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Original Research Article

Geotechnical Investigation of Pavement Failure: A Case Study of Sango Ota - Owode Expressway, Nigeria

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Abstract

This research work is premised on investigating the failing state of the Sango Ota- Owode expressway with design life of 20 years when it was first opened to traffic in 1974. It was reconstructed in 1993 through 2000 when it was fully opened to traffic again. However, it has become unserviceable with several deformations and deterioration all over the entire road. Eight soil samples were collected at the chosen failed sections and five soil samples at the good section for both sub-grade and sub-base, Twenty six samples all together. The soil samples were tested to determine the Atterberg limits, particle size distribution, compaction and California bearing ratio and the results were compared with the Federal Ministry of works and housing (1994) general specification. The Optimum Moisture Content (O.M.C) test result for the sub-grade and sub-base materials shows that none of the eight samples met the required criteria as their values were greater than the maximum of 7% specified. Only three samples of locations at Km 28+100 (o-s), Km 25+069 (o-s) and Km 24+000 (o-s) with values of 8%, 7% and 8% respectively, met the soaked CBR condition of at least 7%, while only two samples of locations at Km 28+100 (o-s) and Km 24+000 (o-s) with subgrade CBR values of 16% and 17%, met the unsoaked criterion. For the sub-base, only samples of location Km 25+069 (o-s) with value of 34% met the soaked CBR value of at least 30% while samples of locations at Km 28+100 (o-s) and Km 25+069 (o-s) with unsoaked CBR values of 80% and 82% respectively, which met the minimum 80% criterion for subbase. From the above undesirable results for the geotechnical investigation, reconstruction of the pavement is recommended.

Keywords: Pavement Failure, Deformation, Subgrade, Sub-base, Compaction, Unconfined Compressive Strength, California Bearing Ratio.

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INTRODUCTION

Pavements are the actual travel surface especially made durable and serviceable to withstand the traffic load commuting on it [5]. Pavements are the major facilities in road transportation; it presents a platform on which vehicles ply. The Pavement is a fixed facility subjected to impose but momentary and continuous loading. It is land based and a layered system of materials with different properties. Its principal function is to receive load from the traffic and transmit it through its layers to the subgrade [7]. Pavements are typically divided into the following three general categories: flexible, rigid and small element.

The rigid pavement is usually constructed of concrete surfacing and it acts like a beam over any irregularities in the underlying supporting materials. The concrete carries all the loads and stresses while the other layers act as support and drain. In small element pavements, the paving elements are made of concrete and produced in varying sizes of not more than one meter. They are been interlocked on leveling sand which acts as the subbase and functions as drain and support for the elements. An example of small element pavement is paving stones (interlocking bricks). In flexible pavements, the loads and stresses are been transferred from the bituminous surfacing through the other layers to the subgrade which carries the load. The subgrade soil is an integral part of pavement structures by supporting the pavement and hence, must give adequate support and stability under adverse loading condition [1]. Flexible pavements are constructed of several layers of natural granular materials covered with one or more water proofed bituminous surface layers and as the name implies, is considered to be flexible. The load distribution pattern changes from one layer to another; this in turn provides comfort and easy ride for drivers and passengers. However, a pavement is said to be defective when it can no longer perform this functions during its design life [8]. The Sango Ota-Owode pavement is a flexible pavement. A pavement designed and constructed is required to serve the purpose for which it was designed throughout its life time with no or little deterioration. That is, it should have adequate surface condition, provide the required service and be efficient in its structural and functional capacity throughout the design life. The Sango Ota-Owode Highway (Idiroko road) is a 33kM Highway which was first opened to use, after construction in December, 1974. It was later reconstructed in the year 1993 through 2000. Its design life was 20 years. The first 10kM from Sango Ota – Owode direction dualized and the others being a single carriage way from kM 11-kM 33. However, it has become unserviceable with several deformations and deterioration all over the entire road. This research is aimed at investigating the causes of incessant failure/ deterioration of Sango Ota – Owode (Idiroko road) pavement, and the specific objectives are therefore, to identify the types and extent of the pavement failure on the road; determine the geotechnical properties of the soil samples collected; Compare the geotechnical results with existing standards and proffer solution.

MATERIALS AND METHODS

Location of Study Area

The Sango Ota - Owode expressway (Idiroko road) is located in Ado-odo local government area of Ogun State, Nigeria. It is a flexible pavement structure that consists of asphaltic surface on stone base material (rolled asphalt), sub base and subgrade courses. It is a section of expressway linking Nigeria with the Republic of Benin. It is one of the Trans-Africa highways because of the transportation of goods and services (Trade) between the two countries. It is located within the geographical coordinates of longitude $6^{0}38^{1}$N and $6^{0}44^{1}$N and between latitude $3^{0}02^{1}$E and $3^{0}14^{1}$E [9].

Materials

Eight (8) designated points were chosen as critically damaged portions and five (5) other stable points chosen for the good portions for both the Subgrade and Subbase of the road. Twenty six (26) samples were collected all together for the subgrade and subbase samples. The samples were obtained at the shoulders adjacent to the chosen failed portions at depths of at least 1.5m in the subgrade and 0.7m in the subbase using an auger. The direction of traffic with respect to sample collection are designated as Sango Ota – Owode (s-o) and Owode – Sango Ota (o-s) lanes. The critically damaged points are Sango (Km 1 + 345(s-o)), Iyana Joju (kM 2 + 050 (s-o)), Oju ore (kM 28+ 100 (o-s)), Honda (kM 25+ 069(o-s)), Iyana Iyesi (Km 24 + 000 (o-s)), Igboloye (Km 19 + 300 (o-s)), Atan (kM 20 + 150 (s-o)) and Owode (Km 31 +100 (s-o)). While the stable samples were obtained at Oja Ota (Km 6+200(s-o)), Covenant (Km 10+025(s-o)), Iju (Km 12+150(s-o)), Ajibawo (Km 23+000(o-s)) and Idedo (Km 26+100(o-s)). Consistency Limits, Sieve Analysis, Compaction and California Bearing Ratio tests were carried out on the samples and then results obtained for the critically damaged portions were then compared with the good portions and extracted Specifications from the Federal Ministry of Works, (1994).

Methodology

Preliminary field investigation was done by obtaining primary data from topographic and geological maps. The visual/ field inspection of the carriageway, shoulders, and drains was carried out and detailed field investigation was done on the samples after obtaining them from the field. The soil samples were then tested in the laboratory to determine: Atterberg limits, particle size distribution, compaction and Califonia Bearing Ratio (CBR) characteristics at the National Laboratory Complex, Nigerian Building and Road Research Institute (NBRRI), Ota, Ogun State. All tests were carried out in accordance to American Society for Testing Materials [2] and British Standard Institution [4]. The soils characteristics were then compared with standards extracted from [6].

RESULTS AND DISCUSSION

Table-1: Standards extracted from the FMW& H General Specifications

PROPERTY	SUBGRADE	SUBBASE
% passing sieve No 200 (75µm) (%)	≥35	≥35
Liquid Limit (%)	≤50	≤35
Plastic Index (%)	≤30	≤12
O.M.C (%)	6 -7	6-7
M.D.D (Mg/m^3)	≥1.8	≥1.6
CBR Soaked (%)	≥7	≥30
CBR Unsoaked (%)	≥15	≥80

(**Source:** FMW & H (1994) General Specification)

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Particle Size Distribution

Figures 1 and 2, shows the Particle Size Distribution of the bad soil samples at Subgrade and Subbase respectively with percentage passing plotted against sieve sizes. Sango Ota- Owode lane is represented by (S-O), while Owode – Sango Ota lane is represented by (O-S). The results shows that the particle size distribution classified the subgrade samples for locations at Sango (Km 1 + 345(s-o)), Iyana Joju (kM 2 + 050 (s-o)), Oju ore (kM 28+ 100 (o-s)), Honda (kM 25+ 069(o-s)), Iyana Iyesi (Km 24 + 000 (o-s)), Igboloye (Km 19 + 300 (o-s)), Atan (kM 20 + 150 (s-o)) and Owode (Km 31 +100 (s-o)) as A-2-4, A-2-6, A-2-6, A-2-7, A-2-7, A-2-7, A-2-6 and A-2-7, respectively based on AASHTO soil classification scheme, and Sc, Sm, Sc, Sc, Sc, Cl, Sm and Cl, correspondingly based on the Unified Soil Classification System (USCS). The Percentage passing sieve No.200 for all subgrade samples except sample 1, collected at Km 1+345 are greater than 35%, implying that they are poor materials. The subgrade samples cannot therefore, be recommended for new repairs. As a result, they need to be completely removed and replaced with better materials for construction. Also, a strong stabilization material may be applied in the subgrade soils to improve their performance.

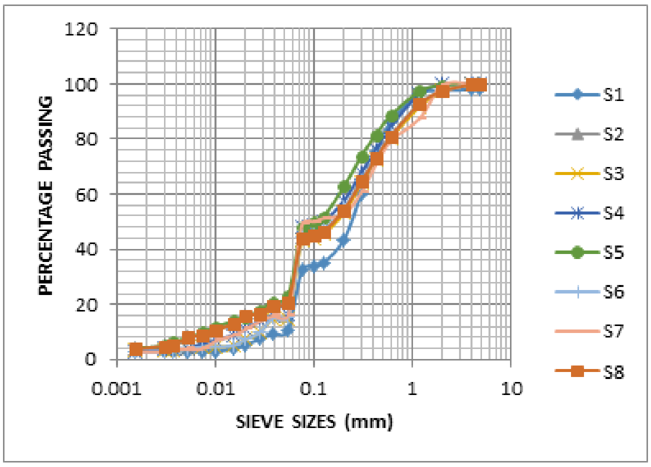

Fig-1: Graph showing the sieve analysis of the sub grade soil samples in the bad sections

Similarly, the particle size distribution results for the subbase samples for locations at Sango (Km 1 + 345(s-o)), Iyana Joju (kM 2 + 050 (s-o)), Oju ore (kM 28+ 100 (o-s)), Honda (kM 25+ 069(o-s)), Iyana Iyesi (Km 24 + 000 (o-s)), Igboloye (Km 19 + 300 (o-s)), Atan (kM 20 + 150 (s-o)) and Owode (Km 31 +100 (s-o)) are classified as A-2-6, A-2-7, A-2-7, A-7-5, A-2-7, A-2-6, A-2-7 and A-2-6, respectively based on AASHTO classification scheme and Sm, Sm, Sm, Sm, Sm, Sc, Sm and Sm, correspondingly based on the Unified Soil Classification System (USCS). The Percentage passing sieve No.200 for all subbase samples except samples 3, 4 and 7, which are 35.87%, 39.74% and 41.31%, respectively, are less than 35% specified for percentage passing sieve No. 200, implying that the samples at these locations need to be removed and replaced or stabilized with a strong additive.

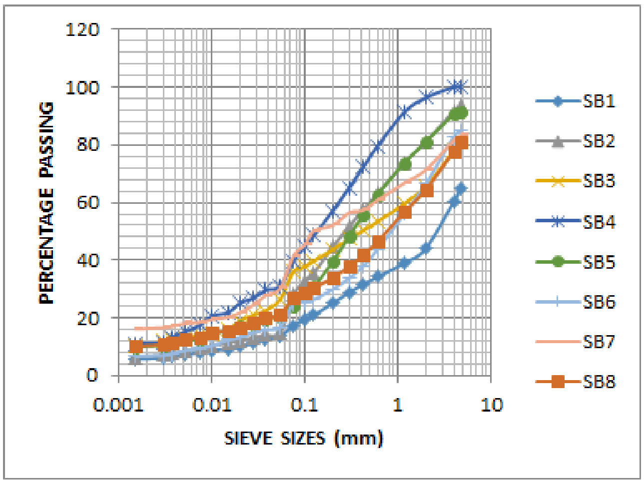

Fig-2: Graph showing the sieve analysis of the sub base soil samples in the bad sections

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The results of the soil classification at the good sections shows that subgrade soil samples at Oja ota(Km 6+200(S-O)), Covenant(Km 10+025(S-O)), Iju(Km 12+150(S-O), Ajibawo(Km 23+000(O-S)) and Idedo(Km 26+100(O-S)) are classified as A-2-4, A-2-4, A-2-6, A-2-4, A-2-6,respectively based on AASHTO soil classification scheme and Sc, Sc, Sm, Sc and Sm correspondingly based on the unifield soil classification system (USCS). The percentage passing sieve No.200 for all the subgrade are less than 35% implying that they are good materials.

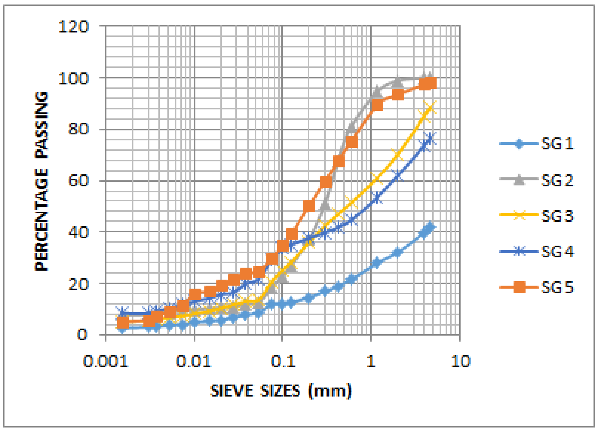

Fig-3: Graph showing the sieve analysis of the sub grade soil samples in the good sections

Similarly, the subbase soil samples are classified as A-2-7, A-2-4, A-2-4, A-2-6 and A-2-7 respectively, based on AASHTO classification scheme and Sm, Sc, Sc, Sm and Sm, correspondingly based on the unified soil classification system (USCS). The percentage passing sieve No.200 for all the subbase samples are satisfactory as none is greater than 35% passing.

In relation of the good sections to the failed sections on the pavement, it can be seen that all the samples collected from the stable section met their respective criteria and are therefore good materials. Hence, the reason for their stability.

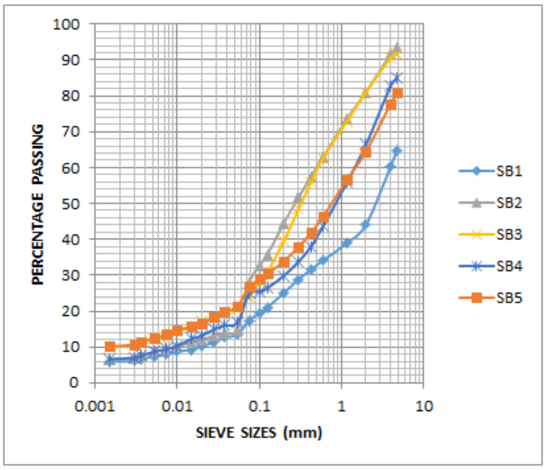

Fig-4: Graph showing the sieve analysis of the sub base soil samples in the good sections

Index and Strength Properties

Atterberg limits of samples at the failed section of the road

The results for the atterberg limits for the subgrade and subbase samples for all in the failed locations are presented in Table-2.

From the standards extracted from FMW & H specifications (Table 1.0), the Liquid limit (LL) for the subgrade material should not be greater than 50%, and hence the liquid limit for subgrade materials of locations at Km 19 + 300 and Km 31 + 100 are 55.0 and 59.6%, respectively, which are greater than 50% specified. The liquid limit obtained for other locations are less than the specified limit. However, the PI values for the subgrade materials for all the locations are less than the specified limit of 30% which met the criteria. The L.L results of subbase samples for all the locations, except location 6 (Km 19+300) exceed 35% specified, while subbase material of locations at Km 1+345, Km

24+000 and Km 31+ 100, with PI values of 10.4, 11.5 and 11.3%, respectively are less than the specified limit of 12% and they met the criteria. This implies that, in relation to liquid limit, samples at all locations except that at Km 19+300, are satisfactory, while in relation to Plastic Index, samples of locations at 1+345, Km 24+000 and Km 31+ 100 are satisfactory.

Table-2: Atterberg limits Result of Subgrade and Subbase samples at the failed sections

Locations	Subgrade			Subbase		
	LL%	PL%	PI	LL%	PL%	PI
Km 1+345 (S – O)	27.0	17.0	10.0	39.0	28.6	10.4
Km 2+050 (S - O)	40.1	25.4	14.7	58.4	40.5	17.9
Km28+100 (O – S)	35.5	21.2	14.3	42.0	27.1	14.9
Km25+069 (O – S)	46.9	29.5	17.4	60.0	36.5	23.5
Km24+000 (O – S)	43.2	26.0	17.2	41.1	29.6	11.5
Km19+300 (O – S)	55.0	35.6	19.4	3.7	21.2	15.8
Km20+150 (S – O)	35.5	22.9	12.6	42.5	28.3	14.2
Km31+100 (S – O)	59.6	39.6	20.0	35.6	24.3	11.3

Specifications: LL for Subgrade and Subbase should not be greater than 50% and 35% respectively. PI for Subgrade and Subbase should not be greater than 30% and 12% respectively
Remarks: LL at Km 19+300 and Km 31+100 for the subgrade are greater than 50% specification. The rest pass the specification while all their PI passes their specification. For the subbase, LL at only Km 19+300 pass the specification while PI at Km 1+345, Km 24+000 and Km 31+100 pass their specification.

Atterberg limits of samples at the good section of the road

The results for the atterberg limits for the subgrade and subbase samples for all locations are presented in Table-3.

All the subgrade samples at the good sections of the road met their respective LL and PI specifications of not greater than 50% and 30%. Only LL for the subbase at Km26+100 with value of 39.0% and PI at Km6+200 with the value of 12.2% did not meet their respective 35% and 12% criterion. This implies that in relation to their plastic index, all samples except for the two samples at the subbase are satisfactory and are therefore good materials.

Table-3: Atterberg limits Result of Subgrade and Subbase samples at the good sections

Locations	Subgrade			Subbase		
	LL%	PL%	PI	LL%	PL%	PI
Km 6+200 (S – O)	42.6	30.0	12.6	28.1	15.9	12.2
Km10+025 (S - O)	42.3	28.4	13.9	33.8	23.1	10.7
Km12+000 (S – O)	37.8	24.7	13.1	34.0	23.0	11.0
Km23+000 (O – S)	35.5	22.7	12.8	28.9	22.6	6.3
Km26+100 (O – S)	41.3	27.9	13.4	39.0	28.6	10.4

Specification: LL for subgrade and subbase should not be greater than 50% and 35% respectively. While, PI for the subgrade and subbase should not be greater than 30% and 12% respectively.
Remarks: All subgrade soil samples pass their respective specifications. LL for the subbase at Km 26+100 is greater than 35% and the PI at Km 6+200 is greater than 12% specification

Compaction

Table 4 show the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for the subgrade and subbase soil samples in the failed sections along the road, while Table 5 shows the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for the subgrade and subbase soil samples in the good sections along the road. The O.M.C for all the subgrade samples obtained at the failed section ranges between 14.0-21.7% and the corresponding values of their M.D.D ranges between 1.6 - 2.1 Mg/m^3. The specified range for O.M.C for subgrade is 6 - 7% while the M.D.D should be at least 1.8 Mg/m^3. The O.M.C for all locations in the subgrade did not meet met the criterion as all values are greater than 7%. The M.D.D values of locations at Km 2+050, Km 25+069, Km 24+000, and Km 31+100 are 1.7, 1.7, 1.7, and 1.6 Mg/m^3 repectively, and are less than 1.8Mg/m^3 specified. This implies that the moisture contents at all locations are inadequate, while the dry densities at the four stated locations are less than the minimum specified. Hence, the subgrade soil need be removed and replaced as they do not meet the O.M.C requirements for compaction, while in relation to

M.D.D, only samples at Km31+100 (s-o) and Km 19+300 met the requirement.

Also, the O.M.C for all the subbase samples ranges between 10.2 – 24.8% and the corresponding values of their M.D.D ranges between 1.6 -2.0 Mg/m^3. All the O.M.C values did not meet the specified criterion, while for the M.D.D values for samples at Km 2+050, Km 25+069, Km 24+000, Km 19+300 and Km 31+100, with values of 1.7, 1.8, 1.6, 1.8 and 1.6 Mg/m^3 respectively, met the criterion. In relation to the O.M.C values, samples at all locations did not meet the requirement for compaction. Hence, the materials should be removed and replaced.

Table-4: Optimum Moisture Content and Maximum Dry Density of soil samples at the failed sections of the road

Locations	Subgrade		Subbase	
	OMC %	MDD Mg/m^3	OMC %	MDD Mg/m^3
Km 1+345 (S – O)	20.4	1.9	14.0	2.0
Km 2+050 (S - O)	21.2	1.7	24.5	1.7
Km28+100 (O – S)	21.0	2.1	10.5	1.9
Km25+069 (O – S)	17.4	1.7	21.6	1.8
Km24+000 (O – S)	18.8	1.7	24.8	1.6
Km19+300 (O – S)	21.6	1.8	10.2	1.8
Km20+150 (S – O)	14.0	2.0	14.2	1.9
Km31+100 (S – O)	21.7	1.6	21.7	1.6

Specification: For Subgrade O.M.C should range between 6-7% and M.DD should be at least 1.8Mg/m^3. For subbase, O.M.C should range between 6-7% and M.DD should be at least 1.6Mg/m^3.
Remarks: None of the subgrade and subbase O.M.C met the criteria while 4 samples of the subgrade did not meet the M.D.D specification.

For the materials obtained at the good sections of the road, the O.M.C for all sub grade ranges between 6.4-8.0% and their corresponding values of their M.D.D ranges between 1.8-2.0Mg/m^3. The specified range of O.M.C for the sub grade is 6-7% and M.D.D should be at least 1.8Mg/m^3. The O.M.C for all locations except at Km 23+000 with a value of 8%, slightly higher than the range 6-7% did not meet the specification. The M.D.D values of all locations met the criterion of at least not less than 1.8Mg/m^3.

Also, for the sub base soil samples, all their O.M.C and M.D.D values met their respective values of 6-7% and at least 1.6Mg/m^3, respectively.

In comparism of the good sections to the failed sections with respect to their O.M.C values and M.D.D values, all locations met the requirement for compaction and are therefore good materials.

Table-5: Optimum Moisture Content and Maximum Dry Density of soil samples at the good sections of the road

Locations	Subgrade		Subbase	
	OMC %	MDD Mg/m^3	OMC %	MDD Mg/m^3
Km 6+200 (S – O)	6.4	1.8	6.6	1.6
Km 10+025 (S - O)	6.9	1.9	6.7	1.6
Km12+000 (S – O)	7.0	1.9	6.9	1.7
Km23+000 (O – S)	8.0	2.0	7.0	1.6
Km26+100 (O – S)	6.8	1.8	6.4	1.8

Specification: For Subgrade O.M.C should range between 6-7% and M.DD should be at least 1.8Mg/m^3. For subbase, O.M.C should range between 6-7% and M.DD should be at least 1.6Mg/m^3.
Remarks: All the subgrade and subbase O.M.C values met the specification except at Km 23+000 (O-S) while in respect to their M.D.D, all samples met the specifications.

California Bearing Ratio

The California Bearing Ratio (CBR) values for both soaked and unsoaked samples for the subgrade and subbase materials in the failed sections along the road are presented in Table-6 while the samples obtained for soaked and unsoaked subgrade and subbase in the good sections along the road are presented in table-7.

The soaked and unsoaked CBR values for the subgrade samples obtained at the failed section along the road ranges between 2 – 8% and 5 – 17%, respectively. The least subgrade CBR values specified for soaked and unsoaked samples are 7% and 15%, respectively. Samples of locations at Km 28+100 (o-s) and Km 24+000 (o-s) with unsoaked CBR values of 16% and 17%, respectively met the specification for unsoaked CBR, and samples of locations at Km 28+100, Km 25+069 and Km24+000 with soaked CBR values of 8%, 7% and 8%, respectively also met the specification for soaked CBR. All samples at other locations do not meet the specification and need be removed and replaced.

Also, the subbase soaked and unsoaked CBR values ranges between 20 – 34% and 59 – 82%, respectively. The specified values for soaked and unsoaked samples for subbase are at least 30% and 80%, respectively. Only sample of location at Km 25+069 (o-s) with soaked CBR value of 34% met the specified soaked CBR value, while samples of locations at Km 28+100 (o-s) and Km 25+069 (o-s), with unsoaked CBR values of 80% and 82%, respectively met the specified unsoaked CBR value. This implies that samples with CBR values lower than the specified do not meet the index properties of soil strength and bearing capacity. These materials are, therefore weak and should be discarded and replaced.

Table-6: Soaked and Unsoaked CBR values for Subgrade and Subbase samples obtained at the failed section along the road

Locations	Subgrade		Subbase	
	CBR Unsoaked	CBR Soaked	CBR Unsoaked	CBR Soaked
Km 1+345 (S – O)	8	6	70	24
Km 2+050 (S - O)	6	2	62	21
Km28+100 (O – S)	16	8	80	25
Km25+069 (O – S)	13	7	82	34
Km24+000 (O – S)	17	8	76	20
Km19+300 (O – S)	5	2	34	22
Km20+150 (S – O)	6	4	68	23
Km31+100 (S – O)	10	2	59	20

Specifications: For Subgrade, values of soaked samples should not be less than 7% while value of unsoaked sample should not be less than 15%. For Subbase, value of soaked sample should not be less than 30% while value of the unsoaked sample should not be less than 80%
Remarks: For Subgrade, only 2 samples each met the soaked and unsoaked criterion while for the subbase, 1 sample for the soaked and 2 samples for the unsoaked met their respective criterion

The soaked and unsoaked CBR values for the subgrade at the good section along the road ranges between 7-9% and 14-20% respectively. From the specifications, the least values for the soaked and unsoaked samples are 7% and 15% respectively. Only sample at Km 23+000 (o-s) with its unsoaked CBR value of 14% did not met the specification. However, its soaked CBR value is just at a value of 7%. This implies that they are good foundation materials.

Also, the soaked and unsoaked CBR values for the subbase ranges between 32-35% and 81-98% which all met the criteria. This implies that they are all good foundation materials.

In comparism of the subgrade and subbase samples obtained at the good sections of the road to the failed section, it can be seen that most of the materials at the failed sections do not meet the specifications for index properties of soil strength and bearing capacity.

Table-7: Soaked and Unsoaked CBR values for Subgrade and Subbase samples obtained at the good sections along the road

Locations	Subgrade		Subbase	
	CBR Unsoaked	CBR Soaked	CBR Unsoaked	CBR Soaked
Km 6+200 (S – O)	16	8	82	34
Km 10+025 (S - O)	18	8	96	34
Km12+000 (S – O)	16	8	87	36
Km23+000 (O – S)	14	7	81	32
Km26+100 (O – S)	20	9	98	35

Specifications: For Subgrade, values of soaked samples should not be less than 7% while value of unsoaked sample should not be less than 15%. For Subbase, value of soaked sample should not be less than 30% while value of the unsoaked sample should not be less than 80%
Remarks: Values of the soaked and unsoaked samples for both the subgrade and subbase are within the specification except for the CBR sample unsoaked at Km 23+000 in the subgrade, however its soaked value is just on the specification mark of not less than 7%.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Most of the geotechnical test results obtained from both the subgrade and subbase courses of the bad portion of the Sango Ota- Owode expressway shows that they did not meet their respective required standards for index properties of soil strength and bearing capacity as compared with the Federal Ministry of Works and Housing (1994) general specification and are therefore not suitable. This is as a result of ingress of water through the openings caused by heavy loading of the pavement and water logged at the road sides. Hence, the materials should be removed and replaced with suitable materials. However, the good section of the road has its subgrade and subbase course materials meet the required specifications and are therefore good materials with respect to their geotechnical test results.

RECOMMENDATION

The following are, therefore, recommended:

i. Small and localized fatigues in the failed sections should be repaired by removing the cracked pavement areas for a short term solution and to be reconstructed in the long run due to the pronounced failures on the pavement.
ii. Geotechnical properties of the constituent layers should also be given adequate attention to enable effective transmission of the load on the pavement to the subgrade without much deformation.
iii. Further investigation should be carried out on the pavement, especially on the asphaltic concrete in order to assist future designs.

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