Sustainable Drainage System for Road Networking

Owuama C. O., Uja E., and Kingsley C. O.

***Abstract*—In built up flat areas flood control is often a challenge. Drainage systems involving open concrete or pipe drains on roads pose significant problems arising from blockade due to anthropogenic factors and sluggish water flow due to very low invert grade. These consequently lead to unfriendly living environment. The sustainability of such drains for effective performance is grossly in doubt. An alternative and sustainable drainage system is a trenchless drain comprising absorption unit and grass cover. The technology provides a cheap, aesthetic and effective method of disposing road surface runoff with minimal distress to users and minimal damage to the environment.**

***Index Terms*—Drain, network, road, sustainability.**

I. Introduction

Road is an indispensible ingredient of development in any society. In built up areas networks of roads are constructed to support human and vehicular traffic. In complement drainage facilities are provided to ensure timely disposal of sewage and surface water runoff generated from expansive impermeable surfaces. The conveyance of such a drain is facilitated if the ground surface or its invert has sufficient slope. An area or drain invert is sufficiently sloped where the grade is greater than 2% [1], [2].

However due to municipal activities these drains may be blocked with refuse, grit, yard or construction materials [3]. This could result to urban flooding.

Flooding can also occur on lowlands, where the slope is not sufficient or on natural channels blocked by construction infrastructure. It presents itself as a deluge of water over a normally dry land. On roads it could cover up to the drive way, even submerging adjacent buildings.

An effective drainage system has the capacity to remove overland flow soon after a rainfall. Conventional systems on roads employ either open concrete drains and/or pipe drains. The drains are not sustainable in areas with insufficient slope, particularly, in a developing economy [2].

To address this flaw and reduce flooding with its attendant problems, and at the same time reduce down slope erosion a sustainable drainage system, the trenchless drain, is proposed as best practice in road engineering on a flat terrain.

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Owuama C. O. and Uja E. are with the Institute of Erosion Studies, Federal University of Technology Owerri, Nigeria (e-mail: Owuamco@yahoo.com).

Kingsley C. O. is with the Department of Civil Engineering, Federal University of Technology Owerri, Nigeria.

II. General Concept of Flood

Flooding is an overflow of large volume of water on a normally dry land and may submerge lands causing deluge. It could be naturally induced as in tidal flooding and fluvial flooding or human induced as in pluvial flooding.

The focus of this paper is specifically on pluvial flooding or urban flooding. Urban flooding is caused by a number of factors such as [4], [5]:

- Weather events such as heavy rainfall and thunderstorms over a short period of time, prolonged extensive rainfall and high tide combined with stormy conditions
- Poor maintenance culture resulting to poor / insufficient drainage networks or inadequate cleansing of water courses
- Poor development and planning issues particularly inappropriate development on flood plains, impermeable built environment or defective flood defense schemes
- Climate change which is a global phenomenon is predicted to increase the risk of flooding.

Minimization of urban flooding can be achieved by providing an effective drainage system.

III. Conventional Drainage System on Roads

Urban roads are often designed with camber towards open concrete drains on both sides of the road. In some cases large diameter pipe drains are used to convey storm water. Culverts are provided at crossings over open concrete drains.

A. Open Concrete Drain

Flow in open concrete drain is similar to flow in open channel. Self cleansing capacity is dependent upon invert slope of the drain. On flat areas, for example New Owerri Nigeria, the general slope is less than 2% generating a flow velocity of less than 0.49 m/s. This is below a permissible velocity of 0.75 m/s that allows self cleansing of drain [2]. Hence siltation and vegetal growth in the drains in conjunction with the stagnant water promote mosquito breeding in the area thereby escalating mosquito related health hazards such as malaria. Open concrete drain is also attractive as waste dump site, Fig. 1, especially where waste disposal regulations are not strictly enforced. However open concrete drain is commonly constructed to allow for its regular cleaning. When silted up or covered up with vegetal growth, its cleaning could be carried out prior to the commencement of the rainy season (April – November). But the labour cost and neglect in the cleansing of the drain may leave room for environmental nuisance, Fig. 1 and Fig. 2.

The shape of a drain is either trapezoidal, rectangular or square [6]. In New Owerri the urban drains are rectangular

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with an average size of 1.5m (width) × 0.75m (depth). Culverts are provided at intervals along the drains as access to buildings, and they often wedge floating or suspended objects, causing obstruction to free flow of water underneath the culvert.

Fig. 1. Waste dump in a concrete drain.

Fig. 2. Water log in a concrete drain.

B. Pipe Drain

Flow in pipe drain simulates flow in conduits, especially at full capacity. Such a drain is suitable in areas with good grade to ensure thorough cleansing, otherwise channel maintenance is difficult. It can easily be blocked or silted up where adequate provisions are not in place to decongest it. In New Owerri Nigeria the existing pipe drains are apparently nonfunctional because of lack of adequate care.

C. Limitation

It is apparent that road drainage system using either open concrete drain or pipe drain on flat terrain poses a number of environmental problems. For instance a rainfall intensity of 100mm/hr (typical of New Owerri) on 500m long and 10m wide asphalt road ideally generates a runoff of $500m^3$ in an hour. This volume of water, if not promptly removed, constitutes flooding with its attendant health hazard and environmental problem. On flat terrain with open concrete or pipe drain, the removal rate is abysmally low. A trenchless drainage system provides an effective and sustainable alternative.

IV. TRENCHLESS DRAIN

Trenchless drain is a composite of absorption field and grass cover aligned on both sides of a road [2]. The concept is centred on the provision of a trench backfilled with relatively permeable material. The arrangement provides a wider surface area for water infiltration. The backfill is either sand or gravel. The grass cover provides the foliage for interception of rain drop, stems and leaves introduce greater roughness while the roots provide greater infiltration channels. The cover, generally, binds the superficial soil particles, restrains soil movement, reduces its erodibility and increases the shear strength through a matrix of tensile fibres. It has been observed that a 2m × 2m trench backfilled with sand per unit length drains water 5 times faster than a 2m wide grassed surface or 20 times faster than the bare surface [7].

The design of a trenchless drain assumes that only the road wash flows towards the road sides and flow down slope is prevented by the relatively flat nature of the terrain. No flow from outside of the road is considered

Equating the volume of inflow to the drain (Q) and the infiltration capacity of the composite drain (F), the theoretical width (w_t) of the drain was obtained [2].

Thus, for a square drain:

$$Q = k_1 1\ (w_r + w_t) \quad (1)$$

$$F = k_2\, 3\, w_t\, k \quad (2)$$

$$W_t = k_1 1\ w_r /(3k_2\, kT^n - k_1 1) \quad (3)$$

where, w_t = theoretical width of a square drain

1 = rainfall intensity

W_r = design road width

K_1, k_2 = coefficients representing losses, generally < 1

T = time factor

n = standing time of water as a pool

k = hydraulic conductivity of insitu soil.

For optimal design or at limiting equilibrium condition the rate at which water flows into the drain is the same as the rate it i.e. $n = 0$, and the equation becomes

$$W_t = k_1 1\ w_r /(3k_2\, k - k_1 1) \quad (4)$$

The factors T, k_1, k_2 are site dependent and can be established empirically.

Ideally, where there are no water losses, $k_1 = k_2 = 1$

$$\text{i.e. } W_t = 1\ w_r /(3k - 1) \quad (5)$$

W_t in apparently the hypothetical width of the drain and is related to the effective design width W_d by

$$W_t = W_d\, \eta \quad (6)$$

where η is effective area factor = porosity of backfill [7]

$$W_d = 1\ w_r /(\ \eta\ (3k - 1) \quad (7)$$

Sketch designs are shown in Fig. 3 and Fig. 4.

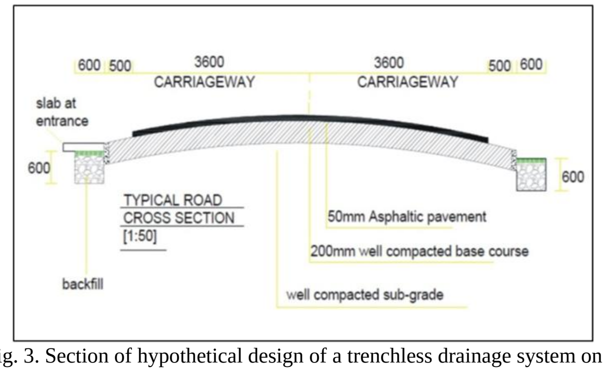

Fig. 3. Section of hypothetical design of a trenchless drainage system on a road section.

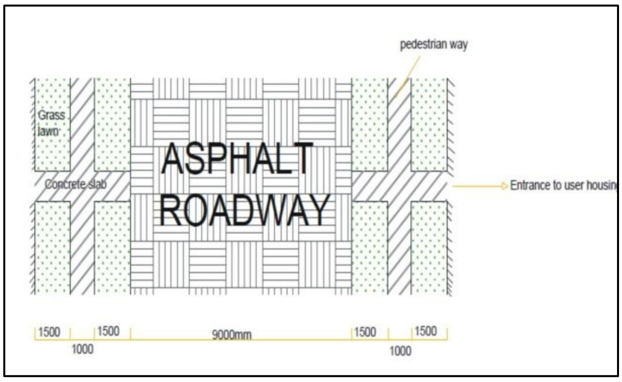

Fig. 4. Plan of a hypothetical design of a trenchless drain on a road plan.

V. Over – Riding Advantages

The benefits of the Trenchless drain over conventional methods in road networking on flat terrain can be assessed using the following parameters.

A. Construction Cost

Open concrete drain is constructed of a mixture of aggregates and cement at a design ratio, and sometimes reinforced with iron bars. For a similarly sized trenchless drain the only construction material is sand or gravel put in place with no mandatory skill. A comparative cost analysis for the various dimensions and composition of drains using local market prices was carried out and the results are illustrated in Fig. 5.

It is observed, for example, that for a given dimension, a reinforced concrete drain is about four times (4 ×) more costly than a trenchless drain constructed of sand aggregate. Open concrete drain requires properly designed culvert at each crossing as against slab if a trenchless drain is constructed. A culvert of known dimension is 10 times more costly than slab of the same size [7].

B. Maintenance Cost

A concrete drain requires regular cleansing for free flow of water to be obtained. But because of high cost, in terms of labour and equipment, during the evacuation of the attendant waste maintenance is done ones in a year, preferably at the onset of the rainy season. Comparatively trenchless drain requires grass cutting when overgrown to maintain its environmental friendliness. The maintenance is easily done at a desired time and at a relatively very cheap operational cost.

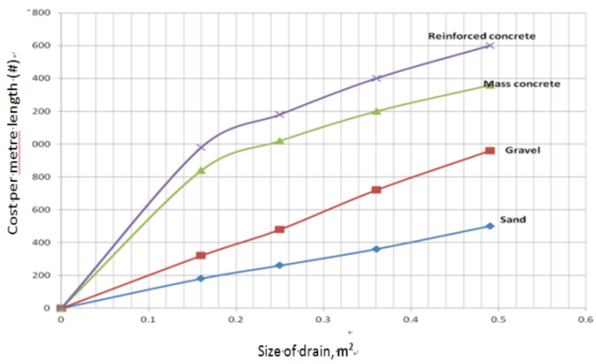

Fig. 5. Comparative cost graphics of various types of drain.

C. Aesthetics

Open concrete drain presents unsightly view especially when not properly maintained. Sometimes it serves as waste dump. Comparatively, the greenish outlook of a trenchless drain merges with nature to beautify the environment and provide a healthy scenario.

D. Flooding

Concrete drain is easily submerged in course of rainfall due to obstructions and low grade terrain. The water may remain stagnant for a good length of time, providing in good breeding ground for mosquitoes. This often results to exponential increase in malaria cases. Trenchless drain does not retain flood water for a period of over 1 hour after a torrential rainfall [7]. It therefore provides minimal opportunity for mosquito breeding.

On heavily flooded roadway it is often difficult for road users to identify the limit of an open concrete drain and such persons may run the risk of falling into the drain. Trenchless drain provides, apparently, a continuous surface cover with no perceived danger to road users.

E. Erosion

Where an open concrete or pipe drain is functionally effective its discharge can cause erosion at the outlet of the drain or culvert, especially where the drain or culvert is not properly terminated. Over 240 well developed gully erosion sites in South East of Nigeria occurred as a result of faulty termination of drains and culverts [8]. However, the Trenchless Drain, at its worst performance, cannot yield significant surface runoff as to initiate erosion down slope.

VI. Limitations of Trenchless Drain

1) The trenchless drain is suitable for areas flatter than 2% grade. For slopes greater than 2% and less than 7% special design features may be introduced. It is not applicable for slopes greater than 7%.
2) The system is not suitable in areas with very low permeability soils such as fat clay
3) Where groundwater level is close to the surface the method is ineffective. If hard pan or rock outcrop is shallower than 1m, the effectiveness of the drain is in doubt.
4) The concept does not accommodate deluge of discharge from built – up environment with impermeable land cover. Such land covers may include interlocking stone, asphalt or concrete slab. A rainfall intensity of 100mm / hr on a plot of built up area (33m by 20m) can generate 660m^3 of water per hour. To handle flows of this nature special design consideration may be added.

VII. Conclusion

Construction of road network in an urban or semi – urban settlement requires a good drainage system that can convey rainfall surface runoff from impermeable surfaces created by road surface and built up areas. The efficiency of such a drain depends upon the road / invert grade, construction standard and ethics adopted, and maintenance culture.

On flat areas open concrete and pipe drains are hardly efficient in the disposal of rainfall runoff, and are unsustainable especially in a developing economy like that of Owerri Nigeria

A sustainable drainage system in such an environment is the trenchless drain with inbuilt drainage facilities comprising water absorption unit and grass cover. Field and laboratory observations have shown that the system is low cost both in construction and maintenance. It disposes accumulated surface water soon after a rainfall and reduces the incidence of erosion downstream since potential concentrated runoff is eliminated. It also introduces aesthetic values to the environment, and an antidote to mosquito breeding which consequently reduces the incidence of malaria.

Built up environments or housing units could be provided with articulate arrangement of trenchless drain, absorption units and green cells within the premises to minimize the volume of water discharge onto the roadway. This concept will reduce the quantum of water concentrating to form a deluge that may ultimately result to urban flooding, fluvial flooding and downstream erosion.

VIII. Further Research

The concept is an innovation and areas of further research may include (a) establishment of empirical factors T (time factor), k_1 (inflow loss coefficient), k_2 (infiltration loss coefficient) for varying climatic conditions, (b) adapt to cases of slope in the range of 2% to 7%, (c) adjustment of design philosophy to accommodate slopes steeper than 7%, and (d) evaluation of its applicability in low permeability soils underlain by pervious stratum, (e) establishment of effective absorption surface for various backfills in the trenchless drain.

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Owuama C. Ozioma is a native of Umunkwo Isiala Mbano LGA of Imo State Nigeria and was born on the 29th September 1955. He holds a BSC (Hons) degree in geology from the University of Ibadan Nigeria in 1978, MSC, DIC in geotechnical engineering from Imperial College London England in 1981, PhD in civil engineering from the University of Benin Nigeria in 1994, and occupies a professorial chair in geotechnical engineering since 2006 at the Federal University of Technology Owerri Nigeria.

He had worked as a materials engineer, geotechnical engineering consultant and national consultant for the UNDP, Government Parastatals and Multinationals for a period of over 30 years. He began his teaching and research career in 1985 at the Rivers state University of Science and Technology Port Harcourt Nigeria before relocating to the Federal University of Technology Owerri Nigeria in 1992, where he is currently the Director of Institute of Erosion studies. He has published over 50 papers in reputable journals.

Professor Owuama belongs to various professional bodies including Nigeria society of Engineers, Nigeria Mining and Geosciences Society, Institute of Industrial Administration, Institute of Corporate Administration, American Association of Advancement of sciences and New York Academy of Sciences. He has been cited in various indexing volumes including Marquis Who is Who, IBC England, ABI Raleigh USA publications.