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OPEN CHANNEL DESIGN IN A MINUTE

BY

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ABSTRACT

In Pakistan the design of channels for irrigation and drainage (both lined and unlined) is usually prepared manually with the help of scientific calculators by the design engineers in various government and private agencies. Besides a lot of time consumed on the manual calculations, errors and doubts are never finished. As a result the design job as well as the execution of various irrigation and drainage projects is delayed. A practice of design using small computer programs has been started in the design office of SCARP-VI, Water, Central Division WAPDA, which gives the design of an open channel in a minute or even in shorter time. The calculations and the results are not only error proof but also give a wide range of record of relative additional informations that helps in the approval of the design from the competent authority. As an experiment two open channels were first designed manually with the help of a scientific calculator which took two days. The same channels were then designed with the help of an IBM computer having programs MAN.BAS and LAC.BAS installed in it, which took only one minute.

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INTRODUCTION

Open Channel Design, a job that involves a lot of calculations, solutions of the equations and determining the optimal parameters, was being done manually with the help of scientific calculators in the Design Office SCARP-VI, Water, Central Division WAPDA, as a part of its following assignments (WAPDA, 1986):-

1. Hydraulic design of irrigation channels and open drains.
2. Design of all the pertinent structures of canals and drains, like culverts, bridges, aqueducts, syphons, falls and drainage inlets tc.
3. Design of tubewells and their pertinent structures.
4. Compilation and review of technical specifications.
5. Compilation of Bill of quantities.

The organization of this design office was originally consisting of 10 design engineers but since 1989 was reduced to 3 design engineers handling almost the same assignments. There were also M/S NESPAK/ILACO, the Consultants, to help the WAPDA engineers uptil 1991, but now the design job is totally done by these three WAPDA engineers in this office. The reduction of staff didn't affect the progress of the office as an IBM computer was given to staff in 1990, to supplement the manual jobs. Two computer programs of channel design were written in March 1991, in BASIC computer language (Gottfried, 1982) on the basis of the design criteria given by WAPDA to the design office SCARP-VI (WAPDA, 1981). An experiment was performed in the office in April 1991 to test these programs which proved very useful and superceded the existing practice, i.e. the manual procedure of design with the help of a scientific calculator.

THE DESIGN CRITERIA OF CHANNELS

The all design offices in WAPDA have to follow the procedure of design in WAPDA's Design Guide (1969), for the design of lines or unlined channels.

This procedure was based on Manning's Equation for the lined and clear water unlined channels and Lacey's Equations for the silt carrying unlined channels.

Th design criteria for the uniform flow open channel is same as by Ven Te Chow (1959), given in his book 'Open Channel Hydraulics'. This Chow Method is the manipulation of Manning's Equation to find the correct parameters for the design of lined and clear water channels. The Manning's roughness coefficient, n, recommended for the lined channels is .018 (average), and for the unlined .03.

Similarly the earthen silt carrying channels are designed with the Equations of Lacey (1932), developed after the research of Kennedy (1895), for non silting. These equations may be introduced one by one as follows :-

Manning's Equation used by Ven Te Chow in Open Channel Hydraulics is modified in such a manner that the left hand side of the equation remains only a section factor, i.e. involving only width, depth and side slope of a channel. This section factor can be assumed and corrected by trial and error to equalise with the right hand side of the equation which consists of the given, natural or fixed data that can't be changed due to one or another reasons, i.e., for a given discharge, Q in cusecs and longitudinal slope S of an area with roughness n, a hydraulic section assumed is o.k. if the following equation satisfies :-

$$AR^{2/3} = \frac{Q_n}{1.486 \sqrt{S}} \qquad (1)$$

Where

A is the cross section calculated from the assumed b and d of the channel in square ft, where b is the bed width and d is the normal depth in ft.

R is the hydraulic radius of the channel in ft, equal to A/P where P is the wetted permitter of the channel in fit.

For a trapezoidal section :-

$$A = b\,d + z\,d^2 \qquad (2)$$

where z is the side slope of the trapezoidal section and :

$$P = b + 2\,d\,(1 + z^2)^{0.5} \qquad (3)$$

For the design of unlined silt carrying channels by Lacey's Method, Lacey's silt factor, f, of the path of the channel and the discharge, Q, in cusecs and Kannedy's C are given and the rest calculations are made with the following Lacey's and Kennedy's Equations :-

$$S = \frac{f^{1.6667}}{1844Q^{1.1667}} \qquad (4)$$

$$V = 0.79\, f^{0.3333}\, Q^{0.1667} \quad (5)$$

$$R = 0.47\, (Q/f)^{0.3333} \quad (6)$$

$$A = 1.26\, \frac{Q^{0.8333}}{f^{0.3333}} \quad (7)$$

$$P = 2.67\, Q^{0.5} \quad (8)$$

Where;

S is the longitudinal slope of the channel, V is the mean velocity in ft/sec, R is the hydraulic radius in ft, A is the cross sectional area in sq ft and P is the wetted perimeter of the channel in ft.

The area A and wetted perimeter, P, calculated by Equation-7 and Equation-8 are used in the Equations, 2 and 3 with side slope, z of 0.5 (fixed) and the following two new equations are developed (WAPDA, 1981) for calculating the bed width, b, and depth d simultaneously :-

$$d = \frac{P - (P^2 - 6.944 \times A)^{0.5}}{3.472} \quad (9)$$

$$b = P\ 2.236\, d \quad (10)$$

The mean velocity V calculated by Equation - 5 is compared with the velocity calculated by the following Kennedy's Equation :-

$$Vo = C\ d^{0.64} \quad (11)$$

where d is the depth of channel calculated by the above Lacey's Equations and C is a Kennedy Coefficient ranging from 0.56 - 1.09 depending upon the soil texture of the bed i.e. in clay or extremely fine soils, its value will be .56 and in coarse silt or hard soil debris its value will be 1.09 (Chow. 1959). If the mean velocity V, calculated by Equation - 5 is greater

than the velocity calculated by the Kennedy's velocity Vo or Equation - 9, the design is considered to be as o.k. otherwise the given Lacey's or Kennedy's C, is doubtful and is informed to the data suppliers.

MATERIAL AND METHODS

In the experiment two channels were to be designed first manually with the help of a scientific calculator, CASIO fx 100 and then using computer programs written on the IMB Skata computer of the said design office. A brief introduction of the computer and computer programming is given as below :-

A computer is a device for performing computations at incredible speeds with great accuracy (Koffman & Fridman, 1987). Because of its capacity for large quantities of data and ability to carry out long sequences of operations without human intervention it may be used in the solution of the problems of science, engineering, and education (McCracken & Salman, 1987). A sketch of computer showing its parts/accessories is given in Figure 1.

A computer program is an appropriate set of instructions stored in a computer's memory for as long as they are needed (Gottfried, 1982). At any time a stored program can be executed causing following 3 things to happen :

1. A set of information called the input data is entered from a keyboard and stored in a portion of the computer's memory
2. Input data is processed to produce certain desired results known as output data.
3. The calculated data and perhaps some of the input data is printed out on a sheet of paper on a printer or displayed visually on a screen called monitor. The three step procedure can be repeated many times if desired thus causing a large quantity of data to be processed in rapid sequence.

The two written computer programs as told earlier were saved, the one is named as MAN.BAS for the design of lined or unlined clear water channels by Chow Method using Manning's formula, and the other is named as LAC.BAS for the unlined silt carrying channels using Lacey's and Kennedy's formulas. Both of these programs (Code listings) are given at APPENDIX - Ia and IIa respectively. The formatting (rounding of decimals) of the output was avoided to know the exact results of the calculations.

In the programme MAN.BAS, computer asks for feeding data of Q, n, S, z, b and d. Values of Q, n, S, z and d are fixed with the help of field data and the corresponding b is first assumed and fed in to the computer. The computer starts calculations with the assumed b and indicates whether the assumption was right or wrong and starts calculation

automatically with an other b = 0.5 ft smaller than the former if the former was giving uneconomical design or 0.5 ft greater if the former was giving design not O.K. This process is repeated until the correct design is underlined.

Similarly in the program LAC.BAS Q,f, C are demanded and when these ar fed the program gives results with Lacey's equations, alongwith the Kenndey's velocity calculated with the help of the depth, d calculated by Lacey's Method in few seconds. The program compares the Kennedy's velocity, Vo, with the Lacey's mean velocity, V, and if V is greater than Vo, it tells that the design is o.k.

THE EXPERIMENT

The following two channels were designed first by calculator and then by running of the above two programs, i.e., 1 MAN.BAS, 2-LAC.BAS, in April, 1991 :-

1. A clear water channel (surface drain) of 100 cusecs is to be designed for a given longitudinal slope of 1/5000 and side slope of 1.5. Maximum allowable depth is 3.5 ft.
2. The above capacity channel is a silt carrying and is to be designed for R.Y.K. District area with a given Lacey's f of 0.87 & Kennedy's C of 0.63.

The design by calculator took two days, i.e., 14th and 15th of April, 1991 and sixteen sheets of paper were consumed on recording of the calculations of design, i.e. trial and errors to find the correct design parameters. The same channels were then designed by the computer programs on 15th April, 1991, which took only one minute.

The following procedure was followed for the design on computer :-

Channel - 1. Put on a computer with a BASIC, GWBASIC or BASICA system programs installed inside the computer, or installed with the help of a floppy disc having system of any of these languages.

When OK prompts on the computer's screen type or copy the program MAN.BAS as given in the APPENDIX-Ia. Save MAN.BAS with the help of key F4. Now run the program with the help of key F2 and type the data as asked on the screen as follows :-

Q, n, S, z, b, d ?

Now the data will be typed by the computer operator as follows : - 100,.03.,0002, 1.5,20,3.5

Pressing the Return key of the computer, will given the results or the output as shown in APPENDIX-Ib, in few seconds.

Again press F2 and type the data as follows :-

100,.03,.0002,1.5,13,3.5

Pressing the Return Key, the computer will give the output as shown in APPENDIX-Ic. Channel 2.Do the same as for the example-1 but instead of MAN.BAS, now copy and save LAC.BAS from the APPENDIX-IIa. Now run the program with the help of F2 and give data of Example-2.

The computer will ask to feed the data as follows :- Q,f, C? Now the data will be typed by the computer operator as follows :-

100,.87,.63

Pressing the Return Key of the computer will give the results or output given in the APPENDIX-IIb in few seconds.

RESULTS AND DISCUSSION

The results of 16 sheets, i.e. 14 for channel no. 1 and two for the channel no. 2, of manual calculations are summarised in Table-1 and Table-II.

The results of computer design, i.e. three output sheets are given as such at the Appendix Ib, Ic, and IIb.

The output of the program MAN.BAS given in APPENDIX-Ib and Ic shows a series of uneconomical or incorrect results and then stopping at the results when the design is o.k. In each iteration the computer calculates cross sectional area in sq ft, wetted perimeter in ft, hydraulic radius in ft, simple velocity in ft/sec and Manning's velocity in ft/sec. Then computer gives left hand side and right hand side of the equation for comparison according to Chow method. The whole job if we do manually will take at least a day for the selection of the right design. But the computer gives in few seconds. The iterations are limited in such a manner that if the assumed or fed bed width, b is lessor than the required one it will start increasing by half ft and if it is greater, it will start decreasing to find the correct design. However a limit of 20 trials is given to save the papers. That is the computer will stop after 20 trials if the assumed b was not within 10 ft plus or minus range of the correct one. The program is again run with another estimated b seeing the first 20 trials output. Second time definitely the estimated value will be closer.

A question may arise as why d was fixed and not the b when both b and d were to be estimated. Like this example, in many cases there is constraint of maximum allowable depth because of fear of additional dewatering expenses if depth goes beyond this.

Just as the program MAN.BAS finds correct bed width, b, with a fixed depth, d = 3.5 ft, the same may give another correct b with another fixed depth according to another field data say 3 ft or 2.5 ft etc. Similarly another program MAN2.BAS may be written and used for the cases where b is necessary to be fixed and the corresponding correct d is desirable, simply by replacing the line no. 21 and 24 of the program MAN.BAS (given in Appendix-Ia) as follows :-

```
21 D = D-. 1:GOTO 3

24 D = D+. 1:GOTO 3
```

The program MAN2.BAS will, thus give a correct d with a fixed b similarly by increasing or decreasing the incorrect estimated d by 0.1 ft or whatever the breakup figure (as it was 0.5 ft for b) the programmer wants and writes in the lines 21 and 24. Similarly the comparison scale, K, is also at the discretion of the programmer which is Q/20 in the program presented here. The K may be decreased to Q/25, Q/30 or Q/50 if more accuracy is needed or increased to Q/15 or Q/10 if o.k. result is not available.

The output of the program LAC.BAS, given in the Appendix-IIb, shows bedwidth b in ft, depth d in ft, Lacey's mean velocity V in ft/sec, hydraulic radius R in ft, longitudinal bed slope So, area A in sq ft, wetted perimeter P in ft and Kennedy's Vo in ft/sec and then tells after comparing V and Vo that the design is O.K. If Kennedy's Vo was not less than Lacey's V then it was to tell that the design is not o.k.

CONCLUSION

The above two programs, MAN.BAS and LAC.BAS introduced in the Design Office of SCARP-VI, WAPDA, have reduced a lot of work load of calculations used in the design of lined and unlined channels. Similar programs may be written for the other design office assignments also for quicker and error proof results. The engineers who were not liking the design job previously due to fear of errors in long mathematical calculations, now will not hesitate after learning the computerised design. The professional engineers who are trained in computer languages, must write similar or better computer programs to change the traditional slow procedures in Pakistani offices into modern computerised methods to save time.

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TABLE - I

SUMMARY OF MANUAL CALCULATIONS FOR THE DESIGN OF A SILT FREE CHANNEL USING MANNING'S FORMULA AND CHOW'S METHOD

Sheet #	b ft	d ft	A sq ft	P ft	R ft	AR .667 (LHS)	RHS	Remarks
1.	50.0	3.5	193.38	62.62	3.09	410.23	142.75	Not o.k.
2.	40.0	3.5	158.38	52.62	3.01	330.27	142.75	Not o.k.
3.	30.0	3.5	123.38	42.62	2.89	250.68	142.75	Not o.k.
4.	20.0	3.5	88.38	32.62	2.71	171.61	142.75	Not o.k.
5.	10.0	3.5	53.38	22.62	2.36	94.63	142.75	Not o.k.
6.	18.0	3.5	81.38	30.62	2.66	156.18	142.75	Not o.k.
7.	12.0	3.5	60.38	24.62	2.45	109.83	142.75	Not o.k.
8.	13.0	3.5	63.88	25.62	2.49	117.48	142.75	Not o.k.
9.	15.0	3.5	70.88	27.62	2.57	132.88	142.75	Not o.k.
10.	17.5	3.5	79.63	30.12	2.64	152.30	142.75	Not o.k.
11.	15.5	3.5	72.63	28.10	2.58	136.76	142.75	Not o.k.
12.	17.0	3.5	77.88	29.60	2.63	148.40	142.75	Not o.k.
13.	16.0	3.5	74.38	28.62	2.60	140.60	142.75	Not o.k.
14.	16.5	3.5	76.13	29.12	2.61	144.51	142.75	o.k.

TABLE - II

SUMMARY OF MANUAL CALCULATIONS FOR THE DESIGN OF A SILT CARRYING CHANNEL OF 100 CUSECS WITH LACEY'S SILT FACTOR OF 0.87 AND KENNEDY'S C OF 0.63, BY LACEY'S METHOD.

Lacey's Mean Velocity,	V	=	1.63 ft/sec
Lacey's Hydraulic Radius,	R	=	2.28 ft
Lacey's Cross Section,	A	=	61.25 sq ft
Lacey's Wetted Perimeter,	P	=	26.7 ft
Lacey's Depth,	d	=	2.8 ft
Lacey's Bed Width	b	=	20.43 ft
Lacey's Bed Slope,	So	=	0.0001995
Kennedy's Velocity,	Vo	=	1.22 ft/sec

V is greater than Vo therefore the design is o.k.

APPNDIX Ia

COMPUTER PROGRAM "MAN.BAS"

```
0   LPRINT   DESIGN OF CHANNEL USING MANNING'S FORMULA
1   PRINT "Q, n, S, z, b, d ?"
2   INPUT  Q, N, S, Z, B, D
3   LPRINT
4   LPRINT "Q="; Q, "n="; N, "S="; S, "z="; Z, "b="; Z, "b="; B, "d="; D
5   A=B*D+Z*D*D
6   P=B+2*D*(1+Z^2)^.5
7   R=A/P
8   LHS=A*(R^.667)
9   RHS=Q*N/(1.486*S^.5)
10  V=Q/A
11  MV=(1.486*R^.667*S^.5)/N
12  LPRINT "The results are as follows :-"
13  LPRINT "A=";A, "P=";P, "R=";R, "V=Q/A="; V; "Mann. V="; MV, "LHS="; LHS,
    "RHS="; RHS,
14  IF LHS<RHS THEN LPRINT "DESIGN IS NOT O.K. ":GOTO 24
15  DD=LHS-RHS
16  K=Q/20
17  IF DD>K THN LPRINT" DESIGN IS UN-ECONOMICAL _____"
18  IF DD>K THEN 19: ELSE IF DD<K AND DD>0 THEN 22
19  I=I+1
20  IF I>19 THEN 25
21  B=B-. 5: GOTO 3
22  IF DD>0 AND DD<K THEN LPRINT"DESIGN IS O.K. ******************"
23  GOTO 25
24  B=B+ .5: GOTO 3
25  END
```

APPENDIX Ib

DESIGN OF CHANNEL USING MANNING'S FORMULA

Q = 100 n = .03 S = .0002 z = 1.5 b = 20 d = 3.5
The results are as follows :-
A = 88.375 P = 32.61943 R = 2.709275 V=Q/A= 1.131542 Mann. V= 1.361838
LHS = 171.8076 RHS = 142.7537
DESIGN IS UN-ECONOMICAL

Q = 100 n = .03 S = .0002 z = 1.5 b = 19.5 d = 3.5
The results ar as follows :-
A = 86.625 P = 32.11943 R = 2.696966 V=Q/A= 1.154401 Mann. V= 1.357708
LHS = 167.8948 RHS = 142.7537
DESIGN IS UN-ECONOMIICAL

Q = 100 n = .03 S = .0002 z = 1.5 b = 19 d = 3.5
The results are as follows :-
A = 84.875 P = 31.61943 R = 2.684267 V=Q/A= 1.178203 Mann. V= 1.353441
LHS = 163.9859 RHS = 142.7537
DESIGN IS UN-ECONOMICAL

Q = 100 n = .03 S = .0002 z = 1.5 b = 18.5 d = 3.5
The results are as follows :-
A = 83.125 P = 31.11943 R = 2.671161 V=Q/A= 1.203008 Mann. V= 1.34903
LHS = 160.0813 RHS = 142.7537
DESIGN IS UN-ECONOMICAL

Q = 100 n = .03 S = .0002 z = 1.5 b = 18 d = 3.5
The results are as follows :-
A = 81.375 P = 30.61943 R = 2.657627 V=Q/A= 1.228879 Mann. V= 1.344466
LHS = 156.1811 RHS = 142.7537
DESIGN IS UN-ECONOMICAL

Q = 100 n = .03 S = .0002 z = 1.5 b = 17.5 d = 3.5
The results are as follows :-
A = 79.625 P = 30.11943 R = 2.643643 V=Q/A= 1.255887 Mann. V= 1.339944
LHS = 152.2855 RHS = 142.7537
DESIGN IS UN-ECONOMICAL

Q = 100 n = .03 S = .0002 z = 1.5 b = 17 d = 3.5

The results are as follows :-

A = 77.875 P = 29.61943 R = 2.629187 V = Q/A = 1.284109 Mann. V = 1.334853

LHS = 148.3949 RHS = 142.7537

DESIGN IS UN-ECONOMICAL

Q = 100 n = .03 S = .0002 z = 1.5 b = 16.5 d = 3.5

The results are as follows :-

A = 76.125 P = 29.11943 R = 2.614234 V = Q/A = 1.313629 Mann. V = 1.329785

LHS = 144.5094 RHS = 142.7537

DESIGN IS O.K. **********

APPENDIX Ic

DESIGN OF CHANNEL USING MANNING'S FORMULA

```
Q= 100        n= .03        S= .0002      z= 1.5        b= 13         d= 3.5
The results are as follows :-
A= 63.875     P= 25.61943   R= 2.493225   V=Q/A= 1.565558  Mann. V= 1.288405
  LHS= 117.4819             RHS= 142.7537
DESIGN IS  NOT O.K.

Q= 100        n= .03        S= .0002      z= 1.5        b= 13.5       d= 3.5
The results are as follows :-
A= 65.625     P= 26.11943   R= 2.512498   V=Q/A= 1.52381  Mann. V= 1.295039
  LHS= 121.3221             RHS= 142.7537
DESIGN IS  NOT O.K.

Q= 100        n= .03        S= .0002      z= 1.5        b= 14         d= 3.5
The results are as follows :-
A= 67.375     P= 26.61943   R= 2.531046   V=Q/A= 1.48423  Mann. V= 1.301408
  LHS= 125.1699             RHS= 142.7537
DESIGN IS  NOT O.K.

Q= 100        n= .03        S= .0002      z= 1.5        b= 14.5       d= 3.5
The results are as follows :-
A= 69.125     P= 27.11943   R= 2.548911   V=Q/A= 1.446655  Mann. V= 1.307528
  LHS= 129.0249             RHS= 142.7537
DESIGN IS  NOT O.K.

Q= 100        n= .03        S= .0002      z= 1.5        b= 15         d= 3.5
The results are as follows :-
A= 70.875     P= 27.61943   R= 2.548911   V=Q/A= 1.410935  Mann. V= 1.313413
  LHS= 132.8868             RHS= 142.7537
DESIGN IS  NOT O.K.

Q= 100        n= .03        S= .0002      z= 1.5        b= 15.5       d= 3.5
The results are as follows :-
A= 72.625     P= 28.11943   R= 2.582734   V=Q/A= 1.376936  Mann. V= 1.319076
  LHS= 136.755RHS= 142.7537
DESIGN IS  NOT O.K.

Q= 100        n= .03        S= .0002      z= 1.5        b= 16         d= 3.5
The results are as follows :-
A= 74.375     P= 28.61943   R= 2.598759   V=Q/A= 1.344538  Mann. V= 1.324569
  LHS= 140.6293             RHS= 142.7537
DESIGN IS  NOT O.K.

Q= 100        n= .03        S= .0002      z= 1.5        b= 16.5       d= 3.5
The results are as follows :-
A= 76.125     P= 29.11943   R= 2.614234   V=Q/A= 1.313629  Mann. V= 1.329785
  LHS= 144.5094             RHS= 142.7537
DESIGN IS O.K. **********
```

APPENDIX IIa

COMPUTER PROGRAM "LAC.BAS"

```
0       PRINT "Q, f, C ?"
1       INPUT Q, F, C
2       LPRINT"         DESIGN OF CHANNEL BY LACEY'S FORMULA"
3       LPRINT "Q="; Q, "f="; F, "C="; C
4       V=. 79*(F^.333)*(Q^.1667)
5       R=. 47*((Q/F)^.333))
6       A=1. 26*((Q^.8333)/(F^.333))
7       SO=(1/1844)*(F^1.6667)/(Q^.1667)
8       P=2. 67*(Q^.5)
9       D=(P^2-6.944*A)^.5)/3.472
10      B=P-2.236*D
11      LPRINT"b="; B, "d="; D. "V="; V, "R="; R. "SO="; SO, "A="' A, "P="' P.
12      KV=C*D^.64
13      LPRINT "Kennedy Vo="; KV
14      IF KV<V THEN LPRINT "DESIGN IS O.K.
15.     LPRINT "************************************************************"
16.     IF KV>V THEN LPRINT "DESIGN IS NOT O.K. CHECK f AND FEED AGAIN."
18      END
```

APPENDIX IIb

DESIGN OF CHANNEL BY LACEY'S FORMULA

Q= 100 f= .87 C= .63
b= 20.42591 d= 2.805945 V= 1.625156 R= 2.281592 SO= 1.995427 E-04
A= 61.25064 P= 26.7
Kennedy Vo= 1.219302
DESIGN IS O.K.

****

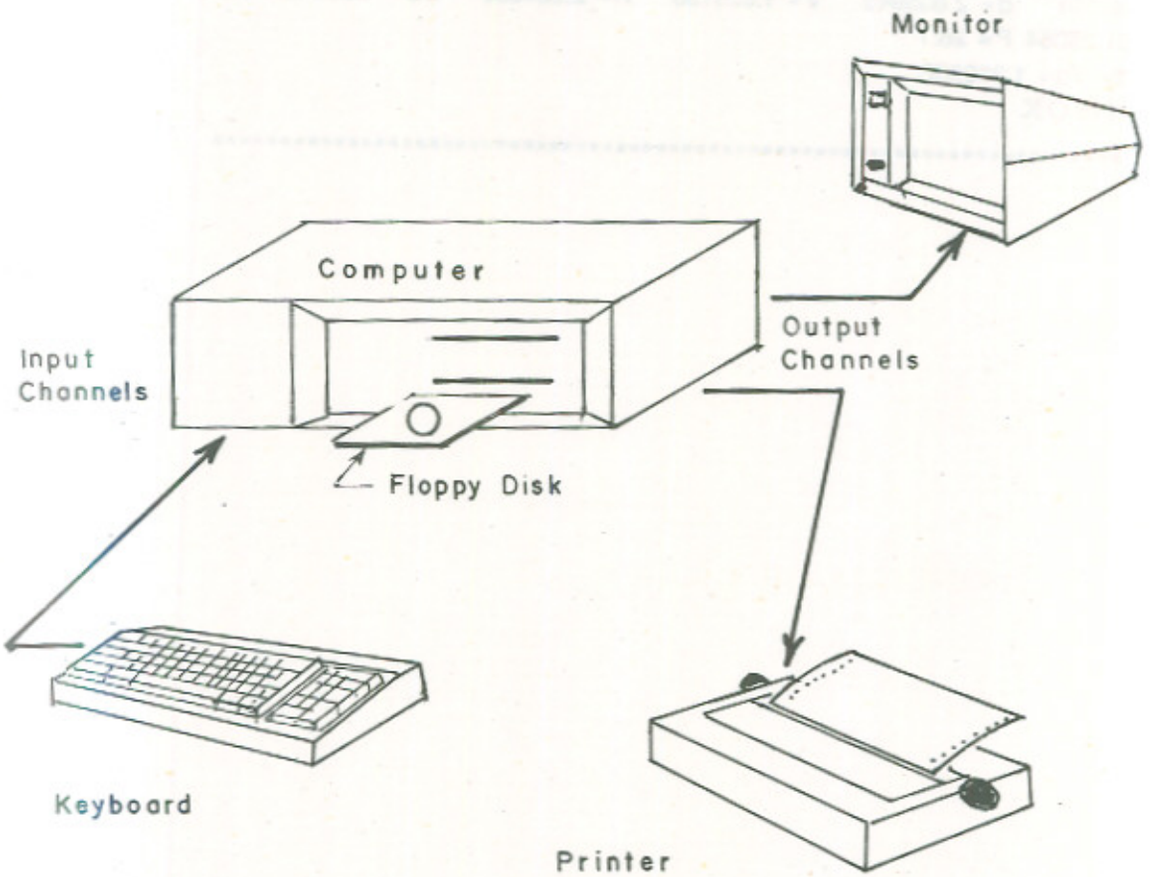


Figure 1. THE COMPUTER & ITS ACCESSORIES

DESIGN OF CHANNEL -1

b = 16·5'
d = 3·5'
S·S = 1·5:1

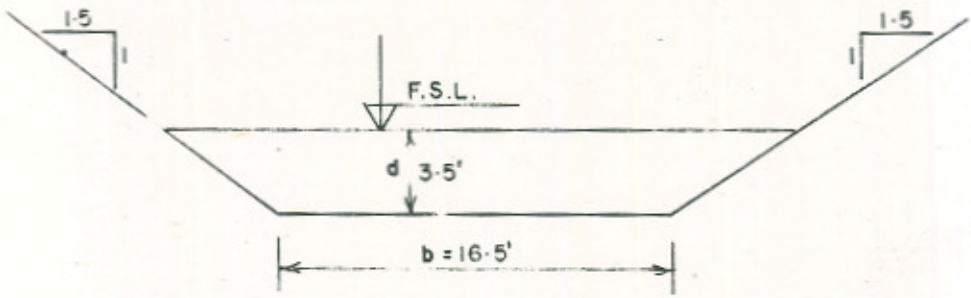


Figure – 2

DESIGN OF CHANNEL -2

b = 20·4'
d = 2·8'
S.S = 0·5:1

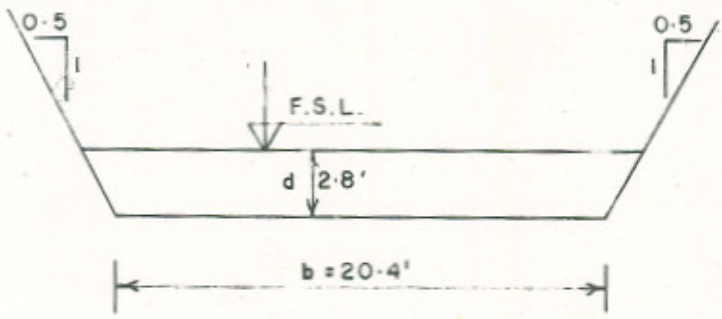


Figure – 3