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REPORT ON
SIND RECTANGULATION
1926-1930

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SUPERINTENDENT SURVEY OF INDIA

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PREFACE

No. 24 Party was formed in October 1926, in order to carry out rectangulation to 64 acres in the territory comprised in the Lloyd Barrage project, along the Indus. From time to time the programme of work was altered, to include a loose network of levelling, and to substitute in the Chief Engineer's area 320-acre for 64-acre rectangulation; and to extend rectangulation and levelling, both on the 64-acre grid, into the commanded area in Khairpur State. The party carried out no topographical survey. It finished work and disbanded in October 1930, a small detachment being formed for further operations in Khairpur.

This account of the surveys describes in some detail the application of the principles laid down in Professional Paper No. 21 (Irrigation and Settlement Surveys, 1926) and includes the detailed orders given to traversers, rectangulators and levellers; but the matter in that paper is not all reviewed.

Chapter I

INTRODUCTORY

1. Brief description of the project area.—The Sukkur Barrage project commands an area of about 12,000 square miles, of which 1,300 lie in Khairpur State and form an independent scheme, although its water is drawn from the Barrage; the main irrigation area is under the Chief Engineer, Lloyd Barrage and Canals Construction. Politically, this territory is almost wholly within British Sind, but it extends also over small portions of Sibi district in Baluchistān and Kalāt State. The irrigable country as a whole lies in the Indus valley, between the bare lower slopes of the Kirthar hills on the west and the high desert of eastern Sind; the headworks at Sukkur are within 60 miles of the Sutlej Valley irrigation, and the lower end of the commanded area is situated only about 26 miles north of the Rann of Cutch. A remarkable feature is the Eastern Nāra river, which takes off from the Indus near Sukkur, penetrates the hilly country to the south-east and south, and 80 miles south of Sukkur re-enters the plain; it is supposed to mark the course of the lost Hakra river. In 1857 it was merely a spill channel which relieved the Indus; a supply channel was then cut, and other works carried out from time to time have converted it into a perennial feeder.

The land falls from 190 feet above mean sea-level, near Sukkur, to 14 feet near the tail, a distance of 215 miles in a straight line. A large part of it is cultivated, some intensively, the old irrigation systems (perennial or inundation) rendering this possible, as the rainfall is very undependable and as a rule extremely scanty. Such forests as there are are strung out along the Indus and Eastern Nāra. The waste land is as a rule irrigable, though some consists of sand-hills, and only requires a high-level supply. Nearly all the Barrage area will receive perennial irrigation. In the intensively cultivated rice land about Lārkāna only inundation canals are desired by the cultivators. The country is subject to disastrous floods, caused by the Indus breaching its *bunds* above or below Sukkur.

Some other features of the country are mentioned in para 6, in connection with their effects on survey work. The situation as regards land holdings, and how it has influenced the programme, is very briefly described in para 5.

2. The old Surveys.—In the summer of 1926 the Survey of India was called upon to undertake a rectangulation survey. The Chief Engineer had already commenced his operations. He had available some rather rough revenue village maps on the 8-inch scale, the 1892-1905 maps of No. 12 Party, mostly on the 2-inch scale, very good considering their age, while No. 17 Party had for the last few years been supplementing the old primary lines of levelling with new primary and secondary lines, the latter being run especially for the Project and providing the whole area with well-distributed bench-marks. The Barrage was carrying out its own contour survey, and in the old "Jamrao" squaring, the revenue and engineering staff had begun to free themselves from the old intricacies of land boundaries.

In this state of affairs a fresh topographical survey, with closely contoured maps, would have been too late for a great part of the work it would have been intended to help in designing; the old maps were accurate, though in want of revision, and in most of the area quite adequate. But the levelling network was not sufficiently close, and the Barrage levellers were compelled to carry their lines from our bench-marks to distances involving rather too great inaccuracies in observation and adjustment, and the desirability was felt of a system of bench-marks at close and regular intervals; in the circumstances, the new bench-marks could be depended upon not to upset the heights already used for construction in progress, and would be available at the commencement of the designing of the watercourses. The system of land squaring had not progressed so far that a fresh plan could not be adopted for the remaining area; under the old scheme there were scattered base-lines each two miles long and running approximately north and south, but not co-ordinated; on each was constructed a square of two miles side divided into squares of 16 2/3 acres (called 16-acre squares). These could be easily divided into squares of about 4 acres. There was thus no external control of areas, and adjoining lay-outs had to be forced into adjustment together. It was decided to abandon the old methods, but not to scrap the work already done in large compact areas.

3. The new Surveys.—The Chief Engineer after consulting the Survey of India, decided on rectangulation to 64 acres, with stone-numbering to allow for subdivision to 16 acres (see diagram No. 1), the revenue authorities for purposes of land allotment and adjustment of holdings subdividing further to 4-acre plots; it was also decided that a close network of Secondary levelling was necessary, but topographical surveys as carried out for the Punjab irrigation projects were not required.

The 64-acre rectangle was chosen on account of the "4-acre" plot mentioned above being already used by the revenue staff; the dimensions had to be altered, to allow of convenient measurement

and exact area. The general slope of the land being from north to south, the 4-acre plots are 528 feet (8 chains) in that direction by 330 feet (5 chains) east and west, and the "small" rectangles of 64 acres measure 32 chains north and south by 20 chains east and west. The main rectangles were accordingly designed 1·6 miles north and south by 2·5 miles east and west, and blocks 16 miles × 25 miles. The considerations which governed these dimensions are explained in "Irrigation and Settlement Surveys, 1926" (Professional Paper No. 21) and need no further discussion. The levelling framework was designed so as to provide a Survey of India height within 3 miles of any point (see diagram No. 3); it was to be built up of lines of "Secondary precision", for the sake of accuracy.

4. Brief history of the Surveys.—Work began accordingly in October 1926, and by the end of the cold weather a considerable area had been traversed, with main rectangle corners laid, and exterior rectangulation had covered nearly 1,300 square miles. At this stage the Chief Engineer decided that we should abandon 64-acre work, and adopt instead of "exterior" followed by "interior" rectangulation, a new plan whereby we divided each main rectangle into only 8 sub-rectangles of 320 acres each.

Another change in the programme was effected in 1927, by the striking out from even 320-acre rectangulation of large areas of sand-hills and of some intensively cultivated areas along certain old irrigation canals, where at present there is no expectation of the cultivators agreeing to the adjustment of boundaries and holdings entailed by the "square" system.

In the season of 1927-28 the levelling was commenced by detachments of No. 17 Party. This was the second season of traverse and the first of 320-acre rectangulation.

In 1928 the secondary levelling programme was dropped and tertiary (on the same framework) adopted instead.

Arrangements were made for the start of traverse work in Khairpur State, to enable 64-acre rectangulation to be carried out later.

In 1928-29 the traverse of the main area was completed, including that of Khairpur State; the 320-acre rectangulation (second season) continued; the tertiary levelling detachments joined No. 24 Party and began work.

In 1929 it was finally decided not to rectangulate in the Rice Canal Division (main corners had already been laid with a view to future sub-rectangulation); the last season of No. 24 Party, 1929-30, saw the completion of the 320-acre rectangulation and tertiary levelling in the British area, and in Khairpur the carrying out of the

64-acre rectangulation and tertiary levelling on 64-acre lines. A small area was traversed on the Eastern Nāra in British territory to guard against the threatened disappearance of boundary marks, and in Khairpur as a basis for a fresh area of 64-acre work.

In the recess of 1930 contoured charts were rough-drafted for Khairpur State.

All work was finished in September 1930 and No. 24 Party disbanded.

5. Causes of changes in programme.—The important alterations have lain in the direction of restricting British rectangulation, substituting tertiary for secondary levelling, and include the taking up of work for the Khairpur State. This last was a natural development, and it need only be noted that as the State had no large staff of surveyors, the rectangulation was to 64-acres and the levelling a close network. The change over in British areas from secondary to tertiary levelling will be discussed later. The other important modifications were the decisions of the Chief Engineer that we should not rectangulate to a smaller plot than 320-acres and that in some large tracts we should not go below even the 4-square mile "main rectangle".

320-acre rectangulation.—The position as regards the adoption of a system of rectangular holdings instead of the ancient survey numbers is that the landowners pay for rectangulation (but not for levelling) and have the option of keeping their old boundaries unchanged. The Barrage survey officer marks out plots of 4 acres, which by means of his "location" operations (chain measurements from our stones to field corners) he can superimpose on his old 8-inch maps, and by a long process of barter, involving some cheap sales of Government land and occasionally the removal of a landowner to an entirely different place, he endeavours to make every holding consist of a whole number of 4-acre plots. In some tracts, the old holdings are so small and so cut up by deep watercourses that to the owners there seems to be no advantage in any change, but very much the contrary, and it cannot be expected that any sub-rectangulation will be called for in the near future. In other areas natural conservatism is still against the change, and even after the new irrigation is opened, some time must pass before the inhabitants realize from the example of their neighbours that rectangulation is an economy. In the meantime only about 800,000 acres of the larger private holdings and 1,500,000 acres of Government estates scattered over the whole province of Sind are open to rectangulation to 4-acre plots. This being so, it was decided in 1927 that to carry out all the 64-acre rectangulation at once would involve much waste of work and also the disappearance of great numbers of stones before they could be utilized; that 320-acre rectangles marked by large stones would be fairly permanent

and not expensive to lay out; and that the Barrage surveys could break them down when necessary, combining other work with that operation. The reasons for the change were exceedingly strong, although the accuracy of the rectangulation below 320-acres is probably not remarkable.

No sub-rectangulation.—The areas already squared under the "Jamrao" system have been mentioned already; they were not traversed by us, and the old plots remain in use. There are however some tracts which, after the main corners were laid, were ruled out from subsequent operations as being full of sand-hills and worthless for irrigation purposes. Large expanses of land in the northern portion of the project area and in blocks G^1, K^1 are at present served by inundation canals and on the whole densely populated. In parts, practically all survey numbers are cultivated, and the owners will not have them cut up. Their case is much the same as that just mentioned, but is worse because inside these areas there are no unoccupied areas for rectangulation, and consequently the inhabitants will not see in their midst any large-scale example of the new system of irrigation. In consequence it is considered enough at present to have introduced an accurate framework of main rectangles, executed cheaply because part of a larger programme, and enabling rectangulation to be proceeded with at some time in the future. Ultimately it is the aim of Government to rectangulate throughout the Barrage zone.

6. Physical conditions affecting the Survey.—The principal difficulties in surveys in Sind are caused by the prevalence of malaria and the shortness of the cold weather. Except in January the *khalāsis* suffer severely, and in bad years the work is liable to be held up. At such times the inhabitants also are as badly affected, and local labour is even more unsatisfactory than usual. Pneumonia is fairly common. In No. 24 Party the issue of quinine (15 grains per man per week in two doses) to all hands was successful, except in the very bad season of 1929-30 in northern Sind. It is noteworthy that the Lower Subordinate officers, who were given mosquito nets that season, were comparatively free from malaria.

Khalāsis were made to put on their jerseys in the evenings to guard against pneumonia, and their scale of clothing included also two blankets each.

The cool weather commences in November; it was found useless to send surveyors out before the 1st, and in fact the outturn of work in that month is generally the lowest. March is hot, and early in April the hot winds make work difficult, and dust storms and haze are liable to prevent instrumental work for days together. In 1929 rectangulation went on, though with difficulty, until late in April; traversing would have been almost impossible. The great

floods occur during the hot weather months, but generally dry up by the end of October. Those of 1929 were still visible in a few isolated patches averaging 7 or 8 square miles each, at the end of March 1930. A year of bad floods is usually followed by severe epidemics of malaria, and a good deal of sickness is attributed to the *khalāsis* drinking stagnant water. Rain storms in the cold weather can stop work for two or three days at a time, the ground becoming boggy or too slippery for movement—especially of camels—even along the roads; but as a rule there will not be more than three storms in the season.

The country in general is fairly open, but the patches of *babul* and thorn forest are bad obstacles. Waste land contains much scrub jungle. A good supply of "American" axes and ash or hickory handles is essential for any line-clearing operations. Nearly all the roads are unmetalled and very rough; motors can be driven at an average speed of 14 m. p.h. They can travel fast over the flat deserts, though the way is often blocked by old watercourses.

Local labour, if obtainable, is not very good. *Khalāsis* have been given Rs. 5/- p.m. temporary increase; food and fuel are expensive. Supply gives no difficulty, though at present in the "*pat*" country along the foot of the slopes to the west of the Indus there are no inhabitants whatever, and food must be transported. Carts are of poor quality, few camels of any sort are available for hire, and the only safe arrangement for a party of any considerable size is to import camels through a contractor. These are expensive, and a *sarwān* will not work by himself, which entails grouping them, but the men will not run away.

6-wheeled motor lorries could operate over the Barrage area very well, and if No. 24 Party's programme of 64-acre rectangulation had not been cancelled, two or three would probably have been bought for moving stones from the railway into the field depots in the summer and for moving camps in the winter.

The survey stones, very hard limestone, have mostly been obtained from quarries at Jungshahi, Karāchi district. The Sukkur and Hyderābād stone is too soft, as is also that from some of the Jungshahi quarries.

As field headquarters, Hyderābād and Sukkur were very satisfactory. Karāchi as a recess station is fairly good, though expensive—and rather hot. It was chosen on account of its being the headquarters of the Lloyd Barrage.

Chapter II

THE WORK DONE AND COST RATES

7. Traverse.—

Season	Total linear miles	Linear miles per man per month 24 working days	Cost rate per linear mile	G. T. connections	Remarks
			Rs.		
1926-27	3,688	40·0	26·7	18	High initial expenses, and training
1927-28	3,145	70 7	11·5	15	"Bonus" payments in force.
1928-29	2,600	74·9	9·5	24	Do. do.
1929-30	315	47·5	18·3*	8	Only a small fragmentary area.
Combined	9,748	48·7	20·2 per sq. m., 15·6	65	

* Approximate.

8. Demarcation of main corners.—

Season	Area square miles	No. of corners	Corners per man-month 24 working days	Cost rate per square mile	Remarks
				Rs	
1926-27	3,590	898	13·0	17·2	Much piecemeal work necessary. High initial costs.
1927-28	4,680	1351	50·8	2·1	Bonus payments in force.
1928-29	4,088	1167	50·1	5·2	Bonus payments in force.
1929-30	252	142	44·3	13·7*	Only a small fragmentary area.
Combined	12,610	3,558	28·4	7·6	

* Approximate.

9. 320-acre rectangulation.—(none in 1926-27).

Season	Stones	Area square miles	Area in sq. m. per man-month 24 working days	Stones per man-month of 24 working days	Testing		Cost rate per square mile	Remarks
					Stones	Percentage of total		
							Rs.	
1927-28	4,932	3,155	37·2	34·8	2,424	49 2	56·4 *	"Bonus" payments in force.
1928-29	5,933	3,244	20·3	37·0	2,940	49·6	45·2	
1929-30	4,525	2,335	22·1	42·9	2,220	49·1	26·4 †	Sales of stores reduced costs.
Combined	15,390	8,734	24 9	43·9	7,584	49·3	41·5	

* Excluding the area converted from Exterior to 320-acre; its cost rate was Rs. 34·2.

† Approximate.

10. Exterior rectangulation, 64 acres.—(two seasons only).

In each main rectangle of 4 square miles, 9 stones were laid along the north edge, and in some cases 3 along the west or east edge.

Season	Stones laid	Area square miles	Work done per man-month 24 working days		Testing		Cost rate per square mile	Remarks
					Stones	Percentage of total		
			Linear miles	Stones			Rs.	
1926-27	2,866	1,294*	15	46·4	1,475	50·5	39 9	Includes training
1929-30	3,231	1,186	26	86·8	1,944	60·2	36·8 †	
Combined	6,097	2,480	19	62·6	3419	56·1	38·4	

* Of this, all but 186 sq ms. was in 1927-28 converted into 320-acre rectangulation.

† Approximate. Increased outturn neutralized by heavy stores expenses.

11. Interior rectangulation.—to 64 acres (1929-30 only).

Stones laid	Area square miles	Work done per man-month of 24 working days	Testing		Cost rate per square mile	Remarks
			Stones	Percentage		
8,302	1,186	33·6 l. miles 9·0 s. miles 63·0 stones	6,191	74·6	Rs. 105·1 *	

This includes the compilation of contoured charts.

* Approximate.

12. Secondary levelling.—(by No. 17 Party, 1927-28 only).

Linear miles	Area	Number of corners connected	Number of other bench-marks	Linear miles per month each detachment	Cost Rates		Remarks
					Per linear mile	Per square mile	
					Rs.	Rs.	
1,073	2,590	313	362	97	37·1	15·4	Excluding cost of bench-marks

13. Tertiary double levelling.—C.E.'s System.

Season	Linear miles	Area square miles	Number of corners and other new bench-marks connected	Number of connections to old bench-marks	Linear miles per month each dett.	Cost Rates		Remarks
						Per linear mile	Per square mile	
						Rs.	Rs.	
1928-29	1,973	5,100	652	151	93	15·3	5·9	Greatest closing error 0·573 foot in 24·3 miles.
1929-30	836	2,300	258	83	84	18·1*	6·6*	
Combined	2,809	7,400	910	234	91	16·1	6·1	Excluding cost of bench-marks

* Approximate.

14. Tertiary levelling.—64-acre system (lines 6·4 miles long) 1929–30.

Area	Linear miles	Single levelling linear miles per man-month 24 working days	Number of ground heights	Ground heights per square mile	Cost rate per square mile	Remarks
					Rs.	
1,062	4,904	80	64,492	61	38·6*	Excluding cost of bench-marks

*Approximate

15. Total work done.—

—	Linear miles	Square miles	Large stones	Small stones	New bench-marks
1. Traverse	9,748	...	...	...	...
2. Main corner demarcation	...	12,610	3,558	...	...
3. Exterior rectangulation 1926-27	...	186*	2,866	...	...
4. 64-acre rectangulation ...	...	1,186	3,231	8,302	...
5. 320-acre ,, ...	...	8,734	15,390	...	.
6. Secondary levelling ...	1,073	2,590	...	...	675
7. Tertiary ,, ...	7,713	7,400	...	...	971
Total ...	...	...	25,045	8,302	1,646

Total area of main corners 12,610 Square miles.
,, ,, rectangulated 10,106 ,,
,, ,, levelled 9,990 ,,

* Excluding the area afterwards converted to 320-acre rectangulation.

16. Combined cost-rate figures as below:—

(*a*) 320-acre rectangulation, and open network of levelling:—

Traverse	Rs.	15·6	per square mile
Demarcation of corners ...	,,	7·6	,,
Rectangulation ...	,,	41·5	,,
Tertiary levelling ...	,,	6·1	,,
Total ...	,,	70·8	,,

(*b*) 64-acre rectangulation, close levelling and compilation of charts:—

Traverse	Rs.	15·6	per square mile
Demarcation of corners ...	,,	7·6	,,
Exterior rectangulation ...	,,	38·4	,,
Interior ,, (including chart compilation)	,,	101·5	,,
Tertiary levelling ...	,,	38·6	,,
Total ...	,,	201·7	,,

Chapter III

TECHNICAL DETAILS

17. Traverse.—The origin of Survey was placed at λ 26° 30′, L. 68° 30′, which is within 1° 20′ longitude of any part of the work; Cassini's projection was employed.

Modern longitude values were used throughout, the graticules on the old 1-inch sheets being corrected. On the whole the work was well controlled; that portion south of latitude 25° 30′ was provided with points on the periphery only, but the main circuits proved well and were adjusted *inter se* by Tandy's method. The traverse down the Eastern Nāra, which was taken up at short notice after the 1929-30 field season had begun, was hampered by the disappearance of trig. stations; a length of 52 miles was without any intermediate support, and had to be carefully built up of small sub-circuits.

The index map (1/M) to blocks shows the old stations and points connected.

The first season's traverse (1926-27) was done at great speed, so as to provide quickly sufficient main corners for the rectangulators to begin; this entailed piecemeal adjustment of circuits, and the subsequent revision of 200 square miles. It is very inadvisable to have rectangulation pressing so closely on the heels of the preliminary traverse.

It was found best, in the interests of accuracy, to make traversers of sub-circuits clear their lines so that the chains could lie on the ground, instead of being pulled over low scrub. Few *tindals* can chain accurately using the top of their sticks instead of pins, and to allow them to use this method seems certain to induce slackness.

The operation of corner-laying was at the outset carried out by "closing" the small circuit by taking only the bearing and distance of the closing peg. It was found to be practically as fast and to provide a better office check, to make the traverser set up and observe the angle at the closing peg.

In other respects the traverse showed no departure from the working rules evolved in No. 23 party.

18. Levelling.—The network of secondary lines by No. 17 Party was executed by the usual methods for this class of work. It

is only necessary to mention that in view of the instability of the ordinary bench-marks in the Sind *kalar* soil and other soft alluvium, such a high standard of accuracy is not necessary.

For the tertiary double-levelling the working rules were based on those of a secondary detachment; they differed in that the two levellers worked throughout the day; they used only one pair of staves, which were of the ordinary telescopic pattern, with flat footings, and not guyed. Iron "plates" took the place of pegs (they are described in Professional Paper No. 21, page 22). Small Zeiss levels were sometimes used, but they are handicapped by their small magnifying power. Each leveller's mean of wires was allowed to differ from his middle wire by 0·005 foot, and the two observers could differ in their rise or fall at any station by 0·010 foot. 8-chain "shots" were allowed.

In 1928-29 the tertiary double-levelling detachments' lines were tied at frequent intervals by an officer carrying out single levelling cross-wise. This was found to have been unnecessary, the double-levelling proving very well between the many secondary bench-marks to which it was connected; the single-leveller joined the party too late to carry out his full intended programme, and so was sent to run connecting lines where the double-levellers' circuits seemed least compact. Personnel could be economized by using double-levellers on a grid of control lines and reliable and fast single-levellers on the final levelling; their lines should of course be short, say 10 miles at most.

In Sind (as already mentioned) there was such abundance of primary and secondary levelling that except for a short length in Khairpur State the tertiary double-levelling consisted of short lines not subsequently used as a framework for subsidiary work. The lines proved well.

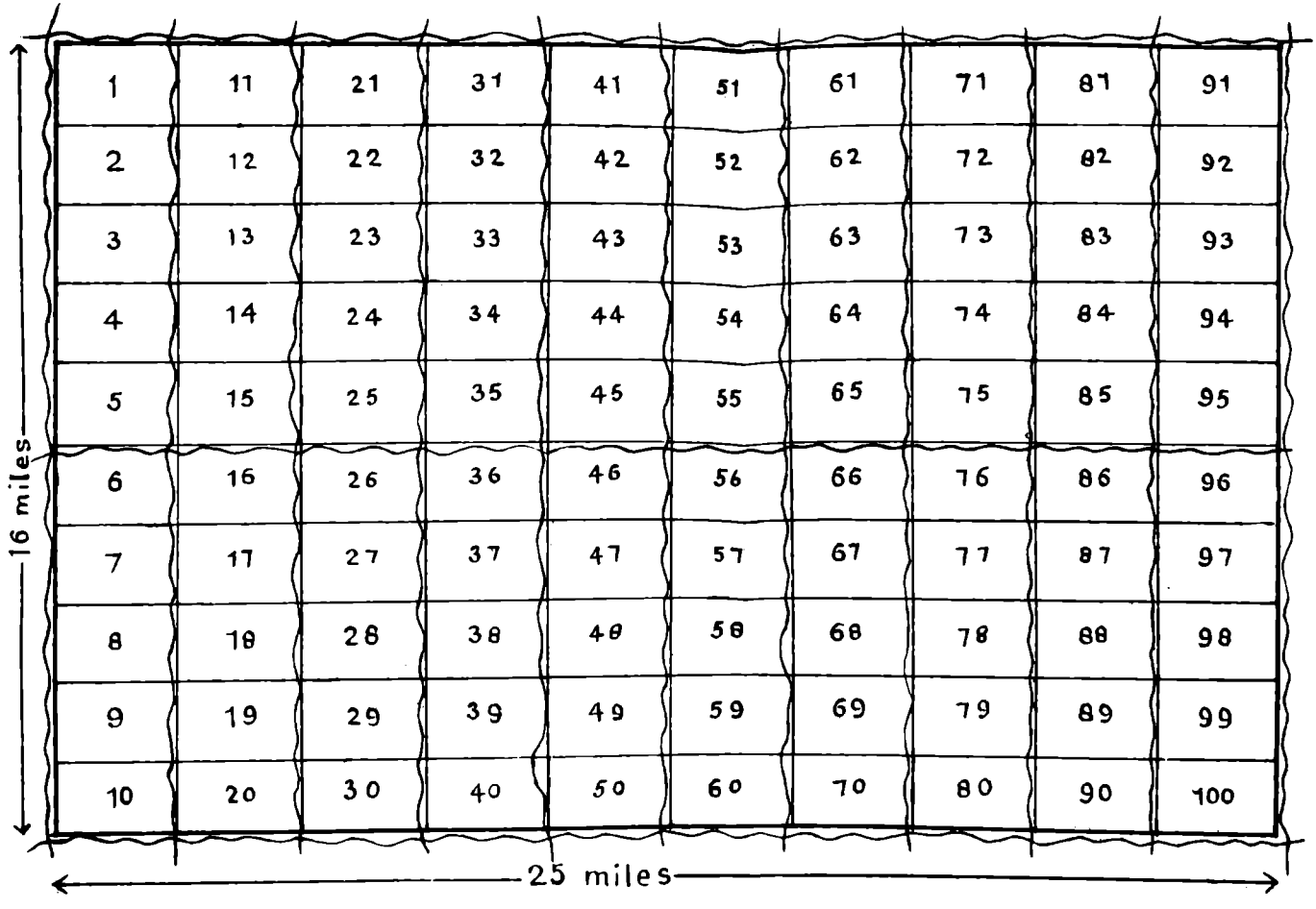
The instability of the bench-marks is the ruling factor as regards the veracity of the computed heights. A great deal of the soil is so light or contains so much salt, that only large marks which have been in the ground at least a year can be called stable. Even then, the dry climate of Sind and the extent of the periodical inundations may result in a bench-mark remaining dry for years, and only then being submerged and finding a more permanent level. As it is, the ordinary bench-mark at a main corner cannot be built until within a year of its being connected by levelling, and in many cases the executive engineers have been unable to build until within 3 months of connection.

It is therefore necessary to provide for the future check or re-levelling of the bench-marks, and some suggestions are therefore put forward (in Chapter VIII).

The heights of the whole network of secondary and tertiary levelling are based on geodetic lines, including those from Hyderābād

Block and Main Rectangles

Scale $\frac{1}{4}$ inch to 1 mile

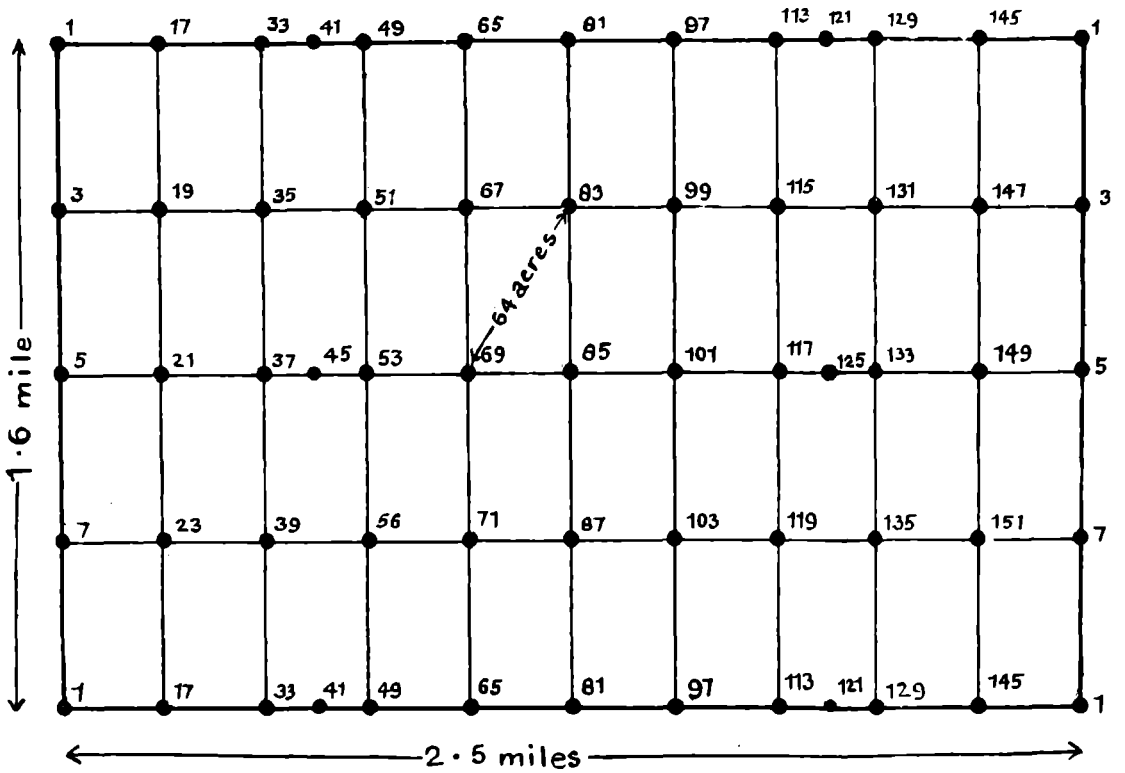


Traverse lines.....

Diagram No. 2

Main rectangle, shewing stone numbering

Scale 2 inches to 1 mile

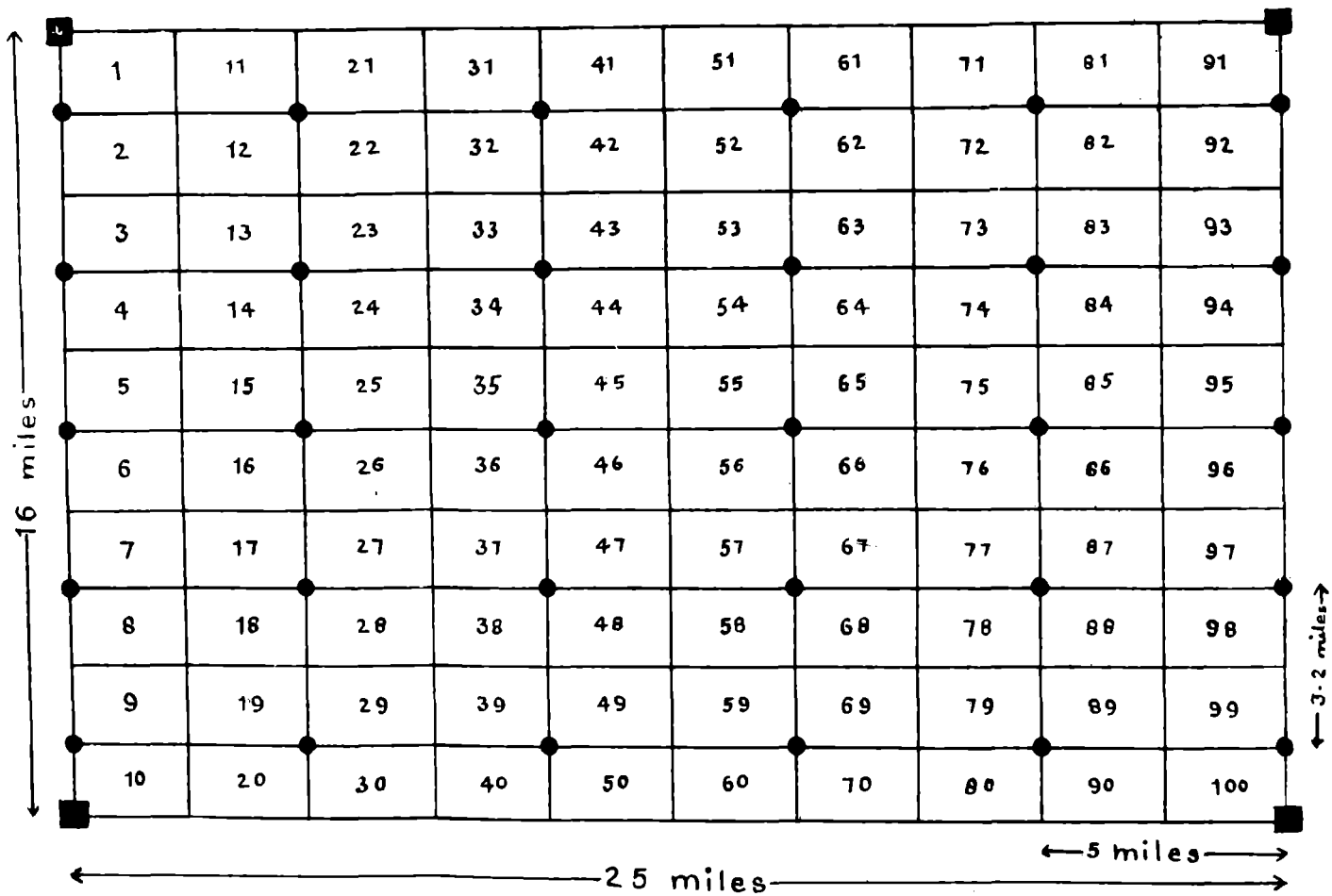


Note—only 320-acre and 64-acre stones shewn; the numbering allows for 16-acre stones being interpolated

Diagram No. 1

Block, Shewing

Chief Engineer's Bench-Marks at main rectangle corners



Scale $\frac{1}{4}$ inch to 1 mile

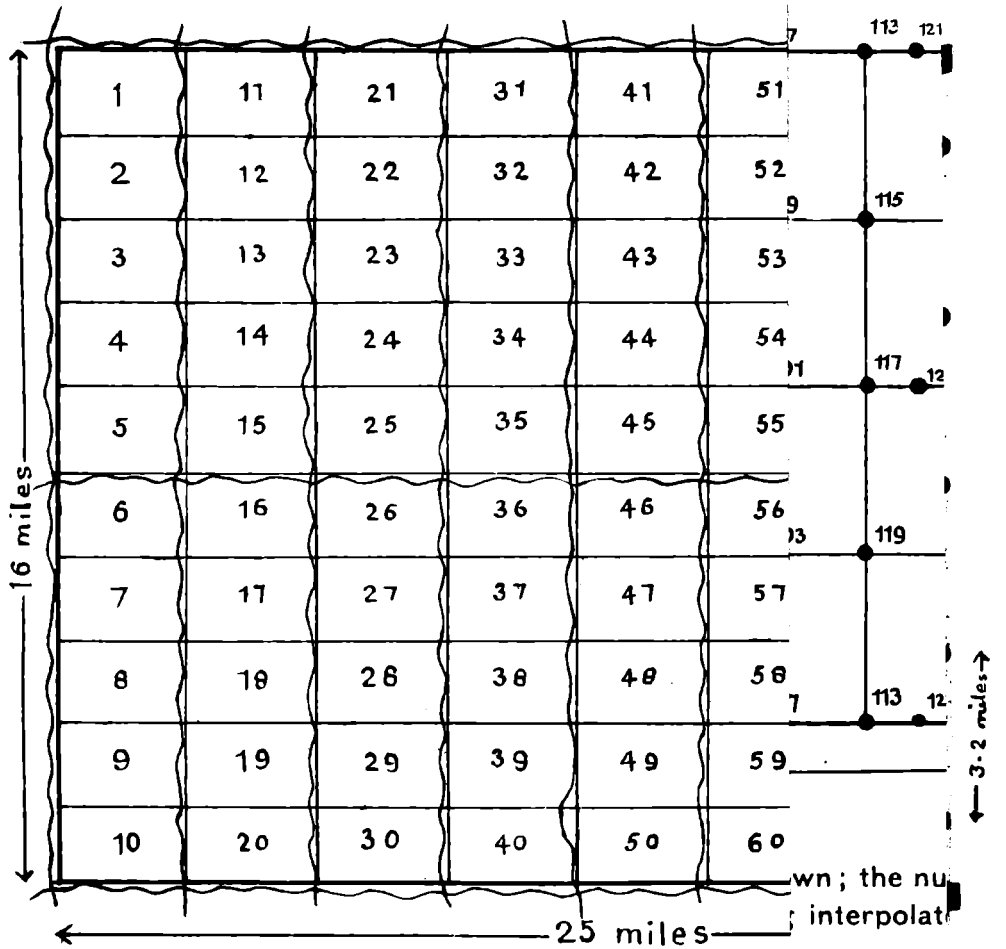
■ .....Survey of India Type B. The reference pillar stands on the main corner, the B.M. near it.

● ..... Low masonry pillars on main corners.

Diagram No. 3

Block and Main tone n

Scale $\frac{1}{4}$ inch to mile



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interpolat

Traverse lines.....

Diagram No

to Sukkur and to Barmer. These lines have not yet been given final heights, the new work on them has been utilized only as regards the latest values for bench-mark differences in height, as given by No. 17 Party. The whole network is in agreement with the secondary lines run before 1927-28, whose heights have been used by the Chief Engineer for several years past. The new primary values when available will of course not be in accordance with them.

The tertiary levelling in Khairpur State comprised double-levelling circuits and single-levelling lines 6·4 miles long (see diagram No. 7). The circuits were tied to the primary line Hyderābād-Sukkur at frequent intervals.

Embedded bench-marks were provided on a liberal scale. The circuits were levelled and computed in the ordinary manner (Professional Paper No. 21, page 24); the single levellers were allowed closing errors of 0·3 foot. The diagram shows the heights they observed; they threw out the heights to the east of their lines by observing right angles by prismatic compass, placing the level $6\frac{2}{3}$ chains from the 64-acre corner, and the fore staff $6\frac{2}{3}$ chains still further east; the back staff standing on the corner. The height of the furthest point was taken in the usual way, that at the instrument by tape measurement from object glass to ground.

The operations were different when forest intervened, in that short shots of $3\frac{1}{3}$ chains were observed, the level being set up twice at $3\frac{1}{3}$ and at 10 chains from the 64-acre corner.

It will be realized that on these east lines there is no check on the initial right angle, the distance or the readings; the position of heights on the north and south lines bounding 64-acre rectangles are more reliable.

N. B.—The levelling was not partālled.—In future surveys, orders should be issued that tertiary single-levellers should observe the top heights of stones near the centres of their lines, in order to make testing possible; *partāl* lines should not be selected by any stereotyped method; which might become known to the single levellers, and thereby cease to be of any use.

19. Rectangulation.—The rules for rectangulators in the next chapter give all the useful information, except as regards errors and their cause. It is essential that the checking of stones should be entrusted to only reliable men; they have it in their power to evade the reporting of bad work, and as they re-embed all stones found out of position, such evasion would go undetected. In No. 24 Party the choice of lines to be checked was not left to the *partāllers*, and Camp Officers re-checked occasionally; but it is impossible to prevent a *partāller* knowing which rectangulator's work he is reporting on.

The usual cause of errors in rectangulation is bad chaining; two chains of different lengths are used, but occasionally a careless rectangulator will botch the count of one chain and choose it as being the correct one, or in order to save time he may omit his final check measurement altogether. There is no excuse for an error in rectangulation.

Where a line runs outside the main corner control, errors have occurred through the rectangulators not having been given orders as to how they should close and check.

Where rectangulation lines are as long as 2½ miles, only theodolites will enable the work to be done reasonably fast; good magnification is necessary. A good rectangulator utilizes his observed angles.

Chapter IV

INSTRUCTIONS GIVEN TO CAMP OFFICERS AND SURVEYORS

20. While omitting those orders which deal with routine only, it is as well to include some which although not of a technical nature deserve to be recorded as likely to be useful to other parties.

21. Camp Officers.—(*i*) The rectangulators' *khākās*, the field records on which they enter details of chainage and stones laid, must be examined and compared with adjoining and *partāl khākās*. They must be legibly written, and the omission of a stone or any unusual entry must be explained. Distances must be recorded in feet only. Rectangulators will sign their *khākās*. The Camp Officer completes the edges, taking care not to confuse the record as to which stones each man has laid, and then adds his signature. Main corners should be coloured black, rectangulators' stones blue, and (on *partāl khākās* only) the *partāllers'* stones red.

(*ii*) As the personnel of each camp is scattered over a large area, the Camp Officer must ensure that the work allotted to each man is ample to occupy him until further orders can reach him. On taking the field the Camp Officer will give each surveyor a statement in writing, with the appropriate charts, detailing his work for the first two months, or longer if possible. The surveyor will be ordered to send in word of the date of probable completion of this work, but the Camp Officer will always keep a vigilant eye on this point, remembering that the cost of a surveyor and his squad averages about Rs. 14/- a day, so that idle days represent a serious loss to Government.

Rectangulation Camp Officers are responsible for extending their work to the proper limit, which may be slightly outside the traversed area. In such places they must give detailed orders to the rectangulators.

(*iii*) Camp Officers will do their utmost to ensure the smooth working of the camel transport, so that the work may not be subject to delays due to *sarwāns* absconding. They will investigate immediately and impartially any complaint received from a surveyor or a *sarwān* and endeavour to remove the cause, if necessary reporting the case to the O. C. Party and to the contractor. If *sarwāns*

abscond, the latter must be informed immediately. The contractor is allowed a week to effect replacements, but the hire of local camels during that period is deducted from his bill. When camels are stolen, Camp Officers should take energetic steps to secure their recovery.

Camp Officers will submit two statements of the camel strength of their camps on the appropriate form each month with the progress reports. The first statement relates to the period from the 16th to the end of the previous month, the second to the period from the first to the 15th of the current month. The bills of each month have to be kept separate.

(*iv*) Stones for the work have been collected at various railway stations and depots scattered throughout the area. Quantities at each depot and railway station have to be checked before the contractor can be paid off. Camp Officers will therefore detail surveyors to proceed direct to particular depots and check their contents personally before stones are withdrawn for the work. The total number of broken and unbroken stones at each depot will be reported to the O. C. Party by the Camp Officer. These depots will not be counted simultaneously over the whole area, but as the work advances the foremost men will be detailed for the check. In addition, every surveyor will report the total number of stones he withdraws from each depot, and the Camp Officer will keep a running account in ledger form of the stock at each depot.

An allowance for breakages of 3% has been made over the whole area, and kept at railway stations.

Surveyors must not draw stones except from the proper depots for their respective areas.

From time to time, as the rectangulation of areas served by depots is completed, Camp Officers will report the number of stones still remaining and await orders as to their disposal.

(*v*) The permissible error in a rectangulation stone is 2 feet in distance and 1 foot in alignment.

(*vi*) The following drills and technical orders are supplementary to the information contained in Chapter IV Topo. Handbook and in "Irrigation and Settlement Surveys, 1926".

The methods here adopted should not be regarded as final solutions of any of the problems. It is the duty of Camp Officers to endeavour to improve on these methods all the time and to report successful variations for incorporation in the orders.

(*vii*) It is essential that Camp Officers should spend by far the greater part of their time in touring. Their visits to their men are not primarily for the purpose of instruction, which should not always be needed; the objects to be kept in view are the maintenance of accuracy and increase of outturn; and an eye must be kept on

the welfare of all personnel. Good surveyors require less inspection than do the slow or inaccurate. Camp Officers must always know where their men are encamped, and when and where they expect to march. Surveyors must always leave chits in their camps saying where they have gone to work.

(*viii*) Drills have been drawn up to ensure that the surveyor organizes his work and utilizes each member of his squad to the best advantage. Surveyors and squads must be practised at Camp H.Q. for three or more days, as found necessary, in these drills before departing to their work, until every man is able to carry out his particular duty without further orders. The best way is first to organize the surveyors themselves into squads of the correct strength, when the Camp Officers can train them by making each surveyor in turn assume the duties of each member of the squad. One full day in average country should suffice for this. The surveyors are then told to apportion the tasks among the members of their squads and to train them for two days or more, if necessary. If the surveyors work close together, the Camp Officers can supervise and pass out each squad in turn on the second day. It will be found that time so spent is very rapidly repaid in the field.

No surveyors should be allowed to leave the Camp H.Q. until he thoroughly understands the contents of the following paras.

(*ix*) Stones must be passed as correct before they are used as bases for other operations, e.g. levelling.

(*x*) Every Sunday surveyors will fill in postcards showing where they expect to camp during the week, and post them to their Camp Officers.

Surveyors are allotted permanent camel transport of four camels each; in waterless areas, five camels will be allowed. Surveyors must realize that their whole work depends upon working harmoniously with their *sarwāns*. It must be remembered that the camel is the *sarwān's* property and he naturally considers its welfare. Surveyors must do likewise and allow a reasonable period every day for grazing. Also camels must never be kept standing about. The surveyor will inform the *sarwān* in good time, usually the night before, at what hour the camels will be loaded. All loads must be packed and ready by this hour so that they can be quickly loaded on to camels and the *sarwān* sent off to the new camp in company with the personal *khalāsi*. The actual march will seldom occupy more than three or four hours, and normally camels can graze for the rest of the day. If camels are not required on any particular day, the *sarwān* should be informed overnight, as camels may then be grazed further afield.

When stones have to be transported, grazing can often be provided from the branches cut when clearing the line. The canal

authorities have also given permission to cut small branches from trees on canal banks, where other grazing is not available. This is a privilege and not a right, and great care must be taken not to deface a tree or cut too much from any one tree. Surveyors will see that *sarwāns* wear the Survey of India badge and carry the permits issued by the canal authorities.

Every surveyor is issued with a medicine box containing simple drugs, with instructions in vernacular. In addition there is a special issue of quinine. From the 1st November to 15th December every surveyor will take himself and give each member of his squad 10 grains of quinine on each Sunday and 5 grains on each Monday. A further issue of quinine will be made later in the field season, when it will again be administered as above from 1st February to 15th April.

Every surveyor must realize that he is provided with a squad to enable him to carry out his duties, and that one of his important duties is to keep every man fit. The members of his squad are often ignorant and careless, and it is the surveyor's duty, as the man in charge, to see that *khalāsis* take all proper precautions in the matter of health. The early mornings are cold and *khalāsis* must wear their jerseys and blankets before they start out to work. In the evening when they return hot and tired, it is dangerous to drink very cold water; also it is essential then to put on jerseys directly they return to camp. It is very noticeable that the squads of certain surveyors always keep fit and strong whereas the squads of others are constantly sick. Surveyors will understand that, in selecting men for retention in the party, preference will be given to those who have shewn that they look after their men and maintain them in a fit state to carry on the Government work.

When the country is too dense for the line cutters to keep ahead of the surveyors, all the men must be turned on to line-cutting. In that case the theodolite, stand etc., will either not be taken on to work, or, if brought, will be concealed in a safe place on the line. The surveyor himself then undertakes the duty of forward flagman, while everyone else is engaged in cutting or removing branches. The surveyor will direct the cutters exactly where to cut so as to prevent them from doing unnecessary work. He will also prevent them from bunching, by allotting each brush or tree to one or two men only. In this way rapid progress can be made even in bad country.

Parts of Sind are thickly wooded with thorny trees. Leather gloves will be worn by *khalāsis* when cutting these. A rope should be tied to a cut branch to clear it away easily and quickly. Tools must be kept sharp. A small set stone is provided for keeping an edge on the axes. Periodically, they should be properly sharpened by a village blacksmith.

A large tree should be felled by cutting half way through the trunk on the side towards which the tree slopes. A rope is then attached to the top branches and while some men pull on it a second cut is made, 4 inches above the first and on the opposite side of the trunk. Care should be taken to prevent the tree falling across the line, as it would then have to be cut up.

The following is for use when visiting a rectangulator :—

(*a*) Is he trained, and capable of reading his verniers ?

(*b*) Is his outturn satisfactory ? Is his work accurate and thorough ?

(*c*) Are his instruments and equipment in good order and adjustment, and complete ?

(*d*) Is his programme mapped out well ahead ?

(*e*) Does he furnish correct and prompt returns and clear *khākās* ?

(*f*) Does his squad work well, and has the *tindal* a good control over it ?

(*g*) Have they any complaints ?

(*h*) Do they acknowledge the correctness of their pay ?

(*i*) Does the surveyor administer quinine as per orders, and are the men healthy ?

(*j*) Are there any complaints by, or against, the *sarwāns* ?

(*k*) The field notebook of each L. S. S. must be entered up at each visit, noting only what is noteworthy.

22. Traversers.—(*i*) The work of the traverser consists in fixing stations on the ground as near as possible to corners of main rectangles. He is given a plane-table and a 1-inch map on which these rectangles are ruled, and he plots the legs of his traverse on the map as he proceeds. After his traverse has been computed, he is sent back to lay stones at the exact positions of the corners, being given for each the bearing and distance of the corner from one of his pegs. The essence of the operation is to fix a peg in the first place as near to the true corner as possible, in order to save working with long rays when laying the corner. To ensure this, the traverser will read his map carefully as he proceeds and verify his position from the numerous canals, tracks etc., he will cross. He will also restrict the legs of his traverse in the neighbourhood of a corner, to lengths of 20 chains or less. Intermediate legs may be as long as 40 chains, but never more, as no advantage is gained thereby and the squad get out of control.

The traverse can be taken to the east or west of the corner, the more open line being selected in each case.

(*ii*) The traverser will work with the 330 and 100-foot steel bands. On main circuits he reads on both faces, one vernier only

on each; on sub-traverses he observes no azimuths, and reads only one face and one vernier. He will also carry the 66-foot steel band, in case of dense jungle being encountered, in which case the 66-foot band will be used instead of the 330-foot one. In the following drills, the mate in charge of the 100-foot steel band works ahead whilst the traverser himself accompanies the 330-foot band to ensure accuracy and to prevent collusion between the mates.

The traverser's work will be organized as follows:—

No 1. The rear flagman should be changed daily, as the work is light; a suitable place for a weak man.

No. 2. Plane-table carrier; during observations with the theodolite, he holds the field book and ink. Directly observations are completed, he takes the plane-table, umbrella, haversack, sight-rule and compass to the forward station and immediately sets up the plane-table, and lays out the instruments upon it before the traverser arrives. He can quite easily be taught to orient the board with the compass.

No. 3. Theodolite carrier; he holds the umbrella during observations. He carries the theodolite and stand and painttin from station to station.

Nos. 4 & 5. Chainmen of the 100-foot steel band.

Nos. 6 & 7. Chainmen of the 330 (and 66)-foot steel band.

No. 8. Forward flagman; he carries the flag and *phaora*. He makes the circle and *challān* after observations are completed, and while waiting for the traverser to arrive he takes the traverser's orders to the line cutter.

No. 9. Spare man; he will be used for carrying letters, and accompanying *sarwāns* with stones; when not so employed, he will assist Nos. 2 and 3 or be used to strengthen the line-cutting party.

Nos. 10, 11 & 12. The line-cutter is in charge of this party. He receives orders as to the direction of the line from the forward flagman, and then goes ahead to prepare the new station. He must have a new station ready by the time the traverser arrives at the forward flag. The most intelligent and efficient man will be selected for this post and given the rank of *tindal*, in charge of the whole squad.

No. 13. The personal man.

The essence of the organization is that when the traverser reaches any station he will find the forward station already prepared.

The sequence of operations for the traverser is as follows:—

The traverser on arrival at a station B will find the plane-table set up and awaiting him. The chainmen will also be there. He marks the distance AB on the map fixing the position of B and draws a ray towards C, which has been previously cleared, as below, by the line-cutter. By eye he estimates the probable position of C (chainmen are very accurate in estimating distance). He can now judge whether the next ray CD is required to be carried forward in a straight line or slightly to the right or left. He demonstrates this to the forward flagman, by stretching out his arms in the direction of the two lines. The forward flagman can also be taught to understand the principle involved by looking at the map. The forward flagman then sets off to the line-cutter at C, explains to him the direction of the new line CD, whereupon the line-cutter proceeds to fix D and clear CD. There are two points to note here:—

(*a*) The forward flagman must be sent forward as soon as possible, so as to give the line-cutter as long as possible to prepare the new line.

(*b*) As soon as the forward flagman removes his flag, the umbrella must be erected, otherwise the line-cutter's party loses touch.

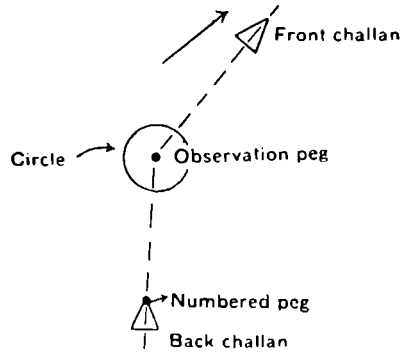
The plane-table is now removed by No. 2 and the theodolite stand substituted, while the traverser is entering both chain measurements in his field book. If the measurements are incorrect, AB must be remeasured. If correct, Nos. 4 and 5 proceed at once to measure the new line BC. The traverser will retain Nos. 6 and 7 by him. They are available to relieve Nos. 2 and 3 during this time.

The traverser now unpacks his theodolite and observes angles. On completion he sends on No. 2 at once to ensure his arrival at C before himself. He now replaces the theodolite in its box, paints the number on the second peg and buries it in the back *challān*. These operations give time for No. 2 to get ahead.

The traverser now proceeds to C, keeping with Nos. 6 and 7 and checking their chaining. On arrival at C he will find the line CD ready and repeats the above operations.

The success of the work depends on the message sent by the traverser to the line-cutter. This may suffer in transmission at the hands of the forward flagman, but with a little patience all parties can be taught to realize exactly what is required. As far as possible, it is best to leave the line-cutter to follow the most open line. Corrections can be made when near the corner, by sending a more precise message both as to the direction and length of line required. The traverser must note when a corner station is about

to be reached, and instruct the forward flagman to cut the double circle round it.



(*iii*) Traverse stations are marked as above. At ordinary stations the peg is surrounded by one circle. At the station nearest the rectangle corner, two circles will be dug. The *challāns* show the direction of the line and are useful for finding stations some months later. Circles and *challāns* will be dug about 6 to 9 inches deep. The earth should be thrown outside the circumference, not inside, as the surface on which the theodolite has to stand should be solid ground.

Pegs which are left exposed to view are liable to be removed, causing great delay in the work when the traverser returns to lay his corner stones.

One peg (the observing peg) should be driven flush with the ground, and concealed after observations are complete. A second peg will be buried in the apex of the rear *challān*, the station number being written on it. When corner stones are being laid, the traverser can find the station by the circle and *challān* marks; identify it by removing the peg in the rear *challān* and reading its number; he observes on the peg inside the circle, which thus is never moved. When work is completed the numbered peg is replaced in the *challān*.

(*iv*) It is essential to reduce the amount of line clearing to a minimum. Although on main circuits the traverser must observe to the peg or pin, on other lines he should observe on points a quarter or half way up the pole, when by doing so line cutting is reduced. As the flagman will not hold the flag quite vertical or steady, the traverser should take at least six or eight means in such cases, and should state in field book, "observation taken to ¼, ½ flag" etc. When setting up the computations, the mean and not three concordant angles will be accepted.

Line cutters must clear all large bushes that impede the line of sight or which make chaining difficult or inaccurate; it is not necessary to cut wide lines, but in block and other main circuits the chain must lie on the ground. In sub-circuits (lines inside a

Corner Form

A As given to traverser

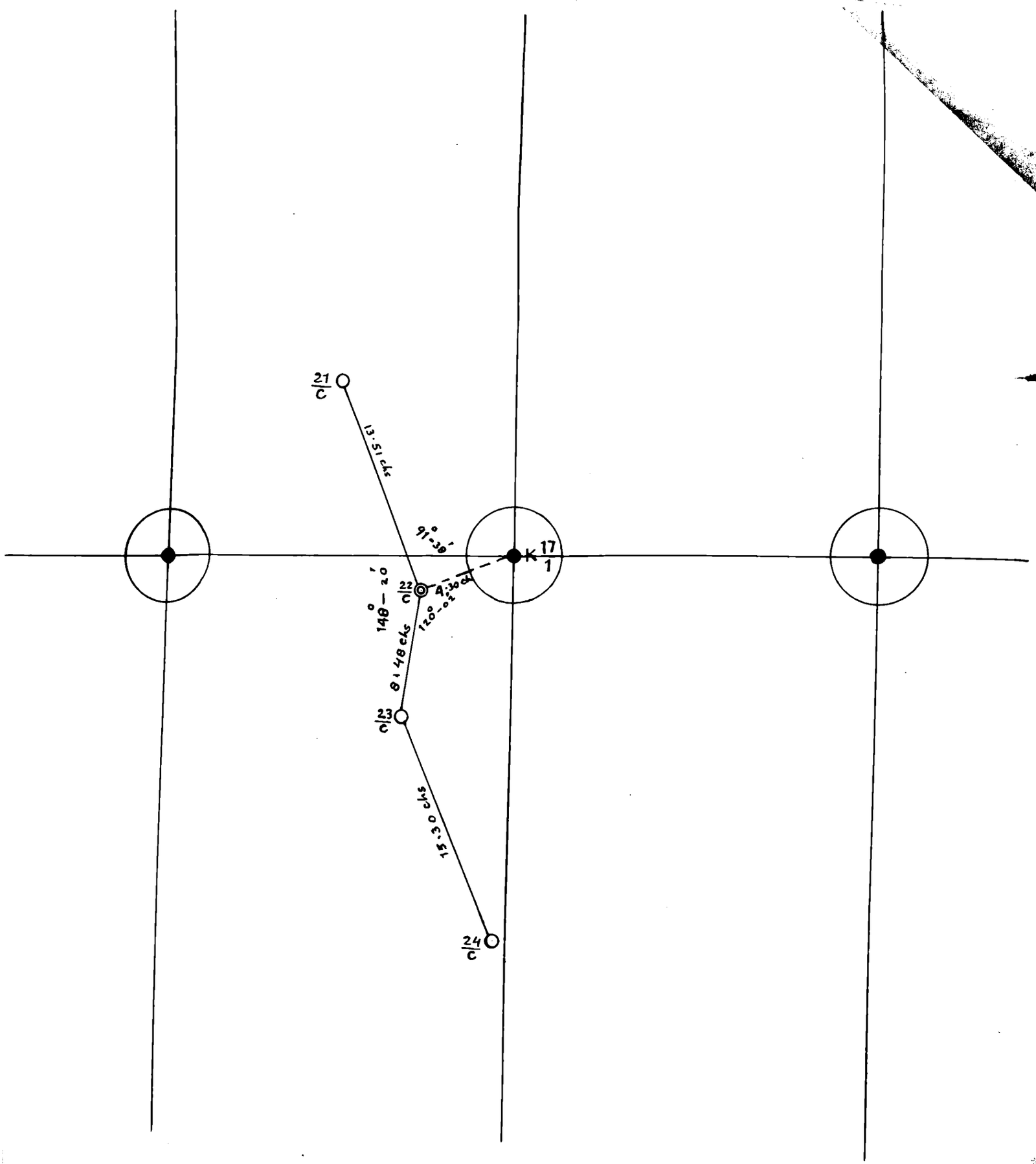


Diagram No. 4

block) it is not usually necessary to cut bushes less than three feet in height. A station can often be sited on a small mound giving a long view over the tops of bushes.

23. Traversers laying main corners.—(*i*) Whenever possible the same traverser revisits the line in order to lay corner stones, as he probably remembers the approximate positions of the pegs and can find them quickly. When this arrangement is not possible, the traverser can stand at the last identified peg and note the direction of the line from the forward *challān*. He will select a tree or other mark on this line on which to march. From the data he will see the length of the line and will convert this distance into paces (approximately 25 paces in a short chain). He will form up his squad in a line on either side of him, separated by small intervals, and they will all advance together, the traverser counting as he goes. Say the distance is 20 chains, approximately 500 paces. After counting 450 paces, the traverser will caution the squad to look out for the peg, and shortly after that one of them should stumble on it.

The same operation is repeated until the station of observation is reached.

Every traverser should discover the length of his own stride by pacing alongside the 66-foot steel band and counting his steps. This figure should then be used as the factor for conversion of chains into paces.

(*ii*) Traversers will lay two stones, one at the north-west corner of every main rectangle and the second due east or west of the corner at a distance of at least 15 chains. These two stones form the base for the rectangulator, and for that reason the greater the distance, the better. The corner stone will be numbered as usual (see diagram No. 1 for the system of numbering) but the second one will be numbered on the top, instead of on the side, thus:—

54/B.L./15 ch. → or ← 20 ch. 54/B.L.

where 54 is the main rectangle number,

B.L. means Base Line,

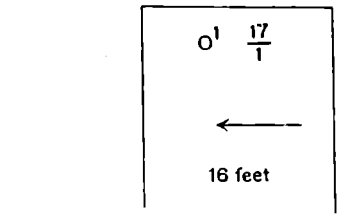
15 ch. → means that the stone is 15 chains from the corner and on the west side of it. In the second example, the stone is understood to be 20 chains away and to the east of the corner.

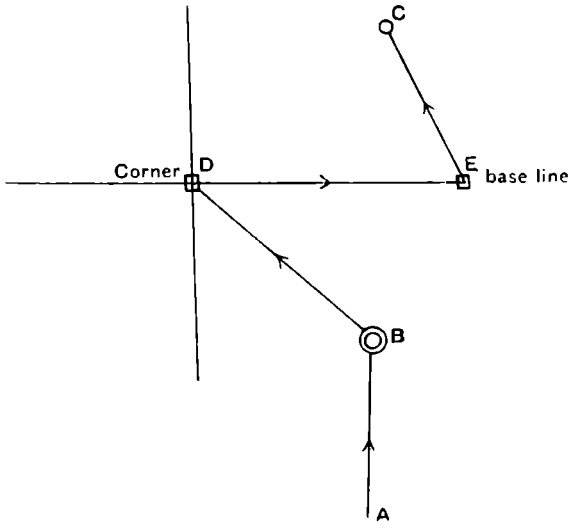
The arrow in each case points to the corner.

This base-line stone will be laid to the east or west of the corner stone, according to the position of the traverse station on which the circuit will be closed and on the relative amount of cutting. The object to be secured is to keep traversers' lines as short as possible and their line cutting down to a minimum.

N. B.—The rectangulator will eventually remove the second stone and use it as a rectangulation stone.

If the corner stone cannot be laid in its correct position (on account of huts, canals etc.), the corner layer will report the case to his camp officer for orders. The rectangulators must have stones on which to close, although they do not require base-line stones at both ends of east and west lines. It will be helpful if the original traverser notes the fact that probably the corner is inaccessible. Rectangulators are responsible for laying stones finally as near as possible to the true corners; the marking should be as under:— (Example only).





(*iii*) Before a traverser starts laying corners he will return his plane-table to Camp H.Q., as it is no longer required.

In laying corners, the traverser is given on a printed diagram the data of the stations A B C. Also the angles ABD and BDE and the distance BD. He is required to site D and E on the ground at a distance apart of 15 to 20 chains, depending on the openness of the country. The base-line stone E may be placed to the west instead of to the east, if less clearing is entailed or obstacles are avoided. The camp officer should note such cases, for the guidance of the

rectangulators. He has to clear the lines BD, DE, and EC. The connection EC is required to prove the circuit. The circuit may be closed on any *peg* other than the starting peg. Also, to minimise line cutting one or more stations may be interposed between E and C (or E and B). The order of the operations is as follows:—

A squad of 13 men is employed as in traversing, and they are given similar duties.

The traverser advances up the line until he reaches peg A, where he stations No. 1. The rest advance to B, the station with the double circle, where the theodolite is set up. No. 8 goes forward to C (if the position of this station is in doubt, the traverser will lay off the direction as a guide to No. 8).

The first essential is for the traverser to satisfy himself that the pegs A, B, and C are the correct pegs in their correct places. If the numbers on the pegs agree with the data and they are found undisturbed in the ground, the pegs can be accepted without further delay. If there is any doubt about the stations, Nos. 4 and 5 will measure BA and Nos. 6 and 7 will measure BC. It is not necessary for them both to measure each line. The traverser at the same time will check the angle.

If the pegs cannot be found they must be relaid from the nearest identified peg, and in this case both chainmen will measure all lines.

The traverser now lays off the angle ABD and directs Nos. 10, 11 & 12 along this line. No. 10 holds the flag while 11 and 12 clear the line. Nos. 6 and 7 follow with the 330 or 66-foot band and stop when they have measured out the distance BD. Nos. 4 and 5 carry the stone to D. A peg is inserted at the approximate position of D.

Leaving his theodolite at B, the traverser now proceeds to D taking both chains with him and satisfies himself that the distance BD is correct. If not, he corrects it and returns to his theodolite to recheck the angle. The peg at D is now correct.

The traverser packs up his theodolite and proceeds to D. No. 1 brings his flag from A to B. On arrival at D the traverser sets up his theodolite over the peg and lays out the line DE as above. Whilst this line is being laid, No. 2 digs the hole for the stone and the traverser paints the number. The stone is then inserted and earth is packed tightly round and rammed. The plumb-bob is let down and a dot $\frac{1}{4}''$ deep and wide is chiselled and a circle painted on the stone. (This mark must be made after insertion, not before).

As soon as the line DE is cleared, Nos. 10, 11 and 12 can clear EC without further delay. The traverser determines the position of E precisely as in the case of D, and then proceeds to E to observe the

angle DEC, and to C to close. He must observe the angle at the closing station C between B and E. If the closing angular error exceeds two minutes, the connection must be revised.

24. Rectangulators, (320-acre).—(*i*) In every rectangle 8 stones will be laid (see diagram No. 5). The corner stone is laid by the traverser and the remaining seven by the rectangulator. The base-line stone is placed by the traverser but must be moved by the rectangulator. Occasionally the position of a stone is already occupied by a house, the bed of a canal, or other obstacle. In any case where a stone cannot be placed in its correct position or when if so placed, it is liable to be moved, it will not be laid in its true position but as near as possible in the east-west line. The stone so displaced will be lettered as below to show that it does not occupy the correct site:—

J 10/41→ 50 ft. or 10 ft.← M 6/85

The nearest 16-acre stone position determines the number to be painted.

The first example shows that the true position of the stone is 50 feet to the east; in the second it is 10 feet to the west.

In the area which was exteriorly rectangulated in 1926-27, 10 stones were laid on the upper lines of certain rectangles. These will remain as they are and the intermediate two stones (Nos. 41 and 121) will not be laid. On the central line of such a rectangle, instead of stones Nos. 45 and 125, No. 37 (or 53) and No. 117 (or No. 133) will be laid, so that they may fall truly south of the stones above them.

In places there are valuable fruit gardens, such as the orange groves in Tharu Shah. Stones cannot be laid in these, nor can any of the fruit trees be cut, owing to the large compensation that would be claimed. In case of doubt reference should be made to the O. C. who will obtain the orders of the Chief Engineer on the matter if necessary.

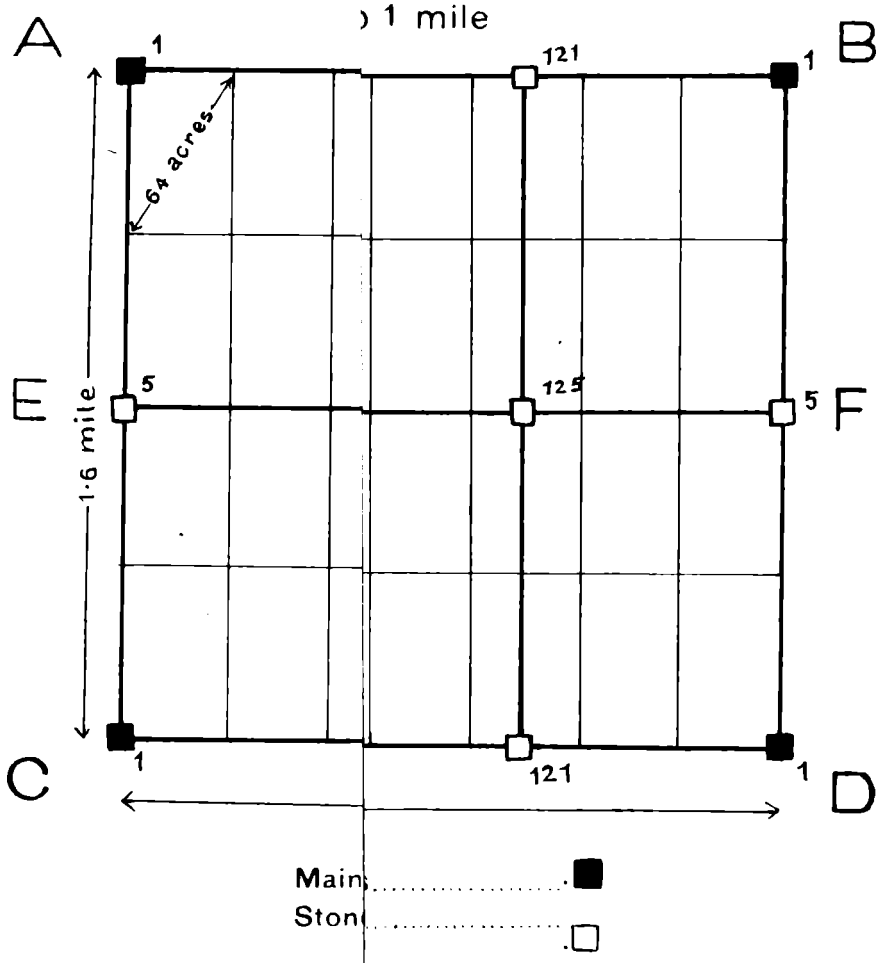
In all such cases, the stones nearest to and inside the boundary will be placed on the actual line of the boundary and numbered as directed above.

(*ii*) A rectangulator has to subdivide the exterior and interior east and west lines of every rectangle (see diagram No. 5) into four equal lengths of 50 chains each. For this purpose he is given a base and can subdivide the exterior line AB. Before he can tackle EF he must determine the points E and F by subdividing the lines AC, and BD. It is not essential to subdivide the outer lines AC, and BD in every case. If a near-by parallel line offers a more open lie of country, in that it avoids a village or entails less cutting, it may be accepted in preference to the outer line.

ngle

gulation

) 1 mile

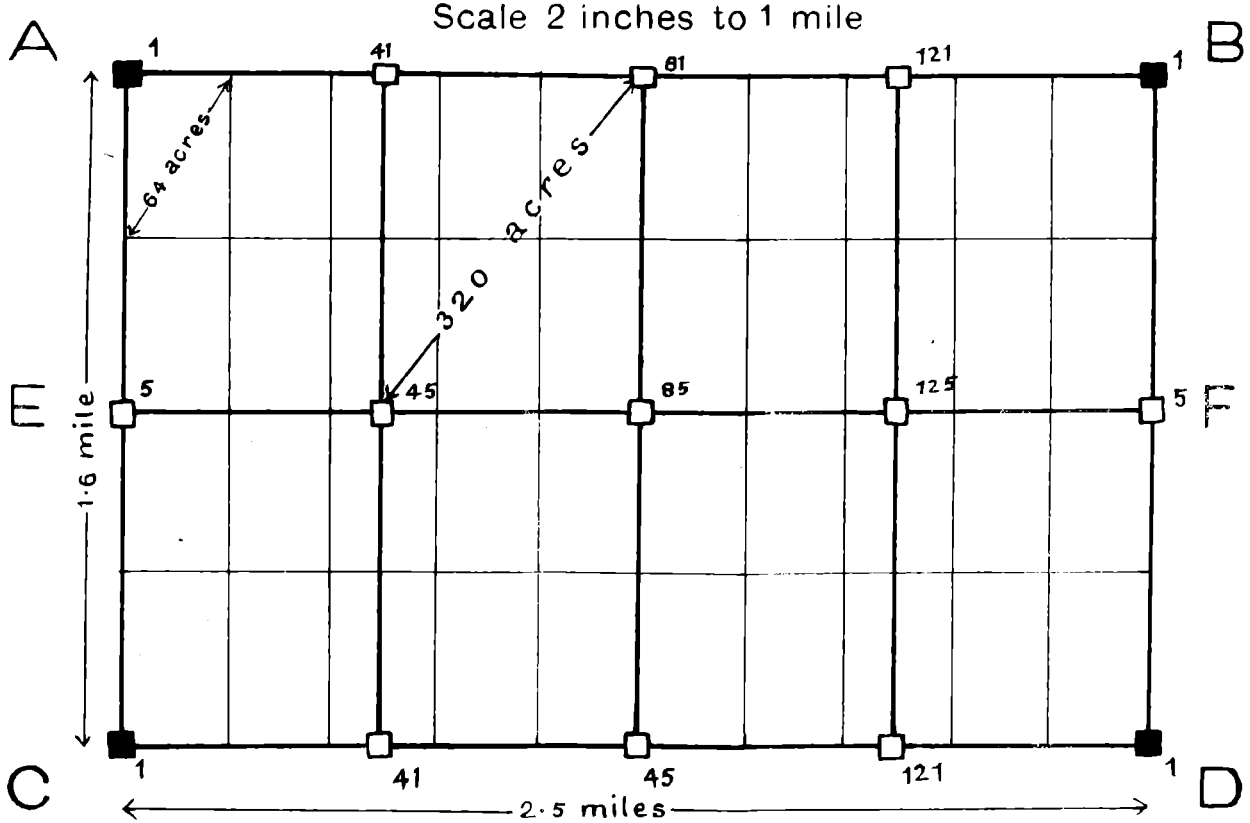


Main rectangle

with

320-acre rectangulation

Scale 2 inches to 1 mile

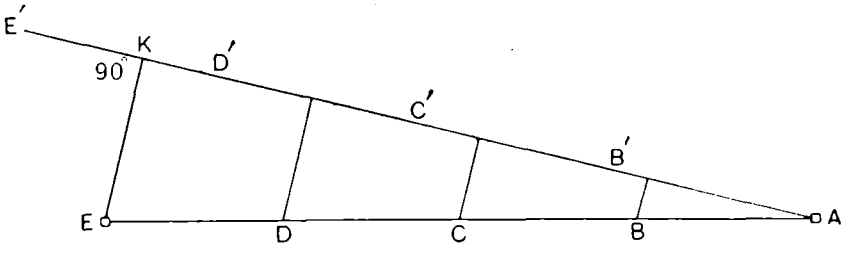


Main corners, laid by traversers.....

Stones laid by rectangulators .....

Diagram No. 5

The practice of running the interior E. and W. line EF before placing both the end stones is not a good one as a rule, as a signal cannot be erected towards which to work.



(*iii*) The subdivision of any line AE will first be considered. The operation is carried out in three stages:—

(*a*) A rectangulator starting from A with a flag on his base-line stone, lays out with his theodolite and clears an approximate line AE′, placing pegs at B′ C′ D′ as he proceeds. On either side of each of these trial stations, he marks an interval of 10 links by pegs, to enable the closing correction to be applied easily.

(*b*) On arrival at E′, he measures the corrections E′K and EK, and returning along the line E′A, he applies these proportionally by means of his chain and optical square at D′, C′, B′, thus fixing the approximate positions of D, C, B, where stones are to be erected.

(*c*) He now advances from A to E, testing the position of the stones B, C, D, for alignment and distance. For this the line AE must be thoroughly cleared. It is evident that care must be taken to lay the initial line AE′ as near its true position as possible, especially in dense country where the labour of clearing two lines AE′ and AE will be very great. The *partäller* checks along the line AE only.

(*iv*) The initial line AE′ if in heavy tree-clad country may not be quite straight. In this connection, raw rectangulators require constant admonition to send alignment flags well forward, though flags for line-clearing purposes only can and must be kept fairly near the line-cutters. The work done on a badly curved initial line is wasted.

In a fairly heavy jungle, the operation (*c*) can be started by means of a proportional offset from a point near A on AE′ to the line AE; line clearing will soon pick up the points B, C, D, E, progressively, being adjusted from time to time.

A practised rectangulator will erect his signal at E as soon as that corner can be found, e.g. the 1-inch map may make it easy to

locate, and in country not heavily forested he can often by doing so place himself on the true line even during operation (*a*), aligning himself between the two signals by means of his theodolite.

(*v*) The rectangulator will now determine the position of E, F (see diagram No. 5) in exactly the same way, except that, having no base-line stones in these lines, he will obtain the initial directions by laying off right angles with his theodolite.

In very open country, if it is found that the points AC, BD etc., are intervisible, it would be quicker to subdivide AB, CD first of all and then determine all the stones on the interior line EF by flagging corresponding stones on the exterior lines and halving the distance between them.

(*vi*) In ordinary country the work will be organized as follows:—

1st operation.—Laying the line AE'.

No. 1 Forward flagman. He will place flags in the alignment as directed by the rectangulator. He will be assisted by Nos. 2 & 3 for line cutting, and carrying flags.

Nos. 4 & 5 will chain, using the 100-foot steel band. At intervals of every 50 chains (i.e. 33 measures of the 100-foot band) they will drive a peg into the ground, together with two smaller pegs at a distance of 10 links on either side of the main peg in the direction of the line.

Nos. 6 & 7 carry the theodolite, stand, signals, paint etc. In very open lines they will be assisted by No. 3; and No. 8 will usually be available to help them. Both Nos. 6 and 7 must be taught to erect and strike the signals single-handed.

No. 8 will at the commencement of the work accompany the camels to the stone depot and be occasionally employed on *dak*. When the *sarwāns* are accustomed to the work, No. 8 will often be available to assist in carrying stores.

No. 9 Personal *khalāsi*.

2nd operation.—Correcting the line E'A. Nos. 1, 2 and 3 will clear the sections ED, DC, BA as soon as flags are erected on the correct positions D, C, B. Nos. 4 and 5 will accompany the rectangulator to apply the chainage corrections. The duties of the remainder are the same as before.

3rd operation.—Testing the line AE. Nos. 1 and 6 will follow in rear and collect flags and signals when directed to do so by the rectangulator. Nos. 2 and 3 will chain, using the 66-foot steel band. Nos. 4 and 5 will chain with the 100-foot steel band. The rectangulator will satisfy himself that the intervals between the stones are correct.

No. 7 will accompany the rectangulator and will erect the theodolite at commanding points to check the alignment.

N. B.—The duties of Nos. 2 and 3 can be interchanged periodically with Nos. 6 and 7, but the other men should not be changed.

(vii) *Notes*:—

(*a*) When station B is finally determined, the rectangulator will take up the base-line stone, scrape off its number, inscribe the new number on it and insert it at B.

(*b*) The tall signal will always be erected at A and not at the base-line stone. The chainmen will start from A so that all intervals will be of equal length (50 short, 33 long measures).

(*c*) If the rectangulator finds a gross error in his position at E′ it may be due to a mistake on his part or on the traverser's part. If his own work proves after check he must correct the position of the stone E by measurement from the four stones to the north, south, east and west of it and report the circumstances to his camp officer. It should not be moved unless the apparent error exceeds 12 feet.

(*d*) *Partālling* must be done systematically, camp officers giving written instructions to the *partāllers* as to which lines to check. When a complete block has beeen rectangulated, its *partāl* should also be completed within a week, and the fact reported to the O. C. Party.

The *partāl* of lines not supported at ends by corner stones laid, requires detailed orders by camp officers.

(*e*) Optical squares must be fairly accurately centered over right-angle points, by means of rough string plumbing, *lathis*, or dropping pebbles.

(viii) Obstacles are avoided by right-angled deviations, using the theodolite and not the optical square. It is often better to use this method on the first clearing, to avoid felling large trees, which might finally be found to be off the true line and so to have been needlessly destroyed and to have wasted hours spent in felling. But as a rule the obstacles consist of buildings or valuable plantations through which the final line cannot be cleared; the preliminary lines and angles must then be measured with special care, and the *partāllers* devote extra attention to the stones.

(ix) The clearing on the initial line should be the minimum necessary; the final line must be thoroughly cleared for a width of at least 3 feet, and all brushwood be dragged away. The *tindal* should be always in full control of the axemen, and by planting flags just ahead of them in the jungle he can prevent their deviating from the line. These flags of course need not be aligned by the rectangulator. Axemen tend to clear too much; they will often waste time cutting down a long tree or bough in the initial line, when a slice off one edge of the trunk would suffice.

(*x*) The numbers to be painted on each stone are clearly shown on the *khākās* and no mistake should be possible.

The numbers and letters should be neatly and clearly printed on one side of the stone before it is placed in the ground; the surface of the stone will first be scraped clean.

Printing ink is supplied in a tube; a little will be squeezed into the paint tin as required. Sticks or ordinary paint brushes will be used for lettering.

If the ink is too thick on a cold day, one or two drops of kerosene should be added to it and the mixture stirred. The addition of too much kerosene ruins the black colour of the ink, making it thin and grey. The numbers are expected to remain legible for months.

Paint brushes must be washed in kerosene directly after use, or they will be ruined; for this purpose a small bottle of kerosene will be carried.

Stones will be laid north and south, the painted side facing south. Small pocket compasses are provided to facilitate orientation.

25. Rectangulators, Exterior (64-acre).—These men have the same orders as 320-acre rectangulators, except that they divide the lines AB, CD into ten portions each, laying 9 stones, and do not work on other lines unless they form part of the double-levelling circuits.

26. Rectangulators, Interior (64-acre).—These are generally new recruits or promoted inferior servants, though the latter are not usually very satisfactory workers. Their work consists in clearing and embedding stones on lines only 1·6 miles long; they employ the same principles, but align by means of flags and field glasses and have no theodolites. They commence their lines by observing right-angles with their optical squares.

Under these conditions, the men must be taught to use their squares properly, and to align by sending their flag as far forward as possible. Their instinct is to prolong a line by short lengths.

27. Tertiary Double-levellers (C. E's area).—See para 18.

28. Tertiary Double-levellers (64-acre area, circuits).—They levelled along lines already rectangulated:—on certain exterior line and along N-S lines forming the limits of the programme (see diagram No. 6). Their technical orders are reproduced *in toto*:—

(*i*) Instruments: Zeiss level No. I, Zeiss level No. II, prismatic compass, 2 telescopic staves, conical iron brads, "level plates" for staff footings; metallic tape.

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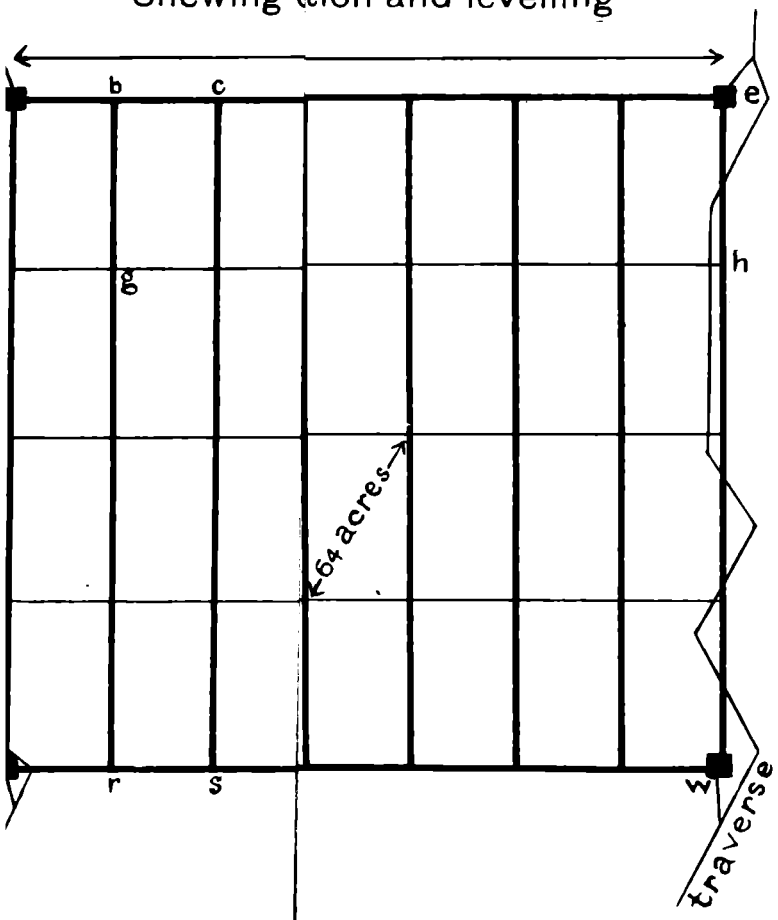
Main Rectaniles or 2,560 acres
Shewing tion and levelling



) 1 mile

a,e,w,q..... ner " stones laid by traversers

b,c,d..... r,s, rior " „ „ „ rectangulators

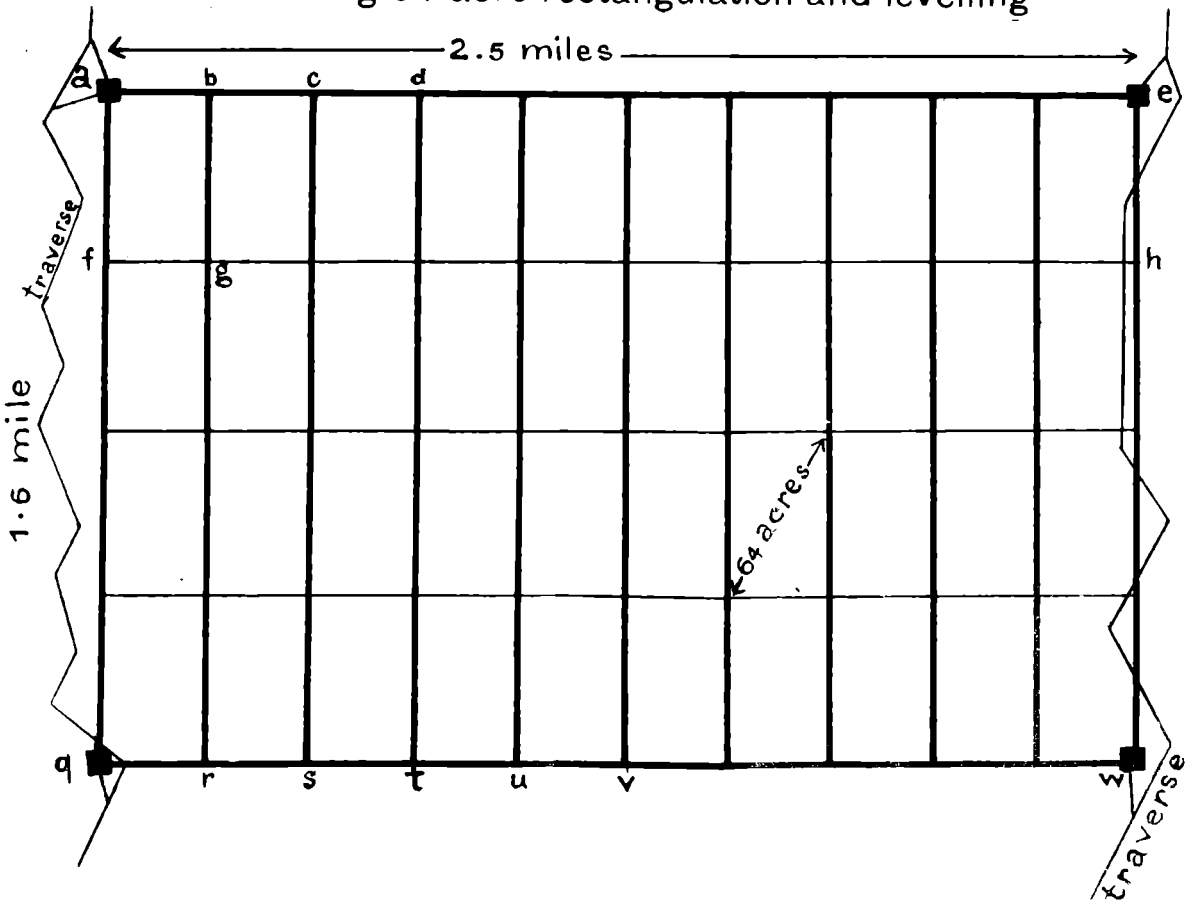
f,g,h etc..... rior " „ „ „ „

Thin lines are not cl q-w and all north-south lines are cleared and d

Lines of single leve outh lines; and in some main rectangles double h edge.

Khairpur Survey

Main Rectangle of 4 square miles or 2,560 acres
Shewing 64-acre rectangulation and levelling



Scale 2 inches to 1 mile

a,e,w,q ..... "corner" stones laid by traversers

b,c,d ..... r,s,t,u,v, etc. ..... "exterior" ,, ,, ,, rectangulators

f,g,h etc. ..... "interior" ,, ,, ,, ,,

Thin lines are not cleared ; the lines a-e and q-w and all north-south lines are cleared and demarcated

Lines of single levelling along all north-south lines ; and in some main rectangles double levelling along the north edge.

Diagram No. 6

No chains, and no guys for staves. Levellers work side by side, using the same pair of staves.

(*ii*) The stones and ground heights to be levelled lie 6½ chains (440 feet) apart E—W and 8 chains N—S; measurements by pacing; the *tindals* must be thoroughly trained to ensure correctness.

(*iii*) Differences allowed: Mean wire — middle wire, 0·005 foot; between levellers at any station, 0·010 foot.

(*iv*) As a rule, "shots" should not exceed 4 chains (this rule was necessitated by the small Zeiss level's short range, but in any case it fitted conveniently into the framework of the 64-acre rectangle).

(*v*) Staves to be plumbed by hand. (Rough string plumbs were used).

(*vi*) As in some places the lines may not be very well cleared, the prismatic compass will be used to assist in keeping direction.

(*vii*) On all stones for "top heights" the position of the brad must be marked with a cross, and should be at the highest points of the surface.

(*viii*) One marked foot-screw must always be placed over the same marked leg, which must always point to the principal staff. The first readings at consecutive stations will be alternately back and forward. The principal staff must be used on the starting and closing points of circuits and all bench-marks, but ground heights and tops of all other stones may be taken by the second staff.

(*ix*) *Natural ground level.*—See para 29 (*viii*) (below).

(*x*) Heights observed: on E—W lines, two ground levels called E^1, E^2 will be observed, dividing the 20-chain distance between each pair of 64-acre stones into 3 equal parts; and the tops of all stones. On lines running N—S along the eastern and western limits of the area, three ground levels S^1, S^2, S^3 will be taken, dividing the 32-chain distance between each pair of 64-acre stones into 4 equal parts; only top heights of stones will be observed where the stones form the ends of lines to be single-levelled, otherwise only ground heights.

On the western limit at stones which do not form terminals for single-levelling, the ground levels E^1, E^2 must be taken (for method, see under single-levellers, below).

(*xi*) A circuit detachment must commence work at an old bench-mark and must pick up all bench-marks on its line. These will be either old or new; levellers must see that they have all descriptions and existing heights with them.

(*xii*) Check-levelling: at least three Primary or Secondary bench-marks should be connected in each case; the Levelling Handbook table for check-levelling will be used.

N. B.—Where several detachments, are at work, the Camp Officer should keep them all informed as to which bench-marks have been accepted; otherwise some check-levelling will be repeated unnecessarily.

(*xiii*) Programmes of detachments are marked out clearly on diagrams of blocks. Levellers must study the system of stone-numbering, and thus avoid a great deal of comparison in the field. Field sheets (13 Lev.) will be completed every third day, and diaries and block diagrams showing lines and bench-marks be submitted weekly.

29. Tertiary Single-Levellers.—(64-acre area). They levelled lines 6·4 miles long, across double-levelled circuits.

(*i*) Instruments—Zeiss level No. I; prismatic compass (mounted on level, or pocket pattern); 2 telescopic staves with "level plates" and conical brads; no guys; metallic tape; measurements by pacing.

(*ii*) The ground heights to be measured lie 8 chains (528 feet) apart N-S, and $6\frac{2}{3}$ chains E-W. The *tindal* must be thoroughly trained to pace correctly.

(*iii*) Observations: for all points except E^1, E^2 readings will be to 0·01 foot; the mean wire must agree exactly with the middle wire. E^1 and E^2 will be observed to 0·1 foot only.

(*iv*) Shots: limited by the framework to 4 chains.

(*v*) Staves will be plumbed by hand. (Rough string plumbs were used).

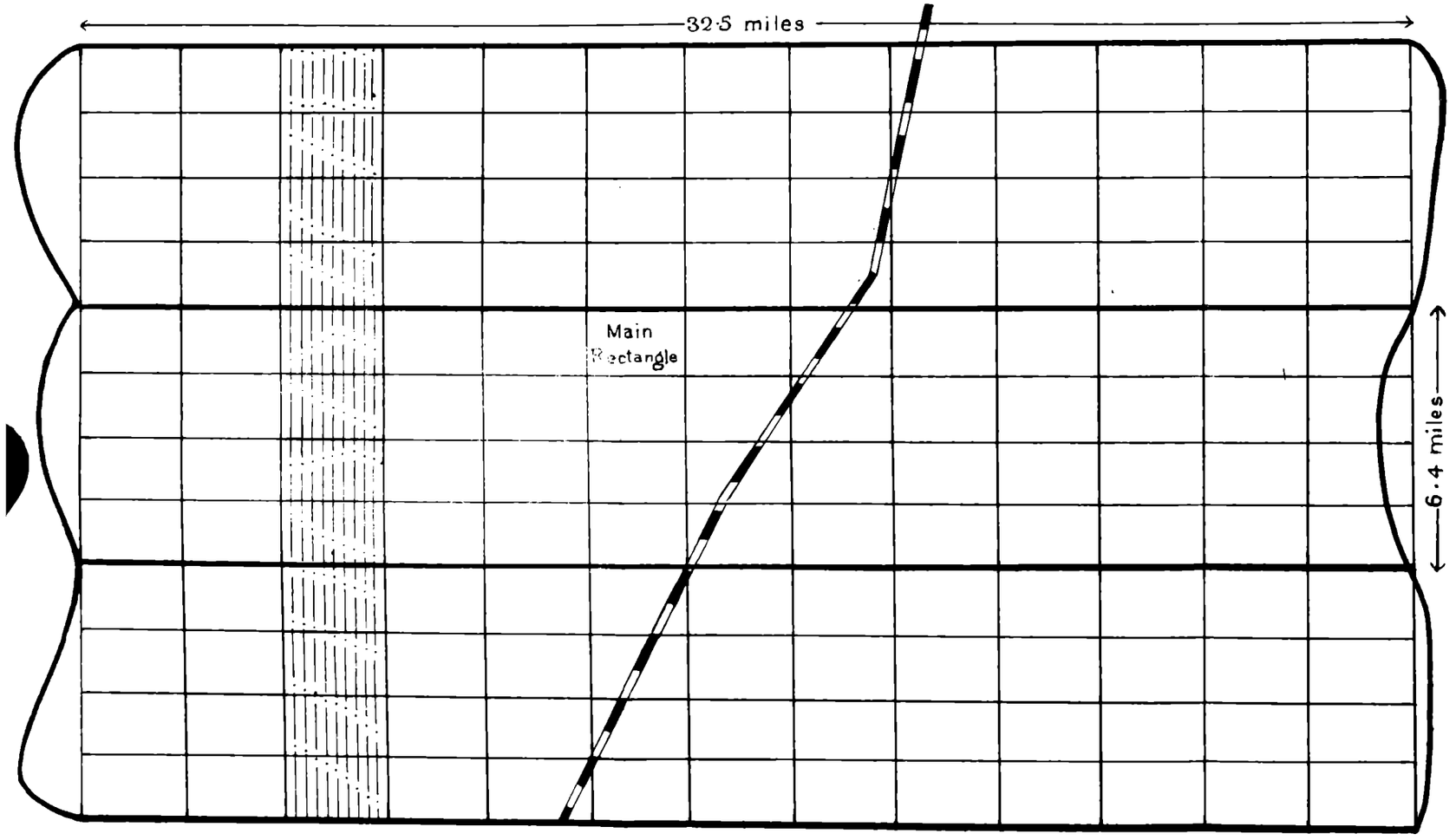
(*vi*) Lines run north and south, and will be found cleared; the greatest length is 6·4 miles or 4 main rectangles. They will always commence from and close on double-levelled 64-acre stones, each marked with a cross for the brad position. Ground levels will also be observed at these terminal stones; at intermediate stones and points only ground heights will be taken.

(*vii*) Ground heights are required at each 64-acre stone and at three intermediate points S^1, S^2 and S^3 in each N-S side of a 64-acre rectangle (intervals 8 chains); and at each intermediate 64-acre stone two additional ground levels will be observed at east points E^1, E^2 (see diagram No. 6). The direction of the line on which E^1, E^2 fall must be carefully determined by the prismatic compass. If the country is open enough, the instrument is set up at E^1, and staves at A and E^2; at E^1 the

Khairpur State Levelling

(Circuits not laid out to conform to blocks)

Scale $\frac{1}{4}$ inch to 1 mile



G.T. primary line.

Tertiary double levelling circuits giving heights to tops of all stones.

" single " giving ground " as in next diagram.

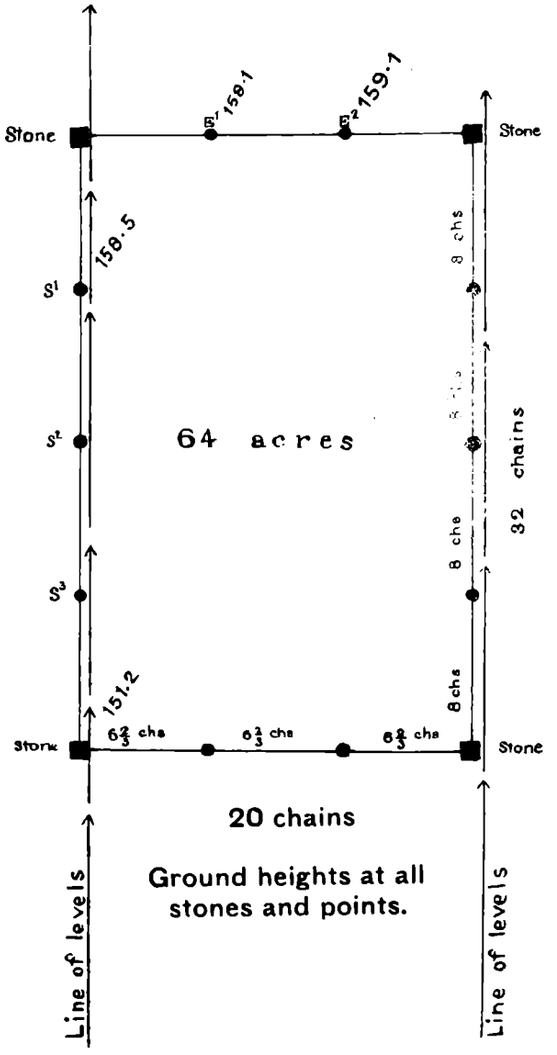


Diagram No. 7

height of the telescope is measured by tape and recorded to 1 decimal place in the intermediate column as the fore reading for E^1. The rise or fall of E^1 and E^2 are placed in brackets and treated as "extra" stations.

To avoid confusion, stone numbers must invariably be entered in the sheets when observing. The system of stone-numbering must be carefully studied.

All stations will be numbered serially in the field sheets, except E^1 and E^2, which will be lettered E (extra).

(*viii*) *Natural ground level.*—Where ground level heights are required, natural ground level must be selected if available within 30 yards of the true position; i.e. heights on small mounds, bunds, canal embankments or in ditches or water-courses are not wanted. If natural ground level is not available within 30 yards, the artificial level at true position will be taken and a note made in the "remarks" column.

(*ix*) Field sheets are to be sent to H.Q. as lines are completed; block diagrams and diaries monthly.

Chapter V

THE PERMANENT MARKS

30. Description.—The large rectangulation stones used for all work done for the Chief Engineer and for the exterior rectangulation in Khairpur, are rough monoliths 2′ 6″ × 9″ × 9″, weighing about 1 cwt. (four to a camel load). The top 10 inches only are dressed, to a 6-inch section. For the first field season they were obtained from the Barrage quarries at Rohri, but the stone was not hard enough to withstand *kalar* decay, and instead there was selected a hard brown limestone from one of the better quarries at Jungshahi, near Karāchi. These cost Rs. 1/4/- each, unloaded at any station in Sind.

The small stones, used for interior marks in the Khairpur rectangulation, are of the same material roughly cut, measuring 2′ in length; the top is nominally 3½″ square, the bottom 3½″ × 2½″. They are of the same dimensions as those used by the Barrage revenue staff. They cost 6½ annas each, unloaded at railway stations in Khairpur State. 12 stones make a camel load.

Bench-marks were constructed by the Barrage Executive Engineers and the State authorities, and as usual the levellers inscribed marks on permanent structures on or near their lines. The ordinary main-corner bench-mark is a concrete masonry pillar 12″ × 12″, and resting on a solid foundation; but in some divisions it is an iron rail of uncertain length driven into the ground, with about 15″ exposed. The concrete resists *kalar*. In the design used at first, the rectangulation stone projects from a large concrete block buried in the ground, the top being the bench-mark. At each Block corner is a Survey of India type B interred mark, with the standard-pattern reference pillar.

Main-corner bench-marks are sometimes sited a few feet south of the corner. This was convenient in cases where the building was delayed, the corner stone being available to the levellers as a temporary mark from which the height of the bench-mark when built could be obtained later in the season. The reference pillars of type B marks stand on the corner, the bench-mark being buried a few feet to the south.

Some of the corner bench-marks were built very shortly before connection, and have probably sunk appreciably since their heights were observed.

31. The conditions in Sind as regards arrangements for the supply of stones are inconvenient, in that many of the villages or hamlets are small and isolated, with no headmen who can be made responsible for the safe custody of stone depots; some stacks have to be left miles from any habitation whatever. Occasionally an inspection bungalow or a railway station could be utilized, the railway authorities giving small plots of ground on lease at a nominal rental but accepting no responsibility. On the whole the loss of stones by theft was negligible, and most cases occurred at depots where owing to reductions in programme the stones lay unused for several months.

In Sind the summer floods often make it very difficult to move stones by road until about the 1st September; it is convenient, and ensures their being at field depots in good time, to have them delivered at railway stations on that date, and counted (by an officer, if available). If good hard stones are supplied, a 3% allowance for breakage is sufficient; the contractor being paid for it, but not for excess breakages.

32. The transport by road to the field depots is best done on contract; as a special case the P.W.D. undertook the work for the first field season, the stones being wanted very urgently, but their rates were no cheaper than those later contracted for.

A stone delivered at a railway station for Rs. 1/4/- may cost another Rs. 1/4/- by the time it is dumped in the field; consequently if a depot requires a large supply, it is economical to leave the surplus 3% in the leased plot on the railway, to be drawn on later by the Camp Officer if he needs them, and carry only the actual number required by the area which the field depot serves.

Stones at depots are counted when first seen by surveyors, not all at once, and on their reports the contractor is paid; shortages can first be made good by his carrying the deficient number from the railway station. This system is open to the objection that thefts from the depot before the surveyor visits it would cause a direct loss to the contractor, but such losses are rare and are allowed for by the contractor when calculating the rates he tenders for the carrying contract.

33. The rates paid for carriage have been generally 11 pies per stone-mile for large stones, and 6 pies for small. On the Eastern Nāra, a deserted region with poor communications, the rate for a small number of large stones was 14 pies. In that region the stones for the 1930-31 programme (the Khairpur Detachment) are to be moved by the State authorities, by water.

In consequence of the great expense of road transport it is occasionally cheaper to buy new stones than to transport old ones across to another part of the country under survey.

34. The contract must provide that the distances used for calculating the bills for carriage are taken from the 1-inch map by the officer in charge of the party (after camp officers have reported where the stones have actually been dumped); owing to the long unbridged stretches along canals, the straight-line distance is not used, but the shortest practicable route.

35. The unused stones left at depots are listed for the Chief Engineer, whose revenue staff may find a use for them later; Executive Engineers have none.

36. The stocks at railway stations and field depots are recorded at party headquarters in a Stone Book, entered up from the details of the actual payments to the contractor and the camp officers' reports.

Chapter VI

WORK IN RECESS

37. Traverse computations.—These having been completed in the field, there remained only the indexing and binding.

38. Levelling computations.—The Chief Engineer's lines were computed in the ordinary manner, as for secondary double levelling, except that the tape-bar comparison was not carried out in the final field season. The usual manuscript lists of heights were sent him.

For the Khairpur close network, the field office carried the work as far as closing all the double-levelling circuits, giving M.S.L. heights to all stones, and checking the closing errors of single-levelling lines. In recess the computation of these lines was completed and the heights entered on MS. sheets, each of which covered the area of one "chart". The heights of bench-marks were listed separately, it not being convenient to enter them on the MS. sheets, and their positions not being accurately enough known to enable them to be plotted on the "charts" (see below).

39. Masavis.—Vandyked skeleton prints were provided by "E" Survey Company. They contained nothing remarkable, except that the stones were shown as hollow circles, which could be neatly filled in by brush, which obviated the use of compasses.

Separate patterns were used for 320-acre and 64-acre rectangulation; lines cleared by rectangulators were shown thick.

A *masavi* was completed for each main rectangle and these were then vandyked and printed by "E" Company.

The comparison in the field of margins of *khākās* was found to expedite the recess work considerably.

40. Contoured charts.—The Khairpur State authorities were desirous of having some form of topographical maps for use when constructing their canal system, but considered that the old 2-inch topo. sheets were quite accurate and detailed enough for their purpose, no revision survey being necessary. They required first the compilation of sheets on the 4-inch scale, showing enlarged topo. detail, the levelling heights, and 1-foot contours drawn in office, and have since decided to have copies printed. Each of these

charts covers the area of four main rectangles, there being thus 25 in a Block. A skeleton chart was drawn and reproduced in blue by "E" Company; on one copy for each sheet the levelling section entered the spot heights, the old detail was pentagraphed up, and the contours were then drawn. This proved rather difficult in places, owing to shifting sand. There were 78 charts.

41. Index mapping.—Besides the usual general purposes ¼-inch index map for the Project, the annual stone charts, progress indexes etc., there was compiled a skeleton ¼-inch index showing all stones laid for the Chief Engineer and indicating in a list those which on account of obstacles had had to be laid away from their proper positions. The map is too large to include in this volume.

Chapter VII

THE FIELD AND RECESS ORGANIZATION

42. Field units.—After the first field season, when one camp had to carry out both traverse and rectangulation in the same blocks, the work was divided, each camp having its own separate area and confining itself as far as was practicable to either one operation or the other. Traverse camps completed their work by laying main corners for rectangulation the following season; a rectangulation camp would execute the rectangulation of all classes in its area. But on occasion traversers have been set to rectangulate in their own camp territory, at the end of the field season, and rectangulators have taken up the revision of the past season's traverse where necessary, or new traverse when a fresh area was suddenly added to the programme.

43. The camp which levelled 64-acre rectangles in Khairpur State did so *pari passu* with the rectangulation, and the headquarters of both camps were together at Khairpur in close touch with each other.

The levelling detachments in the Chief Engineer's territory were not organized as a camp, but each was directly under the O.C. Party; their work was plain double-levelling and their results were not required until the following recess.

44. An important requirement for the general organization is that the traverse and main control levelling of any part of the area should be carried out early enough to permit systematic general adjustments and to give time for the control levelling to be done deliberately.

45. There was some administrative inconvenience in the secondary levelling detachments (season 1927-28 only) working under the Director, Geodetic Branch; but as the necessary main-corner laying (which gives sites for bench-marks) had all been done the previous season, there were no arrangements to co-ordinate between the two Parties concerned. The detachments when they turned from secondary to tertiary levelling, and joined No. 24 Party, were the cause of much correspondence with Executive Engineers

over bench-mark building, and when they were finally placed under Lower Subordinate Officers it became more obvious that they should always belong to the rectangulation party on the spot.

46. If convenient for programme purposes, a traverse camp officer without an assistant, but provided with a reliable head computer, can easily supervise in addition 15 good rectangulators, since the traversers when trained need only rarely be visited in the field; their accuracy and outturn are self-evident; but he must be in close touch with his headquarters, in order to decide himself all questions of traverse adjustment and revision.

Similarly a levelling Camp Officer, who must be a skilled leveller himself, could manage a combined rectangulation and levelling camp of about 40 trained surveyors; most of his attention would be given to pushing on the rectangulation so as not to delay his levellers. But for this he would require an assistant, and in practice it would probably be best not to combine the two operations in one camp, but merely to ensure good liaison.

A camp officer must be provided with a good "camp clerk", to prevent his being too much involved in office work. A camp of over 30 surveyors should have two of these men.

47. The largest camp established was that for the exterior and interior rectangulation in 1929-30, which contained at the start 29 exterior men and *partāllers* and 20 interior men, grouped under 5 old *partāllers*. They and all the exterior men were selected specially; there was a senior Class II officer in charge, without an assistant, and the work was well done.

48. The class of men recruited as traversers, rectangulators or levellers is one of the greatest influences on costs, and it is economical to give high rates of pay for good workers. The promotion of *tindals* to rectangulators was tried in a few cases, but the result was not encouraging; even interior rectangulators must have some managing ability and "drive". Nearly all surveyors were on the usual "purely temporary" rates of pay: 30/- on recruitment, 35/- when trained, and increments when deserved, up to 42/8/-. This scale attracts good men, and also others who should be weeded out early. Interior rectangulators were not recruited until the final field season, when they were offered 25/- on joining and 30/- when trained; the rate was perhaps too low, as the recruits in general were rather too young, though on the whole of a good enough type. It would, as subsequently appeared, have been cheaper to pay the high rates.

49. The field staff of traverse and levelling computers were mainly made up of purely temporary men, but there must be a nucleus of good regular computers—say two men for each camp. On an average, one levelling computer is required for every two levellers.

50. *Partāllers* ought to be regular Survey of India men, but if these are scarce then purely temporary traversers or rectangulators must be selected. One man can *partāl* the work of seven rectangulators in ordinary country; in very open plains he cannot keep up with them.

51. *Khalāsis* were recruited from Rawalpindi and Garhwāl, and were satisfactory; practically none are available locally. They drew Rs. 17/- on joining, as purely temporary hands.

52. The sizes of squads were the same as in the Sutlej Valley surveys, except that a traverser was given an extra *khalāsi*, so that he had in all 13 men; an exterior or 320-acre rectangulator 9, and an interior rectangulator 6. The extra man was given to the traverser from the party reserve, in order to cope with the comparatively heavy forest; more particularly, when the squad drills were devised, it was very apparent that out of 12 men only two would be line-cutters, and adding one axe man would increase the speed of the traverse. In rectangulation the daily distance run is much less, the whole squad of 9 men was available for cutting when wanted, and to increase the speed considerably would have entailed adding 3 or 4 men. Similarly 6 men were sufficient for an interior rectangulator. *Partāllers* require equally large squads on account of the great distances they cover.

53. In each squad which did not contain a regular *tindal* or mate, purely temporary *khalāsis* were selected as such and when trained were given monthly allowances of 1/8/- and -/8/- respectively, which could be cut off for bad work. Much depended on the chaining.

54. As an experimental measure, there was in force for two field seasons a system of paying bonuses to traversers and rectangulators and their *khalāsis* for increased outturn; it was finally terminated as being of doubtful value.

In No. 24 party the plan gave good results in increasing outturns, and reducing costs. It was not applied to levellers, whose outturn it is not desirable to force at the probable expense of accuracy, and would be very difficult to apply to topographical surveys. The radical defects were that in practice it had very little effect in November, December, or January, when daylight hours are short and fever is prevalent, for the men then preferred working at a normal pace for their normal pay, to working harder and perhaps not benefitting appreciably; slow or unambitious men could not hope to earn much, and so did not make much effort to do so at any time; in order to apply the scheme equitably and make it attractive in all conditions of country, the work done on lines which had to be cut through heavy jungle had to be assessed at a higher value in outturn than that in the ordinary fairly open plains, and the assessment was rather a complicated process when the lines had

not been visited by an officer; and the reporting of errors involving fines gave a great deal of power to the *partāllers*, who were all lower subordinates and mostly purely temporary. But the net result was good; the best men gave greatly increased outturns, and the cost of the extra work done all round was afterwards calculated to be about half of its normal costs; the assessing of jungle lines was probably fairly good, as nearly all the "dense" lines lay in well-defined forest areas along the rivers. The *partāllers* do not appear to have taken advantage of their position, except in so far as they may have corrected some of the errors they found and not reported them; a fair number of errors were reported, and judging by the small number so far found by the revenue staff the work as handed over to them is accurate. This point does not of course apply to traversing, which proves itself.

55. On the whole, the scheme is more suitable for a staff of highly trained and fast traversers and rectangulators than for the class of men usually engaged. The final report on its working is given under the Director, Central Circle's Letter No. 7896 of the 24th September 1929 to the Assistant Surveyor General, with suggested rules for any future application of the plan.

56. Transport.—While the programme of No. 24 Party included interior rectangulation, and the carriage of stones (to field depots) in the summer and of camp equipment in the winter would have kept motor transport fairly steadily employed throughout the year, plans were made for the purchase of two or three light six-wheeled lorries. They could have been operated comfortably in the plains of Sind and the local bridges were strong enough for their weight. The reduction of the scheme to 320-acre rectangulation only so cut down the weight of stones and the number of surveyors that the project had to be dropped. In any future scheme of interior rectangulation it will be well to consider the virtues of motor transport for a great part of the work.

57. No. 24 Party depended entirely upon camels, mostly from Shikārpur (Sind). Very good animals were obtained; riding camels cost 30/- per mensem, and load camels 22/- (if one *sarwān* per pair) or 20/- (if one *sarwān* to three camels). The contract stipulated that the contractor must station an agent at each camp headquarters, to replace casualties immediately and to keep the *sarwāns* contented by paying them regularly.

In lower Sind it is impossible at present to hire good camels in any numbers; the local drivers also are too independent to be relied upon.

The rates of pay quoted above are higher than those usually paid in Sind; the desideratum was that there must be no risk of a break-down in programme.

The Government allowance was as follows:—

Each camp officer (he paid the hire of the riding camel)	4 load and 1 riding camel
Each traverser or 320-acre or exterior rectangulator ...	4 load camels.
Each interior rectangulator:	camels were grouped, 3 pairs to every two rectangulators.
Each tertiary double-levelling detachment	11 load camels
Each tertiary single leveller...	2 „ „

The hardest work the camels have to perform for a rectangulator is the carrying of stones from depots. The scale of interior rectangulators' camels was quite adequate.

58. Instruments.—A traverser or a rectangulator should have a transit theodolite. In No. 24 Party most rectangulators had "railway" theodolites, but the absence of the vertical circle was of no appreciable advantage. A 3-inch instrument was tried but found to be too light for use in a high wind, and of too low magnifying power. For chains, a traverser or rectangulator requires a 66-foot and a 100-foot steel band chain, which are easily pulled through jungle and do not stretch; repairs can be made quite well enough by local blacksmiths, without shortening them. A 330-foot band chain is very useful for a traverse line across a large canal. Traversers' plane-tables need not be in first rate order, so long as they are steady on their stands.

Levellers need not be given standard steel tapes for checking staff lengths. A double detachment on control circuits must use Committee Pattern staves (one pair) and large (e.g. Zeiss II) instruments. Giving the second leveller a small instrument retards progress. Double-levellers on ordinary circuits should have small levels and telescopic staves. The "level plates" supplied by No. 17 Party were highly satisfactory.

Steel band chains are much better than the ordinary pattern, especially in jungle. Pocket prismatic compasses should be used only if those mounted on the levels cannot be had.

Intelligent rectangulators should be given tables showing for various chainages the distance off the true line for each minute of arc by which the angle subtended by the signals exceeds 180°. Optical squares are satisfactory enough and are very portable, but men require to be taught how to use them. Interior rectangulators should be given light wooden cross-staves of the simplest pattern.

59. Equipment.—In country containing any considerable amount of forest, the best speed is attained only by the use of good steel "American" axes, weighing about 3½ lbs. (Heavier axes are no better for men not used to them). The handles should be of hickory or ash, which cost little or nothing more than inferior and brittle wood. Two men of each squad should be equipped with these axes, with spare handles. Soft iron *daos* and axes are worse than useless. The carrying of stones by the rectangulators' camels necessitates the use of *kajawas*, which should be made of strong wood and not too light. Hedging gloves are essential when *babul* or other thorny trees or jungle are encountered, i.e. everywhere in Sind; two pairs to a squad are enough.

Surveyors were given double-fly tents of good thickness, the heat being intense; and troops' pattern mosquito nets. Each *khalāsi* had two blankets, as a precaution against chills and pneumonia.

For painting numbers on stones, printing ink was adopted instead of coal tar, as leaving a more lasting impression.

60. The recess organization had to deal with the preparation of *masavis*, the levelling computations and the compilation of contour charts for Khairpur. The *masavi* section in addition carried out a good deal of work in connection with reports and preparations for the field. Altogether, an ordinary traverser or rectangulator who can type well enough for the purpose can dispose of 40 *masavis* a month and undertake miscellaneous work as well. The computations of ordinary double levelling require one computer for every 200 linear miles; half the men should be practised computers, and as a rule they will include the actual first and second levellers. The tertiary network levelling is mostly computed in the field, and in recess one computer will suffice for every four levellers employed in the field.

If heights have to be entered on contour charts, one computer for every 10 levellers should be added. These figures assume a field season of 5½ months and a recess of 6½ months.

The traverse computations in recess are quite negligible.

Compiling the 4-inch contoured charts in No. 24 Party included the pentagraphing of the detail from old 2-inch maps; this operation, including the inking up, takes one ordinary draftsman one day per sheet. To intelligent surveyors (plane-tablers) the contouring is easy, after a little practice, and a man can turn out a sheet in one day.

Chapter VIII

MAINTENANCE AND RECORDS

61. The remarks in this chapter touch on some of the survey work of the Barrage staff; they do not directly concern the Survey of India.

62. Rectangulation stones.—Among the first steps taken by the Lloyd Barrage survey staff when an area of rectangulation is notified to them as completed, is the recording of field measurements taken from the stones to at least two corners of fields or other semi-permanent objects. (This operation enables the revenue survey office to initiate the process of adjusting the old survey-number holdings to the new rectangular plots). So long as the old field and other detail survive, it will be possible to check the positions of the stones; but where this has become impossible, or the check-measurements are too long to exclude uncertainty, it will for some time (i.e. until in the course of development the rectangulation stones have become too well-known to be moved with impunity) be necessary to check positions by stone-to-stone measurements.

63. To do this, it will be sufficient in the case of an occasional stone to measure its distance from the nearest main-corner stones in all four directions, noting also the distances of all other stones on the line. The chaining should be done twice, for safety. The resulting record should indicate at once any shift which may have occurred; but if it is not clear, or if widespread errors involving main corners are apparent, it would be best to employ a traverser to connect together in a circuit all the main-corners suspected, and compute the result; extending the traverse until the computations show that the shifts have been detected. Any good traverser who has been employed on the rectangulation can do this by himself. The working rules of the Survey of India are detailed in "Theodolite Traversing" (Geodetic Branch, Dehra Dūn, 1927). The origin of traverse is lat. 26° 30′, long. 68° 30′. Apparent errors of 12 feet or less in north or east direction may be ignored.

64. It should be borne in mind that many main-corner bench-marks are not sited exactly on corners and so should not be connected; but also that main corners at or near bench-marks are less likely to be tampered with than the others. The main corners are the only stones which were laid by theodolite traverse, and form

the frame for the rectangulation. The fact that the north and south lines through other stones will seldom be found quite straight when cleared, is accounted for by the method of survey in the 320-acre rectangulation; the bends may often be about 3 minutes of arc. If it becomes desirable to straighten these lines, the 320-acre stones 45, 85, 125 inside a main rectangle should not be considered less reliable in easting than those on the north and south edges.

Stone No. 5 is accurate in easting; 41, 81, 121 in northing; 5, and consequently 45, 85, 125 depended on chain measurements for their northing; and 41, 45, 81, 85, 121, 125 did so for their easting.

In the Khairpur State 64-acre rectangulation, on the other hand, the east and west lines inside each main rectangle were not cleared, and will not be quite straight.

65. Levelling.—It is hardly necessary to mention the desirability of preserving the marks, and of avoiding repairs which would affect their height values.

The nature of the soil and the vagaries of flood-water render the maintenance of the levelling more difficult than that of the rectangulation. Generally speaking, the reliability of a mark depends on its own age and character, far more than on the standard of precision of the levelling; in order of merit, the old bench-marks on the pre-1927 primary and secondary lines come first, having as a rule been built substantially, and months in advance of the levelling. The new marks connected by the 1927-30 levelling vary considerably; those cut on existing structures, the tree bench-marks and the iron rails will have remained practically stable; those embedded bench-marks (at rectangle corners) which were built earliest will be almost as good, those built just before they were connected will be unreliable, and ordinary rectangle stones (where bench-marks were not built at all) very unreliable. But (perhaps excepting the marks on existing structures, trees and iron rails) the flooding of an area which has for months or even years remained fairly dry tends to upset all values, and an artificial structure even in ordinary uninundated land continues to sink slowly for an indefinite period especially if the soil is light and contains *kalar*. Occasionally a bench-mark or even a large tract may slowly gain in elevation, but the practical effect in the latter case is generally nil.

66. A bench-mark which is suspected of having altered its height should therefore not be judged by itself, but the neighbouring marks as well if of doubtful character should be examined; they also may have sunk, though to a less extent. The leveller should first connect at least three bench-marks of good repute, if possible avoiding masonry rectangulation marks, and see whether any two of them have maintained their relative heights, in which case they can

both be taken as good. It will generally be quite convenient to connect five marks. The Survey of India bench-marks within a radius of 3 miles from any point can be relied upon to have been given correct relative values when levelled, within one inch in height.

67. The records.—All the professional records of the survey are being lodged with the Director, Frontier Circle, Simla; these comprise the traverse and levelling field sheets and computations, the rectangulation *khākās* and the *masavi* originals, besides various index maps on the ¼-inch scale showing in detail the work done year by year. The Chief Engineer and the Khairpur State authorities have been supplied from time to time with the levelling results and with printed *masavis*; a ¼-inch index map is being reproduced for the Chief Engineer, showing every stone laid in his area and a list of stones laid out of their diagram position (on account of obstacles) and the amount of the displacement.

68. The compiled 4-inch sheets of the Khairpur State area will probably be reproduced and printed off. It may again be remarked that the one-foot contours on these sheets have been drawn in office, with the ground heights as control and the old topographical detail as a guide; they do not pretend to be surveyed or to show the actual shapes of features, but are a convenient help to the eye.

APPENDIX

EQUIPMENT TABLES

(*a*) *Traverser*

INSTRUMENTS		EQUIPMENT—(*Contd.*)	
Chains steel band 66-foot ...	1	Paint tin	1
,, ,, ,, 100 ,, ...	1	Ropes loading	288
,, ,, ,, 330 ,, ...	1	,, for drawing water ...	90
Compass magnetic trough ...	1	Scales and weights ...	1
,, ,, pocket ...	1	Spectacles, dark	1
Field glasses ordinary ...	1		
Lamp bull's eye	1		
Pins for chains	22	TOOLS	
Plane-table complete ...	1		
Sight rule	1	Axes, American with 2 spare handles	2
Tape measuring steel 100 ft. ...	1	Axes, country	2
Theodolite, complete (vernier transit)	1	Axes, Sindhi (light hatchets)...	3
Traverser's instrument box ...	1	Chisel, mason's	1
Traverser's Instrument box containing: brass protractor...	1	*Daos*	2
bow pen ...	1	*Darantis*	2
ink pot ...	1	Hammer, iron	1
dividers ...	1	*Kudalis*	2
		Mallet	1
		Phaora	1
EQUIPMENT		Tent I with *salitas* and pegs ...	1
		,, J ,, ,, ,, ...	1
Badges brass with slings ...	2	Umbrella survey pattern ...	1
Chhagal, canvas	1	Water tanks (camels) ...	2
Chain for cash box ...	1	Water bottles	3
Dols (small buckets) ...	2		
Drums for water	4		
Flags red and white ...	4	MISCELLANEOUS	
,, poles 10 ft.	4		
Gloves hedging pairs ...	2	Stationery and office forms	..
Gunnies	3	Professional forms 2 and 3 Traverse	..
Haversacks	2	Drawing pins	..
Kajawas, pairs	2	Gridded 1″ maps	..
Lantern	1	Printing ink for painting stones	..
Medicine box	1		
Mosquito net	1		

(*b*) *Levellers.*—Double tertiary detachment (control lines only, not ordinary D.L. circuits) or single levelling:—

Articles	Double	Single	Articles	Double	Single
INSTRUMENTS			EQUIPMENT—(*Contd.*)		
Abney level	1	...	Mosquito nets	5	1
Brads, B.M. and peg ...	5	...	Paint tins	1	1
„ conical	...	5	Pegs levelling	200	...
Chains iron 66′	2	...	Ropes loading	700′	70′
Compass prismatic ...	1	1	„ drawing water ...	150′	50′
Level plates	..	3	Scales and weights ...	1	...
Level Zeiss II	2	...	Spectacles dark	5	1
„ „ I	...	1	Stools, recorder's ...	2	...
Pins iron for chains ...	11	...	Tables	2	...
Staves committee pattern ...	2	...	Tent E	1	...
„ telescopic with rough			„ I	4	1
Plumb-bob	...	2	„ J	3	1
Tape linen 100′	1	1	„ G. S. 14′ × 14′ with		
Umbrella, Survey ...	2	1	mallets and pegs ...	1	...
EQUIPMENT			TOOLS		
			Axes country	2	2
			Chisels, mason's ...	2	1
Badges brass with slings ...	3	2	*Daos*	2	1
Buckets	7	2	Hammer, levelling ...	2	1
Chairs	3	1	*Phaoras*	2	1
Chain for cash box ...	1	1	Pickaxe	1	...
Chhagals canvas ...	5	1	*Tasla* (pan)	1	1
Dols (small buckets) ...	1	1	Water tanks (camel) ...	4	...
Drums for water ...	4	2	Water bottles	27	6
Gunnies	6	2			
Haversacks waterproof ...	1	1	MISCELLANEOUS		
„ ordinary ...	3	1			
Kajawas, pairs	8	1	Stationery and forms ...	...	...
Lanterns	5	1	Tube of printing ink ...	...	...
Medicine chest	1	...	Field ink pots	5	2
„ box	...	1	Field sheets 800 ...	800	350

For ordinary D. L. circuits, twice the numbers under "single"; such detachments break up and turn to single levelling.

(c) *Rectangulators*

Articles	Exterior	Interior
INSTRUMENTS		
Chains steel band 66-foot ...	1	1
„ „ „ 100 „	1	1
Pins iron for chains ...	22	11
Field glasses common ...	1	1
Optical square (or cross staff)	1	1
Tape steel 100′	1	1
Theodolite, 5″ Vernier ...	1	...
Umbrella, Survey ...	1	...
EQUIPMENT		
Badges brass with slings .	2	2
Chain for cash box ...	1	1
Chhagals canvas ...	1	1
Dôls (small buckets) .	2	2
Flags on 10′ poles ...	8	8
Gloves hedging, pairs ...	2	2
Gunnies	6	3
Haversacks	2	2
Kajawas pairs ...	2	1 or 2
Lanterns	1	1
Mallets for signals ...	2	2
Medicine box	1	1
Mosquito net	1	1
Paint tins	1	1
Plummets for signals ...	2	2
Ropes, loading, 36′ ...	4	4
„ drawing water, 50′	2	2
Scales and weights ...	1	1
Signals 20′ } Each complete	2	2
„ 30′ } with tops and ropes	1	1

Articles	Exterior	Interior
EQUIPMENT—(*Contd.*)		
Spectacles dark ...	1	1
Sticks for chainmen ...	4	2
Tanks, water (camel) ...	2	2
Tent G.S. 14′ × 14′ } with pegs	1	...
„ I } and *sali-*	1	..
„ J } *tas.*	1	2
TOOLS		
Axes American	2	2
„ spare handles ...	3	2
„ Country	2	1
„ Sindhi (light hatchets)	3	2
Daos	2	2
Darantis	2	2
Hammer	1	1
Kudalis ...	2	2
Phaora	1	1
Water bottles ...	9	6
Water drums	4	3
MISCELLANEOUS		
Stationery and forms including field ink pots.	...	..
Khākās, 1″ maps, stone charts	...	...
Inspection book	...	..
Tube of printing ink ...	...	...

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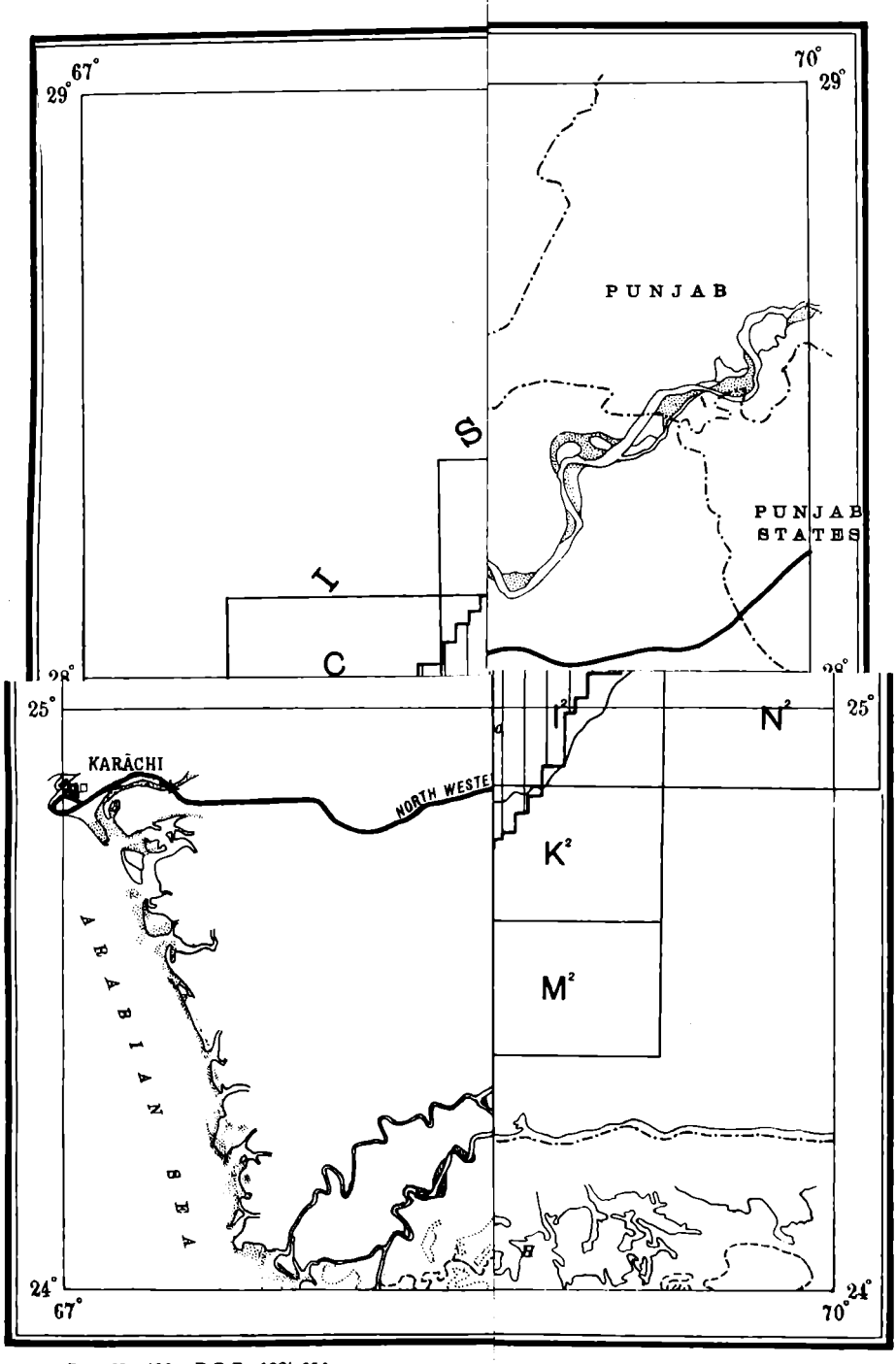

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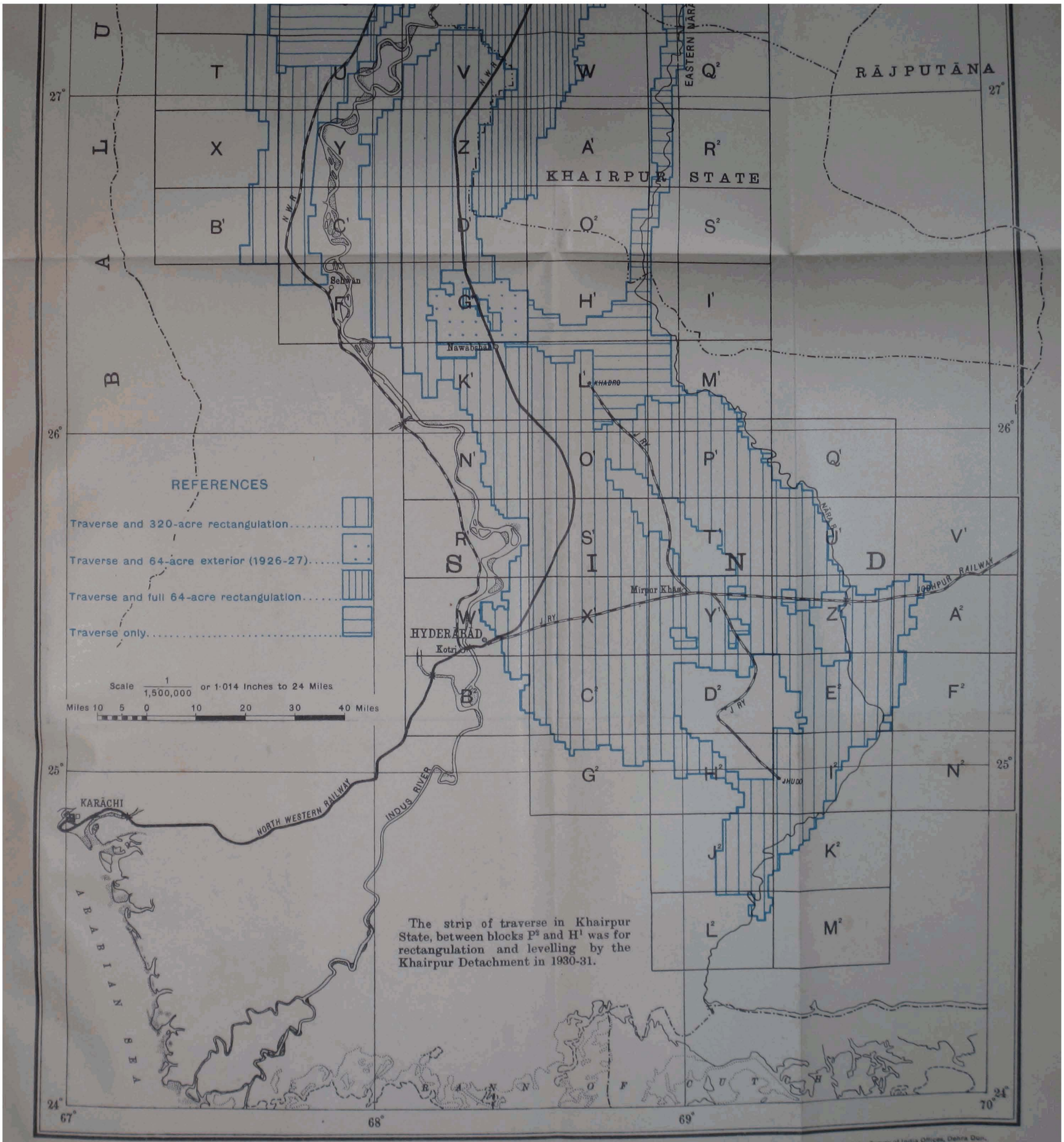

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