(0)}) \qquad \text{.......... (2)}$$

where m = degree of polynomial of the response function

and $0 \le i \le 4$

Assuming Z_i is the fractional portion and S_i, the actual portion of the mixture component, then the total quantity of concrete, S, for a four-component mixture, is given by

$$S = \sum S_i \quad \text{……(3)}$$

Thus,

$$S = S_1 + S_2 + S_3 + S_4 \quad \text{……(4)}$$

If $1m^3$ of concrete is required, dividing both sides of Eqn (4) by S yields:

$$S/S = S_1/S + S_2/S + S_3/S + S_4/S \quad \text{……(5)}$$

Let $S_i/S = Z_i$ ……(6)

Then,

$$1 = Z_1 + Z_2 + Z_3 + Z_4 \quad \text{……(7)}$$

This can be written in compact form as :

$$\sum Z = 1 \quad \text{……(8)}$$

Assuming the point Z_0 is taken as the origin, it implies that

$$z^{(0)} = 0 \quad \text{……(9)}$$

Thus

$$z_1^0 = z_2^0 = z_3^0 = z_4^0$$

Let,

$$b_0 = F(0) \quad \text{……(11)}$$

$$b_i = \frac{\partial F(0)}{\partial Z_i} \quad \text{……(12)}$$

$$b_{ij} = \frac{\partial F^2(0)}{\partial Z_i \partial Z_j} \quad \text{……(13)}$$

$$b_{ii} = \frac{\partial F^2(0)}{\partial Z_i^2} \quad \text{……(14)}$$

Substituting Eqns (11)-(14) into Eqn(2) yields Eqn(15) for 4-component mixture:

$$F(z) = b_0 + \sum_{i=1}^{4} b_i Z_i + \sum_{i=1, j=1}^{4} b_{ij} Z_i Z_j + \sum_{i=1}^{4} b_{ii} Z_i^2 \quad \text{……(15)}$$

Multiplying Eqn (7) by b_0 gives:

$$b_0 = b_0 Z_1 + b_0 Z_2 + b_0 Z_3 + b_0 Z_4 \quad \text{……(16)}$$

Multiplying Eqn (7) successfully by Z_1, Z_2, Z_3 and Z_4 yields respectively:

$$Z_1 = Z_1^2 + Z_1 Z_2 + Z_1 Z_3 + Z_1 Z_4 \quad \text{……(17)}$$

$$Z_2 = Z_1 Z_2 + Z_2^2 + Z_2 Z_3 + Z_2 Z_4 \quad \text{……(18)}$$

$$Z_3 = Z_1 Z_3 + Z_2 Z_3 + Z_3^2 + Z_3 Z_4 \quad \text{……(19)}$$

$$Z_4 = Z_1 Z_4 + Z_2 Z_4 + Z_3 Z_4 + Z_4^2 \quad \text{……(20)}$$

Rearranging Eqns (17)-(20) gives:

$$Z_1^2 = Z_1 - Z_1 Z_2 - Z_1 Z_3 - Z_1 Z_4 \quad \text{……(21)}$$

$$Z_2^2 = Z_2 - Z_1 Z_2 - Z_2 Z_3 - Z_2 Z_4 \quad \text{……(22)}$$

$$Z_3^2 = Z_3 - Z_1 Z_3 - Z_2 Z_3 - Z_3 Z_4 \quad \text{……(23)}$$

$$Z_4^2 = Z_4 - Z_1 Z_4 - Z_2 Z_4 - Z_3 Z_4 \quad \text{……(24)}$$

Substituting Eqns (21) - (24) into Eqn (15) yields Eqn(25)

$$\begin{aligned} Y = {} & b_0 Z_1 + b_0 Z_2 + b_0 Z_3 + b_0 Z_4 + b_1 Z_1 + b_2 Z_2 + b_3 Z_3 + b_4 Z_4 \\ & + b_{12} Z_1 Z_2 + b_{13} Z_1 Z_3 + b_{14} Z_1 Z_4 + b_{23} Z_2 Z_3 + b_{24} Z_2 Z_4 + b_{34} Z_3 Z_4 \\ & + b_{11}(Z_1 - Z_1 Z_2 - Z_1 Z_3 - Z_1 Z_4) + b_{22}(Z_2 - Z_1 Z_2 - Z_2 Z_3 - Z_2 Z_4) \\ & + b_{33}(Z_3 - Z_1 Z_3 - Z_2 Z_3 - Z_3 Z_4) + b_{44}(Z_4 - Z_1 Z_4 - Z_2 Z_4 - Z_3 Z_4) \quad \text{…. (25)} \end{aligned}$$

Factorizing Eqn (25 gives:

$$Y = (b_0 + b_1 + b_{11}) Z_1 + (b_0 + b_2 + b_{22}) Z_2 + (b_0 + b_3 + b_{33}) Z_3 + (b_0 + b_4 + b_{44}) Z_4$$

$$+(b_{12}-b_{11}-b_{22})Z_1Z_2+(b_{13}-b_{11}-b_{33})Z_1Z_3+(b_{14}-b_{11}-b_{44})Z_1Z_4$$
$$+(b_{23}-b_{22}-b_{33})Z_2Z_3+(b_{24}-b_{22}-b_{44})Z_2Z_4+(b_{34}-b_{33}-b_{44})Z_3Z_4 \quad \ldots\ldots\ldots\ldots\ldots(26)$$

Since the summation of constants gives another constant, let

$$\alpha_i = b_0 + b_i + b_{ii} \quad \ldots\ldots\ldots\ldots\ldots\ldots (27)$$

and $$\alpha_{ij} = b_{ij} - b_{ii} + b_{jj} \quad \ldots\ldots\ldots\ldots\ldots\ldots(28)$$

Then, substituting Eqns (27) and (28) into Eqn (26) yields:

$$Y = \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_{12} Z_1 Z_2 + \alpha_{13} Z_1 Z_3 + \alpha_{14} Z_1 Z_4$$
$$+\alpha_{23} Z_2 Z_3 + \alpha_{24} Z_2 Z_4 + \alpha_{34} Z_3 Z_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots (29)$$

In compact form, Eqn (29) becomes:

$$Y = \sum_{i=1}^{4} \alpha_i z_i + \sum_{i=1}^{4}\sum_{j=1}^{4} \alpha_{ij} z_i z_j \quad \ldots\ldots\ldots\ldots\ldots\ldots (30)$$

In Eqn(30), Y is the response function at any point of observation, z_i and z_j are the predictors, and α_i and α_j are the coefficients of the regression equation.

Putting Eqn(30) in a matrix form gives:

$$[Y^{(n)}] = [Z^{(n)}][\alpha] \quad \ldots\ldots\ldots\ldots\ldots\ldots (31)$$

In expanded form, Eqn(31) becomes

$$\begin{pmatrix} Y^{(1)} \\ Y^{(2)} \\ \vdots \\ Y^{(10)} \end{pmatrix} = \begin{pmatrix} Z_1^{(1)} & Z_2^{(1)} & \cdots & Z_3^{(1)}Z_4^{(1)} \\ Z_1^{(2)} & Z_2^{(2)} & \cdots & Z_3^{(2)}Z_4^{(2)} \\ \cdots & \cdots & & \vdots \\ Z_1^{(10)} & Z_2^{(10)} & \cdots & Z_3^{(10)}Z_4^{(10)} \end{pmatrix} \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \cdots \\ \alpha_{10} \end{pmatrix} \quad \ldots\ldots\ldots\ldots (32)$$

Rearranging, Eqn (32) yields

$$\begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \cdots \\ \alpha_{10} \end{pmatrix} = \begin{pmatrix} Z_1^{(1)} & Z_2^{(1)} & \cdots & Z_3^{(1)}Z_4^{(1)} \\ Z_1^{(2)} & Z_2^{(2)} & \cdots & Z_3^{(2)}Z_4^{(2)} \\ \cdots & \cdots & & \vdots \\ Z_1^{(10)} & Z_2^{(10)} & \cdots & Z_3^{(10)}Z_4^{(10)} \end{pmatrix}^{-1} \begin{pmatrix} Y^{(1)} \\ Y^{(2)} \\ \vdots \\ Y^{(10)} \end{pmatrix} \quad \ldots\ldots\ldots\ldots (35)$$

Putting Eqn(32) in a compact form gives:

$$[\alpha] = [Z^{(n)}]^{-1}[Y^{(n)}] \quad \ldots\ldots\ldots\ldots\ldots\ldots(36)$$

where

$[Y^{(n)}]$ = matrix of responses function determined from laboratory tests.

$[Z^{(n)}]$ = matrix of fractional portions obtained from matrix of actual portion.

$[\alpha]$ = matrix of coefficients of the regression function'

It should be noted that fractional portion, Z_i, is the ratio of the actual portions, S_i, to the total quantity of concrete, S. Thus, the values of the fractional portions, Z_i, is obtained from the values of actual portions, S_i, and presented in Table 1. The $Z^{(n)}$ values were used for developing the $Z^{(n)}$ matrix and the inverse $Z^{(n)}$ matrix given in Tables 2 and 3 respectively.

3.2experimental Method

Tests were conducted in the laboratory to determine the values of the response, Y_i, required to determine the final response function for predicting the elastic modulus of concrete. In all, fourteen mix ratios were used for producing 28 cylindrical concrete specimen measuring 100mm in diameter and 200mm in depth. Four out of the fourteen mix ratios were used as control mix ratios for testing the adequacy of the regression response function developed in this work. The cylindrical concrete specimen were produced from Dangote cement, a brand of Portland cement conforming to BS 12 (1978) specifications, river sand that fell within zone 2 of BS 882 grading zone, crushed granite of maximum size conforming to BS 882 and B.S 812 (1983) and portable water. The concrete cylinders were cast, cured in water for 28 days and then, tested in a universal testing machine in accordance with the specifications of BS 1881 (1983). The results of the laboratory tests are presented in Table 4

3.3Costing Of Materials

This section is concerned with the determination of the cheapest of all the concrete mixes that will yield a particular modulus of elasticity. Knowledge of current market price of the constituent (building) materials is very essential in the determination of the total costs of various concrete mixes. The unit prices of these constituent materials are defined as follows:

₦ w = cost of water per kg
₦ c = cost of cement per kg
₦ k = cost of sand per kg
₦ p = cost of coarse aggregate per kg

Calculation of Quantities of concrete constituents.

The predictors, Z_i, are determined from the response function i.e Eqn (29) for predicting the possible combinations of the proportions of the concrete constituents for a desired modulus of elasticity.

It will be recalled that for 1 m^3 of concrete,

$$Z_1 + Z_2 + Z_3 + Z_4 = 1 \quad \ldots\ldots(35)$$

This can be rewritten in a compact form as follows:

$$\sum_{i=1}^{4} Z_i = 1 \quad \ldots\ldots(36)$$

But, the total weight of $1m^3$ of concrete = 2400kg
Therefore,

$$\text{Quantity of water} = \frac{Z_1}{\sum z} * 2400 \text{ Kg} \ldots\ldots (37)$$

where z_1 = proportion of water in 1m3 of concrete.

$$\text{Quantity of cement} = \frac{Z_2}{\sum z} * 2400 \text{ Kg} \ldots\ldots(38)$$

where z_2 = proportion of cement in 1m3 of concrete.

$$\text{Quantity of sand} = \frac{Z_3}{\sum z} * 2400 \text{ Kg} \ldots\ldots(39)$$

where z_3 = proportion of sand in 1m3 of concrete.

$$\text{Quantity of coarse aggregate} = \frac{Z_4}{\sum z} * 2400 \text{ Kg} \ldots\ldots (40)$$

where z_1 = proportion of coarse aggregate in 1m3 of concrete.

COSTS OF CONCRETE

$$\text{Cost of water} = \frac{Z_1}{\sum z} * 2400 * w \ldots\ldots (41)$$

$$\text{Cost of cement} = \frac{Z_2}{\sum z} * 2400 * c \ldots\ldots(42)$$

$$\text{Cost of sand} = \frac{Z_3}{\sum z} * 2400 * k \ldots\ldots(43)$$

Cost of coarse aggregate = $\frac{z_4}{\sum z} * 2400 * p$ …………………………….………… (44)

Therefore, the total cost of concrete is obtained by summing up the costs of its constituents as follows:
Total cost of concrete, C_t = (cost of water + cost of cement + cost of sand + cost of coarse aggregate).

$$C_t = \frac{z_3}{\sum z}\left[\frac{z_1}{\sum z}*2400w + \frac{z_2}{\sum z}*2400c + \frac{z_3}{\sum z}*2400k + \frac{z_4}{\sum z}*2400p\right] \ldots(45)$$

Simplifying Eqn(4) gives:

$$C_t = \frac{2400}{\sum_{i=1}^{4} z}\left[z_1 w + z_2 c + z_3 k + z_4 p\right] \ldots\ldots(46)$$

III. Results And Analysis

The results of the experimental tests are given in Table 4

Table 4.: Experimental results

Exp No	**Mix ratios w/c : c : F.A:C.A**	***Replciates***	**Response symbol**	**MOE (N/mm^2)**	**Average MOE (N/mm^2)**
1	0.5:1:1.5:3	1A	Y_1	40.20	41.30
		1B	Y_1	42.42	
2	0.55:1:2:3	2A	Y_2	55.03	50.04
		2B	Y_2	45.05	
3	0.6:1:2:4	3A	Y_3	24.97	25.21
		3B	Y_3	25.45	
4	0.65:1:3:5	4A	Y_4	19.39	19.24
		4B	Y_4	19.09	
5	0.525:1:1.5:2.25	5A	Y_5	22.13	21.78
		5B	Y_5	21.43	
6	0.55:1:1.5:2.75	6A	Y_6	25.43	26.10
		6B	Y_6	26.77	
7	0.575:1:2:3.25	7A	Y_7	34.20	35.80
		7B	Y_7	37.40	
8	0.575:1:2:3.5	8A	Y_8	25.54	23.68
		8B	Y_8	21.82	
9	0.6:1:2.5:4	9A	Y_9	28.90	28.15
		9B	Y_9	27.40	
10	0.625:1:2.5:4.5	10A	Y_{10}	26.36	25.79
		10B	Y_{10}	25.22	
11	0.575:1:2:3.375	11A	Y_{11}	23.20	27.08
		11B	Y_{11}	22.76	
12	0.5875:1:2.25:3.625	12A	Y_{12}	26.58	23.93
		12B	Y_{12}	26.92	
13	0.625:1:2.75:4.5	13A	Y_{13}	23.35	22.71
		13B	Y_{13}	22.41	
14	0.54:1:1.6:2.6	14A	Y_{14}	18.61	19.69
		14B	Y_{14}	18.97	

where w/c = water-cement ratio
C = Cement
F.A. = Fine Aggregate,
C.A = **Coarse Aggregate**

MOE = modulus of Elasticity.

4.1 **Determination Of The Regression Function For Elastic Modulus**. Substituting the values of obtained from the test results (given in Table 4) into Eqn (33) yields the following coefficients, α

$$\begin{bmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\\ \alpha_4\\ \alpha_5\\ \alpha_6\\ \alpha_7\\ \alpha_8\\ \alpha_9\\ \alpha_{10}\end{bmatrix} = \begin{bmatrix}5351667.6400\\ 888151.9143\\ 1835.219102\\ 2392.479301\\ -10609392.05\\ -5791804.077\\ -5620199.635\\ -699734.4294\\ -786415.528\\ 12085.08274\end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(47)$$

And substituting the values of these coefficients into Eqn (29) gives:

$$\mathbf{Y = 5351667.6400\,Z_1 + 888151.9143\,Z_2 + 1835.219102\,Z_3 + 2392.479301Z_4 - 10609392.05Z_1Z_2 - 5791804.077\,Z_1Z_3 - 5620199.635\,Z_1Z_4 - 699734.4294\,Z_2Z_3 - 786415.528\,Z_2Z_4 + 12085.08274\,Z_3Z_4} \quad \ldots\ldots\ldots (48)$$

The Eqn (49), is the final Osadebe's regression function for optimizing the Modulus of Elasticity of a 28 day concrete**.**

4.2 Test Of Goodness Of Fit Of Osadebe's Regression Function.

(a) **Determination of Replication Error.**

The variation of replicates, S_y at any arbitrary point of observation arising from instruments, tools and weather variation, is determined using Eqn (50)

$$S_y^2 = \frac{1}{V_e}\sum S_i^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (49)$$

$$\text{where} \quad S_i^2 = \frac{1}{(m-1)}\sum_{1\le i\le m}\left[y_i^2 - \frac{1}{m}\left(\sum_{1\le i\le m} y_i\right)^2\right]$$

$m_i - 1$ = degree of freedom

y_i = value of responses at any point

$\bar{y}_i$ = mean of responses

Thus, random error is given by:

$$S_y = \frac{1}{V_e}\sqrt{S_y^{\,2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(50)$$

The replication variance and random error computations are carried out and summarized in Table 5.

Table 5: Computations of Standard Error of Replicates and Replication Variance of Modulus of Elasticity of Test Results.

Exp No	**Replicate**	**Response symbol**	**MOE, y_r (N/mm^2**	$\sum_{r=1}^{m_i} y_r$	$\bar{y}$	$\sum_{r=1}^{m_i} y_r^2$	S_i^2
1	1A 1B	Y_1	40.20 42.42	82.62	41.30	3415.50	2.4642

2	2A 2B	Y_2	55.03 45.05	100.08	50.04	5057.00	49.8002
3	3A 3B	Y_3	24.97 25.45	50.42	25.21	1271.20	0.1152
4.	4A 4B	Y_4	19.39 19.09	38.48	19.24	740.40	0.045
5	5A 5B	Y_{12}	22.13 21.43	243.56	21.78	948.98	0.245
6	6A 6B	Y_{13}	25.43 26.77	52.20	26.10	1363.32	0.8978
7	7A 7B	Y_{14}	34.20 37.40	71.60	35.80	2568.40	5.12
8	8A 8B	Y_{23}	25.54 21.82	47.36	23.68	1128.40	6.9192
9	9A 9B	Y_{24}	28.9 27.4	56.30	28.15	1585.97	1.125
10	10A 10B	Y_{34}	26.36 25.22	51.58	25.79	1330.90	0.6498
11	11A 11B	C_1	20.80 22.76	43.56	21.78	950.66	1.9208
12	12A 12B	C_2	30.58 28.92	59.50	29.75	1771.50	1.3778
13	13A 13B	C_3	24.35 22.41	46.76	23.38	1095.13	1.8818
14	14A 14B	C_4	16.17 17.97	34.14	17.07	584.38	1.62

$\sum S_i^2 = 74.18$

Therefore

$$\text{Replication variance, } S_y^2 = \frac{74.18}{14} = 5.30$$

Replication, Error, $S_y = \sqrt{5.30} = 2.30$

Fishers test

The test of adequacy was performed using fishers test. The computations for Fishers test of Adequacy, are presented in Table 7.

Table 7 :Computations for Fisher's Test of Adequacy

Response symbol	$\mathbf{Y_e}$ (Y_{exp})	$\mathbf{Y_p}$ (Y_{pred})	$\mathbf{Y_e - \bar{Y}_e}$	$\mathbf{Y_p - \bar{Y}_p}$	$\mathbf{(Y_e - \bar{Y}_e)^2}$	$\mathbf{(Y_p - \bar{Y}_p)^2}$
C1	22.98	27.08	0.13	3.727	0.0169	13.8905
C2	26.75	23.93	3.90	0.577	15.21	0.332929
C3	22.88	22.71	0.03	-0.643	0.0009	0.413449
C4	18.79	19.69	-4.06	-3.663	16.4836	13.4176
$\sum$	91.40	93.41			31.7114	28.0545
Mean	**22.85**	**23.353**				

$$S_{exp}^2 = \sum (Y_e - \bar{Y}_e)^2 /(N-1) = 31.7114/(4-1) = 10.570467$$

$$S_{pred}^2 = \sum (Y_p - \bar{Y}_p)^2 /(N-1) = 28.0545/(4-1) = 9.35$$

Using S_{exp}^2 as S_1^2 and S_{pred}^2 as S_2^2 in in Fisher's test equation, then,

$F = \frac{S_1^2}{S_2^2}$ = 10.5705/9.3500 = 1.13

And from Fisher's Table,

$F_{a(3,3)}$ =9.28 and $\frac{1}{F}$ =0.108

Since, Fisher's condition, $\frac{1}{F} < S_1^2 / S_2^2 < F$ is satisfied, the Null Hypothesis ,H_0 ,is also accepted. And so there is no significant difference between the predicted and experimentl results.

4.3 Predicted Costs and mix ratios

The costs and mix ratios corresponding to concrete with an elastic modulus of 36 N/Mm^2 is given below.

Table 6: Concrete mix ratios and costs corresponding to elastic modulus of 36N/mm^2

S/N	Elastic modulus Y(N/mm^2)	Mix Ratios w/c :C:FA:CA	Market-based Costs (₦)	Predicted Costs
1	36	0.64:1.00:2.58:5.98	19,602.98	19,596.72
2	36	0.56:1.00:2.00:3.07	22,545.88	22,560.73
3	36	0.51:1.00:1.62:1.85	25,528.03	25,536.19
4	36	0.50:1.00:1.52:1.42	26,927.58	26,915.23
5	36	0.49:1.00:1.30:1:07	29,076.89	29,082.58
6	36	0.47:1.00:0.95:1.24	30,577.78	30,639.44

where w/c = water – cement ratio
C = cement
F.A = Fine aggregate
C.A = Coarse aggregate

A cursory look at Table 6 shows that the maximum percentage difference between the market-based costs and the predicated costs, is 0.07%. And, the optimum mix and cost of concrete with an elastic modulus of 36N/mm^2 are **0.64:1.00:2.58:5.98** and ₦19, 596.72 respectively.

IV. Conclusions

An optimization model based on Osadebe theory has been successfully formulated for the determination of cost estimates of concrete based on its elastic modulus. In doing so, the first things to be calculated are the proportions that can yield a given elastic modulus, and subsequently estimates of the costs of the predicted mix proportions, are obtained.

Conversely, the model can be used to predict the elastic modulus, E, obtainable from concrete mixture of a given cost and comprehensive strength.

The model can be used to determine optimum concrete mix and its cost based on its elastic modulus. The maximum elastic modulus predictable by the model is 50.04 N/mm^2 and the cheapest mix proportion that yield it, is 0.55: 1.0:2.0:3.0 with a total cost of N22, 387.78.

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