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THE EFFECT OF MOISTURE CONTENT ON PAVEMENT FAILURE ALONG LAGOS – IBADAN EXPRESSWAY

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ABSTRACT

Highway pavement failure in Nigeria has increased in the past decades despite the huge amounts of money appropriated annually for rehabilitation. Apart from losses due to fatalities and disruptions to normal daily activities, annual loss to structural deficiency, functional obsolescence and operating cost is about ₦133 billion. One of the causes is associated with inadequate moisture in pavement materials. This study aimed at examining the effect of moisture on other geotechnical parameters as the factor of pavement failure along Lagos–Ibadan Expressway. Samples were collected at the failed and stable portions on some selected road segments and subjected to laboratory tests including Natural Moisture Content (NMC), Linear Shrinkage (LS), particle size distribution and California Bearing Ratio (CBR). Pavement Distress Score (PDS) was also determined on these road segments. Data generated were subjected to statistical analyses and Models for predicting road pavement performance were also developed. The NMC along the failed sections was on the high side (ranged from 13.11% to 26.89%) compared with the stable sections (ranged from 11.11% to 16.40%). The maximum dry density(MDD) for the samples at failed and stable sections ranged from 1550 kg/m3 to 1860 kg/m3; 1650 kg/m^3 to 1980 kg/m3 respectively while the Optimum Moisture Content(OMC) ranged from 8.30% to 20.30%. The soaked CBR values ranged from 2% to 17% while the unsoaked values ranged from 4% to 25%. The increase in NMC along the failed portions could be as a result of high water table along these sections. PI, CBR and NMC were found to have correlation with PDS. The model developed showed that $PDS = 23.627 + 1.173\text{P} + 2.102\text{CBR} - 1.137\text{NMC}$ with a coefficient of determination, R^2 of (0.956). The study revealed that PI, CBR and NMC parameters was found to be statistically significant (that is $p < 0.05$) at 95% confidence level.

Keywords: *Highway, Pavement failure, Moisture content, Pavement Distress Score, Models*

INTRODUCTION

A good road pavement is an essential element of the national infrastructure and it is constructed to provide the road users a safe, comfortable and robust ride throughout their service life. The structural elements comprises of sub-grade, sub-base, base course and surfacing are designed such that the traffic loads receive are transmitted through these layers to the sub-grade (Ogundipe, 2008). A good road pavement is expected to be in continuous stretch of asphalt but when there is a lack of continuity which results in cracks, potholes, bulges and depression,pavement is said to have been failed (Fuchtbauer, 2005). Pavement failure is a common phenomenon in most parts of the tropics and Nigerian roads are not exempted(Plate 1)
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Plate 1: Typical Pavement failure along Lagos – Ibadan Expressway

One of the major problems associated with it is attributed to moisture accumulating excessively in the pavement layers (Rokade *et al.,* 2012; Arika *et al,* 2009) which eventually can lead to modulus reduction and loss of strength.The consequence of excessive moisture in the pavement is detrimental due to pore pressure, hydraulic scour, detachment and displacement. It accelerate the pumping, stripping of asphalt, rutting, shrinkage cracking, reactive aggregate distress, fatigue cracking, and increased roughness (Halil *et al.,* 2013; Cheng *et al.,* 2002 and Birgisson *et al.,* 2005).

Over time, huge amount of fund has been spenton road rehabilitation in Nigeria to solve the problem of road failure (Michael *et al.,* 2008).In 2006, roads along Akwa Ibom/Calabar in Nigeria with total length of 2500 km were rehabilitated with a total sum of ₦2 billion (Aigbedion, 2007).In the context of this episode, the Federal Ministry of Works and Housing stated that the annual loss due to road failure was ₦80 billion while the vehicle operating cost resulted from this problem was ₦53.8 billion leaving the gross sum per annum loss as ₦133.8 billion (The Nigerian Tribune, 9th of May, 2007).

According to Arora, 2008, the main source of water in the pavements is atmospheric precipitation which provides surface water in form of rain, snow, hail, condensing mist and dew. This water enters the pavement by infiltrating through cracks in the pavement surface, shoulders, side ditches and through other defects in the surface (Rokade *et al.,* 2012; Arora, 2008) and its proximity to the water table.

Robert (1995) established that, the rate of pavement distress increases when there is internal moisture than when there is none. But if pavement is well drained internally, it can live longer than the poorly drained one by a factor of at least three or four (Cadergren, 1989) thereby reduces pavement distress. Distress on the pavement reduces the quality of roads, and makes transportation difficult (Mohammed and Dahunsi, 2012).

One of the ways to establish the state of pavement in terms of distress and ride quality is indexed by pavement distress condition and it measures both functional and structural states of the pavement in terms of physical distress and surface roughness or ride quality by examining whether the condition is above or below predefined minimum acceptance levels and warning levels (Oguara and Iriakuma, 1987). The score ranges between 0% and 100% for the pavement with very poor condition and one without any distress respectively (Figure 1). Generally, Pavement Distress Score (PDS) is defined by Oguara, 2006 as

$$PDS = 100 - \sum_{i=1}^{n} ix \quad \text{............................} \quad (1)$$

PDS is in (%)
Where,
$\sum ix$ is the Total distress deduct points
i= Type of pavement distress noticed on highway
n =Number of distress manifestations considered
x = Distress deduct point
The PDS value obtained after the investigation gives details about the state of road. The values ranged between 0 and 40%, 40 and 80%, and 80 and 100%correspond to reconstruction, overlay and maintenance respectively (Oguara, 2006) (Figure 1).

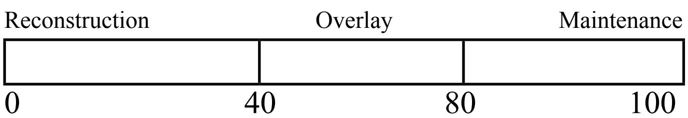

Figure 1: Condition rating as a general indicator of type of maintenance (Oguara, 2006).

THE STUDY AREA

Lagos – Ibadan Expressway was constructed in 1978 and has a total length of 134 km. It lies between longitudes 07.46813°N and 07.4596°N and latitudes 003.91287°E and 003.76509°E (Figure 1) and is located within the sub-equatorial climatic belt with tropical rain-forest vegetation. The mean annual temperature ranges between 24^{0}C-27^{0}C (Adeleke *et al.,* 1978) while the annual rainfall range between 1000 – 1400 mm with relative humidity between 60 – 80%.

The existing road is dual carriageway, comprising 7.3 m paved portion and 0.8 -1.20 m shoulders on both sides. The base course and surfacing at inception was 150 mm crushed stone and 50 mm asphalt concrete wearing course respectively. Overtime, the additional overlays of asphalt concrete has increased the surface thickness to more than 300 mm, and the median has the width ranged between 2.7 m and 11.0 m.

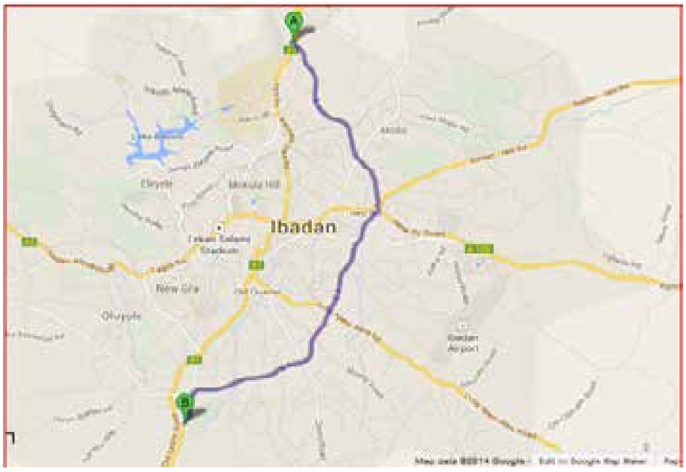

Figure 1: Route Location Map (Ojoo – Toll- gate Ibadan on Lagos – Ibadan Expressway)
Source: Google map

MATERIALS AND METHODS

Soil samples were collected at sixteen (16) selected locations both at failed (8)and stable (8) sectionsfor sub-soil investigationalong the shoulders of the highway at a depth ranged between 0.8 m and 1.7 m based on subgrade formation of the road (Table 1). Tests such as Moisture Content, Atterberg Limits, Particle size distribution, Plasticity Index (PI), Linear Shrinkage (LS), California Bearing Ratio (CBR) tests and soil classification were conducted in accordance with British Standard 1377: 1990.

Pavement failure was measured in terms of Pavement Distress Score (PDS) as recommended by Asphalt Institute, 1977 and Oguara, 1987 to evaluate the pavement condition in terms of distress and ride quality, and data generated were subjected to statistical analyses.

The regression analyses were carried out at 95% confidence limits (5% level of significance) and correlation between dependent and independent variables were determined to further establish the relationship between them.

PDS was chosen as the response (dependent) variable while Plasticity Index (PI), Linear Shrinkage (LS), Percentage passing (fine content) (PP), California Bearing Ratio (CBR) and Natural Moisture Content (NMC) were chosen as predictors (independent) variables.

Table 1: Sample Locations

S/N	Location	Side	Elevation (m)	N	E	Depth (m)	Remark
1	Ch 0 + 040	Ibadan –Lagos	234	07.46817°	003.91311°	0.8	Failed
2	Ch 0 + 120	Ibadan –Lagos	236	07.46637°	003.91438°	1.2	Stable
3	Ch 1 + 300	Lagos –Ibadan	252	07.46503°	003.91585°	1.7	Failed
4	Ch 1 + 420	Lagos –Ibadan	235	07.46398°	003.91679°	1.7	Stable
5	Ch 2 + 320	Lagos –Ibadan	208	07.45393°	003.92069°	1.7	Failed
6	Ch 2 + 500	Lagos –Ibadan	216	07.44941°	003.92100°	1.5	Stable
7	Ch 7 + 420	Lagos –Ibadan	235	07.41660°	003.94208°	1.2	Failed
8	Ch 7 + 460	Lagos –Ibadan	237	07.41004°	003.94337°	1.7	Stable
9	Ch9+900B*	Lagos –Ibadan	229	07.39750°	003.93935°	1.57	Failed
10	Ch10+040B*	Lagos –Ibadan	226	07.39266°	003.93795°	1.7	Stable
11	Ch10+060A*	Ibadan –Lagos	231	07.39671°	003.93846°	1.4	Failed
12	Ch10+120A*	Ibadan –Lagos	226	07.39314°	003.93763°	1.6	Stable
13	Ch15+610A*	Ibadan -Lagos	225	07.35025°	003.91905°	1.62	Failed
14	Ch15 +810	Ibadan –Lagos	226	07.35262°	003.91950°	1.0	Stable
15	Ch 24+360	Lagos –Ibadan	147	07.31861°	003.87270°	1.5	Failed
16	Ch 24 +400	Lagos –Ibadan	183	07.31958°	003.87295°	1.5	Stable

RESULTS AND DISCUSSION

Results of the laboratory tests carried out on the samples were summarized and presented in Table 2. The values of natural moisture content (NMC) at failed portions in all the locations were greater than the values obtained at the stable segments. The NMC values for the failed and stable segments ranged from 13.11% to 26.89% and 11.11% to 16.40% respectively (Table 2). The high values especially at the failed segments suggested that materials have appreciable percentage moisture which could be as a result of high water table in the areas and its migration to the pavement could cause the lubrication of particles, thereby made the pore pressure in the absorbed film to push the soil particles apart thus, led to reduction of the particle interlock and eventually the strength of the pavement is reduced.

The Liquid Limit (LL) values for the failed and stable segments ranged from 33% to 55% and 24% to 50% respectively while the PI ranged from 13 to 26% and 10 to 24% (Table 2) respectively. Generally, according to Federal Ministry of Works and Housing (FMWH) (1994), soils with high values of LL (LL ≥ 50%) and plastic limits (PL) are considered poor foundation materials. For the failed segments, only materials at Ch 7 + 420 and Ch 9 + 900 (LG – IB) with LL 55% and 52% respectively did not meet FMWH(1994) (LL≤ 50% for subgrade materials. The low values of PI recorded at Ch 2 + 320 and Ch 2 + 500 both at failed and stable segments (13% and 10% respectively) indicated that the fine particle sizes were replaced by larger ones.

However, the PI of the soil samples in all the locations was lower than the FMWH Specification (1994) (PI ≤30%). Hence, they show good engineering property because the lower the PI of the soil, the more competent the soil as foundation material (Akintorinwa and Adeusi, 2009).

Table 2: Engineering properties of soil samples

Location	NMC (%)	O.M.C (%)	MDD ($X10^3kg/m^3$)	Specific Gravity	CBR UnSoaked	CBR soaked (24 Hrs)	LL (%)	PI (%)	LS (%)
Ch 0+040(F)	16.03	13.5	1.86	2.552	20	12	43	22	8
Ch 0+120(S)	11.11	11.4	1.96	2.546	22	16	43	17	7.5
Ch 1+420(S)	8.82	10.1	1.95	2.600	14	12	33	18	2.8
Ch 1+300(F)	12.56	8.9	1.94	2.582	25	7	36	18	3.9
Ch 2+320(F)	17.21	8.3	1.87	2.600	22	11	33	13	4.3
Ch 2+500(S)	16.30	10.5	1.98	2.622	25	16	24	10	5.7
Ch 7+420(F)	26.89	20.3	1.55	2.483	4	2	55	25	15.3
Ch 7+460(S)	15.63	17.3	1.80	2.505	5	3	48	24	4.3
Ch10+040B*(S)	14.95	16.1	1.65	2.554	19	13	50	22	6.1
Ch 9+900B*(F)	10.27	19.3	1.65	2.488	16	12	52	26	12.8
Ch 10+120A*(S)	13.11	16.8	1.68	2.514	24	17	46	20	7.8
Ch10+060A*(F)	10.19	18.7	1.71	2.532	20	17	49	21	5.0
Ch15+810(S)	17.15	16.3	1.86	2.581	12	8	46	24	9.2
Ch15+610(F)	16.40	18.9	1.66	2.504	9	7	50	20	10.6
Ch 24+400(S)	13.83	12.8	1.90	2.551	10	7	39	13	3.9
Ch 24+360(F)	12.50	14.3	1.82	2.454	9	5	6	14	5.0

NB: A*, B* and D* in the Tables are representing IB – LG; LG – IB and Depth respectively.

According to Laskar and Pal, 2012, the plasticity of a soil depends on grain size of soil, an increase in percentage of the clay-sized fraction increases both inter molecularand liquid limit thereby increases the PI of a soil but increase in sand content would decrease the PI of soil.

The values of Linear Shrinkage (LS) at failed segments ranged from 5.7% to 15.3% while at stable segments it ranged from 4.3% to 9.2%. Materials collected at failed locations (except at Ch 1 + 300, Ch 2 + 320, Ch10 +060{IB-LG} and Ch 24+360) (Table 2) had high LS values which suggest susceptibility to shrinkage and swelling (LS > 8%, Brink et al., 1992) and could cause differential settlement when subjected to alternate dry and wet seasons of the humid tropical climatic conditions, due to an appreciable amount of clay content in the samples.

Generally, from the grading curves, the grain size ranged from 0.0086 to 0.96 mm (from medium silt to coarse sand) at the failed and stable sections except at Ch 2 + 320 and Ch 24 + 360 (failed sections) and Ch 24 + 400 (stable section) that ranged from medium silt to medium sand fractions (Figures 2 and 3).Based on recommendation of FMWH (1994) for subgrade materials (Percentage passing 0.075 mm ≤ 35%), soil samples at failed locations were described as poorly graded except at Ch 0 + 040 and Ch 1 + 300, and Ch 2 + 320 which could be rated as fairly and well graded respectively. Also, at the stable locations, soil samples were classified as fairly graded except at Ch 7 + 460 and Ch 24 +400, and Ch 2 +500 which were poorly and well graded respectively.However, the results of the tested soil samples showed that samples at failed sections contained more fines than those at the stable locations. According to Akintorinwa and Adeusi, (2009), soils that are largely made up of fine particles are likely to have poor geotechnical properties as foundation materials than those that are largely made up of coarse particles. This could explain the reason for failure along the said failed locations.

The maximum dry density (MDD) and the Optimum Moisture Content (OMC) of the samples at the failed locations ranged from 1550 kg/m^3 to 1940 kg/m3, and 8.30% to 20.30% respectively while at the stable locations, the value ranged from 1650 kg/m^3 to 1980 kg/m^3, and 10.1% to 18.70% for MDD and OMC respectively (Table 2). The low values observed in MDD at some locations are most probably due to the fact that the larger grain sizes are being replaced with the smaller grain sizes. The corresponding decrease in bulk density must have accounted for decrease in MDD. In the same way, the OMC increased with decrease in maximum grain sizes because gradual replacement of the soil particles with smaller ones resulted in an increase in effective surface area of the soil, thus more water would be required to compact it. This could also be another factor contributing to failure along the highway.According to Emesiobi, (2000), the MDD of the samples at the failed locations could be regarded to be ranged from very poor to fair while that of stable locations ranged from poor to good as a sub- grade foundation material.The unsoaked California bearing ratio (CBR) values for the samples ranged from 4% to 25% and 5% to 25% at both failed and stable locations, respectively while soaked CBR values ranged from 2 to 17% (failed locations) and 3 to 17% (stable locations). FMWH (1994) recommended that CBR (unsoaked) and (soaked) for subgrade soils should be ≥ 15% and ≥ 5% respectively. Thus materials at Ch 7 + 420, Ch 7 + 460, Ch 15 + 610, Ch 15 + 810, Ch 24 + 360 and Ch 24 + 460 did not satisfy the two conditions (Table 2). Traces of silt in the soil sample could be responsible for the low values recorded and hence, one of the contributory factors for the failure at the location.

The specific gravity of the tested samples at the failed and stable locations ranged from 2.454 to 2.600 and 2.505 to 2.622 (Table 2).According to De Graft-Johnson (1969), soils with specific gravity between 2.60 and 3.40 are classified as laterite soils. Also, Adeyemiet al., 2014, established the use of specific gravity as an important parameter in evaluation of soils as subgrade materials, most especially in determining the degree of laterization to evaluate index of laterite aggregates for pavements construction, because it correlates well with mechanical strength of soil. In all the locations the values of specific gravity averagely were below the minimum value (2.600) for the specific gravity of laterite soil except at locations Ch 1 + 420(S), Ch 2 + 320(F) and Ch 2 + 500(S) with 2.600, 2.600 and 2.622 respectively. Hence, the degree of laterisation in these locations was low sincethe higher the specific gravity, the higher the degree of laterisation (Badmus, 2010; Gidigasu, 1980).

Regression analysis carried out using statistical analysis (SPSS Release 15.0, 2006) exemplified the relationship between the PDS and properties of soil (NMC, PP, LS, CBR, and PI) were given in Table 3. The non – significant or least significant variables (LS and PP) were removed by the software since they were not considered as the key factors influencing the PDS values (Table 3).

Results of independent variables (NMC, PP, LS, CBR, and PI) correlated with dependent variable (PDS) using polynomial expression was presented in Table 5.

The correlations showed that PI, CBR and NMC gave a strong positive relationship (0.901, 0.950 and 0.999 respectively) while LS (0.645) and PP (0.632) were considered weak.

The result output showed three groups of statistics: the coefficients, the significance tests and the R- squared statistics.

Two types of R - squared observed from the output, were adjustedR2 (0.923) and coefficient of determination R2 (0.956) (Table 5)

The unstandardized coefficient of independent variables PI, CBR and NMC each of which measures the strength of its relationship with the dependent variable (PDS) were 1.173, 2.102 and -1.137 respectively (Table 6).

The linear regression determined the equation of the line that best describes this relationship and the equation generated is

$$PDS = 23.627 + 1.173\mathbf{P} + 2.102\mathrm{CBR} - 1.137\mathrm{NMC}$$

The results obtained from the analysis with independent variables, PI, CBR and NMC revealed that the model is robust and can be used to predict Pavement distress score.

The model suggests that the higher values of PDS are attributed to high values of PI and CBR and lower value of NMC which invariably show that the road is in better state.

The equation generated was used to predict values of the dependent variable from values of the independent variables (Table 3).

The predicted values of PDS were compared with the corresponding measured values and slight differences were observed in the values of these parameters.

From the model equation, the natural moisture content could be adjudged to have strong significant influence on PDS value. It has negative coefficient of regression (-1.137) and statically significant at 0.035 Moisture in the soil material can either prevent permanent deformation or cause it depending on the quantity. Adequate moisture content has positive effect on both the strength, stress and strain behaviour of the unbound granular material (Werkmeister et al., 2003) and when moisture is more, it resulted to excessive pore pressure, thereby increases the relative distance among grains. Consequently, the stiffness is reduced and permanent deformation is increased.

The CBR significantly influenced PDS value. The regression coefficient is positive (2.102), indicating that the higher the CBR value, the higher the % of PDS (that is the better the road pavement condition is), and the relationship is statistically significant at 0.005

From the model equation, the PI has strong significant influence on PDS value. The regression coefficient is positive (1.173), indicating that the higher the value of PI, the higher the % of PDS (that is the better the road pavement condition is), and the relationship is statistically significant (0. 019). A further proof of this is due to the fact that PI is a measure of the difference between LL and PL (that is an index that measures the plasticity of the soil). PL reveals the degree of material's plasticity (the presence of clay in the soil). The greater the PL value, the more clayey the soil is. An increase in PI is an indication of a decrease in PL while LL is constant. And when this condition stands, the PDS increases and it shows that the soil is in its better state because the material with low clay content is less susceptible to pavement distress.

CONCLUSION

The moisture content has great influence on the engineering properties of the pavement and is one the factors that determine the bearing capacity and service life of a pavement.

The investigation carried out along the sections of the highway revealed the followings

(i) That the model is robust and can be used to predict Pavement distress score. It suggests that the higher values of PDS are attributed to high values of PI and CBR and lower value of NMC which invariably indicate the better condition of the road.

(ii) The correlations of PI, Cbr and Nmc with PDS gave a strong positive relationship while LS and PP were too weak.

(iii) From the model equation, the natural moisture content has strong significant influence on PDS value with negative coefficient of regression (-1.137) and statically significant (0.035).

However, based on the above observation, it is therefore pertinent that adequate subsoil investigations be conducted to determine the engineering indices of the underlying materials and other engineering indices of the soils so as to have the best choice that meet the specifications for constructions.During the construction of the road pavement, materials to be used must meet the

Specifications and such materials must have good drainage properties (not be susceptible to swelling or shrinkage) to avoid failure of the pavement structure during rise in water table.

Besides, subsoil drainage system should be provided where there is rise in water table to prevent pavement from being undermined by moistures.

Table 3: Parameters for Model

PDS (%)	PI (%)	LS (%)	CBR (%)	NMC (%)	PP (%)	Cal. PDS	Residual	%Error	Abs Residual
63	22	8	12	16.03	46	62.93998	0.0600201	0.0952699	0.0600200603
51	18	3.9	7	8.82	41	50.995778	0.0042222	0.0082788	0.0042221903
39	10	4.3	11	17.21	30	39.028257	-0.028257	-0.072454	0.0282572226
27	25	15.3	2	26.89	76	27.04131	-0.04131	-0.153001	0.0413102814
60	26	12.8	12	14.95	65	60.110623	-0.110623	-0.184371	0.1106228658
67	21	5	17	13.11	57	66.99919	8.12e-005	0.0001211	8.11689e-005
34	14	5	5	13.83	61	34.07934	-0.07934	-0.0233353	0.0793399112
39	20	10.6	7	17.15	67	38.804793	0.1952069	0.5005304	0.1952068616

Table 4: Coefficients of the Model

Model	Unstandardized Coefficients		standardized Coefficients	T	Significance
(Constant)	23.627	8.324		2.838	.047
PI	1.173	.309	.428	3.801	.019
CBR	2.102	.374	.676	5.615	.005
NMC	-1.137	.363	-.397	-3.134	.035

Table 5: Polynomial Expressions for the Response and Predictors

S/N	Model	R2
1	PDS = 0.004Pi6 -0.493Pi5-22.73Pi4 -547.9Pi3 -72.79Pi2 - 504.24Pi + 14192	0.901
2	PDS = - 0.016Cbr5 + 0.712Cbr4 - 11.24Cbr3 + 79.55Cbr2 - 243.6Cbr + 275.2	0.950
3	PDS=-0.061Nmc6+6.038Nmc5-240Nmc4+4981Nmc3–56931Nmc2+33955Nmc–82449	0.999
4	PDS = 0.013Ls6 – 0.786Ls5 + 18.21.21Ls4 – 215Ls3 + 1357Ls2 - 4317Ls+ 5450	0.645
5	PDS = - 2E – 6Pp6 – 0.077Pp4 + 5.127Pp3 – 186.5Pp2 + 3541Pp - 27381	0.632

Table 6: Summary of the Model

					Change Statistics			
Model	**R**	**R²**	**Adj. R²**	**Std. Error of the Estimate**	**R² Change**	**F Change**	**df1**	**Df2**
1	.978	.956	.923	4.10158	-.025	3.919	1	3

Predictors: (Constant), CBR, NMC, PI
Dependent Variable: PDS

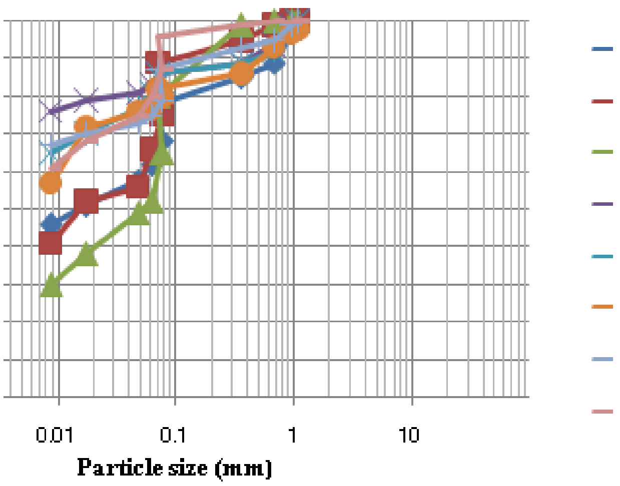

Figure 2: Particle Size Distribution (Failed sections)

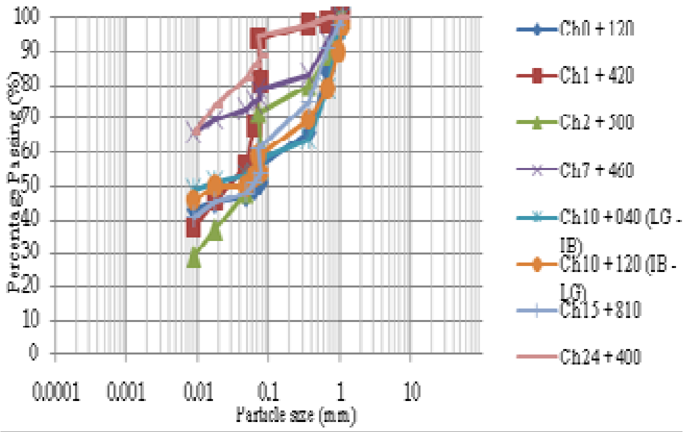

Figure 2: Particle Size Distribution (Stable sections)

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