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Evaluation of an Interactive Copmuter Program for the Design of Grassed Waterways

[1]O.I. Ojo, [1]B.A. Adejumo, [2]A.O. Adewoye and [2]A.P. Adewuyi
[1]Department of Agricultural Engineering, [2]Department of Civil Engineering,
Ladoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria

Abstract: Software for the design of vegetated grassed waterways after the tractive force method of Temple has been developed. The design assumed Bermuda as cover grass with cover factor of 0.9 and stem density of 5380 stem m^{-2}. Also presented the general flow chart for each channel section (trapezoidal, parabolic and triangular) considered. The program was tested using data from literature. The computed design channel depth, d was 0.2 m as against 0.21 m from data (d) and 0.30 m compared to 0.32 m from the data source, the results thus, obtained were satisfactory. The program has the additional advantage of estimating the total cost of establishing the vegetated channel.

Key words: Software-design, bermuda, waterways, tractive force, program

INTRODUCTION

Waterways are mostly used in conservation practice, where there is rainfall of high intensity and run-off occurs. Its purpose in a conservation system is to convey run-off at a non-erosive velocity to a suitable disposal point. A waterway is defined as an open channel in which water flows into a free surface that is subjected to atmospheric pressure and designed to carry a specific discharge. There are three classifications of waterways; these are diversion ditches, terrace channels and designed waterways (Morgan, 2000). Grassed waterways provide an alternative to structural stabilization methods for earth channels exposed to flow only intermittently (Temple, 1983). Grassed waterways is defined as a shaped and grassed channel usually of broad width and shallow depth which is used for carrying water at relatively high velocities into river system or other outlets located in natural depressions or hillside/slope (Morgan, 2000).

A grassed waterway can be classified according to its origin, whether natural or artificial and also according to its various shapes which may be triangular, trapezoidal or parabolic and the use(s) for which such is constructed. This type of waterways has been used for agricultural drainage channels with increasing use for floodways and drainage-ways in more urban settings for both aesthetic and economic reasons.

The advantages of grassed waterways among others include:

Relatively low initial construction cost and aesthetic advantage over structural alternatives like spillways and floodways (Temple, 1991).

It gives a wide range of Manning's roughness depending on grass type and height and not on the climatic conditions.

Farmer-owned equipment such as mould board-plough, disc-plough, pull or push tractor mounted blades and small scrapers can be used for the channel construction where depth is up to 0.31-0.62 m unlike others that require the use of heavy equipment (Barfield and Hayes, 1988).

The behaviour of flow in channel is influenced by so many physical factors and field condition, so complex that the precise design of such channels is beyond the knowledge of theory.

Schwab and Fevert (1980) used the method of Maximum Permissible Velocity (MPV) for the design. He found that the design velocity for grassed waterways is the average velocity rather than the actual velocity in contact with the vegetation or with the channel bed. This method is based on equation of flow velocity,

$$V = \frac{R^{2/3}}{n} S^{1/2} \quad (1)$$

Where,

V = Average design velocity.
n = Manning's roughness coefficient.
R = The channel hydraulic radius.
S = The channel bed slope.

Corresponding Author: O.I. Ojo, Department of Agricultural Engineering, Ladoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria

Shih and Rahi (1981) found that the Manning's roughness coefficient, n increase with decrease in flow depth in a subtropical marsh between June to November. Also that the n value and vegetation density were parabolically related. Ree *et al.* (1977) suggested that the product VR be used as a satisfactory index of channel retardance for design purpose. From a number of experimental curves for various n versus VR, they classified various types of vegetations used in the design of grassed waterways into 5 different retardance classes. This classification of degree of retardance is based on the kind of vegetation and the stage of growth of grass in used.

An infinite curve family equation was suggested by Temple (1980) to replace the original n-VR curves. The equation describing this curve family may be written as:

$$n_R = \exp.\,(C_I\,[0.0133(\ell_n CR_v]^2 - 0.0954\,n\,(R_v) + 0.2971\text{-}4.16]) \quad (2a)$$

Within the limits

$$n_R \le (C_I + 1)/36.0$$
$$0.1 \le R_v \le 36.0$$

in which,

$$R_v\,(V_R/V_{74})\times 10^{-5} \quad (2b)$$

Where

- n_R = A reference valve of Manning's n applicable to vegetation established on relatively smooth-graded, fine-grained soil.
- C_I = A curve index describing the position of the retardance curve within the curve family.
- V = Average flow velocity.
- R = The channel hydraulic radius.
- V_{74} = A reference kinematics viscosity (9.3×10^7 m^2 s^{-1}) at 23°C. The n-VR.

Curves in either graphical or digital form have provided designers with a useful tool which appear to correctly account for the dominant characteristics of flow over submerged vegetation. However, treatment of Manning's n as a unique fraction of the VR product or Reynolds's number for any given grass liming represents a simplification of the complex interaction of the flow with the vegetal elements. An understanding of the fundamental behaviour implied by the n = VR relationship is therefore, essential to its proper application (Temple, 1982).

Tractive force method: When water flows in a channel, a force is developed that acts in the direction of flow on the channel bed. This force which is simply the pull of water on the wetted area is known as the tractive force.

According to Temple (1980), the tractive force parameter used was the shear stress acting on the channel boundary averaged in time and was mostly used for wide channel, defined as:

$$T = YdS \quad (3a)$$

Where,

- T = The total boundary shear stress averaged in time.
- Y = The unit weight of water.
- d = The flow depth.
- S = The slope of the energy grade line.

Temple and Alspach (1992) concluded that effective application of tractive force concepts to vegetal conditions, requires that this shear-stress component be considered separately from shear-stress component be considered separately from that transferred directly to the soil at the soil-water interface.

$$T = Yd\,(S' + S'') \quad (3b)$$

Where,

- S' = The energy slope associated with time average shear at the soil boundary.
- S'' = The energy slope associated with drag on the vegetal elements. Assuming that the energy loss at the soil boundary in the vegetated channel is the same with that in a smoothly graded bare earth channel formed of the same soil material and having the same depth and discharge and with repeated application of Manning's equation yield.

$$S' = (n_s/n)^2\,S \quad (4)$$
$$S'' = (n_v/n)^2\,S \quad (5)$$

in which,

$$n = \sqrt{n^2_s + n_v{}^2}$$

And

- n_S = Manning's resistance coefficient associated with the soil only.
- n_v = Manning's resistance coefficient associated with vegetal drag.
- n = Manning's resistance coefficient for the channel.

But since, n for a vegetated channel deperis on both the vegetal characteristics and flow conditions, this a functional relationship for n_v (C_I, R_v).

Where

- C_I = An empirical parameter describing vegetal conditions in the flow field.
- R_v = A parameter describing the flow conditions.

Dissipation of turbulence associated near the boundary and on the move general properties of the vegetation. With the inclusion of these concepts in Eq. 4 and with the bare earth channel again as the reference condition, a functional form for the relation describing effective shear stress at the soil-water interface as:

$$Te = yd\,([1.0 - f\,(cf)]\,S' + g\,(cf, C_I)\,S'') \qquad (6)$$

With

$$0.0 \leq f\,(cf) \leq 1.0$$
$$0.0 \leq g\,(Cf, C_I)$$

Where

T_e = The effective shear stress at the soil water interface.

C_f = Parameter describing the potential of the vegetal cover to dissipate turbulent eddies in the immediate vicinity of the boundary.

$f\,(C_f)$ = A function describing the vegetal influence on turbulence generated at the soil boundary.

$g\,(C_f, C_I)$= A function describing the vegetal influence on turbulence generated in the flow field by vegetal drag.

As $g\,(C_f, C_I)$ tends to zero, when the vegetal cover is relatively uniform and dense, that is the turbulence generated by the vegetation at a significant distance from the soil-water interfere would not significantly affect condition at the soil boundary $f(C_f)$.
Equation 6 becomes:

$$Te = Yds\,([1.0\text{-}C_f)\,(n_{s/n})^2] \qquad (7)$$

Where,

Y = 9800N m^{-3} (weight of water).

n_s = 0.0156 (a constant).

Temple (1982) in applying Eq. 7 above derived a formula'

$$C_I = K\,(h\,m\,)^1/_3 \qquad (8)$$

Where

C_I = The vegetative retardance or curve index.

K = The relational constant, 2.5.

h = The average height of the plant stem.

M = The density of the stem per unit area.

Bermuda grass (Cynodon dactylon) of the creeping cover group, with estimated cover factor, Cf of 0.90 and reference stem density of 5380 strem/m^2 is widely used for the design of grass waterways especially in the tropics the design of grass waterways especially in the tropics (Webster and Wilson, 1980; Morgan, 2000).

Design program: The program used is a dialogue computer operation (usually involving some form of question and answer interaction where the computer asks questions and the user (designer) provides the answers.

The program was initially written in Quick-Basic and is being updated using Visual Basic 6.0.

It consists of one main program and nine subroutines. Each subroutine open the user to background information and data needed for the successful operation of the design program procedure.

MATERIALS AND METHODS

The design procedures for a given discharge, Q, channel gradient, S and stem height h (h > = 0.005 or < 0.15) was executed in the following steps:-

1 Determination of soil and cover condition critical to stability and channel Capacity design.
2 Choice of desirable channel shape; parabolic, triangular or trapezoidal (Fig. 1).
3 Estimation of stem count, M (Table 1).
4 Computation of vegetal cover factor, C_F (Table 1).
5 Computation of reference curve index, C_I (Eq. 8).
6 Initialization of the constants:-
   - a = 0.01329,
   - b = - 0.09543,
   - c = 0.2971,
   - d = 4.16, $V_{74} = 9.3\times10^{-7}$ $m^2/_5$,
   - Y = 9800 N/M^3 (weight of water),
   - ns = 0.0156
7 Input desired channel length, L
8 Input side slope Z
9 Input channel bed width (if trapezoidal), B
10 Input reference channel width measured at 0.305 m depth (if parabolic), W
11 Estimation of the velocity of flow.
12 Computation of Rv - $(VR/V_{74})\times10^{-5}$) Eq. 2b.
13 Computation of Manning's equation (n_R = exp. (C_I [0.0133 [ln (Rv)]^2- 0.0954 ln (Rv) + 0.2971 - 4.16]) Eq. 2a.
14 Input cost of channel excavation per unit volume (N M^{-2}), G_1

Table 1: Input data to Test run the computer design program

Parameter	Q_1	Q_2	Q_3
Q (m^3 s^{-1})	10	10	6.0
S (%) (Bed slope)	0.03	0.03	0.02
Z (side slope ratio)	2.0	2.0	4.0
h (m)	0.1	0.4	0.16
M (stem m^{-2})	3600	7200	5380
Cf	0.90	0.90	0.90
b (m)	29.2	-	10.0
L (m)	100	100	100
Channel width (m)	-	29.6	5.0
Depth (m)	-	0.305	0.305

Source: Temple (1983), Green and Garton (1983)

15 Input cost of base lining material per unit length G_2.
16 Input cost of side lining material per unit length G_3.
17 Computation of channel cross-sectional Area A. (Table 1).
18 Computation of flow depth, de (Table 1).
19 Computation of channel volume Ve-(Table 1).
20 Computation of channel wetted perimeter, P (Table 1).
21 Computation of hydraulic radius R (Table 1).
22 Computation of channel top width, t (Table 1).
23 Computation of allowable tractive force Te (Te = Yds ([1.0 Cf) (ns/n)^2]).
24 Computation of channel freeboard F = 0.2de from step 18.
25 Computation of total material cost per unit length G5; Cs = μs [volume/Unit length] =μs ts (2E + 2E') = 2T (y + F) $\sqrt{1+Z^2}$.
26 Computation of total cost of material for unit area G6; C = Cb + Cs = bB + K + 2Y (y + F) $\sqrt{1+Z^2}$.
27 Display output of steps 13, 17-26.
28 Display labelled channel section.
29 Return to step 1 for another design computation.
30 Otherwise.

RESULTS AND DISCUSSION

The computer program was test run to determine the following:

Q_1 : The width and depth required for a Bermuda grass lined channel in a silt loam soil. Channel is to be trapezoidal with side slope of 2:1and a bed slope of 3%. The design discharge is 10 m^3 s^{-1} Cover condition is anticipated to have a fair stand of grass with a stem length of 10 cm. Reference stem density was assumed to be 3600 stem m^{-2}. The same data were used to compute for parabolic and triangular channels.

Q_2 : The width and depth required for Bermuda grass lined channel in a silt-loam soil. Channel is to be parabolic and a bed slope of 3%. The design discharge is 10 m^3 s^{-1} cover condition is anticipated to have a fair stand grass with a stem length of 40 cm. Assumed reference stem density to be 7200 stem m^{-2}. The same data were use to compute for trapezoidal and triangular channel.

Q_3 : Design of trapezoidal channel with 4:1 side slope lined with Bermuda grass, down a gradient of 2% and with a discharge capacity of 6.0 m^3 s^{-1}. Assume a limit velocity of 1.8 m s^{-1} on an easily eroded soil and vegetal retardance of B and D, Reference stem density, M = 5380 stem m^{-2} grass height = 0.16 m.

Table 2: Results of Q_1 from data source and computer design computation

Parameter	Data source	Computer	Design	Computation
Channel type:	Trapezoidal	Trapezoidal	Parabolic	Triangular
d (m)	0.2100	0.2000	0.3000	1.7100
f (m)	_	0.0400	0.0600	0.3400
de (m)	_	0.2400	0.3600	2.0600
p (m)	_	30.0900	32.1800	7.6700
t (m)	_	30.1500	32.1700	8.2300
n (Manning's no.)	0.0380	0.0382	0.0389	0.0292
C_I	4.5400	4.5400	4.5400	4.5400
Te (Pa)	1.0400	0.9700	1.4200	14.4200
A (m^2)	_	5.8800	5.8800	7.0600
Ve (m^3)	_	588.2400	587.6400	705.8800
b (m)	29.200	_		

N.B. Bermuda grass lined channel in a silt-loam soil was assumed

Table 3: Results of Q_2 from data source and computer design computation

Parameter	Data source	Computer	Design	Computation
sChannel type:	Parabolic*	Parabolic*	Trapezoidal	Triangular
d (m)	0.3200	0.300	0.1500	1.7100
f (m)	_	0.060	0.0300	0.3400
de (m)	0.3300	0.360	0.1800	2.0600
p (m)	_	31.890	29.8600	7.6700
t (m)	_	31.880	29.9100	8.2300
n (Manning's no)	0.0709	0.795	0.0765	0.0475
C_I	8.0900	8.080	8.0800	8.0800
Te (Pa)	_	0.340	0.1800	5.4300
A (m^2)	_	5.880	4.3500	7.0600
Ve (m^3)	_	587.640	434.7800	705.8800

Table 4: Results of Q_3 from data source and computer design computation

Parameter	Data source	Computer	Design	Computation
Channel type:	Trapezoidal*	Trapezoidal*	Parabolic	Triangular
d (m)	0.3500	0.3100	0.8600	1.1000
f (m)	0.0700	0.0600	0.1700	0.2200
de (m)	0.4200	0.3800	1.0300	1.3100
p (m)	12.9000	12.5900	9.4000	9.0300
t (m)	13.3800	13.0100	9.1900	10.5200
n	0.0602	0.0447	0.0411	0.0407
C_I	_	5.9600	5.9600	5.9600
Te (pa)	_	0.7500	2.4200	3.1500
A (m^2)	4.0000	3.5300	4.8000	5.7600
Ve (m^3)	_	352.9400	479.8900	576.0000

The other input data to test run the computer design program are as shown in Table 1 below.

The results were compared with those obtained manually using the numerical methods as given by Temple (1983) and Green and Garton (1983). Other results are as shown in Table 2-4.

The results for the computation are as presented in Table 2-4. There are slight differences in design parameters compared with results obtained manually from data source. The differences were believed to be due to approximations in manual calculation using the numerical method by the authors. Thus the results obtained under this study were satisfactory.

The following observations were made from the results computed above:

- The depth of flow, d increase in the order: trapezoidal ➜ parabolic ➜ Triangular channels for the same conditions.
- The Manning's roughness number, n increase in the order: Triangular ➜ Trapezoidal Parabolic. ➜
- The Tractive force, Te decreases Triangular Parabolic ➜ Trapezoidal.

The Tractive force method used for the design procedures allows the properties of the soil and those of the vegetation to be considered separately, this eliminating the problem involved in calculating the manning is roughness coefficient, n based on Manning's flow equation which is now a function of flow condition as well as boundary conditions.

CONCLUSION

The importance and advantages of the use of vegetated channels for various agricultural purposes cannot be over emphasized; hence the following should be put into consideration to ensure satisfactory channel construction and maintenance.

This design program should be the future be update to allow flexibility in terms of varieties of vegetative cover as against only Bermuda grass considered.

The designer using this computer program should have an understanding of flow behaviour and knowledge of local condition of the soil which is necessary ingredient to a successful design.

The minimum recommended channel size for trapezoidal channel is breath b = 2m and depth of flow, d = 0.5 m.

This size will help to avoid a case where the design parameters will be two small for easy channel construction and maintenance.

Nomenclature:

A : Channel cross sectional area (m^2).
B : Bed width of a Trapezoidal channel (m).
C_F : Vegetal cover factor.
C_I : Vegetal retardance curve index.
D : Flow depth (m).
H : Average stem length (height) of a gross lining (m).
M : Average number of stems per unit area (stem m^{-2}).
n : Manning is coefficient for the entire channel.
n_s : Manning's coefficient associated with the soil only (0.0156).
P : Channel wetted perimeter (m).
Q : Volumetric discharge of channel (m^3/s).
R : Channel hydraulic radius (m).
Rr : Form of flow Reynold is number assuming a reference viscosity.
S : Energy slope (m m^{-1}).
V : Mean velocity (m s^{-1}).
W : Reference channel width measured at 0.305 m channel reference depth (m).
Z : Cotangent of bank slope angle (measured at water surface).
Y : Unit weight of water (N m^{-3}).
V_{74} : Reference kinetic viscosity (m^2 s^{-1}).
T_e : Effective tractive force (N m^{-2}).
T : Top width of flow (m).

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