Northern Regions on the Right Side of the Indus

(a) Peshawar and Mardan Districts

This area can be divided into four zones. The most important fertile zone with sufficient surface water for irrigation is the valley of Peshawar. It includes the District of Mardan, and the Tehsil of Charsadda. The Mardan and Charsadda Tehsils are irrigated by Upper and Lower Swat Canals and the Valley of Peshawar having the most fertile land is irrigated by canals taken out of the Kabul. The location of these areas is shown in Fig. 11.

The North-Western side of the valley, drained by the Bara river, is generally dry having piedmont soil intermixed with shingles and stones. The alluvium of these two districts at many places contains shingle beds often intercepted by thick clay layers. The surface recharge is low. There are no irrigated fields so that ground water

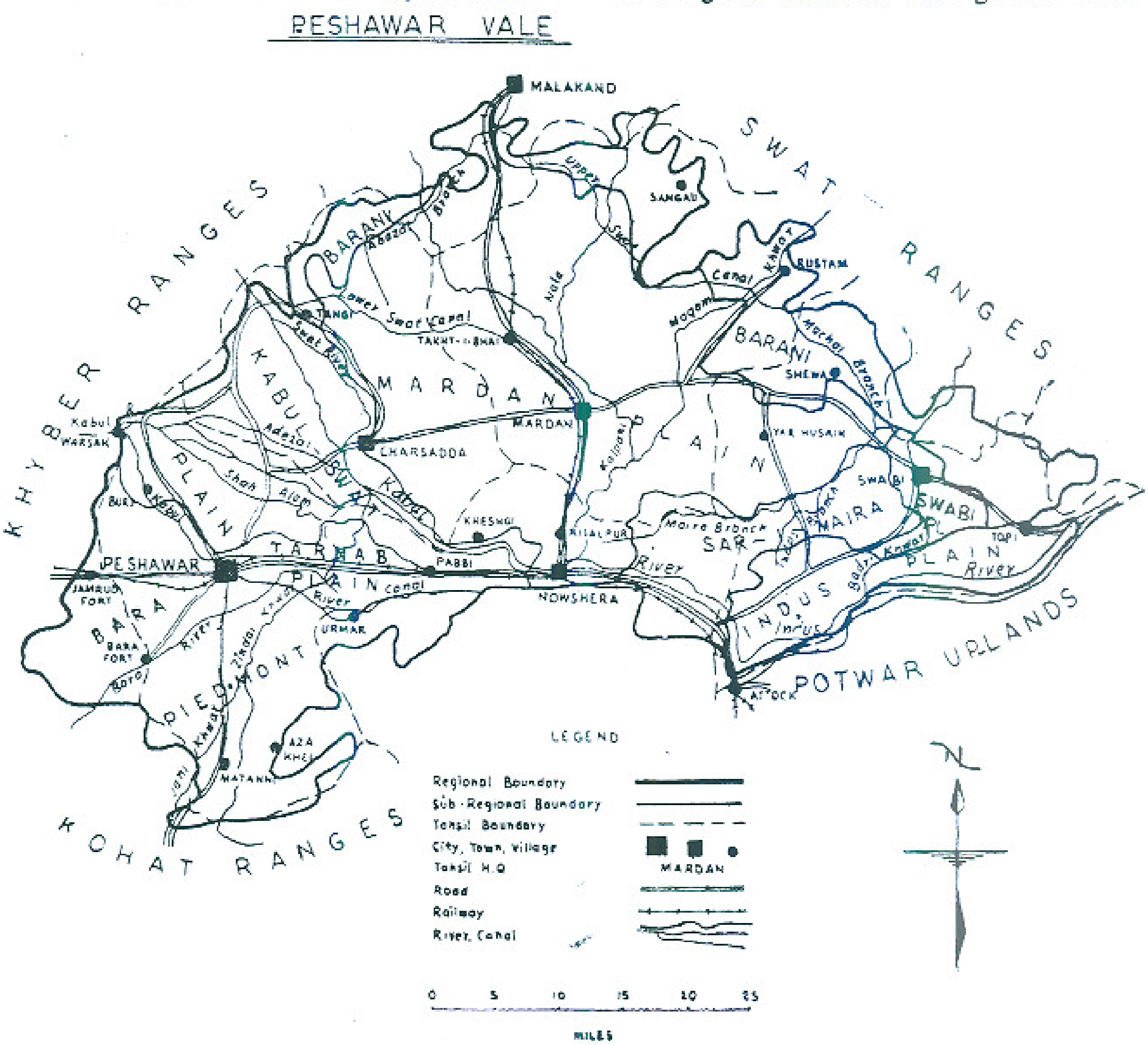

Fig. 11

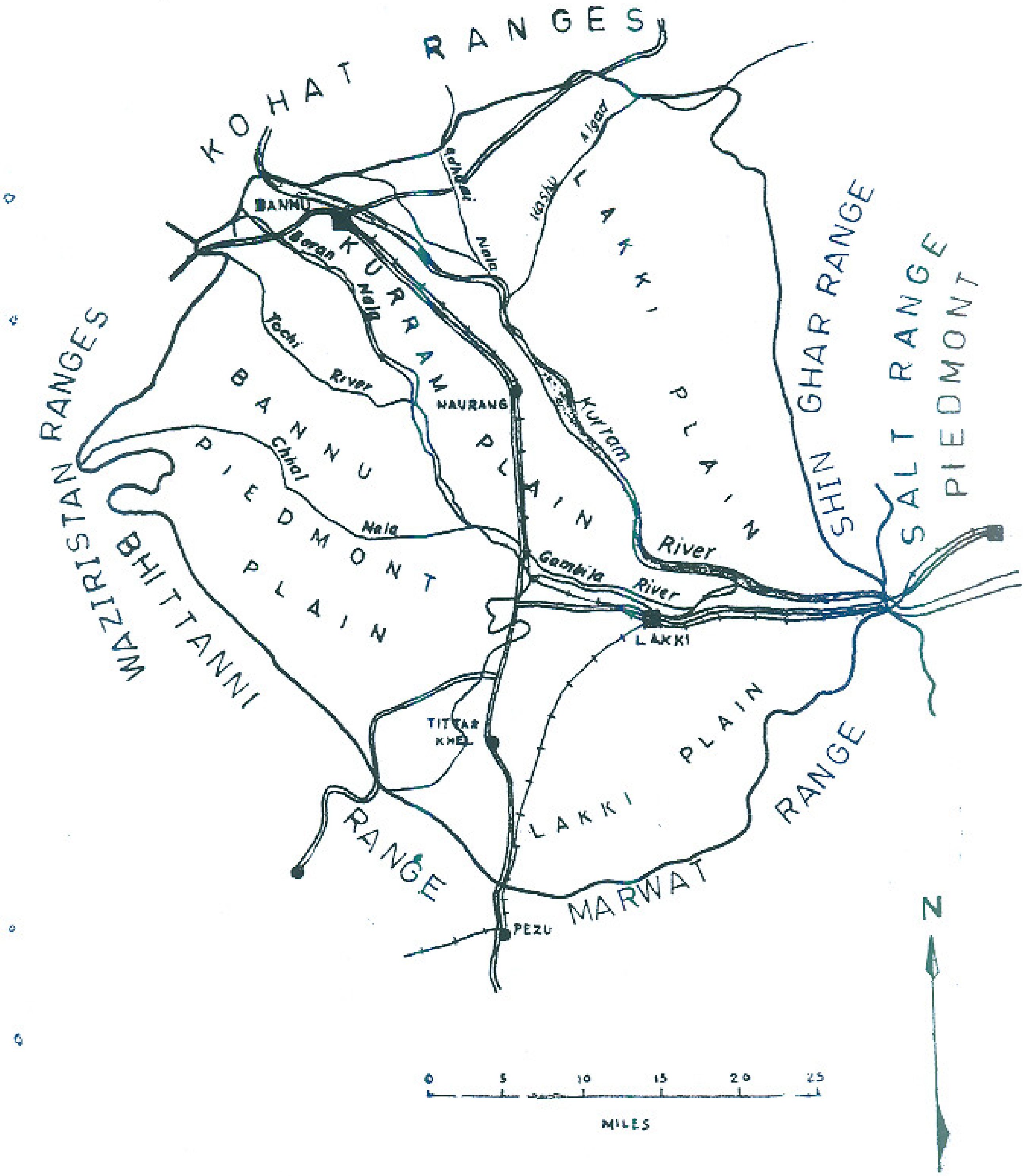
KOHAT RANGES
BANNU
KURRAM PLAIN
LAKKI PLAIN
Kashu Algad
Nala
Baran Nala
Tochi River
NAURANG
Kurram River
BANNU PIEDMONT PLAIN
Chhai Nala
Gambila River
LAKKI
SHIN GHAR RANGE
SALT RANGE PIEDMONT
WAZIRISTAN RANGES
BHITTANNI RANGE
TITTAR KHEL
LAKKI PLAIN
MARWAT RANGE
PEZU
N
0 5 10 15 20 25
MILES

Fig. 12

is very doubtful. On the other hand, aswe move towards the Kabul along Nowshera area, there is increase of infiltration source so that sufficient quantity of good quality water exists in the shingle and sand beds which can be pumped out for irrigation. The shingle formations are highly water yielding; although intermixed with coarse sand, yet successful tubewells can be installed in the valley of Peshawar.

(*b*) *Kohat District*

Adjacent to the district of Peshawar is the district of Kohat followed by Bannu, Dera Ismail Khan and Dera Ghazi Khan. This land formation exists below the foot-hills of the Suleiman Ranges. The district of Kohat in particular contains many small valleys. These are bounded by small *hillocks*. The valleys being small, often one large flood could fill the whole area. Here can exist a possibility of the formation of several aquifer confined between impervious layers. At places, infiltered water exists in the shingle beds. The quantity of water is not large, so that limited number of tubewells can be installed. On this side of the Indus, the land slope is such which does not retain the scanty rainfall to feed the aquifer. Even the infiltration from the Indus is not much, so that at places even close to the river, the ground water is deep and insufficient to be pumped.

(*c*) *Bannu Basin*

Bannu Basin consists of very fertile lands occupied between the Kurrum and Gambila rivers (Fig. 12). This area is irrigated by diversions from the Kurrum and now with the construction of Baran Dam, irrigation facilities have further improved. The area near Lakki is, however, very dry with sand dunes devoid of agricultural facilities.

The formation after a thick soil crust possesses shingles and only the irrigated areas near Bannu and Sarai Naurang have sufficient ground water to be pumped out by tubewells.

Boring in Lakki area has shown similar formation but without usable ground water. Further down near Isakhel, the conditions are again improved. Sufficient good quality ground water is available which can be pumped by tubewells. Already large number of tubewells have been installed in the Tehsil of Isakhel.

(*d*) *Dera Ismail Khan*

Along the right side of the Indus a vast stretch of Sulaiman Piedmont Plain extends to Dera Ismail Khan and to Dera Ghazi Khan up to the Upper Sind Frontier (Fig. 13). Round about Dera Ismail Khan sweet ground water exists and it is being exploited largely by tubewells. Boring in Dera Ismail Khan up to the depth of 1000 feet has not met with shingle bed. Large number of tubewells have also not depleted the ground water resources.

This water may be, as a result of infiltration from the Indus or seepage of surface rain water. Irrigation of the land by the small Paharpur canal can also be a source of infiltration mainly from Agricultural operations.

The area on the right of the Indus and in Potwar are the problem areas where location of ground water, its usable quality and exploitation are real problems.

Boring through shingle beds is difficult and the persistent sufficient yield from formations, which have little surface infiltration, is rather doubtful. Rain water often runs off due to steep slopes through streams which are deep cut and do not retain the water for a long time to infiltrate into the underground formations.

The Baluchistan

Very little is known about the underground geological formations and the availability of ground water in this area. There are a few small valleys like that of Quetta but the rainfall is low, the land slopes are steep and the underground formation retains limited quantity of infiltered water which often flows down through the shingle beds. Large scale investigations for the location of water still need to be carried out in this region.

The Indus Plains

The main Indus Plain starts below the Pubbies and the Salt Range. This constitutes a vast stretch of flat lands, nearly 800 miles in length and more than 350 miles at its broadest point. The width of the plains even at the narrowest point is more than 100 miles. It is one of the wonders of nature both with regard to the extent of the surface area and the vast reservoir of ground water. The land has a very gentle slope, hardly a foot per mile. Small thin strips of land near the foot-hills have slope of 2 to 5 ft. per mile. Near the delta, the slope reduces from 3/4 to 1/2 ft. per mile. Except for a few insignificant out-crops in the Northern region and some limestone formations in the South, there is no discontinuity in the flatness of the lands.

Subterranean buried rocks, some minor Ranges of Aravalli mountains extending from Delhi to Khushab existing across the

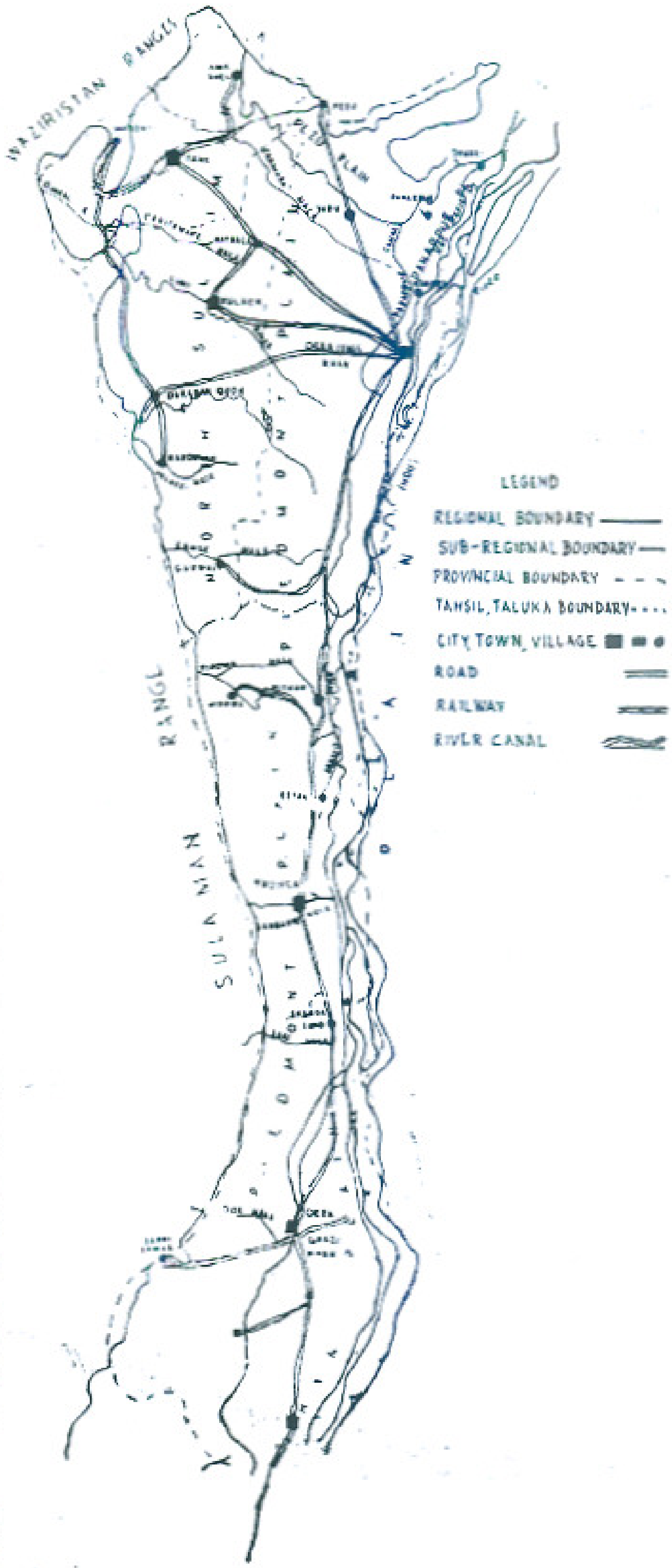

Fig. 13

present Indus Plains had created deep trough which got filled up with the alluvium at places more than 5000 ft. in thickness. Innumerable rivers must have contributed their detritus to the sea brought down by them. Maybe, West Pakistan had three troughs containing deep sea water. One existed upstream of the Delhi Khushab ridge and the rest two might be formed due to the limestone rocks of Rohri-Sukkur and Kotri-Hyderabad Regions[6].

Alluvium deposition in the sea of Indus Plains

The boring information collected from the Indus plains shows that the alluvium deposition had not been subjected to distortion and other geological eruptions. It appears that the rivers of the geological periods have continued to deposit their detritus in the deep sea troughs. The present plains have been formed by two different systems, at first by deposition of the alluvium into the pond of the sea and the second by the deposition of the meandering rivers. So long the deposits were discharged into the sea, one can visualise their deposition like that in a reservoir. A stream entering into a storage of water loses its intensity and the sediment starts depositing. Rarely boulders and shingles enter the pond area. Often these deposit outside the pond, so that regime of the stream above the pond changes. The alluvium as it enters the still pond, gets sorted out, coarse sand depositing in the head reaches followed by the finer sand, silt and clay. Each recharge of water brings in fresh alluvium which deposits on the previous one. Thus clay and silt beds are formed in the deep portions of the pond. By stages the delta rises (Fig. 14) till it appears above the water surface. This process must have happened when the Indus Plains were being built up. Inflow from all sides from the Himalayas and the Sulaiman Ranges must have continued to deposit in the deep sea troughs. There must have been several

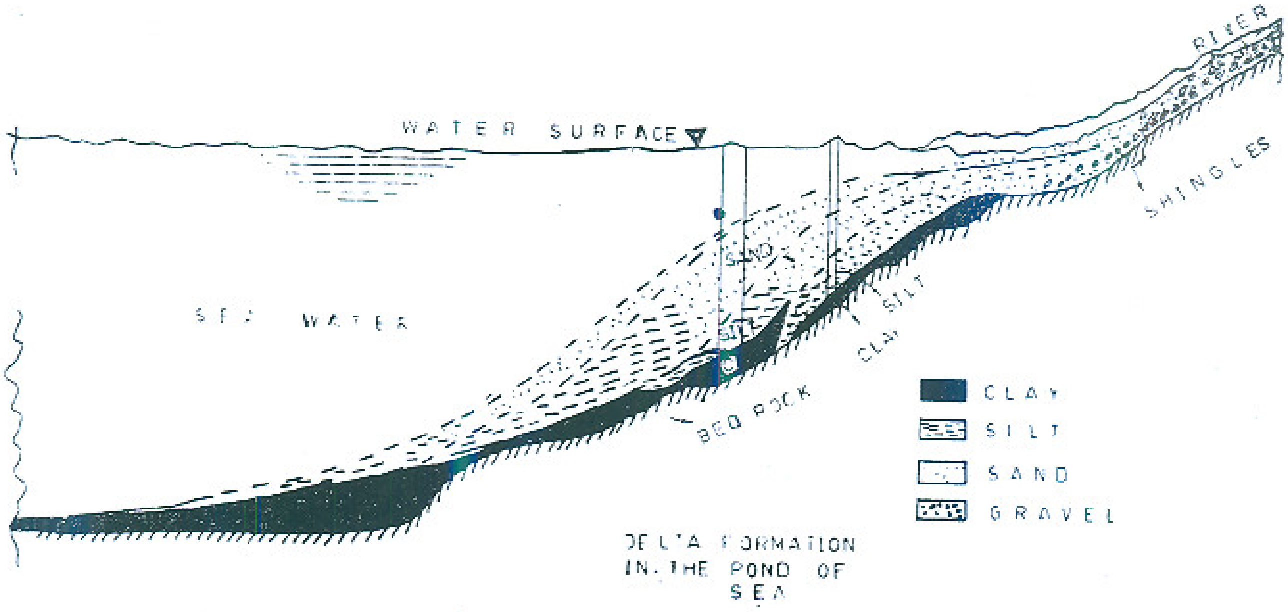

Fig. 14

inlets into the sea. The deposition of various grades could be layed at random at different elevations.

Alluvium deposit on land above the level of the sea

The alluvium deposition on soil surface is quite distinct from that depositing into the sea. A delta is generally very flat so that the sediment transporting channels have a chance of shifting their beds from place to place particularly with varying discharges. The type of the deposition of the alluvium in delta area is also typical. The active bed of a stream can be formed of grades of material representing the average intensity of the tractive forces of the flowing water. The bed material is sorted out and only certain grades remain deposited in the active bed. The finer particles are picked up and carried away. Whenever a stream overflows its banks, the deposition of different grades takes place at different positions across the flood plains. With the decrease in the intensity of flow, the grades of deposition of the alluvium also get sorted out, the clay depositing in the still pond area. The deposition of other grades follows the relative intensity of the flow of water. Discharge of the rivers often varies with seasons. There is every reason to believe that the flood and monsoon seasons even existed in the very early stages as at present. The flow variation in flat alluvium formation results in meandering of the streams, depositing and eroding at certain places and causing changes in the grades of the deposited material. There are many old abandoned beds of the rivers even now in existence. The rivers in the plains often changed their path, several miles apart. The character of the deposition of the alluvium shifts with the shifting of the rivers. An active river stream while shifting its path may start flowing over a clay bed, changing the character of the deposition altogether. The present elevation of the plains below the salt range is 800 to 1000 ft. above sea level, so that all the deposits can be a result of the meandering of the rivers. The extent of the Indus Plain being so wide, there can be little uniformity and regularity of the deposits. The formations of the alluvium are thus very random and variable.

Characteristics of the Indus Alluvium

Below the salt range except close to the foot-hills, shingle deposits are rarely met with. In the boring carried out down to about 1500 ft. below surface, touching at many places the bed rock, shingle formations have not been determined. Three specimens of deep borings up to the rock bed are shown in Fig. 15. Coarse sand with particles above 0.5 mm. is rarely found except in the very thin strip of lands below the foot-hills. Some shingles and boulders are found in the region but in the plains sand finer than coarse grade, between medium and fine ranges, is in existence due to the slope of the country.

High order of Uniformity of sand deposits

Alluvium deposits are often of high uniformity. This is also true for the formation of the Indus Plains. Sieve analysis shows large portion of particles of one grade in a specimen. This property is called the Uniformity Coefficient. It is the ratio of particle size of a specimen 40 per cent retained to 90 per cent retained. If all grades of sand are equal, the Uniformity Coefficient is one. With the admixture of particles of different grades, the value of

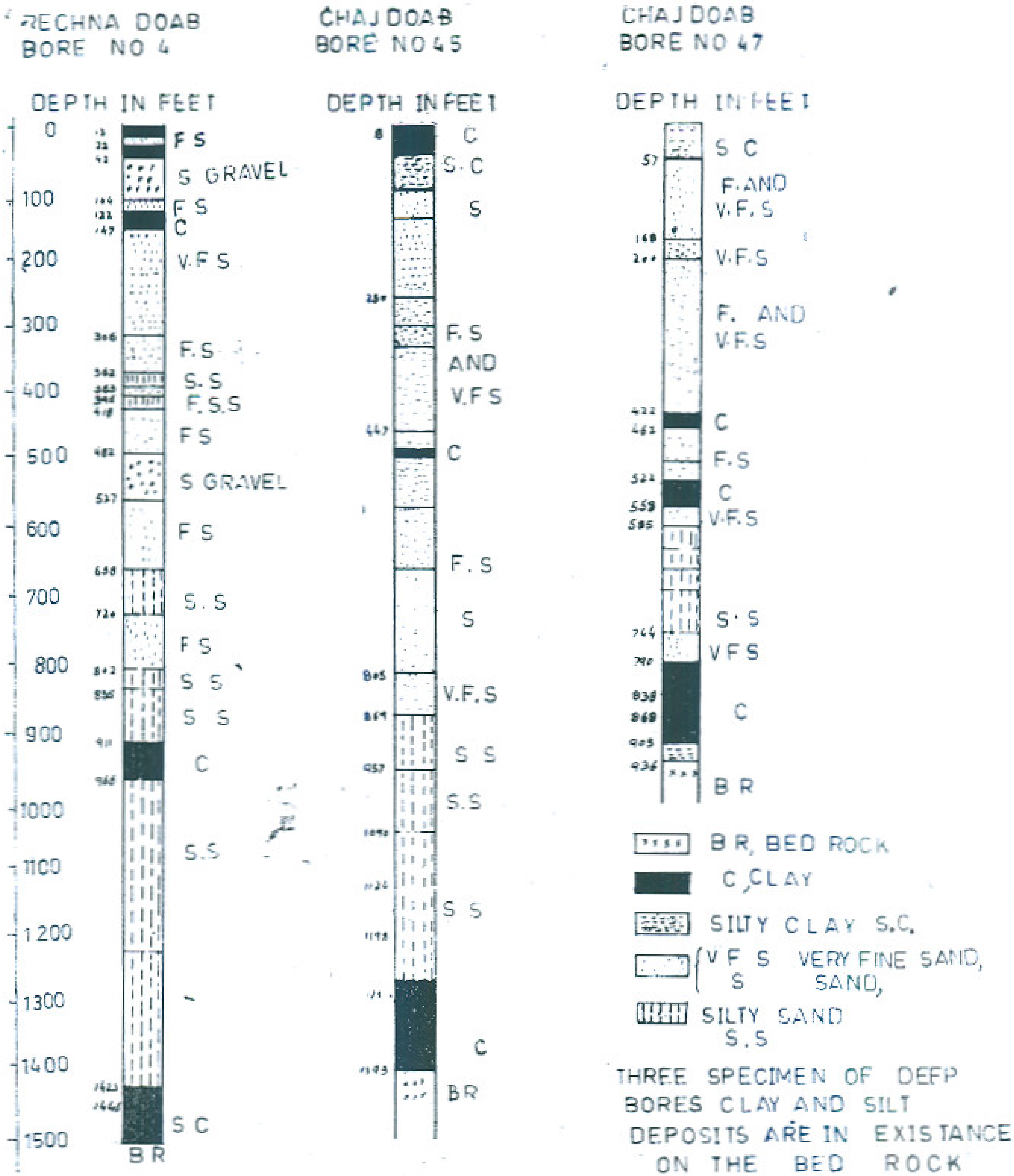
RECHNA DOAB
BORE NO 4
DEPTH IN FEET
CHAJ DOAB
BORE NO 45
DEPTH IN FEET
CHAJ DOAB
BORE NO 47
DEPTH IN FEET
F S
S GRAVEL
C
V.F S
F.S
S. S
F.S.S
F S
S GRAVEL
F S
S . S
S S
C
S.S
S C
B R
S·C
S
F. S
AND
V.F S
F. S
V.F.S
S S
S.S
BR
S C
F. AND
V.F. S
V.F.S
F. AND
V.F.S
S' S
V F S
B R
B R, BED ROCK
C, CLAY
SILTY CLAY S.C.
V F S VERY FINE SAND,
S SAND,
SILTY SAND
S . S
THREE SPECIMEN OF DEEP
BORES CLAY AND SILT
DEPOSITS ARE IN EXISTANCE
ON THE BED ROCK

Fig. 15

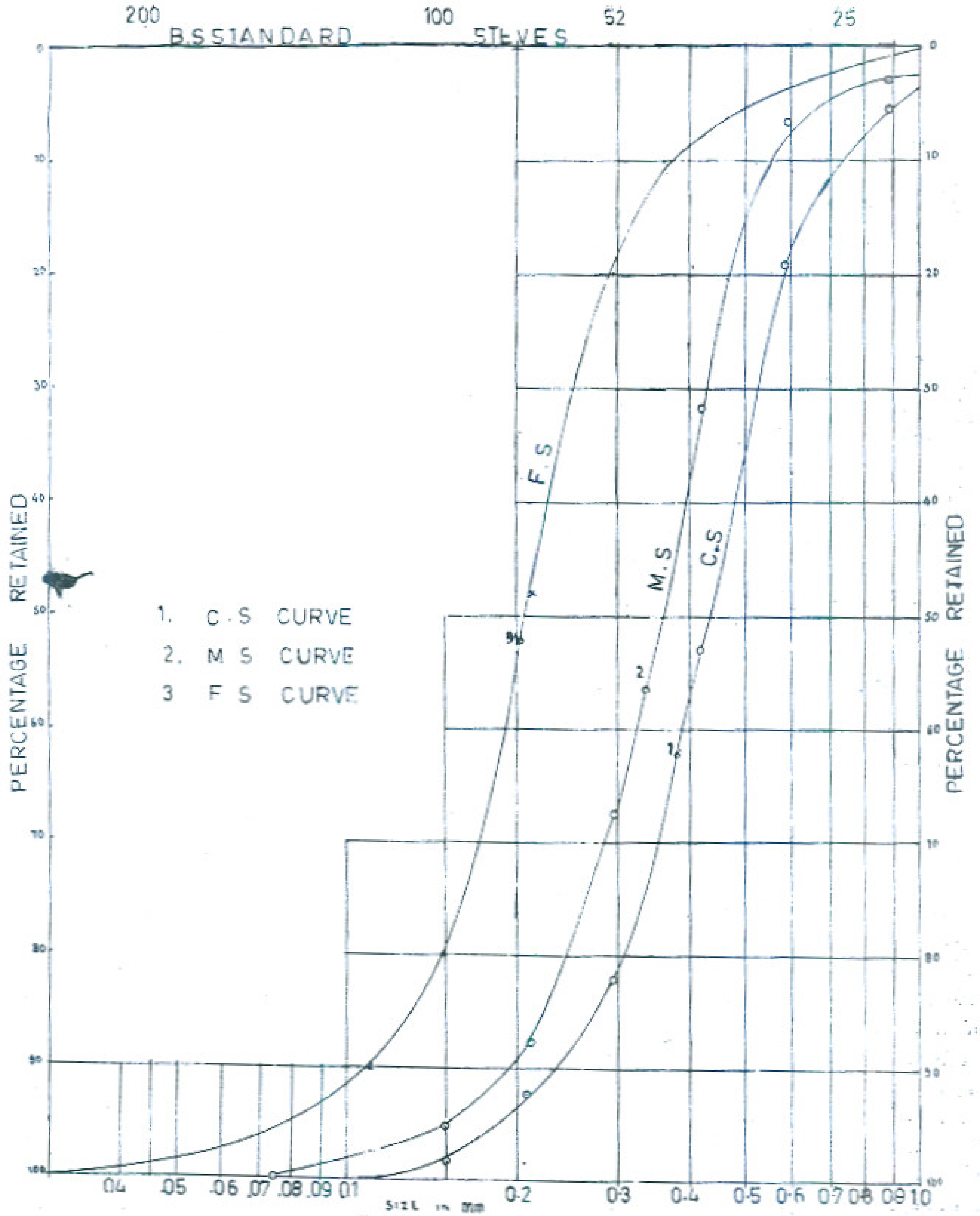
200
100
52
25
B.S STANDARD SIEVES
PERCENTAGE RETAINED
PERCENTAGE RETAINED
F.S
M.S
C.S
1. C.S CURVE
2. M.S CURVE
3 F.S CURVE
.04 .05 .06 .07 .08 .09 0.1
0.2
0.3
0.4
0.5 0.6 0.7 0.8 0.9 1.0
SIZE in mm

Fig. 16

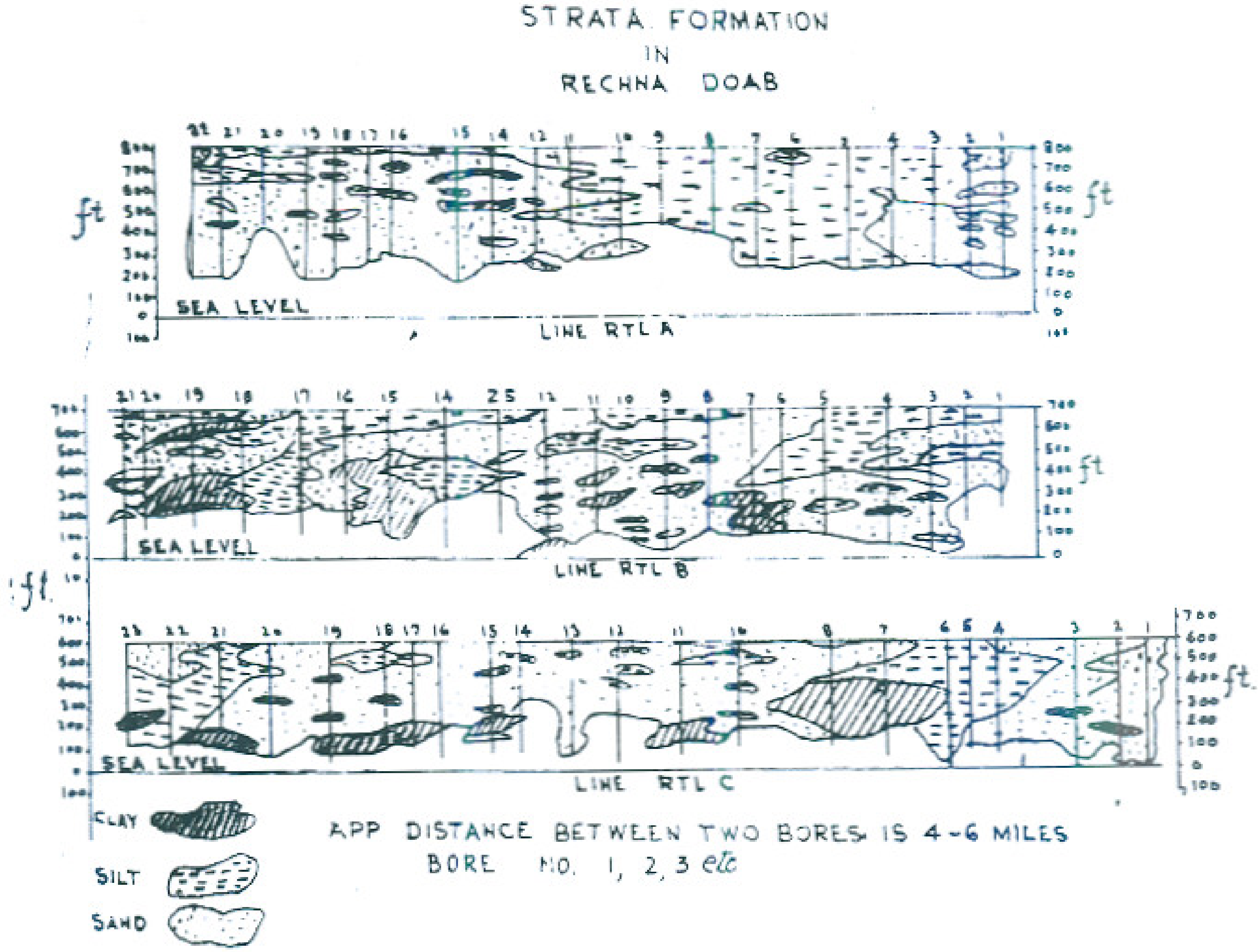

Fig. 17

Uniformity Coefficient increases.

In case of Indus deposit, the uniformity coefficient lies between 1.5 to 2.5. A few typical gradation curves for sands are shown in Fig. 16. The sands irrespective of being coarse grade of medium sand, fine grade of medium sand or fine sand, possess high uniformity coefficient. When coarse grades are also in existence as found for specimens out of Peshawar or Northern Regions above salt ranges the uniformity coefficient increases. The Indus formation thus possesses all the advantages of high uniformity of sand grades.

Non-existence of confined aquifer

Alluvium deposts of the Indus Plains are stratified. The stratification exists in the form of small lenses. A few typical strata of Rechna and Chaj Doabs are shown in Figs. 17 and 18. The sites for which cross-sections are available are shown in Figs. 19 and 20. Results of three deep bores have already been mentioned in Fig. 15. It may be seen that the clay deposits do not cover an extensive area of the formation. It exists as small lenses. The whole Indus formation below the salt range is nearly

STRATA FORMATION IN CHAJ DOAB

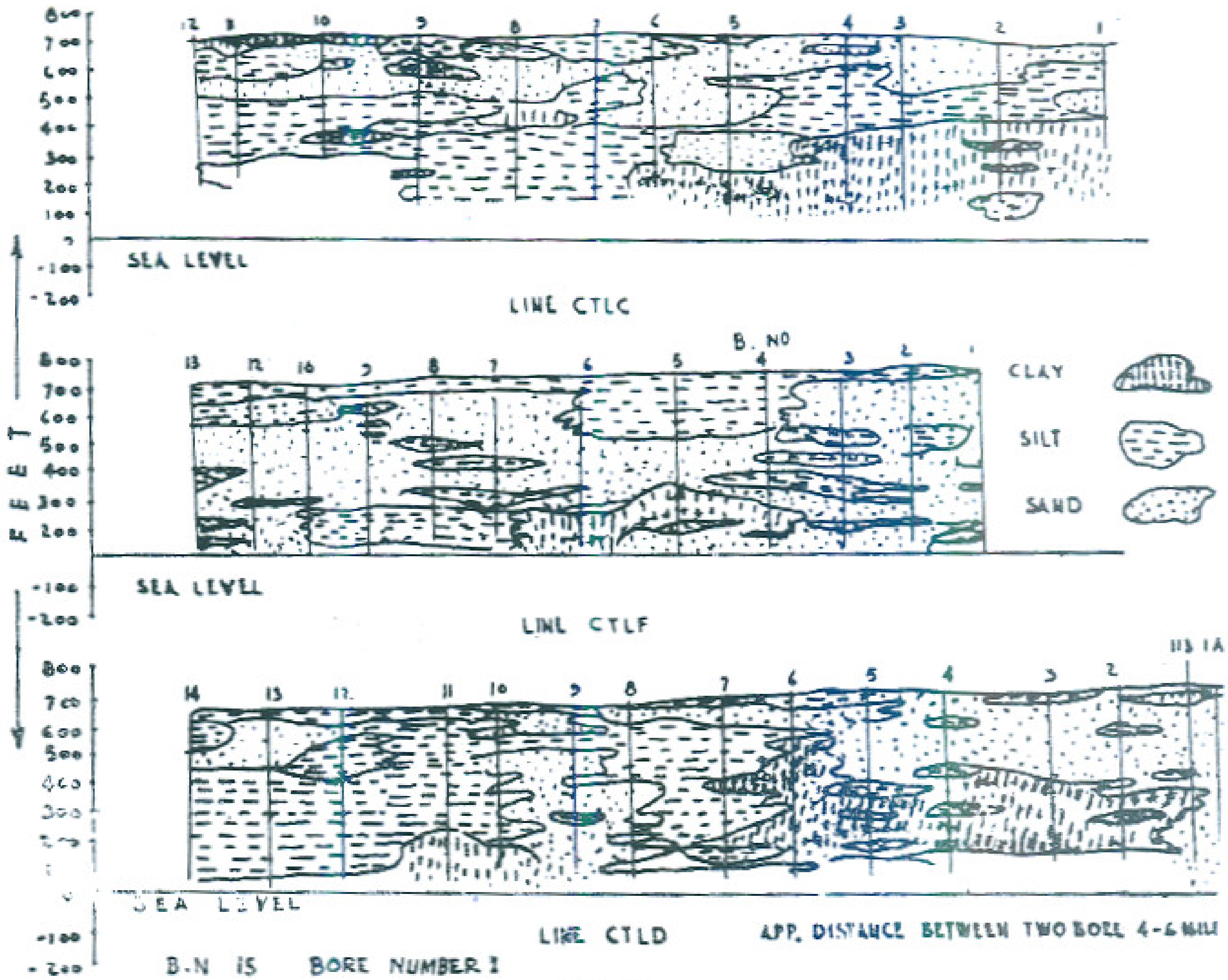

Fig. 18

LOCATION MAP OF TEST HOLES IN CHAJ DOAB

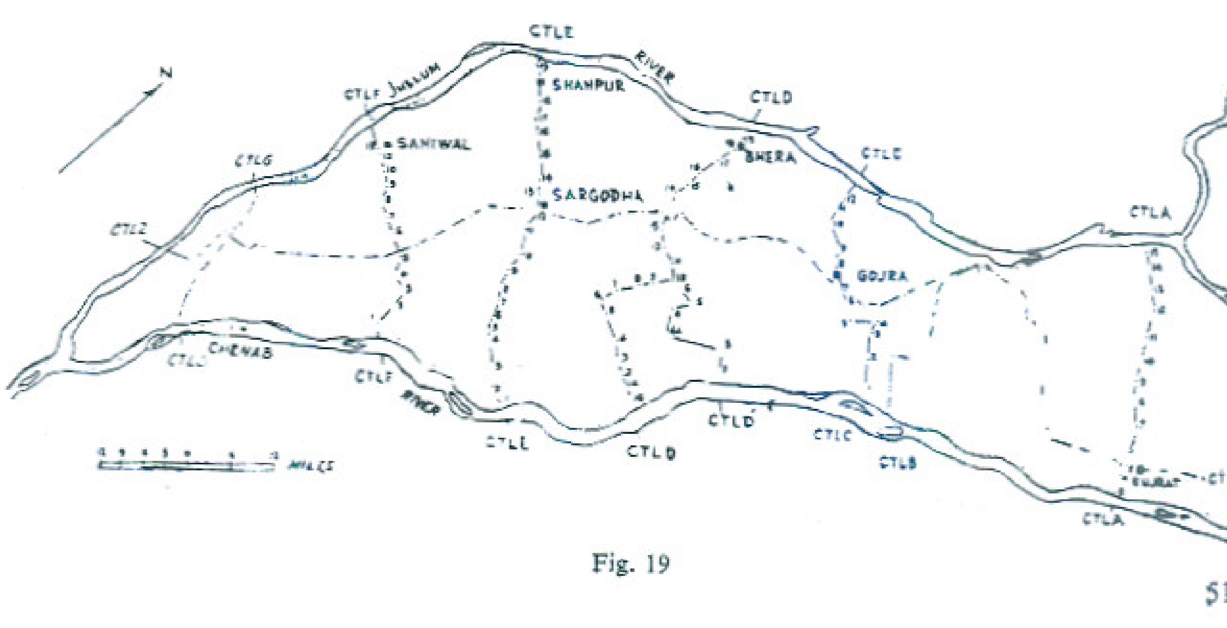

Fig. 19

LOCATION MAP OF TEST HOLES IN RECHNA DOAB

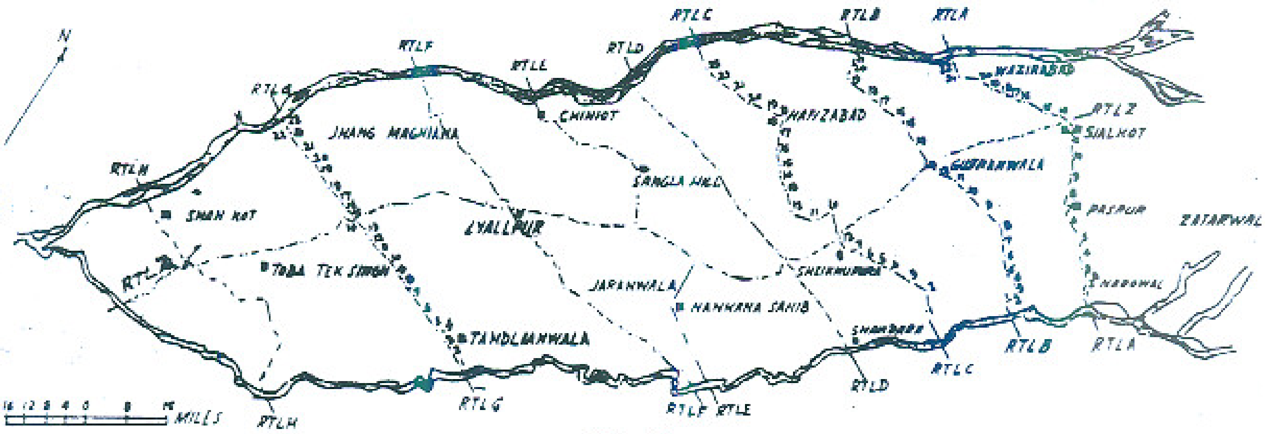

Fig. 20

one connected aquifer. The characteristics of confined aquifer such as artesian pressure, consolidation of formation after withdrawal of water, etc., are not observed in these areas.

The depth of good water yielding sand is about 50% of the total deposits. The silt and fine sand zones which can also yield water constitute the rest. The thickness of sand, silt and clay was worked out from the borings given in Figures 19 and 20 for the four doabs. It was found to have the thickness as shown in table 1.

Yield of water from a formation

(a) *Which water is available for pumping:*— A typical soil moisture profile is shown in Fig. 21.

The moisture content in a profile varies from top downward to watertable.

TABLE No. 1

Type of Strata Formation in Chej and Rechna Doabs, up to a depth of 500 feet

		Chej Doab.					Rechna Doab.				
S. No.	Depth Range (ft.)	Sand, ft.	Silt & fine Sand, ft.	Clay, ft.	% of good yielding formation	% of bad yielding formation	Sand, ft.	Silt & fine Sand, ft.	Clay, ft.	% of good yielding formation	% of bad yielding formation
1.	0—100	45.0	48.5	6.5	45.0	55.0	55.0	41.0	4.0	55.0	45.0
2	0—200	98.0	92.2	10.1	49.0	51.0	120.0	74.0	6.0	60.0	40.0
3	0—300	135.0	143.0	16.6	45.1	54.9	175.0	112.0	13.0	58.3	41.6
4	0—400	170.3	203.2	26.5	42.6	57.4	230.0	140.0	30.0	57.6	42.2
5	0—500	180.0	260.0	60.3	36.0	64.0	285.0	172.0	43.0	57.0	43.0

In table 2 is given the average percentage of the pores found in the formations possessing particles of different sizes.

TABLE No. 2

Pores space and water yield of different granular materials

Materials		Percentage pore space	Percentage water yield
Gravel	..	25—35	25—30
Uniform sand	..	30—40	20—30
Sand	..	35—40	20—25
Sand mixed with gravel	..	20—35	15—20
Fine sand & very fine sand		35—45	10—15
Silt	..	40—50	5—10
Clay	..	45—55	5— 7
Heavy clay	..	50—70	3—5

In nature the particles are seldom spherical, so that it is very difficult to estimate the size of pores. Their percentage with respect to the total volume can only be determined. The work of Fraser and Graton[8] as mentioned further in the text is important for determining the size and percentage of the pores for perfect spheres placed under various possible conditions of packing. For natural grains which are angular, the average pores space is found as given in table 2.

The bigger the size of the particles, the smaller is the pores space. For small gravels it is about 25 per cent but for clays having very small grains, about 0.002 mm. and a smaller diameter, the pores space increases up to 60 or 70 per cent of the total.

The yield of water held between the pores varies with the type of formation classified on the basis of their grain size. The gravels having pores of big size yield practically the whole of their held water. As the particle size decreases, the yield of water is reduced. For instance, in the case of clays or very fine silt, the pores water is held by strong capillary forces due to their small sizes. The yield is insignificant. It is possible to estimate the yield in a laboratory. Referring to Fig. 22 which represents one

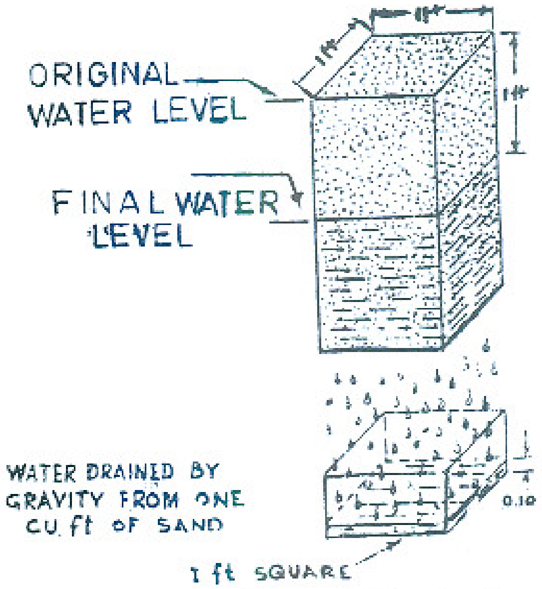

Fig. 22. Yield of water from saturated sand column

square foot section of water saturated sand when it is allowed to drain out, the wate released after draining one foot from an are: of one square foot, is called its yield. I is also called the specific yield. A san column made up of coarse sand can yiel about 25 to 30 per cent of its water held i 40 percent of its pores. The laborator determination of the yield is rarely carrie out. It is the field information which i reliable and is determined.

A natural formation may contain variou types of deposits having different orders c specific yield. The field information is thu a mean of all grades. It is often determine indirectly by the application of a pumpin

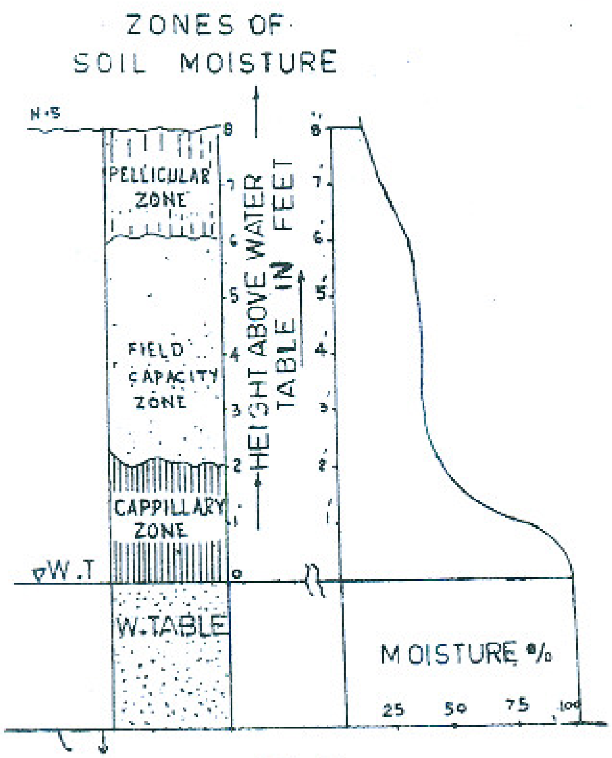

Fig. 21

The top surface is exposed to evaporation and very often contains low moisture content unless it is subjected to inflow of excess moisture. Soil Physicists have named the different zones of varying moisture content. The top zone having low moisture is generally called the pellicular zone through which the moisture continues to be lost by evaporation. This is the zone which receives addition of moisture from the top. Plants usually utilize the moisture content of this zone. This changing moisture zone is followed by a zone of constant moisture percentage. It is called the Field Capacity Zone. It is unsaturated so that some of the pores contain entrapped air. The moisture is held by certain forces of soil grains. The extent of this zone varies at different times with the extent of the top pellicular zone and bottom zone of capillarily moisture.

After the Field Capacity moisture zone lies the capillary zone which exists above the water saturated zone. It is partly saturated and contains more moisture as compared to the field capacity zone. Its moisture content increases from top to bottom and at the level of the free water surface attains the full saturation. From the consideration of water availability none of these three zones yield water when a hydraulic gradient is created. The moisture content in all these zones is held up by certain physical forces and no flow of water by normal suction or creation of a flow gradient is possible.

It is the saturated zone alone below the watertable which yields water under the action of gravity when a flow gradient is established. For this reason the water of this zone is sometimes called the gravitational water.

(b) *Yield of water from a saturated formation:—*

Water is available both from a compact consolidated rock or from granular unconsolidated formation. There are hard types of rocks such as limestone, sand stone and even shale which possesses water only in their fissures and cracks. This water has infiltered from the top sources and fills all the cracks. It is available for pumping. Very often under favourable conditions practically all water retained in these cracks and channels is made available.

The second type of formation is made up of granular materials fragmented from rocks. Such formations are unconsolidated and their pores can retain large volume of water.

The size and volume of the pores depend upon the size of grains of the formation, their shape and degree of consolidation and compaction.

In table 2 is given the average percentage of the pores found in the formations possessing particles of different sizes.

TABLE No. 2

Pores space and water yield of different granular materials

Materials	Percentage pore space	Percentage water yield
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Clay ..	45—55	5— 7
Heavy clay ..	50—70	3—5

In nature the particles are seldom spherical, so that it is very difficult to estimate the size of pores. Their percentage with respect to the total volume can only be determined. The work of Fraser and Graton[8] as mentioned further in the text is important for determining the size and percentage of the pores for perfect spheres placed under various possible conditions of packing. For natural grains which are angular, the average pores space is found as given in table 2.

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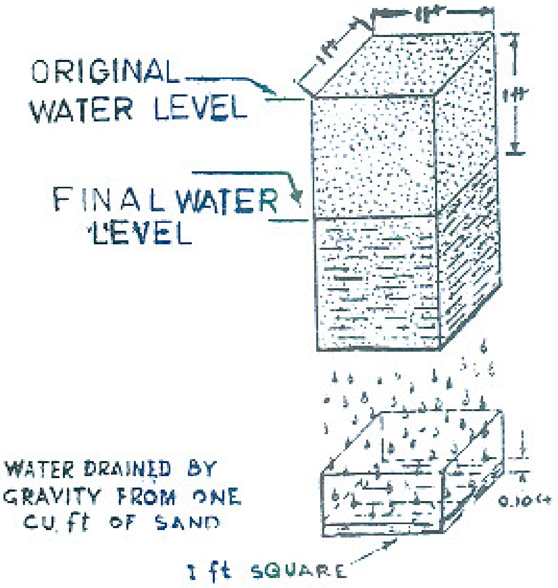

Fig. 22. Yield of water from saturated sand column.

square foot section of water saturated sand, when it is allowed to drain out, the water released after draining one foot from an area of one square foot, is called its yield. It is also called the specific yield. A sand column made up of coarse sand can yield about 25 to 30 per cent of its water held in 40 percent of its pores. The laboratory determination of the yield is rarely carried out. It is the field information which is reliable and is determined.

A natural formation may contain various types of deposits having different orders of specific yield. The field information is thus a mean of all grades. It is often determined indirectly by the application of a pumping

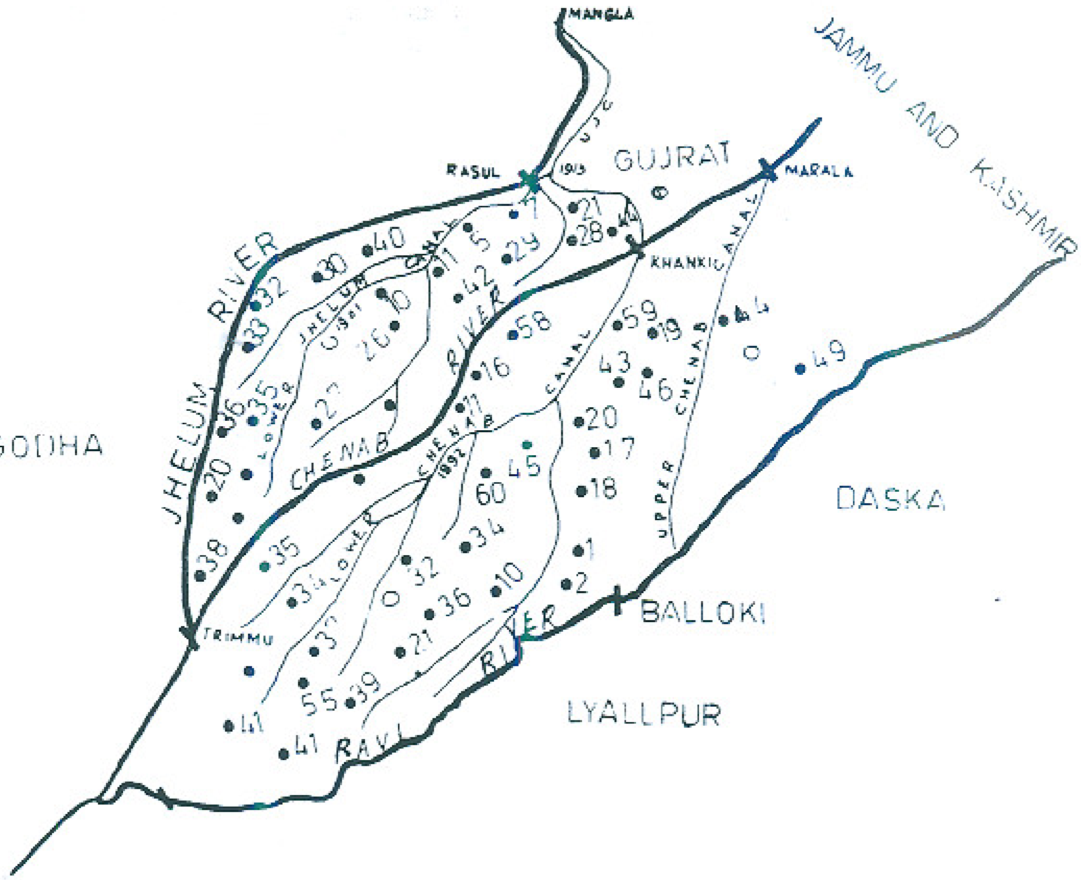

Fig. 23. Showing App. Location of Permeability and Storage coefficient determination sites in Rechna and Chaj Doabs.

test technique developed during recent years. We will explain its determination further on. The specific yield is also called the storage coefficient. Its order varies with the condition of occurrence of water. If a test is conducted in a confined aquifer, the order of storage coefficient of a non-consolidated formation is found equal to 1 or 2×10^{-4}.

In the Indus Plain the aquifer is unconfined, so that the storage coefficient represents the specific yield and lies between 0.01 to 0.3 depending upon the physical conditions of the formation.

Wasid[9] in its programme of ground water investigations has conducted several field tests to determine the storage coefficient. The tests were conducted mainly in the four doabs of the Punjab. The sites of such observations in Rechna and Chaj Doabs only are shown in Fig. 23. The results of fifty-two tests in Rechna doab are given in table 3. The storage coefficient was found to vary between 0.01 to 0.33 or 1 to 33 per cent. Similar 28 tests in Chej, 29 in Thal and 4 in Bari Doab were conducted. Out of 106 test sites, 34 sites had watertable in sand and another 33 had watertable in clay. The results for all the sites are shown in Fig. 24. This also includes the sites with watertable existing in sand or in clay.

The average order of the specific yield for

TABLE No. 3

Lateral permeabilities, specific yields and general test information for Rechna Doab.

Test No.	Site	P_r, Cusecs ft. $\times 10^{-4}$	S_y, decimal fraction	L ft.	D ft.	D ft.	Y °F	Q_w, Cusecs	Drn. hrs.	Max. s_w, ft.
1	2	3	4	5	6	7	8	9	10	11
R-1	Chuharkana Rest House	20	..	146	226	2.8	..	2.05	144	15.00
R-2	—do—	25	..	120	158	2.8	..	1.00	144	15.00
R-6	Chichoki Malian Drain	31	.01	144	288	2.5	..	2.50	144	22.00
R-8	U. G. Branch	16	.22	197	234	4	..	1.82	144	13.00
R-9	Jaranwala	24	.09	119	203	7	..	2.00	144	20.00
R-10	Mianwali Br.	46	.18	132	202	4	..	1.25	144	13.00
R-11	Jhang Branch	09	..	140	243	12	78	1.25	144	14.00
R-16	Jalalpur	48	.12	132	205	6	83	2.00	98	..
R-17	Jahanshah Drain	44	.11	100	202	6	78	1.34	144	16.88
R-18	Mangoki Drain	11	.14	150	301	1.5	..	2.50	144	18.24
R-19	Nokhar	38	.09	130	150	3	78	.83	72	10.00
R-20	Qila Didar Singh	40	.15	100	150	12	..	1.50	96	10.00
R-21	Jaranwala Area	31	.08	160	345	10.8	76	2.50	144	23.20
R-22	Lahore-Sargodha Road Mile 40.	40	.06	144	300	8	91	2.50	156	10.40
R-24	Mannawal Disty.	50	..	120	299	9	84	2.54	144	11.73
R-25	Lakarmandi R. H.	60	.09	130	300	10	86	2.75	144	19.87
R-27	Hitar Wali R. H.	55	.09	116	291	16	86	2.54	144	15.64
R-28	Tail Rody Disty.	52	.06	139	300	8	88	2.54	144	10.63
R-29	Mangtanwala R. H.	38	.09	130	276	8	74	2.50	144	10.05
R-	Lundianwala R. H.	41	..	133	296	5	81	2.54	144	13.06
R-	Chak Jhumra	39	.08	140	234	8.1	84	2.50	72	10.68
R-33	Chiniot R. H.	70	..	99	210	13	..	3.00	120	11.83
R-34	Amin Pur R. H.	42	.14	135	300	18	72	2.50	144	16.13
R-35	Muradwala R. H.	101	.30	129	300	16.5	81	2.54	144	25.17
R-36	Pacca Anna	27	.18	146	300	20	81	2.58	144	19.20
R-37	Gojra	47	.29	143	300	20	84	2.75	144	12.70
R-38	Tandlianwala	41	.21	145	282	25	76	3.06	144	15.78
R-39	Chak No. 210	85	.25	120	300	19	90	3.5	144	17.53

Table 3 (*continued*)

1	2	3	4	5	6	7	8	9	10	11
R-40	Buchrinwala ..	78	.18	146	300	26.7	83	3.00	144	14.
R-41	Kamalia ..	29	.20	140	300	27	83	3.00	48	14.
R-42	Bhanga Disty ..	31	.17	155	300	18	84	3.50	48	14.
R-43	Gujranwala ..	52	.10	140	300	12.4	77	3.00	52	14.
R-44	Daska ..	20	.02	140	236	12	..	3.00	48	20.
R-45	Karial ..	25	..	146	246	5	78	3.00	63	..
R-46	Nandipur ..	28	.02	140	300	6	77	3.50	93	15.
R-47	Kala Shah Kaku ..	32	.07	140	300	10	..	3.00	98	12.
R-48	Mehta Suja R. H. ..	26	.03	140	289	7	82	3.00	80	19.
R-49	Mianwali ..	19	.03	110	232	13	78	3.00	92	16.
R-50	Qila Sattar Shah ..	41	.13	140	303	14.3	84	3.50	98	18.
R-51	Dhoka Mandi ..	18	.10	140	290	12	81	3.50	96	34.
R-52	Buchiana ..	38	..	140	305	21	85	3.00	116	14.
R-53	Sialwala Rest House ..	27	.29	140	283	14	84	3.50	120	22.
R-54	Lyallpur ..	28	.06	151	296	10	82	3.50	120	16.
R-55	Toba Tek Singh ..	28	.24	150	296	28	83	3.50	96	14
R-56	Sultanpur ..	25	.33	150	300	10	82	3.00	96	15
R-57	Kamrana R. H. ..	38	.11	120	275	10	81	3.00	110	15
R-58	R. D. 64 Vanike Disty. ..	27	.12	140	260	9	85	3.50	98	25
R-59	R. D. LCC Pandori ..	12	.11	140	280	10	77	3.00	98	26
R-60	R. D. 19800 Aruri Disty...	30	—06	140	300	16	84	3.00	98	23

Abbreviations

P_r	:	average lateral permeability of screened interval.
S_y	:	specific yield of material at watertable depth expressed as a dimensionle fraction.
L	:	length of test well screen.
D	:	depth of test well.
D_w	:	depth of water at test site.
Y°F	:	temperature of pumped water in °F.
Q_w	:	discharge of test well.
Drn	:	duration of test.
Max. s_w	:	maximum drawdown observed in pumping well (just prior to end of tes

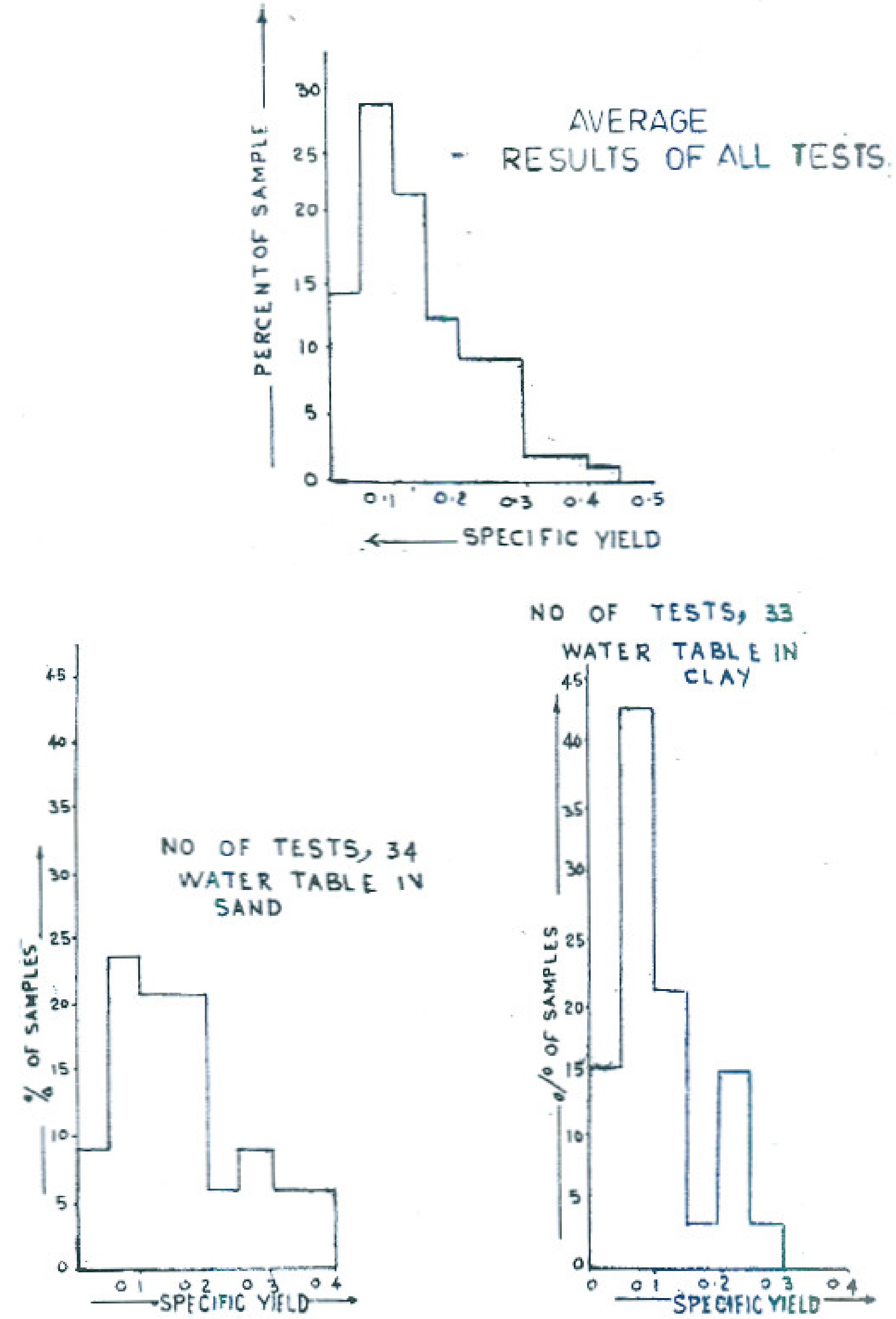

Fig. 24. Specific yield of storage coefficient determined for the Punjab Plains, after Wasid.

about 70% of the sites as well as the mean value is shown in table 4.

TABLE No. 4

Storage Coefficient or specific yield for the Punjab Region of West Pakistan

Sites.	Storage coefficient for 70% of the sites	Mean
(*a*) Average of tests on 106 sites ..	0.03 to 0.19	0.14
(*b*) On 34 sites with watertable in sand..	0.04 to 0.19	0.16
(*c*) On 33 sites with watertable in clay ..	0.02 to 0.13	0.13

Flow through saturated medium

In 1856, Henry Darcy[10], a French Hydraulician, found that the velocity of flow through sand, varied directly as the hydraulic gradient *i.e.,*

$$V \propto H/L$$

$$\text{or} \quad V = K\frac{H}{L} \quad \ldots\ldots\ldots(1)$$

where H is the difference of water head when flow occurs through a length L of a sand medium (Fig. 25). The gradient was denoted by I.

K is a constant and is called the permeability coefficient. It depends upon many physical parameters, such as the grain size, their mode of packing, density or compaction, the physical properties of the liquid such as the viscosity and density, etc. This constant embodies the effects of all these parameters.

For better recollection, it can be denoted by P so that the yield of water, Q through a medium can be expressed as :—

$$Q = PIA \qquad (2)$$

when A = the area of the cross section through which the flow occurs.

P = K, the permeability coefficient and

I = H/L or $\partial H/\partial L$, the hydraulic gradient.

For all conditions of flow of water through a medium, a knowledge of the factor P is very important and several laboratory and field methods have been evolved for its determination.

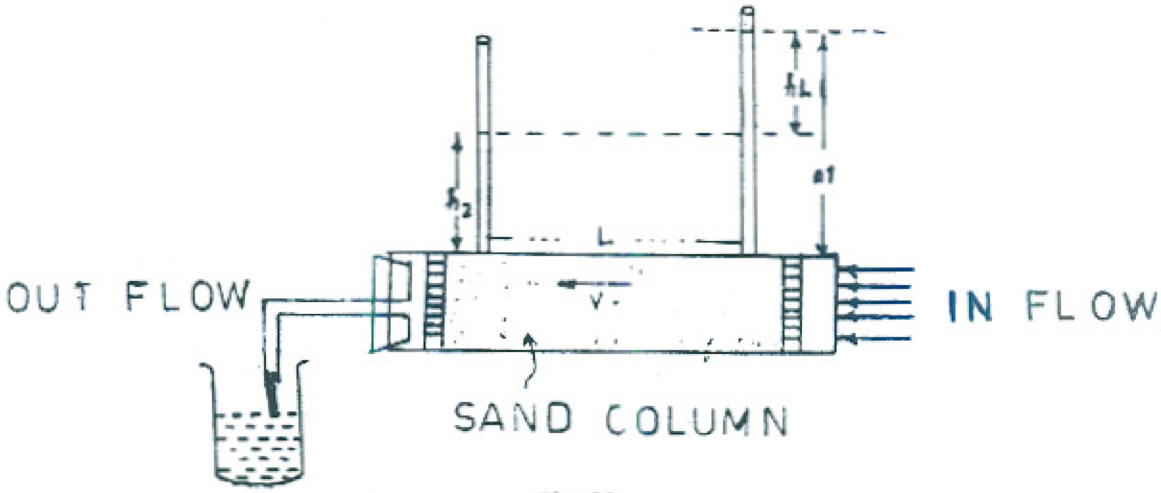

Fig. 25

Laboratory determination of the permeability coefficient

(a) *Constant head permeameters:—*

A laboratory technique to determine the permeability of a medium was developed by Forchhiemer.[11] The method adopted by him is shown in Fig. 26. A source of constant

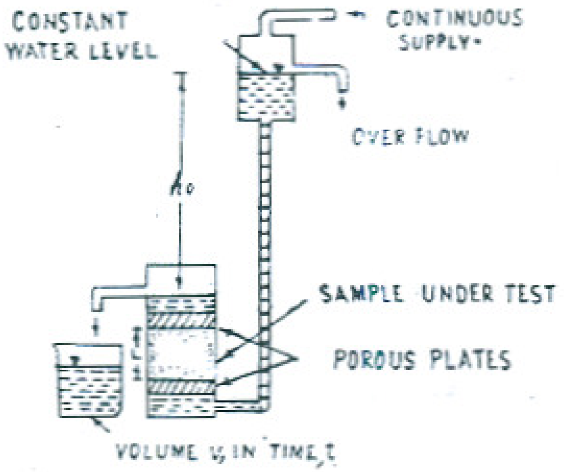

Fig. 26

water head was maintained on a fully saturated and properly packed sand sample. The flow was allowed to be stabilized under constant conditions of water head and the discharge was measured. The cross section of the sand sample contained in the medium was determined. The difference of water heads in a certain length of the sand sample was measured. The mean temperature of the inlet and outlet water was also recorded and the permeability coefficient worked out using the relations

$$Q = PIA$$

$$\text{or} \quad P = \frac{Q}{IA}$$

$$= \frac{Q \times L}{A\,h} \qquad \ldots\ldots(3)$$

For comparative results, the coefficient is converted to a standard temperature which is generally fixed at 20°C (68°F). For conversion[12], table 5 is given which gives the viscosity of water for different temperatures. The permeability coefficient at the two temperatures varies inversely as the viscosity such as :

$$\frac{\gamma_t}{\gamma_{20}} = \frac{k_{20}}{k_t}$$

(b) *Variable head permeameter:—*

Another modification of the constant head technique is called the variable head permeameter. In this method water is allowed to flow through the soil sample and the rate of drop of water head with time is noted.

The experimental technique is shown in Fig. 27.

TABLE No. 5

Temperature and Viscosity of water from International Critical Tables.

Viscosity in millipoises

Temperature °C	0	1	2	3	4	5	6	7	8	9
0	17.236	17.320	16.740	16.296	15.676	15.188	14.726	14.288	13.872	13.476
10	13.097	12.735	12.390	12.061	11.748	11.447	11.156	10.876	10.603	10.340
20	10.087	9.843	9.608	9.380	9.161	8.949	8.746	8.551	8.363	8.181
30	8.004	7.834	7.670	7.511	7.357	7.208	7.064	6.925	6.791	6.661

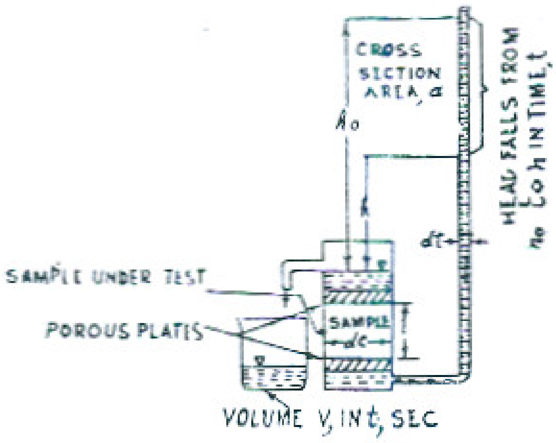

Fig. 27. Variable Head, Permeameter

From Darcy's law we know that :

$$V = \frac{kAh}{L}.\ dt.$$

$$V = a(h_o - h)$$

where a = the cross sectional area of the tube.

h_o = the initial water head and

h = is the water head after time t

so that $dv = -a\ dh$

$$\text{or} - adh = \frac{kh}{L}\ A\ dt$$

$$\text{or} \quad -\frac{dh}{h} = \frac{kd^2c\ dt}{d_t^2\ L} \qquad \text{..........(4)}$$

where d_c = the diameter of the cylinder

d_t = the diameter of the tube.

Integrating (4), we get :

$$-\log h = \frac{k\ d_c^2 t}{d_t^4\ L} + C$$

when $t = o$ and

$h = h_o$

$$C = -\log_e h_o$$

so that :

$$\frac{\log h}{\log h_o} = \frac{k\ d_c^2 t}{d_t^2\ L}$$

$$k = \frac{d_t^2 L}{d_c^2 t}.\ \log \frac{h_o}{h} \qquad \text{.......(5)}$$

The method is very suitable for determining the permeability of consolidated samples which have very low order of permeability coefficient.

The technique of constant head method has been used extensively. In the Irrigation Research Institute, permeability coefficient for a large number of sand samples collected during boring with percussion method was determined by the constant head permeameter.

The average range of the coefficient found for different grades of sand collected from the Indus Plains was found to be within the range shown in table 6.

TABLE No. 6

Type of Formation.	Mean Diameter of particles in mm.	Permeability coefficient, feet per second.
Coarse grade of medium sand.	0.5 to 0.35	(20—6.0) 10^{-4}
Fine grade of medium sand.	0.35 to 0.25	(8.0—3.0) 10^{-4}
Fine sand	0.25 to 0.2	(3.5—1.6) 10^{-4}

By this method the permeability coefficient of a given grade of sand can be determined.

The important precautions during experimental determination of permeability are that the water used must be free from dissolved air, particles of rust and dirt etc., otherwise the results will not be consistent. The water to be used should have a constent temperature. It is usually stored in heat-insulated tank for about 24 hours before use and filtered through glass wool to retain particles of rust and dirt if present.

The packing of sand sample also needs special care. It has to be carried out with completely saturated sand subjected to a suitable number of vibrations during packing. Air should be completely removed and the packed specimen kept for about 24 hours to attain complete compaction. Using these precautions, repeated consistent results are obtained.

Determination of *in situ* Permeability Coefficient

In a laboratory, permeability is determined for disturbed samples. Their repacking, according to the natural conditions, is seldom possible. Alluvium deposits are always stratified, so that permeabilities of different deposits is variable. *In situ* permeability is thus an average for all the stratified layers.

The importance of *in situ* permeability is self-evident and for this reason many field methods have been perfected for its determination.

Equilibrium Method of Permeability Determination

In 1916 Gunter Theim[13], a German Hydraulician, modified the formulae of radial flow into a tubewell, to determine the permeability coefficient.

In Fig. 28 various parameters for a discharging tubewell are shown. The discharge,

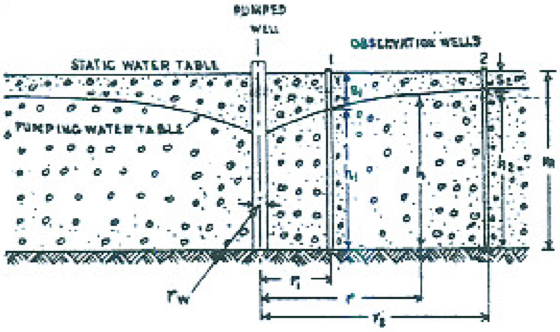

Fig. 28. Field Permeability Determination by Theim Method.

$$Q = PIA$$

$$= P\frac{dh}{dr} . 2\pi rh$$

$$\text{or} \quad \int_{r_1}^{r_2} \frac{dr}{r} = \frac{2\pi P}{Q} \int_{h_1}^{h_2} h.dh$$

Integrating the above,

$$\log_e \frac{r_2}{r_1} = \frac{2\pi P}{2Q} (h_2^2 - h_1^2)$$

$$\text{as} \quad h_2 - h_1 = s_1 - s_2 \text{ and } h_1 + h_2 = 2m$$

$$\log_e \frac{r_2}{r_1} = \frac{2\pi P}{Q} m(s_1 - s_2)$$

$$\text{or} \quad Pm = T \quad = \frac{Q \log r_2/r_1}{2\pi(s_1 - s_2)}$$

$$\text{or } T = \frac{627.7Q \log_{10} r_2/r_1}{s_1 - s_2} \quad \ldots (6)$$

where T = Pm and is expressed in gallons per day per foot and Q is the discharge in gallons per minute, r_1 and r_2 are the respective distances of two observation wells,

s_1, s_2 are the respective draw-down or recovery in observation wells in feet.

In the derivation of this formula it is assumed that:—

(*i*) the aquifer is homogeneous, isotropic and of infinite areal extent;

(*ii*) the discharging tubewell penetrates and receives water from the entire thickness of the aquifer;

(*iii*) the coefficient of permeability is constant at all places and at all times;

(*iv*) pumping has been continued at a uniform rate for a long time to attain hydraulic equilibrium conditions;

(*v*) flow is laminar and radial.

Naturally such conditions are not always met with.

An example of the use of Theim Method for a tubewell No. 8 of Chuharkana Reclamation Scheme is given. The well was pumped for seven days continuously from 22nd April, 1954 to 29th April, 1954. The tubewell discharged 2.798 cusecs at an average depression of 21.14 ft. The tubewell was provided with several observation pipes located at 10, 60, 110, 260, 510 and 1100 feet away from the centre of the well. The stable values of lowering of water level were recorded and taking m equal to 200 ft., the permeability coefficient in ft. per second was determined. The observed data are shown in table. 7

The average value of the permeability coefficient for the type of formation as exhibited in Fig. 29 was found equal to 31.53×10^{-4} ft. per second.

The conditions of West Pakistan Indus Plains are characteristic for this country. There is no extensive impervious boundary layer in existence. It is, therefore, not possible to pump constantly for a long time to attain a stable condition.

In spite of the limitations of Theim formula it is the most simple and easy to use and in many cases gives very satisfactory results.

(*b*) Non-equilibrium Formula

In 1935, a major advance in ground water hydrology took place by the development a new non-equilibrium formula by Theis.[14] He related the rate of lowering of water level in an observation well with the permeability of the medium and its storage coefficient.

Assuming that the water bearing formation to be uniform with the same order of permeability in horizontal and vertical directions existing in a uniform infinite

STRATA CHART OF T/WELL NO.8 PROJECT CHUHARKANA F A O

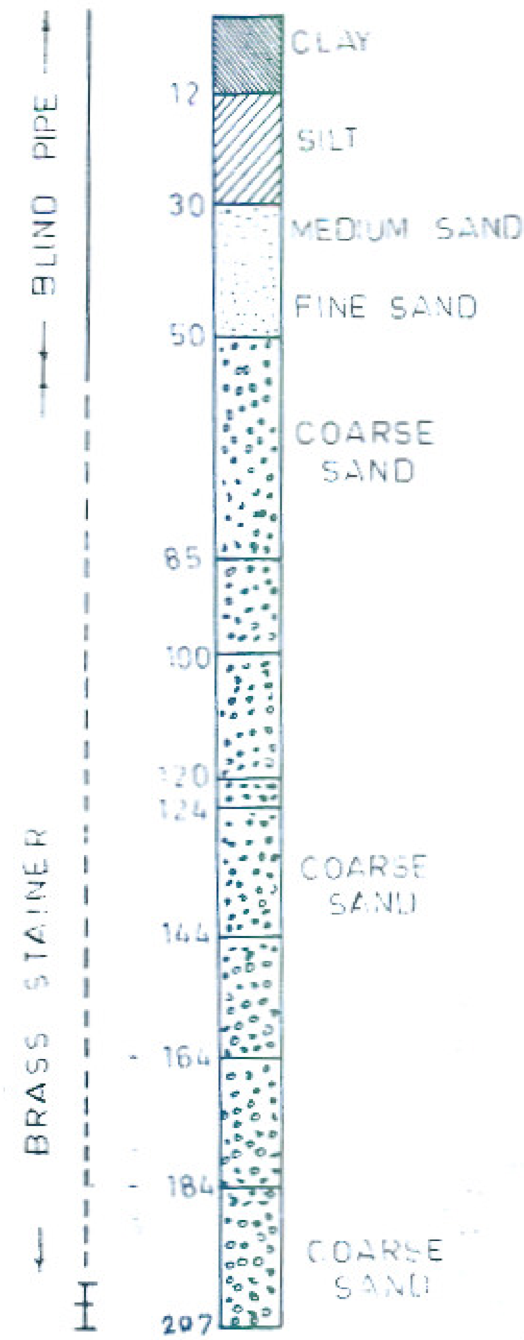

Fig. 29

TABLE No. 7

Permeability coefficient using Theim formula

$$P = \frac{Q(\log_e r_2 - \log_e r_1)}{2\pi m (s_1 - s_2)}$$

S. No.	r_1 in ft.	r_2 in ft.	s_1 in ft.	s_2 in ft.	$s_1 - s_2$ in ft.	m in ft.	$\log \frac{r_2}{r_1}$	Field pe meabili ft /sec.
1	60	110	2.54	1.90	0.64	197.78	0.2632	.00217
2	60	260	2.54	1.20	1.34	198.13	0.6368	.00254
3	60	510	2.54	0.65	1.89	198.40	0.9294	.00259
4	60	1100	2.54	0.34	2.20	198.56	0.2632	.00302
5	110	260	1.90	1.20	6.70	198.45	0.3736	.00280
6	110	510	1.90	6.65	1.25	198.72	0.6662	.00275
7	110	1100	1.90	0.36	1.56	199.88	1.0000	.09664
8	260	510	1.20	0.65	0.55	199.08	0.2926	.00280
9	260	1100	1.20	0.34	0.85	199.23	0.6264	.00380
10	510	1100	165	0.34	0.31	199.50	0.3338	.00566
							Ave :—	.00315

formation receiving no recharge and the well penetrating the full thickness of water bearing formation, he proved that the observed lowering of water level s, was given by a relation:

$$s = 114.6 \frac{Q}{T} \quad W(u) \ldots\ldots\ldots.(7)$$

where s = the draw-down in ft. at any point in the vicinity of a well discharging at a constant rate, Q.

Q = the yield in gallons per minute (gpm).

T = is the coefficient of transmissibility of the aquifer in gallons per day (gpd) per foot and

W(u) = is a well function of u.

This function is an exponential integral written as:

$$\int_{\frac{1.87 r^2 S}{Tt}}^{\infty} \frac{e^{-u}}{u} . du = -0.5772 - \log_e u + u - \frac{u^2}{2.2\,!} + \frac{u^3}{3.3\,!} - \frac{u^4}{4.4\,!} + \ldots$$

In the expression:—

$$u = \frac{1.87 r^2 S}{Tt}$$

where

r = distance in feet from the centr of the pumped well at the poin where drawdown is measurec

S = coefficient of storage. It ha no dimensions.

t = time since pumping started ir days.

For practical application of the above mentioned formula tables were preparec between the well function W(u) and u. An abridged data are given in table[15] No. 8. When W (u) & u or $\frac{1}{u}$ are plotted on double log, the curve so obtained is called a standard curve. When the permeability and storage coefficient of a formation is to be determined, a tubewell is installed at the site. A few observation wells nearly as deep as the

TABLE No. 8

Values of W(u) for different values of u.

u	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
W (u)									
X1	0.219	0.049	0.13	0.0038	0.0011	0.00036	0.00012	0.000038	0.00001
$\times 10^{-1}$	1.82	1.22	0.91	0.70	0.56	0.45	0.37	0.31	0.26
$\times 10^{-2}$	4.04	3.35	2.96	2.68	2.47	2.30	2.15	2.03	1.92
$\times 10^{-3}$	6.33	5.64	5.23	4.95	4.73	4.54	4.39	4.26	4.14
$\times 10^{-4}$	8.63	7.94	7.53	7.25	7.02	6.84	6.69	6.55	6.44
$\times 10^{-5}$	10.94	10.24	9.84	9.55	8.33	9.14	8.99	8.86	8.74
$\times 10^{-6}$	13.24	12.55	12.14	11.85	11.63	11.45	11.29	11.16	11.04
$\times 10^{-7}$	15.54	14.85	14.44	14.15	13.93	13.75	13.60	13.46	13.34
$\times 10^{-8}$	17.84	17.15	16.74	16.46	16.23	16.05	15.90	15.76	15.65
$\times 10^{-9}$	20.15	19.45	19.05	18.76	18.54	18.35	18.20	18.07	17.95
$\times 10^{-10}$	22.45	21.76	21.35	21.06	20.84	20.66	20.50	20.37	20.25
$\times 10^{-11}$	24.75	24.06	23.65	23.36	23.14	22.96	22.81	22.67	22.55
$\times 10^{-12}$	27.05	26.36	25.96	25.67	25.15	25.26	25.11	24.97	24.86
$\times 10^{-13}$	29.36	28.66	28.26	27.97	27.75	27.56	27.41	27.28	27.16
$\times 10^{-14}$	31.66	30.97	30.56	30.27	30.05	29.87	29.71	29.58	29.46
$\times 10^{-15}$	33.96	33.27	32.86	32.58	32.35	32.17	32.02	31.88	31.76

tubewell with strainer of the same length as in the tubewell are installed. As soon as the tubewell is set in operation, recording of the lowering of water level in the observation well is started. Usually time is recorded in minutes, lowering in feet, and discharge in gallons per minute. A typical observation for a pumping test is plotted in Fig. 30. The graph is on a double log scale plotted between log s and log t. The dimensions of the log cycles are the same as those of the standard curve mentioned above.

This curve is now placed on the standard curve plotted between W(u) and u or 1/u. The top curve is moved forward and backward to get a best fit between the two curves as shown in Fig. 31, taking care that the axes of the two curves are exactly parallel. The best matching point is found out and its co-ordinates on both the curves are determined. For instance, in Fig. 31 the best match point is found when s=2.3 ft. and time t is equal to 83 minutes or $\frac{83}{144}$ days.

The corresponding value of $1/u$ is 100 and that of W (u) is equal to 4.038.

Suppose the tubewell was pumping 600 gallons per minute. The transmissibility is determined by using the formulae:

$$T = \frac{114.6\,Q\,(Wu)}{s}$$

$$\text{or } T = \frac{114.6 \times 600 \times 4.038}{2.3}$$

$$= 120{,}000 \text{ gpd per ft.}$$

As one cu. ft. per second is equal to 646000 gpd or roughly equal to 6.5×10^5 gpd.

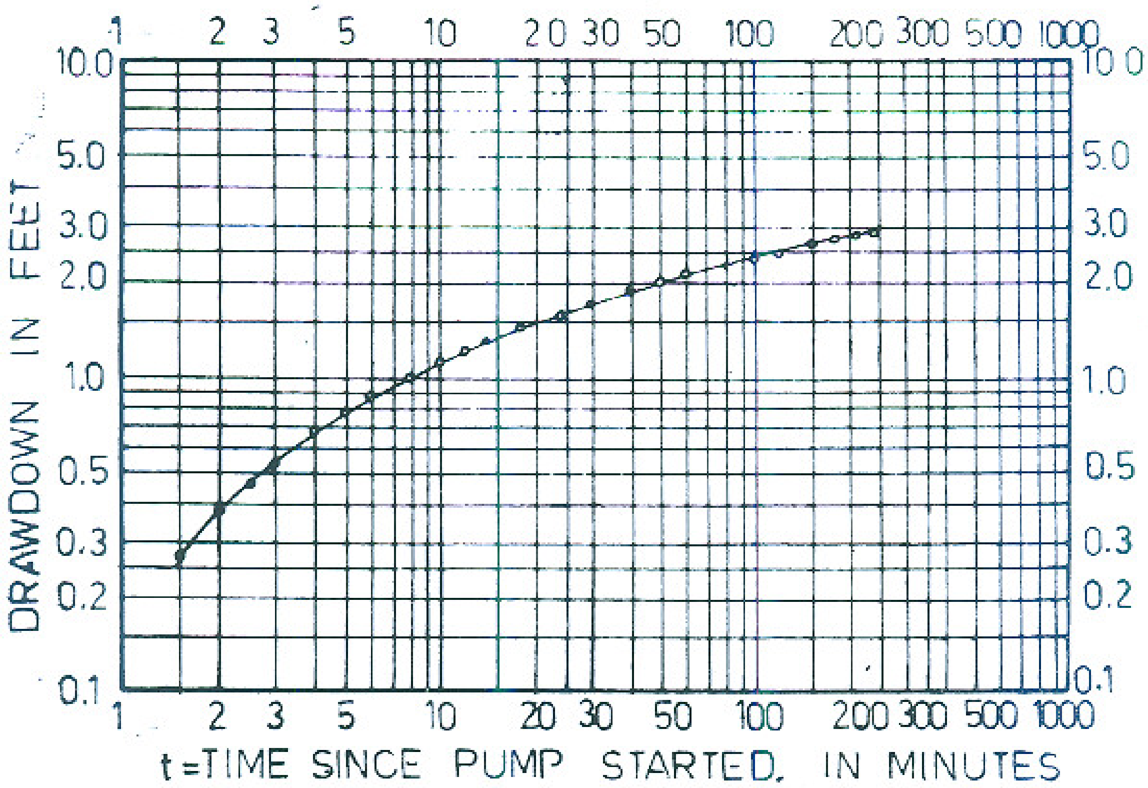
DRAWDOWN IN FEET
t = TIME SINCE PUMP STARTED, IN MINUTES

Fig. 30

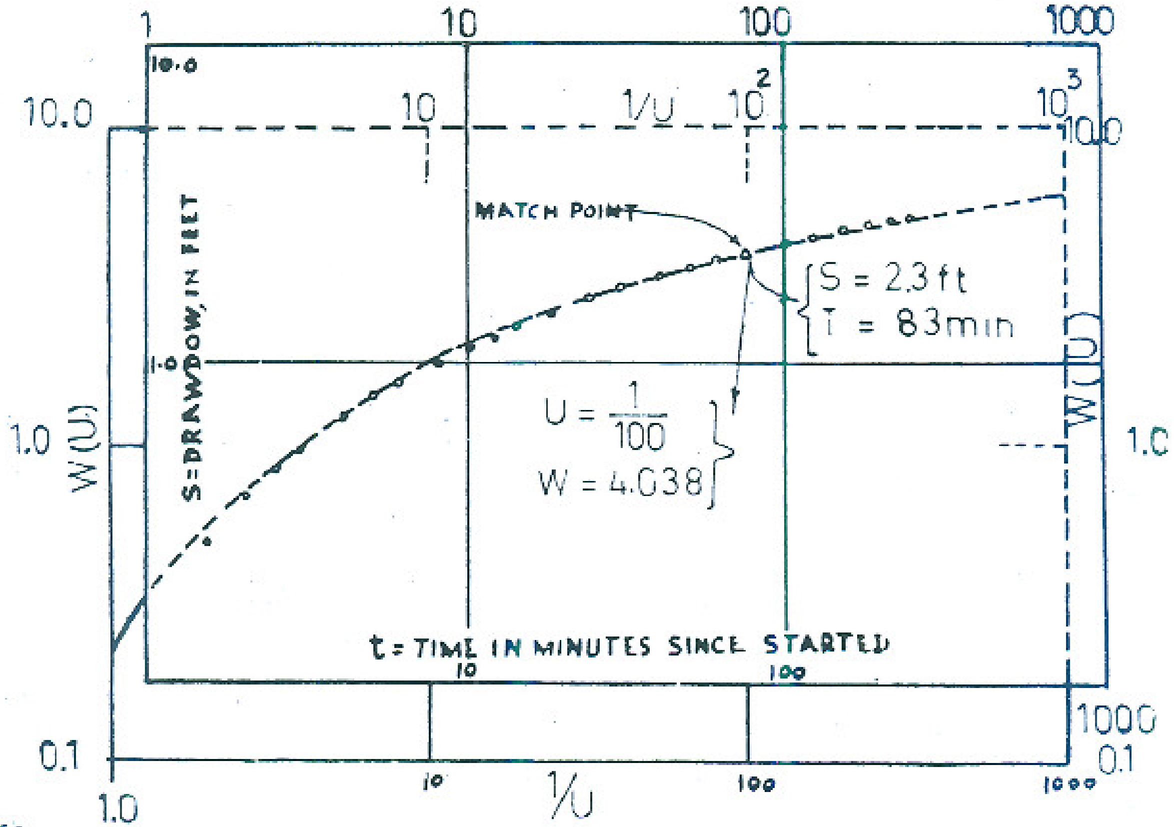
MATCH POINT
S = 2.3 ft
T = 83 min
U = 1/100
W = 4.038
S = DRAWDOW, IN FEET
t = TIME IN MINUTES SINCE STARTED
W(U)
1/U

Fig. 31

$T = 120{,}000$ gpd $= \frac{120{,}000}{646000}$ or 0.18 cuft per second.

Similarly the storage coefficient, S is determined from the relation:

$$S = \frac{uTt}{1.87 r^2}$$

if $r = 500$ ft., $u = \frac{1}{100}$ and $T = 120{,}000$ gpd

we find $S = 120{,}000 \times \frac{1}{100} \times \frac{1}{1.87} \times \left(\frac{1}{500}\right)^2 \times \frac{83}{1440}$

$= 1.216 \times 10^{-4}$

If the standard curve is plotted between W(u) and u, it is convenient to plot the drawdown, s against r^2/t, on double log scale of the same size.

The match point is determined[17] as before. An example of such a case is given in Fig. 32.

In this example r^2/t was found equal to 1.95×10^7 and $s = 1.2$ ft.

The corresponding value for W(u) was 2.15 and for u equal to 7.0×10^{-2}.

The transmissibility T, is determined as before using.

$$T = \frac{114.6 \times Q}{s} W(u)$$

$$= \frac{114.6}{1.2}(500)(2.15) = 103000$$

gpd per foot

Assuming Q = 500 gallons per minute

$$S = \frac{uT}{1.87\, r^2/t} = \frac{(7 \times 10^{-2})(103{,}000)}{1.87 \times 1.95 \times 10^7}$$

$$= 1.98 \times 10^{-4}$$

Jacob Modified Method for Solution of Pumping Data

Jacob[16] pointed out that for small values of r and large value of t, u is very small, so that the drawdown can be expressed :

$$s = \frac{Q}{4\pi T}\left(-0.5772 - \log \frac{r^2S}{4Tt}\right)$$

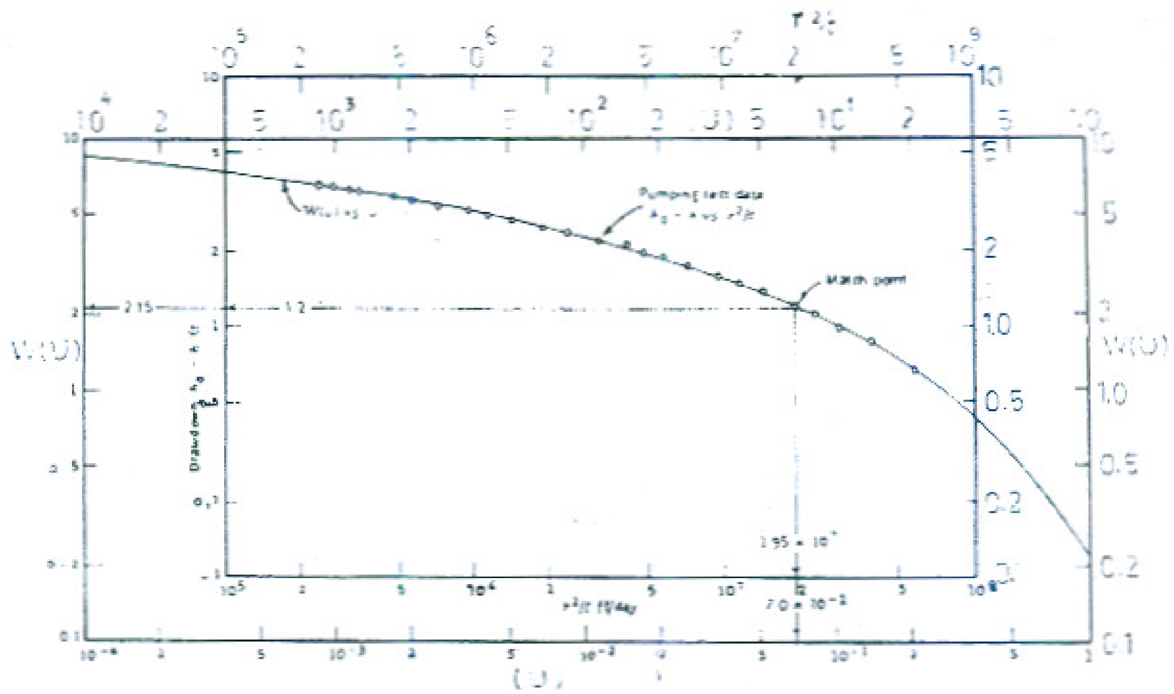

Fig. 32

$$=\frac{2.303\times Q}{2\pi T}\log_{10}\frac{2.25\,Tt}{r^2 S} \quad \ldots\ldots(9)$$

By using relation (9), for very small values of u, we get :

$$s \quad =\frac{Q}{T}\left(\log\frac{0.3\,T\,t}{r^2 S}\right) \quad \ldots\ldots\ldots\ldots(10)$$

If the lowering of water level is determined for one cycle of time, and the unit for discharge is gallons per minute and time is in days, the above formula gives.

$$s \quad =\frac{114.6\,Q}{T}(\log_e t_2/t_1)$$

$$\text{or } s \quad =\frac{264\,Q}{T}\log_{10}(t_2/t_1)$$

$$\text{or } s \quad =\frac{264\,Q}{T},\ \text{because}\ \log_{10} t_2/t_1=1\ldots(11)$$

Jacob[17] also expressed the transmissibility in terms of $\log r$, $\log t$ or $\log r^2/t$ by the following three relations :

$$T \quad =\frac{2.30\,Q}{2\pi\,\partial s/\partial(\log r)}\ldots\ldots\ldots\ldots\ldots(12)$$

$$T \quad =\frac{2.30\,Q}{4\pi\,\partial s/\partial(\log t)}\ldots\ldots\ldots\ldots(13)$$

$$T \quad =\frac{-2.30\,Q}{4\pi\,\partial s/\partial(\log r^2/t)}\ldots\ldots\ldots\ldots(14)$$

Any one of the above formulae can be used to determine the value of T.

The depression of water level in an observation pipe is plotted on an ordinary scale and the time since pumping started is plotted on a logarithmic scale. For all values except when u is smaller than 0.05, a straight line is obtained as shown in Fig. 33. In this case the tube-well was pumping 500 gallons per minute. For one cycle of time, s was found equal to 1.3 feet. T was thus determined using equation 11

$$T \quad =\frac{(264)\,(500)}{1.3}=102{,}000\ gpd\ \text{per ft.}$$

Another simplification of (10) is possible by extending the log t line and determining its value for drawdown equal to zero. This is time t_o and the storage is given by

$$S \quad =\frac{0.3\,T\,t_o}{r^2}$$

In the example quoted in Fig. 33,

$t_o=2.60\times10^{-4}$ days

and $r=200$ ft. so that :

T=102000 gpd per foot.

$$S \quad =\frac{0.3\times102{,}000\times2.6\times10^{-4}}{200\times200}=1.99\times10^{-4}$$

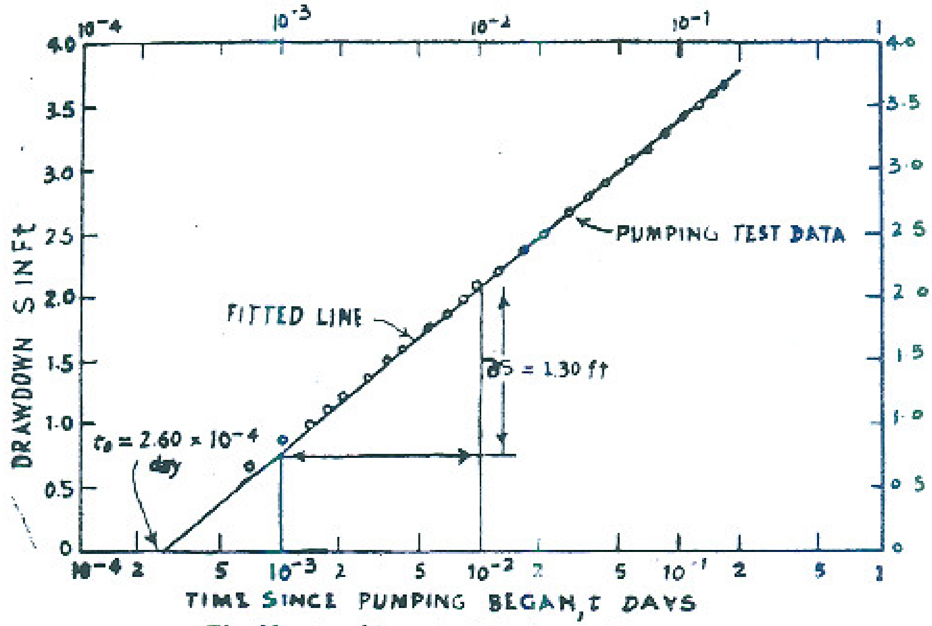

Fig. 33. Jacob's method for determining T and S

Use of distance of observation wells and drawdown relation

Usually there are a number of observation wells placed at different distances from a pumping well. For the same time after pumping had started, a plot between drawdown s, and distance of observation well is also a straight line as shown in Fig. 34.

The lowering for one cycle of distance from pumped well is again determined. For this condition formula (9) is modified to :

$$T = \frac{2 \times 264\ Q}{\partial s}$$

In the figure mentioned above for one cycle of distance from pumped well, s is equal to 10.6 ft., 500 minutes after the start of the test. If the yield is 200 gpm. then

$$T = \frac{528\ Q}{\partial s} = \frac{528 \times 200}{10.6} = 10{,}000 \text{ gpd per ft.}$$

The storage coefficient S is again determined by using :

$$S = \frac{0.3\ Tt}{r_0^2} \text{ in which}$$

t = the time in days since pumping started and

r_0 = the value of log r determined by extending log r line to zero drawdown.

In Figure 34, the value of r_0 is equal to 450, so that the storage S is :

$$S = \frac{0.3\ T \times t}{r_0^2} = \frac{0.3 \times 10{,}000}{450 \times 450} \times \frac{500}{1440}$$
$$= 5.1 \times 10^{-4}$$

Chow's Method of Solution

Chow developed another method for the solution which avoids curve fitting and is unrestricted in application. This is explained by Todd[18] as under.

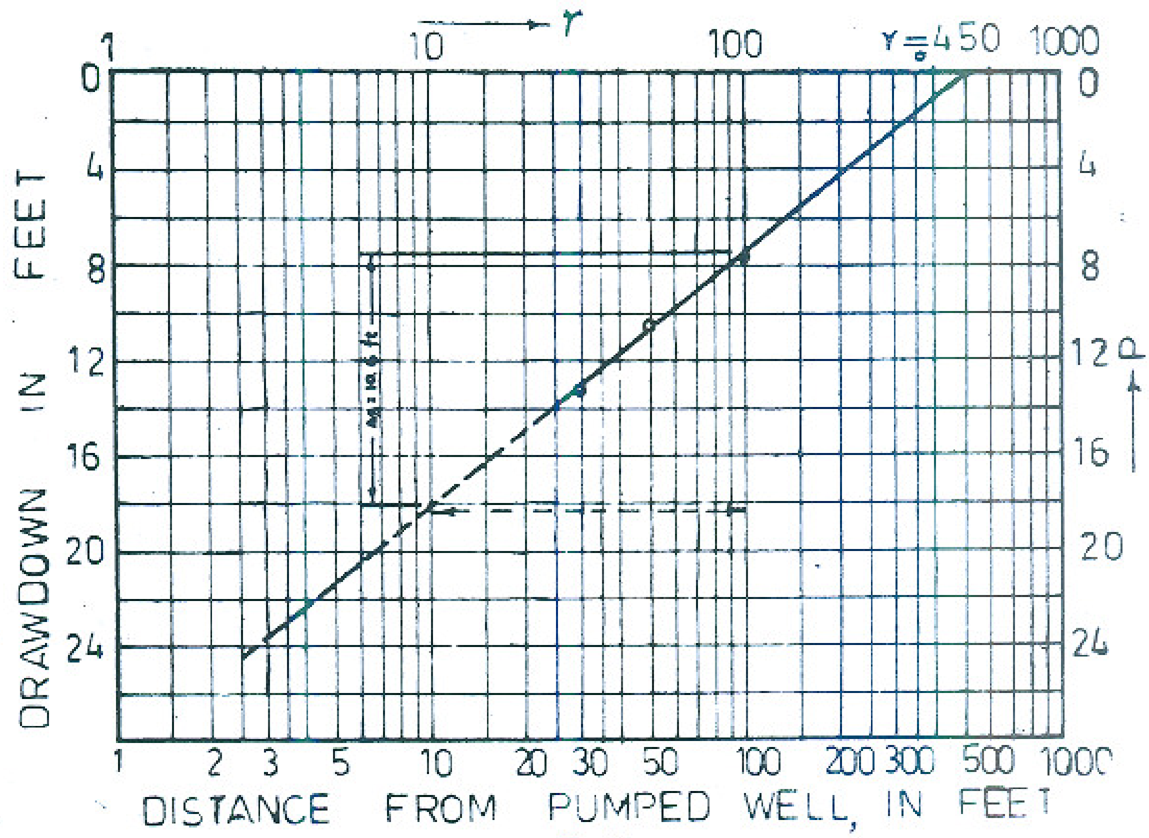

Fig. 34

On a semi log paper, s and log t are plotted as shown in Fig. 35.

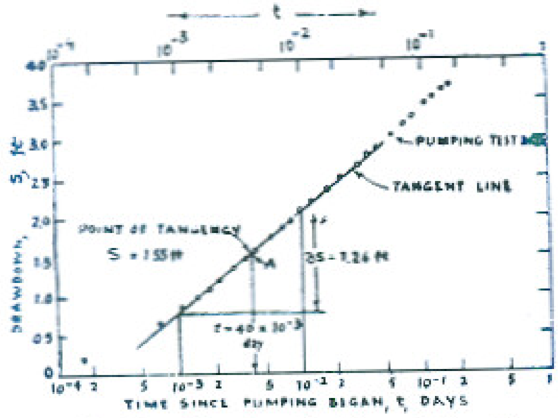

Fig. 35. Chow's method for solution of Equilibrium Equation.

A tangent is drawn to the curve at an arbitrary point. The difference of drawdown, s, is determined in feet for one log cycle of time. The co-ordinates of the point where the tangent is drawn are determined. This gives the value of drawdown, s in feet and log t in days. Now a ratio of this drawdown and that determined for one log cycle of time is worked out. It is called a function F (u), so that

$$F(u) = \frac{\text{difference of drawdown for one log cycle}}{\text{drawdown at the point where tangent is drawn.}}$$

A curve is also plotted between F (u) and W(u) which gives different values of u. This curve is shown in Fig. 36.

The use of this method is explained with reference to the two Figures No. 35 and 36.

The co-ordinates of t and s are :

$t=4.0\times10^{-3}$ days and $s=1.55$ ft.

The value of $s=1.26$ ft. for one time cycle.

Thus $F(u)=\frac{1.55}{1.26}=1.23$

Using the curve W(u) and F(u) in Fig. 35, the value of u is determined. It is found equal to 0.038 for W(u)=2.72.

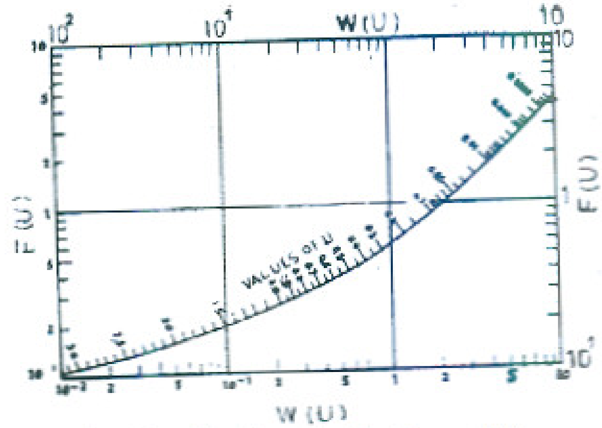

Fig. 36. Chow's method for Permeability determination.

T is determined as under :

$$T=\frac{114.6\ Q}{\partial s}\ W(u)=\frac{114.6\ (500)\ (2.72)}{1.55}$$

=101,000 gallons per day per foot and the storage coefficient is as before equal to :

$$S=\frac{u\ T\ t}{1.87r^2}$$

$$=\frac{(0.038)(101{,}000)^2(4.0\times10^{-3})}{1.87\ (200)\times(200)}=2.05\times10^{-4}$$

where r=200 feet.

Effect of recharge upon drawdown

One of the main assumptions while using the equilibrium or non-equilibrium formulae is that during the test, the aquifer receives no recharge from any source. The condition in West Pakistan is that ground water is not confined, yet at many places there exists a top clay formation which has different order of permeability coefficient.

Usually a tubewell is provided with a top 40 to 80 feet blind pipe followed by a strainer. While pumping, water flows along radial direction to the portion facing the strainer. When a tubewell is pumped and a cone starts developing, the water from the top portion facing the blind pipe trickles downward. These conditions are thus partly against the assumptions of the Theis formulae. Jacob[19], however, tried to investigate such cases under the name of leaky aquifer. He introduced a modification in the method determining the permeability coefficient. However, if the time of pumping is sufficiently long and stable conditions are attained, the results are fairly accurate even under the above-stated conditions.

Permeability determination from the data of water-level recovery:—

When a tubewell is set in operation, the water table falls down in each recording well. The rate of fall is quite brisk in the beginning and then slows down with time. A case of tubewell No. 8 is put forth. Along this, well observation pipes were installed as shown in Fig. 37. When the well was operated the observed drawdown

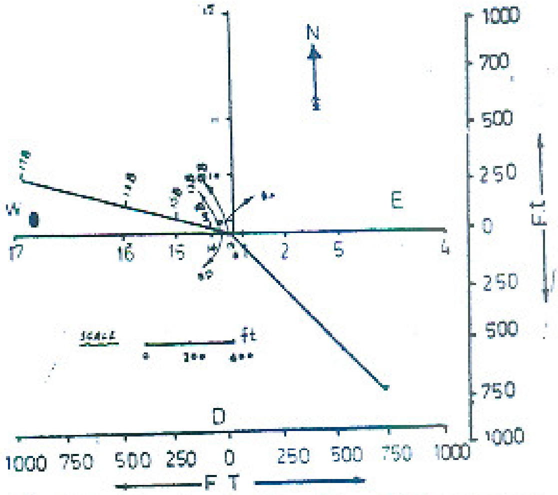

Fig. 37. Plan showing Location of Pipes around Tubewell No. 8, Chuharkana Pilot Project.

at different time periods in observation pipes was plotted as in Fig. 38. If the tubewell stops

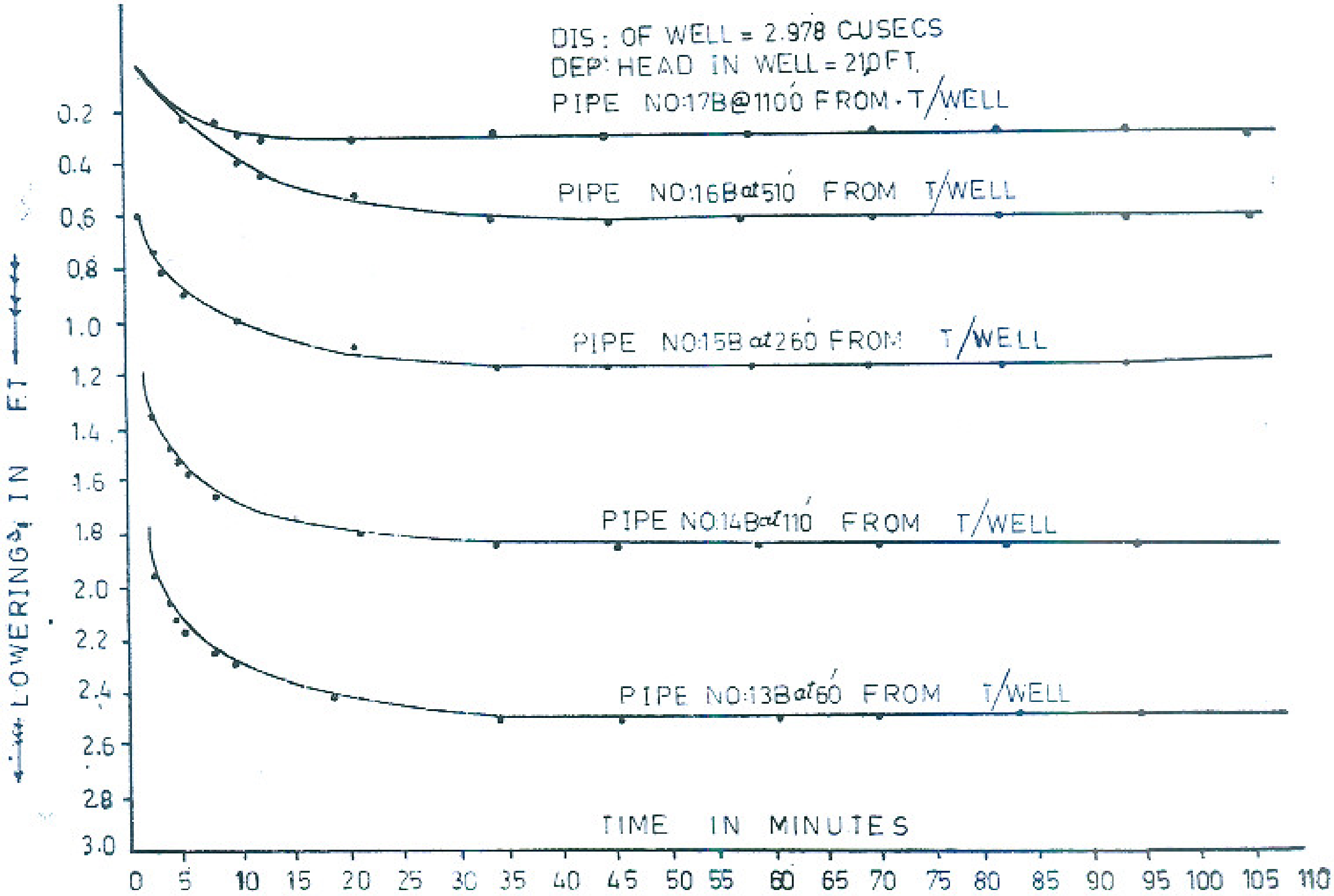

Fig. 38. Lowering of Water table with time in pipes along Tubewell No. 8 Chuharkana ReclamationArea, F.A.O.

working, the watertable starts rising nearly at the same rate at which it had started falling. An observed fall and rise in certain pipes located around tubewell No. 8 of the Churharkana Reclamation Scheme after working for one hour and stopping for the same time is shown in Fig. 39.

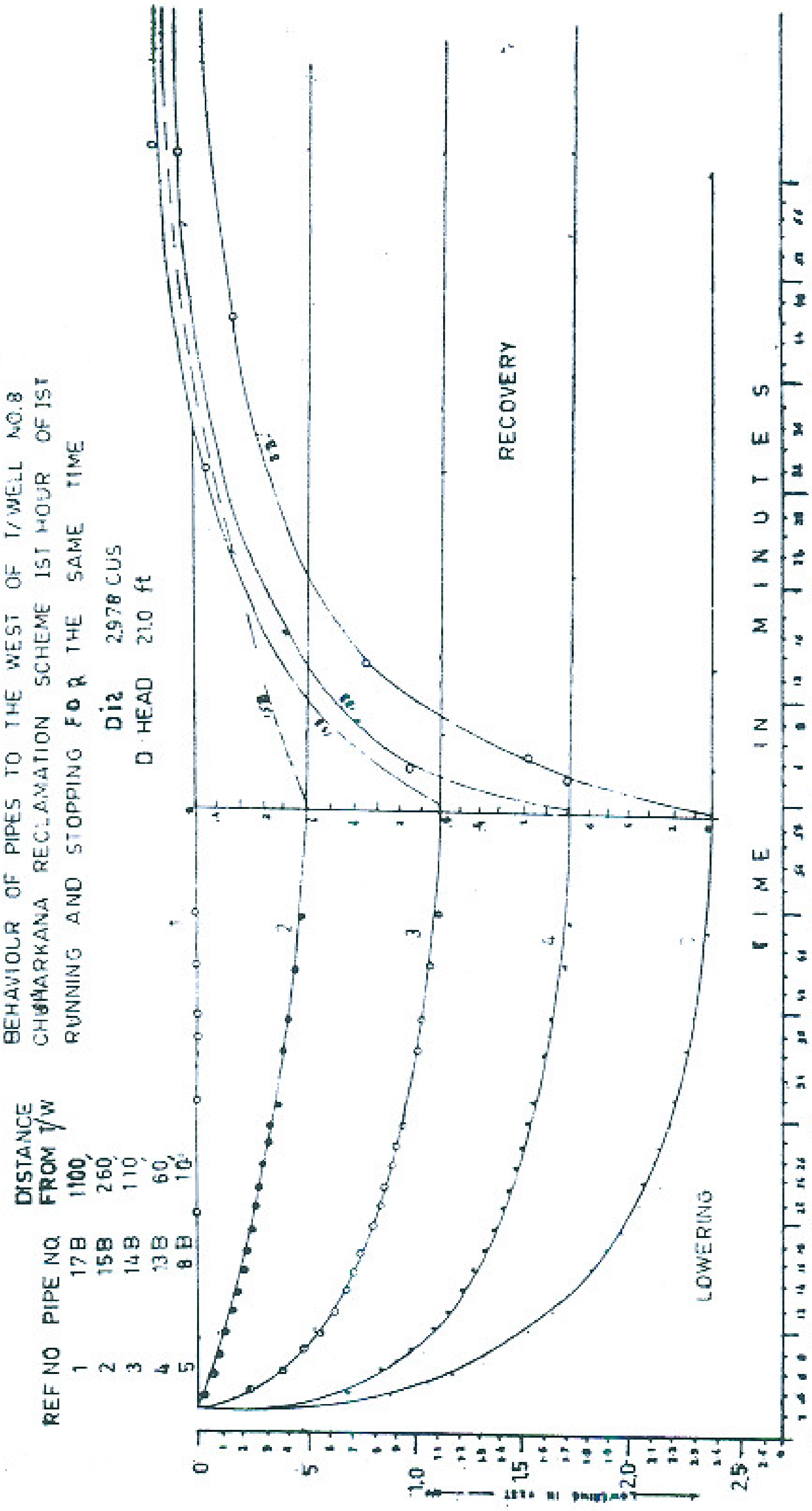

Fig. 39

It is possible to work out the transmissibility from the data of the rise of water level after a tubewell had stopped operating. Theoretically the drawdown and the recovery curves should be identical if the aquifer conditions conform to the assumption of the Theis relation. Very often the time recovery curve for a pumped tubewell is more accurate than its time drawndown curve.

In analysing the time recovery curve, its slope is measured as before. A specimen of this type of curve is shown in Fig. 40. It

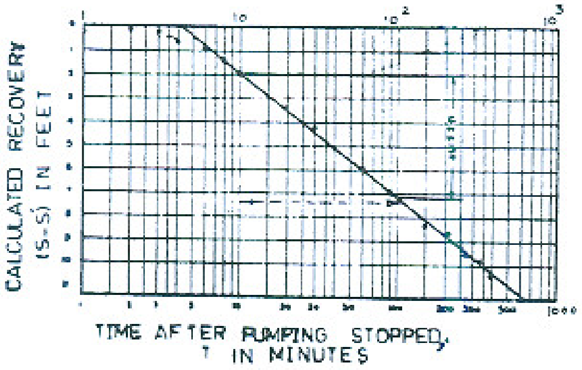

Fig. 40

is plotted between the observed recovery and the time after the pumping had stopped. In the figure mentioned above for a recovery time varying from 10 minutes to 100, the recovery in observation well was 5.2 ft. The transmissibility can as usual be worked out from the formulae

$$T = \frac{264\ Q}{\Delta(s - s')} \quad \ldots\ldots\ldots\ldots\ldots(15)$$

Johnson[20] has explained another method to use the recovery data. It is based upon the determination of the residual drawdown without calculating the recovery from an extension of the drawdown curve. It has been explained that the residual drawdown is related to the logarithm of the ratio t/t' when t is time in minutes since the pumping started and t' is the time in minutes, after stopping pumping. A straight line is plotted between log t/t' and residual drawdown s' as shown in Fig. 41. The transmissibility is determined by the relation :—

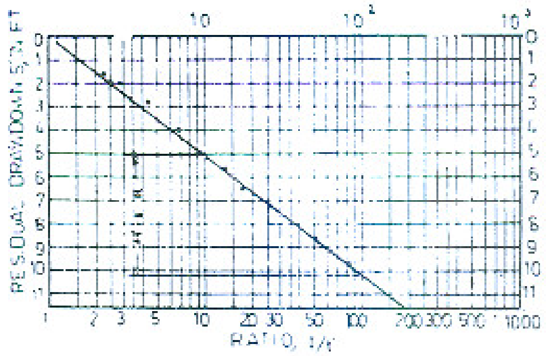

Fig. 41

$$T = \frac{264\ Q}{s'} \log t/t' \quad \ldots\ldots\ldots\ldots(16)$$

Pumping test with varying discharges

Another method is to use the variation of discharge during a pumping test. The procedure is more or less the same as already discussed. In a given observation well, the drawdown is recorded for a particular discharge. Using the already stated formulae, the transmissibility coefficient is determined.

Results of pumping tests in the Northern Regions of West Pakistan

The technique of field pumping tests was started to be utilized in West Pakistan in the year 1951. Tests were started along Upper Gugera Canal[21] at R. D. 112. The method has since been extended to many other sites in the Northern Regions of West Pakistan and Ghulam Mohammad Barrage area.

A very extensive and systematic work was conducted by Wasid during their ground water investigations[9] in the Punjab area where nearly 140 permeability tests were conducted. The sites of such tests are approximately shown in Fig 23 for Rechna and Chaj Doabs only. In table 3 results of 60 tests conducted in Rechna Doab have already been put forth. Similar results are available for 41 sites in Chaj Doab, 43 sites in Thal Doab and 21 sites in Bari Doab. The variation of permeability coefficient with reference to the percentage of site tested is shown in Fig. 42. These figures give the average value of all the test results recorded in the four Doabs. Average values of this factor are shown in table 9. The variation of the coefficient between the maximum and minimum values as well as for 70% of the sites is shown in this table. The highest order of permeability is found for the formation in Rechna Doab followed by those of Thal, Chaj and Bari Doabs respectively. Although there is a considerable variation of permeability coefficient from site to site, for calculation purposes an order of 0.0030 ft. per second can be assumed appropriate for the Punjab plains.

TABLE 9

Results of Field Permeability test in the Punjab Area

K Value in $\frac{1}{100000}$ ft. per second.

Sites	No. of tests	Average	70% of sites	Min.&Max. value.
Rechna	49	38	25—63	10—100
Chej	36	28	18—34	10—50
Thal	35	33	17—37	10—80
Bari	21	26	10—20	10—30
All	141	32	12—39	10—100

Vertical permeability

The alluvium deposits are always stratified. Fine sand, silt and clay occurs in layers.

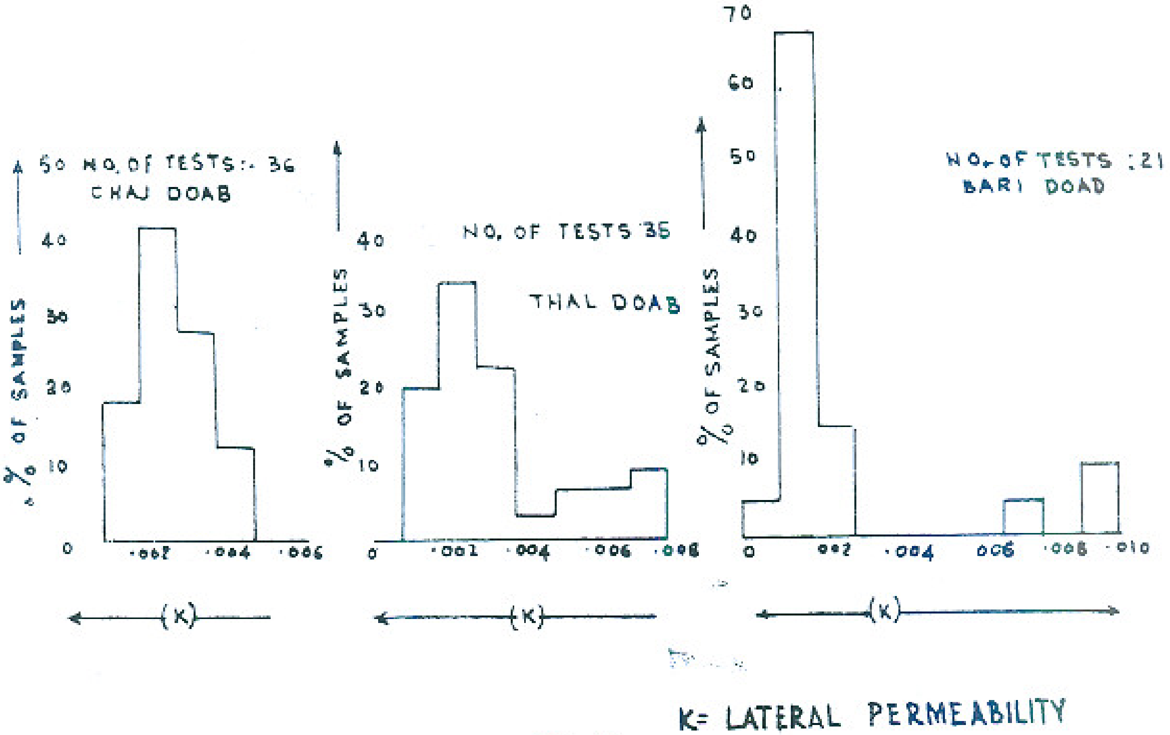

Fig. 42

In case of tubewells, water generally flows horizontally into the strainer the; permeability in this direction is generally high. Some information of vertical permeability is also useful. Jacob has given method for its determination.

Wasid has recently estimated the order of vertical permeability at a few sites in the Punjab plains as shown in table 10. The vertical permeability seems to vary between 10^{-5} to 10^{-3} cusecs per sq. ft. This is the condition for nearly 200 ft. depth of the aquifer which generally contains two or three layers of clay of thickness varying from 5 to 15 ft. The vertical permeability varies according to the existence and thickness of the clay formations.

TABLE 10

Vertical Permeability Conducted in the Punjab Area

Test No.	Site		Vertical Permeability Determined by Jacob's Bessel Function Analysis, Cusecs/ft. $\times 10^{-3}$	Transmissibility Determined in Jacob's Bessel Function Analysis Cusecs/ft.	Lithology of interval, between watertable and top of screen
R—32	Chak Jhumra		0.02	0.45	2′ clay; 24′ fine sand; 16′ medium sand.
R-35	Muradwala R. H.		0.06	1.17	154′ sand with numerous clays streaks.
R—46	Nandipur	..	0.05	0.38	17′ clay; 137′ sand.
R—55	Toba Tek Singh	..	0.04	0.40	43′ fine sand and silt
R—57	Kamrana R. H.	..	0.04	0.53	10′ clay; 60′ sand.
R—58	R. D. Vanike Disty.		0.03	0.41	5′ clay; 68′ find sand.
C—9	R. D. 1000 Khadir Branch.		0.08	0.48	2′ clay; 16′ fine sand, 24′ coarse sand.
C—20	Kot Khan	..	0.01	0.23	5′clay; 6′ fine sand.
C—29	Chak Saidu Phalia		0.12	0.47	70′ fine sand and silt.
C—40	R. D. 170 Shahpur		0.03	0.20	3′ clay; 68′ sand.
B—5	Renala Khurd	..	..	..	2′ clay ; 93′ sand.
B—8	Pakpattan	..	..	..	2′ clay; 61′ sand.
B—9	Near Harrapa	..	..	..	14′ clay' 46′ sand.
B—10	Arifwala	..	0.07	0.15	11′ clay; 55′ sand.

Engineers Honoured

Mirza Mohammad Sadiq awarded Tamgha-i-Khidmat

Mirza Mohammad Sadiq, Deputy Resident Engineer, Mangla Dam, was born in 1934 and graduated from the Punjab College of Engineering and Technology, Lahore in 1953. For about three years he worked as Lecturer in the same Institution before joining the Mangla Dam Organization as an Assistant Engineer.

In 1959 he was sent to Canada for advance training in "Hydraulic Engineering." On return in 1960 he was attached to the Surface Water Resources of West Pakistan as a Senior Engineer. In 1963 he worked with Binnie and Partners, Consultants, Mangla Dam and worked in the Spillway Department of the Project.

Mr. Mohammad Yunus awarded Tamgha-i-Khidmat

Mr. Mohammad Yunus, Director Design, Links, recipient of Tamgha-i-Khidmat was born in 1924 at Gujranwala in which city he got his early education before obtaining his degree in Civil Engineering from the Punjab College of Engineering and Technology in 1945. His original appointment was as a temporary Engineer in the Irrigation Department, where structures for Rasul Hydel and B.R.B.D. link were designed by him. He was promoted as Executive Engineer in 1951 and his services were transferred to WAPDA in 1960, where he worked in Soil Investigation Division. He was later on attached to Messrs Tipton & Kalmbach, Consultants for link canals where he handled the design of Chashma-Jhelum link. He was promoted as Superintending Engineer in 1961 and was posted as Director Design, Links Construction Directorate to handle the design of Taunsa-Punjnad Link.

Mr. Yunus is a member of the Institute of Engineers (Pakistan) and also a Member of the Executive Council of its Lahore Centre.

Mr. Shah Nawaz awarded Sitra-i-Khidmat

Mr. Shah Nawaz Khan, Chief Engineer, Tarbela Dam, was born at Nowshera in May 1920 and graduated from the Punjab College of Engineering and Technology, Lahore in 1942. The same year he joined as an Assistant Engineer and was promoted as Executive Engineer in 1948. He worked at Warsak till its completion in 1960. He originally got title of Tamgha-i-Quaid-i-Azam in March 1961. During this period in December 1955 he was promoted as Superintending Engineer, in charge of the Construction work. His outstanding work at Warsak included the completion of 3½ miles long irrigation tunnels.

In 1960 he joined Mangla Dam Project and two years later his services were placed at the disposal of Messrs. Binnie & Partners, (Consultants for Mangla Dam) who appointed him as their Asstt. Chief Resident Engineer. He was a Pakistani counterpart of Chief Resident Engineer advising him on the policy matters relating to 600 Pakistani employees. He worked as Resident Engineer for the construction of Sukian Dam.

In 1966 he was appointed as a Project Director Tarbela Dam and later on promoted Chief Engineer.

As to his foreign training he was awarded Colombo Plan Fellowship in 1953 and he obtained training in the design and construction of Dams in Canada and then later on with the U.S. Bureau of Reclamation at Denvor, Colorado.

He attended the International Commission on Large Dams held in Rome in July 1961 and attended the International Commission in Instanbul in September 1967 as a Member of the Pakistan Delegation. He is an Associate Member of the Institute of Engineers, Pakistan.

International Council for Building Research

The fourth International Council for Building Research Study and Documentation will be held in Ottawa from 7th to 16th October 1968. The Ottawa meeting will continue till Saturday, the 12th October, when the participants will travel to Washington, D.C. to resume this meeting on 14th of October. This Session in Washington will terminate on 16th of October. This Congress has previously held 3 meetings, these are held every three years. The first meeting was held in 1959 in Rotterdam, second in 1962 in Cambridge and the third one in Copenhagan, in the year 1965.

This is the first time that the Congress will be holding its session outside Europe. It will thus have an opportunity to study the American experience on the construction and management.

At present this Congress collaborates in the research efforts of 170 Organizations in 40 different countries. It thus represents the experience of various countries in the world.

Subjects to be discussed

The main subjects which have been allotted to various members of different countries are as follows. The Congress will have the cooperation of United Nations Agency concerned with Housing, Building and Planning etc.

Organization or CIB member Responsible for "Key" Paper.	Topic
Dr. V. Cervenka Director of Research Institute for Building and Agriculture Czechoslovakia	Human Requirements of Building
Mr. J. van Ettinger President-Director Bouwcentrum, Netherlands	Multi-Storey Blocks *vs.* Single Family Dwellings for Housing

Organization or CIB member Responsible for "Key" Paper.	Topic
Mr. R. J. Crooks Director: Centre for Housing, Building and Planning, United Nations, New York.	Training for Developing Countries
Dr. T. Hisada Director: Building Research Station Japan	Fire and Modern Building Design
Dr. J. C. Weston Director: Building Research Station England	Component Building I
Dr. G. Sebestyen Ministry of Construction, Hungary	Cost of Buildings: Measurement and Comparison
Mr. O. Birkeland Director : Building Research Institute Norway	Regulations and Building Codes I
Dr. L. Holm Director: National Institute for Building Research Sweden	Construction Site, Management I
Dr. H. B. Zackrison Office of Chief Engineers U.S.A.	Construction Site, Management II
Dr. H. F. Legget Canada	Regulations and Building Codes II
M. G. Blachore Director: Centre Scientifique et Technique du Batiment France	Agreement—The Approval of Building Materials
Professor D. Mohan Director: Central Building Research Institute India	New Techniques for Housing in Developing Countries
Mr. H. B. Zackrison U.S.A.	Housing for a Market (N. American Development)
Professor V. L. Ovsyankin Gosstrol U.S.S.R.	Component Building II

INSTITUTE OF ENGINEERS

FOURTEENTH ANNUAL CONVENTION

The Institute of Engineers, Pakistan is holding its 14th Annual Convention at Islamabad from 1st November to fifth November, 1968. The Convention will be inaugurated by Field Marshal Mohammad Ayub Khan on second November, 1968 at Hotel Shehrzad, Islamabad.

The Institute is a National Body of Engineers representing all branches of Engineering Profession. It enjoys recognition by the Government of Pakistan. It awards A.M.I.E. Diploma which is recognized by the Government.

A special feature of this meeting is a Seminar on the "Decade of Engineering Progress" under the guidance of the Revol utionary Regime.

The programme of the Convention will include registration on first November between 10 a.m. to 6 p.m. The Convention will be opened on the second and the proceedings will start from 8 a.m. The President will address the members at 10.15 a.m. Papers will be presented in the morning as well as in the afternoon Session.

The third of November is devoted to Seminar on Decade of Engineering Progress and on fourth November, a visit is arranged to Engineering sites. The last day is to be devoted partly to papers, and partly to the annual General Meeting of the Council etc. etc.