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Structural Relativities of Urbanization: Drainage Design and Gully Spacing for Run-Off and Pollution Management

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ABSTRACT: *This study proposes the critical view that good professional practice in the field of highway engineering design is mandatory to deriving the full benefits of modern built-up environments; with specific reference to the coastal towns of Nigeria, majority of which lies within the Niger Delta estuaries. Consequently, highway designs intended for these extreme weather situations are noticed to be influenced by many crucial variables such as, increasing urbanization, economically advantageous considerations, public policy and social interest, are major causes of design modifications intended to prevent the deterioration of watercourses, water bodies and groundwater through release of untreated pollutants, resource depletion and the loss of natural floodplains to development. Approaches/steps such as data collection, coordination, preliminary concept development, concept refinement (hydrologic and hydraulic design), integrated design documentation and regulatory perspectives therefore are integrated to the general consideration in the design of drainage and gully systems, that are usually channeled into the global river bodies through these estuaries. Importantly, these variables usually evolve at incremental pace with the different stages of the design processes. This report aims at understanding drainage design and gully spacing as affecting the minimization of impacts of development on the quality and quantity of road runoff towards maximizing amenities and biodiversity opportunities.*

KEYWORDS*: Bayelsa State, Drainage Design, Carriageway Construction, gully spacing, Watercourses*

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I. INTRODUCTION TO DRAINAGE SYSTEMS DESIGN AND GULLY SPACING

A rundown of historical perspective of drainage problems, probably over 200 years since the inception of drainage engineering practice, may be found in Hey (2001). Drainage development in terms of surface water removal and discharge systems has today advanced to be known as Sustainable Urban Drainage Systems (SUDS) with emphasis on water quality, catchment flooding, water resources, site amenity and potential for habitat enhancement, growth of population, industrialization, urbanization and technology has added to the increasing complexity in scope and design; as thousands of more spatial miles ranging from urban centers to coastal ports and up to remote farm settlements are covered or envisaged with time.

In view of the foregoing, drainages cascade floodwater current with a complex mix of industrial, urban and agricultural loads of unstable solids and dissolved wastes and fractionally deposits these at points of failure along flow paths (Bovis &Jakob, 1999). These wastes could be contaminants which in some cases routed to coastal ecosystems with the potential to cause harm (Rabalais, 1998). In the coastal towns of the Niger Delta region of Nigeria, extreme weather situations and increasing urbanization are major causes of modification and/ or deterioration of watercourses, water bodies and groundwater through release of untreated pollutants, resource depletion and the loss of natural floodplains to development. This report aims at understanding drainage design

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and gully spacing with respect to the minimization of the impacts of infrastructural development on the quality and quantity of road runoffs towards maximization of amenities and biodiversity opportunities.

II. DRAINAGE AND GULLY SPACING DESIGN PARAMETERS AND DEVELOPMENT

The design and performance criteria of drainage systems in the present day are principally based on storage and conveyance. The relationship between these two variables is what differentiates modern designs from natural drainage systems. That is limiting storage space will make conveyance dependent and where conveyance is limited, storage becomes dependent variable (natural drainage). Thus, the difference lies on the ability of modern drainage designs to maximize conveyance and minimize storage. Storage in this context is simply a temporary detention technique defined by the surface area of the reach and depth. Accordingly, Chow (1959) observed that conveyance reflects “a measure of the carrying capacity of the channel section, independent of the slope of the channel”. This means that the gradient of the slope is an integral factor in the determination of speed and mobility of the chosen conveyance method, and further imply that drainage slope should be designed in symphony with the natural geomorphological scape of the environment except where an otherwise design would serve better interest. In support of this view, it has been suggested that a road drainage system must satisfy two main criteria within its service life span (UNFAO Conservation Guide 1998), these include;

i) It must allow for minimum of disturbance of the natural drainage pattern
ii) It must drain surface and subsurface water away from the road and dissipate it in a way that prevents excessive collection of water in unstable areas and subsequent downstream erosion.

Consequent on this position, it should be observed that the slope shape and gradient of a drainage determine whether water is dispersed or concentrated (US Forest Reserve, 1979).

The road surface and drainage system are linked to provide storage and conveyance of runoff. The design parameters relate to rainfall average return period (risk of flooding), time of entry, maximum rainfall, flow velocities, minimum gradient and pipe diameter obtained through site surveys, tests and investigations. According to the Manning’s equation for river channel $Q = KS^{0.5}$, where the conveyance K is defined by $\left(1.49/n\right)AR^{0.67}$ with Q =discharge, n=roughness factor, A=cross-sectional area of the stream channel, R =hydraulic radius which is the ratio of the cross sectional area A to the wetted perimeter, P $\left(\text{or } R = A/P\right)$. For the purpose of concrete-lined channels, n may be associated to be quite low, 0.18 to 0.2 (Chow, 1959), compared to river channels (n = 1.8 to 2.0) for which the equation was originally designed.

This equation can be applied in the drainage situation by modifying the hydraulic radius to describe the gutter cross section, especially where the top width of the water surface is more than 40 times the depth at the curb. This is done through the integration of the width increment across the section so that:

$$Q = \left(\frac{KS_x^{\ 0.5} S_L^{\ 1.67} T^{2.67}}{n}\right) \qquad \text{-------- (1)}$$

Where K = 0.56), n = Manning's coefficient, Q = flow rate, m^3/s, T=width of flow (spread), m, S_x = cross slope, m/m, S_L = longitudinal slope, m/m (Table 1).

Gully Spacing: The design of gully control distribution in a drainage network must take into consideration the factors associated to local geomorphologic indicators such as type of network, stream order, and stage of development. Spacing of gullies follow the guidance of HA 102/00 with the objective to improve engineers, planners and designers’ management of urban sewerage, drainage systems and reduce impacts of extreme events that may have adverse effects on people and property in the catchment. Gully spacing can be calculated from Table (1). A detail typical design (labelled) is shown in Fig (2).
In view of the combined factors in structural designs, this study finds that a fully documented survey with the following features may be used for a reliable drainage and gully spacing design:
(a) Land survey
- Watercourses;
- Ditches;
- Existing drainage systems & outfalls; and
- Services and existing foundations;
(b) Tree surveys including features of soft landscapes:
- The condition of each tree;
- Its size and form; and

- Details of tree preservation orders etc;
(c) nature-conservation surveys;
(d) Details of how surface water run-off will be dispersed;
(e) Consultation with the Environment Agency;
(f) The depth of the water table and perched water tables;
(g) The impact on adjacent developments and land;
(h) A risk assessment of chemical contamination;
(i) The presence of hazardous materials;
(j) The stability and acceptability of earthworks;
(k) An assessment of subgrade strength;
(l) The frost susceptibility of subgrade;
(m) The suitability of subgrade soils for lime or cement stabilization; and
(n) Recycling of on-site materials.

III. DRAINAGE DESIGN PLANNING FOR ROAD NETWORKS

The design of road networks or highways is incomplete without incorporating drainages and gullies.

Fig 1: Conceptual model of floodwater runoff for understandingwater movement and management

The planned drainage design must be desired to minimize interference with existing drainage patterns, control flooding of the roadway surface for design flood events, and minimize potential environmental impacts from highway related storm water runoff. Plans are therefore necessary for design initiatives to effectively implement and associate all desired variables to culminate through the preliminary to final design (Fig 1).

IV. DESIGN OBJECTIVES OF DRAINAGE AND GULLY SPACING

The aim of drainages installation in road networks is to promote smooth and safe passage of vehicular transport. The function that designed drainage system serves is three fold:
(a) collecting runoff water from the roadway surface and right-of-way (Fig 3),
(b) conveyancing the runoff along and through the right-of-way, and
(c) discharging runoff to a redistribution channel devoid of adverse impacts or surface flooding.

Hydroplaning of surface drainage is a function of transverse and longitudinal pavement slope, pavement roughness, inlet spacing, and inlet capacity. This means that the potential of erosion occurring, runoff quantity and quality must also be integrated into the design. An installed drainage examples is shown in Fig (4).

V. APPROACH OF DRAINAGE DESIGN AND GULLY SPACING

This study found that for a feasible drainage design to apply, few steps may be considered in design of the drainage systems, and these usually evolve with the different stages of design process such as in the following:

i) **Data collection**: These are factors associated with local geomorphologic indicators as noted above. Associated technical data therefore will be assembled and reviewed with background information that may apply to the design process.

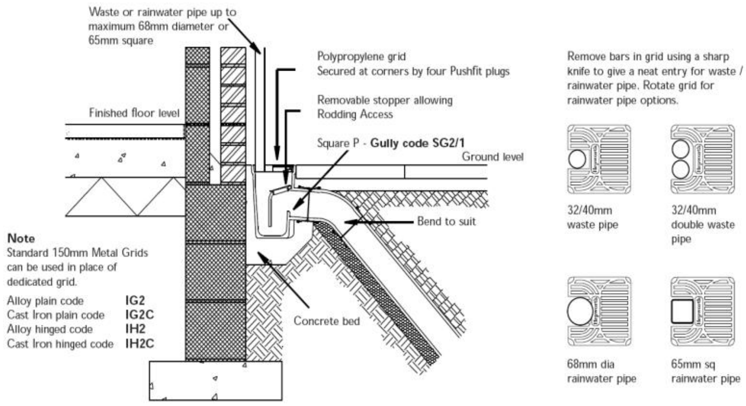

Fig 2: A typical design of gully at ground level with a variation of pipe network

ii) **Agency co-ordination**: The design process must involve co-ordination with regulatory, impacted or non-governmental stakeholders. Apart from Environmental Agency, the Department for Environment, Food and Rural Affairs (DEFRA), governmental regulatory bodies, etc., that may have interests on the potential impacts resulting from the drainage, and quantity and quality issues.

iii) **Preliminary concept development**: Preliminary sketch plans relating the catchment geomorphologic indicators and layout maps may be required here.

iv) **Concept refinement (hydrologic and hydraulic design)**: Consists of primary sequence such as: estimation of runoff parameters and quantities reflecting the preliminary layout, inlet location and spacing, drainage system layout with access holes, connecting mains, outfall control structures, etc., pipe sizes, channels, pump stations, discharge control structures, etc., review of the hydraulic grade line, and revise of plan and design parameters re-computing.

v) **Integrated design documentation**: It embodies a sequence of all the prepared data including the design files and construction plans integrated into one final document, and varies depending on sponsor agency. The final design may consist of reports on the hydrology, open channels, drainages, and pump stations [Brown et al (2001)].

vi) **Regulatory perspectives**: This includes detailed discussions in line with the definitions outlined in Nigeria's Federal Ministries of Environment and Transport regulations and any other runoff water frameworks or policy statements or directives, which establishes a contextual structure for management of water resources within the country. Thus, the envisaged environment at the receiving end of the runoffs can be classed as transitional waters. In this regard, conditions and incidental structural requirements relating the assessment and management of impacts of road projects on water environment has been fully documented (Design Manual for Roads and Bridges, 2008). It should be noted that the importance of this manual cannot be over emphasized. For instance, on the issue of departure from standards, the manual made a significant directive under section 1.3 as follows:

1.3: Unless a departure has been agreed, the implementation of the processes described in this Standard must be applied to all projects. If it is not considered necessary for this Standard to be applied, approval for Departure from Standards must be obtained from the Overseeing Organisation with the departure application clearly stating why this Standard should not be applied.
The forgoing implies a stringent mandatory requirement that is intended, to ensure that a drainage design must enhance environmental sustainability for the entire period of the project lifespan.

vii) **Environmental costs**: The likelihood of environmental costs is associated with environmental risks in terms of damage or failure of the road with SUDS systems. The risks are mitigated through the foreseeable design process, monitoring and to ensure the design performance criteria are met in line with statutory regulations. The associated risks therefore may take the form of:

(a) pollution due to accidental spillage or leakage event into receiving watercourses, and (b) exceedance mediated damages from flood not added in the design and/ or performance failure from design or maintenance.

viii) **Environmental benefits:** SUDS road drainage designs and implementation are associated to a range of environmental benefits such as: diffuse pollution reduction, energy savings, reduction in peak flows and storm runoff volumes, aquifer and river base flow augmentation, deferred investment, amenity benefit SUDS, habitat and biodiversity can be potential enhanced.

Table 1: Gully Spacing design parameters for carriageways

Gradient		**Flatter than**							
		1/150 (0.66%)	**1/150 0.66%**	**1/100 1.00%**	**1/80 1.25%**	**1/60 1.66%**	**1/40 2.5%**	**1/30 3.33%**	**1/20 5.00%**
Gully Spacing (meters)									
Cross Section	**C/Way width**								
1 in 40 (2.5%) Camber	5.5 m	20	30	35	40	45	55	60	75
	6.0 m	20	25	30	35	40	50	60	70
	7.3 m	15	20	25	30	35	40	45	55
1 in 40 (2.5%) Cross fall	3.5 m	10	15	17	20	22	27	30	37
	5.5 m	10	15	17	20	22	27	30	35
	6.0 m	10	12	15	17	20	25	22	27
	7.3 m	7	10	12	15	17	20		

C/Way = carriageway

Fig 3: Drainage and kerb combination design example

Fig **4:** Gully design installation by the kerb on a road side

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