# An Investigation of Highway Structural Pavement Failures (A Case Study of Dayi-Kano Road, Nigeria)

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**Abstract:** This research aims to determine the causes of the structural pavement failures of the failed sections of Dayi-Kano Road-Nigeria with a view of providing good remediation effect. Visual condition survey was carried out to assess the types and degree of distresses on the road. Laboratory tests of Sieve Analysis, Atterberg limits, California Bearing Ratio, and Compaction were carried out to assess the particle size, water content, strength of the flexible pavement component materials. Traffic Volume Count, proportion of commercial vehicles, Maximum Dry Density, and Optimum Moisture Content were all determined. The visual condition survey shows that alligator crack was 65%, depression was 75%, reveling was 30%, edge deterioration was 44% and the distress severity was classified as slight, moderate and severe. This shows that this section of the road was in a bad condition. Hence; the chainages used were 16+00-16+25 to 16+75-16+100. For Sieve Analysis test, the Road-Base average values of Gravel, Sands and Fines were 31.16%, 46.75% and 22.08% respectively. For the Sub-Base, the average values of Gravels, Sands and Fines were 26.50%, 61.43% and 12.07% respectively. While for the Sub-Grade, the average values of Gravels, Sands and Fines were 32.16%, 53.94% and 13.90% respectively. This implies that the particle size distribution of the samples tested were mainly of sands with less amount of gravels. The Atterberg Limits and California Bearing Ratio tests were carried out in the laboratory and the results were shown below: for the Road-Base, the average values of the liquid limit and plasticity index were 39.63% and 28.80% respectively. For the Sub-Base, the average values of the liquid limit and the plasticity index were 38.63% and 28.30% respectively. For the Sub-Grade, the average values of the liquid limit and the plasticity index were 36.23% and 26.57% respectively. For California Bearing Ratio test, the average values of the Road-Base, Sub-Base and the Sub-Grade were 27.76%, 16.11%, and 32.03% respectively. Therefore, for materials to be suitable for Road-Base and Sub-Base courses, it must have liquid limit and plasticity index values not greater than 35% and 12% respectively, and California Bearing Ratio must not be less than 30% (24hrs soaking). For Sub-Grade, the liquid limit and plasticity index values not greater than 50% and 30% respectively, and California Bearing Ratio value of at least 6% (24hrs soaking). Since, Road-Base and Sub-Base were found not satisfying the above specifications, but, Sub-Grade was found to have satisfied the specifications, then the Road-Base and the Sub-Base were the major causes of pavement failures of Dayi-Kano Road. Considering the proportion of the commercial vehicles (5.04%) which was a small proportion, the flexible pavement failures of the road were not caused by the Traffic Volume. For the Compaction test, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) values for Road-Base, Sub-Base and Sub-Grade were found satisfied. This research article can be concluded that, the condition and the materials used for Road-Base and the Sub-Base construction works were parts of the major causes of the failures of the Road (Dayi-Kano Road). It should be noted that, recommendations such: suitable materials should be used for pavement construction, quality control test should be properly carried out , drainage should be properly constructed and maintained after the construction ,and, effective supervision mechanism should be adopted by the Federal and the State Government.

**Key-Words:** Pavement, Structural, Failures, Highway, Road-Base, Sub-Base, Sub-Grade, Compaction, Fatigue.

# 1. Introduction

The causes of pavement failures are numerous. According to a research, (Sani, 2001), distresses developed through a number of mechanism. These include level of stress and strain within the pavement layers which are functions of the stiffness and layer. According to a research, (Hassan, 2006), pavement failures can occur as a result of inadequate design, excessive loading, weathering and climatic condition, and, poor quality construction materials and supervision. The failure of any one or more components of the pavement structure develops the waves and corrugations on the pavement surface or longitudinal ruts and shoving. Highway pavements can be classified into flexible and rigid pavements (Khanna and Justo, 1997).One of the prime causes of flexible pavement failure is excessive deformation in sub-grade soil. This can be noticed in the form of excessive undulations or waves and corrugation in the pavement surface and also depressions followed by heaving of pavement surface (Ajayi, 1987). On the Dayi-Kano Road, the road is a flexible pavement, there were evidence of great distress of varying degrees all along its length. Due to the bad condition of the road, there is high degree of cracks which leads to high rate of accidents on regular basis and has led to loss of so many lives and other properties.

A pavement is referred to as that portion of the roadway, which bears directly the traffic (wheels) loads (Chukwuma, 1992). The pavement carries the wheel loads and transfers the load stress through a wider area on the soil sub-grade. A pavement layer is considered more effective or superior, if it is to distribute the wheel load stress through a larger area per unit depth of the layer (Khanna and Justo, 1997). Dayi – Kano road was constructed in 1975 with life span of 20 years and 134km length. It is necessary that all issues connected to this road, shall be given attention considering the role it plays in the socio-economic development of Kano, Katsina States and the entire Nation. This attempt to investigate the causes of the failures and to suggest possible solution towards rehabilitating this road and to minimize its frequent failures will immensely contribute to the socio-economic development of the Nation as a whole.

This research will also contribute to the academic development, as it will serve as a reference material to similar research or academic works. The research involves the field and laboratory investigations. Hence, the data collected were analyzed and compared with the standard code of practice, so that the causes of the failures can be identified and their solutions can be provided.

# 2. Methods

## 2.1 Visual Condition Survey

The visual condition of the road was surveyed to determine the extent and types of failure at different sections of the road.

## 2.2 Determination of Particle Size Distribution (Sieve Analysis Test)

The determination of particle size distribution was done by the Wet Sieving Method (WSM) in accordance with **BS1377:1990.**

### 2.3 Atterberg Limits Test

The method used in the laboratory was Casangrade Method, BS1377:1990.

**2.3.1 Procedure:** The moisture content (MC) was obtained as equation one below;

$$MC = \frac{\text{mass of wet soil – mass of dry soil}}{\text{mass of dry soil}} x\ 100$$

### 2.4 Bearing Ratio Test (CBR Test)

The procedure for unsoaked CBR test in accordance with the **BS1377:1990** was adopted for the Road-Base samples. Similarly, the procedure for soaked CBR test in accordance with the **BS1377:1990** was adopted for both Sub-Base and Sub-Grade samples.

### 2.5 Traffic Volume Count (Data Collection)

The data were collected along the road on each direction of travel (Dayi-Kano Road, and Kano-Dayi Road) chosen for the study for period of twelve hours (7am-7pm) per day for four days in accordance with Oversea Road Note (TRRL, 2004).

### 2.6 Compaction Test

This test covers the determination of the MDD/OMC relationship using 2.5kg Rammer Method (Standard Method). The compaction test was carried out in accordance with the **BS1377:1990.**



## 3. Results

Table 3.1 Visual Condition Survey:

| Severity | Alligator crack | Depression Extent | Reveling Extent | Edge Deterioration Extent |
|---|---|---|---|---|
| | Area($m^2$) % | Area($m^2$) % | Area($m^2$) % | Length (%) T |
| Slight | 1-10 45.00 | 1-10 50.25 | 1-10 30.00 | 1-10 13.00 |
| Moderate | 11-25 20.00 | 11-25 22 .75 | - - | 11-25 25.20 |
| Severe | - - | - - | - - | 26-50 05.75 |
| Total | 65.00 | 73.00 | - 30.00 | 44.00 |

From table 3.1, the section of the road was in bad condition at the time of visual condition survey.

Table 3.2 Percentage Composition of the Minerals:

| Sample | Coarse Gravel | Medium Gravel | Fine Gravel | Coarse Sand | Medium Sand | Fine Sand | Fines |
|---|---|---|---|---|---|---|---|
| **Base** | **Base** | **Base** | **Base** | **Base** | **Base** | **Base** | **Base** |
| **TP1** | 0.00 | 5.00 | 30.00 | 29.00 | 15.50 | 1.90 | 18.60 |
| **TP2** | 0.00 | 4.50 | 28.00 | 29.00 | 16.00 | 1.95 | 20.55 |
| **TP3** | 0.00 | 3.50 | 22.50 | 30.00 | 15.00 | 1.90 | 27.10 |
| **Sub-Base** | **Sub-Base** | **Sub-Base** | **Sub-Base** | **Sub-Base** | **Sub-Base** | **Sub-Base** | **Sub-Base** |
| **TP1** | 0.00 | 5.00 | 20.00 | 25.00 | 35.00 | 3.99 | 11.01 |
| **TP2** | 0.00 | 5.00 | 21.59 | 20.00 | 30.00 | 8.22 | 15.28 |
| **TP3** | 0.00 | 8.00 | 20.00 | 27.00 | 25.00 | 10.07 | 9.93 |
| **Sub-Grade** | **Sub-Grade** | **Sub-Grade** | **Sub-Grade** | **Sub-Grade** | **Sub-Grade** | **Sub-Grade** | **Sub-Grade** |
| **TP1** | 0.00 | 10.00 | 25.00 | 1 | 1.90 | 4.11 | 9.89 |
| **TP2** | 0.00 | 4.00 | 20.50 | 27.00 | 20.00 | 8.94 | 19.59 |
| **TP3** | 0.00 | 17.00 | 20.00 | 25.00 | 20.00 | 5.76 | 12.24 |

From table 3.2, the Road-Base average values of Gravel, Sands and Fines were 31.16%, 46.75% and 22.08% respectively. For the Sub-Base, the average values of Gravels, Sands and Fines were 26.50%, 61.43% and 12.07% respectively. For the Sub-Grade, the average values of Gravels, Sands and Fines were 32.16%, 53.94% and 13.90% respectively.

Table 3.3: California Bearing Ratio Test

| Sample | Parameters |
|---|---|
| **Road-Base** | **CBR (%)** |
| **TP1** | 32.36 |
| **TP2** | 34.91 |
| **TP3** | 21.89 |
| **Sub-Base** | **CBR (%)** |
| **TP1** | 14.77 |
| **TP2** | 17.45 |
| **TP3** | 16.11 |
| **Sub-Grade** | **CBR (%)** |

| | |
|---|---|
| **TP1** | 24.17 |
| **TP2** | 37.06 |
| **TP3** | 33.43 |

From Table 3.3, the average values of the Road-Base, Sub-Base and the Sub-Grade were 27.76%, 16.11%, and 32.03% respectively.

Table 3.4 Atterberg Limits Test:

| **Sample** | **Trial Pit(TP)** | **Trial Pit(TP)** | **Trial Pit(TP)** | **Average** |
|---|---|---|---|---|
| **Road-Base** | **TP1** | **TP2** | **TP3** | **AVR** |
| **LL (%)** | 33.90 | 41.40 | 43.60 | 39.63 |
| **PL (%)** | 10.50 | 8.50 | 13.50 | 10.83 |
| **PI (%)** | 23.40 | 32.90 | 30.10 | 28.80 |
| **SL (%)** | 9.27 | 10.00 | 8.57 | 9.28 |
| **Sub-Base** | **TP1** | **TP2** | **TP3** | **AVR** |
| **LL (%)** | 33.90 | 37.70 | 44.30 | 38.63 |
| **PL (%)** | 10.50 | 13.00 | 8.50 | 10.67 |
| **PI (%)** | 23.40 | 24.70 | 35.80 | 28.30 |
| **SL (%)** | 0.00 | 7.14 | 5.43 | 4.52 |
| **Sub-Grade** | **TP1** | **TP2** | **TP3** | **AVR** |
| **LL (%)** | 23.30 | 39.80 | 45.60 | 36.23 |
| **PL (%)** | 17.00 | 5.00 | 7.00 | 9.67 |
| **PI (%)** | 6.30 | 34.80 | 38.60 | 26.57 |
| **SL (%)** | 5.71 | 5.00 | 6.43 | 5.71 |



From Table 3.4, for the Road-Base, the average values of the liquid limit and plasticity index were 39.63% and 28.80% respectively. For the Sub-Base, the average values of the liquid limit and the plasticity index were 38.63% and 28.30% respectively. For the Sub-Grade, the average values of the liquid limit and the plasticity index were 36.23% and 26.57% respectively.

Table 3.5 Traffic Volume Count for Dayi Kano Road:

| | **Traffic Direction** | |
|---|---|---|
| | **Dayi to Kano** | **Kano to Dayi** |

| Day | Light Vehicles | Commercial Vehicles | Daily Traffic | Light Vehicles | Commercial Vehicles | Daily Traffic |
|---|---|---|---|---|---|---|
| **Tuesday** | 11,429 | 679 | 12,108 | 11,688 | 605 | 12,293 |
| **Wednesday** | 11,347 | 682 | 12,029 | 11,430 | 637 | 12,067 |
| **Thursday** | 11,594 | 586 | 12,180 | 11,691 | 666 | 12,357 |
| **Saturday** | 10,460 | 434 | 10,894 | 10,570 | 490 | 11,060 |

**SOURCE: Jibril, H.B. (2012).**

Table 3.6 Directional ADT, Number and Proportion of Commercial Vehicles for Dayi-Kano and Kano-Dayi Roads:

| Traffic Direction | ADT | Number of Commercial Vehicles | Proportion of Commercial Vehicles |
|---|---|---|---|
| **Dayi-Kano** | 11,803 | 595 | 5.04 |
| **Kano-Dayi** | 11,944 | 600 | 5.02 |

From Tables 3.5 and 3.6, considering the proportion of the commercial vehicles (5.04%) which was a small proportion, the flexible pavement failures of the road were not caused by the Traffic Volume.



## 4. DISCUSSION

The results obtained from table 3.2 shows that the particle size distribution of the samples tested were mainly of sands with fewer amounts of gravels. From the California Bearing Ratio test, the materials used for the pavement layers were below the required specifications, because, according to the Federal Ministry of Works and Housing of Nigeria clause 6201, for materials to be suitable for Road-Base and Sub-Base courses, it must have liquid limit and plasticity index values not greater than 35% and 12% respectively, and California Bearing Ratio must not be less than 30% (24hrs soaking). For Sub-Grade, the liquid limit and plasticity index values not greater than 50% and 30% respectively, and California Bearing Ratio value of at least 6% (24hrs soaking). Since, Road-Base and Sub-Base were found not satisfying the above specifications, but, Sub-Grade was found to have satisfied the specifications. Then, the Road-Base and the Sub-Base were the major causes of pavement failures of Dayi-Kano Road.

Furthermore, considering the proportion of the commercial vehicles (5.04%) which was a small proportion, as such the flexible pavement failures of the road were not caused by the Traffic Volume. The detail results of Sieve Analysis and Compaction tests are presented in the Appendix.

## 5. CONCLUSIONS

From the Visual Condition Survey data obtained, the road section under study has completely failed as at the time of study which was indicated in the severity percentage of various distresses.

From the CBR and Atterberg Limits tests result, this research article can be concluded that, the condition and the materials used for Road-Base and the Sub-Base construction works were parts of the major causes of the failures of the Road. As such, they should be scarified and replaced with suitable materials.

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# 8. APPENDIX

Table 8.1 Sieve Analysis Test for Road-Base, Sub-Base, and Sub-Grade:

| **Particle Distribution** | **Sieve Size(mm)** | **TP1 %passing** | **TP2 %passing** | **TP3 %passing** |
|---|---|---|---|---|
| **cobbles** | 75 | 100.00 | 100.00 | 100.00 |
| | 63 | 100.00 | 100.00 | 100.00 |
| Coarse gravel | 50.00 | 100.00 | 100.00 | 100.00 |
| | 37.00 | 100.00 | 100.00 | 100.00 |
| | 28.00 | 100.00 | 100.00 | 100.00 |
| Medium Gravel | 20.00 | 100.00 | 100.00 | 100.00 |
| | 14.00 | 97.80 | 97.70 | 94.30 |
| | 10.00 | 95.60 | 95.90 | 92.60 |
| | 6.00 | 87.40 | 89.90 | 87.50 |
| Fine Gravel | | | | |
| | 5.00 | 81.60 | 86.00 | 84.90 |
| | 3.35 | 76.20 | 79.70 | 80.30 |
| Coarse Gravel | 2.00 | 69.40 | 71.90 | 75.10 |
| | 1.18 | 64.10 | 66.50 | 70.40 |
| Medium Gravel | 0.600 | 57.70 | 60.20 | 64.60 |
| | 0.425 | 56.10 | 58.60 | 63.00 |
| | 0.300 | 49.60 | 54.60 | 57.50 |
| | 0.212 | 46.60 | 52.70 | 54.10 |
| Fine Gravel | | | | |
| | 0.150 | 44.90 | 51.60 | 51.00 |
| | 0.063 | 44.40 | 51.00 | 48.80 |
| **SILT/CLAY** passing | 0.063 | 44.40 | 51.00 | 48.80 |

Table 8.2 Compaction Test:

| **Sample** | **MDD (g/cm$^3$)** | **OMC (%)** |
|---|---|---|
| **Road-Base** | **MDD (g/cm$^3$)** | **OMC (%)** |
| **TP1** | 1.91 | 12.02 |
| **TP2** | 1.89 | 13.23 |
| **TP3** | 1.95 | 17.57 |
| **Sub-Base** | **MDD (g/cm$^3$)** | **OMC (%)** |
| **TP1** | 1.82 | 19.50 |
| **TP2** | 1.83 | 19.50 |
| **TP3** | 2.01 | 19.50 |
| **Sub-Grade** | **MDD (g/cm$^3$)** | **OMC (%)** |
| **TP1** | 1.83 | 12.38 |
| **TP2** | 1.81 | 12.63 |
| **TP3** | 1.83 | 11.63 |