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# Some remarks on the principles of hydraulic design criteria for Land Drainage schemes

by

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## 1. Introduction

The Land Drainage Water Supply and Machinery Division of the Ministry of Agriculture in London recently issued a note 'Design of Underdrainage Schemes. In this note specifications are given for the maximum area to be drained with pipes of a given diameter and type.

In a discussion between Mr. TRAFFORD of the above mentioned Division, Mr. VAN SOMEREN of the Cultuurtechnische Dienst and the author several points concerning the problem of hydraulic design of drainage systems remained unclear. One of these points was the big difference in area to be drained by certain types of pipes as proposed by the Dutch 'Drainagestudiegroep' and as given in the English specifications.

Another point was the question, whether the design slope must be based on the slope over the total length of a lateral or only over the lower third of it.

In this note the above two questions will be discussed. Further the note gives a comparison between the Dutch and English specifications. Although the note is simply meant as a discussion paper for the Dutch group it is written in English so that the content is also accessible for our English collegues.

In the note only metric units are used. As far as necessary the following conversions have been applied

| | inch | acre | chain | cm | ha |
|---|---|---|---|---|---|
| inch | 1 | - | - | 2.54 | - |
| acre | - | 1 | - | | 0.4047 |
| chain | 790 | - | 1 | 2011 | - |
| cm | - | - | $.98.10^{-4}$ | 1 | - |
| ha | - | 2,47 | - | - | 1 |

## 2. Basic formulas for the hydraulic resistance of drainpipes

For the computation of the loss of hydraulic head in drainpipes various formula are available. Here only three types are discussed namely

a) The MANNING equation

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

(v in m/sec, R in meter, S in m/m)

b) The equation of VISSER

$$Q = 0.078\, d^{8/3} S^{0.55} \qquad (2)$$

(Q in l/sec, d in cm, S in m/m)

c) The equation for non-perforated smooth plastic pipes found by WESSELING and HOMMA

$$v = 198.2\, R^{0.714} S^{0.572} \qquad (3)$$

(v in m/sec, R in meters, S in m/m)

The latter equation needs certain corrections for perforation and field conditions which will be discussed below.

## 3. The principles of hydraulic design

For the hydraulic design of drainage lines two principles are used

a) The transport principle. The drainline is considered as a transport line, capable to transport a given quantity of water which is assumed to flow from one end of the pipe to the other.

b) The drainage principle. The flow in the line is considered to increase from zero at its upper end to its maximum value at its lower end.

The second principle, generally used in the Netherlands, must be applied, when hydraulic heads must be computed at various places along the drain.

The two principles give differences in transport capacities and hence differences in areas to be drained with a certain diameter of pipe.

The first principle leads rather simply to an area, since

$$Q = \frac{MA}{86.400}$$

(Q in l/sec, A in $m^2$, M in millimeters). Here M is the design discharge rate.

Substitution of the value into the eqs. 1, 2 and 3 yields after some rearrangement; respectively

$$0_{ha} = \frac{0.937}{M} d_{cm}^{8/3} S^{1/2} \tag{1a}$$

$$0_{ha} = \frac{0.674}{M} d_{cm}^{8/3} S^{0.55} \tag{2a}$$

$$0_{ha} = \frac{1.91}{M} d_{cm}^{2.714} S^{0.572} \tag{3a}$$

For eq. 1a n = 0.0135 has been taken.

Applying the drainage principle, generally a constant inflow per unit length of drain is assumed, hence

$$q = \frac{Q}{L}(L - x)$$

indicating that at the lower end (x = 0) the flow equals q = Q, while at the upper end of the line (x = L) q = 0. Further S in eqs. 1, 2 and 3 is taken to be equal to $\frac{dh}{dx}$ so that the resulting equation must be integrated to obtain the relation between h and x. Assuming h = 0 for x = 0, the integration then yields respectively

$$h = 2.15 \cdot 10^{4} d_{cm}^{-16/3} \frac{Q^2}{L^2} \{L^3 - (L - x)^3\} \tag{1b}$$

(h in meters, Q in $m^3$/sec, n = 0.0135)

$$h = 36.7(\frac{Q}{L})^{1.818} \{L^{2.818} - (L - x)^{2.818}\} d^{-8/3} \tag{2b}$$

(h in meters, Q in l/sec)

$$h = 3.02 \cdot 10^{-4} (\frac{Q}{L})^{1.75} \{L^{2.75} - (L - x)^{2.75}\} d^{-4.75} \tag{3b}$$

(h in meters, Q in $m^3$/sec, d in meters)

Taking now for the design slope the slope over the whole line, hence $S = h/L$ and applying this to the b-equations yields after some rearrangement and taking into account the different units:

$$O_{ha} = \frac{1.61}{M} d_{cm}^{8/3} S^{1/2} \qquad (1c)$$

$$O_{ha} = \frac{1.19}{M} d_{cm}^{8/3} S^{0.55} \qquad (2c)$$

$$O_{ha} = \frac{3.26}{M} d_{cm}^{2.714} S^{0.572} \qquad (3c)$$

## 4. The consequences of applying the different principles

The a-equations and c-equations give the maximum allowable area to be drained with a pipe of a given diameter for the transport and the drainage principle respectively. The differences in result can be derived easily. For the same slope, diameter of pipe and drainage rate the Manning formula will give areas which are $\frac{1.61}{0.937} = 1.72$ times higher for the drainage principle than those for the transport principle. For the Visser-equation 1.77 times larger areas and for the Wesseling-Homma equation 1.71 times larger areas are computed for the case the drainage principle is applied.

The above mentioned values hold for the case that the design slope is assumed to be the general slope over the whole length of the line. If the slope over the lower third of the line must be taken, then the drainage principle must be applied, since in the case of transport, a straight slope in the hydraulic head line is incorporated in the equations. Hence for this case the b-equations must be applied. If for the design slope, the lower third

/Substituting

of the line is taken, then one has $S = h/1/3\ L$/a value $x = \frac{1}{3}$ L into eq. 1b and dividing both the right and left hand member of the remaining equation by $\frac{1}{3}$ L yields a slope which is 1.99 times that of the whole line.

Substitution of $x = \frac{1}{3}$ L into eq. 2b yields a slope which is 2.04 times as high as that over the whole line. Finally eq. 3b gives a 2.09 times as high slope. Computation of the allowable area with a slope over the lower third of the line, therefore would respectively yield areas of $(\frac{1}{1.99})^{0.5}$, $(\frac{1}{2.04})^{0.55}$ and $(\frac{1}{2.08})^{0.572}$ times smaller than that computed with the slope over the whole line. The 1/3-slope assumption therefore would yield a reduction in area of respectively 0.71, 0.68 and 0.65.

The results obtained from the above computations have been summarized in table I.

Table I. Summary of results of design computations, all expressed in terms of the transport principle

| Eq. | Principles | | |
|---|---|---|---|
| | transport | drainage | $\frac{1}{3}$ - slope |
| Manning | 1.0 | 1.72 | 0.71 |
| Visser | 1.0 | 1.77 | 0.68 |
| Wesseling + Homma | 1.0 | 1.71 | 0.65 |

From this table it may be concluded that the transport principle gives the same drainable area as the drainage principle combined with the $\frac{1}{3}$ - slope assumption.

## 5. Pipes under field conditions

The flow resistance equations mentioned above are all based on laboratory measurements. The experiments of WESSELING and HOMMA showed that the perforations of plastic pipes increased the loss in hydraulic head by factor $\frac{0.35}{0.3164} = 1.1$ provided that the perforations had been made carefully so that no material in the forms of hairs had been left.

Field measurements in the IJsselmeerpolders showed that for both clay tile and plastic lines, the required hydraulic head is as an average $\frac{1 :}{0.775} = 1.31$ times as high as that computed for well-perforated plastic pipes. This implies that the area to be drained as computed from eq. 3d must be multiplied by a factor $(\frac{1}{1.31 \times 1.10})^{0.572} = (\frac{1}{1.44})^{0.572} = 0.81$.

The Dutch specifications also leave a possible reduction of 25% open to take into account a silting up of the pipes which will occur sooner or later.

In the old specifications, based on Manning's or Visser's formula (cf for instance KUSSE Neth. J of Agr. Sci. 1962) a reduction in area of 50% was generally accepted to take into account possible silting up of the pipes.

## 6. The English specifications

By plotting the computed area for a certain type of drains against the slope, on log-log paper, a straight line is obtained the equations 1a and 1c must give a slope 0.5, as eqs 2a and 2c must give a slope 0.55. The equations 3a and 3c finally will yield a slope 0.572. By plotting the areas given in the English specifications against the slope for which they have been computed, a straight line with a slope 0.54 is obtained for 3" Land tiles for 1 3/4" MUNTZ and BARNELL, Landcoil and for 1 3/4" Lamflex. The data of the English specifications therefore have been compared with those to be computed from Visser's equation. The results are given in table II.

Table II. Comparison of data from the English specifications for 3" Land Tile's with these computed with the aid of eq. 2a, expressed in rates ES/eq. 2a

| Drainage rate | Slope | | |
|---|---|---|---|
| | 4 % | 1 % | 0.1 % |
| 25.4 mm | 0.65 | 0.64 | 0.63 |
| 19.6 mm | 0.66 | 0.65 | 0.63 |
| 12.70 mm | 0.67 | 0.65 | 0.64 |
| 10.16 mm | 0.66 | 0.66 | 0.64 |
| 7.62 mm | 0.62 | 0.65 | 0.65 |
| 6.35 mm | 0.66 | 0.65 | 0.66 |

If the transport principle has been applied a reduction of about 0.65 has been applied. If the drainage principle has been applied a reduction of 0.37 would have been applied which is rather high as compared with the generally accepted 0.5.

The MUNZ and BARNELL 1 3/4" Landcoil give about 5% higher values as would be expected from the smaller diameter ($(\frac{7}{12})^{8/3}$ = 0.221 times the area given for 3" Land Tiles). The Lamflex 1 3/4" gives about 7 to 8% lower values. Therefore it must be concluded that for the three types of pipes discussed up to now different basical equations are used, unless for the diameters for the last two types of pipes a value smaller, respectively larger than 1 3/4" is used.

The English data for the polythene pipes show in the graph a straight line with a slope of 0.57. The results therefore can be computed with the W and H-equation (eq. 3a).

The result is given in table III.

Table III. Comparison of data from the English Specifications for 2" polyetene with those obtained from eq. 3a, expressed in the ratio ES/eq. 3a

| Drainage coefficient | Slope | |
|---|---|---|
| | 4 % | 2 % |
| 25.4 mm | 0.75 | 0.77 |
| 19.05 mm | 0.76 | 0.77 |
| 12.70 mm | 0.76 | 0.78 |
| 10.16 mm | 0.77 | 0.78 |
| 7.62 mm | 0.77 | 0.77 |
| 6.35 mm | 0.77 | 0.77 |

So roughly a reduction factor of 0.75 has been applied. If the drainage principle would have been applied the reduction factor would have been

$$\frac{0.75}{1.71} = 0.45$$

## 7. Comparison of the English and Dutch specifications

For the Dutch specifications eq. 3c has been applied. For the influence of well-perforated pipes under field conditions a reduction factor of 0.81 can be applied (see above). Hence the equation becomes

$$0_{ha} = \frac{2.61}{M} d_{cm}^{2.714} S^{0.572}$$

Table IV gives a comparison of the results computed with this equation and the data for polythene pipes given in the English specifications

Table IV. Comparison of the Dutch and English Specifications for 2" Polythene pipes. Data given in ha

| Drainage rate | 4 % | | 2 % | | 1 % | | 0.1 % | |
|---|---|---|---|---|---|---|---|---|
| | E | D | E | D | E | D | E | D |
| 25.4 mm | 0.676 | 1.45 | 0.458 | 0.89 | 0.31 | 0.61 | 0.08 | 0.16 |
| 19.05 mm | 0.903 | 1.94 | 0.612 | 1.18 | 0.41 | 0.82 | 0.11 | 0.22 |
| 12.70 mm | 1.35 | 2.91 | 0.915 | 1.78 | 0.62 | 1.23 | 0.17 | 0.33 |
| 10.16 mm | 1.69 | 3.63 | 1.15 | 2.22 | 0.77 | 1.54 | 0.21 | 0.41 |
| 7.62 mm | 2.26 | 4.75 | 1.53 | 2.99 | 1.03 | 2.06 | 0.28 | 0.55 |
| 6.35 mm | 2.70 | 5.80 | 1.84 | 3.55 | 1.24 | 2.46 | 0.34 | 0.67 |

The areas for the English specification are about 50% of those of the Dutch. It is obvious that this is due to the difference in applied principle. The English Specifications have been based on the water transport in non-perforated pipe with a reduction factor of 0.77 (see table III).

Taking the result for the transport in non-perforated pipes equal to 1.00, then the English values amount 0.77. The Dutch specifications are based on the drainage principle and computed for flow resistances of perforated pipes under field conditions. The latter requires a reduction of 0.81 as shown above. Since the drainage principle gives 1.71 times higer values for the area, the Dutch Specifications amount therefore 0.81 x 1.71 = 1.39 which is about twice the value 0.77 for the English Specifications. For the Dutch Specifications further a reduction of 25% for possible silting up of the pipes is often applied in practice. This would mean, that the Dutch areas are still about 25% higher than the proposed English ones.

A final remark should be made on the diameter. In the Dutch Specifications the inner-diameter of the pipe was originally proposed. This means that a 2" (5.08 cm) pipe has an inner-diameter of 4.88 cm. A reduction factor of $\left(\frac{4.88}{5.08}\right)^{2.714} = 0.90$ is then easily computed.

If a 2" pipe is compared with a 5 cm pipe, the area changes with a factor $\left(\frac{5.00}{5.08}\right)^{2.714} = 0.96$ which is only 4%. Despite these small differences it should be remarked that the diameter has a rather large influence.

## 8. Summary and conclusions

A comparison of the English and Dutch specifications for the maximum allowable length of laterals in subsoil drainage lead to the following conclusions

a. The English Specifications for polythene pipes is based on another type of flow equation than those for 3" Land tiles and 1 3/4" Landcoil and 1 3/4" Lamflex. Concerning the first type of pipe this is not an agreement with the Dutch specifications, which are based on another resistance equation.

b. For 2" polyetene pipes, the English specifications are based on the flow resistance equation for non-perforated pipes. For the computation of drainable areas the transport principle has been applied with a reduction factor 0.75 to 0.77 for field conditions where as the Dutch Specifications are based on the drainage principle with a reduction of 0.87 for field conditions.

c. The difference of 50% in maximum allowable drained area for polythene pipes is due to the difference in principle applied, namely the transport and the drainage principle.

d. Taking the design slope as the slope over the lower third line would yield for polyetene pipes a reduction factor 0.65 as compared with those computed with the drainage principle.