Mathematical Model for Cost Evaluation of Lateritic Soil Treated with Bagasse Ash and Cement for Low-Cost Roads

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ABSTRACT

Frequent rise in the price of cement in Nigeria has prompted the search for other pozzolanic materials that could be used as supplement or partial replacement for economy. In addition to this is the use of locally available materials like lateritic soils for low-cost roads. However in practical terms, the use of all these materials without proper cost benefit analysis could be misleading. Thus this study was an attempt to develop a mathematical model for cost evaluation. This was achieved by carrying out market survey and cost analysis for all the constituent materials (cement, bagasse ash, water and lateritic soil) in the mix to sum them up using a reference weight of 100 grams of dry soil for determining percentage requirements for all the constituent materials. The model was used to evaluate the cost of stabilizing with only cement (without bagasse ash) and a selected mix proportion that satisfied the requirements for sub-base of road work for the purpose of comparison. The cost for the selected mix was 42.85 kobo for stabilizing 100 grams of lateritic soil while that of stabilizing with only cement was 43.52 kobo which is of greater value of cost but of less quality.

Key Words: Cost, Cement, Bagasse ash, Lateritic soil, Water

1.0 INTRODUCTION

Bagasse-ash is an agricultural material obtained after squeezing out the sweet juice in sugarcane and incinerating the residue to ash. Bagasse is the fibrous residue obtained from sugarcane after the extraction of sugar juice at sugarcane mills or sugar producing factories (Osinubi and Stephen, 2005). The climatic and soil conditions favourable for the production of sugarcane are present in the Northern part of Nigeria and consequently, there is abundant production of it in the area. Sequel to the foregoing is massive generation of sugarcane residue waste which constitutes disposal problems and requires handling. There is yet no adequate awareness about the usefulness of the sugarcane residue in the country, in other words very little value has been attached to it. In some cases, the residue is being utilized as a primary fuel source for sugar mills and also for paper production. However incinerating it to ash and adopting it as admixture in stabilized soils because it has been found to be a good pozolana, adds to its economic value.

The major part of Nigeria is underlain by basement complex rocks, the weathering of which had produced lateritic materials spread over most part of the area. It is virtually impossible to execute any construction work in Nigeria without the use of lateritic soil because they are virtually non-swelling (Osinubi, 1998). The local availability of the of these lateritic soils presents them as an attractive option with regards to more expensive natural aggregates in reducing the cost of construction and maintenance of road works.

The importance of cement stabilization of lateritic soils has been emphasized by researchers with soil-cement mixtures being used as sub-base or base courses of low-cost roads. However, excessive addition of cement becomes uneconomical; therefore the use of locally available materials to add to stabilized materials has been very common in recent research works. Thus the cheap agricultural waste (bagasse ash) becomes a partial replacement/supplement for the more expensive cement. Bagasse ash has been globally confirmed to be a good pozzolana because of its high silica content which indicates that there is a promising potential in the agricultural material to serve as an admixture

[Osinubi and Stephen (2005), Osinubi and Stephen (2007), Mohamed (2007), Silvo and others (2008), Osinubi and others (2009a), Osinubi and others (2009b), Osinubi and Ijimdiya (2009), Ijimdiya (2010), Ijimdiya and Osinubi (2011)] .

Because of limited resources, there is a need to be very conscious not to be wasteful. The process of mathematical modelling and prediction gives a guide in decision-making for materials requirement. Many researchers in the past have done well in optimizing construction materials such as Lixiaoyong (2011), Arimanwa and others (2012), Ezeh and Ibearugbulem (2009), Ezeh and Ibearugbulem (2009), Onwuka and others (2013) and so on. However, many of these attempts never considered the cost benefit analysis of the construction materials involved. Therefore sometimes it might be an extravagant claim to presume that a certain construction material is preferred over the other without properly considering cost.

In other words, it would be beneficial to have a means of possibility for predicting the cumulative cost of the constituents of the stabilized matrix (cement, bagasse ash, water and lateritic soil) in order to have a clear picture of the cost requirement of each material mix for decision-making. Therefore this study focused on developing a mathematical model for evaluating the cost of different mixes of the stabilized matrix for cost effectiveness.

2.0 Cost Analysis for the Stabilized Matrix

Practically speaking, little or no value has been attached to neither bagasse residue nor its ash because of its low demand. In the markets where sugar cane is sold and sugar factories, the bagasse residues are littered around the surroundings without much value. Definitely as the awareness of its usefulness increases, the demand will rise and the value/cost shall equally rise. It is therefore necessary to attach cost to the bagasse ash in order to make this work meaningful. The cost of the other materials should also be considered depending on the prevailing market prices of materials for appropriate basis for comparison and formulation of the model. The bagasse ash, cement and the optimum moisture content were all measured as a proportion of the weight of the dry soil. Therefore using 100 grams of dry soil as a reference weight, the corresponding weights of cement, bagasse ash and water could be determined as well as their unit cost.

2.1.1 Cement Cost

1 bag of cement = 50 kilograms = N1,400.00

Thus, 50,000 grams = N1,400.00

1 gram = 140,000 kobo/50,000grams = 2.8 kobo

1% = 1g = 2.8 kobo

2.1.2 Projected Cost of Bagasse Ash

Cost of 100,000 kilograms of Bagasse Ash

Haulage cost for (100,000 kilograms) = N180,000.00

Processing (energy + labour) for 100,000 kilograms = N180,000.00

Cost of bagasse residue to yield 100,000 kilograms = N 40,000.00

Total = N400,000.00

Therefore, 100,000 kilograms = N400,000.00

1 kilogram = 40,000,000 kobo/100,000,000 grams = 0.4kobo

1% = 1g = 0.4kobo

2.1.3 Cost of Water

1 tank = 1000 gallons = N2,500.00

1000 gallons = 4546 litres = 4546×10^3 millilitres

1 millilitre = 250,000 kobo/4546×10^3 millilitres = 0.055 kobo

Density of water = 1000 kilograms/m^3 = 1 gram/milliliter

In other words, 0.055 kobo/millilitre

1% = 1gram = 0.055kobo

2.1.4 Cost of Lateritic Soil

5 tonnes = 5,000 kilogram = N10,000.00

Thus, 5,000,000 grams = N10,000.00

1 gram = 1,000,000 kobo/5,000,000grams = 0.2 kobo

Therefore, 100 gram = 0.2×100 = 20 kobo

3.0 Formulation of Model

The model should be formulated to cover the total cost of all materials present in the lateritic soil stabilized with cement and bagasse ash for a specified quantity of lateritic soil. This would make it possible that for any particular mix proportion of constituents which yielded the desired result of strength properties at a given compaction characteristics, the total cost could be evaluated based on a fixed mass of lateritic soil (100) grams and the required contents of the other constituent materials measured by weight of the dry soil. The model as formulated is shown as follows:

The total cost of stabilizing 100grams of soil = Cost of percentage of cement content + Cost of percentage of bagasse ash content + Cost of percentage of water requirement + Cost of 100 grams of lateritic soil.

The expression for the cost of each mix of stabilized soil matrix is given as

$2.8\,E + 0.4\,Z + 0.055\,P + 20$ = Cost of stabilizing 100 grams of soil (kobo) ....(2.1)

Where, E = Cement content (%)

Z = Bagasse ash content (%)

P = Optimum moisture content (%)

4.0 Application of Cost Evaluation with the Model

Okonkwo (2014) stabilized lateritic soil deposit in Oboro, Ikwuano Local Government Area of Abia State with cement and bagasse residue collected from Panyam district, Mangu Local Government Area of Plateau State which was incinerated into ash. The optimum moisture content and strength characteristics were given as follows:

Table 1.0: Variations of Optimum Moisture Content with Increase in Bagasse Ash Content at 2%, 4%, 6% and 8% Cement Contents

Bagasse Ash Content (%)	Optimum Moisture Content (%)			
	2% Cement	4% Cement	6% Cement	8% Cement
0	16.50	17.90	18.24	20.39
2	16.80	17.97	18.41	20.56
4	17.71	18.30	18.91	21.24
6	18.74	19.69	20.85	21.63
8	19.58	20.48	21.66	22.08
10	20.23	21.29	22.39	22.63
12	20.81	21.71	22.71	23.05
14	21.32	22.17	23.29	23.95
16	22.01	22.85	23.75	24.69
18	22.22	23.21	24.23	25.02
20	22.62	23.54	24.44	25.31

(Source:Okonkwo, 2014)

Table 2.0: Variations of California Bearing Ratio with Increase Bagasse Ash Content at 2%, 4%, 6% and 8% Cement Contents

Bagasse Ash Content (%)	California Bearing Ratio (%)			
	2% Cement	4% Cement	6% Cement	8% Cement
0	22.30	57.99	83.34	147.16
2	23.57	84.44	93.70	175.12
4	25.42	85.20	104.94	196.37
6	26.48	93.04	117.07	209.09
8	25.13	109.13	123.68	221.03
10	25.11	121.03	135.59	230.24
12	24.98	135.19	176.12	242.05
14	24.92	152.10	196.50	251.31
16	24.70	163.59	207.26	265.30
18	24.31	161.38	220.08	271.80
20	24.23	160.96	239.16	276.30

(Source: Okonkwo, 2014)

Table 3.0: Variations of Unconfined Compressive Strength at 7 days with Increase in Bagasse Ash Content at 2%, 4%, 6% and 8% Cement Contents

Bagasse Ash Content (%)	Unconfined Compressive Strength (KN/m^2) at 7 days curing			
	2% Cement	4% Cement	6% Cement	8% Cement
0	213	419	549	942
2	228	454	642	998
4	248	492	683	1049
6	273	534	801	1087
8	292	575	854	1132
10	308	613	907	i180
12	321	642	941	1221
14	335	665	985	1298
16	349	697	1018	1366
18	353	717	1057	1396
20	364	733	1073	1424

(Source: Okonkwo, 2014)

The Nigerian General Specification (1997) recommends the value of 180% for California bearing ratio at mix in place conditions for stabilized materials used for low-cost roads. In the other hand for unconfined compressive strength, the minimum conventional values at 7 days for cement-stabilized materials of 750-1500(KN/m^2), 1500-3000(KN/m^2) and 3000-6000(KN/m^2) for sub-base, base (lightly trafficked roads) and base (heavily trafficked roads) respectively were adopted in evaluating their strength.

From the foregoing conditions, it appears that at the mix of 6%, 12% and 22.71% for cement, bagasse ash and optimum moisture content respectively almost satisfied the for sub-base requirements 176% and 941KN/m^2 for California bearing ratio and unconfined compressive strength at 7 days respectively. Then using the model in Equation (2.1) gives:

$2.8(6) + 0.4(12) + 0.055(22.71) + 20 = 42.85$ kobo

Considering stabilizing the soil with only cement (without bagasse ash) and using Equation (2.1) to determine the cost of stabilizing 100grams of soil gives:

$2.8(8) + 0.4(0) + 0.055(20.39) + 20 = 43.52$ kobo

It is evident that between the costs of the two mixes for stabilizing 100grams of soil that the cost of stabilizing with only cement (43.52 kobo) would be significantly more expensive than the cost of stabilizing with the selected mix of cement and bagasse ash (42.85 kobo) in the long run when much weight of the soil is being used for road construction work. This has clearly shown the cost benefit of using bagasse ash as admixture to cement. Besides, at 8% cement content with no bagasse ash had California bearing ratio of 147.16% which fell short of the 180% California bearing ratio value as stipulated by the Nigeria General Specification (1997) though it had a strength of 942 KN/m^2.

In addition for purely local roads with very low volume of traffic, lower values of the combination of California bearing ratio and unconfined compressive strength that would be suitable not necessarily the standard could be adopted. Then using any of the optimization techniques to determine optimum contents for constituent materials and cost evaluation could be carried out to determine the most economical mix.

Conclusions

After the study on ensuring that economy and good quality of the cost of materials for road work are guaranteed. The following were achieved:

i. A mathematical model was developed for determining the cost of stabilizing 100 grams of lateritic soil at any given mix.

ii. The cost of stabilizing 100 grams of lateritic soil using a selected mix that marginally satisfied the requirement for sub-base of road work was found to be 42.85 kobo while the cost of stabilizing with only cement was 43.52 kobo which appears to be more expensive.

iii. The mathematical model appears to be very useful in cost benefit analysis for any desired mix proportions of constituent materials.

iv. The mathematical model could be adjusted to suit any condition of variations in the prices of materials assuming market forces affect them.

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