NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

THE USE OF ARTIFICIAL INTELLIGENCE IN PREDICTING THE STRENGTH CHARACTERISTICS OF QUARRY WASTE DUST STABILIZED RECLAIMED ASPHALT PAVEMENT

M.Sc. THESIS

Samuel Adakole OKPE

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Approval

We certify that we have read the thesis submitted by **Samuel Adakole OKPE**titled "**THE USE OF ARTIFICIAL INTELLIGENCE IN PREDICTING THE STRENGTH CHARACTERISTICS OF QUARRY WASTE DUST STABILIZED RECLAIMED ASPHALT PAVEMENT**" and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Educational Sciences.

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Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

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Abstract

THE USE OF ARTIFICIAL INTELLIGENCE IN PREDICTING THE STRENGTH CHARACTERISTICS OF QUARRY WASTE DUST STABILIZED RECLAIMED ASPHALT PAVEMENT

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The end of this work presents results obtained from stabilization of R.A.P in addition with quarry waste dust and cement while using artificial intelligence (AI) to predict the strength characteristics of the material combination as pavement material. R.A.P + QWD + C samples were compacted with various energy level to ascertain its physical and strength index properties. R.A.P shows improvement with QWD as the sieve analysis grading from coarse aggregate of 99.80% to fine aggregates of 0.20%. Generally, MDD ranges 1.48-1.99 Mg/m^3 and OMC ranges 8.8-12.6% for QWD-cement stabilized RAP. It was observed that the CBR decreases with an increase in QWD content. Peak CBR of 52.0% and 78.0% for (un-soaked and soak BSH) was obtained at 60% RAP +34% QWDW + 6%CE mix proportion. However, the BSL for soaked samples revealed the highest performance of the prediction model for soaked CBR using the BSL compaction effort indicating correlation values of 0.99551, 0.83225, 0.58939 and 0.90082 while BSH for soaked samples recorded the lowest correction at 0.11726 and 0.009304 respectively for the model training, validation, testing and overall performance. The overall performance of the model measured correlation of prediction range 0.53958 - 0.89535 for unsoaked CBR while 0.74133 – 0.90082 for soaked CBR using. These performance parameters of the model used for predicting the soaked/unsoaked CBR values using the RBSL, BSL, WAS and BSH compaction effort showed a relatively satisfactory output.

Keywords: Reclaimed asphalt pavement, Quarry waste dust, California bearing ratio, Artificial Neural Network, Compaction

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List of abbreviation

RAP: Reclaimed Asphalt Pavement

QWD: Quarry Waste Dust

CE: Cement

CBR: California Bearing Ratio

MDD: Maximum Dry Density

OMC: Optimum Moisture Content

ANN: Artificial Neural Network

CHAPTER I

Introduction

1.0 Preamble

Recent the use of artificial neural networks (ANNs) to solve multi-variable analysis has been utilized by many researchers due to their capacity to handle such analysis. A structured ANN is like a black box such that after training, numerical values can be inputted while the ANN will produce some values which is a representative of the predicted numerical value the components for the input can be a factor. Recently, more and more new types of ANN structures, such as the Support Vector Machines, Deep Learning Neural Network, and Radial Basis Function Network for various research areas have popped out, as well as other algorithms like tabu and genetic are newly applied for training the ANN. Deep neural network (DNN), happens to be a fast-growing artificial intelligence (AI) technique.

In Nigeria roads are been control by federal, state or local government and grouped as trunk A, B and C respectively. These roads are usually not maintained to be in safe and good conditions over time and hence become deplorable which further leads to high cost of either maintenance, reconstruction and rehabilitation to make it safe for road users. In recent time the demand for good road base and sub-base construction materials are on high demand due to population growth, urbanization and increase in vehicular movements and most times such materials are not ready available within the construction zone and the cost of material haulage tend to affect the overall project cost therefore to overcome this problem, the different alternatives generated waste materials, including RAP scarified from failed highway pavement deposited in large quantities along reconstructed road alignment, is stabilized with quarry waste dust which is deposited in large quantities as waste in production site, and cause not only environmental hazards but disposal problems. They are characterized to ensure that the composition satisfy the requirement for the base or sub-base materials of highway pavement. As a result of non-availabilities and disposal issues of construction materials during road construction it has facilitated various research to obtain alternative waste materials that could be recycled into road construction materials as sub base and base materials has led to the use of quarry waste dust obtained from rock blasting at rock quarry site and recycled crushed pavement obtained by scarifying existing road surface. The waste materials are then blended with cement (CE) to withstand cyclic loading from traffic and to satisfy highway construction materials requirements and also solving environmental disposal issues. Research shows that quarry waste products and other associated waste from rock quarry are treated as waste materials without recycling as stated by center for clean products (Uni. Of Tennesse USA 2011) while Gandolfi et al, (2006) and Safiuddin (2001) says majority of quarry waste can be recycled back into construction activities such as road construction as a subbase or base material. Quarry waste dust has been used in concrete production due to its cementing potential to replace river sand partially by Celik et al, (1996). Due to abundance of quarry waste products in some countries such as Australia, the products have been used replacement for fine aggregates in road construction (Dumitru, 2000). Such products have been successfully utilized from waste material to recycled construction material (Ilangovana, 2008). After several years of service, the binder in the RAP becomes aged and much stiffer than desired. RAP binders over long period needs to be modified as it contains some physical properties that makes RAP undesirable to be used as construction material as stated by Chen, 2007. This has made recycled crush pavement to become important alternative during road rehabilitation and maintenance and also solving environmental disposal issues. (Taha, 2002).

Recycled crush pavement has also been utilized in stabilization with coal fly ash during construction, the laboratory results show properties such as material strength and stiffness improved. The resilient modulus Mr and CBR values increased to 195Mpa and 24% respectively and RSG stabilization the value increased to 195Mpa and 96% from 90Mpa and 48% respectively before stabilization (Edil,2007 and Hatipoglu, 2008). Li et al. (2008) reported that the value of CBR increased to 154% when RSG is stabilized with coal fly ash (Little, 2008). This research work presents the use of RAP stabilized with QWD using cement as additive as alternative highway construction material and thereby providing economic and environmental disposal challenges solutions (Kennedy et al. 1998, Anouksak and Direk 2006).

This research focused at utilizing quarry waste dust stabilized RAP using Portland cement additive, as highway pavement material to ascertain the strength characteristics and to develop a predicting model using the artificial neutral network.

1.1 Statement of Problem

It is quite common, in countries such as Nigeria that the soil found in the construction place do not satisfy the technical requirements of the project, the haulage distance of satisfactory materials to construction location and its cost implication on the overall project cost and also government regulations in control borrow pits location due to environment hazards associated as shown in Fig.1-4, hence there is a need to resort to one of the suitable methods of low cost road construction, followed by a process of stage development of the roads using the appropriate compactive efforts, to meet the growing needs of the road traffic. In Nigeria roads are been control by federal, state or local government and grouped as trunk A, B and C respectively. These roads are usually not maintained to be in safe and good conditions over time and hence become deplorable which further leads to high cost of either maintenance, reconstruction and rehabilitation to make it safe for road users. In recent time, as a result of these challenges the demand for good road base and sub-base materials has increased due to increased constructional activities in the road sector and paucity to the availability of constructional materials along the road alignments.

Figure 1.

Abandon laterite borrow pits at Asaba Delta State Nigeria.

Figure 2.

Edo State Government Officials inspecting gully erosion site caused by borrow pit.

Figure 3.

Stockpile of crushed reclaimed asphalt pavement along Gboko-Makurdi Road.

Figure 4.

Stockpile of scarified reclaimed asphalt pavement along Gboko-Makurdi Road.

1.2 Aim and Objectives

The research aims to overcome the above stated problems using RAP scarified from failed highway pavement deposited in large quantities along reconstructed road alignment and stabilized with quarry waste dust which is deposited in large quantities as waste in production site thereby causing not only environmental hazards but disposal problems. They are characterized to ensure that the composition satisfy the requirement for the sub-base or sub-grade materials of highway pavement. The waste materials are then blended with cement (CE) to withstand cyclic loading from traffic and to satisfy highway construction materials requirements and also solving environmental disposal issues.

1.3 Scope and Limitation

The evaluations of the waste were limited to laboratory experiments; the result can be used as a control values relative to field results hence recommend such control values should be translated into field values by construction companies. The materials are limited to one source each for RAP, QWD and cement. Therefore, the materials were investigated to find its suitability as sub base or sub grade highway pavement materials and characterized by particle size distributions, specific gravity, compaction characteristics, California bearing ratio, durability and water absorption characteristics.

CHAPTER II

Literature Review

2.1 The use of ANN in Pavement Construction.

Artificial neural network is being used in various segments of pavement construction such as compaction quality control in construction, material performance and cost control. ANN can be used as a cost estimating tool for construction activities by checking factors responsible for costing and also artificial intelligence AI has the capacity of predicting future data from past or present data with limited errors as well as estimating staff's productivity, earthwork production through simulation and predict improvement in such performance over time.

Compaction quality control affects the asphalt pavement performance and deterioration degree. ANN in asphalt compaction was monitored using real time compaction with intelligent roller by Commuri el al (2008) at various energy level of compaction and observed the vibration signal. Imran et al., 2018 further developed the sub-grade stiffness using deep multiple-layer perceptron neural network MLPNN with 2-hidden layers during compaction. The sub-grade modulus was obtain using four stiffness level of calibrated ANN outputs. The use of ANN in concrete construction the slump serves as the determinant of the workability of the concrete as done by Oztas et al. (2006).

The sub-grade modulus of resilient is influence by the properties of soil and the environmental changes of which ANN statistical method was used in prediction analysis by (Khasawneh et at., 2019 and Saha et al., 2018).

2.2 Quarry Waste Dust

Quarry dust is cohesionless sandy material acquired either naturally or artificially by mechanical disturbance of parent rock for construction purposes. Quarry dusts are composed of large particles whose diameter ranges from 0.050mm to 5.0mm and fine particles whose diameter is less than 4.75mm. Quarry dust is used on large scale on highways as surface finishes material and can also be used as a partial replacement for river sand in concrete production. It is of light weight or high-density aggregates, coarse-grained and can be the source from the following rocks; gabbros, quartzite, schist, granite and basalt. Granite was the first to be quarried and this was done in the1700s and was quarried from the Urr valley.

2.2.1 Mineral Properties of Quarry Waste Dust

The resistance to stripping, hardness and toughness of some parent rock types used as aggregate in hot mix asphalt (HMA) as outlined below.

Table 1.

Properties of Rocks for Hot Mix Asphalt.

S/No	Type of Rock	Resistance to stripping	Hardness and Toughness	Type of Rock
1	Granite	Fair	Fair	Igneous
2	Syenite	Good	Fair	Igneous
3	Diorite	Good	Fair	Igneous
4	Basalt	Good	Good	Igneous
5	Diabase	Good	Good	Igneous
6	Limestone	Poor	Good	Sedimentary
7	Sandstone	Fair	Good	Sedimentary
8	Chert	Good	Fair	Sedimentary
9	Shale	Poor	Poor	Sedimentary
10	Gneiss	Fair	Fair	Metamorphic
11	Schist	Fair	Fair	Metamorphic
12	Slate	Good	Fair	Metamorphic
13	Quartzite	Good	Fair	Metamorphic
14	Marble	Poor	Good	Metamorphic

2.2.2 Chemical Properties Aggregates

While chemical properties of aggregates are relatively not important for consideration in aggregates but when used as pavement materials there are some important factors to be considered as in hot mix asphalt the chemical reaction of the materials determines the asphalt binders properties.

2.2.3 Physical Properties

The physical properties of aggregates have direct impacts on how the aggregates perform as pavement materials as outlined by Robert et al, 1996 citing common physical properties of aggregates.

i. Size and gradation of aggregate.
ii. Abrasion resistance and toughness
iii. Durability and soundness of aggregates
iv. Surface texture and particle shape of the aggregate.
v. Specific gravity of aggregate.
vi. Moisture content
vii. Cleanliness and deleterious material content.

These are not the only physical properties of aggregates but rather the most commonly measured. Tests used to quantify these properties are largely empirical. The physical properties of an aggregate can change over time. For instance, a newly crushed aggregate may contain more dust and thus be less receptive to binding with an asphalt binder (Roberts et al, 1996).

2.3 Reclaimed Asphalt Pavement

Reclaimed Asphalt Pavement (RAP) is the term given to removed and or reprocessed pavement materials containing asphalt and aggregates. RAP is mostly generated during pavement rehabilitation and reconstruction and contains high-quality, well-graded aggregates coated with asphalt cement when properly crushed and screened. A substantial amount of RAP is recycled and used in roadway structures in some form, usually incorporated into asphalt paving using hot or cold recycling, and also sometimes used as aggregates in base or sub-base construction. (Osinubi and Edeh, 2011). When asphalt concrete is produced, is it being used in recycled hot mix asphalt, in cold-mix asphalt or stabilization material in granular form while the unused are stockpiled and eventually reused.

Figure 5.

Extraction of RAP by Julius Berger Nigeria Plc along airport road Abuja.

2.3.2 Highway Uses And Processing Requirements.

Reclaimed Asphalt Pavement RAP has much application in highway construction. These applications include but are not limited to hot and cold mix design of asphalt as replacement alternatives of subbase and base granular materials, stabilization materials and fill or embankment materials. (Edeh et al 2011).

2.3.3 Asphalt-Concrete Aggregates and Asphalt-Cement Supplements.

Reclaimed Asphalt Pavement when used in asphalt paving applications (hot mix or cold mix), can be processed at either a central processing facility or on the job site (in-place processing). The process of introduction via recycling can either be achieved by hot or cold procedure. When used as alternative material it provides more asphalt cement binder and hence reduces the asphalt cement demanded during new or recycled asphalt mixes (Edeh et al 2011).

2.5.0 Road Pavements Stabilization

Due to non-availability of good materials and to reduce environmental disposal waste and other reasons has led to the use of stabilization in road construction where desire materials are not available. Cost management is the major reason for stabilization where the engineer tries to construct a road pavement free from challenges during the design life time with limited financial implication. There are various ways such cost can be control such as; reduction in construction and maintenance cost throughout the design life span of the pavement or extended pavement life.

Scarcity of quality construction materials has become major factor in accessing the location of desirable materials thereby leading to haulage from a distance location and impacting on the over cost of road construction. To overcome this challenge local available materials are stabilized to required bearing capacities. Materials that derive their shear strength partly from cohesion and friction are best materials for stabilization. To achieve a successful stabilization, the materials most be able to sustain its strength and stability over time and because of this, not all materials can be successfully stabilized. According to (Watson, 1994) soft clay yield better result than sandy soil when stabilized with cement. Materials to be stabilized as a base material should be usable as a sub-base material without stabilization unless proven by experience (Netterberg, 1987).

Cracking is a major challenge with layer stabilization as they crack to certain degree which is as a result of environmental factors like change in temperature and moisture content which are not avoidable. The rate of cracking depends on some factors but stronger materials produce wiser cracks than weaker a material at greater cracking space.

Figure 7.

Cement stabilization by Julius Berger Nigeria Ltd along airport road Abuja.

A. Functions of Sub-base

In road construction sub-base is an integral part flexible and rigid pavement design as it is the structural layer that spreads the traffic wheel load to avoid over stressing of the sub-grade. It is the separator layer between the base and sub-grade and it is the layer upon which other layers are been transported before laying and compacting. Materials selected for sub-base depends on design functionality of the layer and in-situ moisture condition expected in the location as it also serve as the drainage layer. Stabilization of sub-base can be applied in both flexible and rigid pavement depending on various reasons and benefits (Lay, 1986).

B. TYPES OF STABILISATION.

There are many different reasons for using stabilization, ranging from lack of good quality materials to a desire to reduce aggregate usage for environmental reasons. Ultimately the main reason for using stabilization will usually be cost savings. The engineer is trying to build a problem-free pavement that will last for its intended design life for the most economic price. The cost savings associated with stabilization can take many forms including reduced construction costs, reduced maintenance costs throughout the life of the pavement or an extension of the normal pavement life (Watson, 1994).

The location of suitable materials for road construction will become increasingly difficult as conventional high-quality materials are depleted in many areas. The costs of hauling materials from further away may also increase, thus compounding the problem. One solution to this problem is to stabilize locally available materials that presently may not conform to existing specifications for bearing capacity.

There are different types of stabilization, each having its benefits and potential problems. Below are few examples of various types of stabilization although not all of them are suitable for all situation.

B1. Mechanical Stabilization.

The most basic form of mechanical stabilization is compaction, which increases the performance of a natural material. Mechanical stabilization of a material is usually achieved by adding a different material to improve the grading or decrease the plasticity of the original material. The physical properties of the original material will be changed, but no chemical reaction is involved. For example, some material rich in fines could be added to a material deficient in fines to produce a material nearer to an ideal particle size distribution curve. This will allow the level of density achieved by compaction to be increased and hence improve the stability of the material under traffic. The proportion of material added is usually from 10 to 50 percent. Provided suitable materials are found in the vicinity, this type of stabilization is more cost-effective compare of other forms of stabilizing poorly graded materials and improve them to a well graded material. When there is heavy traffic, the strength and stiffness obtain from mechanical stabilization is lower than that of chemical stabilization and therefore would require stabilizing agent to improve the mixed materials final properties (Lay, 1986).

B2. Cement Stabilization.

In cement stabilization, ordinary Portland cement is the most frequently used although other types of cement can also be used as well. When cement is added to a material in the presence of water it produces a hydrated calcium aluminates and silicate gel which result to materials bonding and crystallization. The strength derived from cement stabilization is obtain from the physical strength of hydrated cement matrix and cement hydrates of material and lime chemical reaction.

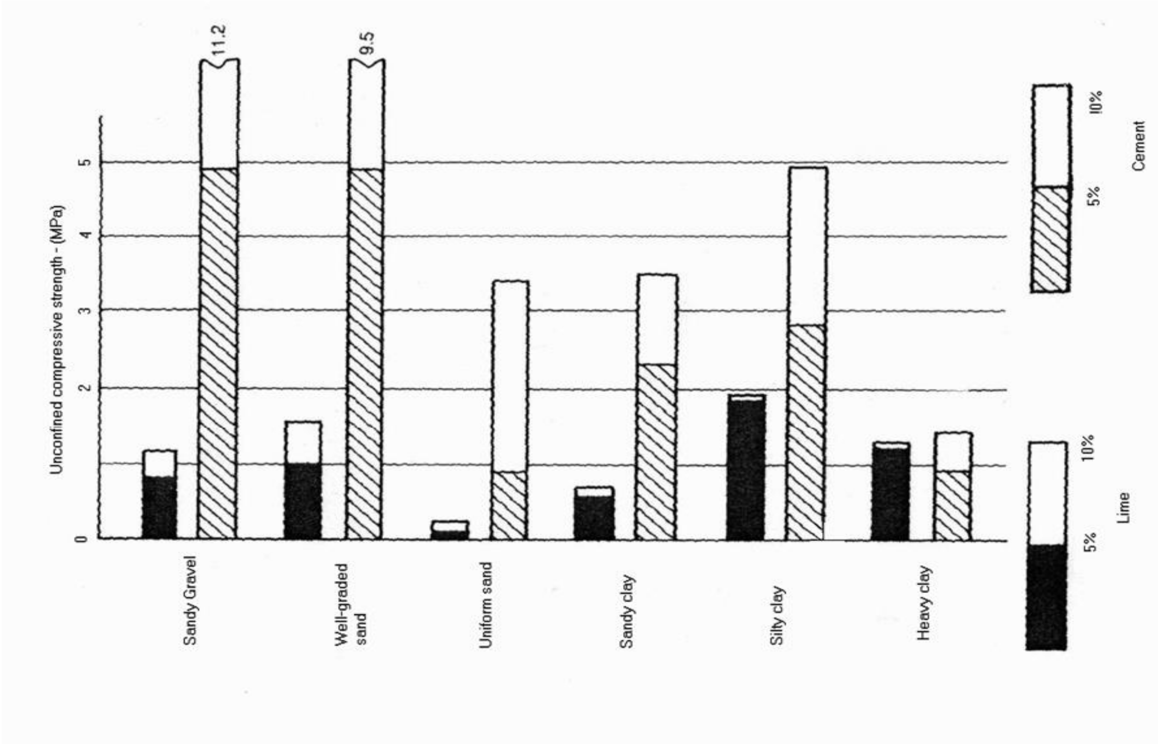
The improvement of granular material is achieved with the addition of cement proportion which should be less than 10 percent because when its more than 15 percent would result to conventional concrete as the strength of materials usually increase with rise in cement content generally. For each 1 percent of cement, the increase in strength ranges 500-1000kPa in UCS strength while 200-400MPa for elastic modulus (Lay 1986/88). After stabilization, it would increase within the range 2000-20000MPa.

Cement-material stabilization can be done in-situ or at batching plant and convey to site for placement.

Cement is mostly used than lime in stabilization because of the cost effectiveness and higher strength associated with the use of cement, the availability of cement and hazardous nature associated with lime. The prices of cement and hydrated lime are almost similar but the strength obtain from cement is not same at equal amount of lime hence more strength is gain with cement than lime in stabilization. Shewood (1993) graphically present the effect of cement and lime on 7days strength of various soil types as shown in figure 8 below.

Figure 8.

Effect of lime & cement on 7-day strength of various soil types. After Sherwood (1993)



B2.1. Soil Cement:

In soil cement stabilization the content of cement is usually less than 5 percent (Lay,1986) which can be mixed in-situ or at batching plant and lay up to 300mm layer at a time and can be achieve by breaking the soil and adding cement and there after compacting it.

B2.2. Cement Bound Granular Material Stabilization:

Cement bound granular material stabilization CMD is similar to cement soil stabilization but stronger form which used coarse aggregates in place of soil and work best if the coarse aggregates has little amount of fine content and this is mix at batching plant and not in-situ.

B2.3. Lean concrete Stabilization.

Lean concrete stabilization has higher content of cement than cement bound granular material and acts more like a concrete. It can be achieve using coarse and fine crushed aggregates. The material usual strength is given as 6-10 MPa at 7day crushing strength.

B3. Lime Stabilization.

Early Roman empire roads were constructed using lime stabilization process but the discovery of Portland cement in 19th century replace the use of lime with cement as the stabilizer although lime is till currently in use in some part of Africa and Northern America. Materials with clay content tend to be more effective due to the positive reaction of clay and lime during the stabilization. There are some researches trying to use lime in place of cement as binder but was not successful according to Watson,1994. Lime can be obtained from limestone by the application of heat and addition of water. Lime can be classified as;

I. Hydrated lime ($Ca\ (OH)_2$)
II. Carbonate lime ($CaCO_3$)
III. Quicklime (CaO)

Hydrated lime and quicklime are the only line product that can be use as stabilizer in road pavement. They usually in solid form, mix with water and applied as slurry and there is a violent reaction of lime in the presence of water which could result to burns externally or internally when handled by inexperience personnel without personal protection equipment.

B4. Bitumen Stabilization

The bitumen often acts as a glue which bind the material together thereby prevent water ingress. Bituminous material serves as an impervious pavement layer to prevent capillary action. Due to viscosity Bitumen at ambient temperature, bitumen emulsion or cut back bitumen can only be use for stabilization such that as evaporation occurs and emulsion are broken down, the bitumen will be deposited on the materials.

In most countries cement is cheaper than bitumen thereby making bitumen stabilization more expensive as stabilizing agent during construction.

B5. Pozzolanas stabilization:

Pozzolanas stabilization is the use of materials which contain little or no amount of cementitious properties but react at the presence or lime or water or cement to produce some cementitious properties. Pozzolanas are found in volcanic origin while artificial pozzolanas are heat products of some natural products such as fuel ash obtain from coal, rice husk ash and quarry waste dust (Sherwood, 1993, (Montgomery, 1991).

B6. Non-Pozzolanas stabilization:

Non-pozzolanas are chemical stabilizing products in the form of ionic, acid oil base and sulphonated products. Naturally cementitious chemical reaction does not take place except as a result of some factors such as exchange of ions and water absorption resulting to greater strength due to better compaction of materials have has clay content which makes this form of stabilization cheaper (Paige-Green, 1998).

C. Suitable Materials For Stabilization

The effects of proposed stabilizer on stabilizing materials such as soil have to be tested to ensure its suitability and compatibility and such test differs from countries but often includes grain size analysis, plastic and liquid limits test, soil acidity test and sulfate test. Initial Consumption of Lime (ICL) test is another critical chemical test done when cement or lime are stylizing agents to clay soil because to achieve strength gain, pH (>12.4) have to be maintain in the chemical reaction and varies considerably for different soils.

An alternative exists with FDR, where the pavement can be strengthened by "building the pavement down" (Figure 9).

Figure 9.

Using FDR to "build the pavement down." (Gregory et al.).

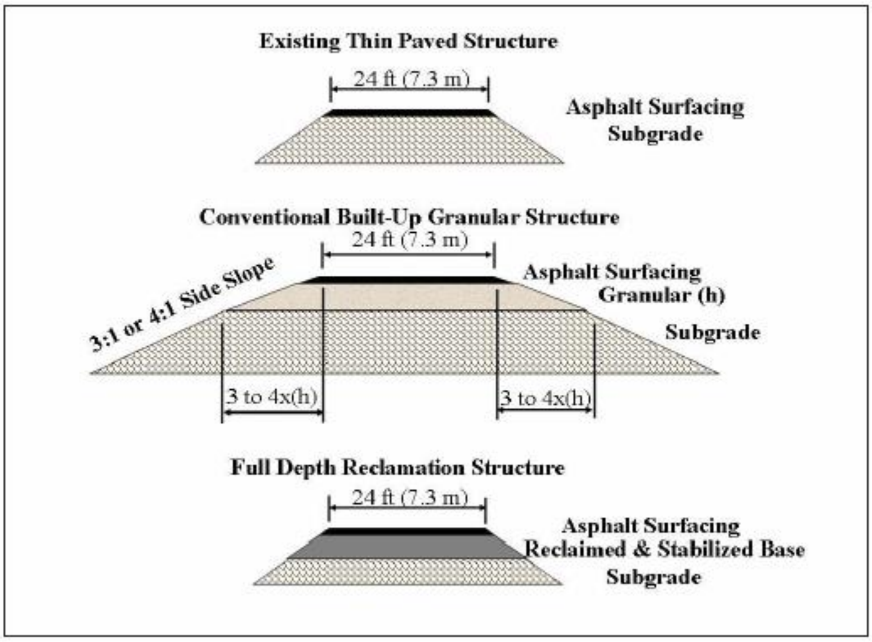


Table 2.

Flexible pavement rehabilitation strategies advantages and disadvantages (Gregory E. et al, 2007).

Solution	Advantages	Disadvantages
Thick Structural Overlay	• Provides new pavement structure • Quick construction • Only moderate traffic disruption	• Elevation change can present problems for existing curb & gutter and overhead clearances • Large quantity of material must be imported • Old base/subgrade may still need improvement • High cost alternative
Removal and Replacement	• Provides new pavement structure • Failed base and subgrade are eliminated • Existing road profile/elevation can be maintained	• Long construction cycle requiring detours and inconvenience to local residents/businesses • Increased traffic congestion due to detours, construction traffic • Rain or snow can significantly postpone completion • Large quantity of material must be imported • Old materials must be dumped • Highest cost alternative
Recycling Surface, Base and Subgrade with Cement (Full-Depth Reclamation)	• Provides new pavement structure • Fast construction cycle • No detours • Minimal change in elevation, thus eliminating problems with curb/gutter, overhead clearances • Minimal material transported in or out • Conserves resources by recycling existing materials • Local traffic returns quickly • Rain does not affect construction schedules significantly • Provides moisture- and frost-resistant base • Least cost alternative	• May require additional effort to correct subgrade problems • Some shrinkage cracks may reflect through bituminous surface

CHAPTER III

Methodology

3.1 Materials

3.1.1 Reclaimed Asphalt Pavement (RAP)

RAPobtained during the studyweretakenat a stocked pile of RAPalong Otukpo – Enugu Roadin Benue state Nigeria during road rehabilitation and crushed to pass through a 20mm diameter sieve as stated by ASTM C702-98 (2003).

3.1.2 Quarry waste dust (QWD)

QWD obtained during the study were taken at Gboko quarry plant in Gboko LGA of Benue state Nigeria and crushed to pass through a 20mm diameter sieve as stated by ASTM C702-98 (2003).

3.1.3 Cement

The cement CE used for this research as an additive was Dangote Ordinary Portland cement.

3.2 Methods

The mix samples were prepared by varying the proportions of cement from 0-6% in the mix while quarry waste dust varies in the range of 0-100% increase in 10% concentration and the resulting mixes are then mixed with varying proportions of RAP in the range 0-100% also increased in 10% concentration. These combinations produced a total of 41 different test specimens. Particle size distribution of the samples, compaction tests, California Bearing Ratio (CBR), and Durability test, were performed following the relevant sections of B.S 1377: (1990) and ASTM codes. Specimens for the Durability test and (CBR) were prepared at the optimum water contents (OWC) and maximum dry densities (MDD) subjected to Reduced British Standard Light (RBSL), British Standard Light (BSL) West African Standard (WAS) and British Standard Heavy (BSH) compaction energy for the quarry waste dust-cement stabilized RAP mixtures. This laboratory research aims to determine the adequate mix ratio of RAP+QWD+CE to withstand the cyclic traffic load also the procedure used is done in such a way that as one sample increases in 10% concentration the other sample decrease by 10% concentration. (Edeh et al. 2012). Table 3 present a summary of RAP+QWD+CE mix proportions.

Table 3.

Summary of mix proportions.

RAP (%)	QWD% + 0% C	QWD%+ 2% C	QWD % + 4% C	QWD% +6% C
100	0	–	–	–
90	10	8	6	4
80	20	18	16	14
70	30	28	26	24
60	40	38	36	34
50	50	48	46	44
40	60	58	56	54
30	70	68	66	64
20	80	78	76	74
10	90	88	86	84
0	100	98	86	84

3.2.1 Physical Properties

The grain size analysis of RAP, QWD and various proportions of RAP+QWD+CE was done as stated in ASTM D691304 (2009). For liquid limit and plastic limit the samples wereoven dried and samples passing sieve size 0.425mm aperture and the following ASTM D6913-04 (2009). The sample results show the materials are not cohesive and also not plastic therefore minimum criterion was adopted from the classification chart as stated by (Das 1998). For specific gravity, an oven-dried portion of the range between 50 -100g of RAP+QWD+CE and passing through sieve 2.00mm aperture according with ASTM C 127 (1994) procedures.

3.2.2 Compaction Test

Compacting relationship was developed for the various samples of RAP+QWD+CE. The sample part was divided into six parts, each weighing 3000g. One part of the division is first used as control, applying the one-point method of compaction; assumed moisture within the PI range of the material was added to the prepared fresh sample, mixed to even moisture distribution in the material. With a rammer of 2.5kg falling freely through the height of 300mm (RBSL/BSL) the material was compact in 3-layers, subjected to 15blows for (RBSL) and 25blows for (BSL) while a rammer of 4.5kg falling freely through the height of 450mm (WAS/BSH) the material was compact in 3-layers, subjected to 15blows for (WAS) and 25blows for (BSH) The weight of (sample + mold) is measured and recorded, part of molded-sample is taken, weighed and ovum dried for 24-hours to determine the instantaneous moisture in the sample.3% moisture variation is added consecutively to the same sample, mixed thoroughly and subjected to the appropriate compaction energy. This is repeated until a moisture range is determined, where material bulk density is observed to have undergone a fall. The five (5) parts that remain of the sample point are each treated, applying the pre-determined percentage moisture range to achieve two (2) rising points to a peak and two (2) falling points. This procedure is repeated on all prepared sample points to achieve the curve a pattern of the moisture density relation, which eventually provides the MDD (g/cm3) and OWC (%) ASTM D698-07e1 (1994).

3.2.3 California Bearing Ratio

This test was carried out on RAP, QWD and RAP+QWD+CE for various sample ratios and it's been carried out on a purpose-made loading frame, as mounted in the laboratory. The sample is placed directly under the plunger. The annular surcharge weights are placed on the surface of the sample and the jack is screwed up so that the plunger is just touching the surface of the sample. The test is carried out by subjecting the sample to plunger penetration. The dial reading of the plunger pressure loading is recorded at 0.5mm, 1.0mm, 1.5mm, 2.0mm, 2.5mm, 3.0mm, 3.5mm, 4.0mm, 4.5mm, 5.0mm, 5.5mm, 6.0mm, 6.5mm, 7.0mm and 7.5mm penetration respectively. A machine factor of 0.122 is considered per division of the dial reading scale, to determine the plunger loading in kilo-Newton. The plunger is raised from the specimen and the mold is removed. The depression on the surface is filled with a little dry sample and turned over on the base plate to repeat the process on the bottom of the sample. The specimen is de-molded and compact again at the same OMC, then soaked for 24hours. That which is soaked for 24hours is subject to penetrometer test for top and bottom in other to ascertain the strength development of the soil material. The load exerted at 2.5mm and 5.0mm is considered the critical loading of the material at the top and bottom. The highest CBR result is considered the CBR value of sample ASTM D1883-07e2 (1994).

3.2.4 Durability

The durability test is a test for obtaining a comparative measure of the resistance of base, sub base and subgrade materials used for highway constructions, to loss in strength in accordance with the procedures described in BS 812-112 (1990) and was carried out for RAP, QWDand RAP+QWD+CE mix samples. A test specimen is compacted in a standardized manner into an open steel cup, having an internal diameter of 102mm and an internal depth of 50mm. the specimen is subjected to 15-blows of standard impacts from a dropping a metal rammer with a mass of 13.5kg, with cylindrical shaped lower end, 100.0mm diameter and 50mm long with a 1.5mm chamfer at the lower edge, and case hardened. The resistance level of the material is obtained by carrying out a sieve analysis of the impacted sample and because both quarry waste dust and RAP are non-plastic materials, aggregate impact value was used as a bases to access the degree of resistance of the materials when impacted for the various mix designs. This experiment attempts to stimulate the load carrying characteristics of the highway pavement replicated by the standard compaction energies during the pavement construction, while impact load represents the traffic load that maybe using the highway pavement in its lifetime. When the materials have impacted the level of increment during sieve analysis shows the strength loss of quarry waste dust stabilized RAP mix. While AIV considers the percent passing sieve 2.36mm aperture for coarse aggregates, a new criterion of percent passing sieve 0.075mm aperture was used for the quarry waste dust stabilized RAP mixes and compared to the value of conventional aggregates.

3.2.5 Water Absorption Rate

The water absorption rate of the various mix proportions was also determined from the durability test by taking the weight difference of the mix as compacted and its weight under uniform moisture distribution (UMD) and partially immersed in water (PIIW) conditionsto ascertain the rate at which the samples absorb water since they gain strength when soaked in water for 24-hours and was obtained to range 0.69-1.47g. Concerning highway construction the water absorption rate indices were specified by (Joel et al 2010).

3.3 ANN in data prediction

Data are imported from a csv file and divided into Train, validation and test. Training data are used to develop the training model while the validation data used to develop the test to fitness model. Changes ae then made on parameters like layer numbers, nodes and epoch in the network on a trial-and-error bases and visualization help in getting the favorable result. The data are divided into three groups namely;

I. Training group data

   Training set: A set of examples used for learning, that is to fit the parameters of the classifier.

II. Validation group data

   Validation set: A set of examples used to tune the parameters of a classifier, for example to choose the number of hidden units in a neural network.

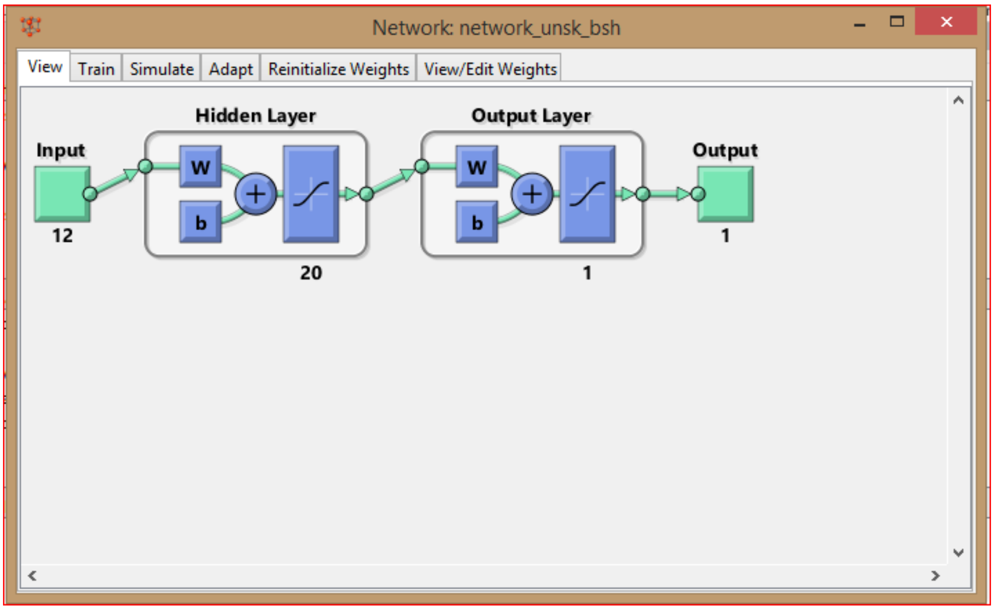
III. Test group data

Test set: A set of examples used only to assess the performance of a fully-specified classifier.

The test group data was assigned 20.0% of the total data set while 80.0% assign to training group data also from the training group 20% is further assign to validation group and the rest as training group of data.

Figure 5.

Schematic Diagram of the Built ANN Model



CHAPTER IV

Results and Discussion

4.1. Oxide and Chemical Composition Of QWD and RAP

The oxide composition of quarry waste dust is given in table 4.1. The calcium oxide (CaO) content is 2.35% and the silicon oxide (SiO_2) content is 70.01%. The CaO/SiO_2 ratio, which is indicative of the cementing potential, is 0.034. Hence, quarry waste dust is not self-cementing. SiO_2+AL_2O_2+Fe_2O_3=86.19%, and loss on ignition (LOI), which is the indication of the amount of unburned coal in the ash is 1.01%. This result shows that quarry waste dust is not self-cementing. While the oxide composition of reclaimed asphalt pavement (RAP) the cementing potential is given as 0.124(CaO/SiO_2) and the summation of SiO_2 + Al_2O_3 + Fe_2O_3= 80.70% shows RCP is not a self-cementing material.

4.2. Grain size analysis

The grain size analysis or the particle size distribution curve of the RAP stabilized quarry waste dust using cement as additive are shown in figures.6-7. The gradation of stabilized RAP shows that at 100% RAP, composed of 99.8% coarse aggregate and 0.2% fine with an AASHTO classification of A-1 (granular materials) but when stabilized with QWD and cement, it is composed of 94.7599.5% coarse particles and fine particles in the range 0.5-5.25% with an AASHTO classification of A-3 (non-plastic sand). The grading curves also shows that the material compositions of various QWD + CE stabilized RAP are well graded (GW) under the USCS classification, since their uniformity coefficient, Cu > 4 and grading coefficient, 1<Cz<3. The improved particle size grading of quarry waste dust may be due to flocculation – agglomeration of the particles of quarry waste dust, cement as well as RAP particles into larger effective matrix (little, 1999).

Figure 6.

Grain size analysis of 100-90% RAP and various sample mix of RAP+QWD+CE.

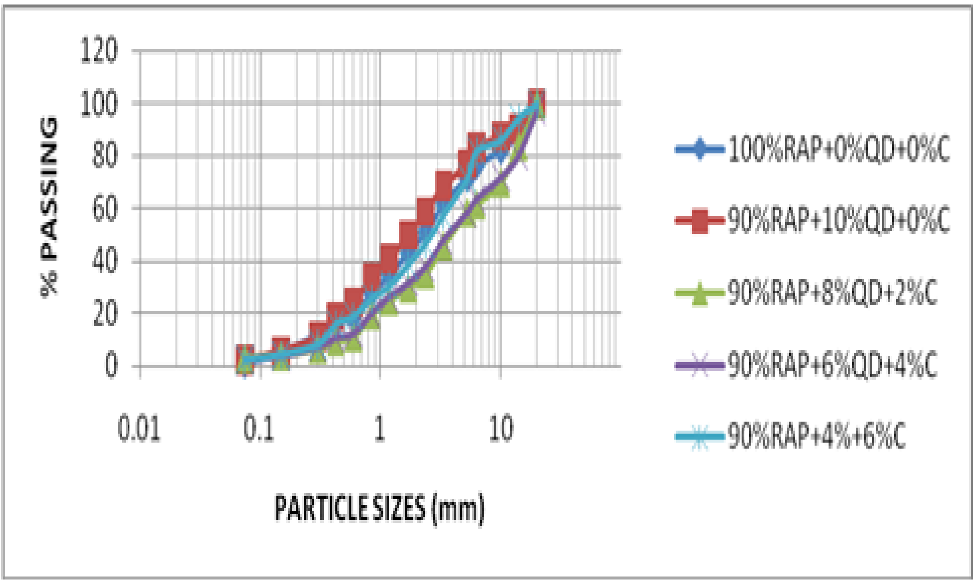
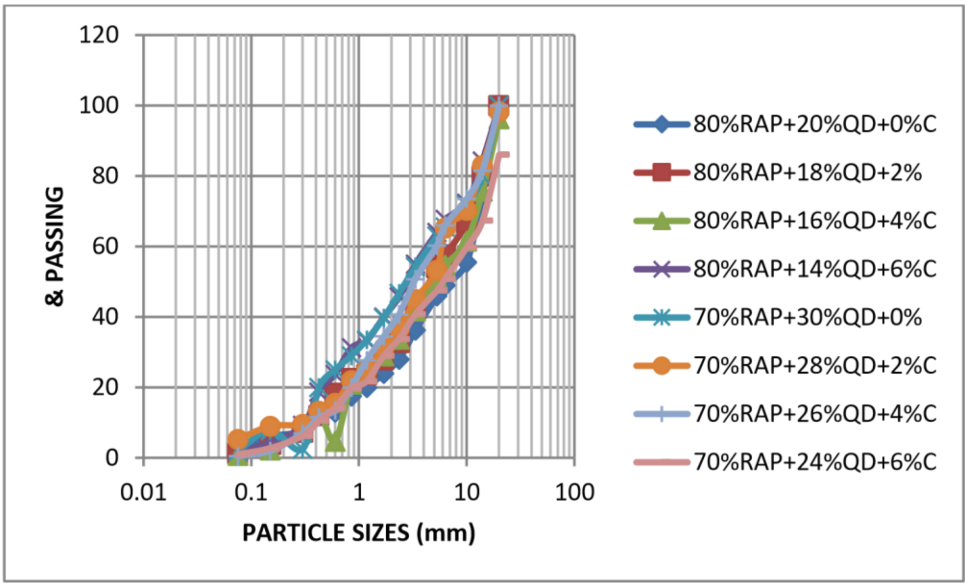


Figure 7.

Grain size analysis of 70-80% RAP and various sample mix of RAP+QWD+CE



4.3. Specific gravity

The specific gravity of RAP, quarry waste dust and cement are 2.27, 2.85 and 3.15 respectively as obtained from the laboratory experiment. The SG of RAP falls within the range of

1.94 -2.30 stated in Federal Highway AdministrationFHWA (2008). The specific gravity of RAP stabilized quarry waste dust using cement as additive did not show any specific trend however, peak value of 2.49 was recorded for 80% RAP + 14% QWD + 6% Cement. Quarry waste dust stabilized RAP fall under A-1 to A-3 AASHTO classification.

Table 4.

Presents the various specific gravity of 100% RAP, 100% QWD and various RAP+QWD+CE.

100% RAP, 100% QWD and RAP + QWD + CE samples specific Gravity								
	0% Cement		2% Cement		4% Cement		6% Cement	
RAP (%)	QWD (%)	S.G	QWD (%)	S.G	QWD (%)	S.G	QWD (%)	S.G
100	0	2.28	-	-	-	-	-	-
90	10	2.34	8	2.56	6	2.19	4	2.43
80	20	1.89	18	2.07	16	2.44	14	2.67
70	30	2.01	28	2.23	26	2.65	24	2.18
60	40	2.00	38	2.12	36	2.09	34	2.31
50	50	2.43	48	2.12	46	2.51	44	2.08
40	60	2.03	58	2.22	56	2.13	54	1.99
30	70	2.43	68	2.52	66	2.07	64	2.81
20	80	2.39	78	2.74	76	2.91	74	2.09
10	90	2.77	88	2.60	86	2.56	84	2.91
0	100	2.65	-	-	-	-	-	-

4.4. Compaction characteristics

Samples for the compaction test were done with four (4) compaction energy levels namely reduced British standard light, RBSL (reduced proctor), British standard light, BSL (standard Proctor), West Africa Standard, WAS and British Standard Heavy, BSH to determine water and density characteristics of the samples. As the cement percentage increases, maximum dry density (MDD) increases as well while optimum water content (OWC) decreases. The MDD increases from 1.48Mg/m^3 (RBSL), 1.51 Mg/m^3 (BSL) 1.63 Mg/m^3 (WAS) and 1.64 Mg/m^3 (BSH) at 100%RAP+0%QWD+0%CE to 1.96 Mg/m^3 (RBSL), 1.98 Mg/m^3 (BSL), 1.98 Mg/m^3 (WAS) and 1.99 Mg/m^3 (BSH) at 0%RAP+100%QWD+0%CE. Correspondingly, their OWC decreases from

12.6% (RBSL), 12.2% (BSL), 11.9% (WAS) and 11.7% (BSH) at 100%RAP+0%QWD+0%CE to 11.5% (RBSL), 11.3% (BSL), 10.8% (WAS) and 10.5% (BSH) respectively. While MDD range 1.48-1.99 Mg/m^3 and OWC range 8.8-12.6% for QWD-cement stabilized RAP. The Increase in MDD is a result of fine aggregates of QWD leading to a densematrix also the specific gravity of cement which is 3.15 is mixed with RAP with a specific gravity of 2.26 leading to greater specific gravity if combined which will lead to an increase in MDD of the entire mixture. The decrease in optimum water content (OWC) is a result of the reaction between QWD and cement which will decrease the surface area needed to be coated as the number of cement increases, which makes the mix use more water for the hydration of cement. The observed trend of MDD and OMC with higher QWD and cement contents in the RAP + QWD + C mixes may be attributed to the insufficiency of water in the system that resulted in self-desiccation and consequently lower hydration. It is known that if no water movement to and from RAP + QWD + C paste is permitted; the reaction of hydration uses up the water until too little is left to saturate the soil surfaces and the relative humidity within the paste decreases.

Table 5.

Variation of MDD and OMC for samples of RAP+QWD+Cusing RBSL.

	0% cement			2% cement			4% cement			6% cement		
RAP (%)	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC
100	0	1.48	12.6	–			–			–		
90	10	1.5	12.4	8	1.48	11.4	6	1.53	10.8	4	1.6	10.6
80	20	1.51	12	18	1.5	10.3	16	1.55	9.5	14	1.65	8.7
70	30	1.52	12	28	1.56	11.3	26	1.58	12	24	1.68	11.7
60	40	1.53	11.9	38	1.6	11.5	36	1.62	11.3	34	1.7	10.8
50	50	1.61	11.8	48	1.61	11.2	46	1.65	10.8	44	1.75	10.4
40	60	1.62	11.8	58	1.63	11.1	56	1.67	10.6	54	1.78	10.2
30	70	1.7	11.5	68	1.65	11.1	66	1.7	10.7	64	1.83	10.5
20	80	1.84	11.5	78	1.86	11	76	1.84	10.9	74	1.87	10.4
10	90	1.95	11.5	88	1.91	10.5	86	1.94	10.8	84	1.97	10.2
0	100	1.96	11.5	–	1.92	10.5	–	1.95	10.8	–	1.98	10.2

Table 6.

Variation of MDD and OMC for samples of RAP+QWD+C using BSL.

	0% cement			2% cement			4% cement			6% cement		
RAP (%)	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC
100	0	1.51	12.2	–			-	-	-	-	-	-
90	10	1.51	11.5	8	1.5	11.3	6	1.56	10.4	4	1.66	10.1
80	20	1.52	11.5	18	1.52	11.2	16	1.57	9	14	1.68	8.4
70	30	1.57	11.5	28	1.57	11.2	26	1.6	10.8	24	1.7	10.6
60	40	1.58	11.5	38	1.61	11.2	36	1.65	10.7	34	1.73	10.6
50	50	1.63	11.5	48	1.65	11.1	46	1.67	10.5	44	1.76	10.2
40	60	1.64	11.2	58	1.66	11	56	1.69	10.3	54	1.81	10
30	70	1.72	11.2	68	1.69	11	66	1.73	10.5	64	1.85	10.2
20	80	1.88	11	78	1.88	11	76	1.85	10.5	74	1.88	10.1
10	90	1.98	10.8	88	1.95	10.5	86	1.96	10.4	84	1.97	10
0	100	1.98	9.6	–	1.98	10	–	1.97	10.5	–	1.99	10

Table 7.

Variation of MDD and OMC for samples of RAP+QWD+C using WAS.

	0% cement			2% cement			4% cement			6% cement		
RAP (%)	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC
100	0	1.63	12.6	–			-	-	-	-	-	-
90	10	1.64	12.4	8	1.65	12.5	6	1.72	12.3	4	1.74	12.1
80	20	1.64	12.4	18	1.66	12.2	16	1.75	12.1	14	1.75	12
70	30	1.66	12.3	28	1.68	12	26	1.77	11.8	24	1.78	11.7
60	40	1.69	12.1	38	1.69	11.8	36	1.79	11.6	34	1.81	11.5
50	50	1.7	11.9	48	1.72	11.6	46	1.85	11.4	44	1.83	11.3
40	60	1.72	11.7	58	1.77	11.6	56	1.87	11.2	54	1.87	11
30	70	1.78	11.5	68	1.81	11.4	66	1.92	10.9	64	1.91	10.8
20	80	1.88	11.3	78	1.88	11.1	76	1.96	10.7	74	1.95	10.6
10	90	1.94	10.8	88	1.96	10.5	86	1.97	10.5	84	1.97	10.4
0	100	1.98	10.1	–	1.98	10.2	–	1.98	10.3	–	1.99	10.1

Table 8.

Variation of MDD and OMC for samples of RAP+QWD+C using BSH.

	0% cement			2% cement			4% cement			6% cement		
RAP (%)	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC	QWD (%)	MDD	OMC
100	0	1.64	12.7	–			-	-	-	-	-	-
90	10	1.66	12.5	8	1.7	12.4	6	1.74	12.2	4	1.76	12
80	20	1.66	12.4	18	1.72	12.2	16	1.75	12	14	1.78	11.8
70	30	1.68	12.3	28	1.75	12.1	26	1.78	11.9	24	1.81	11.6
60	40	1.71	12.1	38	1.78	11.9	36	1.81	11.7	34	1.83	11.4
50	50	1.73	11.9	48	1.81	11.7	46	1.83	11.5	44	1.86	11.2
40	60	1.74	11.8	58	1.83	11.5	56	1.87	11.3	54	1.89	11.1
30	70	1.77	11.6	68	1.86	11.3	66	1.91	11.1	64	1.92	10.7
20	80	1.86	11.4	78	1.91	10	76	1.95	10.8	74	1.96	10.4
10	90	1.91	10.7	88	1.96	10.8	86	1.97	10.4	84	1.97	10.2
0	100	1.98	10.5	–	1.98	10.4	–	1.99	10.3	–	1.99	10.1

4.5. California bearing ratio

The California bearing ratio (CBR) of the various proportion of RAP, quarry waste dustand cement for the un-soaked and soaked at 100% RAP is given as 20 % and 23 % for RSBL, 25 % and 29 % for BSL, 37 % and 43 % for WAS and 43 % and 46 % for BSH. It was observed that the CBR decreases with an increase in QWD content due to the high QWD content which alters the mixture into a friable state thereby reducing the strength. Peak CBR was 52.0% (BSH un-soaked) while 78.0% (Soaked BSH) was obtained at 60% RAP +34% QWD + 6%CE mix proportion. The general CBR results show higher CBR values after soaking the test sample for 24-hours of water, indicating the possibility of an increased strength under the soaked condition with time. Usually, a minimum of 80% CBR value is required forbase material, 30-80% for sub-base material and 10-30% for subgrade materials. (Nigerian General Specifications, 1997). Agglomeration of the materials could contribute to the CBR results in variation patterns when quarry waste dust stabilized RAP (Hatipoglu et al; 2008) and the uniform distribution of quarry waste dust mixture (Li et al; 2009). The main factors responsible for the strength of soil are its cohesive nature and its resistance to friction. Pozzolanic strength gain during the hydration process leads to the higher CBR values for soaked samplesthan for unsoaked samples. (Little, 1999).

Table 9.

Variation of CBR of various proportions of RAP + QWD + C mixes using RBSL, BSL, WAS and BSH.

MIX DESIGNS	UNSOAKED RBSL	SOAKED RBSL	UNSOAKED BSL	SOAKED BSL	UNSOAKED WAS	SOAKED WAS	UNSOAKED BSH	SOAKED BSH
100%RAP+0%QWD+0%C	20	23	25	29	37	43	43	46
90%RAP+10%QWD+0%C	45	47	29	34	52	59	57	59
90%RAP+8%QWD+2%C	29	44	32	50	35	44	38	49
90%RAP+6%QWD+4%C	24	28	30	39	44	53	49	55
90%RAP+4%QWD+6%C	30	42	31	40	43	49	52	49
80%RAP+20%QWD+0%C	20	23	23	32	37	46	47	48
80%RAP+18%QWD+2%C	25	31	30	38	43	52	51	54
80%RAP+16%QWD+4%C	28	33	31	42	39	54	42	56
80%RAP+14%QWD+6%C	23	28	33	38	36	53	38	58
70%RAP+30%QWD+0%C	25	30	26	41	41	58	44	58
70%RAP+28%QWD+2%C	29	33	28	43	43	57	47	59
70%RAP+26%QWD+4%C	30	37	33	48	47	60	47	61
70%RAP+24%QWD+6%C	29	32	28	36	52	62	54	62
60%RAP+40%QWD+0%C	36	43	26	28	43	59	47	62
60%RAP+38%QWD+2%C	18	26	31	38	35	64	36	64
60%RAP+36%QWD+4%C	22	30	30	34	38	57	39	60
60%RAP+34%QWD+6%C	27	32	30	52	42	67	44	70
50%RAP+50%QWD+0%C	18	40	21	41	34	40	39	43
50%RAP+48%QWD+2%C	26	39	24	36	45	52	49	55
50%RAP+46%QWD+4%C	30	38	19	37	49	53	53	56
50%RAP+44%QWD+6%C	23	41	23	36	43	45	52	49
40%RAP+60%QWD+0%C	23	28	19	25	47	57	47	59
40%RAP+58%QWD+2%C	16	23	25	30	32	45	36	49
40%RAP+56%QWD+4%C	18	20	16	17	24	32	34	38
40%RAP+54%QWD+6%C	17	19	23	36	31	38	37	42
30%RAP+70%QWD+0%C	12	16	15	21	26	31	38	38
30%RAP+68%QWD+2%C	20	29	22	27	32	42	35	44
30%RAP+66%QWD+4%C	14	19	16	23	29	32	39	42
30%RAP+64%QWD+6%C	22	31	26	39	32	37	37	42
20%RAP+80%QWD+0%C	10	21	18	42	28	39	30	45
20%RAP+78%QWD+2%C	15	19	16	39	32	40	35	46
20%RAP+76%QWD+4%C	13	23	16	26	29	34	34	41
20%RAP+74%QWD+6%C	10	20	20	27	31	37	37	46
10%RAP+90%QWD+0%C	16	29	18	26	26	29	32	36
10%RAP+88%QWD+2%C	7	22	20	29	25	35	31	39
10%RAP+86%QWD+4%C	5	18	16	18	23	31	29	35
10%RAP+84%QWD+6%C	8	19	13	22	21	32	32	38
0%RAP+100%QWD+0%C	12	26	10	19	23	36	33	41
0%RAP+98%QWD+2%C	11	20	14	23	27	39	31	43
0%RAP+96%QWD+4%C	6	16	8	20	21	31	32	34
0%RAP+94%QWD+6%C	8	12	11	18	20	29	30	34

4.6. Durability characteristics

The durability properties which is related to the strength loss resistance of the samples of quarry waste dust used in stabilizing reclaimed asphalt pavement using cement as additive and passing through sieve 14mm aperture and retained on sieve 2.36mm aperture compacted at their respective OMC and MDD and also subjected to impact analysis. The conventional criterion of maximum allowable loss in strength of 20% which translate to 80% resistance to loss in strength by Ola (1974) was adopted for the various proportions of quarry dust stabilized RAP combinations. The use of 0-6%cement additives at 0%RAP+100%QWD did not meet the durability requirement as the impact values range 20.10-36.35% which translates to 63.65-78.90% resistance to loss in strength respectively were less than 80% of specified resistance value. This is an indication that the various proportions of quarry waste dust (QWD) using 0-6% cement additives at RBSL, BSL, WAS and BSH compactive efforts alone cannot provide the needed adhesion to make it durable. Hence, the various proportions alone cannot be used to achieve the successful stabilization of highway pavement materials. But the various proportions using 0-6% cement additives for the other mixes using RBSL, BSL, WAS and BSH compactive energies at their respective OMC and MDD have their impact values in the range 20.00 - -10.30% which translates to 80-110.30% resistance to loss in strength as they are more than 80% specified resistance value thereby satisfying the durability criterion. The use of quarry dust stabilized RAP shows an increase in resistance to loss in strength with an increase in quarry dust content and a decrease in compaction energy level for the quarry dust stabilized RAP passing sieve 14mm aperture but retained on the sieve2.36mm aperture before impact analysis which could be as a result of larger surface area of quarry waste dust stabilized RCP passing sieve 14mm aperture but retain on sieve 2.36mm aperture which degrade with impact and the fine aggregate content increase in the mix samples. The main factor responsible for strength of soil particles in contact and the pozzolanic strength gained due to complete chemical process of hydration of lime in the mixes (little, 1999).

4.7. Water absorptionproperties

The water absorption rate of the various mix proportions was also determined from the durability test by taking the weight difference of the mix as compacted and its weight under UMD and PIIW conditions so as to ascertain the rate at which the samples absorb water since they gain strength when soaked in water for 24-hours and was obtained to range 0.69-1.47g.

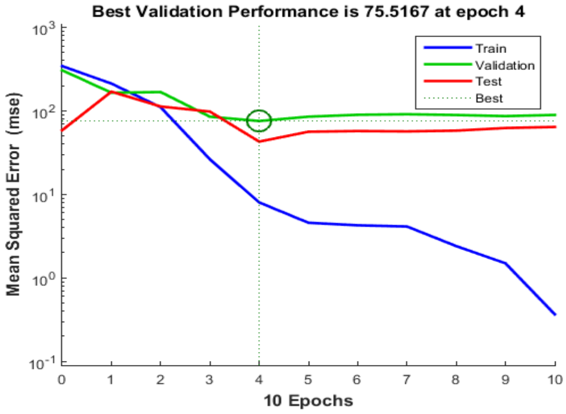
4.8 Performance of ANN Model for Prediction of Strength Characteristics

Results of the performance of the built ANN model for predicting strength characteristics for QWD, RAPand QWD-cement stabilized RAP using the RBSL, BSL, WAS and BSH energy levels during training, validation, and testing were evaluated using the number of learning epochs and goodness of fit tests of the distributions.

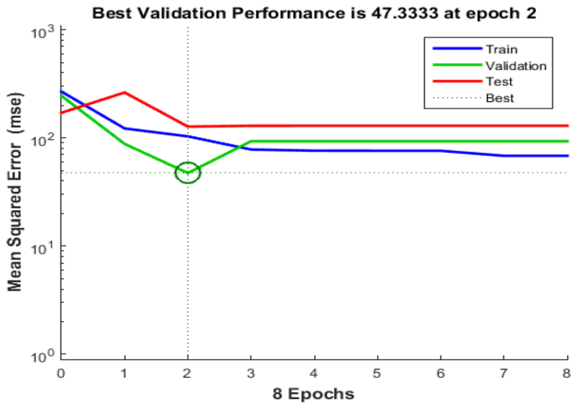
Figure 8 presents the performance of the ANN model learning process for predicting the unsoaked CBR values for the various energy levels.

Figure 8:

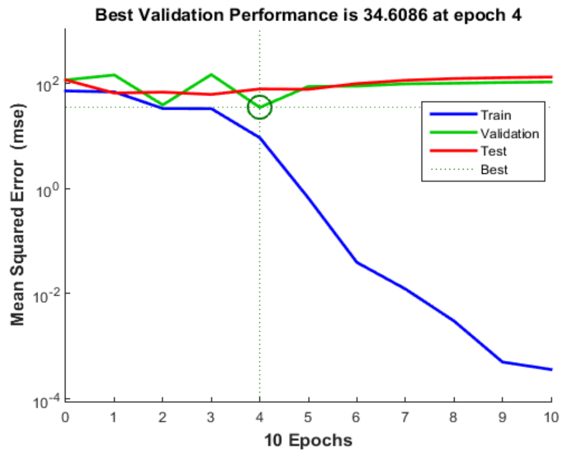
Performance of ANN Model for Predicting Unsoaked CBR



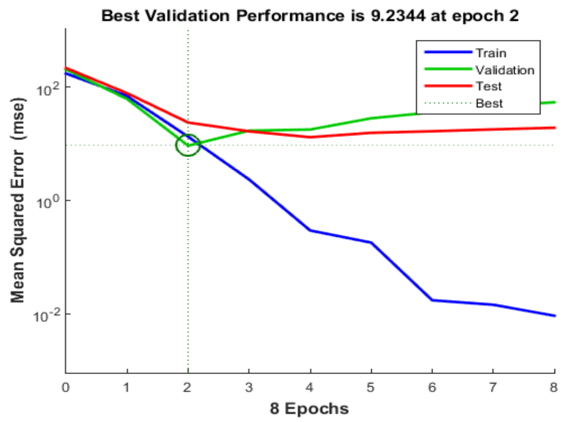
(a) Learning Process for RBSL



(b) Learning Process for BSL



(c) Learning Process for WAS



(d) Learning Process for BSH

Figure 8(a) revealed that the training, validationand testing processes improved systematically with less mean square error up to the 4th learning epoch. The training curve decreased at a relatively higher rate thereby signifying a good fit for predicting the unsoaked CBR values of samples using the RBSL energy level with minimum mean square errors. Afterward, the validation and test curves diverge from the training curve indicating failure in prediction with a high error margin. This could be alleviated by introducing an early stoppage criterion in the learning process to terminate the training, validationand testing processes at the 9th, 76th and 45th objectives respectively, at the 4th epoch for optimum performance with minimum mean square errors.

Figure 8(b) revealed a systematic increase in the accuracy of predictions up to the 2nd learning epoch for the training, validation, and testing processes. At the 2nd epoch, the validation curve decreased sharply to signify a minimum error. The training, validationand testing curves raised and maintained relatively constant levels of error margin for the prediction of the unsoaked CBR of the samples using the BSL energy level with minimum mean square error. The stoppage criterion for termination of the training, validationand testing processes were at the 102^{nd}, 47^{th} and 105^{th} objectives respectively at the 2^{nd} epoch for optimum performance with minimum mean square errors.

Figure 8(c) revealed that the training process reduced the error of prediction as the number of epochs increased. For the validation and testing, there was no significant increase in estimation errors as the process continued beyond the 4^{th} epoch. The optimum mean square error occurred at 9.0, 34.61 and 100 for the training, validation and testing respectively.

Figure 8(d) showed a similar trend established by the previous learning processes. The best performance occurred up to the 2^{nd} epoch, beyond which the training process maintained its reduced error trend, however, the validation and testing process increased error estimation as the epochs increased. This trend, indicated that optimum performance of the learning process for predicting the unsoaked CBR occurred when the estimated mean squared error for the training, validation and testing processes of the model were 11.0, 9.23 and 35.00 respectively.

Below is the fitness analysis of the ANN model for predicting strength characteristics for QWD, RAP and QWD-cement stabilized RAP using the RBSL, BSL, WAS and BSH energy levels for unsoaked CBR for model training, validationand testing.

Figure 9 showed the correlation analysis of results obtained from the built ANN model for predicting unsoaked CBR using the RBSL compactive effort.

Figure 9:

Goodness-of-Fit Test of ANN Model for RBSL Unsoaked CBR

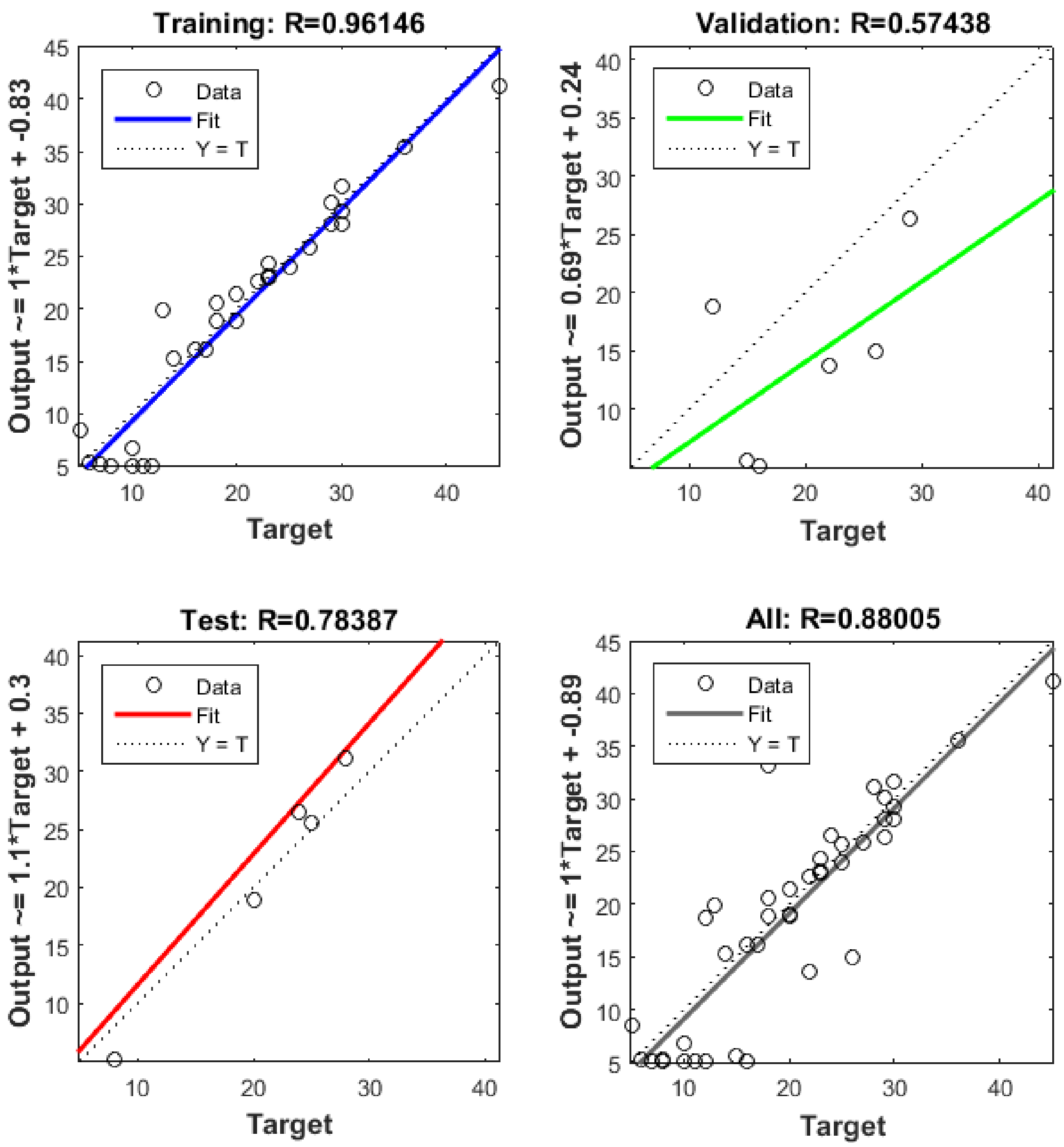


Figure 9: showed that the correlation between the predicted and the observed unsoaked CBR was measured at 0.9615, 0.5744 and 0.7839 for the model training, validationand testing respectively. The overall performance of the model in predicting the unsoaked CBR values were estimated at a correlation of 0.88002, which indicated a relatively fair performance of the built ANN model.

Figure 10 showed the correlation analysis of results obtained from the built ANN model for predicting unsoaked CBR using the BSL compactive effort.

Figure 10:

Goodness-of-Fit Test of ANN Model for BSL Unsoaked CBR

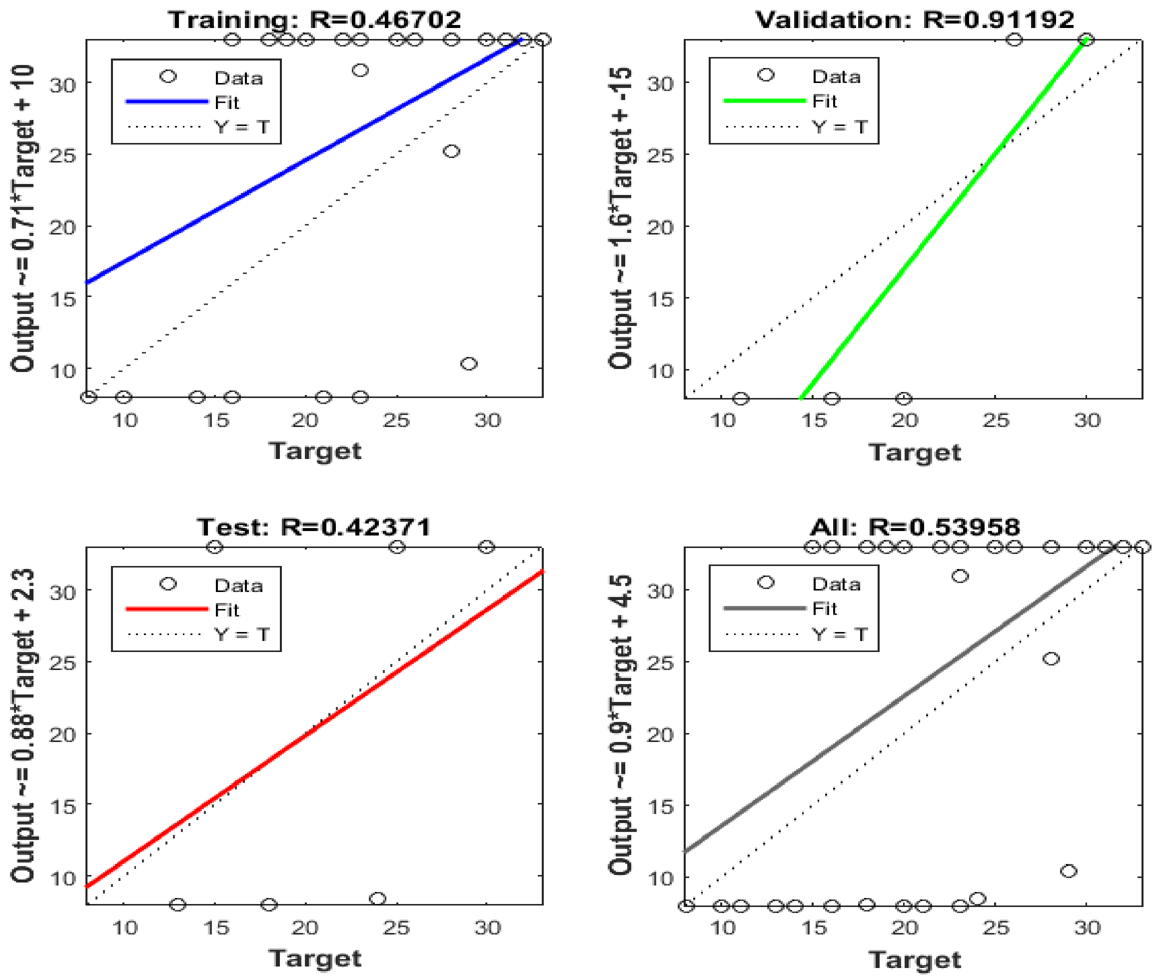


Figure 10 revealed a relatively poor performance – below average for the model training and testing processes, while the validation process recorded a relatively high performance compared to the training and testing processes. The overall performance of the built ANN model was estimated at 0.5395 which was below average (50%) and hence said to have performed relatively poorly.

Figure 11 shows the correlation analysis of results obtained from the built ANN model for predicting unsoaked CBR using the WAS compactive effort.

Figure 11

Goodness-of-Fit Test of ANN Model for WAS Unsoaked CBR

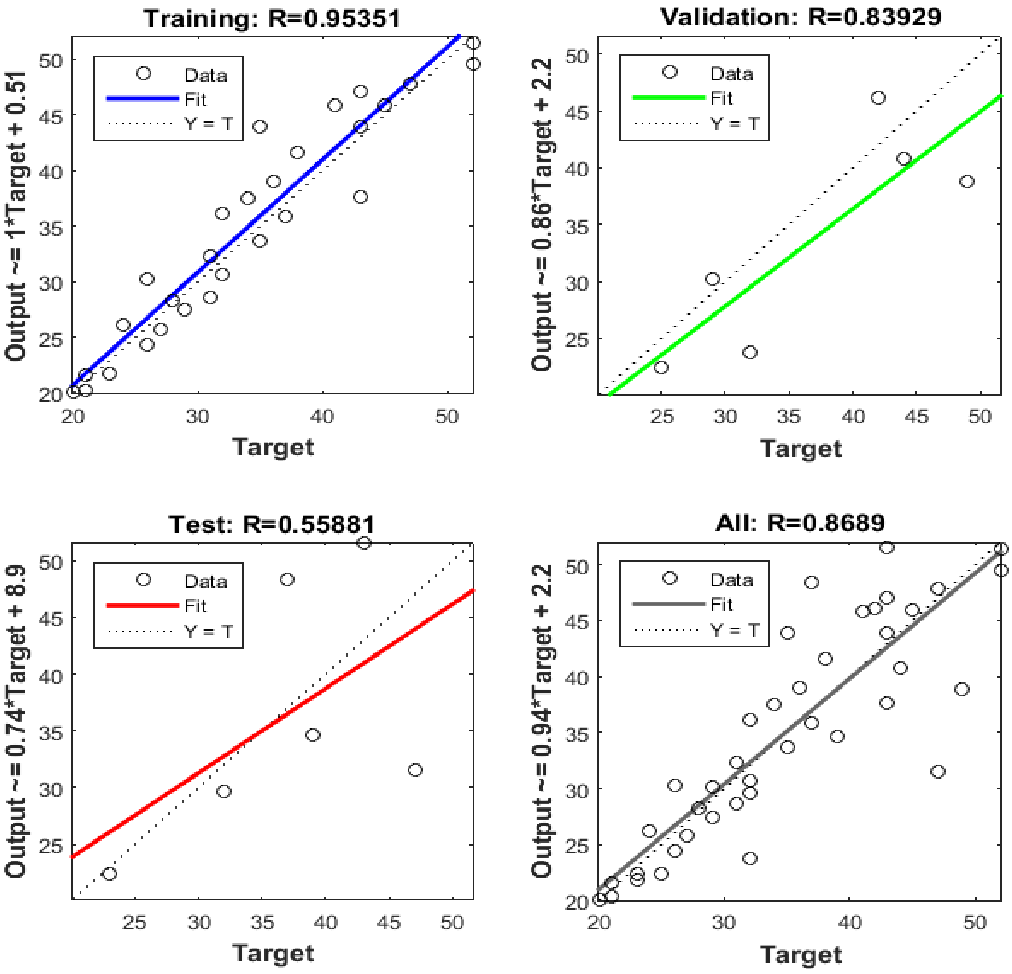


Figure 11, revealed a relatively high correction between the observed and predicted unsoaked CBR values for model training at 0.95351, while model validation and testrecorded 0.83929 and 0.55881 respectively. The overall performance of the ANN model for the WAS compactive energy levels was estimated at 0.8689 which was relatively satisfactory.

Figure 12 shows the correlation analysis of results obtained from the built ANN model for predicting unsoaked CBR using the BSH compaction effort.

Figure 12:

Goodness-of-Fit Test of ANN Model for BSH Unsoaked CBR

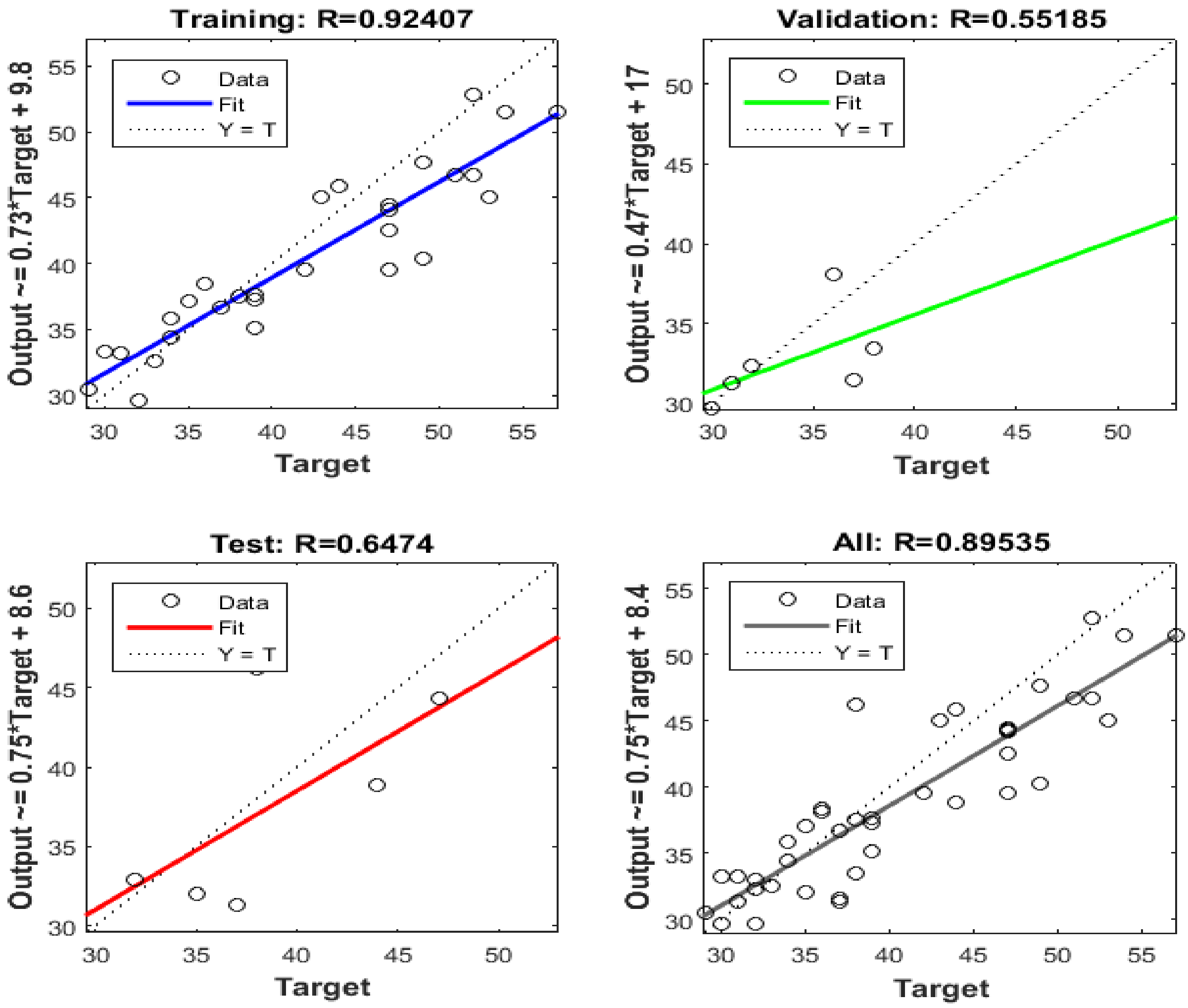
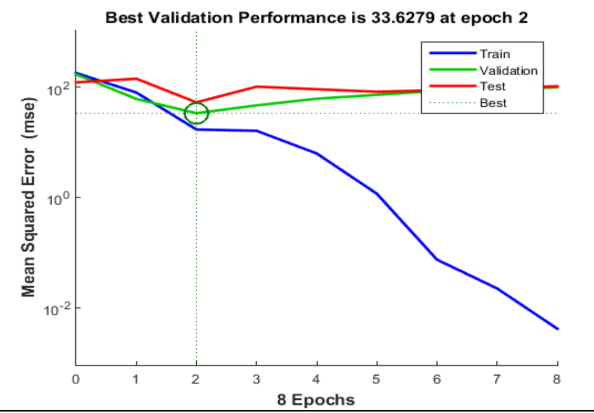


Figure 12 revealed a relatively high correlation between variables for predicting unsoaked CBR values for the training process at 0.92407. There was relatively low correction between the variables for model validation and testing at 0.55185 and 0.6274 respectively. The overall performance of the model was estimated at 0.89535 which indicated a relatively satisfactory output.

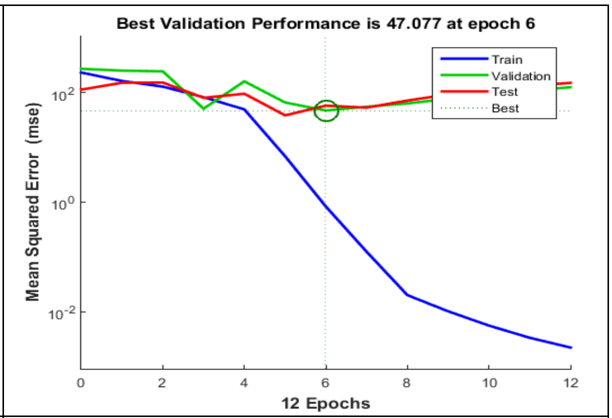
Figure 13 presents the performance of the ANN model learning process for predicting the soaked CBR values for the various compactive energy levels.

Figure 13:

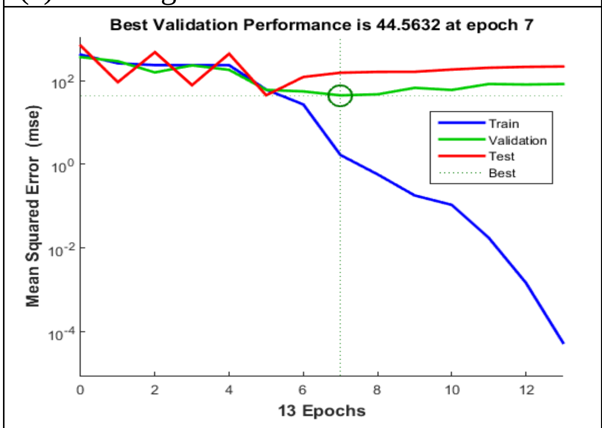
Performance of ANN Model for the Soaked CBR



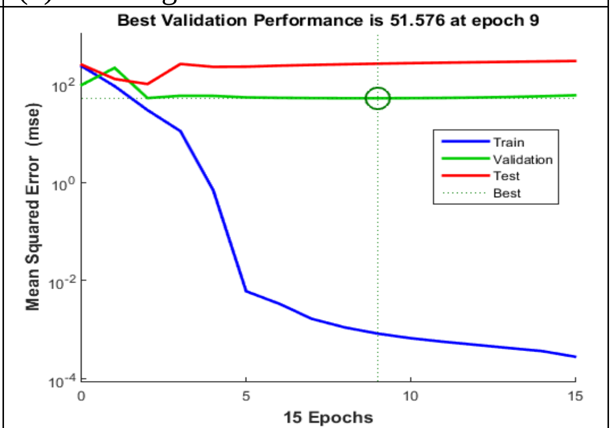
(a) Learning Process for RBSL



(b) Learning Process for BSL



(c) Learning Process for WAS



(d) Learning Process for BSH

Figure 13(a) revealed that the recommended terminal epochs for optimum performance of the built ANN model occurred at the 2nd epoch as the training errors continue to reduce. At that point, though the training error was reduced continuously, the validation and testing processes maintained the level of means square error. The estimated errors for the training, validation and testing were 10.0, 33.63 and 60.0 respectively.

Figure 13(b) showed that there was a reduction in estimated errors at the start-up to the 6th epoch, then a slight rise again for the validation and testing processes. Estimated errors for the training, validation and testing were 1.0, 47.0 and 55.00 respectively. This process of predicting the soaked CBR values using the BSL compaction effort lasted longer and recorded relativelyfewer errors compared to previous simulation experiments in this study. From Figure 13(c), the prediction of soaked CBR values using the WAS compaction energy levels showed a similar trend compared to the previous processes. It revealed thatthe optimum process occurred at the 7th epoch with error margins measuring 130, 44.56 and 4.0 for model training validation and testing respectively. Figure 13(d) revealed that there was negligible error estimation for the training process at the 9th epoch, however, the validation and training processes recorded 51.53 and 110.0 as the performance of the process for predicting the soaked CBR values generated from the BSH compaction effort.

Figure 14 shows the correlation analysis of results obtained from the built ANN model for predicting soaked CBR using the RBSL compaction effort.

Figure 14:

Goodness of Fit Plots for the RBSL for soaked samples

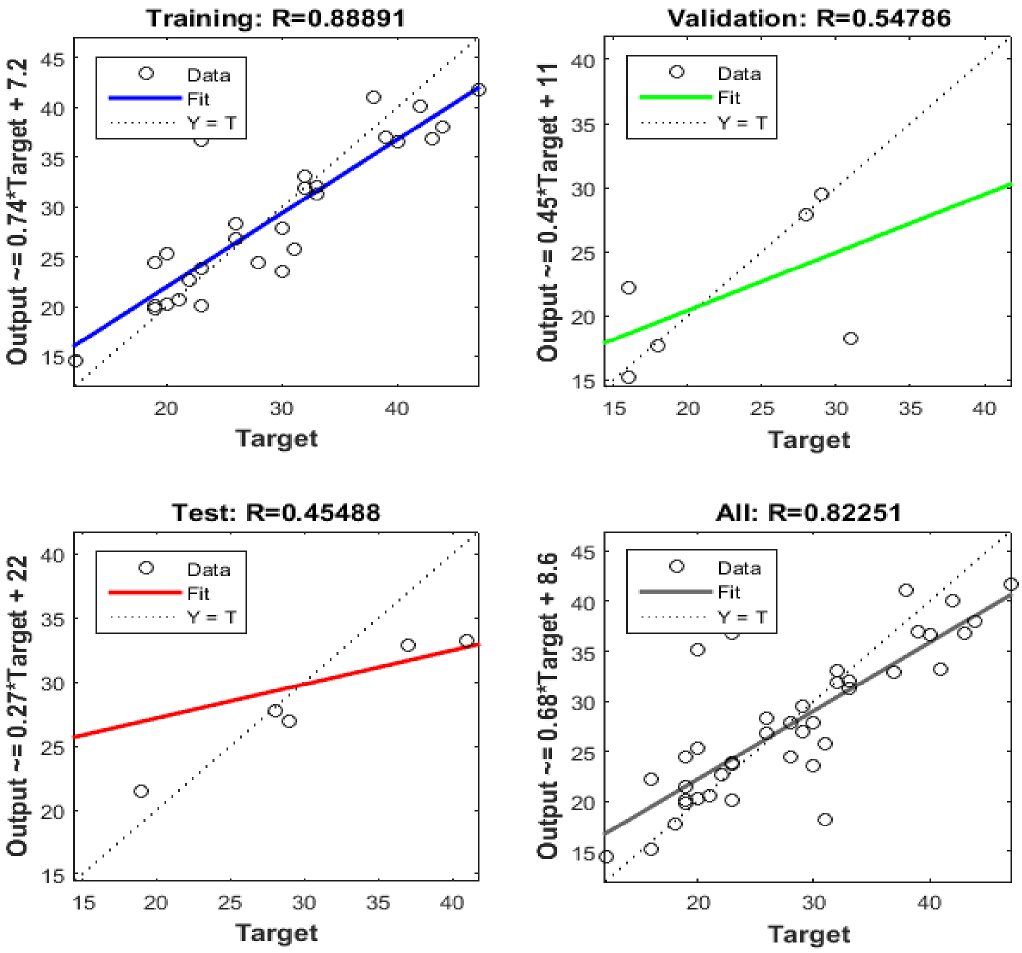


Figure 14 revealed that there were correlation values of 0.88891, 0.54786, 0.45488 and 0.82251 for the model training, validation, testing and the overall performance of the model for predicting the soaked CBR using the RBSL compaction effort. The average performance of 0.82251 of the model was satisfactory compared to the previous experiments in this study. Figure 15 shows the correlation analysis of results obtained from the built ANN model for predicting soaked CBR using the BSL compaction effort.

Figure 15:

Goodness of Fit Plots for the BSL for soaked samples

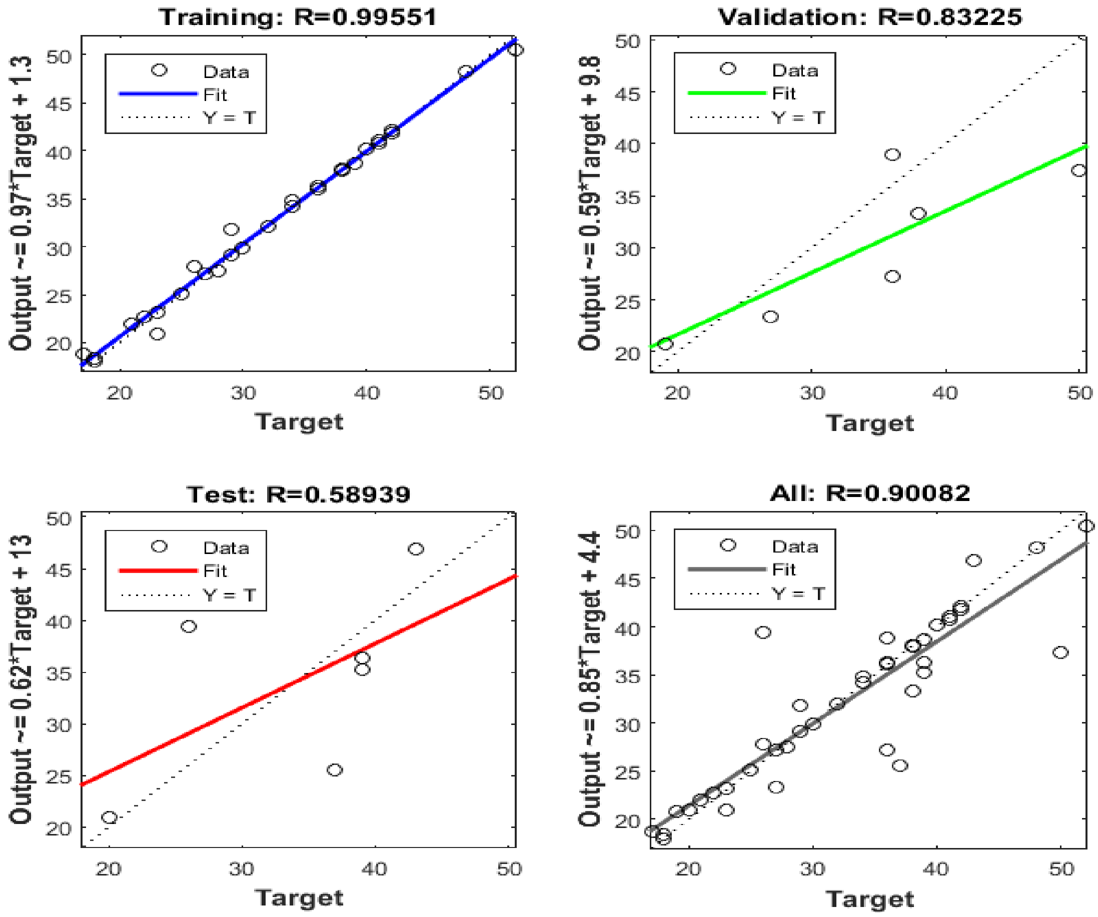


Figure 15 revealed that the performance of the prediction model for soaked CBR using the BSL compaction effort indicated correlation values of 0.99551, 0.83225, 0.58939and 0.90082 for the model training, validation, testing and overall performance. This performance parameterindicated a relatively high-performance index compared to the predictions performed for the RBSL compaction effort using the built model.

Figure 16 shows the correlation analysis of results obtained from the built ANN model for predicting soaked CBR using the WAS compaction effort.

Figure 16:

Goodness of Fit Plots for the WAS for soaked samples

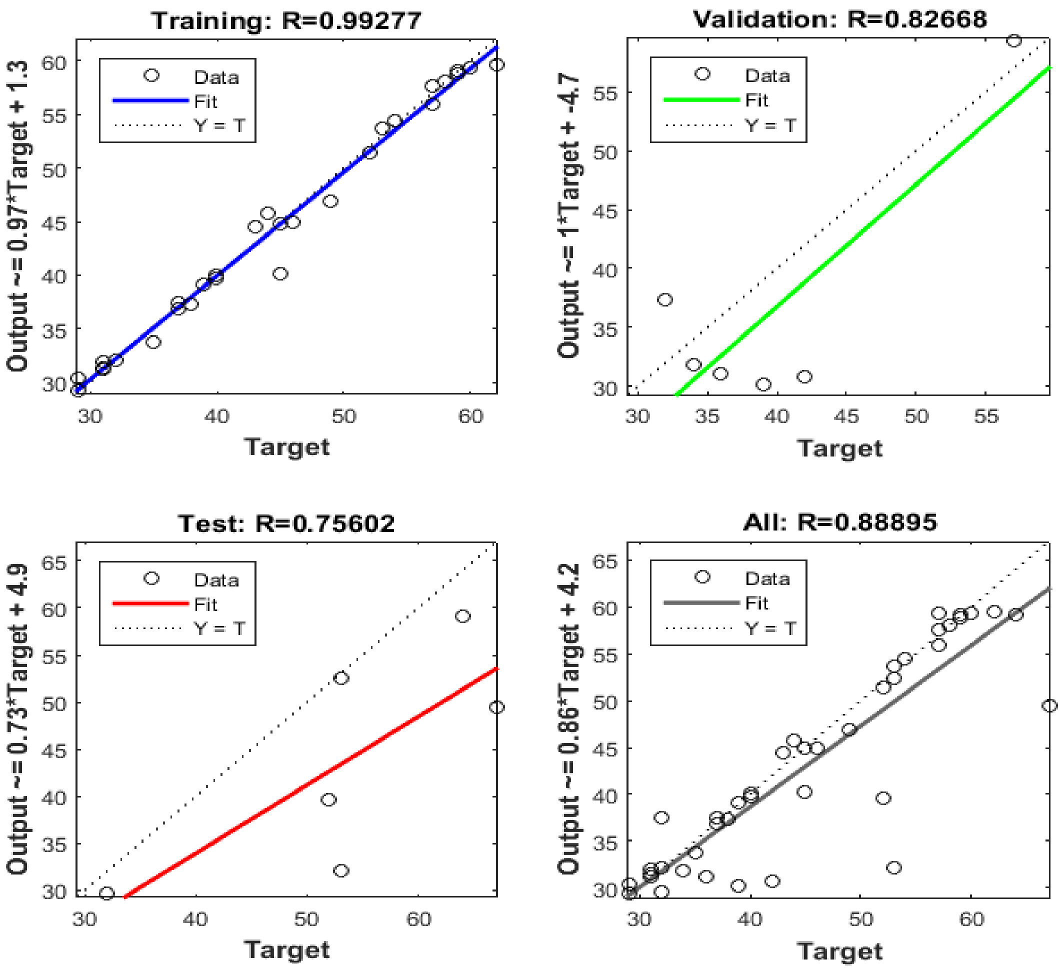


Figure 16 revealed a relatively low performance for the prediction of soaked CBR values compared to those carried out using the WAS compaction effort. It measures of correlation for the training, validation and testing were 0.99277, 0.82668and 0.75602 respectively. The overall performance of the model measured the correlation of prediction at 0.88895. The performance parameters of the model used for predicting the soaked CBR values using the WAS compaction effort showed a relatively satisfactory output.

Figure 17 shows the correlation analysis of results obtained from the built ANN model for predicting soaked CBR using the BSH compaction effort.

Figure 17:

Goodness of Fit Plots for the BSH for soaked samples

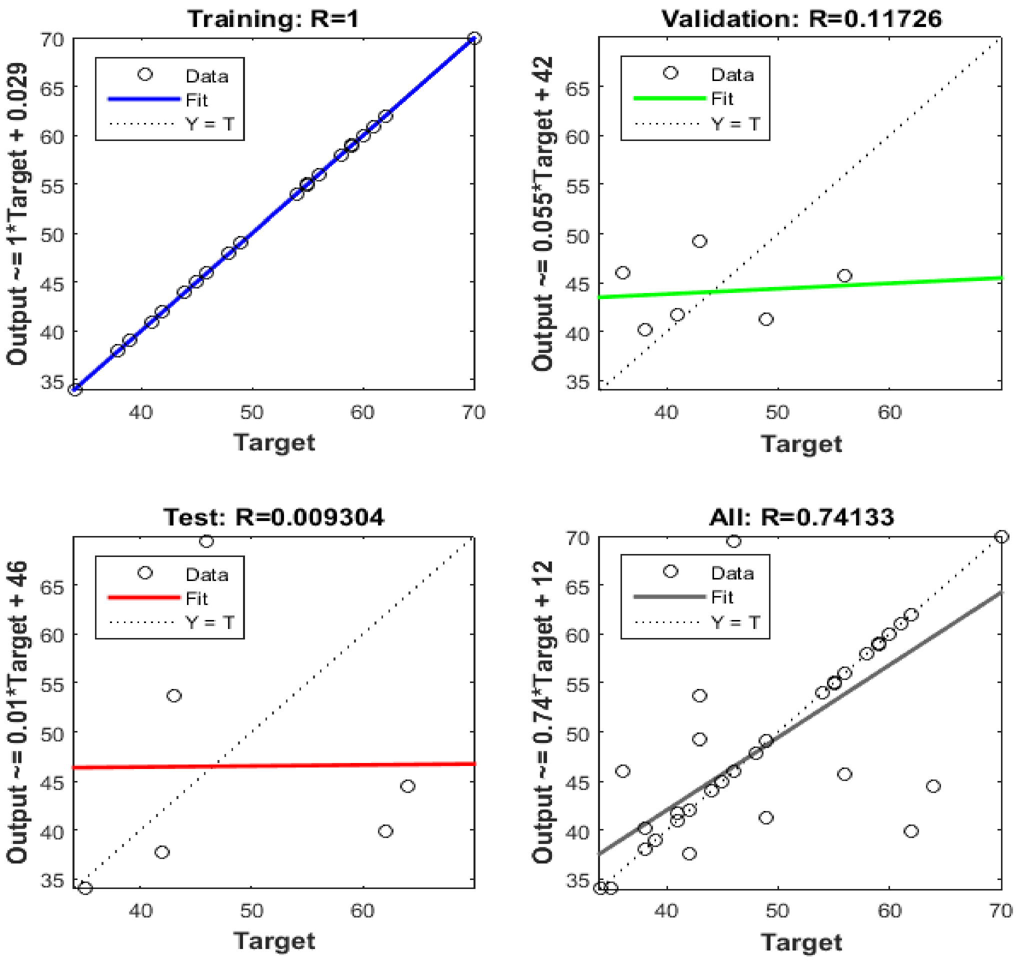


Figure 17 revealed that the training process of the model achieved excellent performance with a unit correlation value. However, its validation and testing processes recorded relatively low corrections at 0.11726 and 0.009304 respectively. This low correlation values for the validation and testing were attributed to the high measure of mean square error values recorded during the process. Hence, the overall performance of the model was affected thereby having an overall correlation value of 0.74133.

CHAPTER V

Conclusions and Recommendations

5.1 Conclusions

Various compactive efforts were used in to evaluation while an artificial neural network was used in predicting the strength (CBR) properties from the evaluated laboratory data. The particle size distribution curve shows RAP improved from 99.8% coarse particles and 0.2% fines to 94.75-99.5% coarse particles and 0.5-5.25% fine. The SG of 100.00 % RAP, 100.00 % QWD and 100.00 % cement were 2.27, 2.85 and 3.15 respectively which RAP falls under the FHWA (2008) specification of 1.94-2.30 while in the other mix designs there was no trend but ranges from 1.89-3.15 for RAP stabilized quarry waste dust using cement as additive.

The compaction characteristic result shows an increase in cement content to the mix design improves the maximum dry density (MDD) from 1.48-1.99 Mg/m3 while a decrease was observed in the optimum moisture content (OWC) from 8.8-12.6% for QWD-cement stabilized RAP as the compactive effort increase. The Increase in MDD is a result of fine aggregates of QWD leading to a dense matrix also the specific gravity of cement which is 3.15 is mixed with RAP with a specific gravity of 2.26 leading to greater specific gravity if combined which will lead to an increase in MDD of the entire mixture.

Usually, a minimum CBR value of 80% is required for the base (Nigeria general specification 1997) from the result the various mix design did not meet the requirement for base material using RBSL, BSL, WAS and BSH compactive efforts but could be used as a subgrade and sub base materials. For quarry waste dust stabilized RAP using cement as additive shows that the various mixes satisfy the durability requirement as their impact values range from 10.30 – 20.00% which translates to 80-110.30% strength loss resistance as they are greater than 80% specified resistance. The use of 0% RAP content as their resistance to loss of strength range from 20.10-36.35% which translates to 63.65-78.90% and is less than the 80% specified resistance value as stated by Ola (1974).

However, the BSL for soaked samples revealed the highest performance of the prediction model for soaked CBR using the BSL compaction effort indicating correlation values of 0.99551, 0.83225, 0.58939 and 0.90082 while BSH for soaked samples recorded the lowest correction at 0.11726 and 0.009304 respectively for the model training, validation, testing and overall performance. The overall performance of the model measured correlation of prediction range 0.53958 - 0.89535 for unsoaked CBR while 0.74133 – 0.90082 for soaked CBR using. These performance parameters of the model used for predicting the soaked/unsoaked CBR values using the RBSL, BSL, WAS and BSH compaction effort showed a relatively satisfactory output.

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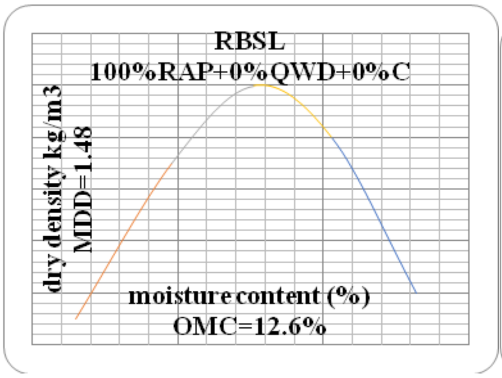
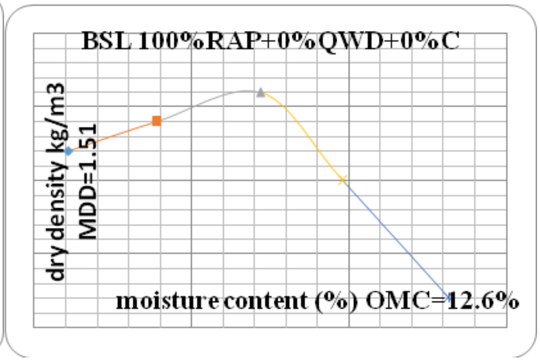
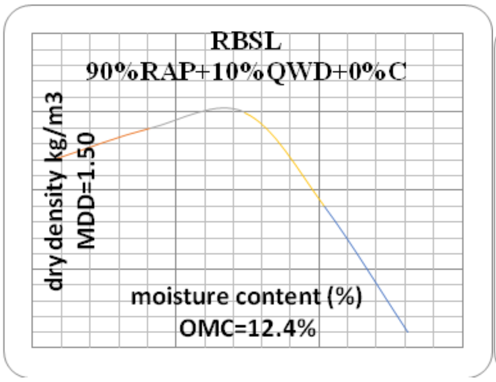
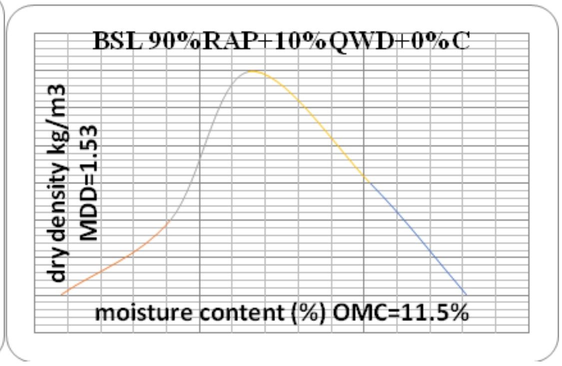
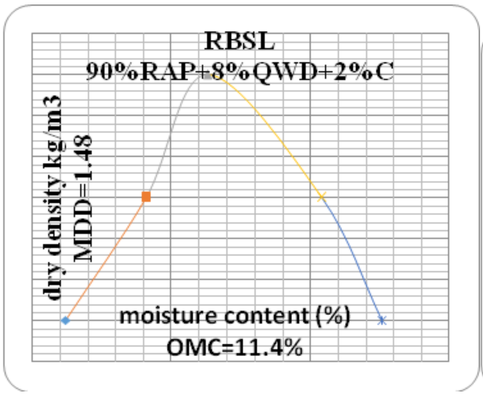
Appendix A: Some samples of compaction results graph

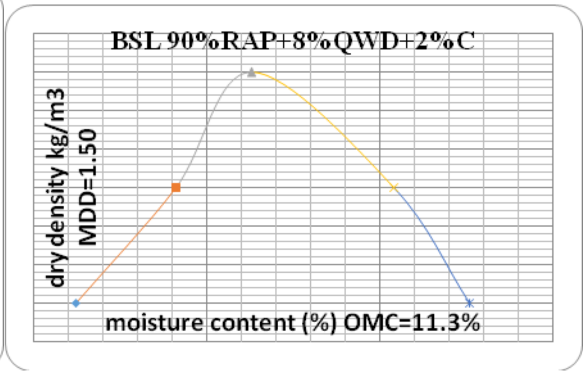


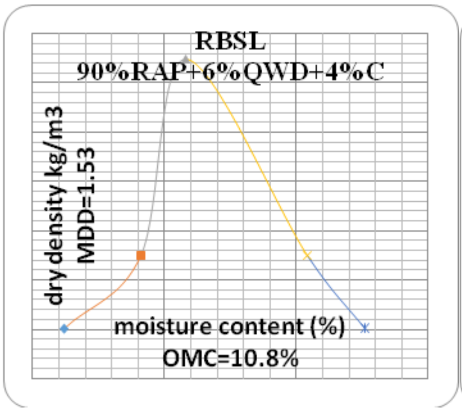


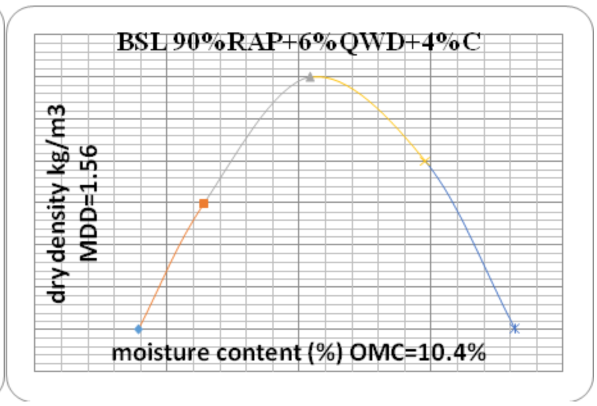


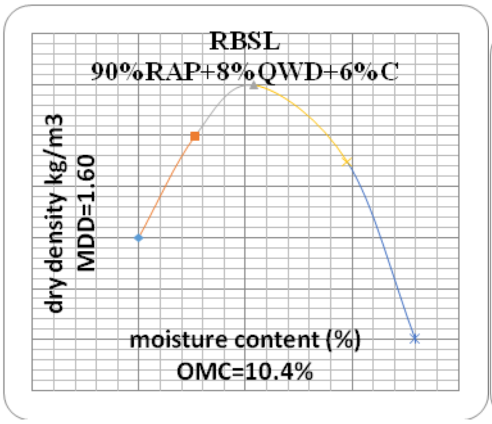


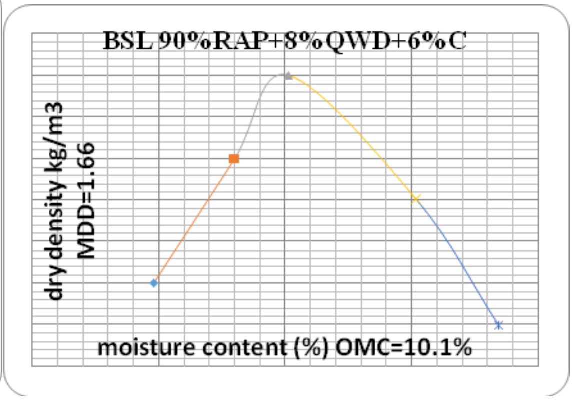


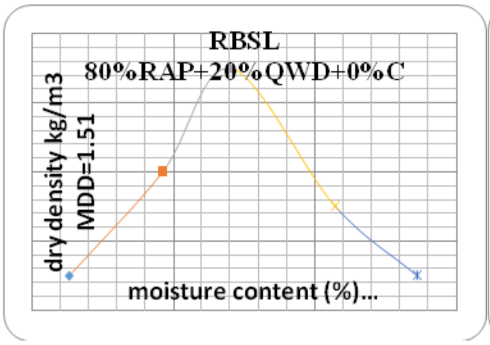


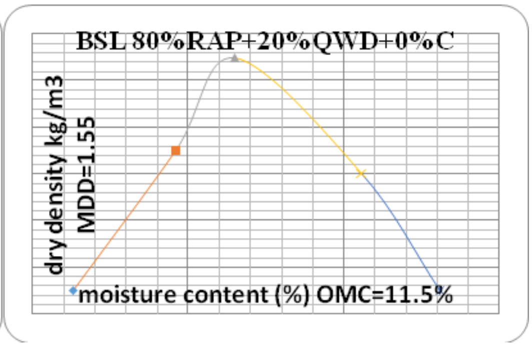


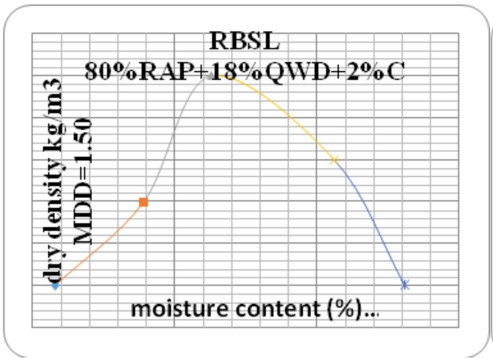



RBSL
90%RAP+8%QWD+6%C
dry density kg/m3
MDD=1.60
moisture content (%)
OMC=10.4%


BSL 90%RAP+8%QWD+6%C
dry density kg/m3
MDD=1.66
moisture content (%) OMC=10.1%


RBSL
80%RAP+20%QWD+0%C
dry density kg/m3
MDD=1.51
moisture content (%)...


BSL 80%RAP+20%QWD+0%C
dry density kg/m3
MDD=1.55
moisture content (%) OMC=11.5%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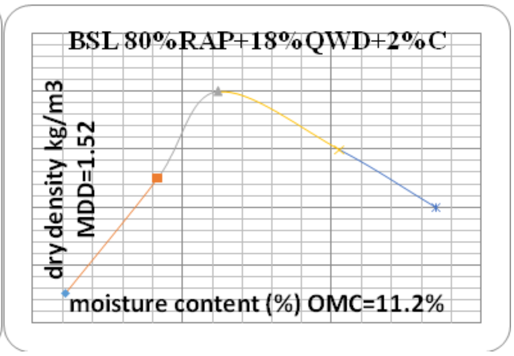
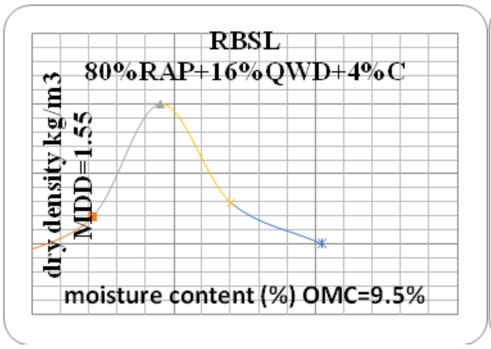
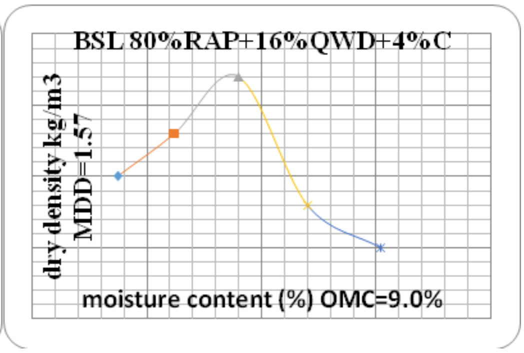
dry density kg/m3
MDD=1.50
moisture content (%)...


BSL 80%RAP+18%QWD+2%C
dry density kg/m3
MDD=1.52
moisture content (%) OMC=11.2%


RBSL
80%RAP+16%QWD+4%C
dry density kg/m3
MDD=1.55
moisture content (%) OMC=9.5%


BSL 80%RAP+16%QWD+4%C
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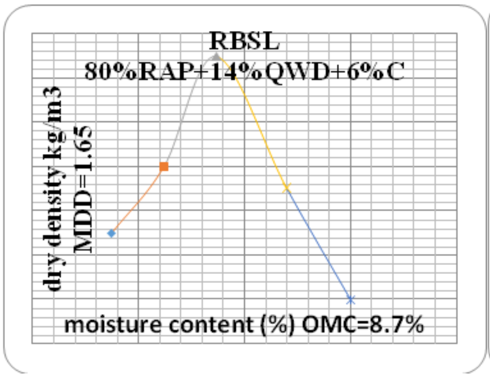
MDD=1.57
moisture content (%) OMC=9.0%



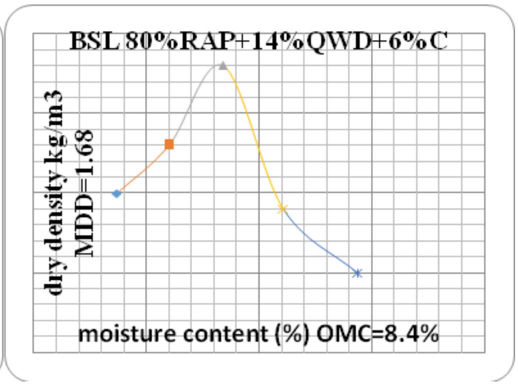


Table 10.

Resistance to loss in strength and water absorption rate of the variuos mix proportions

MIX PROPORTIONS	RBSL 7DAYS PIIW	RBSL 14DAYS UMD	BSL 7DAYS PIIW	BSL 14DAYS UMD	WATER ABSORPTION
100%RAP+0%QWD+0%C	108.6	110.3	108.7	108.8	1.01
90%RAP+10%QWD+0%C	98.4	98.9	90	97.6	1.22
90%RAP+8%QWD+2%C	98.7	99.1	87	84.2	1.23
90%RAP+6%QWD+4%C	109.2	109.8	110.1	108.4	1.07
90%RAP+4%QWD+6%C	109.5	108.9	109.7	109.3	0.99
80%RAP+20%QWD+0%C	85.2	88	90	81.98	0.95
80%RAP+18%QWD+2%C	84.13	99.43	98.8	101.2	1.24
80%RAP+16%QWD+4%C	81	83.2	84.54	86.9	0.87
80%RAP+14%QWD+6%C	82.54	87.63	90.01	91.89	0.69
70%RAP+30%QWD+0%C	87.3	83.28	89.12	82.76	1.02
70%RAP+28%QWD+2%C	85.79	86.34	84.73	81.64	1.11
70%RAP+26%QWD+4%C	83.35	91.74	86.47	84.69	1.09
70%RAP+24%QWD+6%C	96.67	92.59	80	90.55	0.89
60%RAP+40%QWD+0%C	86.4	88.04	80.34	81	0.79
60%RAP+38%QWD+2%C	84.3	84.13	84.8	80	1.00
60%RAP+36%QWD+4%C	82.97	80.35	80.78	83	1.32
60%RAP+34%QWD+6%C	97.22	96.88	95.57	100.6	1.37
50%RAP+50%QWD+0%C	82.7	87.72	80	80.89	1.43
50%RAP+48%QWD+2%C	85.3	83.29	88	90	1.23
50%RAP+46%QWD+4%C	101.24	80	93	82.3	1.06
50%RAP+44%QWD+6%C	92.67	96.8	89.47	95.8	0.90
40%RAP+60%QWD+0%C	94.99	81.1	83.1	80.4	0.69
40%RAP+58%QWD+2%C	97.39	87	90	84.7	1.00
40%RAP+56%QWD+4%C	103.9	88.87	83.23	98	1.04
40%RAP+54%QWD+6%C	89	100.99	96.64	95.32	1.08
30%RAP+70%QWD+0%C	90.3	87	82	85.43	0.89
30%RAP+68%QWD+2%C	89.4	96.54	80	82.45	0.98

30%RAP+66%QWD+4%C	101.08	101.98	90.97	88.65	1.00
30%RAP+64%QWD+6%C	99.14	99.69	108.65	111.7	1.13
20%RAP+80%QWD+0%C	103	80.29	105.04	83.9	1.15
20%RAP+78%QWD+2%C	80.9	87.65	98	90.45	0.93
20%RAP+76%QWD+4%C	88.21	81.21	89.93	81.26	1.16
20%RAP+74%QWD+6%C	93	94.32	81.46	80.02	1.09
10%RAP+90%QWD+0%C	80	80.34	87.4	84.21	1.03
10%RAP+88%QWD+2%C	86.54	80.17	89	84.23	0.98
10%RAP+86%QWD+4%C	80.01	81.16	90.02	93.01	1.11
10%RAP+84%QWD+6%C	80.2	80.34	80.34	82.06	1.10
0%RAP+100%QWD+0%C	62.41	79.84	76.94	79.5	1.31
0%RAP+98%QWD+2%C	78.9	70.11	74.7	76.54	1.37
0%RAP+96%QWD+4%C	70	73.61	68.23	63.65	1.28
0%RAP+94%QWD+6%C	72	74	67.9	79	1.30

NEAR EAST UNIVERSITY YAKIN DOĞU ÜNİVERSİTESİ

<u>ETHICS LETTER</u>

TO GRADUATE SCHOOL OF APPLIED SCIENCES

REFERENCE: SAMUEL ADAKOLE OKPE (20205032)

I would like to inform you that the above candidate is one of our postgraduate students in the Civil Engineering department he is taking a thesis under my supervision and the thesis entailed: **THE USE OF ARTIFICIAL INTELLIGENCE IN PREDICTING THE STRENGTH CHARACTERISTICS OF QUARRY WASTE DUST STABILIZED RECLAIMED ASPHALT PAVEMENT**. The data used in his study was our data obtained from expermental work.

Please do not hesitate to contact me if you have any further queries or questions.

Thank you very much indeed.

Best Regards,

Assoc. Prof. Dr. Shaban Ismael Albrka Ali

Student's Supervisor & Head of Transportation Unit
Civil Engineering Department,
Faculty of Civil and Environmental Engineering,
Near East Boulevard, ZIP: 99138
Nicosia / TRNC, North Cyprus,
Mersin 10 – Turkey.
Email: shabanismael.albrka@neu.edu.tr

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