Design of Stormwater Drainage for Student Hostel Area at Federal University of Technology, Gidan-kwano, Minna, Niger State

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Abstract

This research work is embarked upon to prevent developing areas from such problems as flood hazard, road deterioration, and soil erosion. Stormwater runoff is the direct response of a watershed to precipitation and includes the surface and subsurface flow that enters a ditch, storm drain, stream or other concentrated flow during and following the precipitation. In this study, the rational method was adopted in estimating the volume of runoff. Manning's Formula was adopted in designing and sizing the stormwater drains and culverts for a catchment area of 98 hectares. The area was divided into seven (7) sub-catchments. The estimated flow for the sub-catchment areas are 2.893m^3/s, 3.089m^3/s, 3.492m^3/s, 2.492m^3/s, 4.367m^3/s, 2.695m^3/s, and 2.336m^3/s. The sizes of the rectangular drains are 0.80m x 1.00m, 0.8m x 1.2m, 1.0m x 1.2m, 0.8m x 0.8m, 1.2m x 1.7m, 0.8m x 1.00m, 0.8m x 1.0m. They are designed such that the drain capacity will be adequate and economically sufficient at peak discharge. The culverts box are designed to drain away stormwater from the catchment area with various sizes as 2m x 4m and 2m x 2m.The benefits of this project work are, it would prevent soil erosion in and around the foundation of structures within the campus, prevents landscape from drowning and it will contribute to the development and growth of Gidan-kwano campus.

Keywords

Stormwater, Runoff, Drainage

1. Introduction and Concept

Development not only increases runoff quantity, but can also introduce new sources of pollutants from everyday activities associated with residential, commercial, and industrial land uses (CTDEP, 2004). Consequently, most rainfall is directly converted into stormwater runoff. For example, a one-acre parking lot can produce 16 times more stormwater runoff each year than a one-acre meadow (Schueler, 2005). The cumulative effect of an increase in site imperviousness throughout a watershed can drastically change the hydrology and overall ecological health of the whole system. Studies have shown that at 25 percent impervious cover, stream stability decreases, habitat disappears, water quality declines, and biological diversity dwindles (NRDC, 1999).

Stormwater is water from precipitation such as rain, sleet or melting snow. Stormwater runoff is the direct response of a watershed to precipitation and includes the surface and subsurface runoff that enters a ditch, storm drain, stream or other concentrated flow during and following the precipitation. Runoff plays an active role in the hydrologic cycle (West, 2010). Due to increase densification along with urban infrastructure development in Gidan-kwano campus; deforestation, use of corrugated roofs and paved surfaces is on the rise. The combined effect of this results in higher rain drop intensity and consequently accelerated and concentrated runoff. Coupled with inadequate integration between the road and urban stormwater drainage, infrastructure provision, and poor management; a significant proportion of the area is exposed to flooding hazards/risks.

The aim of this paper is to design stormwater drainage for hostel area within Gidan-Kwano campus of the Federal University of Technology. The objectives include to; Carry out a topographical survey of the area; Produce street guide map and topographical map of the area, and Design the layout and size the culvert and drain for the area. This paper will suggest ways of alleviating the drainage problem of the area, and the final outcome of the project will suggest ideas and ways of proper layout, planning, and designing of a suitable and adequate drainage network for the area.

1.1 Drainage System

Close conduit and surface drainage are types of the drainage system.

a. Surface drainage/Open channel: is a conduit in which a liquid flows with a free surface and receive overland flow.
b. Close conduit/Closed channel: It consists of underground pipes and flows normally occur under pressure (Schueler, 2005).

The cost of providing close conduit is about one and a half times the cost of constructing an open channel for draining the same area. However, open channel requires frequent cleaning and constitute a cause of air pollution during a period of flow stagnation. The open channel is preferred to close conduit because of the economy (Jimoh, 1999). The purpose of the adequate drainage system is to eliminate the harmful accumulation of rainfall runoff, which could cause damage to properties via erosions and floods.

1.2 Channel Shape Determination:

Channel shapes are generally determined for a particular location by the following considerations: Efficiency; Economy; Terrain; Flow regime; Quantity of flow to be conveyed; Safety; Width of the right of way; and Environment and aesthetics. The most commonly used Open Channel shapes include the following: Trapezoidal shapes, Rectangular shapes, and "V" shaped channels.

1.3 Rainfall Intensity and Rainfall Patterns

The rainfall intensity represents a rate of rainfall, and its magnitude depends upon the storm duration and the return period of the rainfall intensity. The peak of the rainy season in Nigeria is between July and September, and flooding of urban areas occur at this time. The amount of rain that falls on Nigeria varies with season (Adefolalu, 1986; Jimoh and Webster, 1996). The analysis reported herein was based on daily rainfall data collected from federal Meteorological Department and reports. The rainfall depth during 1999 was 705mm, which is higher than the previous two years, but lower than the mean rainfall over the 40-year record. Thus the flooding in 1999 was expected to be higher than flooding in the previous years (Jimoh, 1999).

1.4 Runoff Prediction

The characteristic of the rainfall plays an important role in determining the amount of runoff that will occur. A light, gentle rain may be intercepted by vegetation or absorbed by soil while a sharp intense rainfall of short duration may result in a large amount of runoff because the rainfall rate exceeds the infiltration rate. For hydraulic designs on very small watersheds, a complete hydrograph of runoff is not always required. The maximum or peak of the hydrograph is sufficient for the design of the structure in question. Since Kuichling's original development, the rational method became the basis for the design of many small structures (David et al, 2007).

1.5 Rational Method

The rational method is based on a simple formula that relates runoff-producing potential of the watershed, the average Intensity of rainfall for a particular length of time (the time of concentration), and the watershed drainage area. The runoff Q (m^3/s) from a drainage area (in hectares) is expressed as

$$Q_{discharge} = CiA \tag{1}$$

Where; $Q_{discharged}$ = design discharge (m^3/s), C = runoff coefficient (dimensionless), i = design rainfall intensity at the time of concentration read from the chosen IDF curve (m/s), A = watershed drainage area (m^2). The runoff coefficient, C, depends on the type of terrain, and its slope. Future changes in the terrain must be anticipated in the design of the drainage system to avoid problems at a later date. Standard values are listed in Table 1:

Table 1 - General runoff coefficients for the rational method.

Terrain type	Runoff Coefficient Gradient < 0.05 (Flat terrain)	Gradient > 0.05 (Steep terrain)
Forest and pastures	0.4	0.6
Cultivated land	0.6	0.8
Residential areas & light Industry	0.7	0.8
Dense construction & heavy Industry	1.0	1.0

Source: (Federal Urban and Coordinating Bureau, 2008)

The Intensity-Duration-Frequency (IDF) curves is a family of curves use to relate between these three components; storm duration, storm intensity, and storm return. A curve with a return period of 25 years will show the worst storm that can be expected in a 25 year period.

The time of concentration, Tcon, of a watershed is defined to be the time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet. To know which value to take from the IDF curve, the time of concentration has to be calculated. Tcon = 0.02 x $(L_{max})^{0.77}$ x $(S_{av})^{-0.383}$ Where; Lmax is the maximum length of flow in the catchment (m); Sav is the average gradient of the catchment area. We look for the rainfall intensity on the chosen curve, at the duration of a storm equal to the time of concentration which we calculated.

2. Methodology

2.1 Survey Work

The first operation to be carried out on any engineering work is the site visit, termed reconnaissance, this is done to know the situation on the ground and knows the avenue of approach for the design. After reconnaissance, a topographical survey of the site was carried out.

2.2 Data Processing

The collected data was analyzed with the help of Microsoft Excel, surfer8, Civil CAD and AutoCAD soft wares and presented in tables and charts; which include street guide map, Google map containing existing development of the area, the structure of the area and a topographical map containing development plan of the area.

2.3 Design

The design of a drainage project requires a detailed map of the area with a scale between 1:1000 and 1:25000. The contour interval should be small enough to define the divides between the various sub drainages within the system. The AutoCAD software was used to determine the layout of the proposed drains and culverts. The civil CAD software was used to develop the chainage at 25m intervals for each proposed drain of the study area and the design levels were also established. The principles of stormwater design are; Sustainability; Level of service; Cost-effectiveness; Design Criteria; Environmental impact

2.4 Hydraulic Analysis

<u>Sizing a Drain to Cope With the Design Peak Runoff Rate:</u> With the design peak runoff rate known, a drainage system must be planned together with

other structures like roads and buildings to assure they are all adapted to one another. The size of the drain can be calculated with the formula:

$$Q_{sizing} = 1000 \text{ x } \left(\frac{A \text{ x } R^{0.67} \text{ x } S^{0.5}}{N}\right) \quad (2)$$

Where; Q_{sizing} is the capacity of discharge of the drain (in l/s); A is the cross-section of the flow (in m^2); R is the hydraulic radius of the drain (in m); S is the gradient of the drain; N is Manning's roughness coefficient

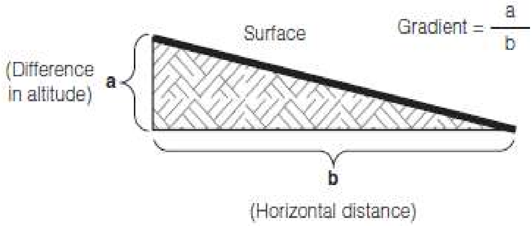

Figure 1 The gradient of a terrain

Slope = $\frac{\Delta y}{\Delta x}$, it can be determined from topographical map of the area.

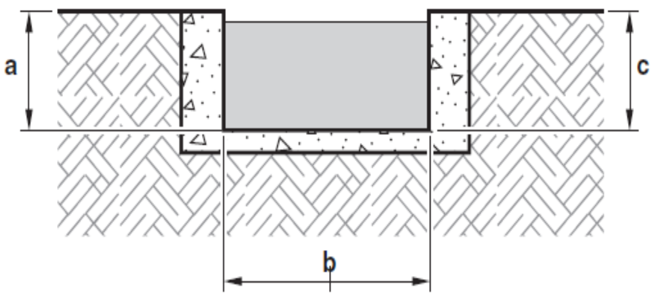

Figure 2 The cross-section of a storm drain

Where a and c are the heights of the drainage wall and b is the width of the drainage.

$$\text{Hydraulic radius} = (a \text{ x } b) / (a + b + c) \quad (3)$$

At section = a x b

This calculation will probably have to be repeated a number of times to find the adequate size of the drain. After a time of concentration has been determined, check for the rainfall intensity on the chosen curve (25 years return period), at the duration of a storm equal to the time of concentration which has been calculated.

Sizing a Culvert Computation base on the barrel is as follows;
Parameters such as Breadth, b, and Height, y have to be assumed, Using manning's formula,

$$Q_{sizing} = \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \times A \quad (4)$$

Where, Q_{sizing} = Discharge through the culvert, R = Hydraulic radius, S = slope of the terrain, A = cross-sectional area of the barrel.

The sizes are adequate when the values of Q_{sizing} are greater than the various values of $Q_{discharged}$

3. Results and Discussion

3.1 Estimation of flow

The procedure explained in section 1.5 above was followed for estimation of flow in each sub-catchment, AutoCAD was used to determine the Area and Length of flow in each sub-catchment. Flow characteristic of each sub-catchment is presented in Table 2.

3.2 Hydraulic Analysis

The procedure explained in section 2.4 above was followed for the various Sizing below. It is ensured that the drain dimensions will be adequate at peak discharge, Some reserve will be needed so that the drain is not completely filled with water, and because the calculated discharge rate does not take into account deposited solids, and lack of maintenance, which will usually reduce the efficiency of the system.

Table 2 Summary table of result showing flow characteristic for the seven (7) catchments

Sub-catchment	Area (ha)	Slope	Intensity (mm/hr)	Time of concentration (minutes)	Length of flow (m)	Discharge (m^3/s)
1.	9.84	0.023	175	10.78	540.28	2.893
2.	10.57	0.016	174	12.94	577.61	3.089
3.	13.86	0.008	150	24.84	961.85	3.492
4.	8.53	0.035	175	12.65	819.32	2.492
5.	20.47	0.003	127	37.23	980.93	4.367
6.	9.22	0.023	174	12.69	674.12	2.695
7.	7.99	0.014	174	12.40	506.28	2.336

Sizing the drain: The hydraulic parameter of the drain system is summarized in Table 3.

Table 3 Summary table for various sizing of drains for the catchments.

Sub-Catchment	cross-sectional Area (m^2)	Hydraulic Radius (m)	Depth (m)	Width (m)	Discharge (m^3/s)
1.	0.8	0.286	0.8	1.00	3.50
2.	0.96	0.343	0.8	1.2	3.95
3.	1.2	0.375	1.0	1.2	3.71
4.	0.64	0.267	0.8	0.8	3.30
5.	2.04	0.498	1.2	1.7	4.68
6.	0.8	0.286	0.8	1.00	3.50
7.	0.8	0.286	0.8	1.00	2.73

Sizing a culvert

Table 4 Summary table of result of sizing of the culvert.

Culvert	Area (m^2)	Hydraulic Radius (m)	Depth (m)	Width (m)	Discharge (m^3/s)
1.	8	1.00	2	4	51.50
2.	4	0.67	2	2	25.75

4. Conclusion And Recommendations.

4.1 Conclusion

It has been evident from the findings of this research work that the estimated flow for the various sub-catchment areas are $2.893m^3/s$, $3.089m^3/s$, $3.492m^3/s$, $2.492m^3/s$, $4.367m^3/s$, $2.695m^3/s$, and $2.336m^3/s$. Adequate and economically sufficient rectangular drain of various sizes as 0.80m x 1.00m, 0.8m x 1.2m, 1.0m x 1.2m, 0.8m x 0.8m, 1.2m x 1.7m, 0.8m x 1.00m, 0.8m x 1.0m are designed such that the drain capacity will be adequate at peak discharge. The culverts box are designed to drain away storm water from the catchment area with various sizes as 2m x 4m and 2m x 2m.

The benefits of the designed drains and culverts are, it would prevent soil erosion in and around the foundation of structures within the campus, prevents landscape from drowning, and it will contribute to the development and growth of Gidan-kwano campus.

4.2 Recommendations.

It is recommended that:

(i) Improvement in the integration of road and urban stormwater drainage infrastructure in the development of the campus.

(ii) In subsequent designs, wastewater discharge from existing buildings should be put into consideration to obtain an adequate stormwater drain and culvert sizes.

(iii) Water/stream draining into the land (if there is any) should also be duly considered in the design of stormwater drainage.

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