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Original Article

Causes of pavement failure of Edunabon – Sekona road, Osun State, Nigeria

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ABSTRACT

The study investigated the Edunabon-Sekona road, Osun State, in Southwest Nigeria, to determine the causes of its failure. A condition survey of a five kilometre stretch of the road was carried out to visually assess and characterize the pavement distresses. In-situ density tests were conducted using the core cutter method at intervals of 500 m along the route. Soil samples were collected at these intervals for laboratory tests and selected engineering properties were determined, using standard procedures. Deflection at every point as well the representative rebound deflection was determined using appropriate equations. The condition survey showed widespread distresses. The average in-situ density (IDD) value was 1.55 g/cm^3, while the maximum dry density (MDD), relative density (RD) and deflection (δ) mean values were 1.94 g/cm^3, 80 % and 0.66 mm, respectively. The representative rebound deflection (δ_{rrd}) was 1.10 mm. The study concluded that the pavement failed due to the low relative density and representative rebound deflection values of the subgrade.

1. Introduction

Road transport is the predominant mode in Nigeria, for the movement of persons, goods, and provision of services. This is so as the country's economy is mainly agrarian, and the need to move food and cash crops to places of consumption is inevitable [1]. Consequently, the need to put the roads in serviceable condition cannot be overemphasized. Gupta & Gupta [2] pointed out that 15 to 40 % of vehicle operating costs can be saved, if roads are in serviceable condition. Highway failures are common features in Nigeria; its rate in recent years is unprecedented. Sadly, this had been noted even in the pre-colonial era [3]. Various forms of road deformation features characterize most major highways. The most common include, cracking, corrugation, potholes, pavement incision, routing, and rutting [3]. Chukweze [4] pointed out that occasional flooding of highways as a result of 'bath hub' on the pavement surface and failed road shoulder due to inefficient drainage capacity constitute some of the major deformation features of the highways. Onuoha *et al*. [5] characterized the road failures along Onitsha- Enugu expressway, like potholes, bulges, polish/pavement surface wash, longitudinal/block cracks, drainage collapse, depressions/sinking of roadway, over flooding of the carriageway, gullies, trenches, rutting and raveling. The nature and complex variability of residual soil, the host of road pavement foundation, particularly, in the basement complex terrain, as well as geological stuctures such as fault, fracture, and litho-contact that are unfavourable to road pavement stability have been reported by [6] as the main causes of the Edunabon- Sekona road failure. The authors [6] on the basis that most soil's geotechnical characteristics and stability performance are a function of the soil resistivity attribute the very low (<100 Ωm) resistivity of the residual soil to incompetent clayey material, with charcteristic high moisture content and porosity, and active inelastic subsoil under imposed traffic load.

The structural adequacy of a pavement is measured either by non-destructive means which measures deflection under static or dynamic loadings or by destructive tests which

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involve removing sections of the pavement and testing these in the laboratory [7]. Visual condition surveys, high speed road monitor (HSRM), deflectograph and side force coefficient routine investigation machine (SCRIM), are major types of pavement routine assessment methods [8].Visual condition surveys are subjectively based as it involves technical personnel compiling information on the condition of the pavement by visual means and determining ratings. The HSRM survey identifies specific and discrete locations where more established, more costly and time consuming methods of analysis are used. These methods do not assess the structural integrity of pavements. The deflection beam is a more widely used instrument for assessing the structural integrity of flexible pavement [9]. Radar could assist the engineer to investigate beneath the pavement surface, but cannot comprehend in the way of direct information on the structural condition of the materials [10]. In a developing country like Nigeria, deflection measuring equipment are too costly to acquire and maintain. Destructive test method could therefore be easier to adopt. Compaction is crucial in most highway embankment construction. Loose soils should be compacted to increase their unit weight and strength characteristics. Moisture content is another factor that has a strong influence on the degree of compaction achieved by a specified soil; others include soil type and compaction effort [11]. The compaction process alters ground soil voids by mechanical force means, reducing its hydraulic conductivity and settlement, and increasing shear resistance and bearing capacity. The field compaction efficiency, also known as relative density, is defined as the ratio of field and laboratory compaction performances [12]. Some of the roads defects aforementioned were observed on the section of Edunabon - Sekona road under investigation. Falade et al. [6], had noted these defects in their study, pointing out the circle of the road pavement failure, after every rehabilitation process. In probing the factors that were likely to cause these distresses, they adopted the use of combined magnetic and electrical resistivity methods, and concluded that, the recurrent pavement distresses on the study route, as caused by the clayey nature of the subsoil and the underlying geologic features. This is a qualitative narration of the road failure phenomenon, as it did not provide rehabilitation design parameters. It also does not provide basis for pavement design purposes, to develop rehabilitation strategies [7]. This study consequently looked at providing soil and pavement deflection parameters that could be used to determine pavement failure criteria.

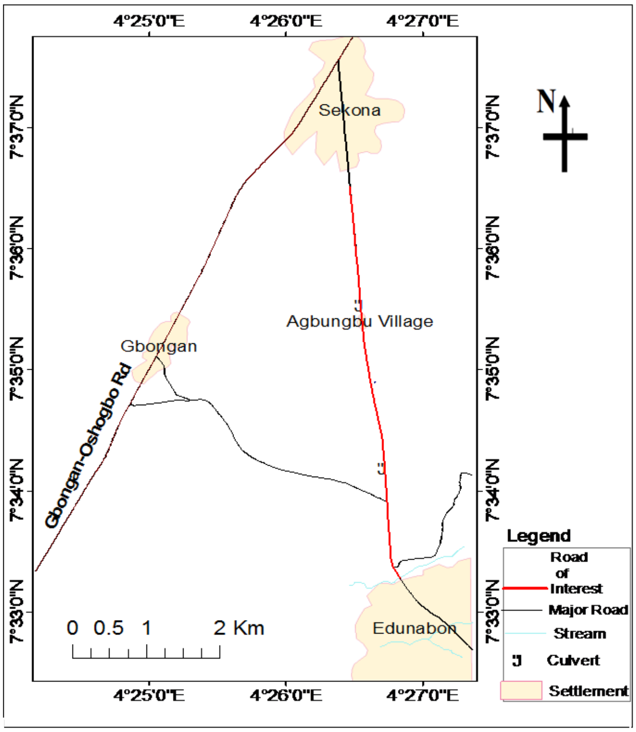
2. Methodology

2.1. Study Route

The study route is as shown on Plate 1. It is part of the larger route from Sekona to Onikoko. The section under study is from Edunabon to Sekona.

2.2. Inventory and Condition Survey

A data capturing instrument was designed for the inventory and condition survey of the route, which elicited information on the road classification and description, road design standards and maintenance conditions and route details. Others were, names of start and end communities, settlements, road ownership, types of vehicles plying the route, number of intersections and locations as well as types of drainage features on the route. The elicited information were used to comprehensively identify and understand the current status of the route.



Source: Department of Geography, Obafemi Awolowo University, Ile-Ife

Plate 1: Study Route

2.3. Geotechnical Investigation

Field (in-situ density test) and laboratory investigations (particle size distribution, atterberg limit, and compaction tests) were carried out in the course of the study, at 500 m intervals along the route using standard procedures.

2.4. Field Tests

The core cutter method was adopted for the determination of the dry density as this is usually suitable for fine grain soils where the cutter can easily be used to collect samples.

The bulk density, γ and dry density, γ_d were computed using equations 1 and 2, respectively [13].

$$\gamma = \frac{M_2 - M_1}{V} \text{ (g/cm}^3\text{)} \qquad (1)$$

$$\gamma_d = \frac{\gamma}{1+\omega} \text{ (g/cm}^3\text{)} \qquad (2)$$

Where: M_1= mass of core cutter (g)
M_2 = mass of core cutter and soil (g)
V = volume of cutter (cm^3)

2.5. Laboratory Tests

Soil samples were collected at a minimum of 500 mm below the road surface and taken to the laboratory; classification and compaction tests were carried out according to BS 1377: Part 2 and Part 4 respectively [14]. The requisite soil parameters, such as, atterberg limits, particle size distribution, natural moisture content (NMC), optimum moisture content (OMC), and maximum dry density (MDD) were determined ([15]; [11]; [16]; [12]). The relative compaction (RD) was computed using equation 3:

$$F_g = \frac{F_P}{L_P} \qquad (3)$$

where

F_g= relative compaction

F_p= field density

L_p= laboratory density (MDD)

2.6. Deflection Computations

Destructive method was adopted for the determination of the deflection values at test locations along the route. The deflection equation stated in equation 4 was developed from the Benkelman beam deflection (BBD) values for a flexible pavement [17].

The deflection at each location was computed using equation 4 as proposed by [18]; [19]; and the representative rebound deflection was computed using equations 5 and 6 [13].

$$\delta = 1.971 - 1.645RD \qquad (4)$$

$$\delta_{rrd} = \delta_{avg} + 2s \qquad (5)$$

$$s = \sqrt{\frac{\sum(\delta - \delta_{avg.})^2}{n-1}} \qquad (6)$$

where:

δ = deflection

RD = relative density.

δ_{rrd} = representative deflection for the section

δ_{avg} = average deflection for the section

s = standard deviation

n = number of points

3. Results and Discussion

3.1. Inventory and Condition Survey

The road starts at Edunabon and ends at Sekona and traverses through Agbungbu village. It is a Federal road plied by all types of vehicles. It is a flexible pavement with a carriage width of 7.5 m and a 2.75 m wide shoulder; this conforms to the Federal Ministry of Works and Housing specifications [20]. Its cross section consists, of 100 mm asphaltic concrete surfacing, 150 mm stone base and 150 mm sub base lateritic soil. There is no road furniture except for the milepost. There are widespread and varied distresses on the pavement as shown on Plate 2a-c. edge and shoulder damage, pothole, and alligator cracks respectively. Others include, rutting (Plate 3) and delineation (Plate 4) [21]; [22]. There are no intersections within the stretch of the route. The drainage structures along the route include 4 no. pipe culverts (at chainages, 1+500, 2+700, 3+650 and 5+000) and 3 no. box culverts (at chainages 0+500, 1+000 and 1+600). Most of the cultverts are in poor service conditions. The culvert at chainage 4+500 is in such a condition as shown on Plate 5, silted and over grown with weeds.

3.2. Geotechnical Investigations

The results of the geotechnical investigation on Table 1 showed that the soils consisted of silty or clayey gravel sand soils at chainages (stations) 0+000, 0+500, 1+000, 2+000, 2+500,3+000, 3+500, 4+000, 4+500 and 5+000, A-2- 6, A-2- 4, A-2-4, A-2- 6, A-2- 4, A-2- 4, A-2- 6, A-2- 4 and A-2- 4, respectively and are classified as excellent to good subgrade materials. Silty soils at chainages 1+500 and 4+500, A- 4 and A- 4, respectively and classified as fair subgrade materials [11]. This is correlated by the group index (GI) results (Table 1).The soils are silty clay (SC) according to the unified soil classification system (USCS) [12]. These classifications are acceptable for subgrade purpose [23]. This collaborates the findings of [6], that, this soil which directly hosts the pavement foundation (subgrade) with relatively high resistivity values of (209-410 Ωm), is typical of a competent material; and noted that the road pavement structure is founded on clayey sand/lateritic top soil. The compaction test result is shown in Table 2. As can be observed from the table, the values of the natural moisture content (NMC) at all the chainages are lower than those for the optimum moisture content (OMC), which put the soils on the dry side of the compaction curve [24], with concomitant lower values of in-situ dry density, as compared to the maximum dry density (MDD) values. This is in agreement with [12] postulation that, if moisture is not adequate to create lubrication, the unit weight of the compacted soil will be relatively low. The mean MDD value of 1.94 g/cm^3 indicates that the soil is acceptable for use as a subgrade [25]. This corroborates the finding from the aforementioned geotechnical reports. The mean relative density value of 80 % (< 100 %) does not satisfy the specification for compacted subgrade soil [23]. Das [11] pointed out that to ensure adequate strength in the construction of highway embankments, loose soils must be compacted to increase their unit weight, which will in turn ensure an increase in the strength characteristics of the resulting foundation base (subgrade).

3.3. Route Deflection

The deflection and relative density graphs for the route are shown in Figure 1. It shows the relationship between the relative density and the deflections. The average deflection value for the route is 0.66 mm, while its representative rebound deflection value is 1.10 mm. Using the template in Table 3 [18], the pavement has failed. The template is based on minimum relative density (RD) of 95 % for embankment construction by [13], and 100 % relative density (RD) specification by Federal Ministry of Works and Housing, 1997 [18].

(a) Edge and Shoulder Damage

(b) Pothole

(c) Alligator Cracks

Plate 2. Failures at CH. 0+000 – 0+500

Plate 3. Rutting Btw. CH. 3+000 and CH. 3+500

Plate 4. Delineation at CH. 4+500

Plate 5. Culvert Inlet at CH. 4+500 Overgrown

Table 1: Soil Classification

CHAINA	%	%	%	LL (%)	PL (%)	PI (%)	GI	SUBGR	AASHT	USCS
0+000	55	39	23	28	17	11	0	Excellent	A-2-6	SC
0+500	77	61	28	29	22	7	0	Excellent	A-2-4	SC
1+000	88	67	21	27	20	7	0	Excellent	A-2-4	SC
1+500	81	70	49	26	21	5	2	Fair	A-4	SC
2+000	53	40	29	33	20	13	0	Excellent	A-2-6	SC
2+500	63	50	36	29	21	8	0	Excellent	A-2-4	SC
3+000	79	62	36	22	18	4	0	Excellent	A-2-4	SC
3+500	59	49	40	34	22	12	1	Good	A-2-6	SC
4+000	51	38	28	27	20	7	0	Excellent	A-2-4	SC
4+500	80	65	38	26	18	8	0	Excellent	A-4	SC
5+000	64	47	12	20	13	7	0	Excellent	A-2-4	SC

Table 2: Compaction Tests Result

Location	NMC (%)	OMC (%)	IDD (g/cm^3)	MDD (g/cm^3)	RD (%)
0+000	6	9	1.44	1.93	75
0+500	6	11	1.56	1.92	81
1+000	4	8	1.51	1.95	77
1+500	6	13	1.79	1.88	95
2+000	7	11	1.03	1.97	52
2+500	7	12	1.73	1.94	89
3+000	3	11	1.79	1.94	92
3+500	10	13	1.21	1.9	64
4+000	7	11	1.53	1.98	77
4+500	5	9	1.86	1.97	94
5+000	3	9	1.57	1.94	81
Mean	6	10	1.55	1.94	80

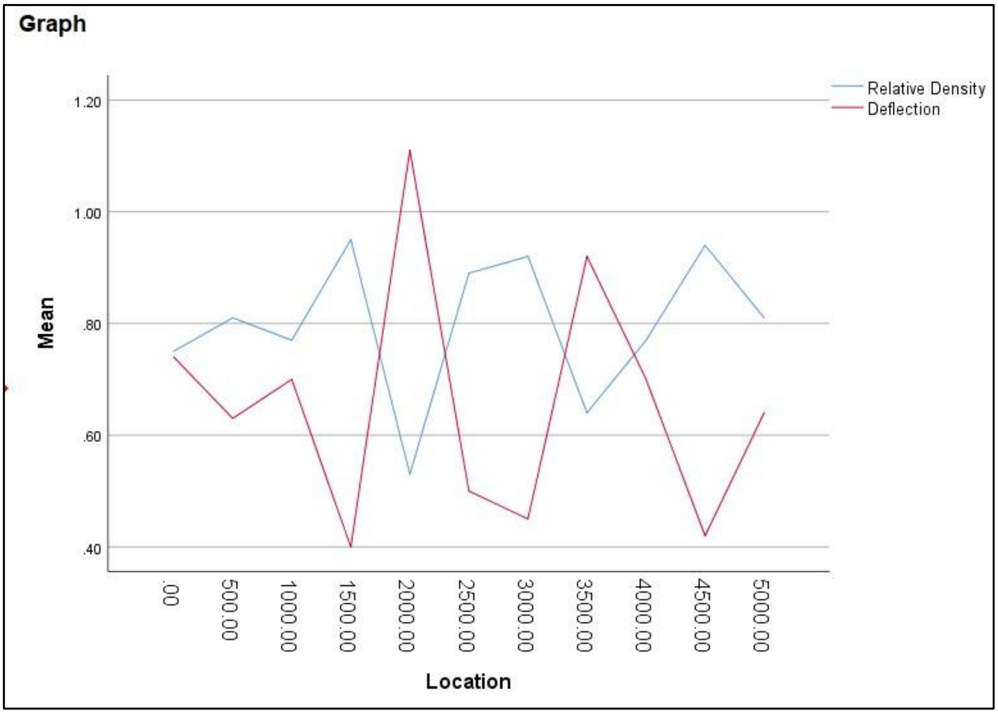


Fig 1. Relative Densities and Deflections of Route

Table 3: Pavement Deflection Template

Representative Rebound (δ_{rrd})	Pavement Condition
δrrd ≤ 0.56mm	Good
0.56mm ≤ δrrd ≤ 0.64mm	Fair
δrrd > 0.64mm	Poor

Source: [17]

4. Conclusion

The study showed that the widths of the carriageway and shoulder meet the standard required by the Federal Ministry of Works and Housing (FMWH). There are no road signs and markings. The pavement surface distresses are varied and widespread. The drainage structures are in a poor level of service. The geotechnical properties of the subgrade soils are suitable for highway construction. However, its compacted property which could be related to the bulk low subsoil resistivity as observed by Falade et al. [6] does not meet the requirement of the FMWH. The pavement has deflected irrecoverably. The study concluded that the pavement failed due to the low relative density and representative rebound deflection values of the subgrade.

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Conflict of Interest

I declare that there is no conflict of interest

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