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Hydraulic Performance of Perforated Pipes

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Abstract Subsurface drainage plan is more often than not as per the proportion of punctured territory to add up to surface zone at that point separate between laterals would be concluded by the accessible observational relations. Be that as it may, a few other controlling impacts are typically overlooked, for example, the proportion of punctured region to cross sectional range of the pipe, the impact of punctured pipe width. This paper ponders the impact of beforehand disregarded overseeing parameters on seepage execution and pressure driven movement for punctured channels. Physical Model is constructed at the hydraulics laboratory of Civil Department in Shoubra Faculty of building, Egypt to explore diverse stream administrations, real stream designs, and the impacts of already recognized parameters.

The examination uncovered the ideal proportion of zone of apertures that is suggested for the plan, opening inflow limit along the deplete pipe length, and configuration bends that assistance in defining up the limit states of future numerical models. Additionally, conventional plan conditions must be changed in accordance with represent the impact of non-consistency of inflow, to the full streaming channel, along its longitudinal direction.

Keywords Perforated pipes, Subsurface drainage, Experimental model

1. Introduction

The actual hydraulic performance of porous pipes, i.e. the stage - storage relationship, is poorly understood. The resulting flow is quite complex with porous media flow through the aggregate, multiple orifice flows into the pipe and pipe flow with lateral inflow along the length. Perforated pipes are usually used in the industrial fields for in or ex-filtration. The most common uses include French drains, to reduce runoff from perforated storm sewer pipe system, infiltration trenches and basins, subsurface drain (relief drainage or interceptor drains), under-drains in porous pavement and organic filters [1]. Stuyt, et. al, [2] discuss the water flow into and inside the drain for de-watering purposes are investigated according to Ernst [3] that flow towards a subsurface drain can be described as:

$$Q = (22 \ to \ 38)d^{2.667} s_e^{\ 0.5} \qquad (1)$$

Where Q is the flow discharge through pipe (m^3/s), d is the pipe diameter (m) and S_e is the hydraulic gradient. However, nowhere does it mention the use of some type of filter fabric or sock to prevent the surrounding sediment from clogging the pipe.

Due to human impact on the surrounding urban environment, the hydrological cycle has been significantly altered from its natural state of storm-water runoff from land into receiving waters. The Environmental Protection Agency (EPA) has undertaken the task of protecting receiving waters from, more than 62 million acres of urban development throughout the country [4-5]. The EPA took the approach to control the storm-water stress or load by using best management practices (BMP) to assist in the restoration of receiving water [1].

Infiltration systems have become popular in aiding in the disposal of storm water runoff because of their ability to retain water and infiltrate it into the ground [1]. The filtration/infiltration basin is typically shallow basins with an engineered soil media and an under-drain system. Filtration systems have an under-drain system where as it is not as common in the infiltration trench. This system allows storm water to be detained and infiltrated into the soils and then discharged into the receiving water through the use of the under-drain [6].

Perforated pipes are also used in the construction industry for subsurface drainage which are installed beneath the ground surface to release and convey infiltrated runoff or groundwater. The perforated pipe is used to remove excess water from the soil [7] and to ensure that the drawdown requirements of the design are met. Abdel-Mageed and Ghanem [8] studied the effect of perforated pipe length on the collected discharge of subsurface drainage systems. Also Stuyt, et al [2] focused on the water flow into and inside the drain from the aquifer de-watering point of view. More recently, Schwartz [9] treated a porous pipe underdrain in a previous pavement as an orifice at atmospheric pressure. This effectively ignores any losses from the flow entering and flowing along the pipe. A similar simplifying assumption was made by Akan [10] in the analysis of bio-retention cells.

Based on the aforementioned literature review, no studies had been focused on the hydraulic performance of perforated pipes and effect of diameter which would be discussed through the current research.

2. Dimension Analysis

Solution of any fluid flow problem usually comprises numerous variables. Normally, in order to establish such relationship between those variables, the tool of dimensional analysis could be employed. From this viewpoint it may be stated that flow rate through perforated pipes of subsurface drainage could be evaluated as a function of the following measured variables:

$$Q = f(Q_s, H, S, D) \tag{2}$$

Where Q is the flow discharge capacity through the perforated pipe, Q_s is the flow rate through a similar length, diameter and type of imperforated pipe, H is the total driving head, D is pipe diameter, and S the holes percentage which can be defined as percentage of total area of the holes in perforated pipe (A_{holes}) to the pipe surface area (A_s) which can be written as follows:

$$S = \frac{A_{holes}}{A_s} \tag{3}$$

While the difference in head (Δh) between the upstream and downstream ends of the perforated pipe can be evaluated as follows:

$$\Delta h = f(W.H, S, D, Fr) \tag{4}$$

Where W.H is the water head above the pipe

Since none of the aforementioned variables comprise mass, the number of dimensions for dimensional analysis would be only limited to length and time. Thus, the repeating variables would be chosen as gravitational acceleration (g) and pipe diameter (D). Therefore, the following dimension groups could be obtained:

$$S = \frac{A_{holes}}{A_s}, Q_{con} = \frac{Q}{Q_s}, NH = \frac{\sum A_{holes}}{A_{cross}}, \frac{Q}{\sqrt{gD^5}}, H_{ratio} = \frac{\Delta h}{D}, Fr_{relative} = Fr * NH, \Delta H_{relative} = \frac{\Delta h}{Ho} NH$$

Where Q_{con} is the conveyance ratio which equals to the ratio between the total accumulated discharge at the outlet of the collection pipe (Q) and the total discharge from a similar imperforated pipe that has the same length, diameter, skin friction, and static head (Q_s), NH is normalized holes which the total area of the holes in the perforated pipe (A_{holes}), divided by the cross section of the perforated pipe Across. $Fr_{relative}$ is the Froude number multiply by the normalized holes, $\Delta H_{relative}$ is the ratio between the change in head and the initial head multiply by the normalized head

3. Experimental Setup

The experimental work was carried out in the Hydraulics Laboratory of Shoubra Faculty of Engineering, Benha University. The model - as shown in Figures (1 and 2) – consists of adjustable constant water surface head glass tank of 1.0 m long, 0.3m width and 0.75m height which was placed on a horizontal, hard table of 0.6 m above the ground level. To allow water circulation system and measuring flow discharges accurately, the glass tank was connected to a hydraulic bench. The glass tank was acquainted to accommodate 6 perforated pipes of different diameters parallel to the flow direction. The centerlines of those pipes were affixed at two different levels of 3 pipes each at 0.1 m and 0.35 m above the glass tank bed level. The upstream ends of the 6 perforated pipes at two levels were firmly plugged. While each of the three pipes at the lower level was adjusted in such a way as to be identical with that of the other three in the upper level. Also each of the 6 perforated pipes in the two different levels can be independently tested by blocking the downstream ends of the other 5 ones. The flowing discharge from the downstream end of the tested perforated pipe was spill into a volumetric measuring reservoir out of the glass tank, as shown in Figure (2).

Figure 1: Layout of the Experimental Setup

The perforated (collection) pipes were simulated by PVC pipes of 14.14, 17.025, 22.22, and 28.812mm inner diameter and different percentage of holes which was varied from 0.14% to 3.5%.Water was supplied to the glass tank through an electric centrifugal pump of 2.5 l/sec maximum capacity which is lifting water from another provided Arm-Field tank. The glass tank was equipped with a multi-level overflow pipe to allow for various constant head settings. Ten piezometers were connected to the perforated pipes at the upstream end distributed towards the downstream end to accurately measure the head difference and change inside the pipe, an eleventh piezometer was inserted beside the tank to measure the water level acting on the pipe.

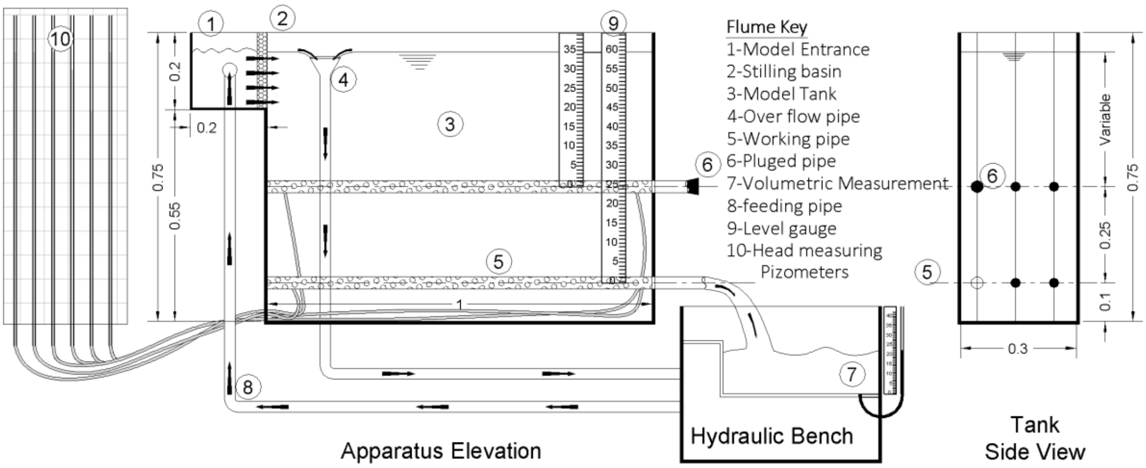

Figure 2: Layout of the Experimental Setup

Series of runs at different water head magnitudes were carried out and the collected discharges and the corresponding head losses were recorded. The experiments were carried out mainly by using four different perforated pipe sizes of 14.14 mm, 17.025 mm, 22.22 mm and 28.812mm for inner diameter with different percentage of opening holes which were varied from 0.14% to 3.5%. Tests were carried out under different water heads which were varied from 0.1 to 0.6m for each pipe. The collected discharges were measured using the provided flow meter in an Arm-Field tank. A total of 192 experiments were conducted and the primary details of carried out tests are listed in Table (1).

Table 1: Primary Details of the Conducted Tests

Pipe No.	**Pipe diameter**		**Tested holes**		**Water head (m)**
	Inner (mm)	**Outer (mm)**	**Number**	**Diameter (mm)**	
1	14.412	16.24	36 & 68	2, 3 & 4	0.1, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5& 0.6
2	17.025	19.925	36, 68 &100	2 &4	0.1, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5& 0.6
3	22.22	24.86	36, 68 &100	2 & 5	0.1, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5& 0.6
4	28.812	32.01	36, 68 &100	2 & 6	0.1, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5& 0.6

4. Result Analysis

The straightforward analysis for the conducted tests illustrated that Renold’s number is varied from 6000 to 72000 with standard deviation of 12513. This in other words means that the flow type for the carried out tests can be specified as turbulent flow which is ranged between oscillating and steady turbulent flow [11]. The achieved results for the effect of pipe size, water head, ratio of open holes to pipe surface area and the design of perforated pipe and the predicted gain head of the pipe would be illustrated through the following sub-sections**:**

4.1. Pipe Size Variations

Figure (3) illustrates the achieved relationship between the perforated pipe diameter and the conveyance ratio (Q_{con}=Q/Q_s) which was achieved through five different tests. This revealed such adverse proportional between the two influences. This in other words means that any increases in pipe diameter will eventually lead to enhance (Q_s) more than that for (Q) which accordingly means a certain decrease in the conveyance ratio (Q_{con}). For this reason the increase in perforated pipe diameter will lead to a certain decrease in the conveyance ratio. On the other hand, also Figure (3) illustrates that the decreasing rate in the conveyance ratio for large diameter pipes is much more than that for smaller ones. If the designer need to increase the discharge collected from same area of holes in the perforated pipe with the same head must decrease the diameter of pipe.

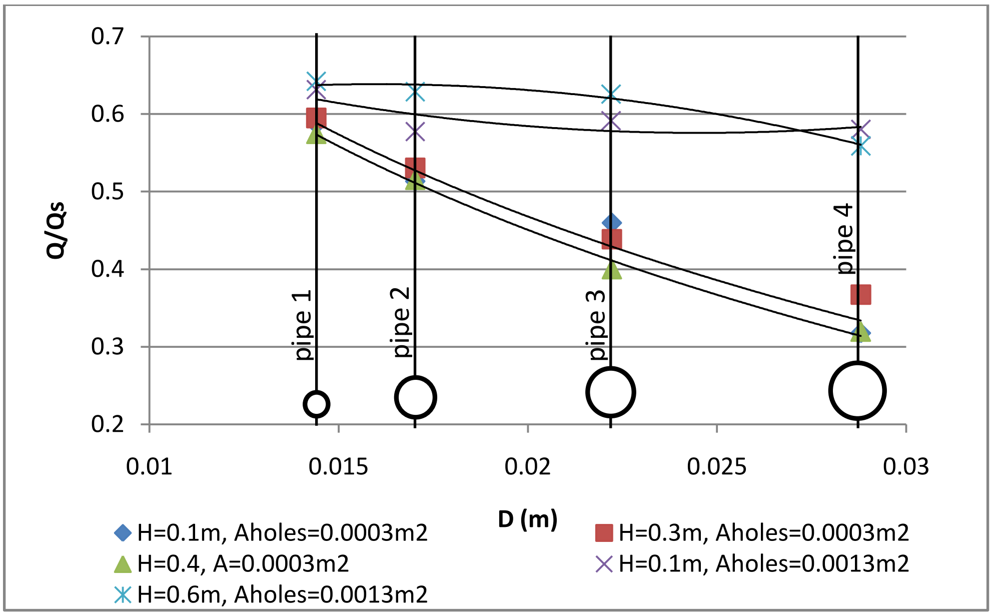

Figure 3: Relation between Pipe Diameter and Conveyance Ratio

The percentage of losses in pressure head measurements along the length of a perforated collection pipe of 4.0mm holes size and the number of holes 100 for static head of 36cm for different pipe diameter is presented in figure 4. It has been noted that the interior losses in the pressure head increases as the pipe diameter increases.

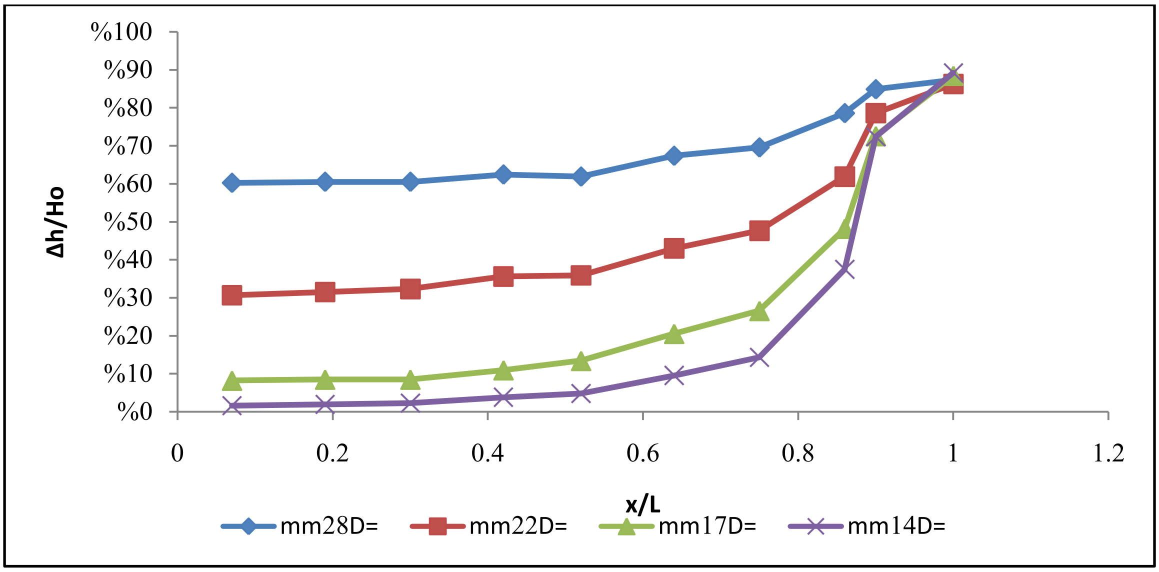

Figure 4: Relation between Pipe Diameter and head ratio for Ho=36cm

4.2. Water Head Variations

The calculated head ratios ($H_{ratio} = \frac{\Delta h}{D}$) from the experimental data were illustrated against the attained water head above the perforated pipe as shown in Figure (5). This revealed such proportional increase It can be notice the logical increasing head ratio with increase of water head also it can be noted that the head ratio increase with increase the percentage of holes (S%) for same pipe and same water head.

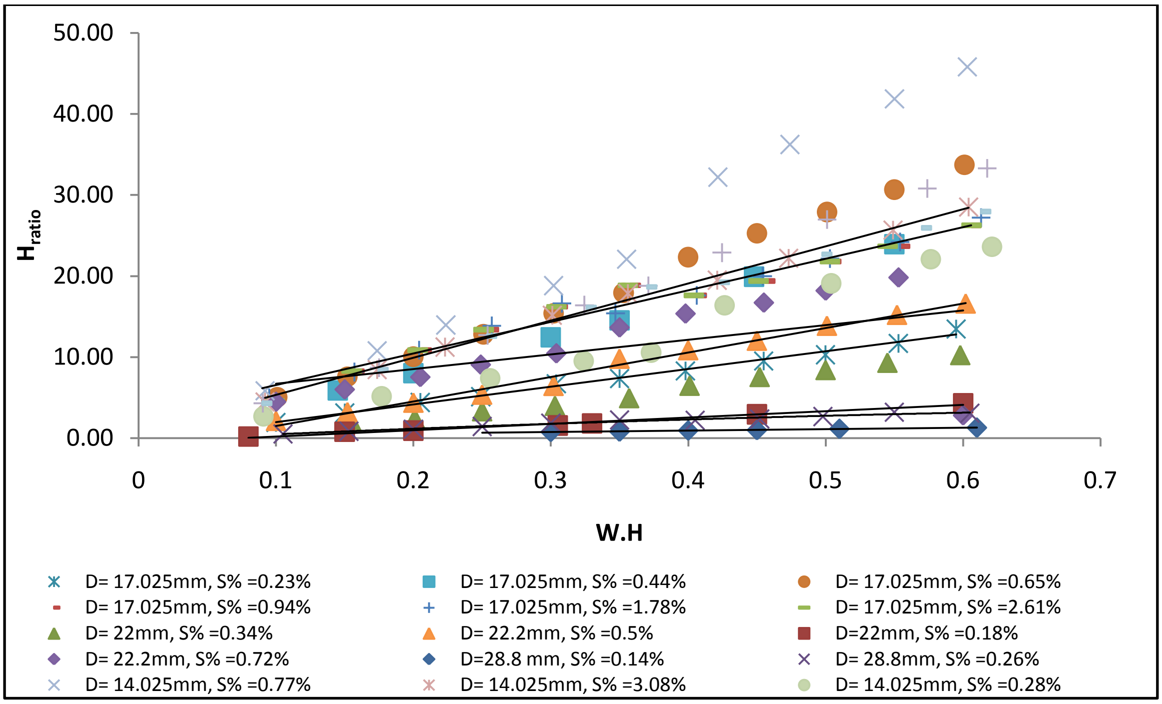

Figure 5: Relation between Water Head and Head Ratio

Figure (6) illustrates the deduced relationship between the conveyance ratio (Q/Q_s) and water head which revealed that the conveyance ratio is nearly constant for the entire applied range of water head for same pipe and holes percentage. Those observations approved the attainable results of similar study that carried out by Kolodgie and Winkle [12] for flow of fluids through perforated plates. The pressure head measurements throughout the length of a perforated collection pipe of 22cm in diameter and the hole percentage S% is 20.2% and static head of 63 cm for different number of holes per section is presented in figure 7. It has been noted that the interior pressure head increases as the number of hole per section increases to 0.9 of the distance.

Figure (8) shows an example of the effect of initial head on head ratios along the pipe for pipe with diameter 28cm and the hole percentage is 3.97%. It shows that the head ratios increase with increase the initial head. The percentage of loss increases with increase of the initial head.

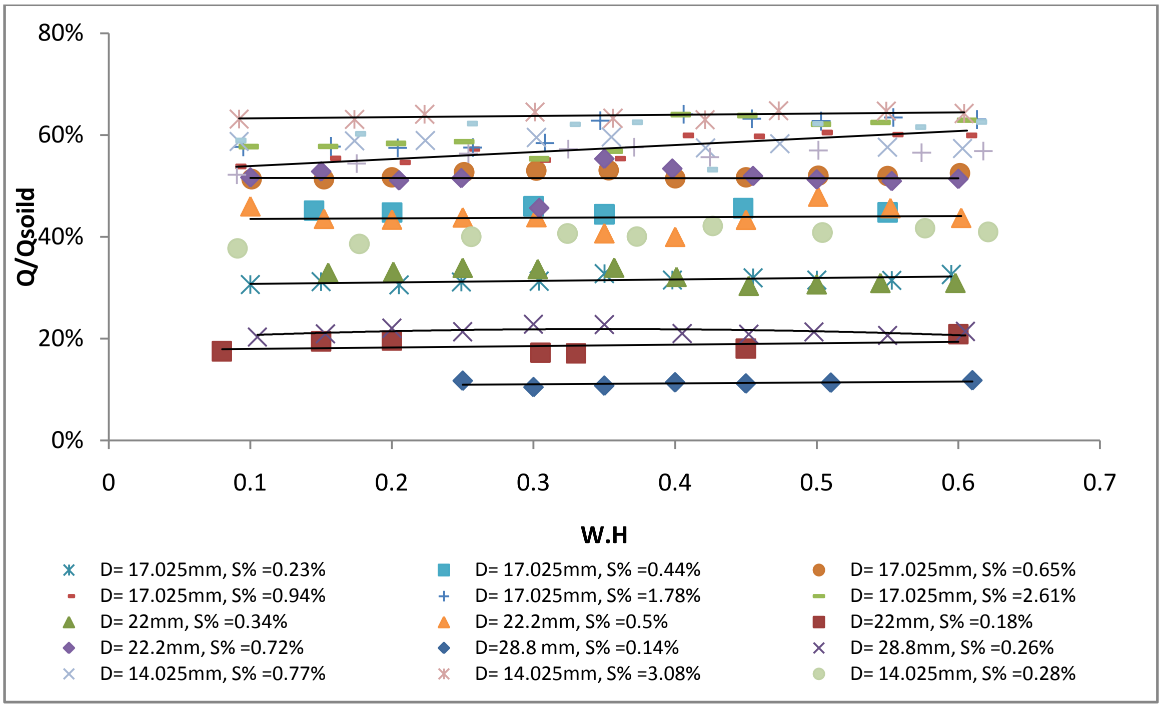

Figure 6: Relation between Water Head and Conveyance Ratio

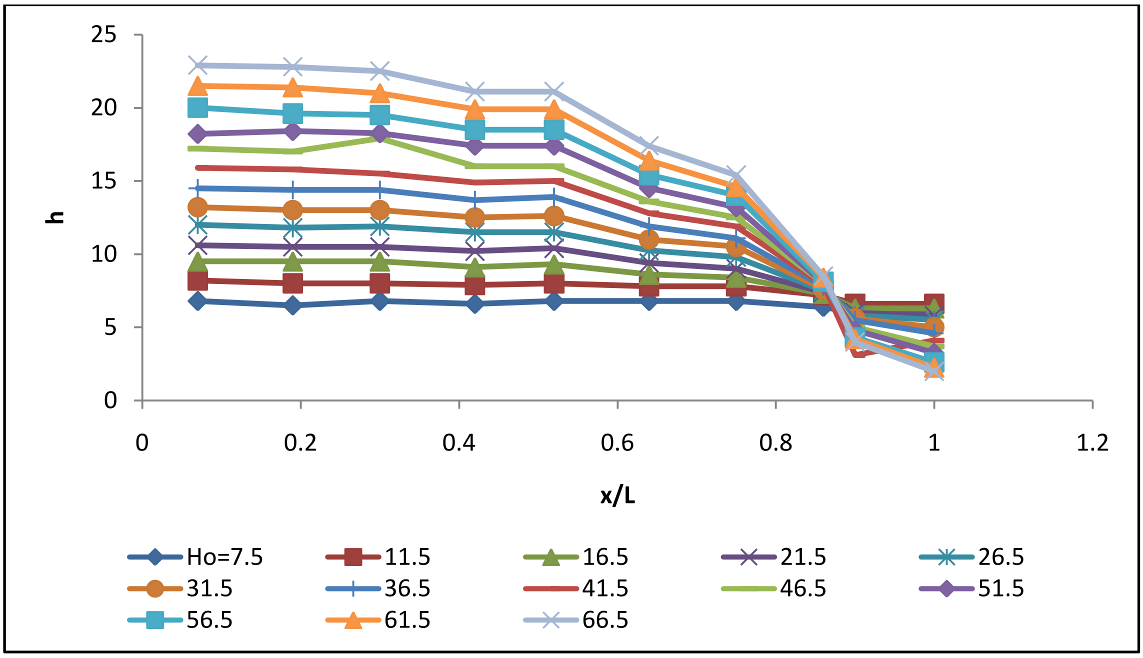

Figure 7-a: the pressure head along the pipe distance for D_{pipe}= 28cm, S%=3.97%, NH=51.02%

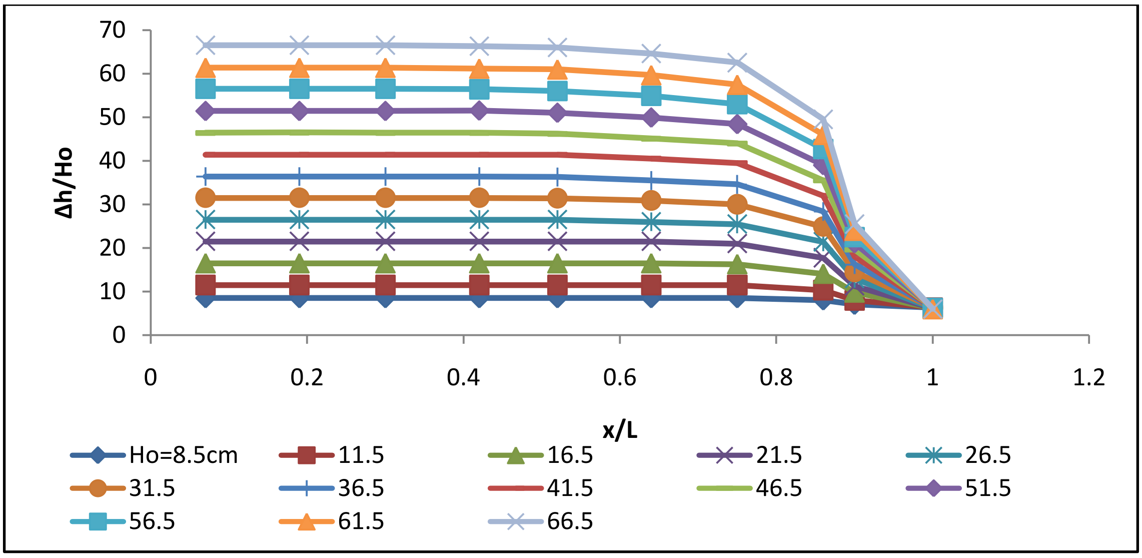

Figure 7-b: the loses pressure head along the pipe distance for D_{pipe}= 22cm, S%=20.2%, NH=204.1%

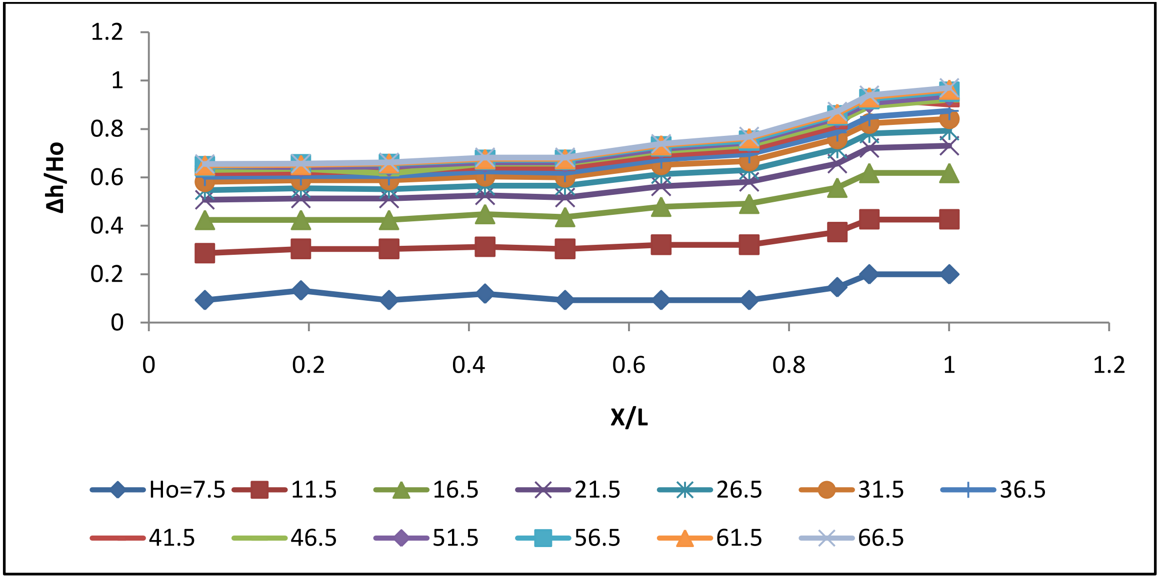

Figure 8: Effect of initial head on the head ratios along the distance (For D_{pipe}=28cm, S%= 3.97%)

4.3. Effect of the Pipe Holes Percentage

The conveyance ratio can be defined as the ratio between the total accumulated discharge at the outlet collection of the perforated pipe to that discharge from similar solid pipe which has same length, diameter, skin friction and applied static head. The conveyance ratio simply compares between the different pipes in order to reveal the effect of the holes pattern and geometry on the collected discharges. Moreover, the discharge from solid pipe is used for normalization purposes. For this reason, Figure (9) illustrates the relationship between conveyance ratio and percentage of perforation for different holes diameters and the corresponding static head. It is interesting to note that the relationship between Q/Q_s and S – as shown in Figure (9) - can be distinguished into three different regions. The first region is a rabid linear relationship up to S = 0.62% and can be mathematically described by the following linear equation: Q_{con} = 0.85 S. The second region is located between S = 0.62%up to 1.15%and can be considered as transition zone which is also linear relation with less rate of increase than that of the first region. The conveyance ration (Q/Q_s) within this region lays from 0.51 to 0.6 as shown in Figure (9). The third region starts at perforation ration of (Q_{con} =Q/Q_s= 0.60) with nearly linear horizontal curve from S= 1.15% up to 3.0%. This in other words means that any increase for the perforation percentage more than S=1.15% up to 3.0%, the corresponding conveyance ration (Q/Q_s) would be a constant value of about 60%. This also means that if the perforation in collection pipe is performed with S=1.15% or more, the accumulated discharge at the outlet collection of the perforated pipe would be pipe equal to 60% of the discharge from solid pipe. The figure specifies that there is no significant effect of hole diameter and static head in the relation between conveyance ration and percentage of perforations (S). Therefore while making design of laterals these will be no specific perforation for a certain hole size as long as the required percentage of perforation is maintained.

Figure (10) illustrates the relation between normalized holes ($NH = \frac{\sum A_{holes}}{A_{cross}}$) and conveyance ratio for different static heads, different collection pipe lengths and different hole diameters. The figure shows that %S is not sufficient to fully describe the flow conveyance because the relation between %S and conveyance ratio depends on the pipe length.

Figure (11) shows the relation between relative initial Froude number (Fr*NH) and relative change in head (Δh/Ho*NH) for all runs. The figure shows that the relative initial Froude number gives a parabola relationship and can be mathematically described by the following equation $\frac{\Delta h * NH}{H_o} = -0.008(F_r * NH)^2 + 0.413(F_r * NH) + 0.034$

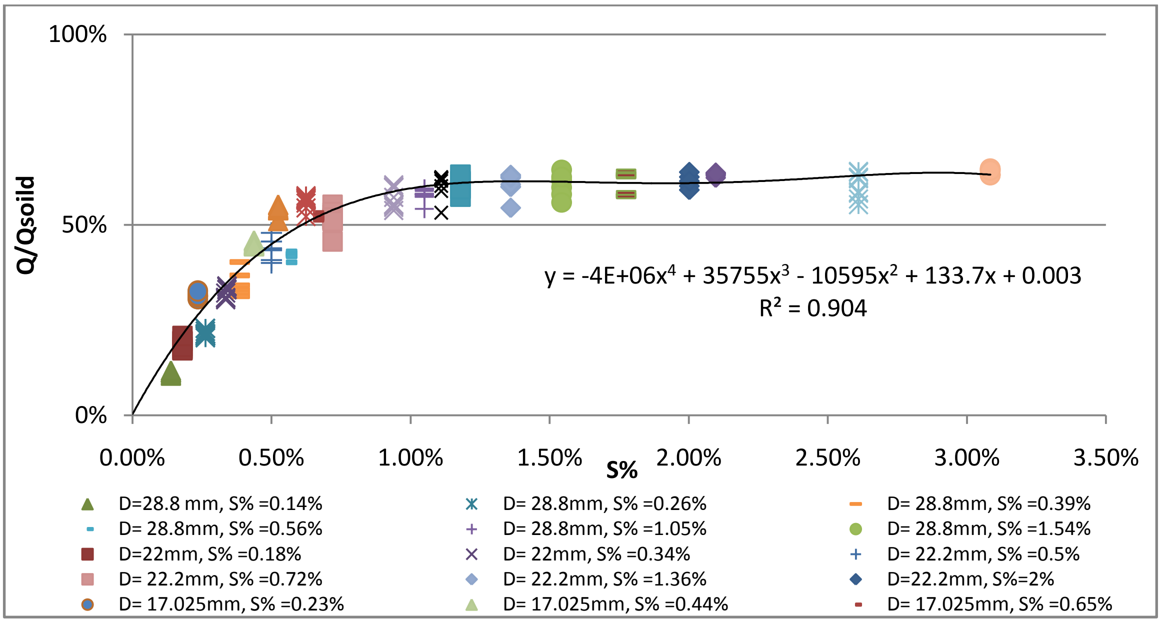

Figure 9: Relation between Conveyance Ratio and perforation Percentage

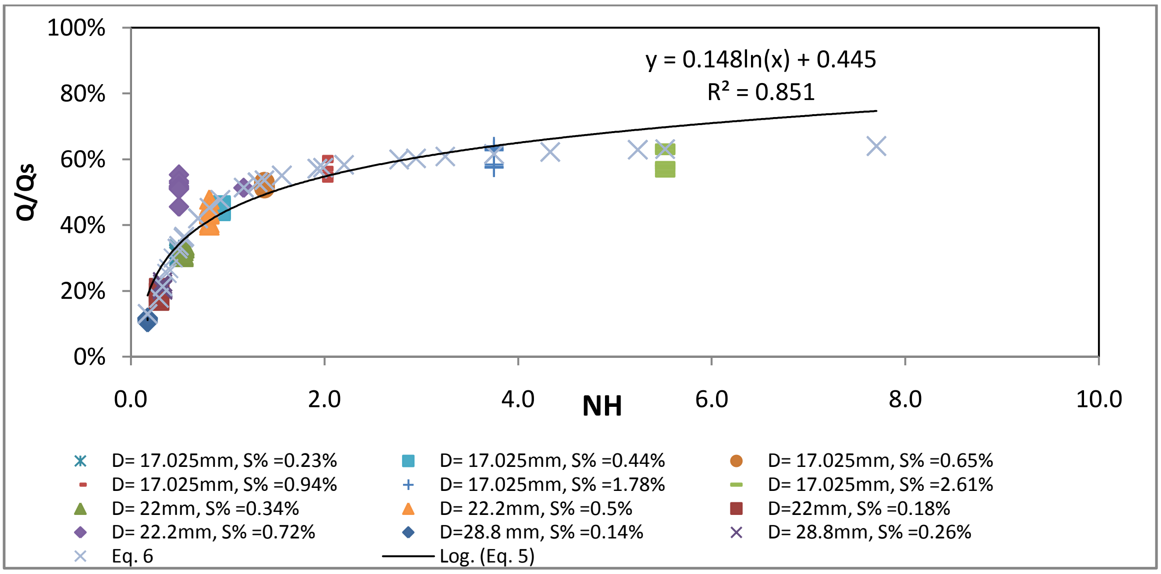

Figure 10: Relation between Conveyance Ratio and normalized holes

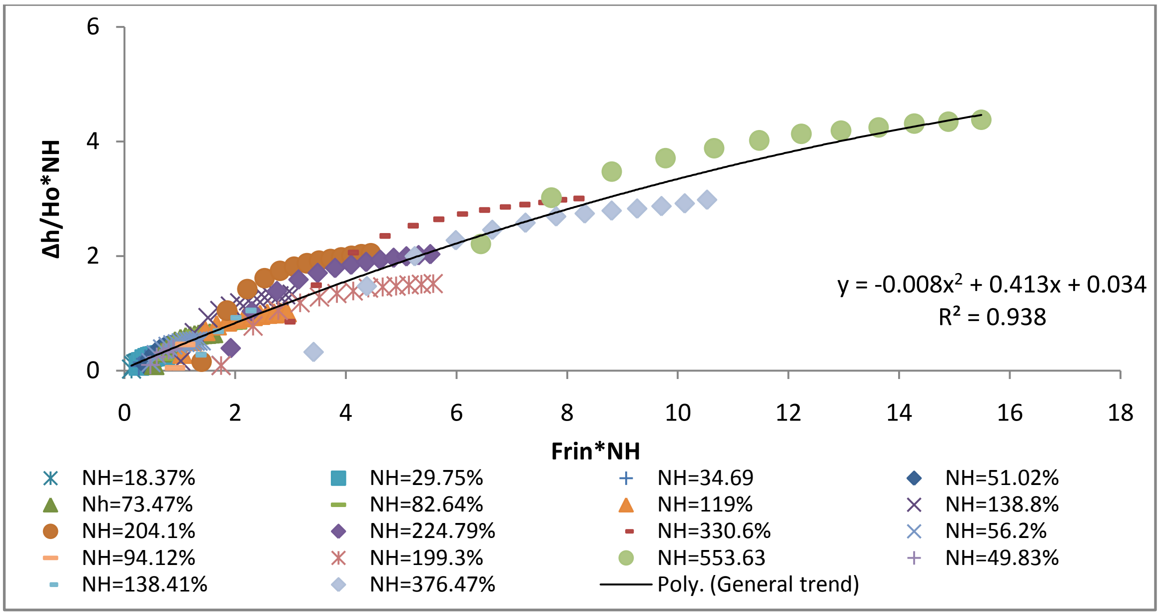

Figure 11: Relation between relative Froude number and relative change in head

4.4. Effect of Reynolds Number

Figure (12) illustrates the relationship between the conveyance ratio (Q/Q_s) and Renold's numbers(R_e). This revealed that the conveyance ratio is nearly constant for the entire range of Renold's number for the same perforated pipe. Those observations approved the attainable results of similar study that carried out by Kolodgie and Winkle [12] for flow of fluids through perforated plates.

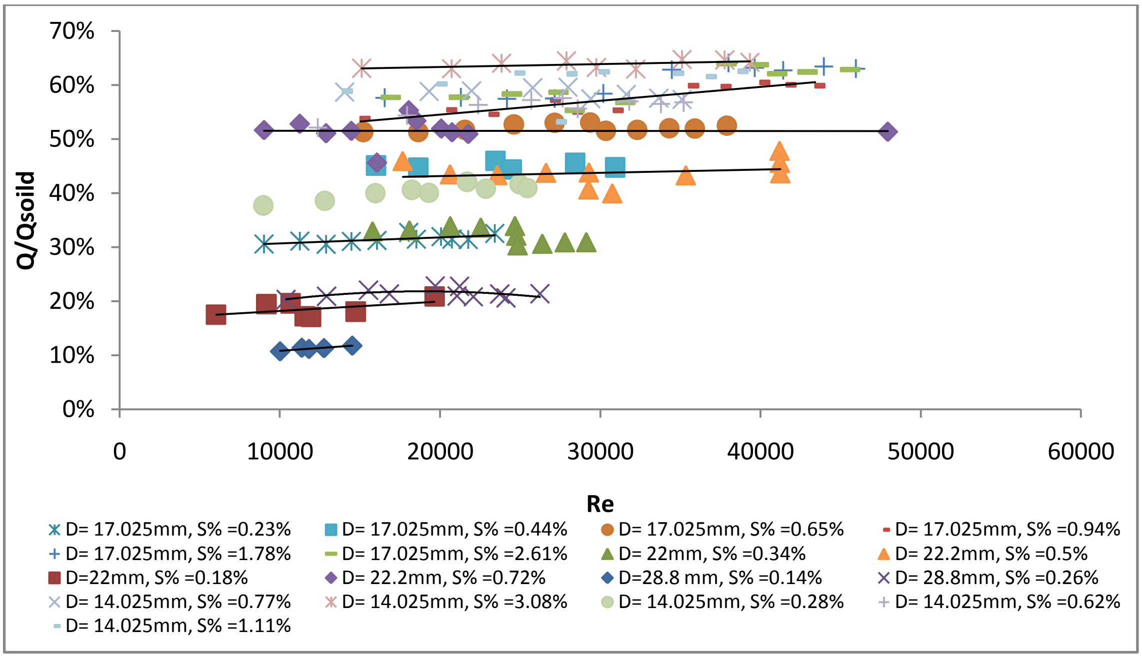

Figure 12: Relation between Conveyance Ratio and Renold's Number

4.5. Effect of head ratio

Figure 13 shows the pizeometers connected to perforated pipe in the tank to measure the profile of water pressure inside the pipe from inlet to outlet compared with the water level in the tank.

Figure 13: The pizeometers connected to perforated pipe

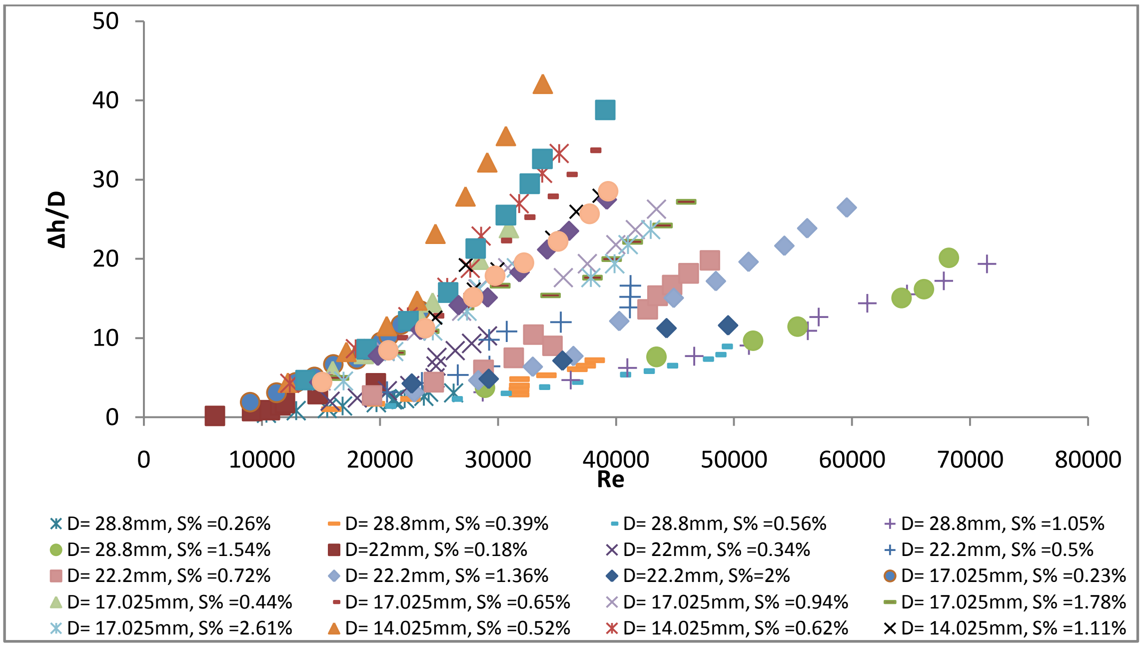

Figure 14: Relation between Head Ratio and Renold's Number

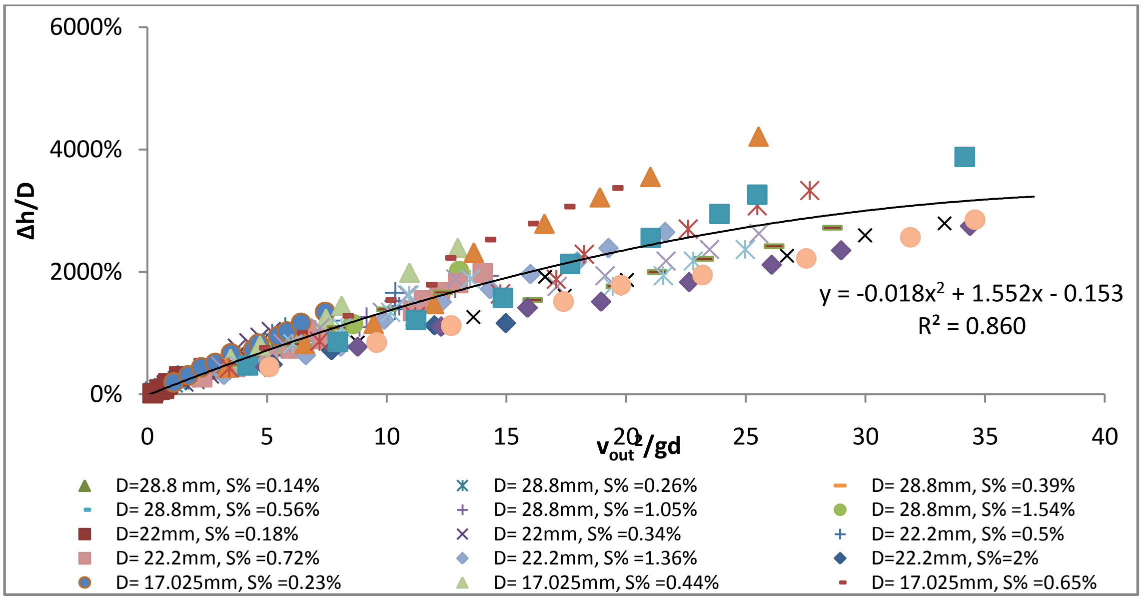

Figure 15: Relation between Head Ratio and (v_{out}^2/gd)

The linear stepwise regression has been employed to find the mathematical relationship between the dependent variable Q/Q_s and independent variables (S, NH, D, A, H, and Re). Stepwise skim states to include the independent variables to the model of the highest correlation with the dependent variable and at the same time exclude those which not affect the model. The best model has adjusted R^2 is 0.91 at confidence level of 95%. The head loss ($\Delta h/L$) has been also modeled by the Non-linear stepwise method with the same independent variables. Nonlinear Regression Analysis of 25 different models is carried on by the same package. The models were defined as power mathematical relations. To show some of the nonlinear models, Table 2 present 10 best models. The equations 6 and 7 give the highest coefficient of multiple determination (R^2) to predicate the collected discharge from the perforated pipe. Equation 9 gives the highest regression to give the different head between the inlet and outlet of the pipe.

Table 2: Regression Analysis

No	Equation	A	b	c	d	R^2
1	$Q = exp(a*D + b*Aholes + c*H + d)$	69.42	716.84	1.53	-10.30	0.8
2	$Q = exp(a*D + b*H + c*S\% + d)$	90.25	1.5264	38.366	-10.74	0.72
3	$Q/Q_s = S/(a + b*S + c*sqr(S))$	1.19E-2	2.2537	-0.17	0	0.83
4	$Q/Q_s = S/(a + b*S - c*S\char`^2)$	6.24E-3	0.8873	-20.22	0	0.83
5	$\frac{Q}{Q_s} = aln(\sum a_h/A) + b$	0.148	0.445	0	0	0.85
6	$\frac{Q}{Q_s} = a + b/(\sum a_h/A) + c/(\sum a_h/A)^2 + d/(\sum a_h/A)^3$	0.66	-0.183	5.53E-03	1.68E-03	0.91
7	$\frac{Q}{Q_s} = a + b*ln(S) + c*ln(S)^2 d*ln(S)^3$	-2.90	-2.168	-0.417	-2.42E-02	0.9
8	$\Delta h/D = a + b*(v^2/gD) + c*(v^2/gD)^{2.5}$	0.165056	1.403708	-2.50E-03	0	0.865
9	$\Delta h = exp(a*D + b*H + 932.257*S - 49.42)$	1311.48	2.36	932.257	0	0.93
10	$\frac{\Delta h}{D} = a(\frac{v^2}{2g})^2 + b(\frac{v^2}{2g}) - c$	-0.018	1.552	0.153	0	0.86

5. **Conclusions**

The experimental study to investigate the influence of percentage of holes, diameter of pipe, and the water head on the collected discharge in perforated pipe prompted the accompanying conclusion:

1- The conveyance ratio is nearly constant for the entire range of Renold's number for the same perforated pipe.

2- The decreasing rate in the development extent for huge width pipes is impressively more than that for smaller ones. In case the maker need to fabricate the discharge assembled from a same area of openings in the punctured pipe with a comparable head must reducing the width of pipe.

3- Any extension for the puncturing rate over level of holes rise to 1.15% up to 3.0%, the relating transport extent would be a relentless estimation of around 60%.

4- The level of apertures isn't adequate to completely depict the stream movement in light of the fact that the connection amongst %S and transport proportion relies upon the pipe length. And The results indicate that the normalized holes total area ratio (NHTAR) is the most relevant design parameter that governs the conveyance in the perforated pipe and the drainage performance

5- at long last the paper furthermore gives some condition to help the organizer to plot the perforated pipe

References

[1]. Field, R., Tafuri, A. N., Muthukrishnan, S., Acquisto, B. A., & Selvakumar, A. (2006). The Use of Best Management Practices (BMP) in Urban Watersheds. Lancaster: DEStech Publications, Inc.

[2]. Stuyt, L., Dierickx, W., & Martinez Beltran, J., (2005), "Materials for subsurface land drainage systems", Food and Agriculture Organization of the United Nations, Rome, 2005.

[3]. Ernst, L. F. (1956). Calculation of the steady flow of groundwater in vertical cross-sections. Netherlands Journal of Agricultural Sciences, 4, 126–131.

[4]. Demographia, (2005), "Demographia. Retrieved January 15, 2013, from Estimated Urban Land Area: Selected Nations: http://www.demographia.com/db-intlualand.htm N.Y.

[5]. Lansford, T. (2010). Encycolpedia of the Nations. Retrieved January 15, 2013, from United States of America, http://www.nationsencyclopedia.com/economies/Americas/United-States-fAmerica.html

[6]. North Carolina Department of Transportation. (2008). Stormwater Control Devices. North Carolina: NCDOT.

[7]. Department of the Army. (1997). BMP: Subsurface Drain. In U. S. Engineers, Engineering and Design - Handbook for the Perperation of Storm Water Pollution Prevention Plans for Construction Activities (pp. C 175 - 181). Washington.

[8]. Abdel-Mageed, N.B. and Ghanem, A.M. (2010), "Effect of Perforated Pipe Length on the Inlet Discharge of Subsurface Drainage Systems", Journal of Engineering and Applied Science, Vol. 58, No. 6, Dec. 2011, pp. 495–507.

[9]. Schwartz, S.S., (2010),"Effective Curve Number and Hydrological Design of Pervious Concrete Storm-Water Systems", Journal of Hydrologic Engineering, pp.465 – 474, 2010.

[10]. Akan, A.O., (2013), "Preliminary Design Aid for Bio Retention Filters", Journal of Hydrologic Engineering, 2013, pp.318 - 323.

[11]. Chow, V. T. (1959).“Open Channel Hydraulics." McGraw-HILL Book Company, Inc., New York.

[12]. Kolodgie PA Jr; Winkle MV (1957) Discharge coefficient through perforated plates. AIChE J. 3:305-312.