

透水性基礎地盤의 浸透量(Ⅱ)

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7. 數值解析法에 의한 浸透流解析

가. 均質土層에서의 浸透流

x, z 平面에서 二次元의 흐름에 對하여 誘導한 Laplace의 方程式은 다음과 같다.

$$k_x \frac{\partial^2 h}{\partial x^2} + k_z \frac{\partial^2 h}{\partial z^2} = 0 \dots\dots\dots (9)'$$

그림. 12는 浸透流가 일어나는 地域에서 水頭를 나타낸 것이다.

水水平方向의 흐름에 對해서는 Taylor의 級數를 使用하여 다음과 같이 나타낸다.

$$h_1 = h_0 + \Delta x \left(\frac{\partial h}{\partial x} \right)_0 + \frac{(\Delta x)^2}{2!} \left(\frac{\partial^2 h}{\partial x^2} \right)_0 + \frac{(\Delta x)^3}{3!} \left(\frac{\partial^3 h}{\partial x^3} \right)_0 + \dots\dots\dots (38)$$

$$h_3 = h_0 - \Delta x \left(\frac{\partial h}{\partial x} \right)_0 + \frac{(\Delta x)^2}{2!} \left(\frac{\partial^2 h}{\partial x^2} \right)_0 - \frac{(\Delta x)^3}{3!} \left(\frac{\partial^3 h}{\partial x^3} \right)_0 + \dots\dots\dots (39)$$

(38)식과 (39)식을 더하면

$$h_1 + h_3 = 2h_0 + \frac{2(\Delta x)^2}{2!} \left(\frac{\partial^2 h}{\partial x^2} \right)_0 + \frac{2(\Delta x)^4}{4!} \left(\frac{\partial^4 h}{\partial x^4} \right)_0 + \dots\dots\dots (40)$$

로 되고 Δx 가 아주 작은 것으로 假定하면 (40)식의 右邊 第3項과 그 以後의 項을 無視할 수 있다.

따라서

$$\left(\frac{\partial^2 h}{\partial x^2} \right)_0 = \frac{h_1 + h_3 - 2h_0}{(\Delta x)^2} \dots\dots\dots (41)$$

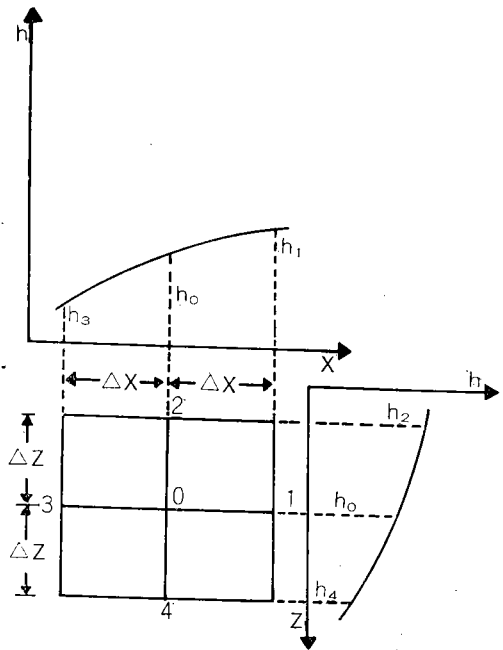


그림. 12. 흐름에 對한 水頭

로 되고 z 方向에 對해서도 같은 方法으로 구해서 (42)식을 얻을 수 있다.

$$\left(\frac{\partial^2 h}{\partial z^2} \right)_0 = \frac{h_2 + h_4 - 2h_0}{(\Delta z)^2} \dots\dots\dots (42)$$

(41)식과 (42)식의 값을 (9)'식에 代入하면 Laplace의 方程式은 다음과 같이 된다.

$$k_x \frac{h_1 + h_3 - 2h_0}{(\Delta x)^2} + k_z \frac{h_2 + h_4 - 2h_0}{(\Delta z)^2} = 0 \dots\dots\dots (43)$$

等方性의 土層에 對해서 考慮하면 $k_x = k_z = k$, $\Delta x = \Delta z$ 로 되고 (43)식은 다음과 같이 간단히 나타낼 수 있다.

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$$k \left\{ \frac{h_1 + h_2 + h_3 + h_4 - 4h_0}{(\Delta x)^2} \right\} = 0$$

따라서

$$h_0 = \frac{1}{4}(h_1 + h_2 + h_3 + h_4) \dots\dots\dots(44)$$

(44)식은 Darcy의 法則 $q=kiA$ 를 考慮해서 誘導될 수 있다.

[a] 그림. 13(a)에서 斜線을 친 部分을 나타낸 流路를 통해서 点 1로부터 点 0로 흐르는 流量에 對해서 다음과 같은 식이 얻어진다.

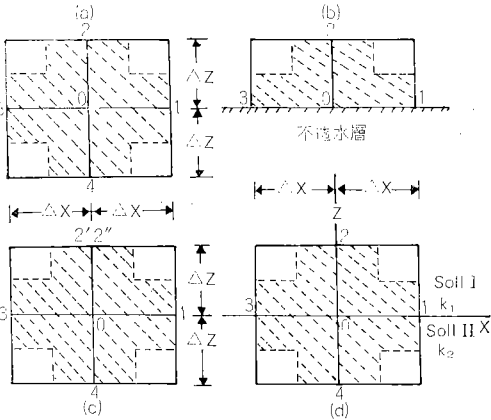


그림. 13. 流 路

$$\left. \begin{aligned} q_{1-0} &= k \frac{h_1 - h_0}{\Delta x} \Delta z \\ q_{0-3} &= k \frac{h_0 - h_3}{\Delta x} \Delta z \\ q_{2-0} &= k \frac{h_2 - h_0}{\Delta z} \Delta x \\ q_{0-4} &= k \frac{h_0 - h_4}{\Delta z} \Delta x \end{aligned} \right\} \dots\dots\dots(45)$$

点 0에 流入되는 流量은 点 0에서 流出되는 量과 같어야 하므로 다음과 같은 식이 成立된다.

$$q_{in} - q_{out} = 0$$

따라서

$$(q_{1-0} + q_{2-0}) - (q_{0-3} + q_{0-4}) = 0 \dots\dots\dots(46)$$

$\Delta x = \Delta z$ 로 取하고 (45)식을 (46)식에 代入하면 다음과 같이 된다.

$$h_0 = \frac{1}{4}(h_1 + h_2 + h_3 + h_4)$$

[b] 만약 点 0가 그림. 13(b)와 같이 透水層과 不透水層의 境界에 位置하였다면 (44)식은 다음과 같이 변경된다.

$$\left. \begin{aligned} q_{1-0} &= k \frac{h_1 - h_0}{\Delta x} \frac{\Delta z}{2} \\ q_{0-3} &= k \frac{h_0 - h_3}{\Delta x} \frac{\Delta z}{2} \\ q_{0-2} &= k \frac{h_0 - h_2}{\Delta z} \Delta x \end{aligned} \right\} \dots\dots\dots(47)$$

흐름의 連續性에 의해서 流入量과 流出量은 같어야 하므로

$$q_{1-0} - q_{0-3} - q_{0-2} = 0 \dots\dots\dots(48)$$

로 되고 $\Delta x = \Delta z$ 로 놓고 (47)식을 (48)식에 代入하여 (49)식을 얻는다.

$$\frac{h_1 - h_0}{2} - \frac{h_0 - h_3}{2} - (h_0 - h_2) = 0$$

$$h_0 = \frac{1}{4}(h_1 + 2h_2 + h_3) \dots\dots\dots(49)$$

[c] 만약 点 0가 그림. 13(c)에서와 같이 말뚝 밑에 位置해 있다면 다음과 같은 식이 얻어진다.

$$\left. \begin{aligned} q_{1-0} &= k \frac{h_1 - h_0}{\Delta x} \Delta z \\ q_{0-3} &= k \frac{h_0 - h_3}{\Delta x} \Delta z \\ q_{4-0} &= k \frac{h_4 - h_0}{\Delta z} \Delta x \\ q_{0-2'} &= k \frac{h_0 - h_2'}{\Delta z} \frac{\Delta x}{2} \\ q_{0-2''} &= k \frac{h_0 - h_2''}{\Delta z} \frac{\Delta x}{2} \end{aligned} \right\} \dots\dots\dots(50)$$

흐름의 連續性에 의해서 流入量과 流出量이 같아야 하므로

$$q_{1-0} + q_{4-0} - q_{0-3} - q_{0-2'} - q_{0-2''} = 0 \dots\dots(51)$$

로 되고 水頭의 方程式은 다음과 같이 나타낼 수 있다. 即 2'와 2''점은 같은 높이로서 널말뚝의 反對面에서 水頭 h_2' 와 h_2'' 를 갖는 点들이다.

앞에서와 같은 方法으로 $\Delta x = \Delta z$ 로 놓고 (50)식을 (51)식에 代入하면 다음과 같이 된다.

$$h_0 = \frac{1}{4} \left\{ h_1 + \frac{1}{2}(h_2' + h_2'') + h_3 + h_4 \right\} \dots\dots(52)$$

나. 成層土에서의 浸透流

앞에서 誘導한 (44)식은 等方性的의 흙에 對한 것으로 等方性的의 한 土層에서 다른 土層으로 浸透할 때에는 (44)식은 勿論 修正되어야 한다. 그림. 13(d)에서 浸透流가 透水係數 k_1 인 Soil I에서의 半과 透水係數 k_2 인 Soil II에서의 半에 位置해 있다면 다음과 같이 나타낼 수 있다.

$$k_x = \frac{1}{2}(k_1 + k_2) \dots\dots\dots(53)$$

만약 Soil II를 Soil I으로 代置한다면 h_4 의 位置에서 h_4' 의 水頭가 생길 것이다. 또 Soil I과 Soil II를 흐르는 流速은 같어야 하므로

$$k_1 \frac{h_4' - h_0}{\Delta z} = k_2 \frac{h_4 - h_0}{\Delta z} \dots\dots\dots(54)$$

여기서

$$h_4' = \frac{k_2}{k_1}(h_4 - h_0) + h_0 \dots\dots\dots(55)$$

로 되고 Laplace의 連續方程式 (9)'식에 의하여 다음과 같이 나타낼 수 있다.

$$\frac{k_2 + k_2}{2} \frac{h_1 + h_3 - 2h_0}{(\Delta x)^2} + k_1 \frac{h_2 + h_4' - 2h_0}{(\Delta x)^2} = 0 \dots\dots\dots(56)$$

$\Delta x = \Delta z$ 로 놓고 (55)식을 (56)식에 代入하면 다음과 같다.

$$\frac{1}{2}(k_1 + k_2) \left[\frac{h_1 + h_3 - 2h_0}{(\Delta x)^2} \right] + \frac{k_1}{(\Delta x)^2} \left\{ h_2 + \left[\frac{k_2}{k_1}(h_4 - h_0) + h_0 \right] - 2h_0 \right\} = 0 \dots\dots\dots(57)$$

$$h_0 = \frac{1}{4} \left(h_1 + \frac{2k_1}{k_1 + k_2} h_2 + h_3 + \frac{2k_2}{k_1 + k_2} h_4 \right) \dots\dots\dots(58)$$

이들 方程式의 應用은 數值的인 例로서 잘 나타낼 수 있으므로 그림. 11과 같은 댐의 여러 地点에서 水頭를 決定하는 問題를 取扱해 본다.

$\Delta x = \Delta z$ 로 하고 댐에서의 流線網이 對稱이므로 댐의 左側部分의 半에 對해서만 생각한다.

透水性의 土層에서 여러 點에서의 水頭 h 를 決定하는 順序는 다음과 같다.

① 流線網의 概略圖를 그리고 그림. 14(a)에서와 같이 여러 格點(grid point)에 水頭값을 定한다. 여기에서 定한 水頭값 h 는 모두가 퍼센트(percent)임에 注意해야 한다.

② 제 1열의 水頭만을 考慮한다(即 $i=1$ 일 때).

$i=1$ 과 $j=1, 2, 3, \dots, 22$ 에 對한 $h_{(i,j)}$ 는 그림. 14(a)에서와 같이 모두가 100이다. 이들 값은 境界條件으로부터 正確한 값을 쉽게 알 수 있다. 다음에 $i=1$ 이고 $j=23, 24, \dots, 28$ 에 對한 값은 모두가 推定한 값이다.

이들 格點에 對한 浸透條件은 그림. 13(b)에 나타낸 것과 類似하다. 그리고 (49)식에 의해서

$$(h_1 + 2h_2 + h_3) - 4h_0 = 0$$

혹은

$$h_{(i,j+1)} + 2h_{(i+1,j)} + h_{(i,j-1)} - 4h_{(i,j)} = 0 \dots\dots\dots(59)$$

그림. 14(a)의 水頭값은 假定值이므로 (59)식은 滿足하지 않는다.

例를 들면 $i=1$ 과 $j=23$ 이라면 $h_{(i,j-1)}=100$, $h_{(i,j)}=84$, $h_{(i,j+1)}=68$, 및 $h_{(i+1,j)}=78$ 이다.

만약 이들 값을 (59)식에 代入하면 0이 아니고 다음과 같은 값이 나온다.

$$[68 + 2(78) + 100] - 4(84) = -12$$

만약 -12 가 R (R =殘差)과 같고 $h_{(i,j)}$ 에 $\frac{R}{4}$ 을 더하면 (59)식은 滿足될 것이다. 그래서 $h_{(i,j)}$ 의 새로 修正된 값이 그림. 14(b)에서와 같이 $84 + (-3) = 81$ 이 된다.

같은 方法으로 $i=1$, $j=24$ 인 點에 對하여 修正한 水頭는 다음과 같이 구할 수 있다.

$$[84 + 2(67) + 61] - 4(68) = 7 = R$$

따라서

$$h_{(1,24)} = 68 + 7/4 = 69.75 \approx 69.8$$

$h_{(1,25)}$, $h_{(1,26)}$ 및 $h_{(1,27)}$ 의 修正한 값이 같은 方法으로 決定될 수 있고 $h_{(1,28)}=50$ 인 것은 境界條件에 의해서 正確히 알 수 있다.

③ $i=2, 3$ 및 4열에 對하여 $j=2, 3, \dots, 27$ 에 對한 $h_{(i,j)}$ 는 (44)식에 의해서

$$(h_1+h_2+h_3+h_4)-4h_0=0$$

혹은

$$h_{(i,j+1)}+h_{(i-1,j)}+h_{(i,j-1)}+h_{(i+1,j)}-4h_{(i,j)}=0 \dots\dots\dots(60)$$

$h_{(i,j)}$ 의 精確한 값을 알기 위하여 ②에서와 같은 過程을 밟는다. 殘差 R 은 (60)식에 값을 代入하여 計算될 수 있고 精確한 水頭는 $h_{(i,j)} + \frac{R}{4}$ 로서 주어진다.

對稱에 의해서 $i=2, 3$ 및 4에 대한 $h_{(1,28)}$ 의 修正값은 처음에 假定한 것과 같이 모두 50이다. 修正된 水頭는 그림. 14(b)에 나타냈다.

④ $i=5$ 열에 대한 $j=2, 3, \dots, 27$ 에 대하여 考慮한다.

(58)식에 의해서

$$h_1 + \frac{2k_1}{k_1+k_2}h_2 + h_3 + \frac{2k_2}{k_1+k_2}h_4 - 4h_0 = 0 \dots\dots\dots(61)$$

$$k_1 = 5 \times 10^{-3} \text{cm/sec}, \quad k_2 = 2.5 \times 10^{-3} \text{cm/sec}$$

$$\frac{2k_1}{k_1+k_2} = \frac{2 \times 5 \times 10^{-3}}{(5+2.5) \times 10^{-3}} = 1.33$$

$$\frac{2k_2}{k_1+k_2} = \frac{2 \times 2.5 \times 10^{-3}}{(5+2.5) \times 10^{-3}} = 0.667$$

이 값을 사용하면 (61)식은 다음과 같이 나타낼 수 있다.

$$h_{(i,j+1)} + 1.333h_{(i-1,j)} + h_{(i,j-1)} + 0.667$$

$$h_{(i+1,j)} - 4h_{(i,j)} = 0$$

③에서와 같이 그림. 14(a)에서 水頭를 사용하여 殘差 R 을 計算한다. 修正된 水頭값은 $h_{(i,j)} + \frac{1}{4}R$ 로 주어진다.

對稱의 條件으로부터 點 $i=5, j=28$ 에서의 水頭는 처음에 假定한 바와 같이 50이다.

⑤ $i=6, 7, \dots, 12$ 와 $j=2, 3, \dots, 27$ 에 대한 $h_{(i,j)}$ 는 (44)식을 사용하여 구한다. ③에서와 같은 方法으로 修正한 水頭를 구하고 $j=28$ 의 水頭는 假定한 바와 같이 50이다. 이들 값을 그림. 14(b)에 나타냈다.

⑥ $i=13$ 과 $j=2, 3, \dots, 27$ 에 대한 $h_{(i,j)}$ 는 (49)식에서 구한다.

$$(h_1+2h_2+h_3)-4h_0=0$$

혹은

$$h_{(i,j+1)} + 2h_{(i-1,j)} + h_{(i,j-1)} - 4h_{(i,j)} = 0$$

그림. 14(a)에서 適當히 주어지 水頭의 값을 가지고 殘差를 구하고 ②에서와 같이 修正한 水頭를 구한다. 對稱의 條件으로부터 $h_{(13,28)} = 50$ 이다. 이들 修正한 값은 그림. 14(b)에 나타냈다.

⑦ 새로운 水頭값을 가지고 ②로부터 ⑥까지 반복한다. 이 반복은 殘差가 無視될 수 있을 때까지 여러번 반복한다.

위에서 說明한 方法으로 殘差 $R_{(i,j)}$ 가 0이 될 때까지 그림. 15의 順序에 따라서 시행하면 各 點에서의 水頭가 구해진다.

그림. 16(a)은 等方性 土層위의 塹에 대해서

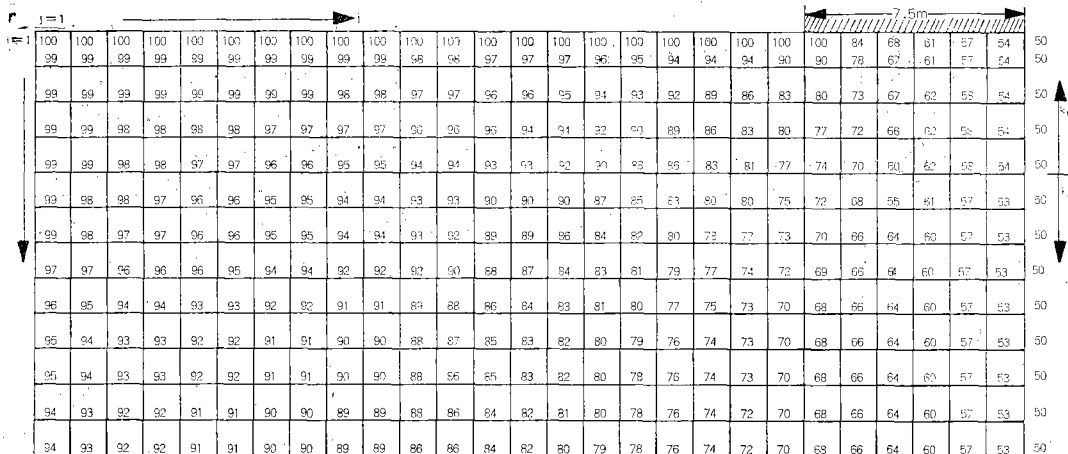


그림. 14(a). 數值解析法에 의한 水頭計算(最初의 假定值)

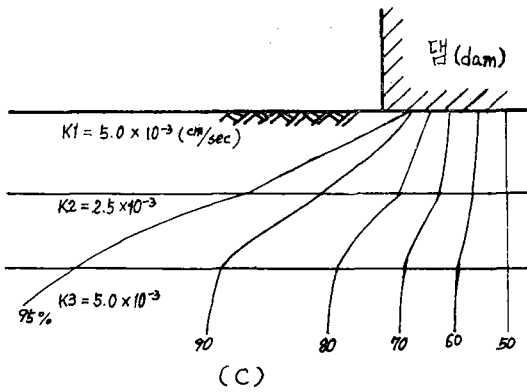


그림. 16. 댐밀의 등수頭線

盤에서 298回 반복한 것으로부터 얻은 修正된 수頭값으로 그린 등수頭線을 나타내고 있다.

이와 같이 해서 등수頭線이 決定되면 이에 直交하도록 流線을 그려서 流線網을 作圖할 수 있다.

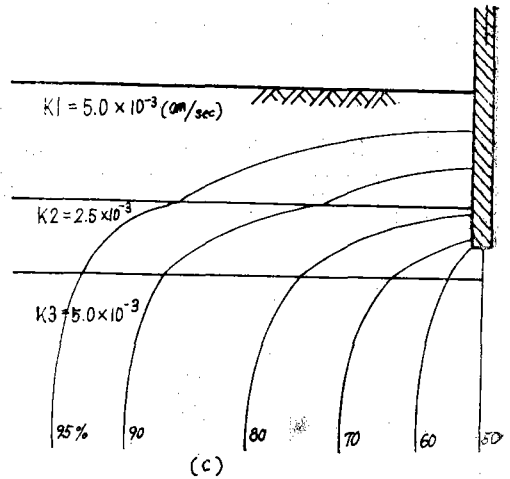
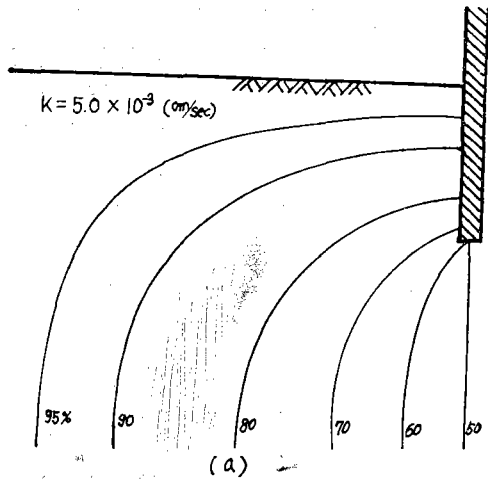
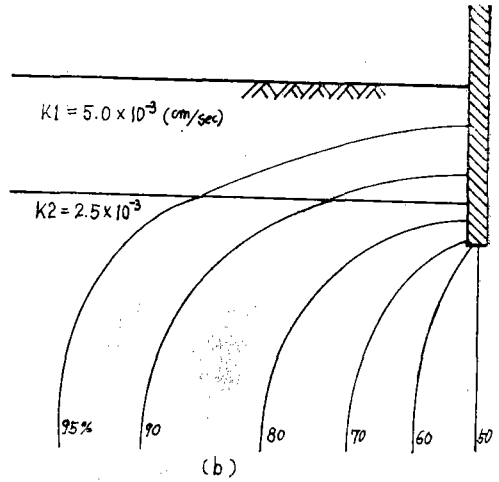


그림. 17. 널말뚝밀의 등수頭線

<다음호계속>

透水性基礎地盤의 浸透量(II)

附錄 表-1. 댐밑에서의 修正한 水頭값

표 1-1. 1層으로 된 地盤에서 209回 반복한 값(그림 16(a))

100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.0	99.4	99.4	99.4	99.4	99.3	99.2	99.1	99.0	98.9	98.7	98.6	98.4	98.2
99.0	99.0	99.0	98.9	98.7	98.6	98.4	98.2	98.0	97.8	97.5	97.2	96.8	96.4
99.0	98.8	98.6	98.4	98.1	97.9	97.6	97.4	97.1	96.7	96.3	95.9	95.4	94.7
99.0	98.6	98.2	97.9	97.5	97.2	96.9	96.6	96.2	95.7	95.2	94.6	94.0	93.2
99.0	98.3	97.8	97.3	97.0	96.6	96.2	95.8	95.3	94.8	94.2	93.5	92.7	91.8
99.0	97.8	97.2	96.8	96.4	96.0	95.6	95.1	94.6	94.0	93.3	92.5	91.6	90.6
97.0	96.8	96.5	96.2	95.8	95.4	95.0	94.5	93.9	93.2	92.5	91.6	90.6	89.5
96.0	96.0	95.9	95.6	95.3	94.9	94.5	93.9	93.3	92.6	91.8	90.9	89.8	88.6
95.0	95.3	95.3	95.1	94.9	94.5	94.0	93.5	92.8	92.1	91.3	90.3	89.2	88.0
95.0	94.9	94.9	94.8	94.5	94.2	93.7	93.2	92.5	91.7	90.9	89.9	88.7	87.5
94.0	94.5	94.6	94.5	94.3	94.0	93.5	93.0	92.3	91.5	90.6	89.6	88.5	87.2
94.0	94.4	94.5	94.4	94.2	93.9	93.5	92.9	92.2	91.5	90.6	89.5	88.4	87.1
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	84.9	75.6	68.3	61.8	55.8	50.0
97.9	97.6	97.2	96.7	96.0	95.0	93.3	89.9	82.1	74.6	67.8	61.6	55.7	50.0
95.9	95.3	94.6	93.6	92.4	90.6	88.2	84.4	78.8	72.8	66.9	61.1	55.5	50.0
94.0	93.2	92.1	90.8	89.2	87.1	84.3	80.7	76.1	71.0	65.7	60.5	55.2	50.0
92.3	91.2	89.9	88.4	86.5	84.2	81.4	77.9	73.8	69.3	64.6	59.8	54.9	50.0
90.7	89.5	88.0	86.3	84.3	81.9	79.1	75.7	72.0	67.9	63.6	59.1	54.6	50.0
89.4	88.0	86.4	84.6	82.5	80.0	77.2	74.0	70.5	66.7	62.7	58.5	54.3	50.0
88.2	86.8	85.1	83.2	81.0	78.5	75.8	72.7	69.4	65.8	62.0	58.1	54.1	50.0
87.3	85.7	84.0	82.0	79.8	77.4	74.7	71.7	68.5	65.0	61.4	57.7	53.9	50.0
86.5	85.0	83.2	81.2	79.0	76.5	73.8	70.9	67.8	64.5	61.0	57.4	53.7	50.0
86.0	84.4	82.6	80.6	78.4	75.9	73.3	70.4	67.3	64.1	60.7	57.2	53.6	50.0
85.7	84.1	82.2	80.2	78.0	75.6	72.9	70.1	67.0	63.8	60.5	57.1	53.5	50.0
85.6	84.0	82.1	80.1	77.9	75.4	72.8	70.0	66.9	63.8	60.4	57.0	53.5	50.0

표 1-2. 2層으로 된 地盤에서 249回 반복한 값(그림 16(b))

100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.0	99.4	99.6	99.6	99.6	99.6	99.5	99.5	99.4	99.4	99.3	99.2	99.0	98.9
99.0	99.2	99.2	99.2	99.2	99.2	99.1	99.0	98.9	98.7	98.6	98.4	98.1	97.8
99.0	99.0	99.0	98.9	98.9	98.8	98.7	98.5	98.4	98.2	97.9	97.6	97.3	96.8
99.0	98.9	98.7	98.6	98.5	98.4	98.3	98.1	97.9	97.6	97.3	97.0	96.5	96.0
99.0	98.6	98.3	98.1	97.9	97.7	97.5	97.3	97.0	96.7	96.3	95.8	95.2	94.4
99.0	98.1	97.7	97.5	97.3	97.1	96.8	96.6	96.2	95.8	95.3	94.7	94.0	93.1
97.0	97.1	97.0	96.8	96.7	96.5	96.2	95.9	95.5	95.0	94.4	93.7	92.9	91.9
96.0	96.2	96.3	96.2	96.1	95.9	95.7	95.3	94.9	94.3	93.7	92.9	92.0	91.0
95.0	95.5	95.7	95.7	95.7	95.5	95.2	94.9	94.4	93.8	93.1	92.3	91.3	90.2
95.0	95.1	95.3	95.4	95.3	95.2	94.9	94.5	94.0	93.4	92.7	91.8	90.8	89.7
94.0	94.7	95.0	95.1	95.1	95.0	94.7	94.3	93.8	93.2	92.5	91.6	90.5	89.3
94.0	94.6	94.9	95.0	95.0	94.9	94.6	94.2	93.7	93.1	92.4	91.5	90.4	89.2
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	85.8	76.7	69.3	62.6	56.2	50.0
98.7	98.4	98.1	97.6	96.9	95.9	94.2	90.9	83.3	75.8	68.9	62.4	56.2	50.0
97.4	96.9	96.2	95.4	94.2	92.5	89.9	86.2	80.5	74.4	68.2	62.0	56.0	50.0

96.3	95.6	94.7	93.5	91.9	89.8	87.0	83.2	78.4	73.0	67.3	61.5	55.8	50.0
95.3	94.4	93.3	92.0	90.2	88.0	85.0	81.3	76.9	71.9	66.6	61.1	55.6	50.0
93.6	92.5	91.2	89.6	87.6	85.2	82.2	78.7	74.6	70.1	65.3	60.3	55.2	50.0
92.1	90.8	89.3	87.6	85.5	83.0	80.0	76.7	72.8	68.7	64.2	59.6	54.8	50.0
90.8	89.4	87.8	85.9	83.8	81.2	78.3	75.0	71.4	67.5	63.3	59.0	54.5	50.0
89.7	88.3	86.6	84.6	82.4	79.9	77.0	73.8	70.3	66.6	62.6	58.5	54.3	50.0
88.9	87.4	85.6	83.6	81.4	78.8	76.0	72.9	69.5	65.9	62.1	58.1	54.1	50.0
88.3	86.7	85.0	82.9	80.7	78.1	75.3	72.2	68.9	65.4	61.7	57.9	54.0	50.0
87.9	86.4	84.6	82.5	80.2	77.7	74.9	71.9	68.6	65.2	61.5	57.8	53.9	50.0
87.8	86.2	84.4	82.4	80.1	77.6	74.8	71.8	68.5	65.1	61.4	57.7	53.9	50.0

표 1-3. 3層으로 된 地盤에서 281回 반복한 값(그림 16(c))

100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.0	99.4	99.5	99.5	99.5	99.5	99.4	99.4	99.3	99.2	99.1	99.0	98.8	98.7
99.0	99.1	99.1	99.1	99.0	98.9	98.8	98.7	98.6	98.4	98.2	98.0	97.7	97.4
99.0	98.9	98.8	98.7	98.6	98.4	98.3	98.1	97.9	97.6	97.4	97.0	96.6	96.2
99.0	98.8	98.5	98.3	98.2	98.0	97.7	97.5	97.2	96.9	96.6	96.2	95.7	95.1
99.0	98.4	97.9	97.6	97.3	97.0	96.7	96.4	96.0	95.6	95.1	94.5	93.9	93.1
99.0	97.8	97.2	96.8	96.5	96.1	95.7	95.3	94.9	94.3	93.7	93.0	92.2	91.2
97.0	96.7	96.3	96.0	95.6	95.2	94.8	94.3	93.8	93.1	92.4	91.6	90.6	89.5
96.0	95.7	95.4	95.1	94.8	94.4	93.9	93.4	92.8	92.0	91.2	90.3	89.2	88.0
95.0	95.1	95.0	94.7	94.4	94.0	93.6	93.0	92.3	91.6	90.7	89.8	88.7	87.4
95.0	94.8	94.6	94.4	94.1	93.8	93.3	92.7	92.0	91.3	90.4	89.4	88.2	87.0
94.0	94.3	94.4	94.2	94.0	93.6	93.1	92.5	91.9	91.1	90.2	89.2	88.0	86.7
94.0	94.2	94.3	94.2	93.9	93.5	93.1	92.5	91.8	91.0	90.1	89.1	87.9	86.6
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	85.6	76.4	69.0	62.4	56.1	50.0
98.5	98.2	97.8	97.4	96.7	95.7	94.0	90.7	83.0	75.5	68.7	62.2	56.1	50.0
97.0	96.5	95.8	94.9	93.7	92.0	89.5	85.8	80.2	74.0	67.9	61.8	55.9	50.0
95.6	94.9	94.0	92.8	91.3	89.2	86.4	82.7	77.9	72.5	67.0	61.3	55.6	50.0
94.4	93.5	92.4	91.1	89.3	87.1	84.2	80.6	76.2	71.3	66.1	60.8	55.4	50.0
92.2	91.1	89.7	88.2	86.2	83.9	81.0	77.6	73.6	69.3	64.6	59.8	54.9	50.0
90.1	88.9	87.4	85.6	83.5	81.1	78.3	75.1	71.5	67.5	63.3	59.0	54.5	50.0
88.3	86.9	85.2	83.4	81.2	78.8	76.1	73.0	69.6	66.0	62.2	58.2	54.1	50.0
86.7	85.1	83.4	81.4	79.3	76.8	74.1	71.2	68.1	64.7	61.2	57.5	53.8	50.0
86.0	84.4	82.6	80.6	78.4	76.0	73.4	70.5	67.4	64.2	60.8	57.2	53.6	50.0
85.5	83.9	82.1	80.1	77.9	75.5	72.8	70.0	67.0	63.8	60.5	57.0	53.5	50.0
85.2	83.6	81.8	79.8	77.6	75.1	72.5	69.7	66.7	63.6	60.3	56.9	53.5	50.0
85.1	83.5	81.7	79.7	77.5	75.0	72.4	69.6	66.7	63.5	60.3	56.9	53.5	50.0

附錄 表-2. 널말뚝밑에서의 修正한 水頭값

표 2-1. 數值解析을 위한 널말뚝 주변의 假定한 水頭값

100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	98.0	98.0	97.0	97.0	96.0
99.0	99.0	99.0	99.0	99.0	98.0	98.0	98.0	98.0	98.0	96.0	95.0	93.0
99.0	99.0	99.0	98.0	98.0	97.0	97.0	97.0	97.0	97.0	95.0	94.0	90.0
99.0	99.0	99.0	98.0	98.0	97.0	96.0	96.0	96.0	96.0	94.0	92.0	89.0
99.0	99.0	98.0	98.0	97.0	96.0	95.0	95.0	95.0	95.0	93.0	90.0	87.0

透水性基礎地盤의 浸透量(II)

99.0	99.0	98.0	97.0	96.0	95.0	94.0	94.0	94.0	92.0	87.0	83.0
99.0	98.0	98.0	97.0	96.0	94.0	93.0	93.0	93.0	90.0	87.0	83.0
99.0	98.0	97.0	95.0	93.0	93.0	93.0	92.0	92.0	87.0	84.0	80.0
98.0	98.0	97.0	95.0	93.0	92.0	92.0	92.0	90.0	85.0	83.0	77.0
98.0	98.0	97.0	95.0	93.0	92.0	92.0	90.0	88.0	85.0	79.0	73.0
98.0	97.0	95.0	95.0	91.0	91.0	91.0	90.0	87.0	83.0	78.0	73.0
98.0	97.0	95.0	95.0	91.0	91.0	91.0	90.0	85.0	80.0	77.0	72.0
98.0	96.0	95.0	94.0	91.0	90.0	90.0	88.0	84.0	79.0	75.0	70.0
98.0	96.0	95.0	94.0	91.0	90.0	90.0	86.0	82.0	78.0	74.0	70.0
97.0	96.0	94.0	94.0	91.0	90.0	89.0	86.0	82.0	77.0	74.0	70.0
97.0	96.0	94.0	94.0	91.0	90.0	89.0	86.0	82.0	77.0	74.0	70.0
97.0	96.0	94.0	94.0	91.0	90.0	89.0	86.0	82.0	77.0	74.0	70.0
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
95.0	94.0	93.0	92.0	91.0	90.0	90.0	88.0	85.0	80.0	80.0	50.0
93.0	92.0	91.0	90.0	88.0	86.0	84.0	82.0	80.0	75.0	75.0	50.0
90.0	89.0	87.0	85.0	84.0	82.0	80.0	78.0	76.0	74.0	74.0	50.0
87.0	85.0	82.0	80.0	80.0	78.0	76.0	74.0	72.0	70.0	70.0	50.0
83.0	80.0	78.0	76.0	74.0	72.0	70.0	68.0	64.0	60.0	60.0	50.0
80.0	78.0	76.0	73.0	70.0	68.0	66.0	64.0	62.0	60.0	60.0	50.0
78.0	74.0	70.0	68.0	66.0	64.0	62.0	60.0	58.0	58.0	58.0	50.0
75.0	70.0	67.0	64.0	60.0	60.0	58.0	58.0	57.0	57.0	57.0	50.0
73.0	70.0	65.0	60.0	59.0	58.0	58.0	57.0	57.0	57.0	57.0	50.0
70.0	67.0	60.0	59.0	59.0	58.0	57.0	57.0	57.0	57.0	56.0	50.0
70.0	67.0	60.0	59.0	58.0	57.0	57.0	57.0	57.0	55.0	55.0	50.0
68.0	65.0	60.0	58.0	58.0	57.0	56.0	55.0	55.0	55.0	55.0	50.0
68.0	65.0	60.0	58.0	57.0	57.0	56.0	55.0	55.0	55.0	55.0	50.0
67.0	64.0	60.0	58.0	57.0	57.0	56.0	54.0	54.0	54.0	54.0	50.0
67.0	64.0	60.0	58.0	57.0	57.0	56.0	55.0	55.0	54.0	54.0	50.0
67.0	64.0	60.0	58.0	57.0	57.0	55.0	55.0	53.0	53.0	53.0	50.0
67.0	64.0	60.0	58.0	57.0	57.0	55.0	55.0	53.0	53.0	53.0	50.0

표 2-2. 1層으로 된 地盤에서 305回 반복한 값[그림 17(a)]

100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.0	99.3	99.4	99.3	99.2	99.1	99.0	98.8	98.7	98.5	98.3	98.2
99.0	99.0	98.9	98.7	98.5	98.2	97.9	97.6	97.3	97.0	96.7	96.3
99.0	98.7	98.5	98.1	97.7	97.4	96.9	96.5	96.0	95.6	95.1	94.5
99.0	98.5	98.1	97.6	97.1	96.5	96.0	95.4	94.8	94.1	93.5	92.8
99.0	98.4	97.7	97.1	96.4	95.7	95.0	94.3	93.6	92.8	91.9	91.1
99.0	98.2	97.4	96.6	95.8	95.0	94.1	93.3	92.4	91.5	90.5	89.4
99.0	98.0	97.0	96.1	95.2	94.2	93.3	92.3	91.3	90.2	89.1	87.9
99.0	97.7	96.6	95.6	94.6	93.6	92.5	91.4	90.3	89.1	87.8	86.5
98.0	97.2	96.2	95.2	94.1	92.9	91.8	90.6	89.3	88.0	86.6	85.2
98.0	97.0	95.9	94.8	93.6	92.4	91.1	89.8	88.5	87.0	85.6	84.0
98.0	96.8	95.6	94.4	93.1	91.9	90.5	89.1	87.7	86.2	84.6	82.9
98.0	96.7	95.4	94.1	92.8	91.4	90.0	88.6	87.1	85.5	83.8	82.1
98.0	96.6	95.2	93.8	92.4	91.0	89.6	88.1	86.5	84.9	83.2	81.3
98.0	96.4	95.0	93.6	92.2	90.7	89.2	87.7	86.1	84.4	82.6	80.8
97.0	96.0	94.7	93.4	92.0	90.5	89.0	87.4	85.8	84.1	82.3	80.4
97.0	95.8	94.6	93.2	91.8	90.4	88.9	87.3	85.6	83.9	82.0	80.1

97.0	95.8	94.5	93.2	91.8	90.3	88.8	87.2	85.5	83.8	82.0	80.0
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
98.0	97.8	97.6	97.4	97.2	97.0	96.9	96.7	96.6	96.6	96.6	50.0
96.0	95.6	95.2	94.8	94.4	94.0	93.7	93.4	93.2	93.1	93.1	50.0
94.0	93.4	92.8	92.2	91.6	91.0	90.4	90.0	89.7	89.6	89.6	50.0
92.1	91.3	90.5	89.6	88.8	87.9	87.1	86.4	85.9	85.8	85.8	50.0
90.2	89.2	88.2	87.1	86.0	84.9	83.7	82.7	81.9	81.6	81.6	50.0
88.4	87.2	86.0	84.6	83.3	81.8	80.3	78.8	77.5	76.8	76.8	50.0
86.6	85.3	83.9	82.3	80.6	78.8	76.8	74.6	72.4	70.7	70.7	50.0
85.0	83.5	81.9	80.1	78.1	76.0	73.5	70.5	66.8	61.3	61.3	50.0
83.6	81.9	80.1	78.1	75.9	73.5	70.7	67.3	63.1	57.5	57.5	50.0
82.3	80.5	78.5	76.4	74.0	71.4	68.4	64.9	60.7	55.8	55.8	50.0
81.1	79.2	77.2	74.9	72.5	69.7	66.6	63.2	59.2	54.8	54.8	50.0
80.2	78.2	76.0	73.7	71.2	68.4	65.3	62.0	58.2	54.2	54.2	50.0
79.4	77.3	75.1	72.7	70.2	67.4	64.4	61.1	57.6	53.8	53.8	50.0
78.8	76.7	74.4	72.0	69.4	66.6	63.7	60.5	57.1	53.6	53.6	50.0
78.3	76.2	73.9	71.5	68.9	66.1	63.2	60.1	56.8	53.4	53.4	50.0
78.1	75.9	73.6	71.2	68.6	65.8	62.9	59.9	56.6	53.4	53.4	50.0
78.0	75.8	73.5	71.1	68.5	65.7	62.8	59.8	56.6	53.3	53.3	50.0

표 2-3. 2層으로 된 地盤에서 309回 반복한 값 [그림 17(b)]

100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.0	99.4	99.5	99.6	99.5	99.5	99.4	99.3	99.2	99.2	99.1	98.9
99.0	99.1	99.2	99.2	99.1	99.0	98.8	98.7	98.5	98.3	98.1	97.9
99.0	99.0	98.9	98.8	98.6	98.5	98.3	98.0	97.8	97.5	97.2	96.9
99.0	98.9	98.7	98.5	98.3	98.0	97.7	97.4	97.1	96.7	96.3	95.9
99.0	98.6	98.3	97.9	97.5	97.1	96.7	96.2	95.7	95.2	94.6	94.0
99.0	98.4	97.9	97.4	96.9	96.3	95.7	95.1	94.4	93.7	93.0	92.2
99.0	98.2	97.5	96.9	96.2	95.5	94.8	94.0	93.2	92.4	91.4	90.4
99.0	98.0	97.1	96.3	95.6	94.7	93.9	93.0	92.1	91.1	90.0	88.8
98.0	97.5	96.7	95.9	95.0	94.1	93.1	92.1	91.0	89.9	88.6	87.3
98.0	97.2	96.3	95.4	94.4	93.4	92.4	91.2	90.0	88.8	87.4	86.0
98.0	97.0	96.0	95.0	94.0	92.9	91.7	90.5	89.2	87.8	86.4	84.8
98.0	96.9	95.8	94.7	93.5	92.4	91.1	89.8	88.5	87.0	85.5	83.8
98.0	96.8	95.6	94.4	93.2	91.9	90.7	89.3	87.9	86.3	84.7	82.9
98.0	96.6	95.3	94.1	92.9	91.6	90.3	88.9	87.4	85.8	84.1	82.3
97.0	96.2	95.1	93.9	92.7	91.4	90.0	88.6	87.0	85.4	83.7	81.8
97.0	96.0	94.9	93.8	92.5	91.2	89.8	88.4	86.8	85.2	83.4	81.6
97.0	96.0	94.9	93.7	92.5	91.2	89.8	88.3	86.8	85.1	83.4	81.5
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
98.8	98.7	98.6	98.4	98.3	98.2	98.0	97.9	97.8	97.8	97.8	50.0
97.7	97.4	97.2	96.9	96.6	96.3	96.0	95.8	95.5	95.4	95.4	50.0
96.5	96.2	95.8	95.3	94.9	94.4	94.0	93.6	93.2	92.9	92.9	50.0
95.4	94.9	94.4	93.8	93.2	92.6	92.0	91.3	90.7	90.0	90.0	50.0
93.3	92.6	91.8	90.9	89.9	88.9	87.9	86.8	86.0	85.5	85.5	50.0
91.3	90.3	89.2	88.0	86.7	85.3	83.8	82.2	80.8	80.1	80.1	50.0
89.3	88.1	86.8	85.3	83.7	81.8	79.7	77.4	75.0	73.2	73.2	50.0
87.5	86.1	84.5	82.8	80.8	78.6	75.9	72.8	68.7	62.6	62.6	50.0

透水性基礎地盤의 浸透量(Ⅱ)

85.8	84.2	82.5	80.5	78.3	75.7	72.7	69.1	64.5	58.3	50.0
84.4	82.6	80.7	78.5	76.1	73.3	70.1	66.3	61.8	56.4	50.0
83.1	81.2	79.1	76.8	74.3	71.4	68.1	64.4	60.1	55.3	50.0
82.0	80.0	77.8	75.4	72.8	69.9	66.6	63.0	59.0	54.6	50.0
81.1	79.0	76.8	74.3	71.6	68.7	65.5	62.0	58.2	54.2	50.0
80.4	78.2	76.0	73.5	70.8	67.9	64.7	61.3	57.7	53.9	50.0
79.9	77.7	75.4	72.9	70.2	67.3	64.2	60.8	57.3	53.7	50.0
79.6	77.4	75.1	72.6	69.8	66.9	63.9	60.6	57.2	53.6	50.0
79.5	77.3	75.0	72.4	69.7	66.8	63.8	60.5	57.1	53.6	50.0

표 2-4. 3層으로 된 地盤에서 298回 반복한 값[그림 17(c)]

100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.0	99.4	99.5	99.4	99.4	99.3	99.2	99.1	99.0	98.9	98.7	98.6
99.0	99.1	99.0	98.9	98.8	98.6	98.4	98.2	98.0	97.7	97.5	97.2
99.0	98.9	98.7	98.5	98.2	97.9	97.6	97.3	97.0	96.6	96.3	95.9
99.0	98.7	98.4	98.0	97.7	97.3	96.9	96.5	96.0	95.5	95.0	94.5
99.0	98.6	98.1	97.6	97.2	96.7	96.2	95.6	95.1	94.5	93.9	93.2
99.0	98.3	97.6	96.9	96.2	95.5	94.8	94.0	93.3	92.4	91.6	90.7
99.0	98.0	97.0	96.1	95.2	94.3	93.4	92.5	91.5	90.5	89.4	88.3
99.0	97.6	96.5	95.4	94.3	93.2	92.1	91.0	89.8	88.5	87.2	85.9
98.0	97.0	95.8	94.6	93.4	92.1	90.9	89.5	88.1	86.7	85.2	83.6
98.0	96.8	95.6	94.3	93.0	91.6	90.3	88.9	87.4	85.9	84.3	82.6
98.0	96.7	95.3	94.0	92.6	91.2	89.8	88.3	86.7	85.1	83.5	81.7
98.0	96.6	95.1	93.7	92.3	90.8	89.3	87.8	86.2	84.5	82.8	80.9
98.0	96.4	94.9	93.5	92.0	90.5	88.9	87.3	85.7	84.0	82.2	80.3
98.0	96.3	94.7	93.3	91.8	90.2	88.6	87.0	85.3	83.6	81.7	79.8
97.0	95.9	94.5	93.1	91.6	90.0	88.4	86.8	85.1	83.3	81.4	79.5
97.0	95.7	94.4	93.0	91.5	89.9	88.3	86.6	84.9	83.1	81.2	79.3
97.0	95.7	94.3	92.9	91.4	89.9	88.3	86.6	84.9	83.0	81.2	79.2
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
98.5	98.3	98.2	98.0	97.9	97.7	97.6	97.5	97.4	97.4	97.4	50.0
97.0	96.7	96.4	96.1	95.8	95.5	95.2	94.9	94.7	94.7	94.7	50.0
95.5	95.0	94.6	94.1	93.7	93.2	92.7	92.3	92.0	91.9	91.9	50.0
94.0	93.4	92.8	92.2	91.5	90.9	90.2	89.6	89.1	88.7	88.7	50.0
92.6	91.8	91.1	90.3	89.5	88.6	87.7	86.8	86.0	85.0	85.0	50.0
89.8	88.8	87.7	86.6	85.4	84.1	82.7	81.3	80.0	79.2	79.2	50.0
87.1	85.8	84.4	83.0	81.4	79.6	77.7	75.6	73.5	71.8	71.8	50.0
84.4	82.9	81.3	79.5	77.5	75.4	72.9	70.1	66.5	61.2	61.2	50.0
82.0	80.2	78.3	76.2	73.9	71.4	68.6	65.3	61.4	56.4	56.4	50.0
80.8	78.9	76.9	74.7	72.3	69.7	66.7	63.4	59.5	55.1	55.1	50.0
79.8	77.9	75.7	73.5	71.0	68.3	65.3	62.0	58.4	54.3	54.3	50.0
79.0	77.0	74.8	72.4	69.9	67.2	64.3	61.0	57.6	53.9	53.9	50.0
78.3	76.2	74.0	71.6	69.1	66.4	63.5	60.3	57.0	53.6	53.6	50.0
77.8	75.7	73.4	71.0	68.5	65.8	62.9	59.9	56.7	53.4	53.4	50.0
77.4	75.3	73.0	70.6	68.0	65.3	62.5	59.5	56.4	53.2	53.2	50.0
77.2	75.0	72.8	70.3	67.8	65.1	62.3	59.3	56.3	53.2	53.2	50.0
77.1	75.0	72.7	70.3	67.7	65.0	62.2	59.3	56.3	53.1	53.1	50.0