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Design Charts and Design Equations for Trapezoidal Earthen Open Channels

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Abstract
Earthen trapezoidal open channels are widely used for various essential purposes. Easy and accurate design is necessary to obtain the dimensions that assure non-silting non-scouring water velocity to maintain these channels. In this paper, employing the Manning equation, design charts are established for each of the common equations of non-silting non-scouring water velocity. For each equation, relating water depth and bed width, three design charts are presented for different side slopes. Every design chart includes a direct relation between the discharge and the water depth for various longitudinal channel slopes. Knowing the discharge and the longitudinal slope, the water depth is obtained immediately from the design chart. Substituting in the velocity equation, the bed width is determined. From the established design charts, it is found that at each specific water depth, the relation between the discharge and the longitudinal slope is proportional for drains and is inversely proportional for canals. Regression analyses are employed to obtain design equations to find the water depth, which maintains non-silting non-scouring water velocity, for different types of soils and longitudinal channel slopes. For each longitudinal slope, a regression analysis is applied, and a design equation is obtained. All the obtained equations are integrated into only two general design equations for trapezoidal earthen open channels, which assure non-silting non-scouring water velocity and have coefficients of determination of almost 1.00. The developed design charts and equations are applied to a main canal in Egypt obtaining very accurate results.
Keywords: Non-silting; Non-scouring; Velocity; Canals; Drains; Unlined open channels.

1. Introduction
Earthen open channels are widely used for various purposes such as irrigation, flood protection, and drainage of agricultural lands. The trapezoidal cross section is common for these channels with different side slopes according to the type of soil.

There are several methods to design cross sections of open channels. One of these methods is non-silting non-scouring design that cares about the velocity of water through the channels. Low water velocity means that the velocity of the flow keeps the silts in suspension and does not permit them to fall reducing the area of the section. High water velocity means that the velocity of the flow keeps the stability of the section. It does not push particles from the bed and the sides to move away affecting the stability of the sides and increasing the area of the section.

In this paper, design charts are created in order to obtain the dimensions of the cross sections that guarantee non-silting non-scouring water velocity. These design charts include different types of earthen trapezoidal open channels with various types of soils. Regression analyses are employed to obtain design equations that can be used also to design these earthen trapezoidal open channels.

A universal solution to forecast the behavior of urban catchment for urbanization in terms of natural land-water cycles and its application in planning existing or new urban catchments were provided [1]. "According to Kopacz, *et al.* [2]" it was predicted that the demand for water in the agricultural sector of the Grybów commune, Małopolska province in Poland would increase by about 5.5% by 2030. Therefore, the activities monitoring the awareness of water saving and proper water management are important.

A lot of researches and attempts were made to attain the design of open channels for different uses. "According to Marangu, *et al.* [3]" the suitability of trapezoidal cross section with segment base in drainage system design was investigated for steady uniform open channel flow, where the effects of the channel radius, area of the cross section, the flow depth and the manning coefficient on the flow velocity had been presented graphically.

The effects of the width to depth ratio (b/d) on the cost of a trapezoidal concrete-lined channel were analyzed and a relation was developed to calculate the width to depth ratio according to a given discharge and bed slope by using linear genetic programming techniques [4].

"According to Kentli [5]" two different algorithms were applied for optimal design of canal sections considering seepage and evaporation losses and triangular, rectangular and trapezoidal cross-sections were optimized. Explicit solutions for the trapezoidal cross section using the non-dimensional forms of the governing equations in the normal and critical flow depths were obtained [6].

"According to El-Hazek [7]" design of best hydraulic section of open channels was presented by employing spreadsheets. Knowing the discharge, the longitudinal slope and the side slopes of the cross section, both the water depth and the bottom width were obtained.

A methodology to determine the optimal canal dimensions for a specific discharge was developed taking into consideration two constraints (minimum permissible velocity as a limit for sedimentation and maximum permissible velocity as a limit for erosion of canal) [8].

"According to Blackler and James [9]" different case studies were conducted indicating that the differences between the least-cost and most efficient cross sections were closely related to the channel lining to land acquisition cost ratio. A design for minimum earthwork cost of canal sections for triangular, rectangular, trapezoidal, and circular shapes were introduced applying non-linear optimization technique [10].

There are many online websites that serve the hydraulics of open channels. Some sites ask for paying charges [11]; and other sites provide free calculations [12]. All these sites employ different software for open channel flow. No site can design the required dimensions (water depth and bottom width) of the cross section in general, and specifically the non-silting non-scouring cross sections. Hydraulic calculations sites require always either the water depth or the bottom width.

The most widely used formula to design open channels is Manning equation [13]. It obtains the water velocity (v) through the open channel in terms of roughness of bed (n), longitudinal slope of channel (S), area of water (A), and the wetted perimeter (P). Introducing the continuity equation, Manning equation can obtain the discharge. However, both the water area and the wetted perimeter are functions in the water depth (y), the bed width (b), and the side slope (z:1). The side slope is assumed according to the type of the soil. Thus, Manning equation becomes one equation with two variables. In order to solve it, there must be a relation between the water depth and the bed width.

The most common relations between the water depth and the bed width are the best hydraulic section and non-silting non-scouring velocity. For instance, the best hydraulic channel section can be obtained for a given discharge (Q) by minimizing either P or A.

Kennedy's theory states that the suspended silt carried by flowing water rises towards the surface due to a vertical component of eddy current that is formed above the bed width of the channel [14]. A critical velocity is the velocity that maintains the channel free from both silting and scouring. This method is solved by try and error [15, 16].

"According to Kowalczyk, *et al.* [17]" an upward trend between the content of suspended solids and the concentration of biogenic components was found in Szreniawa River, Poland. The discharged industrial effluents caused gross pollution of the streams as most of the parameters including total dissolved solids (TDS) and turbidity recorded high values that exceeded the permissible limits of water quality [18].

Soil erosion in arid lands of Tunisia showed values oscillating between 0 and 163 $Mg.ha^{-1}.year^{-1}$ with very high annual erosion rates of an average rate of 3 $Mg.ha^{-1}.year^{-1}$ [19]. "According to Azmeri, *et al.* [20]" the actual conveyance efficiency was smaller compared to that of the designs in Krueng Baro, Aceh Province, Indonesia. The water loss was due to the damage to the channel lining and channel erosion resulting in high sedimentation and leakage.

Some trials were done to avoid try and error solution for the non-silting non-scouring velocity. Graphical solution, called "Nomograph", was adapted by assuming mainly the bed width [COLUMBIA COUNTY STORMWATER MANAGEMENT DESIGN MANUAL; U.S. DEPARTMENT OF TRANSPORTATION; [21]. "According to KÖVÁRI" design charts were introduced for different shapes of channels cross sections, which are not clear and difficult to be used.

There is a method to detect S that maintains the flow velocity non-silting non-scouring for a specific Q [22]. Knowing the value of Q, R is determined from a chart, and y is obtained from another chart. The ratio between b and y is calculated from R. Then b is got, and consequently the A is calculated. Substituting A in Manning equation concerning Q, the proper S is found. This method needs going through two charts in addition to making many calculations.

Accurate, simple and fast design of earthen trapezoidal open channels is essential for many countries to assist reclamation of new lands to face growth of population. For instance, Egypt, where the Nile River is the main source of irrigation water, the water is delivered to farms through a comprehensive delivery system of open channels with a total length of more than 30,000 km [23]; NATIONAL WATER RESOURCES PLAN FOR EGYPT 2017]. Drainage network in Egypt includes a system of large open channels having a total length of more than 17,000 km. That is in addition to the required channels for new reclaimed land.

In this paper, Manning equation will be used to obtain design charts and design equations for the sections with non-silting non-scouring velocity for trapezoidal earthen open channels with different side slopes 1:1, 3:2, and 2:1.

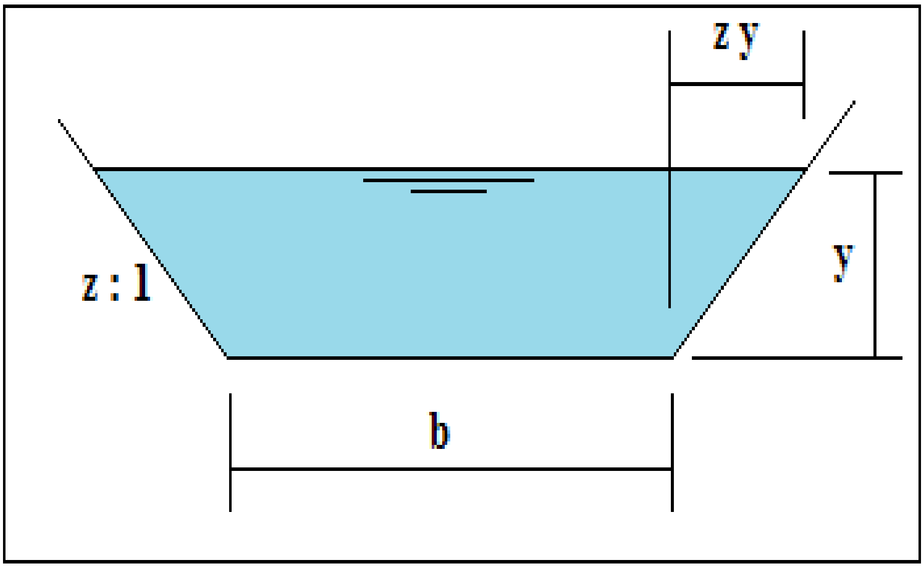
2. Methods

In this paper, Manning equation is employed together with equations of non-silting non-scouring water velocity that relate the water depth and the bottom width. "According to Chow [13]" Manning equation can be expressed as:

$$Q = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} A \qquad (1)$$

Where: Q = discharge (m^3/sec) & n = roughness coefficient & R = hydraulic radius = A / P (m) & A = area of water of the section (m^2) & P = wetted perimeter of the section (m) & S = slope of the bed of the channel (cm/km) & b = bed width (m) & y = water depth (m) & z:1 = side slope.

Fig-1. Typical Trapezoidal Cross Section for an Open Channel



For average conditions, the value 1/n is taken to be 40 for canals and 33 for drains, [22, 24]. The longitudinal slope is taken equal to the slope of the water surface (S = i) to maintain a uniform flow of water through the channel. Three side slopes are studied representing different types of the soils. These side slopes are 1:1, 3:2 and 2:1, [22, 25].

For earthen open channels, the water velocity is preferred to be non-silting non-scouring velocity. The widely used equations for canals are Eq. 2 for $y \leq 1.62$ m and Eq. 3 for $y > 1.62$ m [25, 26].

$$y = \frac{(i+8)^2 * b}{650} \quad (2)$$

$$y = 0.1\left(\frac{i}{2} + 4\right) b^{\frac{1}{2}} \quad (3)$$

The commonly used equations for drains are the following Eq. 4 through Eq. 7 [25, 26]. For $i \leq 10$ cm/km, Eq. 4 and Eq. 5 are used for $b \leq 2$ m and $b > 2$ m respectively. While for $i > 10$ cm/km, Eq. 6 and Eq. 7 are used for $b \leq 2$ m and $b > 2$ m respectively.

$$y = 0.96\, b \quad (4)$$

$$y = 1.5\, b^{\frac{1}{3}} \quad (5)$$

$$y = b \quad (6)$$

$$y = 1.75\, b^{\frac{1}{3}} \quad (7)$$

Employing Manning equation, design charts are established for each of the equations 2 through 7. For each equation, three design charts are presented for three side slopes with z equals 1.0, 1.5 and 2.0. Every design chart includes the relation between the discharge and the water depth directly for various longitudinal channel slopes. Knowing Q and i (S = i), the water depth y is obtained immediately from the design chart. Substituting in the proper equation among Eq. 2 through 7, the bed width b is obtained.

These values for y and b are the required dimensions of the channel cross section that make the water velocity in the channel satisfies the non-silting and non-scouring condition.

Regression analyses are employed to obtain design equations that can be used also to design different types of earthen trapezoidal open channels. For each longitudinal slope, a regression analysis is applied obtaining a design equation that relates the discharge and the water depth directly. All the obtained equations are integrated into two general design equations.

3. Results and Discussion

3.1. Design Charts for Canals

For canals of expected $y \leq 1.62$ m, Eq. 2 was applied with Manning equation for various values of i (S = i). The obtained results were presented graphically forming design charts, as shown in Fig. 2, Fig. 3 and Fig. 4.

It could be seen from Fig. 2, Fig. 3 and Fig. 4 concerning canals of $y \leq 1.62$ m that the discharge increased as the longitudinal slope decreased at each specific water depth.

Fig-2. Design Chart for Canals of y ≤ 1.62 m and z = 1.0

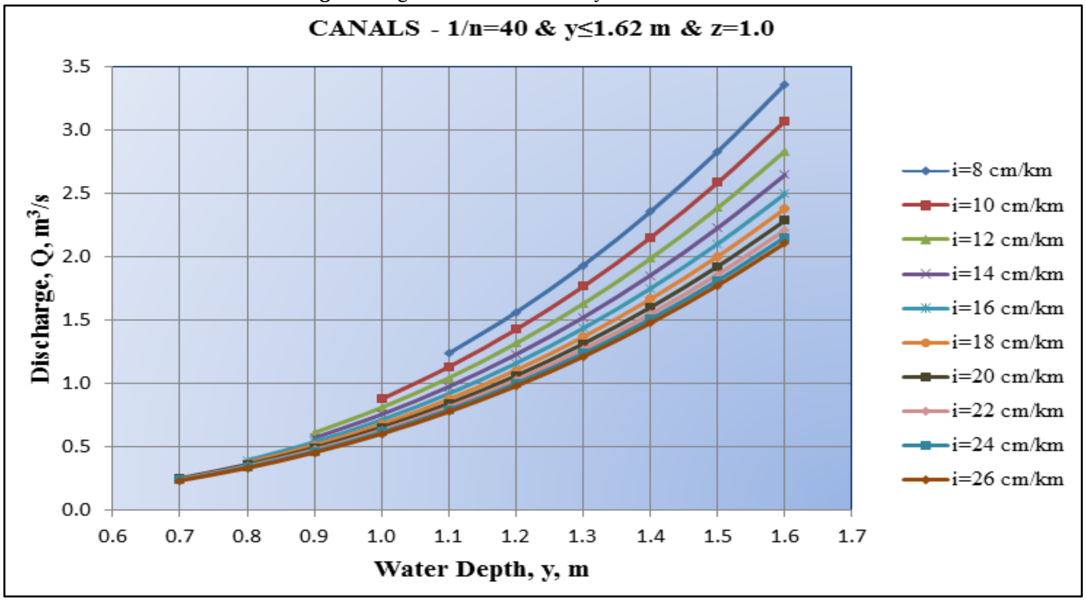


Fig-3. Design Chart for Canals of y ≤ 1.62 m and z = 1.5

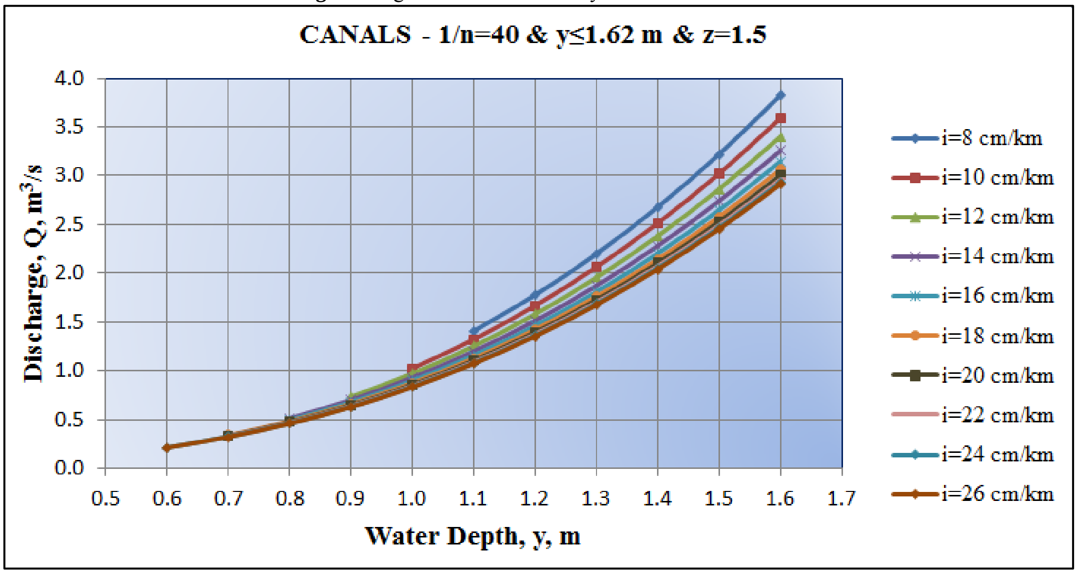
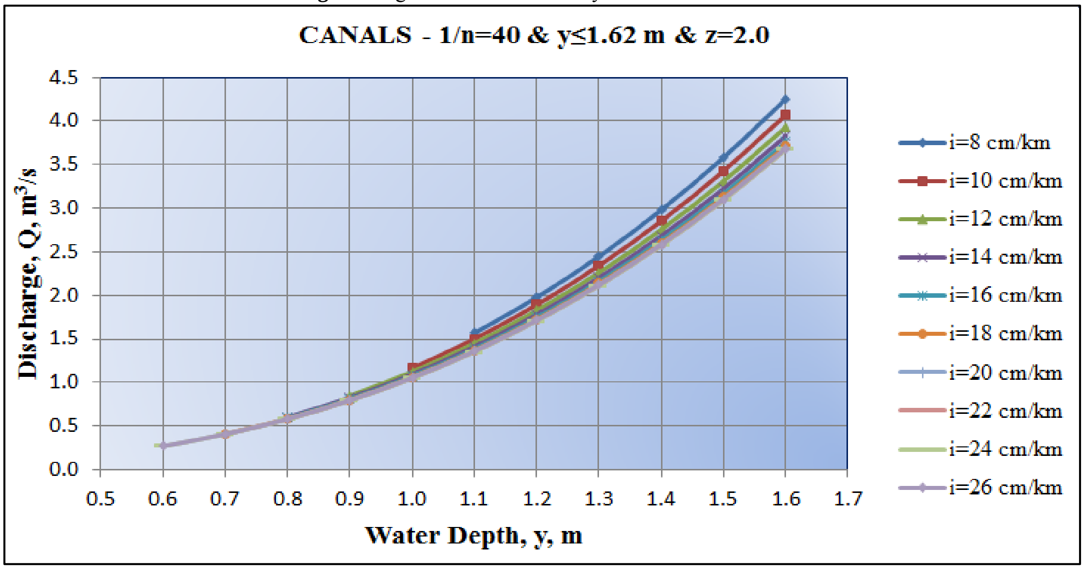


Fig-4. Design Chart for Canals of y ≤ 1.62 m and z = 2.0



For canals of expected y ≤ 1.62 m, Eq. 2 was applied with Manning equation for various values of i (S = i). The obtained results were presented graphically forming design charts, as shown in Fig. 5 through Fig. 13.

Fig-5. Design Chart for Canals of y > 1.62 m, z = 1.0 and Q < 20 m^3/s

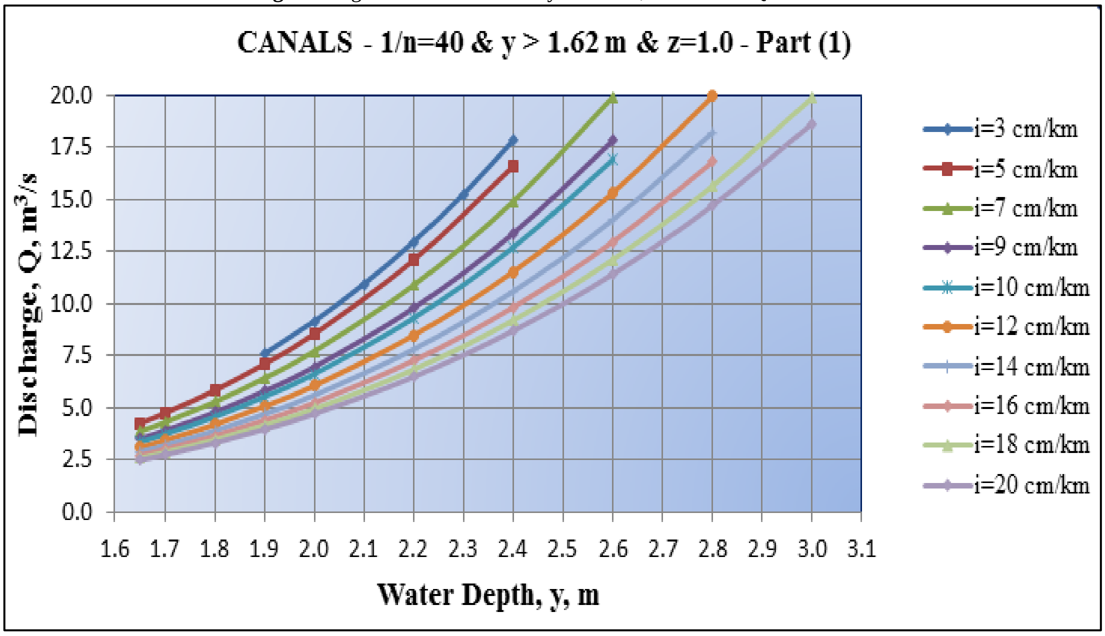


Fig-6. Design Chart for Canals of y > 1.62 m, z = 1.0 and 20 < Q < 100 m^3/s

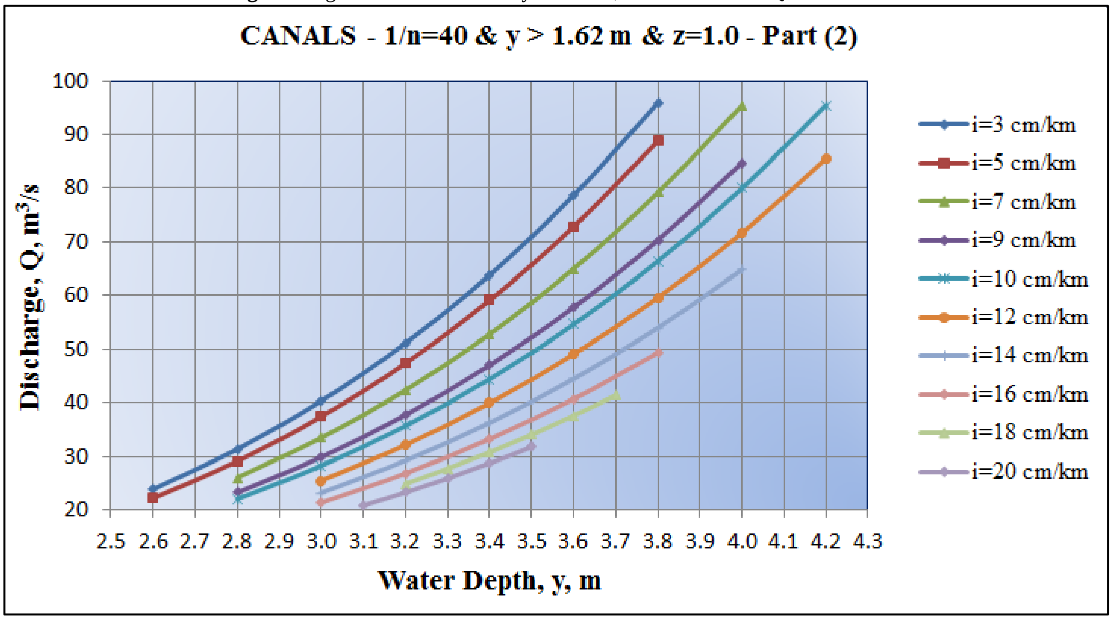


Fig-7. Design Chart for Canals of y > 1.62 m, z = 1.0 and 100 < Q < 280 m^3/s

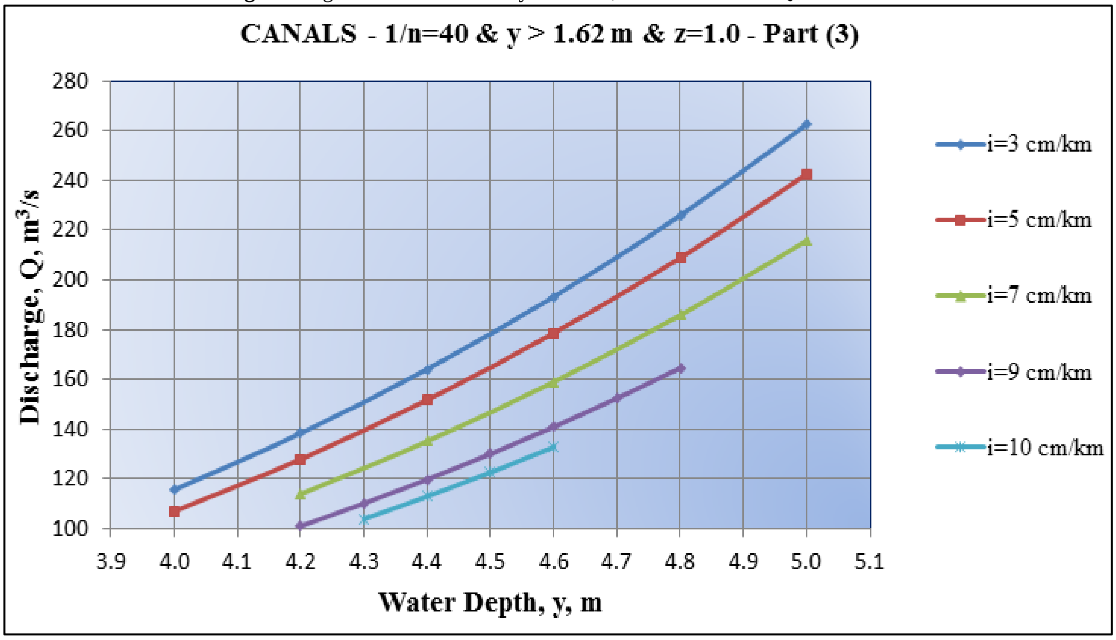


Fig-8. Design Chart for Canals of y > 1.62 m, z = 1.5 and Q < 20 m^3/s

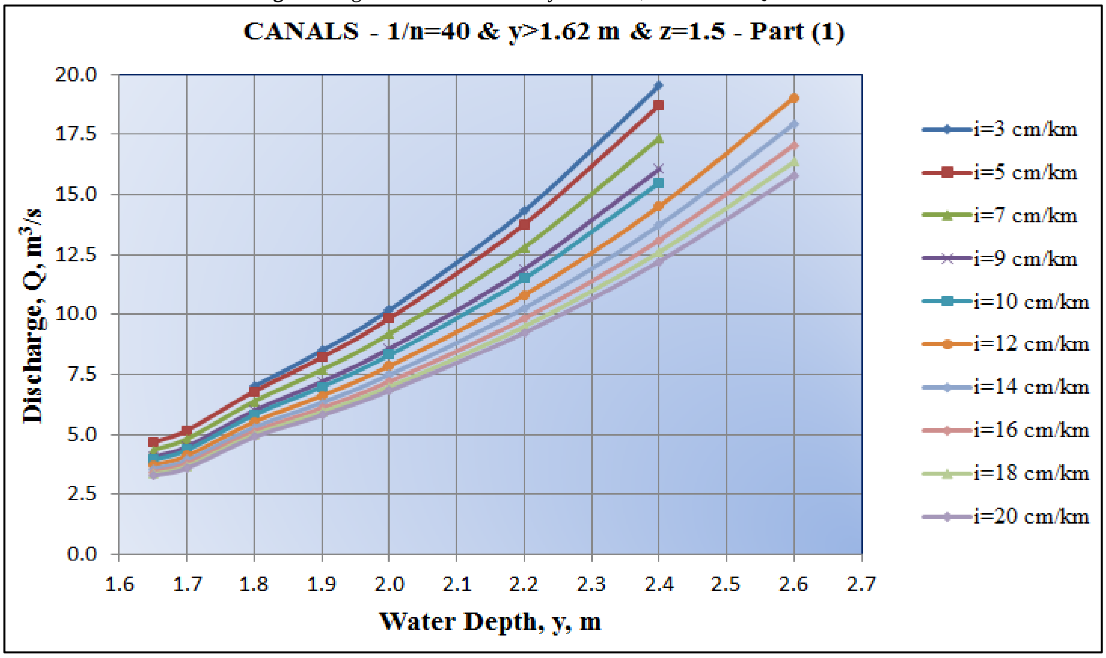


Fig-9. Design Chart for Canals of y > 1.62 m, z = 1.5 and 20 < Q < 100 m^3/s

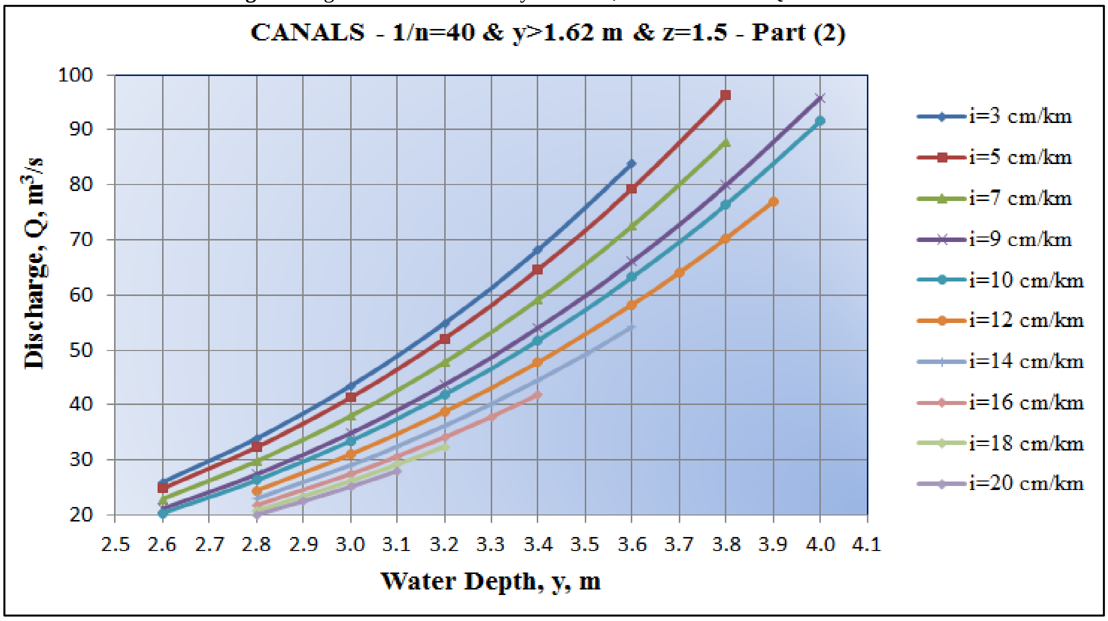


Fig-10. Design Chart for Canals of y > 1.62 m, z = 1.5 and 100 < Q < 280 m^3/s

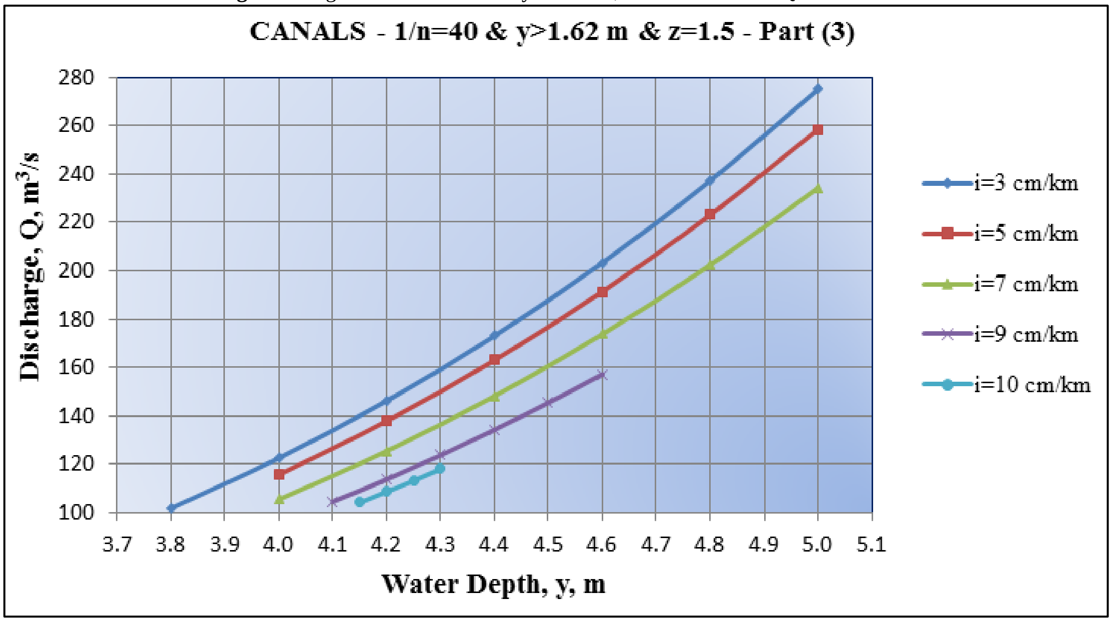


Fig-11. Design Chart for Canals of y > 1.62 m, z = 2.0 and Q < 20 m^3/s

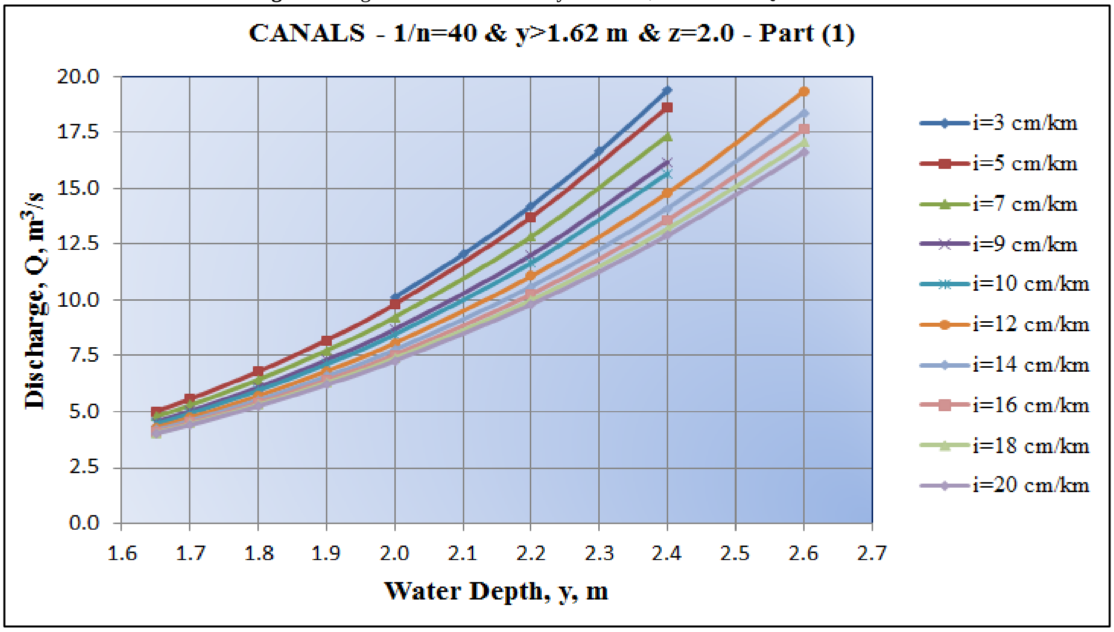


Fig-12. Design Chart for Canals of y > 1.62 m, z = 2.0 and 20 < Q < 100 m^3/s

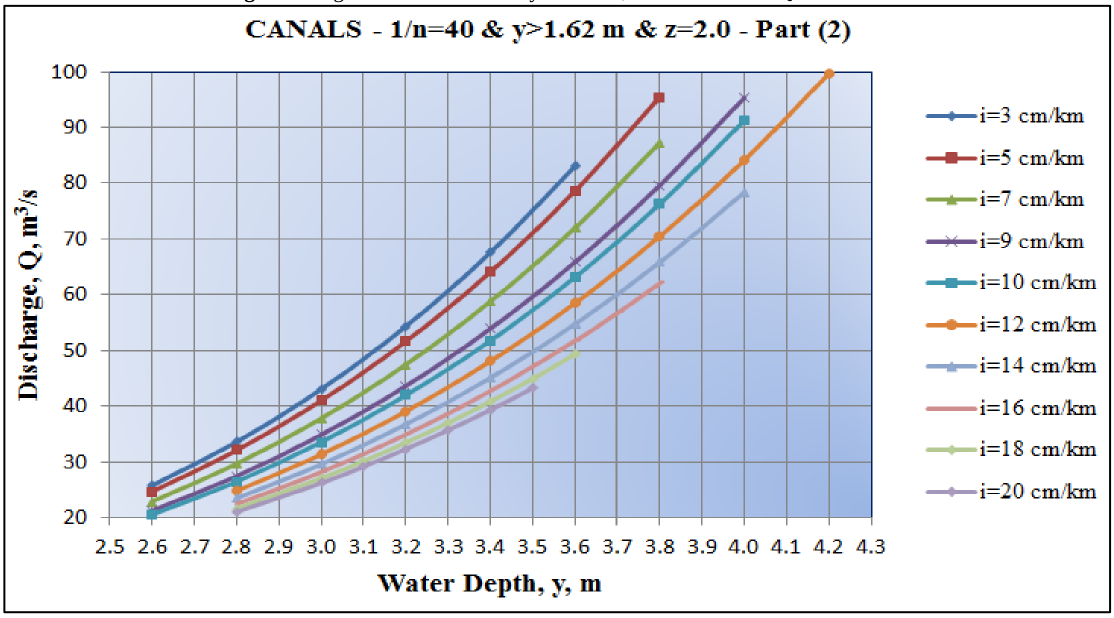
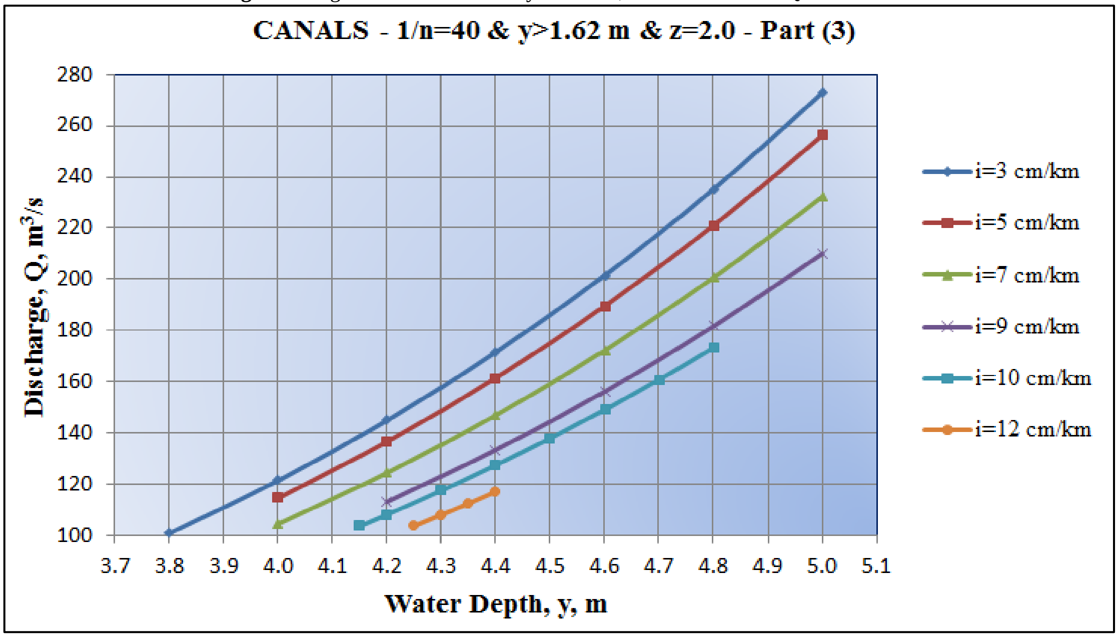


Fig-13. Design Chart for Canals of y > 1.62 m, z = 2.0 and 100 < Q < 280 m^3/s



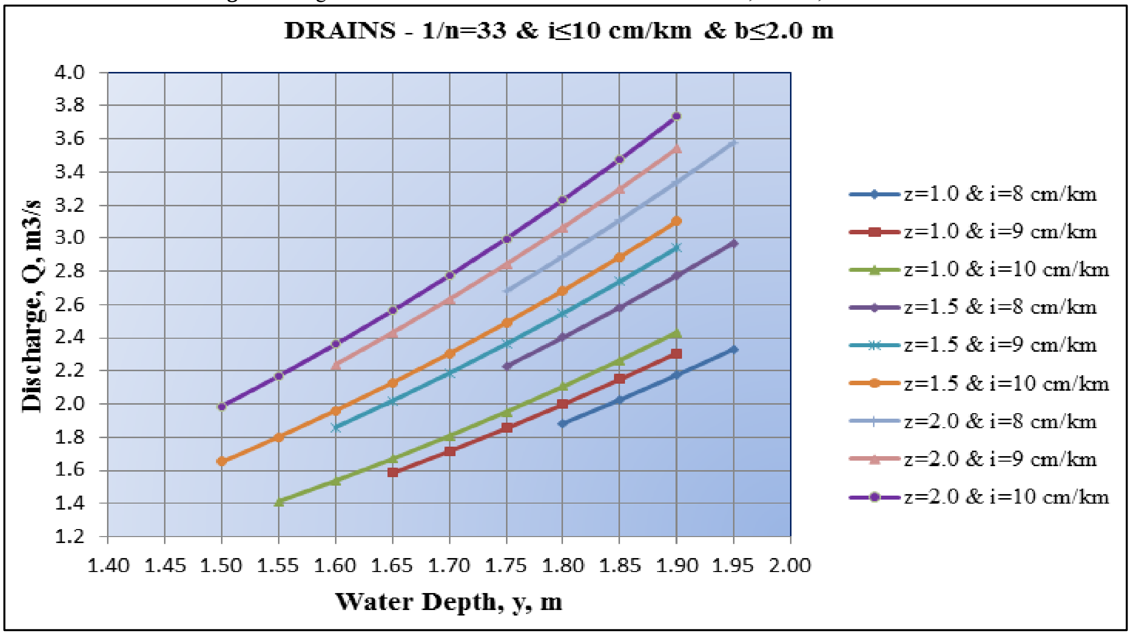
It could be seen from Fig. 5 through Fig. 13 concerning canals of y > 1.62 m that the discharge increased as the longitudinal slope decreased at each specific water depth.

To check the accuracy of the developed design charts to design the trapezoidal earthen open channels, these design charts were applied to an existed main canal. Ibrahemia canal is one of the longest irrigation canals in Egypt with 316.3 km length [27]. The discharge of Ibrahemia canal at km 122.0 is 117.65 m^3/s with y = 4.01 m, z = 1.5, b = 35.0 m and i = 6 cm/km. Applying the design chart of canals introduced in Fig. 10, it was found that y = 4.07 m and consequently b was 34.3 m employing Eq. 3.

3.2. Design Charts for Drains

For drains of i ≤ 10 cm/km and expected b ≤ 2.0 m, Eq. 4 was applied with Manning equation for the three values of z and various values of i (S = i). The obtained results were presented graphically forming design charts, as shown in Fig. 14.

Fig-14. Design Chart for Drains of i ≤ 10 cm/km and b ≤ 2.0 m, z = 1.0, 1.5 and 2.0



It could be seen from Fig. 14 concerning drains of i ≤ 10 cm/km and b ≤ 2.0 m that the discharge increased as the longitudinal slope increased at each specific water depth.

For drains of i ≤ 10 cm/km and expected b > 2.0 m Eq. 5 was applied with Manning equation for the three values of z and various values of i (S = i). The obtained results were presented graphically forming design charts, as shown in Fig. 15 through Fig. 23.

It could be seen from Fig. 15 through Fig. 23 concerning drains of i ≤ 10 cm/km and b > 2.0 m that the discharge increased as the longitudinal slope increased at each specific water depth.

Fig-15. Design Chart for Drains of i ≤ 10 cm/km and b > 2.0 m, z = 1.0 and Q < 20 m^3/s

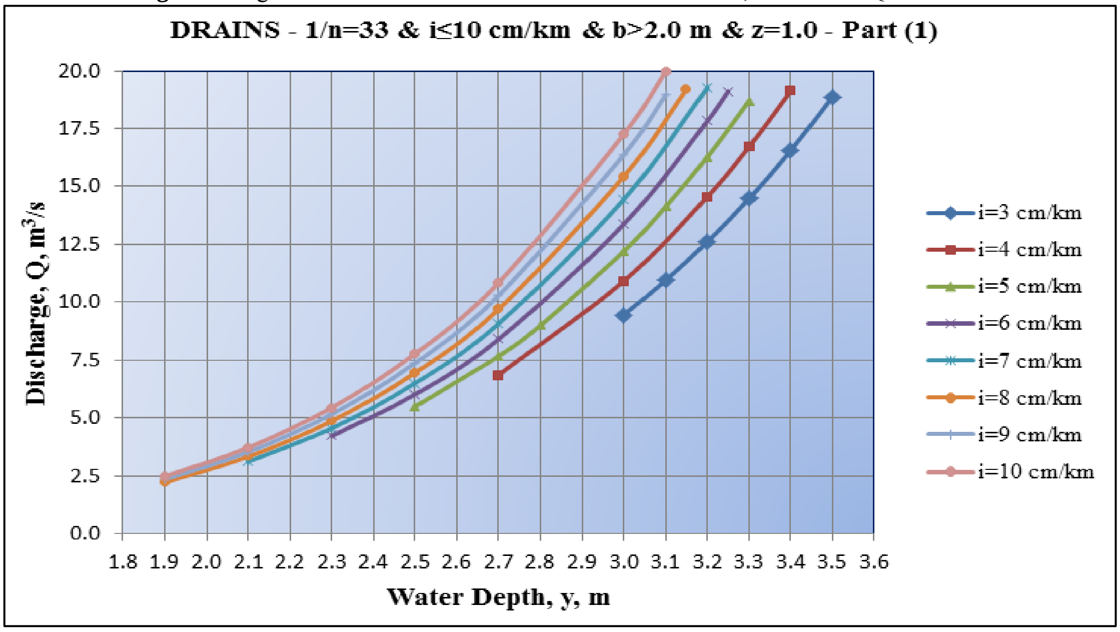


Fig-16. Design Chart for Drains of i ≤ 10 cm/km and b > 2.0 m, z = 1.0 and 20 < Q < 80 m^3/s

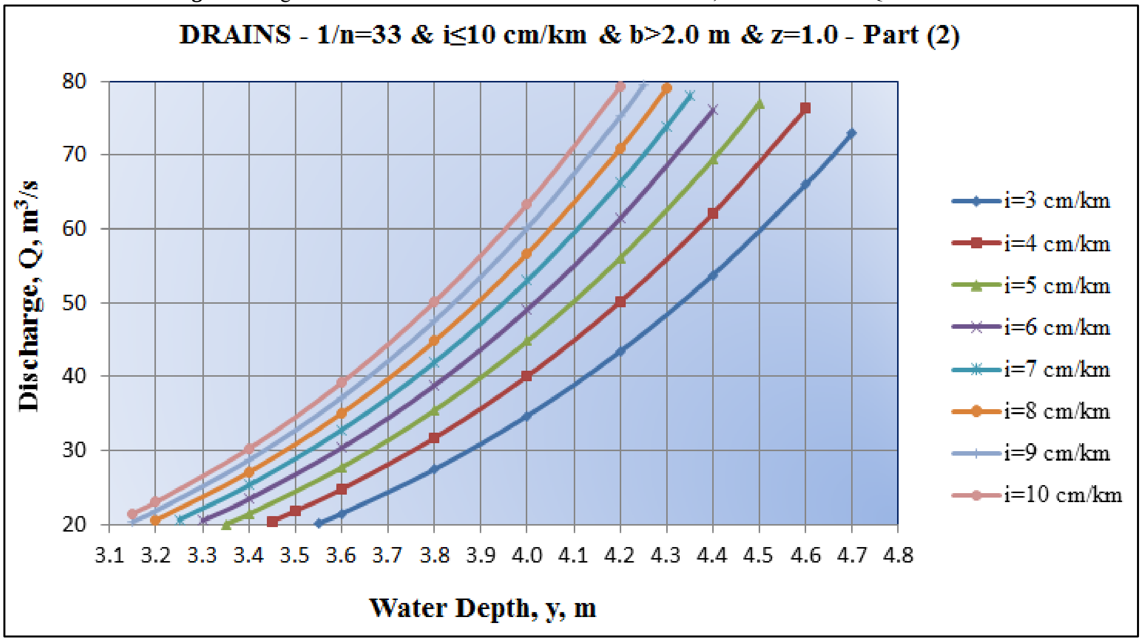


Fig-17. Design Chart for Drains of i ≤ 10 cm/km, b > 2.0 m, z = 1.0 and 80 < Q < 180 m^3/s

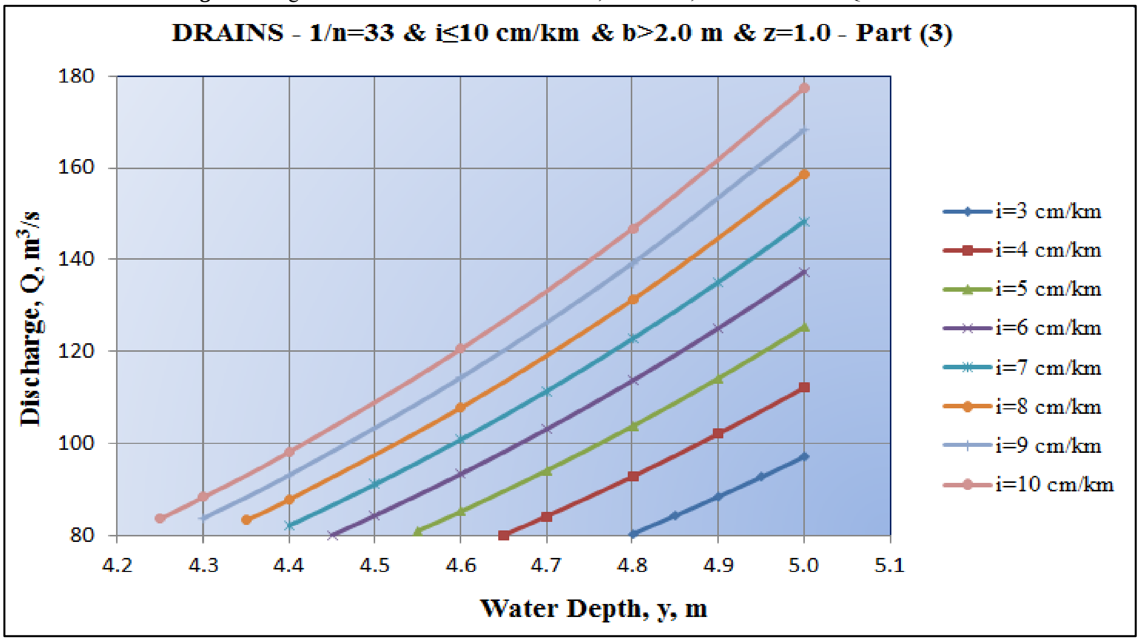


Fig-18. Design Chart for Drains of i ≤ 10 cm/km and b > 2.0 m, z = 1.5 and Q < 20 m^3/s

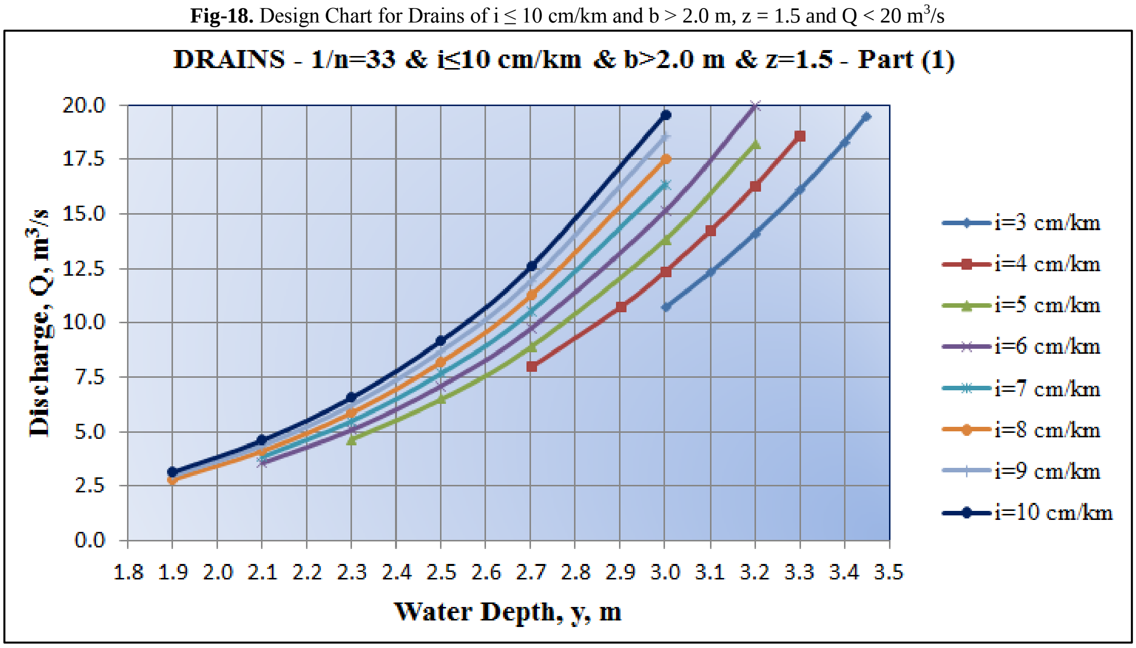


Fig-19. Design Chart for Drains of i ≤ 10 cm/km and b > 2.0 m, z = 1.5 and 20 < Q < 80 m^3/s

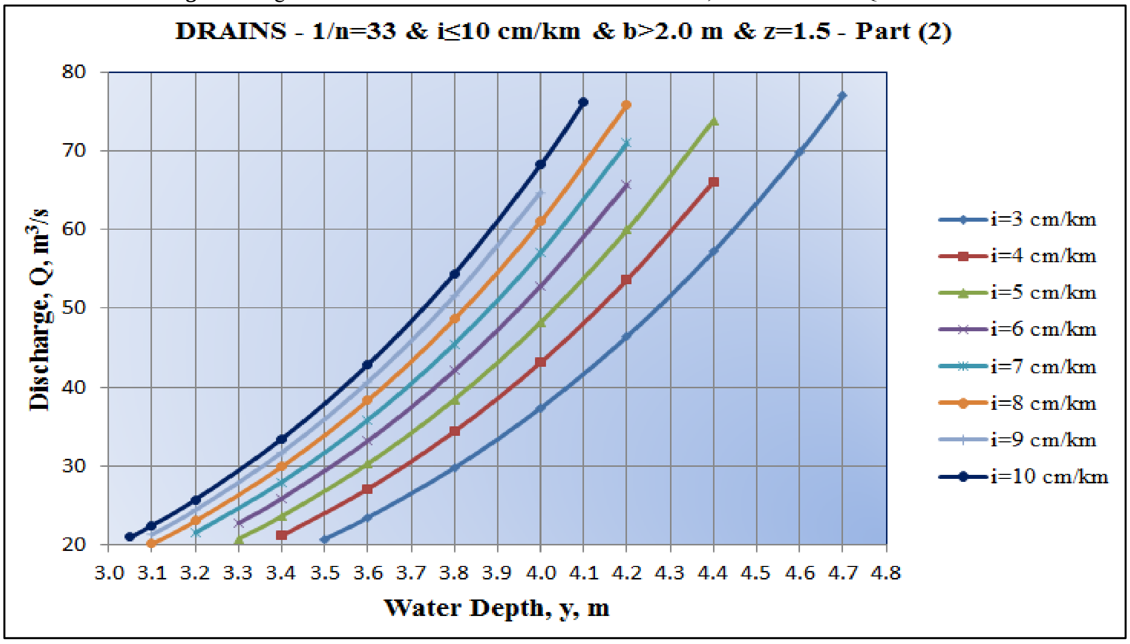


Fig-20. Design Chart for Drains of i ≤ 10 cm/km, b > 2.0 m, z = 1.5 and 80 < Q < 200 m^3/s

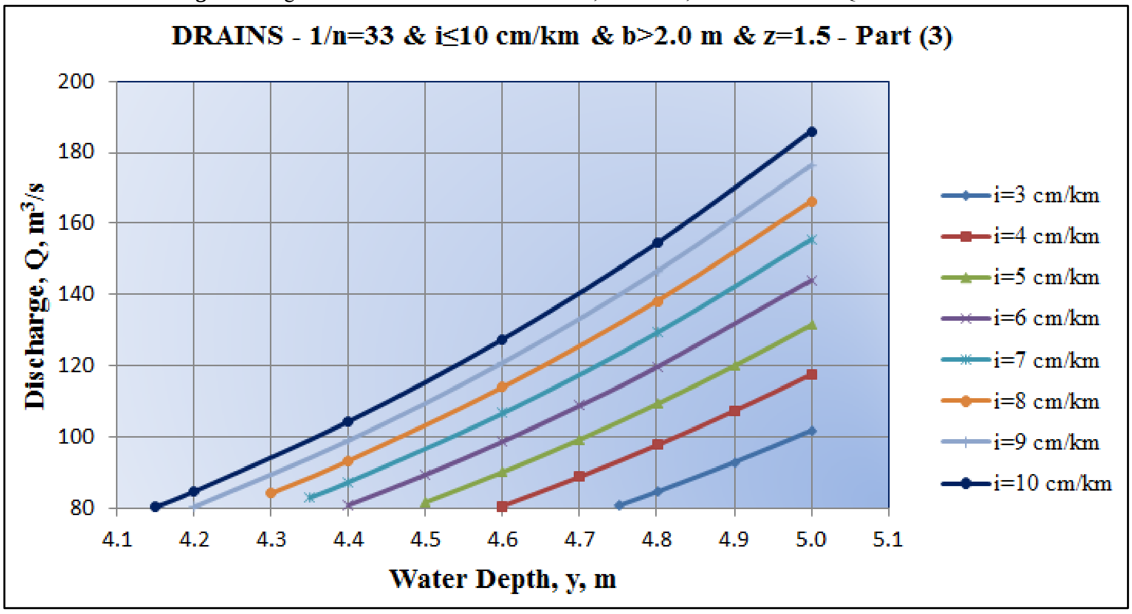


Fig-21. Design Chart for Drains of i ≤ 10 cm/km and b > 2.0 m, z = 2.0 and Q < 20 m^3/s

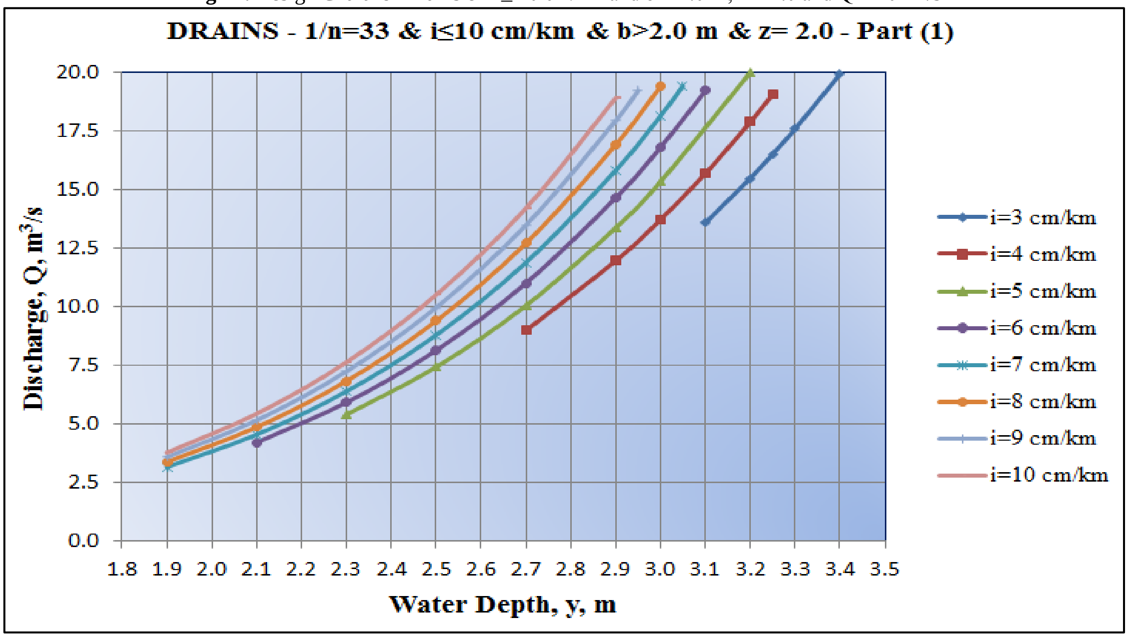


Fig-22. Design Chart for Drains of i ≤ 10 cm/km and b > 2.0 m, z = 2.0 and 20 < Q < 80 m^3/s

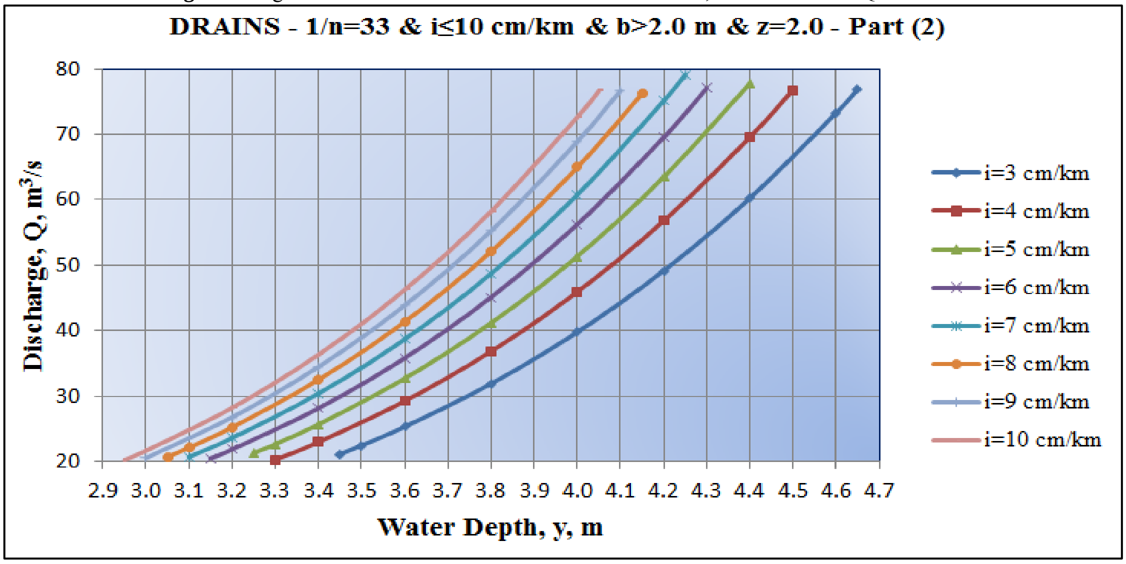
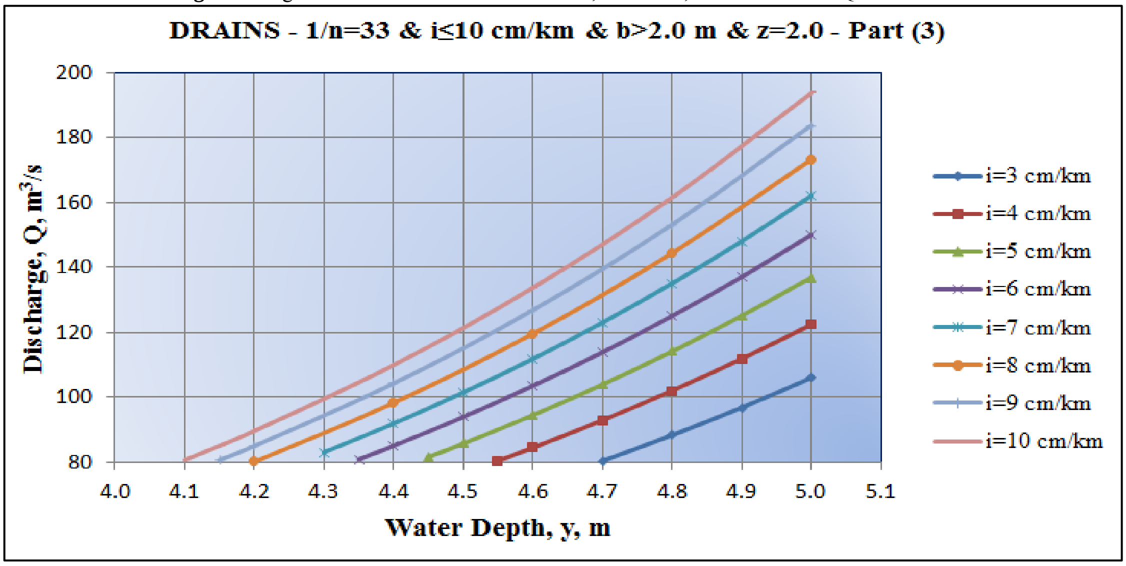


Fig-23. Design Chart for Drains of i ≤ 10 cm/km, b > 2.0 m, z = 2.0 and 80 < Q < 200 m^3/s



For drains of i > 10 cm/km and expected b ≤ 2.0 m Eq. 6 was applied with Manning equation for the three values of z and various values of i (S = i). The obtained results were presented graphically forming design charts, as shown in Fig. 24, Fig. 25 and Fig. 26.

It could be seen from Fig. 24 through Fig. 26 concerning drains of i > 10 cm/km and b ≤ 2.0 m that the discharge increased as the longitudinal slope increased at each specific water depth.

Fig-24. Design Chart for Drains of i > 10 cm/km and b ≤ 2.0 m, z = 1.0

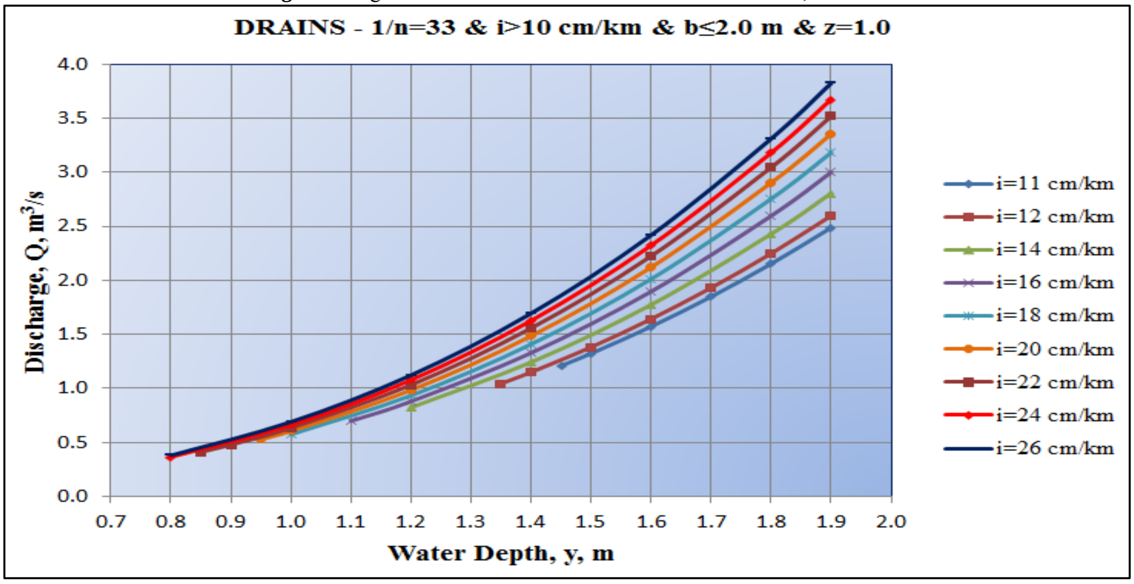


Fig-25. Design Chart for Drains of i > 10 cm/km and b ≤ 2.0 m, z = 1.5

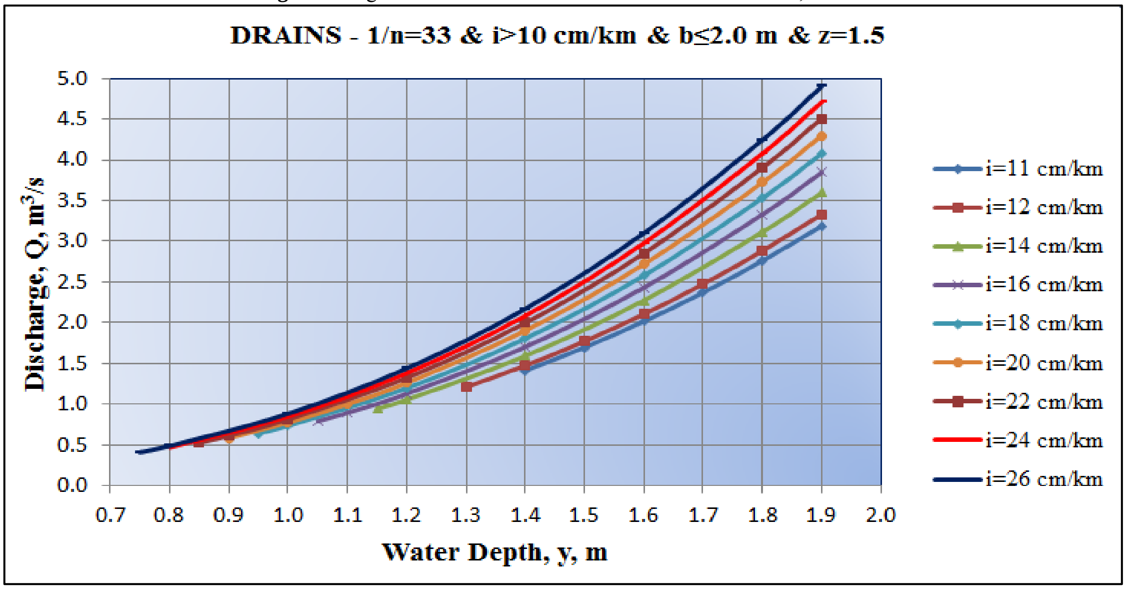
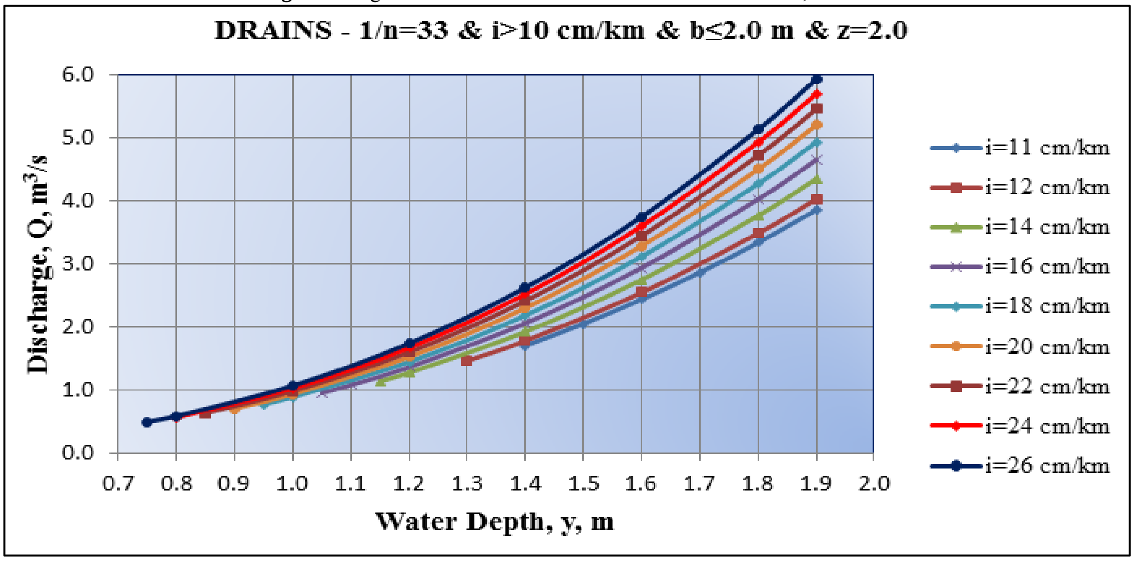


Fig-26. Design Chart for Drains of i > 10 cm/km and b ≤ 2.0 m, z = 2.0



For drains of i > 10 cm/km and expected b > 2.0 m, Eq. 7 was applied with Manning equation for the three values of z and various values of i (S = i). The obtained results were presented graphically forming design charts, as shown in Fig. 27 through Fig. 32.

It could be seen from Fig. 27 through Fig. 32 concerning drains of i > 10 cm/km and b > 2.0 m that the discharge increased as the longitudinal slope increased at each specific water depth.

Fig-27. Design Chart for Drains of i > 10 cm/km and b > 2.0 m, z = 1.0 and Q < 20 m^3/s

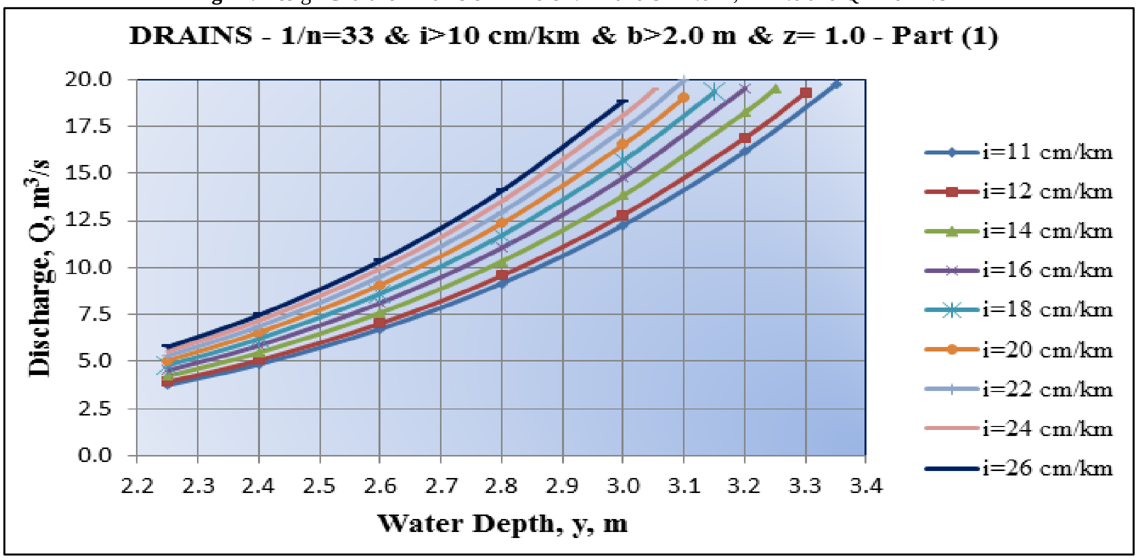


Fig-28. Design Chart for Drains of i > 10 cm/km, b > 2.0 m, z = 1.0 and 20 < Q < 140 m^3/s

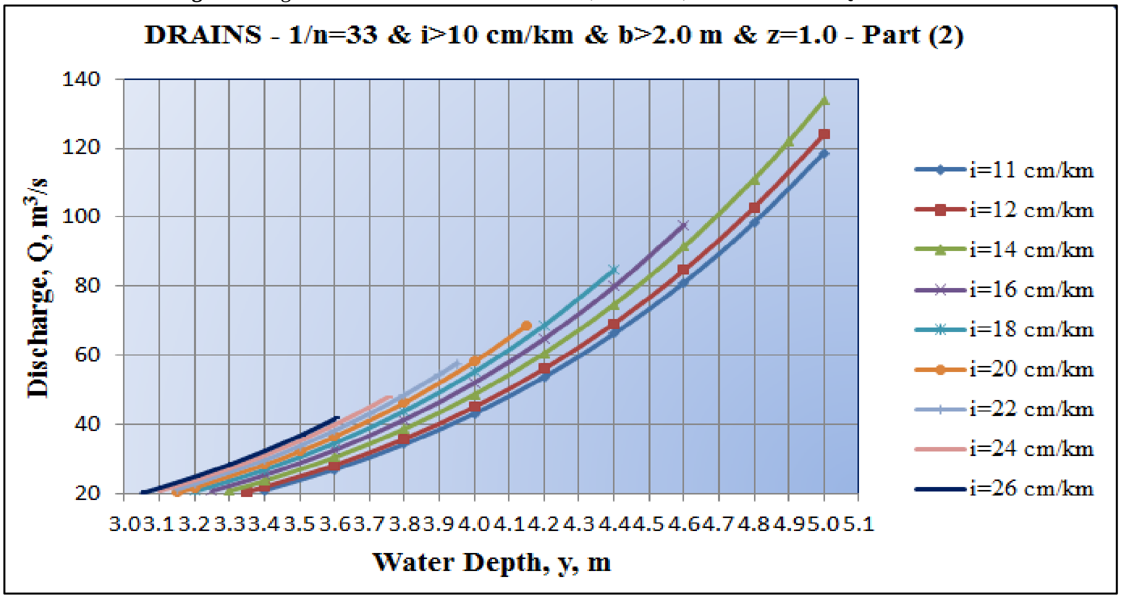


Fig-29. Design Chart for Drains of i > 10 cm/km and b > 2.0 m, z = 1.5 and Q < 20 m^3/s

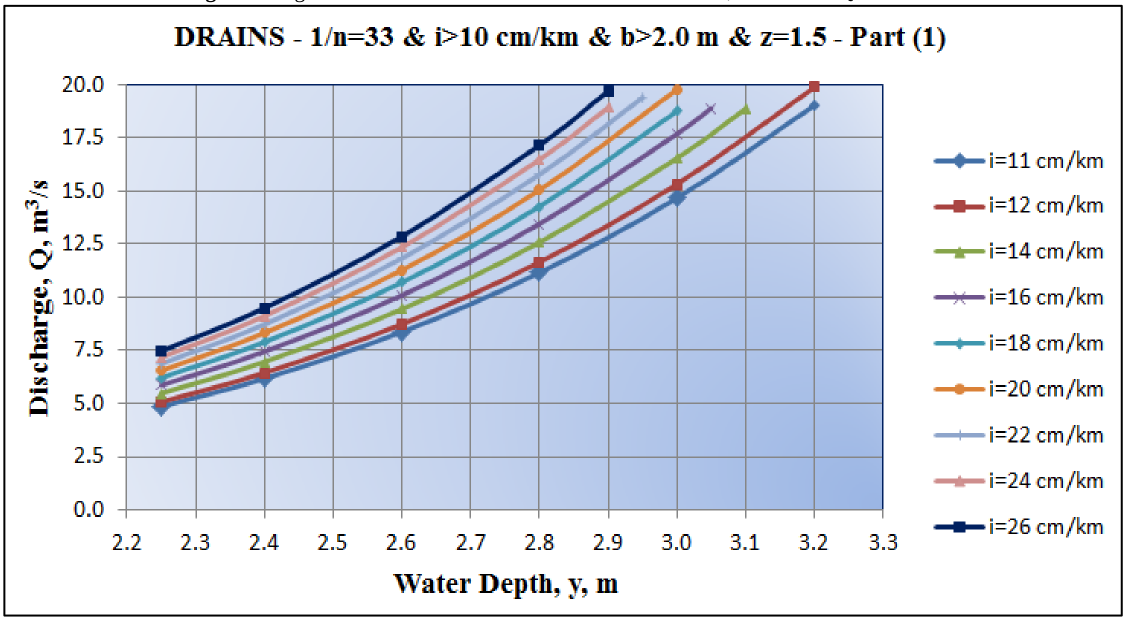


Fig-30. Design Chart for Drains of i > 10 cm/km, b > 2.0 m, z = 1.5 and 20 < Q < 160 m^3/s

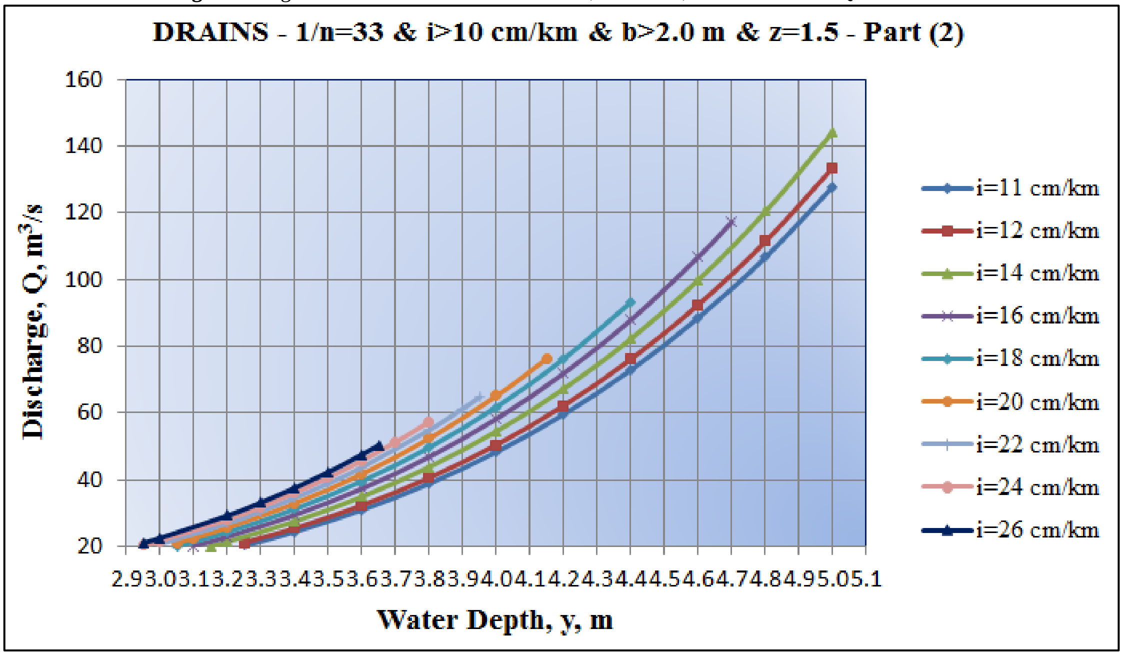


Fig-31. Design Chart for Drains of i > 10 cm/km and b > 2.0 m, z = 2.0 and Q < 20 m^3/s

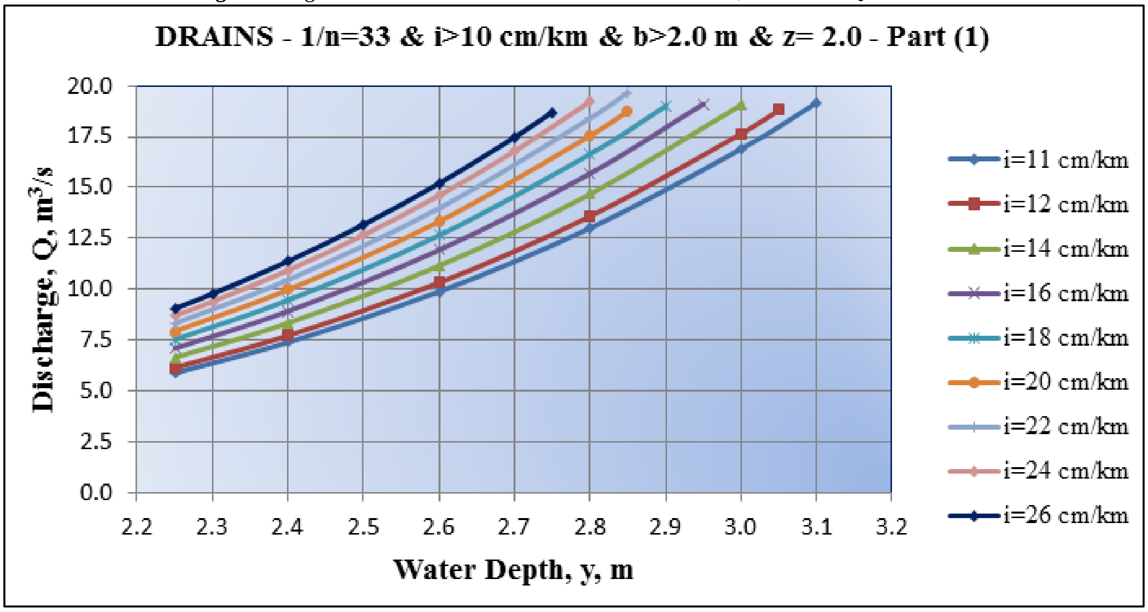
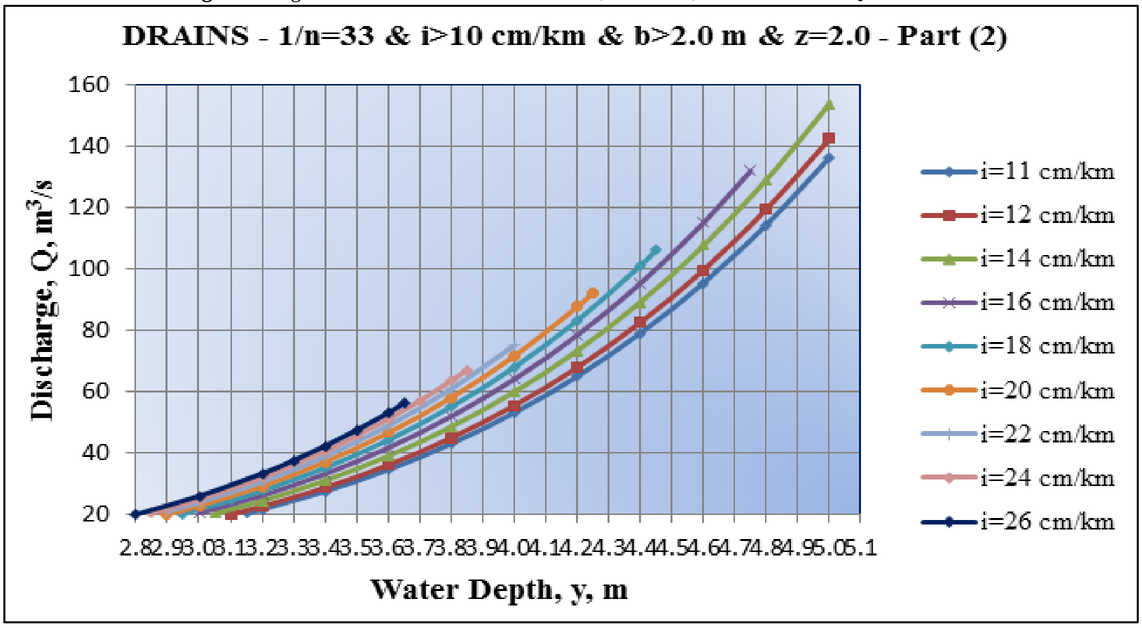


Fig-32. Design Chart for Drains of i > 10 cm/km, b > 2.0 m, z = 2.0 and 20 < Q < 160 m^3/s



It must be noted that only the plotted values of the discharge (Q) and the corresponding values of the water depth (y) for every specific value of the longitudinal channel slope (S) in the design charts obtain the required non-silting non-scouring velocity of water, which is normally in the range of 0.3 to 0.9 m/s (± 5%) for the studied types of soils.

For example, in Fig. 2 for S = i = 8 cm/km, Q = 1.24 m^3/s, and y = 1.1 m, the velocity would be 0.3 m/s. For a smaller y of 1.05 m, Q would be 1.09 m^3/s giving a velocity of 0.28 m/s, which would cause silting.

For another example, in Fig. 7 for S = 9 cm/km, Q = 164.7 m^3/s, and y = 4.8 m, the velocity would be 0.93 m/s. For a bigger y of 4.9 m, Q would be 177.6 m^3/s giving a velocity of 0.95 m/s, which would cause scouring.

3.3. Design Equations for Trapezoidal Earthen Open Channels

Regression analyses were employed to obtain design equations that could be used to design trapezoidal earthen open channels with various types of soils. For each longitudinal slope in Fig. 2 through Fig. 32, a regression analysis was applied, and a design equation was obtained, which related the discharge and the water depth directly for non-silting non-scouring water velocity. All the obtained equations were integrated into two general design equations; Eq. 8 and Eq. 9.

Equation 8 was developed from Fig. 2 through Fig. 4, Fig. 14, and Fig. 24 through Fig. 26. While equation 9 was developed from Fig. 5 through Fig. 13, Fig. 15 through Fig. 23, and Fig. 27 through Fig. 32.

$$Q = C\, y^{2.666} \tag{8}$$

$$Q = \alpha\, y^{\beta} \tag{9}$$

Where: Q = discharge, (m^3/sec); y = water depth, (m); C, α, β are constants.

The values of coefficients of determination (R^2) for design equation (Eq. 8) were equal to 1.00 and for design equation (Eq. 9) ranged between 0.9979 and 1.00.

Values of C, α and β were deduced from regression analyses and were presented in Tables 1, 2 and 3.

Additionally, instead of using the values of the coefficient C in Table 1, the coefficient C could be calculated employing equations, which were deduced from regression analyses and were illustrated in Table 4 for canals and in Table 5 for drains.

Table-1. Coefficient C for Eq. 8 ($Q = C\,y^{2.666}$)

i, cm/km	Canals, 1/n = 40 and y ≤ 1.62 m			Drains, 1/n = 33 and b ≤ 2.0 m		
	z = 1.0	**z = 1.5**	**z = 2.0**	**z = 1.0**	**z = 1.5**	**z = 2.0**
8	0.9595	1.0927	1.2157	0.3931	0.5012	0.6032
9	---	---	---	0.4169	0.5316	0.6398
10	0.8763	1.0252	1.1635	0.4395	0.5603	0.6744
11	---	---	---	0.4492	0.5760	0.6958
12	0.8089	0.9716	1.1235	0.4692	0.6016	0.7267
14	0.7552	0.9302	1.0943	0.5068	0.6498	0.7850
16	0.7126	0.8987	1.0741	0.5418	0.6947	0.8392
18	0.6789	0.8752	1.0609	0.5747	0.7368	0.8901
20	0.6522	0.8580	1.0534	0.6057	0.7766	0.9382
22	0.6311	0.8457	1.0503	0.6353	0.8146	0.9840
24	0.6145	0.8375	1.0507	0.6636	0.8508	1.0278
26	0.6015	0.8325	1.0540	0.6906	0.8855	1.0697

Table-2. Coefficients α and β for Canals for Eq. 9 ($Q = \alpha\,y^{\beta}$)

i, cm/km	Canals, 1/n = 40 and y > 1.62 m					
	z = 1.0		**z = 1.5**		**z = 2.0**	
	α	**β**	**α**	**β**	**α**	**β**
3	0.7243	3.6606	0.8431	3.5930	0.8431	3.5859
5	0.6847	3.6449	0.8028	3.5882	0.8408	3.5465
7	0.6264	3.6263	0.7641	3.5572	0.8156	3.5026
9	0.5745	3.6030	0.7296	3.5209	0.7934	3.4555
10	0.5535	3.5874	0.7155	3.5017	0.7851	3.4317
12	0.5213	3.5470	0.6923	3.4644	0.7802	3.3747
14	0.4957	3.5078	0.6766	3.4261	0.7896	3.3058
16	0.4776	3.4653	0.6656	3.3918	0.7950	3.2548
18	0.4630	3.4274	0.6581	3.3615	0.8068	3.2027
20	0.4553	3.3816	0.6548	3.3323	0.8198	3.1574

Table-3. Coefficients α and β for Drains for Eq. 9 ($Q = \alpha\,y^{\beta}$)

i, cm/km	Drains, 1/n = 33 and b > 2.0 m					
	z = 1.0		**z = 1.5**		**z = 2.0**	
	α	**β**	**α**	**β**	**α**	**β**
3	0.0623	4.5644	0.0828	4.4144	0.1007	4.3181
4	0.0742	4.5432	0.1001	4.3829	0.1274	4.2553
5	0.0855	4.5217	0.1224	4.3193	0.1583	4.1807
6	0.0968	4.4980	0.1409	4.2830	0.1836	4.1396
7	0.1086	4.4707	0.1522	4.2830	0.2109	4.0942
8	0.1213	4.4385	0.1721	4.2421	0.2254	4.0942
9	0.1286	4.4385	0.1825	4.2421	0.2391	4.0942
10	0.1345	4.4429	0.1907	4.2460	0.2490	4.1000
11	0.1063	4.3399	0.1636	4.1130	0.2249	3.9518
12	0.1106	4.3412	0.1708	4.1130	0.2348	3.9523
14	0.1182	4.3510	0.1834	4.1167	0.2549	3.9492
16	0.1328	4.3070	0.2012	4.0929	0.2798	3.9250
18	0.1435	4.2889	0.2240	4.0490	0.3047	3.8989
20	0.1549	4.2647	0.2427	4.0212	0.3297	3.8740
22	0.1643	4.2538	0.2594	4.0030	0.3629	3.8264
24	0.1762	4.2275	0.2770	3.9802	0.3866	3.8089
26	0.1855	4.2161	0.2939	3.9611	0.4153	3.7772

To assure the accuracy of the presented design equations to design the trapezoidal earthen open channels, these design equations were applied to Ibrahemia main canal in Egypt, [27]. The discharge of Ibrahemia canal at km 122.0 is 117.65 m^3/s with y = 4.01 m, z = 1.5, b = 35.0 m and i = 6 cm/km. Applying the design equation (Eq. 9) of open channels, it was found that y = 4.07 m and consequently b was equal to 34.3 m employing equation 3.

Table-4. Equations Developed to Calculate Coefficient C for Canals (Eq. 8: $Q = C\,y^{2.666}$)

Canals, 1/n = 40, y ≤ 1.62 m		
z	**Equation**	**Coefficient of Determination, R^2**
1.0	$C = 0.0011\ i^2 - 0.0551\ i + 1.3243$	0.9978
1.5	$C = 0.0009\ i^2 - 0.0459\ i + 1.3921$	0.9968
2.0	$C = 0.0008\ i^2 - 0.0370\ i + 1.4512$	0.9939

Table-5. Equations Developed to Calculate Coefficient C for Drains, (Eq. 8: $Q = C\,y^{2.666}$)

Drains, 1/n = 33, b ≤ 2.0 m			
Case	**z**	**Equation**	**Coefficient of Determination, R^2**
i ≤ 10 cm/km	1.0	$C = 0.1390\ i^{0.5}$	1.0000
	1.5	$C = 0.1774\ i^{0.5}$	1.0000
	2.0	$C = 0.2133\ i^{0.5}$	1.0000
i > 10 cm/km	1.0	$C = 0.1354\ i^{0.5}$	1.0000
	1.5	$C = 0.1737\ i^{0.5}$	1.0000
	2.0	$C = 0.2098\ i^{0.5}$	1.0000

Also, instead of using the values of the coefficients α and β in Tables 2 and 3, the coefficients α and β could be calculated alternatively employing equations, which were deduced from regression analyses and were illustrated in Table 6 for canals and in Table 7 for drains.

Table-6. Equations Developed to Calculate Coefficients α and β for Canals, (Eq. 9: $Q = \alpha\,y^{\beta}$)

Canals, 1/n = 40, y > 1.62 m		
z	**Equation**	**Coefficient of Determination (R^2)**
1.0	$\alpha = 0.0009\ i^2 - 0.0362\ i + 0.8330$	0.9970
1.5	$\alpha = 0.0007\ i^2 - 0.0274\ i + 0.9198$	0.9995
2.0	$\alpha = 0.0007\ i^2 - 0.0177\ i + 0.8992$	0.9129
1.0	$\beta = -\ 0.0005\ i^2 - 0.0049\ i + 3.6833$	0.9979
1.5	$\beta = -\ 0.0001\ i^2 - 0.0132\ i + 3.6475$	0.9927
2.0	$\beta = -\ 0.0002\ i^2 - 0.0213\ i + 3.6581$	0.9974

Table-7. Equations Developed to Calculate Coefficients α and β for Drains, (Eq. 9: $Q = \alpha\,y^{\beta}$)

Drains, 1/n = 33, b>2.0 m			
Case	**z**	**Equation**	**Coefficient of Determination, R^2**
i ≤ 10 cm/km	1.0	α = - 0.0004 i2 + 0.0159 i + 0.0173	0.9971
		β = 0.0018 i2 - 0.0435 i + 4.6855	0.9689
	1.5	α = - 0.0009 i2 + 0.0276 i + 0.0068	0.9972
		β = 0.0044 i2 - 0.0819 i + 4.6268	0.9772
	2.0	α = - 0.0018 i2 + 0.0457 i - 0.0225	0.9980
		β = 0.0076 i2 - 0.1306 i + 4.6461	0.9937
i > 10 cm/km	1.0	α = - 3E-06 i2 + 0.0055 i + 0.0446	0.9978
		β = - 0.0001 i2 - 0.0047 i + 4.4176	0.9588
	1.5	α = 3E-05 i2 + 0.0078 i + 0.0722	0.9976
		β = - 0.0002 i2 - 0.0034 i + 4.1879	0.9665
	2.0	α = 0.0002 i2 + 0.0071 i + 0.1267	0.9992
		β = - 0.0005 i2 + 0.0056 i + 3.9565	0.9867

4. Conclusions

Easy and accurate design is necessary to obtain the dimensions that assure non-silting non-scouring water velocity to maintain earthen open channels.

Design charts are established for non-silting non-scouring water velocity for different types of soils and longitudinal channel slopes. Every design chart includes a direct relation between the discharge and the water depth for various longitudinal channel slopes. Knowing the discharge and the longitudinal slope, the water depth is obtained immediately from the design chart.

Twelve design charts are presented for canals (1/n = 40). It is concluded that the discharge increases as the longitudinal slope decreases at each specific water depth.

Nineteen design charts are presented for drains (1/n = 33). It is concluded that the discharge increases as the longitudinal slope increases at each specific water depth.

For the studied values of water depth for both canals and drains, it is found that only the plotted values of the discharge in the design charts obtain the required non-silting non-scouring velocity of water.

Regression analyses are employed, and two general design equations are obtained to find directly the water depth, which maintains non-silting non-scouring water velocity, for different types of soils and longitudinal channel slopes. Knowing the discharge and the longitudinal slope, the water depth is obtained directly from the design equation.

The values of coefficient of determination (R^2) for design equations of canals (1/n = 40) are equal to 1.00 for $y \leq 1.62$ m and range between 0.9979 and 1.00 for $y > 1.62$ m.

The values of coefficient of determination (R^2) for design equations of drains (1/n = 33) are equal to 1.00 for $b \leq 2.0$ m and range between 0.9990 and 1.00 for $b > 2.0$ m.

Design charts and design equations are applied to a main canal in Egypt obtaining very accurate results.

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