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Design Formulation of Stable Stream Channels in the South Eastern Nigeria

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Abstract- Channels formed in alluvial or other granular materials are said to be in regime or stable if their geometry remains substantially unchanged by scour or sediment deposition. This however does not preclude minor channel erosion during yearly cycle of flow but is does require that opposing effect should cancel out on an annual basis. The regime concept was initially formulated on the experience gained from canal systems but since the concepts is based on the theory of channel self-adjustment, it has been found applicable both for unlined canals and natural streams. It is now acceptable practice to design stable canal systems from a set of regime equation determined from natural streams in the locality of the works. In this paper the set of regime equations determined from the survey of the natural streams in Abia state is presented. The equations are compared with the regime equations developed for some other countries and that developed for Imo State by Prof. B.A. Nwachukwu. It is found that the present set of equations conform to those other equations with some little differences in the coefficient and exponents. The new set of equations is proposed for the design of stable or non-erodable channels in Abia state and it is suggested that the study should be extended to Anambra and Ebonyi states to determine if the equations are consistent for this large geographical area, the South East of Nigeria.

Keywords-*Design, Regime, Equations, Channels and Discharge*

I. INTRODUCTION

When an artificial channel is used to convey sediment laden water, both bed and banks of the channels tend to scour or fill, causing changes in the channel depth, gradient and width, until a state of balance is attained at which the channel is said to be in regime. The adjustments in width, depth and slope may give rise to a change in channel pattern. This means therefore, that the artificial channel has four degrees of freedom to achieve stability. The design and maintenance of efficient irrigation canal system in the civil engineering is the outcome in particular of this theory which, besides, is also applied for the design and operation of drainage, waste water and power channel. Above all, it is used for scour and bank erosion determination, prevention and control. Although the regime theory was formulated or derived from observations in canals, the regime concept has been shown to be in agreement with the data from natural streams. The regime study of natural streams could therefore evolve an approach for the design of stable channels and provide a clear picture of the effect of land-use changes in a drainage basin. For example, land use development changes which tend to increase basin erosion are expected to modify the stream regime as follows:

a. Increase the bed material load

b. Increase the bankfull width

c. Raise the water-surface elevation for specified discharge, resulting in more flooding

d. Reduce the mean depth for specified discharge

e. Steepen the channel slope by aggradation

f. Increase the main velocity process, particularly at low stages

g. Enhance braiding process, particularly at low stages.

The need for analysing and classifying river regime was recognized in the scientific programme for the International Hydrologic Decade, 1965 – 1975 (UNESCO, 1064) and the study presented here is in line with this objectives.

II. A BRIEF REVIEW OF THE REGIME THEORY

The development of regime theory took place in irrigation systems of the Bari-Doab area in the Punjab area situated in the effort of the Anglo-Indian engineers. The volume of literature dealing with regime theory is enormous. The first regime equation was proposed by Kennedy in 1895. His empirical equation is:

$$V_0 = 0.84D^{0.64}$$

Where V_0 is the mean velocity for the dominant discharge, Q. This discharge is assumed to correspond to the bankfull flow in the river. D is the mean depth. Lindly in 1919 presented a paper on regime flow channel and gave the following equations for non-silting and non-erodable flow conditions:

$$V_0 = 0.95\ D^{0.57}$$

$$V_0 = 0.57\ W^{0.355}$$

$$W = 3.80\ D^{1.61}$$

This was the initial introduction of bed width, W, as regime variable. Geral Lacey in 1929 and 1933 in his paper entitled "Stable Channels in Alluvium" and "Uniform flow on Alluvial Channels" proposed the following cost of equations

$P = 2.667\ Q^{1/2}$

$R = 0.47247\ Q^{2/3}/F^{1/3}$

$A = 1.260\ Q^{5/6/f}$

$S = 0.000542\ f^{2/3}/Q^{1/6}$; $f = 1.76\sqrt{d}$

In the above equations, P is the channel perimeter, R is the hydraulic radius, A is the corss-sectional area, and S is the Channel slope. F is a silt factor and D is the mean diameter of the material in mm.

Thomas Blench in 1951 presented his concept of the regime theory by amending the Lacey's equations in such a way that effect of side and bed of the channel can be evaluated separately by means of the bed factor F_b and side factor Fs. His equations are:

$$W = \frac{F_b Q^{1/2}}{F_s}$$

$$D = \left(\frac{F_s}{Fb^2}\right)^{1/3} Q^{1/3}$$

$$S = \frac{Fb^{5/6} Fs^{/12}}{Q^{1/6}(3.63g)^{1/4}}$$

Blench further recommended $Fb = \frac{V^2}{D} Fs = \frac{V^3}{W}$

All the equations so far discussed were derived from data obtained in Indian canals. Fortunately however, the investigations by, American engineers on the applicability of the regime theory to American streams (Leopold and Maddock, 1953; Simons and Albertson, the same magnitude of constants and exponents. Yet different constants and exponents have been reported for Canadian conditions, (Eray 1973, Kellerhals 1967) and for British rivers (Naxon 1959; Chartton et al 1978; Hey and Thorne 1967). Hence, one might conclude that regime equations depend on the conditions on which they are based and are valid only within the range of observed data.

III. METHOD OF DATA COLLECTION

The field surveys for this study were carried out between September and October 2014. Five streams which appeared relatively stable based on reconnaissance surveys were selected. The criteria for selection of sites were as follows:

a. the bed of the stream should be formed predominantly in alluvium and be free from the constrains such as bedrock outcrops or regulating structures.

b. the site should preferable be at or immediately adjacent to a permanent gauging station.

c. the stream should have a well-defined flood plain with similar range of vegetation types on both banks

d. it should be possible to wade across the stream since it was not possible to obtain a boat or vehicle to carry it around the state.

The key data obtained included cross-sections, velocity, bed and bank materials and descriptions of vegetation on flood plain, on stream banks and with channel. The cross-sections were surveyed across the channel and the adjacent ground to the highest flood level using a levelling instrument. At each study reach, about five cross sections were surveyed. The cross-sections were spaced approximately five channel widths apart but where the channel sections appeared irregular, cross-sections were located at points of various channel type, width and curvature (such as bends, crossings, islands etc). All sections for each stream were tied to absolute elevations datum. Measurement of velocities were taken at two points in the verticals. The velocity data were used to compute discharges for the survey stages. Bed and bank materials were collected at locations considered representative for the reach. The samples were stored in polythene bags. There were properly labelled for identification purposes and taken to the laboratory for analysis.

IV. DATA PRESENTATION AND ANALYSIS

Figure 1 shows a typical cross-section and definition of key channel properties. For each stream, a tentative bankfull stage was drawn on the cross-sections that have well defined flood plains or benches without reference to other sections. Next, the height of these tentative bankfull stages above their survey stages were determined and averaged. This mean depth above the survey stages was transferred to all cross-sections to arrive at the adopted bankfull stages. This approach was recommended by Neill (1967). Bankfull discharge was determined by means of a relative stage-versus discharge curve, where available, or otherwise computed using the mannings equation. For the computed bankfull discharges, the mannning's 'n' was established from discharge measurements during the surveys and the channel slope was determined from water surface profile.

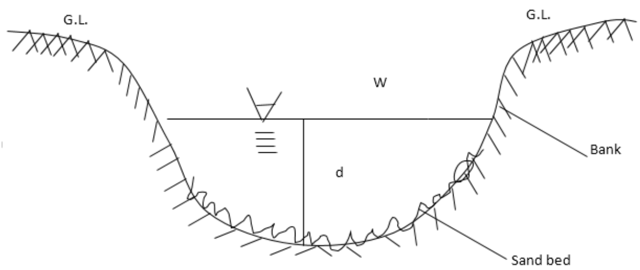

Figure 1. A typical section of Anya Stream. W = Width of the stream (6.9), D = Depth at a particular section (1.2m)

The grain size distribution curve were used for analysing the bed materials. It could be verified that all the selected streams have sandy beds. The banks were sandy with little fine. The flood plains and banks were covered by grass and shrubs.

Computed key hydraulic parameters at bankfull stages for the five streams are shown in Table 1. The water surface width at bankfull stage, Ws, the hydraulic radius R, the cross-sectional area A and the wetted perimeter P have been plotted against bankfull discharge. The resulting equations are:

$A = 3.09\ Q^{0.624}$

$Ws = 4.34\ Q^{0.365}$

$P = 5.16\ Q^{0.367}$

$R = 0.48\ Q^{0.349}$

$V = 0.398\ Q^{0.310}$

It can be seen that the set of equations for Abia State are of the same form as the previously established regime equations but vary in the coefficients and exponents.

TABLE I. KEY HYDRAULIC PARAMETERS AT BANKFULL STAGE

Name of stream	Q M^3/S	A (M^2)	V (M/S)	Ws (M)	P (M)	So $(X10^{-4})$	R (M)	+n
Ehimiri	0.96	2.13	0.46	4.10	5.14	2.40	0.42	0.019
Isieke	1.63	3.48	0.47	5.35	6.65	1.21	0.52	0.015
Ohimiri	2.84	6.31	0.44	6.79	8.65	1.41	0.37	0.021
Anya	4.14	7.81	0.53	6.91	9.17	1.95	0.85	0.024
Ihie	0.80	2.57	0.31	4.43	5.58	1.78	0.46	0.026

$$+n = \frac{R^{2/3} So^{1/2}}{V}$$

The width-discharge relation is one of the best documented relations in fluvial hydraulics and a comparison of few of these relations is given in Table 2 which includes the present study.

TABLE II. WIDTH-DISCHARGE RELATIONS

Investigation	Discharge	Coefficient	Exponent	Comment
Lacey (1929)	Bankfull	2.67	0.5	Sand bed canals (Imperical Units)
Leopold and Maddock (1953)	Mean Annual 2 years flood	Varies	0.5	American Rivers (Imperical Units)
Bray (1972)	Bankfull	2.38	0.527	Albert gravel bed rivers (Imperical Units)
Hey and Thorne (1986)	Bankfull	Varies	0.5	British Rivers (Metric Unit)
Nwachukwu (1988)	Bankfull	4.9	0.5	Imo State sand bed Rivers (Metric Unit)
This study	Bankfull	4.34	0.365	Abia State sand bed streams (Metric Unit)

The results of the present study confirm the regime concept that a natural stream adjusts its cross-sectional properties in an orderly manner when a consistent definition of discharge is adopted as the only imposed variable. The available data was not sufficient and did not have the variability needed to establish the slope-discharge relations. When more data become available, the slope-discharge relation will be determined.

V. SUMMARY AND CONCLUSION

Two basically different theories are currently used to design non-erodable channels. These are the regime theory and the limiting tractive force theory. The relationships established in this study inspite of their limitations, provide a useful guide for the design of non-erodible channels in the range of conditions upon which they are based. The range of valid conditions include channels formed in tropical sandy materials with sand beds and banks or slightly cohesive banks. Further studies would be required to establish the slope-discharge relationship. Other relevant hydraulic factors evaluated from the study include the meanings n, the Lacey's silt factor, f and Blench's bed and side factor F_b, Fs. The manning's n was shown to vary from 0.019 to 0.026 and was fairly in agreement with the relation.

$n = (d_{95})^{1/6}/53.80$

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