

Interlocking Paving Stones Pavement as a Solution to Marshy Roads

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Abstract

This study is focused on the use of interlocking paving stones pavement for marshy roads and high groundwater table terrain. The permeable interlocking paving type of stones was used to combat intrusion of underground/saline water for the road of case study (Akin-Adesola Street, Victoria Island, Lagos). Hydrogeologic data, i.e., groundwater level information for marshy roads terrain including the area of case study was obtained in form of investigation hole/borehole data. Different scientific tests and researches put together show the effectiveness and durability of the modified exfiltration system type of permeable pavement for high ground water table terrain.

Keywords: groundwater table, permeable pavements, marshy roads, seepage

1. Introduction

1.1 General Overview

The nearness of the saturated zone to the land surface and the manner of fluctuation of this zone has direct effect on the geotechnical properties of the soil. These in turn influence the stability of structures (houses, bridges, dams, roads, etc.) (Brattebo & Booth, 2003; NRAA, 2011).

The implementation of Sustainable Drainage Systems presents a series of design options that permit a designer to select the best solution for a particular site. Sustainable Drainage Systems include grass swales, filter strips, retention ponds, wetlands and permeable pavements. Permeable interlocking concrete pavements are the best option for effective stormwater management and surface/subsurface drainage interactions. Also Pore water under pressure beneath road pavements on marshy sites rises through capillary action to the surface above the groundwater level and can adversely affect road pavement structure if there is inadequate subsurface drainage facility (Scholz & Grabowiecki, 2007). This type of pavement together with the open graded aggregate beneath it also provides storage and filtering capabilities. Permeable pavements allow run-off to pass through the surface rather than running off it as would normally be the case. The pavement structure and the materials used must therefore be designed with this in mind. Depending on ground conditions, either a fully tanked system or an exfiltration permeable pavement system can be specified.

In areas underlain with highly permeable soils, the captured water infiltrates into the sub-soil. In areas containing soils of lower permeability, water can leave the pavement through an underdrain system. The water that passes through and leaves the pavement is referred to as exfiltrate (Hunt & Collins, 2008). Several different types of permeable pavement exist. Main differences among each pavement type are in the total pore space, spatial arrangement of the underlying pervious layers, and structural strength. The most common types include permeable concrete (PC), permeable asphalt (PA), permeable interlocking concrete pavers (PICP), concrete grid pavers (CGP), and plastic grid pavers. Permeable interlocking concrete pavers (PICP) are available in many different shapes and sizes. When laid, the blocks form patterns that create openings through which rainfall can infiltrate. These openings, generally 8 to 20 percent of the surface area, are typically filled with pea gravel aggregate, but can also contain top soil and grass. ASTM C936 specifications (2001b) state that the pavers be at least 60 mm (2.36 in) thick. Typical installations consist of the pavers and gravel fill, a 38 to 76 mm fine gravel bedding layer, and a gravel base-course storage layer (ICPI, 2004).

In the early 18th century the popularity of paving stones reached the shores of North America and have gained prominence ever since. Here in Nigeria, those applied on roads around the National Art theatre at Orile Igamu in Lagos state since early 1970s still remain till date with minimal maintenance.

Akin-Adesola Street, Victoria Island, Lagos was constructed in the late 1960s with a soil/cement stabilized base and asphalt wearing finishes which however experienced constant failure. This failure can be observed in the large potholes created at various spots along the highway. The street chosen as a case study is a major road that runs through the center of Victoria Island, Lagos and a vital link between two major roads, Ahmadu Bello way running parallel to the Atlantic Ocean at the Bar Beach, while at its other end, the Ozumba Mbadiwe Avenue, running parallel to the Lagos lagoon. The 1.7 km dual carriageway of 16 m width receives traffic from Ikoyi Island through the Falomo link bridge.

The specific objective of this research is to present the permeable type of interlocking stones pavement as a solution to marshy roads.

1.2 Interlocking Pavement Options

The interlocking paving stones with its interlocking arrangements (especially permeable interlocking paving stones) allow for both surface and subsurface drainage of seepage of underground water without losing its property of strength and durability (see Figures 1 and 2)(Bean et al., 2007). This option has proved effective in this area of case study with its high ground water table. With some unique spacer designs, interlocking paving stones can be installed in two very different ways:

For water drainage:

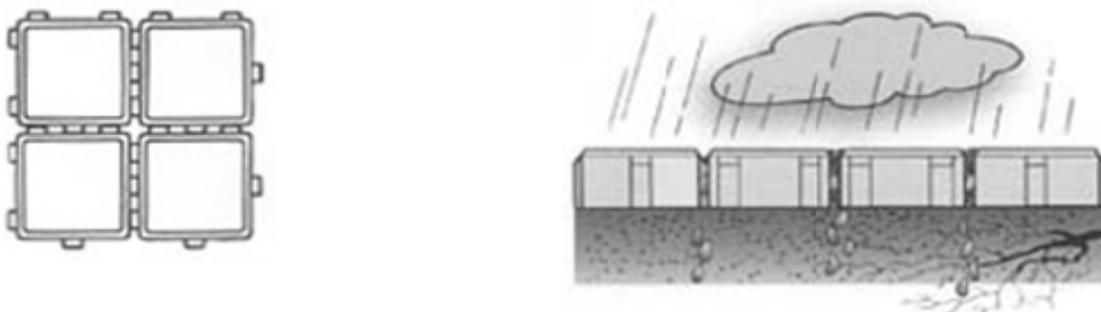


Figure 1. Permeable Pavement - for water drainage: Installed in closed assembly with spacer on stone. Joints filled with gravel

For turf growth:

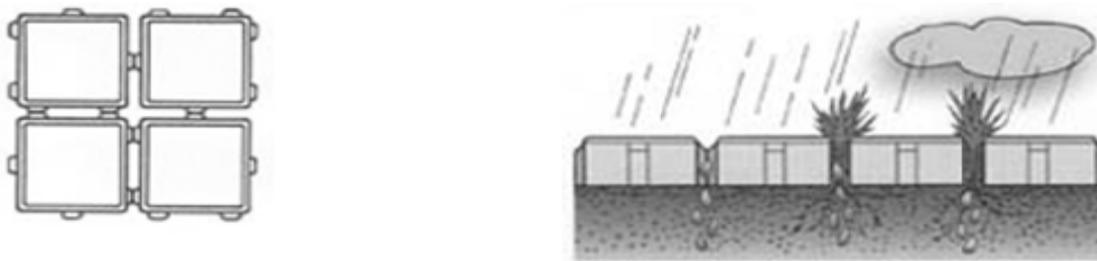


Figure 2. Permeable Pavement - for turf growth: Installed with larger joints - spacer on spacer - filled with a soil-gravel mix

Paving stones are produced in different shapes and sizes (Imai et al., 2003). Typical examples of interlocking paving stones are shown in Figure 3 (ICPI, 2004). The edges of each paving stone are shaped to accommodate the next one for proper bonding. Each paving stone acts as a rigid beam. The number of paving stones contained per square meter creates a chain link with the ability to be easily lifted to allow access to underground services with minimum delay or disruption. Each square meter contains units of the precast paving stones arranged in interlocking form.

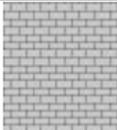
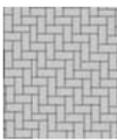
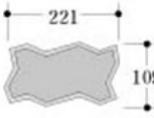
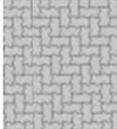
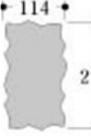
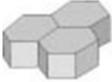
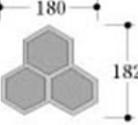
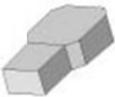
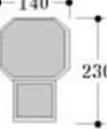
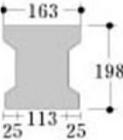
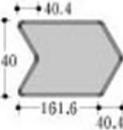
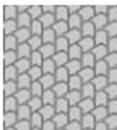
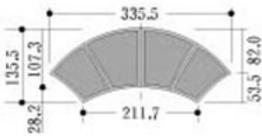
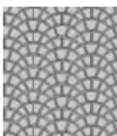
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Figure 3. Interlocking Pavement Blocks

2. Method

The borehole/investigation hole information relating to ground water level was obtained from both private and public hydro geological and drilling organizations such as the Lagos State Water Corporation, Arcbode Engineering Company, Afrex Ventures Limited, etc. Information was also obtained from investigation holes dug in the course of this study.

Hydro geological surveys reveal Victoria Island to be in a sedimentary environment which is characterized by sand and clay layers containing the retention water flowing into or away from the sea (Longe, 2011). The geophysical survey data show that almost the whole area of Ikoyi, Victoria Island and partially Apapa are covered with saline water.

A 150 cm diameter hand auger was used for boring investigation holes which were dug at seven locations namely: Ogba, Ifako-Ijaye; International Airport, Ikeja; Ikeja Military cantonment; Iganmu, Apapa; First Avenue, Ikoyi; Akin Adesola street, Victoria Island; Water Works, Victoria Island. Each hole was dug with a hand auger to a depth of two meters. Water level indicator was dropped in each hole to mark the depth of the water at different zones. The result is presented on Table 2. The object of this test is to know the ground water level at the chosen area of study.

2.1 Construction

A modified exfiltration system permeable interlocking concrete pavement (PICP) was designed for the case study road. The O-Type (Figure 3) of interlocking pavement blocks was used with concrete spacers. The construction of the permeable pavement is illustrated in Figure 4. From an engineering viewpoint, permeable pavements are infiltration trenches with paving over them to support pedestrian and vehicular traffic. Much of the design and construction is derived from experience with infiltration trench design, which has been used for years as a way to reduce stormwater runoff and recharge groundwater (Collins et al., 2008).

The existing asphalt wearing course as well as the soil/cement stabilized base was scarified using an excavator to strip and cart away into haulage trucks to dumping sites. This was followed by excavation to required depth. High strength concrete was used for the concrete pavers. Cement, quarry granite dust and coarse granite aggregate (12 mm) are mixed in ratio 1:1:3 with an expected crushing strength of not less than 40 N/mm² fully cured. The quality could be best achieved by both vibrating the stone dust, cement and aggregate together and simultaneously compressing them with a mild water/cement ratio of not more than 30% to 35% into a mould of the required paving stone shape. The molded concrete is placed on pallets which could be wooden or metallic for easy carriage and transfer to curing sites. After curing for 28 days, the paving stones were removed from the pallets and stored. The permeable interlocking pavement was designed according to BS 7533-3: 2005 and ICPI, 2004. The full pavement section for the road using an exfiltration system (Figure 4) is:

Wearing Surface: 208 × 138 × 80 mm O-Type permeable pavers

Bedding Course: 50 mm thickness of 6 mm single size crushed stone.

Road Base Course: The total thickness of roadbase materials used inside the exfiltration system was:

Designed thickness - (Roadbase) - 100 mm

(Sub-base 1) -250 mm

Total thickness - 350 mm

This total thickness of roadbase was formed with 20-5 mm, 100 mm thick base and 150 -50 mm, 250 mm thick sub-base. The aggregates complied with BS 13242: 2002. The details are;

Roadbase -100 mm, 20 - 5 mm coarse graded crushed rock aggregate

Sieve Size (mm)	Percentage Passing (%)
37.5	100
20	90 - 100
14	40 - 80
10	30 - 60
5	0 - 10
2.36	0

Sub-base (1) - 250 mm, 150 - 25 mm coarse graded crushed rock aggregate

Sieve Size (mm)	Percentage Passing (%)
150	100
100	45 - 75
75	12 - 50
50	0 - 10

Geotextile: - Woven geotextile was used

Edge Restraint: precast concrete kerb profile matched to project requirements was used 150 mm wide and 300 mm deep.

The second Sub-base (Sub-base (2)) as indicated in Figure 4 has materials that complied with the requirements of the local authority. Table 1 gives the gradation for the sub-base (2) material suitable for exfiltration system interlocking concrete paving. Sandy gravel (50 - 0.5 mm), 100 mm thick was spread throughout the excavated area as the sub-base (2) in direct contact with the subgrade. Geotextiles were placed on the uncompacted subgrade and over the sides of the excavated area. The geotextiles were secured so that it will not move or wrinkle as aggregate is placed. The subgrade was not compacted but the sub-base (2) was lightly compacted for smooth placing of the geotextile. 150 - 25 mm coarse graded crushed rock aggregate sub-base (1) material was spread in 100 to 150 mm lifts and compacted with a static roller. 80 mm diameter perforated PVC outlet pipe cloaked with geotextile material spaced at 10 m interval connected to subsurface side drain was placed in the sub-base (1) layer. 150 mm perforated PVC pipe embedded in clean coarse granular material was used as the underground subsurface drainage on both sides of the road.

The 20 - 5 mm coarse graded crushed rock aggregate road base layer was spread and compacted as one 100 mm lift. These stone materials should be moist during compaction. When all lifts were compacted the surface was topped with a 50 mm thick layer of moist 6 mm single size crushed stone. This layer of finer crushed stone was screeded and levelled over the road base. Following the completed base preparations, edge restraints (kerbs) were installed to prevent lateral movement of interlocking stones; to prevent the escape of laying course material and to enhance esthetic appearance of installation. Granular material was used to backfill on the outer edge of the restraint. Permeable Paving stones were laid with an optimum of 12 mm joint widths in the required pattern. 6 mm concrete spacers placed side by side provided 12 mm joint width. Alignment of paving stones was checked by string lines and adjustment made as necessary to ensure that installation pattern would continue throughout the project. A mechanical plate tamper was used for tamping the entire paving stone surface in both directions until the surface was bedded down uniformly. 6 mm crushed stone was filled into the spaces between the interlocking paving stones ensuring that all joints are completely filled.

Table 1. Sub-base (2) materials

ASTM Sieve	% Passing	BS Sieve	% Passing
2 in	100	53.0 mm	100
1 in	70-90	26.5 mm	70-90
½ in	50-75	13.2 mm	50-75
¼ in	35-60	6.7 mm	35-60
8	25-50	2.4 mm	25-50
40	10-25	425 µm	10-25
200	5-15	75 µm	5-15

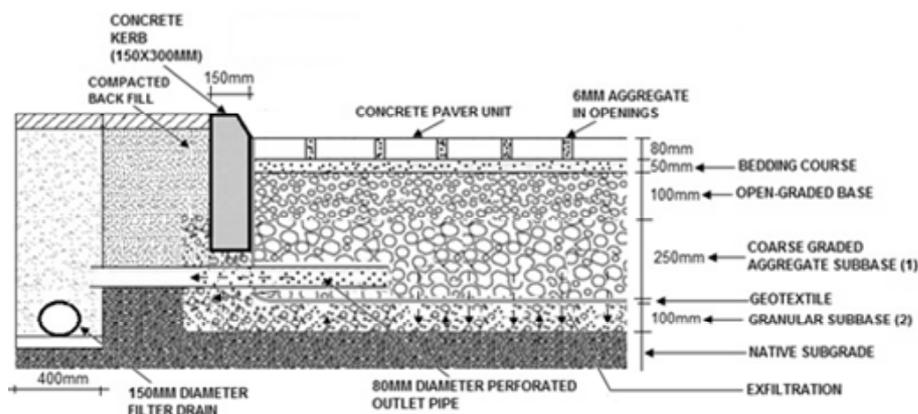


Figure 4. Construction features of the modified exfiltration system with perforated outlet pipe and subsurface side drain

3. Results and Discussion

The results of the test for ground water level using investigation holes for the road of case study and its environs is presented in Table 2.

Table 2. Result of investigation holes

S/N	Sites	Results (m)
1	Ogba, Ifako-Ijaye	No water within the depth
2	International Airport, Ikeja	No water within the depth
3	Ikeja Military Cantonment	No water within the depth
4	Iganmu, Apapa	1.78
5	Akin-Adesola street, Victoria Island	0.20
6	First Avenue, Ikoyi	1.98
7	Water Works, Victoria Island	0.25

As a result of the low accuracy of investigation holes which were to a depth of 2 m, geophysical logging data were obtained from Lagos state water corporation (Table 3 - 6). Victoria Island (case study area) falls along the coast of Lagos state. Information concerning borehole correlation of wells along the coast of Lagos state was supplied by Lagos state water corporation.

From the geophysical investigation data (Table 5 and Table 6), it was found that the subgrade below the site has sand to considerable depth (about 30 meters) is sufficiently permeable to allow an exfiltration system to be adopted. In this instance an additional thickness of sub-base material was added. It was found that Victoria Island area generally has a high ground water table which is saline in nature. This has been responsible for incessant pavement failure on the road of the case study. The terrain is made up of loose sand which is highly porous and permeable hence the need for a pavement construction technology that will allow porous materials to be used in filling the terrain to a certain thickness before laying the interlocking paving stones.

Due to the high water table especially during the peak rainy season the modified exfiltration system adopted (Figure 4) has perforated outlet pipe cloaked with geotextile material from the sub-base course to subsurface side drain spaced at 10 m interval on both sides of road. This provision was made to channel exfiltration sideways to the underground subsurface side drains during rise in ground water table to forestall hindrance of exfiltration from the open graded base due to rise in water table. Excess pore water due to the application of axle load on the pavement is dissipated through the coarse granular road base materials and the subsurface drainage facilities. The exfiltration system comprise essentially of the road base, sub-base (1) and 80 mm diameter perforated outlet pipe cloaked with geotextile material above the geotextile layer. The geotextile layer permits exfiltration when groundwater level is low and can allow rise in groundwater level during the peak of rainy season.

Table 3. Geophysical logging results: Iganmu, Apapa

Depth (m)	Description of Layer
0-10	Sand (laterite and water)
10-38	Clayey sand (Brackish water)
38-53	Sand (Clean and slightly fresh)
53-60	Clay
60-88	Sand (Clean and fresh)
88-96	Clay
96-129	Sand (not very clean but fresh)
129-150	Clay
150-158	Sand (fresh water)

Table 4. Geophysical logging results: First Avenue, Ikoyi

Depth (m)	Description of Layer
0-28	Sand (clean, fresh water)
28-35	Clay
35-45	Sand (not clean but fresh water)
45-62	Clayey sand
62-75	Clay
75-115	Sand (saline)
115-127	Clay
127-151	Sand (clean but slightly saline)
151-154	Clay
154-173	Sand (fresh water)

Table 5. Geophysical logging results: Akin-Adesola street, Victoria Island

Depth (m)	Description of Layer
0-27	Sand (saline water)
27-50	Clay
50-90	Sand (saline water)
90-98	Clay
98-120	Sand (saline water)
120-130	Clay
130-165	Sand (fresh water)
165-170	Clay
170-192	Sand (clean and fresh water)

Table 6. Geophysical logging results: Water Works, Victoria Island

Depth (m)	Description of Layer
0-35	Sand (saline water)
35-65	Sandy clay
65-100	Sand (saline and not clean)
100-105	Clay
105-132	Sand (saline and clean)
132-143	Clay
143-150	Sand (Brackish and clean)
150-154	Clay
154-205	Sand (fresh water and not too clean)

Figure 5 shows groundwater level observations at 150 meters interval along the road for eight weeks during the peak rainy season in the months of June and July from chainage 0+000 m to 1+650 m along the 1.7 km road. The minimum depth to groundwater level which represents the worst condition remained 0.20 meters, the maximum was 0.30 meters and the average depth to water table was 0.24 meters. The high amount of annual rainfall is above 2500 mm in coastal Lagos, Nigeria (Oni, 2003). The pavement performance of other marshy roads in the case study environs (i.e., 1st Avenue, Ikoyi, Water Works road, etc.), with asphalt wearing course was adjudged to be poor (showing defects) compared to the two year performance of the case study road with permeable interlocking stones pavement. It is noted however that the other asphalt wearing course roads have existed for a much longer period, and that there would be need for a long term performance evaluation for the permeable interlocking paving stones pavement. Longer performance of this type of pavement in view of the higher cost of

construction and maintenance would eventually attract the government to adopt this option for all the other roads in the case study area.

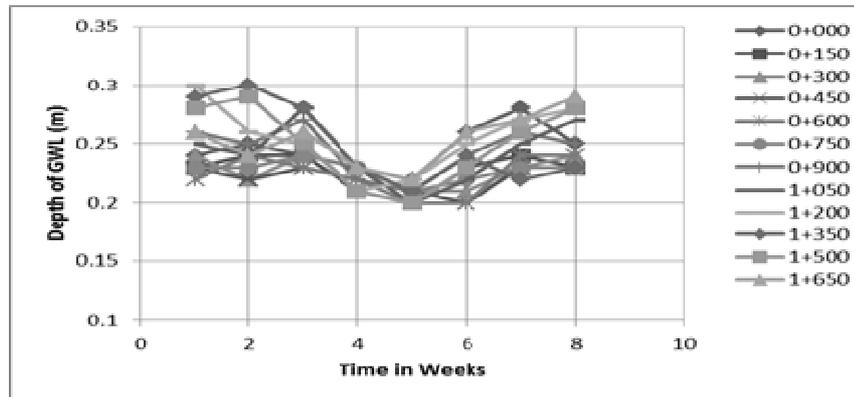


Figure 5. Changes in depth to groundwater level during 8 weeks of monitoring from chainage 0+000 m to 1+650 m

4. Conclusion

A modified exfiltration system permeable interlocking concrete pavement (PICP) was designed and has been constructed for the case study road. The exfiltration system comprise essentially of the road base, sub-base (1) and 80 mm diameter perforated outlet pipe cloaked with geotextile material above the geotextile layer. The geotextile layer permits exfiltration when groundwater level is low and can allow rise in groundwater level during the peak of rainy season. Pre-cast permeable interlocking paving stones are highly recommended for high water table terrain. It has several advantages over other paving types especially in the swampy or marshy terrain. The minimum depth to groundwater level which represents the worst condition remained 0.20 meters during eight weeks of monitoring showing effectiveness of the designed system. The pavement performance of other marshy roads in the case study environs (i.e., 1st Avenue, Ikoyi, Water Works road, etc.), with asphalt wearing course was adjudged to be poor (showing defects) compared to the two year performance of the case study road with permeable interlocking stones pavement. It is noted however that the other asphalt wearing course roads have existed for a much longer period.

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