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Road pavement collapse from overloaded trucks due to traffic diversion: A case study of Minna-Kateregi-Bida Road, Nigeria

Mustapha Mohammed Alhaji [a,*], Musa Alhassan [a], Taiye Waheed Adejumo [a], Hamidu Abdulkadir [b]

[a] Civil Engineering Department, Federal University of Technology, Minna, Niger State, Nigeria
[b] Department of Geology and Mining, IBB University, Lapai, Niger State, Nigeria

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ABSTRACT

Sudden failure of road pavement structure from Minna through Kataeregi to Bida in Niger State, Nigeria, occurred in 2020 due to high traffic volume of overloaded trucks. The high traffic volume was necessitated by the collapse of two alternative routes (Tegina-Makera-Mokwa and Lambata-Bida-Mokwa roads) that were previously being used by these heavy trucks. Methodology used to study the causes of this sudden failure includes interaction with the Niger State Ministry of works, visual route survey of the entire road, conduction of trial pits within the worst sections of the road and collection of soil samples for analysis and finally, generation of soil profile within these sections to show the probable causes of the sudden failure. Result of visual route survey revealed that the entire stretch of the road which geologically cut across basement complex from Minna to Kataeregi and Bida basin from Kataeregi to Bida, has failed with potholes, pavement cracks, ruts, large depressions and embankment failures. However, some sections were observed to have collapsed completely. Trial pits conducted within the collapsed sections also showed defects including thick organic soil layer underlying road embankment, clay of high plasticity underlying organic soil layer and shallow water table within the region of the basement complex. A long and high embankment across a wide river channel was observed to have failed due to the failure of the thin metal sheet tubes employed to move the heavy flood water across the embankment. It was then concluded that these defects resulted from poor geotechnical investigation prior to construction and the poor expertise of the firm involved in the construction of the road.

1. Introduction

The anticipated traffic volume used in the design of roads are usually conceived by intensive traffic counts whose results are largely affected by the other sister road networks around that region. These sister road networks assist to distribute the regional traffic so as to reduce traffic volume on each of other road structures and consequently, the axle load transferred to the subgrade of these road pavements. Any obstruction that prevents traffic flow through any of these sister roads will results in to realignment of traffic flow which will result to sudden increase in traffic volume on other sister roads and consequent failure of those roads. This sudden failures according to Sharma et al. [10], can result in to serious accidents.

Good and qualitative road network is essential for the development of the socioeconomic aspect of every country [1]. Nigeria has a

* Corresponding author at: Associate Professor of Civil Engineering, Federal University of Technology, Minna, Nigeria.
E-mail address: a.mustapha@futminna.edu.ng (M.M. Alhaji).

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total of 200,000 km road network across the country of which 32, 000 km are Federal roads, 30,000 km are state roads and 130,000 km are local government roads. Out of all these road networks, only about 39, 500 km are paved of which very large section of the paved roads are in poor condition. These road networks have been designed using specified axle load with anticipated traffic volume [3,4,5,6]. According to Federal Ministry of Works and Transportation in Nigeria, conventional methods of road design were used for the design of these roads and do not consider the design for heavy trucks as put forward by Barber and Ladd [11].

The traditional movement of heavy trucks which transfer goods and services (Agricultural goods and Petrol gas) between north and south in Nigeria, follows two major routes which are economical and faster depending on the departure point of the truck. The first route is the road from Sokoto through Funtua to Tegina down to Mokwa while the second route is that from Abuja through Lambata to Lapai down to Bida which meet the major road at Mokwa. These two routes were shorter and economical for heavy trucks moving goods and services to and from Lagos where the major Nigerian seaport is located. Most of heavy trucks travelling to Lagos and other parts of southern Nigeria ply these two routes. However, Jacob et al, [12] have confirmed that more than 94% of these trucks are always overloaded which has always reduced the life expectancy of these roads. The effect of overloaded trucks on conventionally designed roads have been analyzed by various researchers [11,13,16,15,14]) and have all reported negative response by the road sublayers.

Timely and appropriate maintenance of these roads would have help prolong the service life of the road pavements. However, the negative effect of some regulatory bodies as pointed out by [17], affected the services of The Federal Road Maintenance Agency (FERMA) in Nigeria. Extremely poor road maintenance culture exhibited by the FERMA in Nigeria which is confirmed by Ewadh et al [2] has led to the sudden collapse of some of these sister routes leading to diversion of heavy trucks to a fairer (Abuja-Minna-Bida) road as shown in Fig. 1.

This route used to be less busy with heavy trucks because it was farthest and less economical. Invariably therefore, the traffic volume of heavy trucks along Abuja-Minna-Bida road escalated tremendously causing sudden collapse of the pavement along this route. The common type of failure observed on this route is deep flow rutting which according to Said and Hakim, [9] is an excessive deformation of bitumen pavement layer in the wheel path and increases with increasing number of repeated loads. It usually originates from all the pavement sublayers including the subgrade. According to Kaloush and Witczak, [8] and Blab and Harvey, [7], flow rutting in pavement is caused by densification due to repeated axle loads and shear deformation with the formation of upheavals. The section of the route that suffered worst pavement failure is the Minna-Bida road which span a distance of about 82kM. The aim of this study therefore, is to evaluate the response of the sub pavement layers, including the subgrade, to unravel the possible causes of these flow rutting failure so as to suggest possible remedial measures that could guide the road pavement designers and road construction firms.

2. Description and geology of studied area

According to Federal Ministry of Works, Nigeria, Minna – Kateregi – Bida road was first constructed from 1986 to 1988 by Albishir Nigeria Limited. The road was designed with a service life of 20 years. Due to major pavement failures observed on many sections of the road, the entire road was rehabilitated by the Niger State Government in 2006 by Triacta Construction Company Limited. Since after this major maintenance, the road has been stable but undergoing its gradual deterioration with very little or no maintenance, until recently when the heavy trucks following the two sister routes diverted to Abuja-Minna-Bida road.

Geologically, the entire span of the 82 km road, span through two major geological origins (The basement complex from Minna to Kataeregi and the Bida basin from Kataeregi to Bida). The geology of the basement complex sections of the road have been studied by

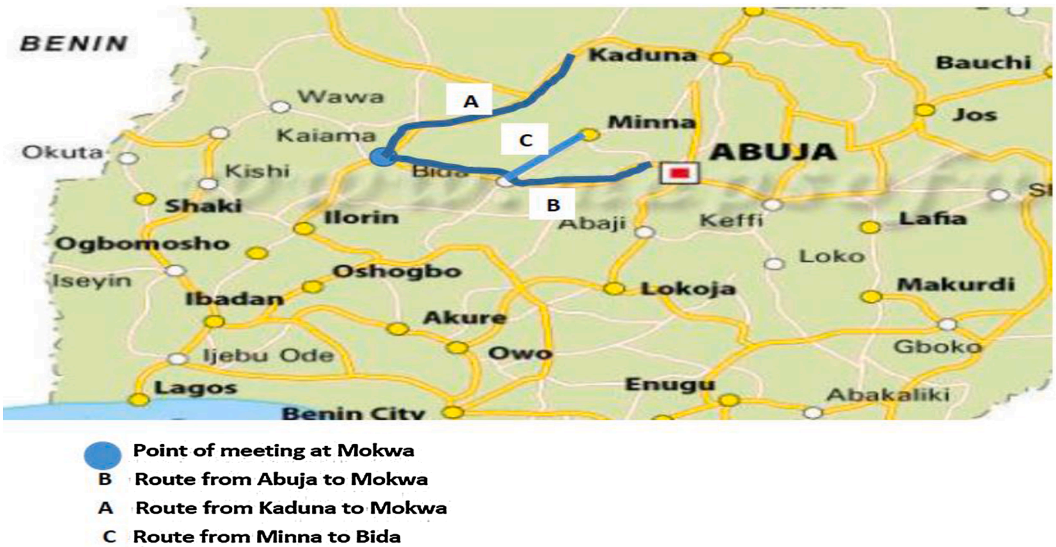

Fig. 1. Road Map Showing the Studied Routes in Nigeria.

various authors. Some of these studies involves the work of Alabi [18] and Pius et al [19], who studied the geology of granitic rocks around Minna. The author observed that eight granitic masses occur as Minna batholiths and forms a continuous ridge in north–south direction. The granitic rocks were observed to vary from medium porphyritic to coarse variety from light color to medium dark color as evident in Fig. 2. Also of interest is the work of Olose et al [20], who studied the mineralization potential of amphibolite schist at Gadaeregi along Minna – Bida road as shown in Fig. 2. Investigation by the author revealed that the area is underlain majorly by migmatite-gneiss, amphibolite-schists and granite. The Bida basin commenced after Kataeregi along Minna – Bida road which is shown in the geologic map, to consist majorly of felspathic sand stone and silt. According to Obaje et al. [22], Bida basin is an intracratonic sedimentary basin spanning from Kontagora in the north to areas slightly beyond Lokoja in the south. According to the author, the basin has average depth to bedrock of about 3.4 km. However, depth to bedrock of 4.7 km were observed in some areas. The basin was reported to have high potential for existence of hydrocarbon. The properties of clays observed in some sections of this basin indicates that they consist majorly of hydrated siliceous aluminosilicates [21]. The very low magnitude of magnesium oxide and potassium oxide revealed that the clay soils are non-expansive types of clay and the low plastic limits recorded are indications of kaolinite clay soils.

2.1. Responses of sub pavement layers observed

Study on pavement performance and responses have been carried out by Montepara et al [29], Masad et al [30], whose work centered mainly on the determination and evaluation of configurations of pavement failures. The response to flexible pavement distresses usually manifests in form of failure modes [31]. The response observed on this studied road manifested through alligator cracks on the road, complete strip off of the road surface, wide and deep depression below the subgrade layer, rupture of pavement surface in some sections and large potholes.

2.2. Method of experimentation

The method used in this study involves visual observation of the entire stretch of the 82 km road, consultation with the Federal Ministry of Works and Housing in Nigeria to deduce the complete history of the design and construction of the road and interaction with stakeholders in the road construction industries. Thereafter, the sections of the road with total collapse were studied using 2.0 m

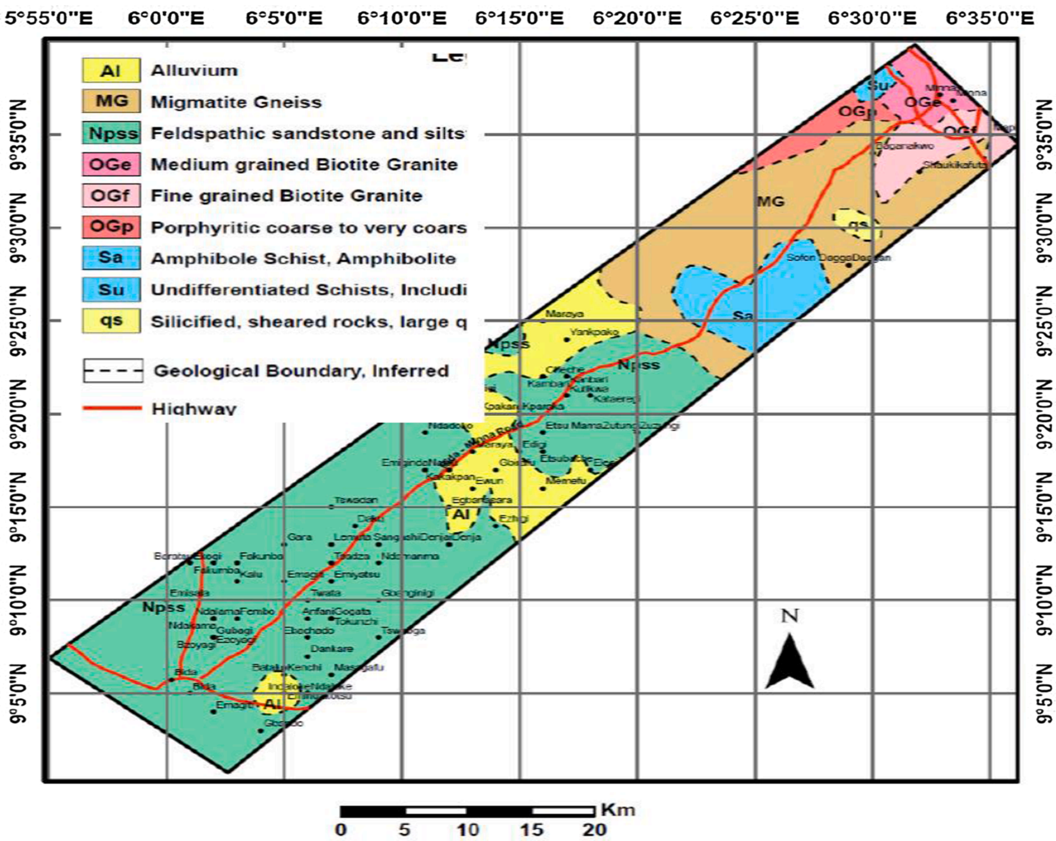

Fig. 2. Geological map along Minna – Kateregi – Bida road.

depth of trial pits to ascertain the response of the pavement sublayers and the subgrade to overloading from heavy trucks. Soil samples were collected at varied depths within the trial pits and characterized to determine the nature of the subsoils around the collapsed sections.

Fig. 3a is a typical example of thick organic top soil underlying the road embankment while Fig. 3b indicate occurrence of shallow water table in some sections of the road. Fig. 3c and 3d are similar with the former having a thin layer of dark organic soil between brownish lateritic soil from the top while the later have highly plastic clay layer between a reddish brown soil from the top (see Fig. 4).

3. Results and discussion

3.1. Visual inspection

Though, almost all sections of the road from Minna – Kataeregi – Bida have failed, the first section of the road within the basement complex recorded worst pavement failure compared to the section within the Bida basin. Visual observation also revealed that some sections of the road have collapsed completely rendering the movement of vehicles almost impossible. These sections include roads from Chainages (CH 16 + 672 – CH 19 + 000, CH 22 + 320 – CH 25 + 100, CH 26 + 153 – CH 27 + 790, CH 32 + 000 – CH 33 + 781, CH 36 + 790 – CH 37 + 780, CH 44 + 320 – CH 45 + 885, CH 56 + 192 – CH 58 + 580, CH 65 + 467 – CH 66 + 035, CH 79 + 637 – CH 79 + 836, CH 80 + 889 – CH 81 + 343). These sections of the road consist of closely-spaced potholes, asphalt surface has strip off almost completely, ruts, depressions, cracks and other forms of failure.

A section from CH 56 + 000 to CH 59 + 000 consists of a wide basin which was filled with high embankment and the running water channeled across the road through two bridges and many thin metal tubes. While the two bridges were observed to be grossly inadequate to channel the water across the road, the thin metal sheets tubes, intended to also channeled flood water across the embankment were observed to be rotten and failed under the embankment load, thus reducing the rate of water flow through the embankment as shown in Fig. 5. These Setbacks have allowed ingress of water in to the embankment, thereby causing the collapse of pavement over this embankment within some sections as shown in Fig. 6.

3.2. Sublayer soils of pavements in collapsed sections

As stated earlier, some sections of the road have collapsed completely making it extremely difficult for motorists to ply. Trial pits were conducted on these sections and the soils collected were tested according to the method highlighted in BS 1377 (1992).

(a) Thick organic top soil under road embankment, (b) Shallow water table below road embankment

(c) Trial pit with varied soil layers and water (d) Varied soil strata with layer of clay

Fig. 3. Trial pit with (a) thick organic top soil (b), shallow water table, (c) varied soil layer (d) Bida basin.

(a) Stripped asphalt surface with depression

(b) Rough surface with wide potholes

(C) Pavement surface with depressions

(d) Pavement with alligator cracks

Fig. 4. Pavement surface with (a) stripped asphalt surface, (b) wide potholes, (c) depressions, (d) cracks.

Fig. 5. Hollow metal sheet as water channel.

Fig. 6. Pavement failure over the embankment.

3.3. Profile of section between CH 16 + 672 and 19 + 000

This section of the road falls within the basement complex. Four trial pits were conducted on this section of the road which were taken to 2.0 m depth each. Index properties test were carried out on the soil samples collected and the results analysed and presented in a profile as shown in Fig. 7.

The profile consists of 0.3 m – 0.8 m thick brownish lateritic fill material brought in during the road construction. This layer was intruded by yellowish brown silty soil from trial pit 3 to trial pit 4, which classified as A-4 based on American Association of State Highway and Transportation Officers (AASHTO) soil classification system. Some researchers ([25,26,23,24]) have reported the effect of road subsoil materials on the strength and stability of the road structures. However, this type of soil can serve as natural subgrade material for road structures with optimal stability. A little lens of organic soil was observed very close around TP3. Water table was observed to be generally shallow at depth of between 0.6 m and 1.0 m below the lateritic fill material. The influence of water table on the performance of pavement sub-structures have been identified by Bassam [27] and Toll et al [28]. The authors have revealed that high water table affects the strength of pavement sublayers grossly. According to Adlinge and Gupta [32], the shallow underground water table can seep in to the upper road structure through capillary rise which must have weakened the sublayers of the road structure thereby resulting to sudden failure with heavier traffics.

3.4. Profile of section between CH 22 + 320 and 25 + 100

This stretch of the road is also located within the basement complex section of the road. Five trial pits (TP5 – TP9) were conducted within this section as shown in Fig. 8. The profile shows brownish lateritic embankment brought in during the road construction as the upper layer, followed by relatively thin layer of organic matter content. The presence of this layer of organic matter is an indication that the organic top soil was not removed before placement of lateritic fill embankment. This layer is under-lain by a relatively thick yellowish brown silty clay soil layer spanning through the entire stretch of the profile. The layer classified as A-6 to A-7-6 based on AASHTO soil classification system which is susceptible to swelling and shrinkage. Below this layer is a stable brownish gravelly lateritic soil. Shallow water table was observed in some sections along the chainages as shown in the profile. The total collapse of the pavement observed in this stretch of the road must have resulted from combined action of organic soil underlying the embankment, highly plastic clay underlying the organic soil and the action of shallow water table observed in some sections along the stretch of the road. Adlinge and Gupta [32] have also shown that poor subgrade like organic soil and heavy clay can be overstressed by heavy traffics, thereby leading the sudden failure of pavement structures (see Figs. 9 and 10).

3.5. Profile of section between CH 32 + 000 and 33 + 781

This section of the road also exists within the basement complex section. It consists of three trial pits (TP12 to TP14) taken to depth of 2.0 m each. The profile is covered from the top by a brownish lateritic fill which is underlain immediately by a relatively thick clay of high plasticity (CH) based on unified soil classification system. The layer is then underlain by stable brownish lateritic soil down to depth of 2.0 m. Water table was also recorded at shallow depth of between 1.2 m and 1.8 m. The collapse of this stretch of the road is clearly due to depression of the clay stratum due to axle load from heavy trucks plying this road. The shallow water table has always kept the clay under perpetual softness due to continuous presence of moisture through capillary rise.

3.6. Profile of section between CH 36 + 790 and 37 + 780

This section of the road also falls within the basement complex with two trial pits (TP 15 and TP 16). The profile comprises of relatively thick lateritic embankment which was placed during construction. It is followed by thin layer of organic soil which thinned out towards TP16. A relatively thick, yellowish brown to greyish clayey soil layer cutting across the entire stretch of the section, was

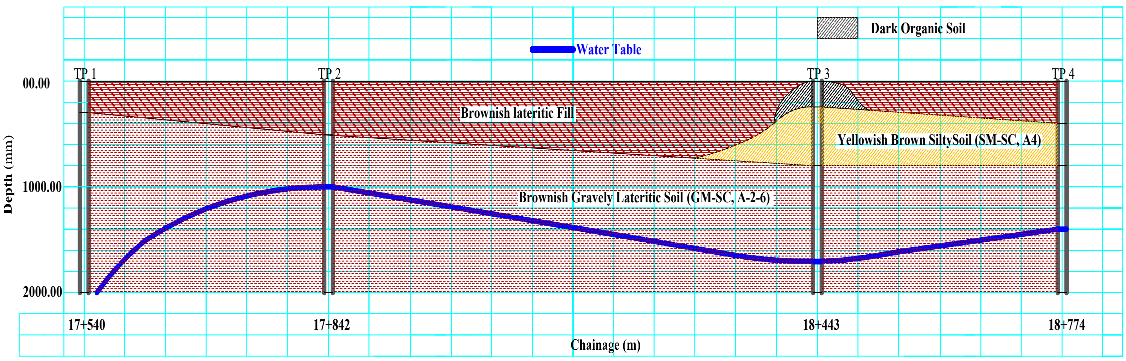

Fig. 7. Profile within collapse section from CH 16 + 672 and 19 + 000.

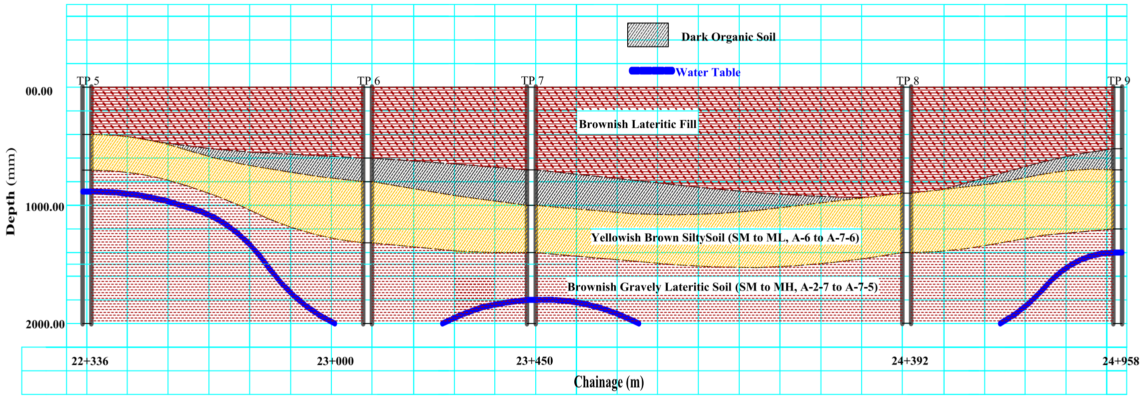

Fig. 8. Profile within collapse section from CH 22 + 320 and 25 + 100.

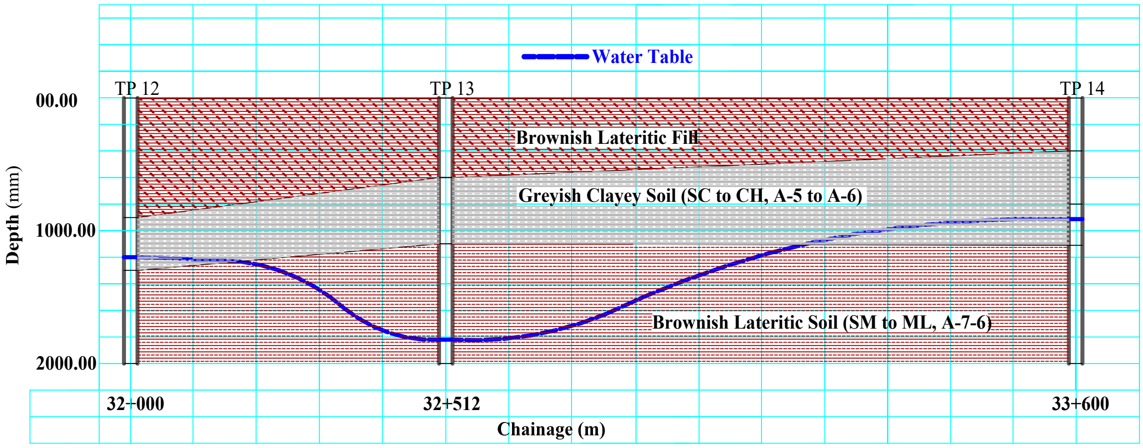

Fig. 9. Profile within collapse section from CH 32 + 000 and 33 + 781.

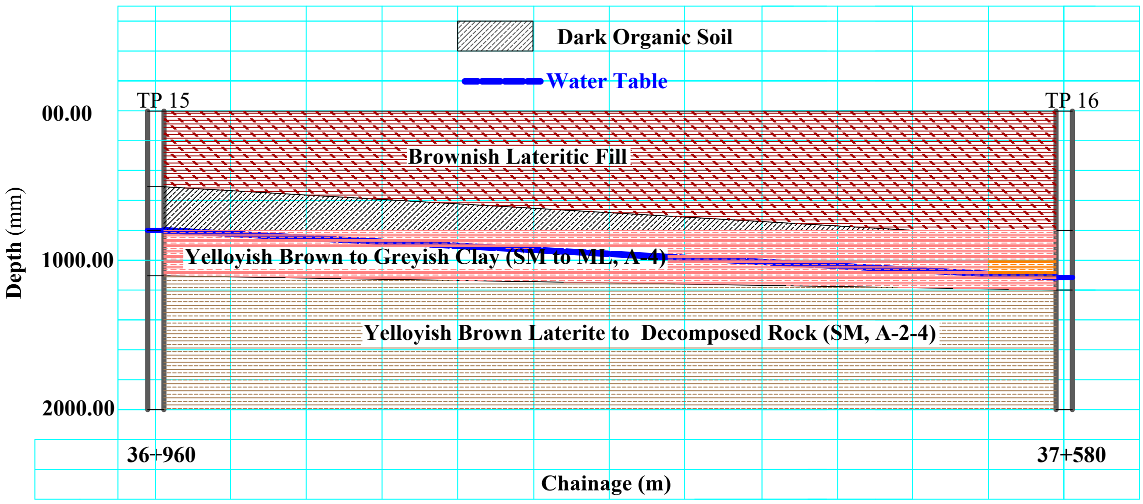

Fig. 10. Profile within collapse section from CH 36 + 790 and 37 + 780.

observed below the organic soil layer. Stiff lateritic soil layer was recorded below the greyish clayey soil. Water table was observed at shallow depth of between 0.8 m and 1.2 m. It can therefore be inferred that the collapse of this section is attributable to shallow water table and the organic material underlying the road embankment.

3.7. Profile of section between CH 55 + 520 to CH 59 + 100

This section of the road, which stretched for about 4.0 kM, falls under Bida basin and comprises of trial pit 20 to 25. The channel consists of a body of water dammed by the embankment and tends to flow across the road through two bridges and some sheet tubes. These sheets were observed to have failed under the embankment disallowing free flow of water across the embankment. This must have informed the water table observed in trial Pits 22 to 25 in Fig. 11. The profile showed thick, reddish brown lateritic embankment ranging from 0.8 m thickness to 4.5 m thickness. This embankment was brought in during construction without the removal of the dark organic soil immediately below the embankment. A localized greyish clayey soil was observed in TP21 which intruded the underlying brownish silty soil synonymous to basin soils. Failure of this embankment as shown in Figs. 5 and 6 must have resulted from a combined effect of the organic soil below the embankment and the failure of the sheet tubes used to channel water across the embankment. The mode of failure of embankment under this condition can be likened to the study by Bardet et al (2015) and Kuliczkowska [33] who both explained the process as progressive erosion of bedding, cavity formation and subsequently, pavement collapse. Infiltration of ground water with soil particles in to the pipe is another great threat to pavement structure. This will cause the soil underneath to subside and consequently lead to the failure of the pavement (see Fig. 12).

3.8. Profile of section between CH 65 + 405 to CH 66 + 125

This failure section also falls under the Bida basin which contains TP27 to TP28. The profile is covered from the top by a brownish lateritic fill material which was also brought in during construction of the road. This layer of the soil is underlain by organic soil within the area of TP28 which in turn, is underlained by relatively thick yellowish brown silty soil which cut across the entire stretch of the section. The entire profile, without water table, was than underlained by lateritic soil with occasional gravels. The collapse of this section of the road can be attributed to the organic soil directly below the embankment and the loose nature of the silty soil prevalent on this site. The organic matter indicates poor subgrade which cannot resist the pressure from heavy traffics.

3.9. Possible remedial measures

The possible remedial measures will depend on the nature and causes of the failure. The sections with stable subgrade but consists of shallow water table can be repaired by increasing the embankment height so as to take the pavement structure far from the water table.

Where the embankment is founded directly above weak organic soil as well as fat clay, this section of the road should be excavated to remove the poor subgrade materials and replaced with better materials.

The section with failed sheet pipes transporting water across high embankment can be rectified by removing the failed sheet pile, replaced with more stable material and recompacted to predetermined density.

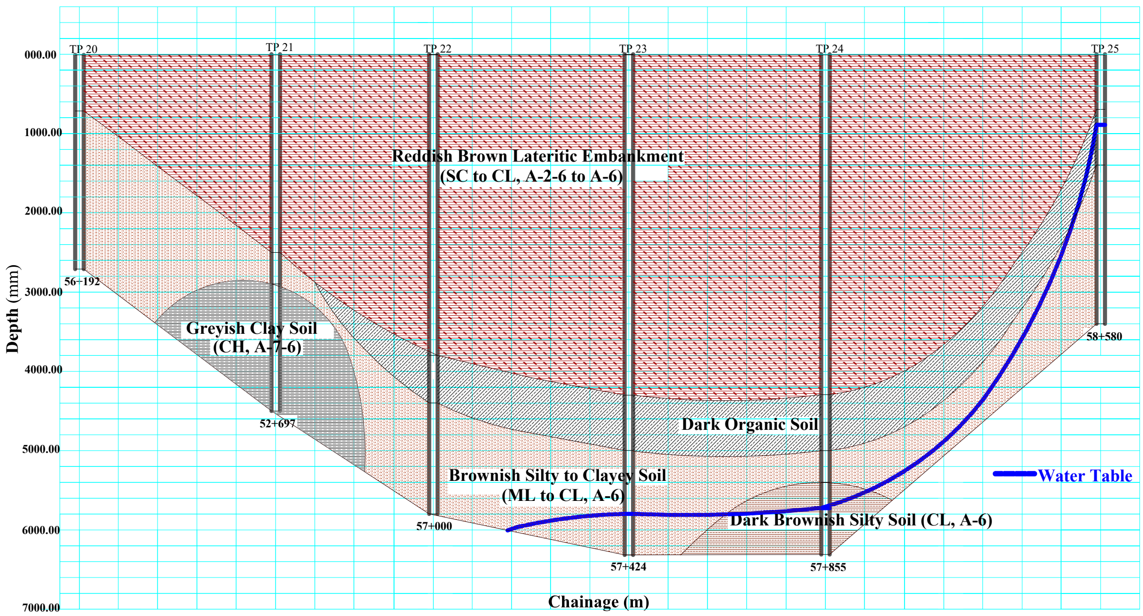

Fig. 11. Profile of Trial pits at Critical Failed section between CH 55 + 520 to CH 59 + 100.

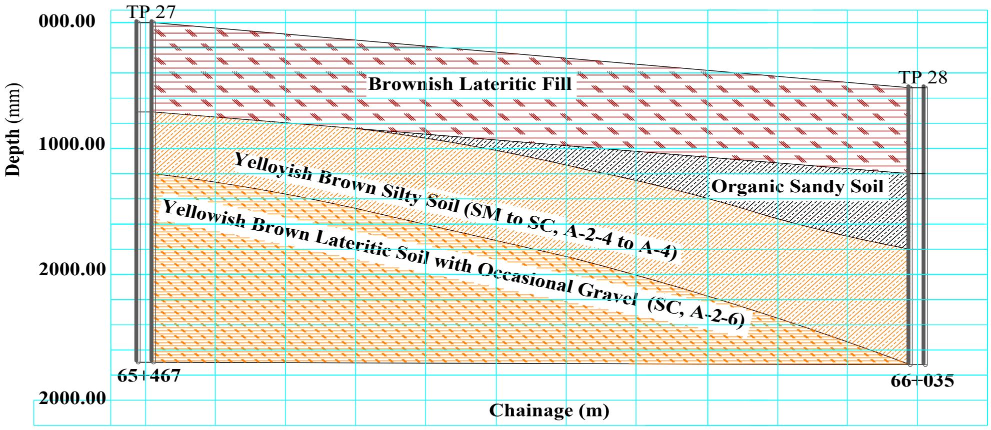

Fig. 12. Profile of Trial pits at Critical Failed section between CH 65 + 405 to CH 66 + 125.

4. Conclusions

The response of road pavement structure to high volume of overloaded heavy trucks, plying Minna-Kataeregi-Bida road (Route C) was studied. The high volume was observed to have resulted from the obstructions on Tegina-Mokwa road (Route A) and Lambata-Bida-Mokwa roads (Route C).

Visual observation and geological studies revealed that the entire stretch of the road cut across The basement complex and Bida basin. The common failure types observed ranges from asphalt pavement cracks, potholes, ruts and depressions.

Trial pits conducted on the collapse sections of the road showed pavement defections within the basement complex ranging from, road embankment Overlying a relatively thick organic soil layer, shallow water table and clay of high plasticity directly below organic soil layer. Within the section of Bida basin, reddish brown silty soil devoid of shallow water table is prevalent which forms the subgrade for road within this section.

About 4.0KM high embankment constructed between CH 55 + 520 to CH 59 + 100 within the Bida basin was observed to have failed due to the failure of the sheet tubes used to move the flood water across the embankment.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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