CHAPTER 7

STANDARD METHODS OF DETERMINING THE HYDRAULIC PROPERTIES OF SAND

(1) Description of Apparatus and Methods

Fig. 64 illustrates the apparatus used for taking undisturbed samples of sand and the procedure adopted in sampling.

An open excavation is made to the required depth and samplers pressed in horizontally and vertically, as in Fig 64 (*a*). The sampler used consisted of a cylinder of thin sheet metal with an inside diameter of 3·5 in., a cutting edge formed by bevelling on the outside and a flanged end for screwing on a sieve cover at the other end. When testing fine sand, a fine sieve (U.S. No. 40) backed by a coarse rigid sieve (approx. U.S. No. 4) was screwed onto the flanged end while the sampler was still in place, thus sealing off the trimmed end of the undisturbed sand sample. Finally, the sampler was dug out and trimmed on the other end to 0·5 in. below the cutting edge, as in Fig. 64 (*b*). Obviously only moist sand can be sampled in this way.

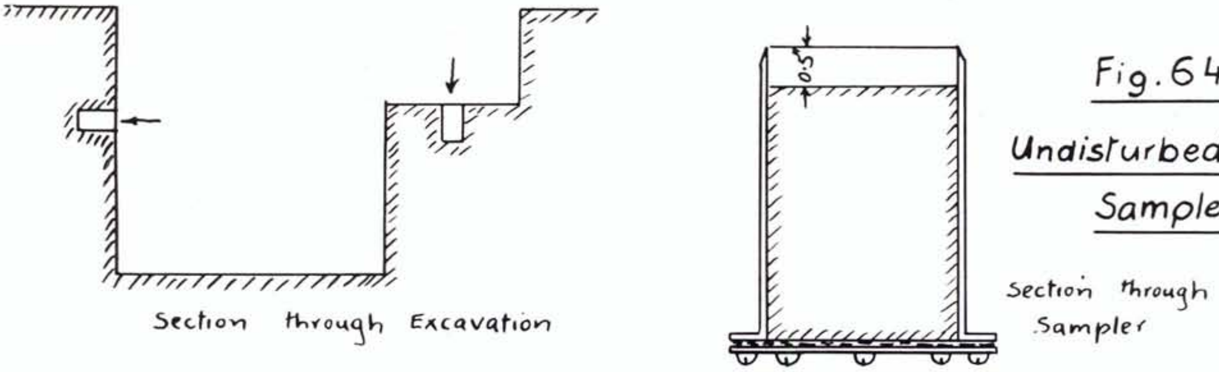

Fig. 64 Undisturbed Samples

(a) Sampling (b) Trimming of Sample

With the apparatus used by the author the total height of the trimmed sample was 4·19 in., giving a volume V_1 of 40·3 cu. in. or 661 cubic centimetres. The next step is to determine the properties of the sample. W_1 = weight of the sample as taken is determined.

The sample plus sampler is next placed in a vessel and submerged in water and the total weight of apparatus plus contents determined. The following diagram shows how the submerged weight of the sample is deduced by subtracting the weight of apparatus filled with water only from the weight previously determined.

W_2 = submerged weight =

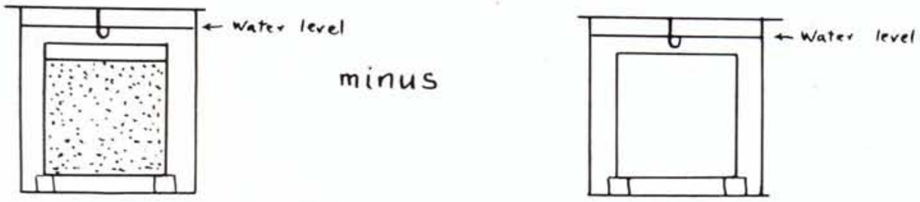

Fig. 65

The permeability is next determined with the sample still in its undisturbed state of compaction. The apparatus is illustrated in the following sketch.

Inflow adjusted to keep water level constant.

Note: Water level A is kept constant by siphon feed from a large vessel.

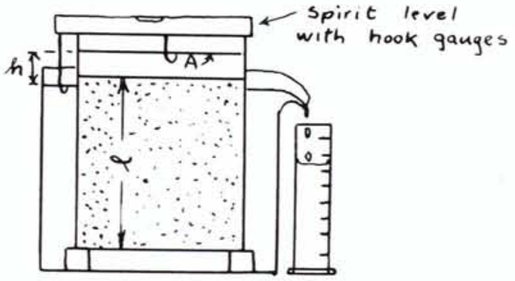

Fig. 66

Coefficient of permeability $k = \frac{q}{a}\frac{l}{h}$

where q is the rate of discharge and a the full cross-section of the sample.

The sampler is now removed from the vessel and placed on the scale the moment the free water disappears from the surface. This gives a rough check on the saturated weight, which is, however, more accurately deduced from the submerged weight W_2.

The sample is now removed from the sampler and dried in an electric oven. W_3 = weight of sample dry.

V_2 the volume of the dry material when poured loosely into a cylinder of known dimensions and V_3 the volume when consolidated by ramming in thin layers, are next determined.

The angle of repose is determined by pouring the dry material from a low height onto a flat table and measuring the slopes with a clinometer.

Finally the material is subjected to a sieve analysis.

The densities of the samples in various conditions of compaction and moisture content are also determined. Formulae are as follows (mainly following the notation adopted in Reference No. 12):

Unit weight of dry material, $\gamma_d = \frac{W_3}{V_1}$

Unit weight as sampled, $\gamma_a = \frac{W_1}{V_1}$

Unit weight of saturated material $\gamma = 1 +$ submerged unit weight $= 1 + \frac{W_2}{V_1}$ [12]

Unit weight of dry material, loose $\gamma_o = \frac{W_3}{V_2}$

Unit weight of dry material, maximum compaction, $\gamma_{max} = \frac{W_3}{V_3}$

Finally, a full list of "index properties" is compiled for each sample in accordance with the following system:

(1) Allen Hazen's effective size, D_{10}

Allen Hazen's uniformity coefficient, $\frac{D_{60}}{D_{10}}$

"Fifty per cent size", D_{50}

Porosity of undisturbed sample $n = \gamma - \gamma_d$

Void ratio of undisturbed sample $e = \frac{n}{1-n}$

Void ratio of loose sample $e_o = \frac{\gamma_d}{\gamma_o}(1 + e) - 1$

Void ratio of compacted sample $e_{min} = \frac{\gamma_d}{\gamma_{max}}(1 + e) - 1$

Relative density of indisturbed sample $D_r = \frac{e_o - e}{e_o - e_{min}}$

(2) Water content of sample immediately after sampling, $w = \frac{\gamma_a - \gamma_d}{\gamma_d}$

The water content when saturated $= \frac{\gamma - \gamma_d}{\gamma_d}$

The degree of saturation immediately after sampling, $S_r\ (\%) = \frac{\gamma_a - \gamma_d}{\gamma - \gamma_d}\ 100$

(3) Permeability k

(4) Angle of repose ϕ

(2) Some Typical Samples from Sand Storage Dams

Three representative samples analysed by the author will now be described, one from the Bulskop sand storage dam in the mica schist area and two from the Gamams sand storage dam with a catchment consisting largely of quartzite country. In the latter the deposits fall clearly into two distinct major groups, fine sand and coarse sand respectively, hence the tabulation of the results of two samples. In the mica schist catchment fine sands are by far the most important part of the deposits. Samples were taken for testing permeability in a horizontal direction.

SAMPLE 1.—REPRESENTATIVE SAMPLE FROM THE BULSKOP DAM. ROUNDED AND REGULAR QUARTZ AND HORNBLENDE GRAINS WITH A LARGE PROPORTION OF MICA FLAKES

Grain size (in.)	Percentage finer than this grain size	Method of determination Sieve, U.S.A. No.	Grain size (in.)	Percentage finer than this grain size	Method of determination Sieve, U.S.A. No.
0·188	100·0	4	0·018	99·5	40
0·094	100·0	8	0·012	98·5	50
0·047	100·0	16	0·009	49·4	80
0·037	100·0	20	0·006	34·0	100
0·023	99·5	30	0·003	4·0	200

Allen Hazen's effective size $D_{10} = 0{\cdot}004$

Allen Hazen's uniformity coefficient $\frac{D_{60}}{D_{10}} = \frac{0{\cdot}010}{0{\cdot}004} = 2{\cdot}5$

"Fifty per cent size" $D_{50} = 0{\cdot}009$ in.

$D_{15} = 0{\cdot}0045$ in.

$D_{85} = 0{\cdot}011$ in.

Note D_{15} and D_{85} are of importance in drainage of sediments by filters (page 73).

SAMPLE 2.—REPRESENTATIVE OF FINE SAND GAMAMS DAM. ROUNDED AND ANGULAR QUARTZ GRAINS WITH A FAIR PROPORTION OF MICA FLAKES

Grain size (in.)	Percentage finer than this grain size	Method of determination Sieve, U.S.A. No.	Grain size (in.)	Percentage finer than this grain size	Method of determination Sieve, U.S.A. No.
0·188	99·4	4	0·018	95·8	40
0·094	99·0	8	0·012	83·7	50
0·047	98·2	16	0·009	13·5	80
0·037	97·9	20	0·006	11·0	100
0·023	96·4	30	0·003	1·5	200

Allen Hazen's effective size, $D_{10} = 0{\cdot}006$

Allen Hazen's uniformity coefficient $\frac{D_{60}}{D_{10}} = \frac{0{\cdot}011}{0{\cdot}006} = 1{\cdot}8$

"Fifty per cent size" $D_{50} = 0{\cdot}0115$

SAMPLE 3.—REPRESENTATIVE OF COARSER SAND GAMAMS DAM. ROUNDED AND ANGULAR QUARTZ GRAINS WITH A FAIR PROPORTION OF MICA FLAKES

Grain size (in.)	Percentage finer than this grain size	Method of Determination Sieve, U.S.A. No.	Grain size (in.)	Percentage finer than this grain size	Method of Determination Sieve, U.S.A. No.
0·188	88·4	4	0·018	21·9	40
0·094	79·9	8	0·012	14·2	50
0·047	74·5	16	0·009	2·5	80
0·037	68·8	20	0·006	2·0	100
0·023	25·2	30	0·003	1·0	200

Allen Hazen's effective size $D_{10} = 0{\cdot}011$

Allen Hazen's uniformity coefficient $\frac{D_{60}}{D_{10}} = \frac{0{\cdot}036}{0{\cdot}011} = 3{\cdot}3$

"Fifty per cent size" $D_{50} = 0{\cdot}032$

Further Properties of the Samples

		Sample No. 1	Sample No. 2	Sample No. 3	
Weight	$W_1 =$	910	1,190	1,255	*gram*
	$W_2 =$	456	547	649	,,
	$W_3 =$	827	945	1,097	,,
Volume	$V_1 =$	661	661	661	*c.c.*
	$V_2 =$	665	680	680	,,
	$V_3 =$	568	612	592	,,
$\gamma_a = \frac{W_1}{V_1}$	$=$	1·38	1·80	1·90	
$\gamma_d = \frac{W_3}{V_1}$	$=$	1·25	1·43	1·66	
$\gamma = 1 + \frac{W_2}{V_1}$	$=$	1·69	1·83	1·98	
$\gamma_o = \frac{W_3}{V_2}$	$=$	1·24	1·39	1·62	
$\gamma_{max} = \frac{W_3}{V_3}$	$=$	1·46	1·54	1·85	
$n = \gamma - \gamma_d$	$=$	0·44	0·40	0·32	
$e = \frac{n}{1-n}$	$=$	0·79	0·67	0·47	
$e_o = \frac{\gamma_d}{\gamma_o}(1 + e) - 1$	$=$	0·80	0·72	0·51	
$e_{min} = \frac{\gamma_d}{\gamma_{max}}(1 + e) - 1$	$=$	0·53	0·55	0·32	
$D_r = \frac{e_o - e}{e_o - e_{min}}$	$=$	0·04	0·29	0·22	
$W = \frac{\gamma_a - \gamma_d}{\gamma_d}$	$=$	0·10	0·26	0·14	
$W_{sat} = \frac{\gamma - \gamma_d}{\gamma_d}$	$=$	0·36	0·28	0·19	
$S_r(\%) = 100\frac{W}{W_{sat}}$	$=$	28%	93%	74%	
k	$=$	11 ft./day	10 ft./day	97 ft./day	
ϕ	$=$	31°	33°	35°	

Notes on the significance of D_r and γ_a:

Relative density $D_r = 0$ means material completely uncompacted.
$D_r = \infty$ means material with compaction equal to the maximum attainable in the laboratory.
$D_r = 1$, compaction such that void ratio is midway between that of loose and completely compacted material.

The samples taken are, therefore, all three in a relatively uncompacted state. They were all taken within 2 ft of the surface.

γ_a and units derived therefrom such as w, S_r, etc., show the moistness of the sample when taken. They are given here merely for the sake of completeness. Moisture content determinations are of interest where a number of samples are taken to explore the capillary zone, etc. The moisture which the isolated samples from the three dams happened to contain when taken is of no immediate significance.