# PERMEABILITY COEFFICIENT USING A NEW PLASTIC DEVICE

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The value of the coefficient of permeability of several granular materials determined with the widely used metal compaction mold from the standard compaction test is compared to a plastic device developed by the author. In general, the plastic device provides values 2 to 9 times larger than does the metal mold. If the coefficient of permeability, k, of the porous stone used in the metal mold is separately determined and k-values adjusted for a two-layer system, the plastic mold provides values about 2 to 3 times larger.

•THE metal compaction mold shown in Figure 1 is widely used to determine the coefficient of permeability of most soils. This is in spite of the several permeability devices reported by others (2, 3, 4). The use of the metal mold is of questionable validity, however, for both cohesive (and relatively impermeable) and granular soils. The advantage of using the compaction mold for cohesive soils is that one can compact a specimen to some density, then interchange the base of the standard compaction cylinder with the permeameter base that contains a porous stone and drainage outlet, and then add the top that contains a water inlet and air bleed valve. For granular soils, one simply fills the mold in several layers. Various densities can be achieved by using a noncommercial rod, to which a 9.8-cm diameter plate has been attached, and a rubber mallet (1) (Fig. 2). By inserting the plate into the partly filled mold and applying pressure while simultaneously rapping the sides of the mold with the mallet, one can obtain some rearrangement of soil grains and change in density.

A discussion of the determination of k for cohesive soils is beyond the scope of this paper (except to point out that, for small values of k, it is mandatory to use a thin sample, say, less than 3 cm thick). For $k = 1 \times 10^{-3}$ cm/min and a constant hydraulic gradient of $i = h/L$ of 30, the time for a drop of water to travel through a 3-cm sample is about

$$T = 3/(30 \times 10^{-3}) = 100 \text{ min}$$

For an 11.6-cm mold, the time is about 390 min, or approximately 6½ hours. Without special precautions, sample drainage or evaporation may take place during this length of time. Either of these factors will of course invalidate the test results. This means it is almost mandatory to use a consolidation test setup to determine the coefficient of permeability of cohesive soils.

Saturation, without entrapping air, is a problem with the metal compaction mold. The most efficient method (1) is to submerge the airtight system into a container of water and allow water to back up through the exit tube until water stands in the entrance tube to the static water level of the saturation container. The disadvantage of this method is that the sand may expand without one being able to visually determine this. A simple computation indicates that, if the sand in the mold expands, say, 0.40 cm, which is a distinct possibility, the change in the void ratio of the soil for $G = 2.65$ and $\gamma = 1.65$ gram/cm$^3$ is approximately as follows:

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$$\text{Area of mold} = 0.7854(10.16)^2 = 81.1 \text{ cm}^2,$$
$$\text{Volume} = 81.1(11.6) = 940.8 \text{ cm}^3,$$
$$\Delta V = 81.1(0.40) = 32.4 \text{ cm}^3, \text{ and}$$
$$\text{Change in void ratio} = 9.0 \text{ percent}$$

Since it has been found that $k = f(e^2)$, this value can represent a considerable error in k. The soil expansion and saturation problems are avoided in the ASTM test D2434-68 via use of a plastic cylinder having a spring that confines the soil specimen. The ASTM apparatus is rather complicated, however, compared to the device used by the author in the series of tests described here.

## APPARATUS AND PRELIMINARY PROCEDURE

To obtain valid results for comparison, it was necessary to first modify the standard compaction permeability device to avoid sample drainage. This was done by installing an exit gooseneck as shown in Figure 1. The gooseneck could be used as a telltale for the degree of sample saturation; i.e., when the inlet source is clamped, the exit flow immediately halts if the sample is saturated; otherwise, flow continues until the entrapped air expands to equilibrium pressure.

The standard commercially available permeability device has a rather small inlet orifice, which was not modified. It was evident early in the testing that this was probably a factor of some importance; however, to determine the exact effect would require a complete redesign of the permeameter cover. The redesign would have to include an orifice enlargement as well as provide a means of diffusing the water so that the full force of the entering stream of water does not strike the soil at a single point as allowed in the present device. The ASTM device also has a problem of diffusing the entering water when a wire screen is used rather than a porous stone.

Because the standard device is already constructed and in use, it was the primary objective of this study to determine if the device was satisfactory as built. If the device was unsatisfactory compared to the author's device, what kind of error could one reasonably expect, could these be reduced, and what are the probable causes?

In earlier work, the author had noted that one could put water in an empty metal compaction permeameter with a time lag noted before the water flowed into the exit tube. The first step, therefore, was to determine the coefficient of permeability of the 1.3-cm thick porous stones. This was done for both sides of several stones when the stones had been used enough to have one side impregnated with fines. Table 1 gives the results. At this point, the author was aware that one might debate the validity of Darcy's law ($v = ki$) because these flow rates could be nonlaminar. On the other hand, as the flow rates are to be compared, it did not seem unreasonable to use the Darcy equation for the computations.

Table 1 indicates that the effect of the porous stone is a significant parameter when using these devices or any device using a porous stone including the ASTM-recommended permeameter configuration. The coefficient of permeability of the standard compaction mold without any porous stone was $347 \times 10^{-3}$ cm/sec. The value is indicative of the rate of water flow through the mold and indicates that the entrance orifice provides a significant constriction or resistance to flow.

The plastic device developed by the author is shown in Figure 3. This device uses a No. 200 mesh screen top and bottom to confine the sample. A diffuser is used in the base to break up the entrance flow of water. This ensures that the flow is relatively uniform and of negligible entrance velocity across the base of the sample. Parts are machined such that flow restrictions are a minimum. The tail water is fixed such that the sample cannot possibly drain—through use of a large-diameter circular overflow weir. The exit tube is relatively large in diameter so that it can accommodate large flow quantities. The system is constructed such that, when the base is watertight, the soil sample cannot expand. Provision is also incorporated to put a vacuum on the sample. In spite of the fact that the sample uses a No. 200 mesh screen, the device is rugged enough so that, with reasonable care, one can build samples to almost any density that is possible with the metal mold. If the screen becomes torn, it is relatively simple to cut and glue (epoxy) a new screen in place.

## TESTING

A series of tests was undertaken using both graded and ungraded materials. Very fine sand and gravel were eliminated because the primary effort was toward testing the two devices on materials in a size range that could be used as filter materials for underdrainage systems. The size ranges used represent many of the more common sand deposits found in nature.

To reduce human error as much as possible and to spot erratic results if there were any, the following were test criteria:

1. The same density (as closely as possible) was used for a given soil.
2. The same differential head was used; however, this resulted in a hydraulic gradient of $i = h/L$ for the two molds—$i_{\text{metal mold}} = 178.5/11.6 = 15.4$, and $i_{\text{plastic mold}} = 178.5/20.3 = 8.8$.
3. At least three separate samples were built in each device, and at least three separate test runs were made. In most cases four test runs were made because little extra time was involved.
4. All k-values were reduced to k at 20 C for ease of comparison.
5. The time to obtain the flow quantity, Q, for a set of data was held constant as given in Table 2.
6. De-aired water (but not distilled) was used in all tests.
7. Saturation was obtained in the metal device by attaching the de-aired water source to the exit tube and applying a very small head to back the water up through the sample. If the gooseneck telltale indicated too much entrapped air, the sample was discarded. Saturation of the plastic device was done entirely by visual inspection.
8. Samples were oven-dried and carefully reblended with the source material to make the next test sample.

The results were remarkably consistent for each type of device. A typical set of data is given in Table 2.

Table 3 gives a summary of the testing program. The k-values shown are the average values for three tests. Figure 4 shows the sieve analyses of the soils used. The one-size soils given in Table 3 are the separated portions of a large sample of the coarse sand.

The author considered both the usual computational procedure and a procedure including the capability of the porous stone to give effectively a two-layer soil system. This required a computation (Appendix) as follows:

$$k_{soil} = \frac{L_{soil}}{\frac{L_{rs}}{k_{rs}} - \frac{L_{rock}}{k_{rock}}} \qquad (1)$$

where $k_{soil}$ is the nominal computed coefficient of permeability of the soil and rock system. The derivation, identification of terms, and use of Eq. 1 are given in the Appendix.

The data given in Table 3 indicate the effect of applying Eq. 1 instead of the usual computation for k of

$$k = \frac{QL}{Aht} \qquad (2)$$

where L = soil sample length of 11.6 cm. This has a considerable effect on the computed coefficients of permeability of the soil. The values given in Table 3, identified as $k_{nominal}$ for the metal mold, are obtained by using Eq. 2.

Figure 1. Standard compaction mold permeameter.

Figure 2. Modifying density of granular materials.

Figure 3. Plastic mold device.

Device disassembled; note overflow weir with top screen and diffuser with bottom screen assembly.

Building a sample.

Device assembled and in operation.

Table 1. Coefficients of permeability of porous stones.

| Stone Number | Side 1 Up (cm/sec × $10^{-3}$) | Side 1 Down (cm/sec × $10^{-3}$) |
|---|---|---|
| 28 | 2.27 | 2.31 |
| 7 | 2.00 | 1.87 |
| 30 | 2.32 | 2.31 |
| 2 | 2.27 | 2.29 |

Table 2. Permeability data of fine sand-coarse sand mixture.

| Device | Time (sec) | Flow Quantity ($cm^3$) | Temperature (deg C) |
|---|---|---|---|
| Plastic mold[a] (diameter of 7.6 cm and length of 20.3 cm) | 100 | 745 | 22 |
| | 100 | 733 | 21.5 |
| | 100 | 729 | 21.5 |
| | 100 | 720 | 21.5 |
| Metal mold[b] (diameter of 10.16 cm and length of 11.6 cm) | 70 | 828 | 24.5 |
| | 70 | 821 | 24.5 |
| | 70 | 820 | 24.5 |
| | 70 | 829 | 24.5 |

[a] $k_{20} = 1.74 \times 10^{-2}$ cm/sec.

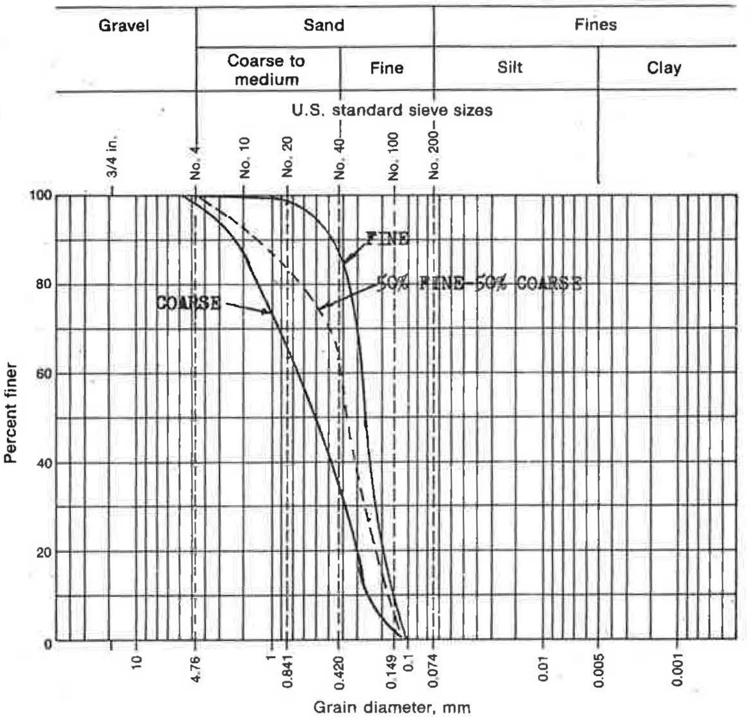
[b] $k_{20} = 8.49 \times 10^{-3}$ cm/sec.

Table 3. Summary of test data.

| Material | Sieve Passing | Sieve Retained | $k_{nominal}$ Metal Mold[a] (cm/sec × $10^{-3}$) | $k_{soil}$ Metal Mold[b] (cm/sec × $10^{-2}$) | k Plastic Mold (cm/sec × $10^{-2}$) | Ratio $k_{plastic}/k_{nominal}$ | Ratio $k_{plastic}/k_{actual}$ | Unit Weight of Soil[c] (gram/cm$^3$) |
|---|---|---|---|---|---|---|---|---|
| Fine sand | — | — | 8.25 | 1.38 | 1.71 | 2.07 | 1.24 | 1.70 |
| Coarse sand | — | — | 7.85 | 1.28 | 3.50 | 4.46 | 2.73 | 1.82 |
|  | No. 50 | No. 100 | 3.57 | 0.433 | 0.875 | 2.45 | 2.03 | 1.57 |
|  | No. 30 | No. 50 | 11.0 | 2.37 | 5.85 | 5.32 | 2.47 | 1.62 |
|  | No. 20 | No. 30 | 11.1 | 2.39 | 7.26 | 6.54 | 3.03 | 1.60 |
|  | No. 10 | No. 30 | 13.3 | 3.80 | 9.59 | 6.98 | 2.52 | 1.58 |
|  | No. 4 | No. 10 | 14.4 | 4.70 | 1.33 | 4.94 | 2.74 | 1.78 |
| Coarse sand with sand passing No. 60 sieve removed | — | — | 11.4 | 2.05 | 5.63 | 4.94 | 2.74 | 1.78 |
| 50 percent fine sand and 50 percent coarse sand[d] | — | — | 8.15 | 1.35 | 1.74 | 2.13 | 1.28 | 1.77 |

[a] Using Eq. 2 with L = 11.6 cm (usual method of computation).
[b] Using Eq. 1.
[c] Metal and plastic molds used same density.
[d] Average values shown include values from Table 2.

Figure 4. Sieve analysis of soils used.



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Page 59, in Table 3, following the "Coarse sand" entry, the 5th and 6th lines should read:

No. 10 No. 30 13.3 3.80 9.59 7.21 2.52 1.58
No. 4 No. 10 14.4 4.70 13.3 9.23 2.82 1.78

## CONCLUSIONS

From the data given in Table 3, it appears that one should use permeability data from the compaction mold with caution. This device seems to give values of coefficient of permeability on the order of 2 to 9 times too small. The analysis given here indicates that the error can be reduced to about a factor of two if the metal mold is considered as a two-layer soil system. To use the two-layer soil system requires slight modification of the mold (the gooseneck) and determination of the k of the porous stone. Table 3 also indicates that, as the soil sample becomes finer (appreciable material smaller than the No. 100 sieve), the effect of the porous stone on the computed value of k decreases, which is in agreement with Eq. 1.

The discrepancy factor of two between the coefficients of permeability determined by using the plastic and the metal molds, after correcting the metal mold data as a two-layer system, is probably due to the small entrance orifice of the metal mold.

Use of the plastic device proved to be superior to the metal mold because of the following characteristics:

1. A two-layer computation is not needed;
2. Saturation is facilitated;
3. Soil expansion is not a problem;
4. If material segregation occurs, it can be visually observed and the sample rebuilt if necessary; and
5. Tail water control is not a problem.

It might be pointed out also that, in the use of the plastic device, the application of a vacuum to saturate a sample can actually produce the opposite effect. This is because any vacuum that is larger than the vapor pressure of water will vaporize the water (even de-aired water) when the water inlet is opened, producing an air (water vapor) bubble at the base of the soil sample. The author was never able to remove these bubbles when they formed and finally abandoned the use of a vacuum and instead very carefully controlled the inlet flow with periodic vacuum application to the water in the soil. He then reopened the exit tube so that the vacuum was returned to atmospheric pressure prior to adding more water. This process was repeated as deemed necessary until the water was level with the overflow weir.

## REFERENCES

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# APPENDIX

## DERIVATION AND USE OF EQUATION 1

The following steps are used to derive and use Eq. 1:

1. Compute the apparent coefficient of permeability of the soil ($k_{nominal}$) using Eq. 2

$$k = QL/Aht$$

Here L is the metal mold height of 11.6 cm. Using data from Table 2 as an example, we can consider the following: average Q = 824.5 cm and is collected in 70 sec at a test of T = 24.5 C. The area of the standard compaction mold used in the test is 81.1 $cm^2$. Substituting these values gives

$$k_{24.5\,c} = 824.5(11.6)/81.1(178.5)(70) = 9.45 \times 10^{-3} \text{ cm/sec}$$

$$k_{20\,c} = 0.901(9.45 \times 10^{-3}) = 8.49 \times 10^{-3} \text{ cm/sec}$$

The average $k_{20}$ value for the three tests on this material is $8.15 \times 10^{-3}$ cm/sec as given in Table 3.

2. Vertical flow through a two-layer soil mass using the continuity of flow concept (saturation = 100 percent) is

$$\frac{L_{total}}{k_{equivalent}} = \frac{L_1}{k_1} + \frac{L_2}{k_2}$$

And for the soil-porous stone system this becomes

$$\frac{L_{rs}}{k_{rs}} = \frac{L_{soil}}{k_{soil}} + \frac{L_{rock}}{k_{rock}}$$

Because $k_{soil}$ is desired, rearranging yields

$$k_{soil} = \frac{L_{soil}}{\frac{L_{rs}}{k_{rs}} - \frac{L_{rock}}{k_{rock}}} \qquad (1)$$

Values to use in Eq. 1 are $L_{soil}$ = 11.6 cm and $L_{rs}$ = 12.9 cm (rs = rock + soil); the values of $L_{rock}/k_{rock}$ are given in Table 1. One may compute the values of $k_{rs}$ as proportional to the thickness $L_{rs}$ using the computed values of $k_{nominal}$. Thus,

$$k_{rs} = \frac{12.9}{11.6} k_{nominal}$$

Using the 50 percent fine-50 percent coarse sand value of $k_{nominal}$ from Table 3 and the No. 28 stone data from Table 1 of $2.3 \times 10^{-3}$ cm/sec, the following are computed:

$$L_{rs}/k_{rs} = 12.9(11.6)/12.9(8.15 \times 10^{-3}) = 1{,}425$$

$$L_{rock}/k_{rock} = 1.3/(2.3 \times 10^{-3}) = 565$$

Substituting into Eq. 1

$$k_{soil} = 11.6/(1{,}425 - 565) = 1.35 \times 10^{-3} \text{ cm/sec}$$

Other entries in Table 3 are computed in a similar manner.

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