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PROFESSIONAL PAPER NO. 21.

IRRIGATION AND SETTLEMENT SURVEYS 1926

BY

MAJOR J. D. CAMPBELL, D.S.O., R.E.

PUBLISHED BY ORDER OF
COLONEL COMMANDANT E. A. TANDY, R.E.
SURVEYOR GENERAL OF INDIA.

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INTRODUCTION

The object of this report is to place on record the survey work which has been carried out in recent years in connection with Irrigation Projects in the Punjab. It is intended to serve as a guide both to irrigation engineers and to survey officers, when initiating such work in the future. Section I & II deal with preliminary considerations and will be of interest to the Irrigation and Revenue Departments as well as to the Survey of India. Sections III to VI are devoted to methods of work, outturn to be expected and cost rates. Only new methods have been dealt with, which fall outside the normal work of the Survey of India Department, as everything pertaining to the latter is fully described in other professional publications.

SECTION I

OBJECTS OF RECTANGULATION AND ITS ATTENDANT OPERATIONS, WITH A BRIEF HISTORY OF WORK IN THE PUNJAB

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1. *Definitions*

Rectangulation may be defined as the dividing up of any portion of land surface into rectangles of fixed size by accurate methods, and demarcating their corners with permanent marks.

The area which can be so divided, without change of origin, is subject to the ordinary limitations governing the use of rectangular co-ordinates and it should not be carried further than about 2 degrees East or West of the origin.

The general lay out of rectangulation, as hereafter described, is subdivided into blocks, and main and small rectangles, which may be defined as follows :—

Blocks. These are multiples of main rectangles, sheets, and charts and form a convenient basis for design of main traverse and levelling circuits. Their lettering is utilized in the numbering of stones, charts and sheets.

Main rectangles. These are the rectangles the corners of which are independently fixed by traversing, all further breaking up being subsequently accomplished by sub-division.

Small rectangles. This term is used for the ultimate rectangles as demarcated and levelled for purposes of the project.

2. *Objects and advantages.*

Rectangulation combines, in a single operation, the requirements of the Irrigation and Revenue Departments as regards engineering and administration.

3. *Irrigation.*

In a note on the subject, the Chief Engineer Irrigation Works Punjab has written as follows :—

> " The aim of an Irrigation Project is to bring water by gravity flow from its natural source the river, through the main canal, into distributaries, and so deliver it, through the water-courses, to the individual irrigators at the highest points of the unit rectangles.
>
> The detailed contoured maps are thus invaluable, firstly to the general design of the Project as a whole, secondly, to the accurate

3. (Contd.) "alignment, design and estimate of the main canal and distributaries, while thirdly, the Rectangulation system and its attendant levels together with necessary topographical features, are essential to the correct design, estimate and construction of the water-courses on which the success of the Project very largely depends. Indeed it is not too much to say that the great success of the older Colony Canals is due, in a large measure, to their system of rectangulation and levelling, for without it, the highly efficient and well designed system of water-courses, which the canals possess, could not have been obtained".

4. The Chief Engineer, Lloyd Barrage and Canals Construction, in a note to the Government of Bombay recommending a similar system for the Sukkur Project, tabulates the advantages from an irrigation point of view as follows:—

"(*a*) To enable an efficient and economical lay-out of water-courses and thereby ensure equitable distribution of water.

(*b*) To facilitate the economical use of water.

(*c*) To facilitate inspection of irrigation and crops by all concerned, by the owner himself as well as by Government officials.

(*d*) To facilitate assessment of irrigation dues and levy irrigation charges in the simplest and most equitable manner possible.

(*e*) To avoid loss of head of water by making the channels follow the sides and diagonals of squares, instead of allowing them to wriggle over the face of the country.

(*f*) To have a simple graphic record of irrigable areas and so avoid having to depend largely on the lower grades of the revenue and irrigation staff for information.

(*g*) To arrive at a definite unit of irrigation *i.e.* the acre, recognisable for purposes of assessment, instead of the present unit, the survey number, of indefinite shape and size, for which full assessment is chargeable whether wholly or only partially cultivated.

(*h*) To enable accurate data to be obtained for the imposition of penalties for breach of rules".

5. *Revenue.* A further quotation from the report by the Chief Engineer, Irrigation Works, Punjab, will illustrate the advantages of the rectangulation system as providing a permanent basis for settlement and its necessary plans.

OBJECTS OF RECTANGULATION

" Settlement and Land Revenue assessment efficiency have been greatly increased by Rectangulation, as it has provided fields of regular shape and size, and, what is more important, of fixed boundaries, while the consequent economy in the cost of operations of the bi-annual assessment is considerable ". 5. *(Contd.)*

A brief history of the irrigation surveys in the Punjab has been compiled by the Chief Engineer, Irrigation Works Punjab as follows:— 6. *History.*

" (*a*) The first system of Rectangulation introduced in this Province was on the Lower Chenab Canal (surveyed 1890, constructed 1892-1900), where the area to be irrigated consisted of unsurveyed barren wastes. It was thus essential first to prepare a detailed contour survey for purposes of design and construction of irrigation channels. The necessary preliminary to this was to divide up the waste area suitably by means of some system of rectangulation which would permit levels to be obtained at some fixed distance apart.

(*b*) The system was so devised as to provide, in addition to the above, units suitable for allotment to irrigators, which units would be capable of sub-division into smaller units suitable for registration of irrigation and for revenue assessment. Originally the unit selected was the square (popularly known throughout the Punjab as 'Murraba', of 1100 feet side and approximately 27·7 acres in area). This unit was sub-divided into 25 smaller units of rather more than an acre.

(*c*) In the earlier Irrigation Projects, *i.e.* the Lower Chenab Canal (surveyed 1890, constructed 1892-1900) and the Lower Jhelum Canal (surveyed 1888-98, constructed 1898-1917), the frame work of the Rectangulation was laid out by the Irrigation Branch. The Revenue Department then carried out the division and sub-division into units and sub-units, and the Irrigation Branch completed the levelling, contouring and mapping.

(*d*) While this system was a very great step forward it had its defects in that:—

(*i*).—The work was not as accurate as it could have been, and

(*ii*).—the various systems of Rectangulation on the different Projects, and indeed in different portions of the same Project, were not correlated to, but independent of, each other. Consequently the aid of the Survey of India was sought and they laid out the frame-work of the Rectangulation by base lines at about 5 miles intervals, while the Revenue and Irrigation Departments completed the work as before.

(*e*) With the advent of the Survey of India into the field of operation the former unit, namely the 'Square' of 27·7 acres,

6 (Contd.) disappeared, the new unit, the 'Rectangle', of 25 acres, of sides 1100 – 990 feet, taking its place. (The zamindars however continuing the popular term 'Murraba' which is not now strictly correct but is in general use).

The sub-division into 25 equal parts continued, each sub-unit being as before called a 'Kila', though now of exactly 1 acre in area.

(*f*) The valuable help thus afforded by the Survey of India next led to still further co-operation by them in the surveys and plans for the Thal Project. Here, in addition to the base lines, they laid out rectangles of 100 acres, and materially helped the work of the Irrigation Branch levelling, by running lines of precise levels and providing bench marks at close intervals, and also, for the first time, by printing contoured maps for the Irrigation Branch.

(*g*) This co-operation was still further extended on the Sutlej Valley Project, now under construction, where the entire area (over 9 million acres) has been rectangulated into 100 or 25 acre rectangles as desired. Also this entire area has been levelled, contoured, and mapped in detail.

(*h*) In the surveys for the Haveli Project to be undertaken in 1926-7-8 the Survey of India will again do all the rectangulation, levelling, contouring and topography as in the case of the Sutlej Valley Project. They will also do the mapping and printing, and in this they are co-operating so as to enable the Irrigation Branch to improve on the maps as supplied hereto ".

7. The following are the Projects for which, in varying degree, the Survey of India has carried out survey operations.

Name of Party	Locality	Field Season
Riverain Detachment ...	Lower Bari Doab Canal	1906 to 1909 & 1911 to 1914
Riverain Detachment ...	Gujrat Rectangular Survey, Upper Jhelum Canal	1913-14
Sind Sagar Party, (Punjab)	Sind Sagar Doab (Thal Project)	1917-21
Sind Sagar Party, (No. 23 Party)	Sutlej Valley Project	1920-26
No. 23 Party	Haveli Project	1926- (In progress)
No. 24 Party	Sukkur Project	1926- (In progress)

SECTION II

PRELIMINARY CONSIDERATIONS FOR DECISION BETWEEN THE IRRIGATION AND REVENUE DEPARTMENTS AND THE SURVEY OF INDIA BEFORE PREPARING THE SCHEME

RECTANGULATION

8. *Main rectangles.*

(*a*) *Size.* The size of main rectangles is governed by survey considerations alone and should be the largest possible compatible with the possibility of sub-division, within permissible limits of error, by the methods employed. They must be capable of sub-division into rectangles of the dimensions required by the Irrigation and Revenue Departments, and their size should be determined after that of the small rectangles.

The actual limit of size has been found to be about 3 miles by 2 miles in very open country but, as finality in methods of work has not necessarily been obtained, this should not be considered as fixed. In ordinary country about 2½ miles by 1½ miles is preferable.

(*b*) *Orientation.* Rectangles may be orientated in any direction, either true North and South, or in relation to the general slope of the ground. It is inadvisable to change the orientation unless absolutely necessary, as there would be considerable confusion at the junction of the different systems. North and South, or East and West, are the most convenient and should be adhered to whenever possible. As a result of the method of demarcation, all sides of main rectangles are cleared on the ground, but only those sides of the small rectangles which are parallel to the short sides of main rectangles. As levelling is greatly facilitated by being carried out along cleared lines, main rectangles should be so orientated that their short sides lie in the direction of levelling, which is usually that of the slope of the ground. Under the Block circuit system of levelling hereafter described, this can usually be effected by correct planning of circuits. In that case the only factor affecting the orientation of the long and short sides is that traversing is reduced to a minimum by being carried along the latter which should therefore lie in the most suitable direction.

9. *Small rectangles.*

(a) Size. The size of small rectangles is decided by the Irrigation and Revenue Departments. The governing considerations are that they should be capable of sub-division into final plots of the desired

9. (*Contd.*) dimensions and that they should be of the size necessary to provide levels at points desired for the planning of the project. Thus, if it is intended to sub-divide eventually to 1 acre, the small rectangles may be 100 or 25 acres, whereas, if the final plots are to be 2 acres, they should be 64 or 16 acres. It is not usual for the Survey of India to sub-divide below the size necessary to give the requisite number of levels. Further sub-division can conveniently be carried out by the departments concerned. In the Sutlej Valley, the Survey of India carried out demarcation to 100 acres, whereas sub-division to 25 acres was done by the Revenue staff. The disadvantage of this system was that, as levelling was to be to 25 acres, it was necessary for the levellers to wait until the 25 acres rectangulation had been carried out by another department, over which the Survey of India had no control, before they could start work. As the closest co-ordination is necessary to get quickest and most economical results, it will usually be better for the same agency to carry out the levelling and the rectangulation to the size required for it.

(*b*) *Orientation.* The orientation of small rectangles is not of much importance if the difference between the long and short sides is not great. If the short sides lie in the direction in which the levels are run, the distance between levels along these sides is slightly decreased and increased along the long sides, and the Irrigation Department should decide which arrangement they prefer.

10. *Dimensions of an acre.* These vary with local conditions. In the Punjab, where the karam is the unit of measurement by Revenue surveyors, an acre 220 feet by 198 feet has been adopted, these lengths being measureable in karams (5½ feet). In Sind, where the Revenue surveyors use a 33 feet chain, or half a Gunter's chain, an acre of 4 by 2½ Gunter's chains, or 264 feet by 165 feet has been proposed.

11. *Numbering of stones.* In the Sutlej Valley, where rectangulation was carried out by the Survey of India to 100 acres, and by the Revenue staff to 25 acres, the system of numbering allowed for 25 acre stones being included, so that numbering by the Survey of India was not consecutive. It is therefore necessary to decide down to what sized rectangles the system of numbering is to apply, before it can be devised.

The method of numbering stones actually adopted is illustrated in plate II a. It consists of the sub-division of a block into numbered rectangles and the numbering of the stones falling in each of these, starting from the north-west corner. Thus the stones of numbered rectangle No. 5, in Block A, are A $\frac{5}{1}$, $\frac{5}{2}$ and so on. It permits of many variations, by different sub-divisions of the block.

It is important that the system should give symmetrical results for the final maps and charts, because it is not possible to number all stones on these, and the numbering of any stone should therefore be easily calculable. It is also convenient that the numbering should be symmetrical

as regards khakas, but this should be subservient to the above consideration. Both these results are obtained if the numbered rectangle is a sub-division of both a main rectangle, *i.e.* of a khaka, and of a sheet or a chart, as was the case in the Sutlej Valley. 11. *(Contd.)*

When an exact number of main rectangles falls in a sheet or chart, the numbered rectangles might coincide with them, this system being very convenient for use in the field. Alternatively the numbered rectangles might coincide with sheets or charts. This would be inconvenient as regards khakas unless the numbering on these were rendered symmetrical by there being an exact number of main rectangles in a sheet. But the advantage from the point of view of a clear numbering system for the sheets is so great, that the former disadvantage, which can be got over by numbering stones on khakas at head quarters before issue, might very well be overruled. Where final rectangles included in the numbering system are very small, this system would result in very high numbers and might be ruled out on that account. These alternative systems are illustrated in plates II a, b, c.

LEVELLING

Levels are provided at the corners of small rectangles and at intermediate points along their sides, (see plate X). The number and positions of levels should be decided by the Irrigation Department. It should be decided whether additional levels are required where lines cut topographical features. The question is discussed in para 14. Special orders are also required on the question of ground levels, as discussed in para 51. 12.

The Irrigation Department normally requires level charts showing positions and values of levels. The scale and size of these charts depend on the use to which they will ultimately be put. 13 *Level charts*

(*a*) *Not based on detail survey.* Contour sheets combined with the level charts are usually contoured at 1 foot intervals. Where no detail survey is undertaken, these can be prepared but it must be understood 14. *Contour sheets.*

Page 7, para. 14, line 6 from bottom

For "As details are taken" *read* "As levels are taken"

rectangle corners or points at fixed distances between them, it follows that these cannot be utilised to show ridges, depressions, or the true shape of the ground. An improvement can be effected by taking additional levels at topographical features but any work of this sort can be but a partial remedy, as such levels can only be obtained along the lines

14 (*Contd.*) of levelling, and all features or portions of features not cut by these will be missed. Contouring without detail survey can never be regarded as satisfactory, though it may be useful, provided its limitations are understood. It must be realized that the accuracy of the contours depends largely on the distance apart of levels and, where the necessities of the project only demand say 100 acre rectangles, a very great deal of the accuracy, which could be obtained with say 25 acre rectangles, is sacrificed. An example of this kind of contour sheet appears in plate XVII.

(*b*) *Combined with detail survey.* Very much improved contour sheets can be prepared by consideration of levels combined with detail, even though contouring is not done on the ground. To carry out accurate contouring at 1 foot interval would be a very costly and lengthy undertaking and would almost certainly be prohibitive, both in time and cost. If however highly trained personnel were available, the question of accurate contouring on the ground might in some cases be considered.

It would be possible to effect a compromise by contouring only difficult portions on the ground. The extent to which this would be feasible or desirable would depend on circumstances such as nature of the ground, time, and personnel available. In normal slightly undulating or nearly flat ground, contour sheets based on levels and detail should be quite satisfactory, even if prepared in office, especially when based on 25 or 16 acre levelling.

DETAIL SURVEY

15 *Scale* The scale of survey should conform to that of the level and contour sheets. In the case of recent surveys, 4 inches to 1 mile has been found convenient, and, in the case of the Haveli Project, compiled reductions on scale 1 inch to 1 mile have also been asked for.

16. *Omission of unnecessary detail.* It is important to decide what detail should be shown and what omitted. Detail should not be omitted because it is not required for the preliminaries of the project, and due consideration should be given to what will eventually be required for planning the final details. All existing detail could usually be shown on the scale of survey without undue overcrowding, but it is desirable not to confuse the plans by showing anything which is unnecessary. Trees and various jungle and scrub symbols are usually shown on Survey of India maps, but would not generally be required on these special maps, and if not, should be omitted. Cultivation boundaries are unlikely to be useful. They are of no interest to the Irrigation Department and must, of necessity, all disappear as soon as new irrigation is introduced. Village boundaries are very troublesome to survey, especially when not clearly demarcated, and under certain circumstances, such as the prospect of their being speedily scrapped, might not be required.

PRELIMINARY CONSIDERATIONS

17. *Names.*

Names of all villages and hamlets should be shown but it may not be necessary to show those of wells, which are usually numerous in this type of country. The names of these wells are seldom permanent, depending on who is the owner at the time of survey. The wells themselves are of great importance, but the Irrigation Department usually gives numbers to them and is not interested in temporary names. As the saving of typing effected by omitting them is very considerable and the reproduction of maps much accelerated, permission should be sought to do so, as has been done in the later sheets for the Sutlej Valley Project.

18. *Special surveys near weir sites.*

In the case of a special survey undertaken for the Panjnad Weir Site of the Sutlej Valley Project most of the detail survey fell outside the rectangulated area. In order to give the engineers datum levels, pillars were built by them in suitable positions, which were fixed by traverse and levelled. Pillars and their levels were shown on the 4 inch maps and the co-ordinates of the former supplied.

It may be necessary, where rivers with fluctuating channels and banks are concerned, to survey them annually in the neighbourhood of Weir Sites. If in such areas rectangulation, with levelling based on it, is too far off to satisfy requirements, it may be desirable to fix and level points as described above. These pillars would form permanent fixed points on which annual surveys could be based. A specimen of the Panjnad Weir Survey appears in plate XX.

19. *Rectangulation and contour sheets combined with existing survey maps.*

In the event of detail survey not being required and existing surveys being considered adequate, contour sheets could be prepared combined with the latter, but as existing maps would probably be on a small scale, it might not be possible to show contours at 1 foot interval. Even if contouring were not required, it would probably be useful to provide a set of existing maps with rectangulation plotted on them, this being the most convenient way of recording it.

PRINTING

20.

The printing of detail sheets and level charts should be carefully considered, keeping in view the uses to which they are to be put. The Irrigation Department have to use those plans to prepare their project. If suitably printed therefore, they can also be used conveniently as a basis for final plans showing the completed work, which plans will in their turn have to be reproduced. Plans for the Haveli Project have been very carefully considered on these lines and the conclusions arrived at are embodied in sample plans (plates XVIII a & b). In addition, a black print of topographical detail only will be printed and a series of 1 inch to 1 mile maps prepared by reduction (plate XXI).

20. (Contd.) The objects of these are :—

(*a*) Plate XVIII a. For planning distributaries, the contours being emphasized and the detail subordinated.

(*b*) Plate XVIII b. For planning water-courses, etc., and as a basis for final plans. These sheets, except for levels, will be printed in a blue which will not reproduce, so that the Irrigation Department can show all details required on their final plans. These details only, together with levels, will appear on reproduction.

(*c*) The black print, showing topographical detail only, is intended to clear up any points which may not be clear on the combined plans.

(*d*) The 1 inch to 1 mile maps are intended to illustrate reports.

Plate XIX shows a sheet as prepared for the Sutlej Valley Project, in black only, with contours in brown.

PROGRAMME

21. *Co-ordination.* It is necessary to co-ordinate the rectangulation, levelling and detail survey so that maps may reach the engineers in as short a time as possible.

Normally rectangulation is started first, preceded by any necessary triangulation or traversing. Levelling may proceed *pari passu*, as soon as rectangulation is sufficiently advanced to permit of a start, and, as levelling is a quicker operation, the same area should usually be rectangulated and levelled in one field season. Detail survey should preferably start the following field season, although it may be desirable, in case of great urgency or to employ personnel, to make it follow the rectangulation more closely, remembering that normally the latter is necessary as a basis for the survey. It must also be remembered that, where detail survey is taken up prior to levelling being completed and results received, no attempt can be made to contour any portions on the ground.

Taking into consideration the personnel available, a rough programme should be drawn up in conformity with the above and approved by the Irrigation Department.

22. *Summary of points for decision.* (*a*) Dimensions and orientation of small rectangles. Size is a multiple of that of final plots, involving settlement of the dimensions to be adopted for the acre. Orientation depends on the desired arrangement of levels.

(*b*) Dimensions and orientation of main rectangles, the former being mainly a survey consideration, orientation being such as to bring cleared lines in the direction of levelling and to satisfy requirements of traversing.

22. *(Contd.)*

(*c*) Numbering of stones.

(*d*) Number and position of levels and whether intermediate levels should be taken to indicate topographical features and changes of slope. What orders should be issued *re* ground levels on mounds and artificial ground.

(*e*) Scale and form of level charts, which will be that of contour and detail sheets.

(*f*) Whether, in the event of no detail survey being asked for, contour sheets are required, after consideration of their probable usefulness and their limitations.

(*g*) In case a detail survey is required, scale of survey and whether compiled maps on smaller scale are required, what detail should be shown and if any can be omitted. Whether the nature of the ground is likely to necessitate any contouring being done on the spot. As rectangulation is usually confined to high ground, not liable to inundation, it is probable that detail survey will be required to extend outside the rectangulated area and this point should be decided.

(*h*) Whether any special surveys are required near weir sites.

(*i*) In the event of existing detail surveys being considered adequate, whether any contour sheets are required based on them or, if not, the question of plotting rectangulation on existing maps.

(*j*) Form of printing of detail, level, and contour sheets and number of copies required.

(*k*) Rough programme of work to be carried out each year so that it may be completed when required.

SECTION III

PRELIMINARY WORK PRIOR TO TAKING THE FIELD

GENERAL

23 In addition to the usual correspondence with local officials which is necessary when a party takes the field, a Government notification should be issued to ensure that survey marks and stones are not tampered with. The following is a copy of the Punjab Government notification issued for the Sind Sagar Doab Rectangulation, which may be taken as an example.

Revenue and Agriculture Irrigation. Notification No. 9930R dated Lahore the 30th April 1918.

> " Under Section 107 (1) of the Punjab Land Revenue Act 1887, it is hereby notified that rectangular survey for the purpose of canal alignment, colonisation and the preparation of a record of rights is being made by the officer in charge of the Sind Sagar Party of the Survey of India Department in the area situated between the river Indus and the rivers Jhelum and Chenab, lying within the limits of the Mianwali, Shahpur, Muzaffargarh and Jhung districts, respectively, and commonly known as the Sind Sagar Doab, and that pillars of stone, iron and wood will be erected as survey marks in the said area by the said officer ".

On the strength of this notification, district officials should be asked to issue stringent orders, that no survey stone or mark should be tampered with under threat of punishment.

RECTANGULATION

24. *Preliminary work.*

(*a*) Selection of the most suitable origin and computation of corners of existing 1 inch or smaller scale maps relative to it.

(*b*) Showing on 1 inch maps the projected main rectangles relative to the same origin. As these maps will have to be issued to triangulators or traversers, a sufficient number must be prepared for them and for other purposes.

(*c*) Preparation of an index map on convenient scale, say 1 inch to 4 miles, showing blocks and rectangles, (see plate III).

(*d*) Despatch of index map for reproduction.

(*e*) Division of the area into zones, each containing a stone depot. Distance apart of depots should average 4 or 5 miles or as considered convenient, considering the form of transport available, (see plate III).

(*f*) Calculation of number of stones required for each zone adding 5 % for breakages and arranging for their supply at the depots.

(*g*) Decision as to method of numbering of stones (see plates II a, b, c. and para 11) and preparation of a block plan showing this. This plan should be approved by the Irrigation Department before reproduction. 24. *(Contd.)*

(*h*) Plotting, on a copy of index map, of all existing triangulation and traverse data for consideration of triangulation or traversing required.

(*i*) Preparation of khakas and reproduction of a sufficient number of copies (see plate V).

LEVELLING

Levelling for the Sutlej Valley Project, which can be taken as typical, was of three kinds:— 25. *Alternative methods.*

(*a*) *Control level circuits.* These consist of secondary double levelling circuits, with necessary tie lines to connect interred and inscribed bench marks and to join with the nearest lines of high precision levelling, (see plate VIII). The system should be devised so as to provide bench marks as near to as many blocks as possible, so as to enable connections to be made with tertiary double levelling circuits.

It is essential that this control levelling should be absolutely reliable and hence accuracy should not be sacrificed to speed and outturn.

(*b*) Tertiary double levelling round the perimeter of the area and in the form of circuits which were sub-divisions of blocks (see plates IXa, IXb).

(*c*) Tertiary. single levelling along rectangulation lines starting and closing on double-levelled stones.

An index map should be procured from the rectangulation party, showing the whole area as sub-divided into blocks, and a block index showing division of blocks into rectangles and system of numbering of stones. Lines of levelling can then be planned, bearing in mind that levelling (c) should follow cleared lines which will be parallel to the short sides of main rectangles. Plates IX a, b, show typical sub-divisions of blocks into main rectangles, books and circuits. 26. *Index map.*

It is necessary, before levelling (a) is commenced, that a sufficient number of interred bench marks (Type B"—see plate XVI) should be built. This work is usually done by the Irrigation Department who should be informed what is required. The bench marks are embedded from 4 to 8 miles apart over the area. Secondary double levelling is usually carried along roads or other easy routes and interred bench marks should be placed, as far as possible, on stable ground and on sites where they are likely to be preserved, such as in villages, bungalow compounds etc. This work should, whenever possible, be done the 27. *Embedded bench marks.*

27. (*Contd.*) season before work is commenced, and before the rains. When ground is unstable the constructor should dig down to firm and solid ground for the foundations of the bench marks, but normally they are embedded with their tops 2 feet below ground. They should be suitably inscribed on the top, substituting for G.T.S. initials referring to the Irrigation Project (see plate XVI).

28. *Referring pillars* Masonry referring pillars have also to be built, which may conveniently be about 10 feet North of the bench marks. They should have suitable inscriptions such as those in the Sutlej Valley which were S.V.C. B.M. 10 ft.

29. *Inscribed bench marks.* Bench marks should also be built at canal rest-houses which fall near the lines to be levelled, by inscribing stone slabs let into verandah floorings. When selecting a site for such bench marks, care should be taken to see that the roof is not below 10 ft. high, so that a levelling staff can be placed on the mark.

30 *Forms.* In addition to the usual forms in use by the Survey of India Department, special forms have to be prepared. Those used in the Sutlej Valley are shown in plates XII-XV. Plate XII illustrates a page of the level book. Plate XIII shows the form used for adjustment of Block circuits of tertiary double levelling, plate XIV that used for recording tertiary double and single levelling. Plate XV is the levellers' diary form.

DETAIL SURVEY

31. *Village maps.* Where village boundaries are required to be shown, village maps have to be obtained through the Director of Land Records and reduced to the scale of survey. This is a considerable undertaking, as the scale of village maps is generally large, and it is necessary to use some method by which a large staff can be employed on the work simultaneously. A convenient method of doing this has been found to be as follows. Assuming that village maps are on the scale of 24 inches to the mile and reductions are required to the scale of 6 inches to the mile, transparent glass negatives are prepared, ruled into squares of convenient size, say $\frac{1}{4}$ inch. Squares one sixth this size are ruled and printed in blue on rag litho paper. The glass negatives are placed over the maps and reduction effected by eye, square by square, on the squared paper. Where time is short, boundaries only may be shown on reductions, as it is seldom that village maps are sufficiently accurate or complete to permit of much use being made of the detail. It must be remembered that village maps are original records and every care should be taken in their use and in packing them for transit. Boxes containing them should always be opened by a gazetted officer and if they are received in bad

condition, a report to that effect should be immediately sent to the Revenue Department. They should always be packed flat in tin lined boxes. 31. *(Contd.)*

As final sheets are prepared by direct photography from plane table sections, a specimen should be projected with, as far as possible, all borders, headings, foot-notes etc., and printed in black on field sections before taking the field. Rectangulation lines should be shown, but it may be desirable, for the sake of clearness, to omit minor sub-divisions. A projection of about 20 inches by 15 is a convenient size, but the exact size of the sheets is affected by that of the rectangles. 32. *Plane tables.*

As conventional signs will usually differ from those in normal use in the Department, it is desirable to prepare specimens for use by plane-tablers, showing any which do not appear on the tables at the foot of the plane table sections. 33. *Conventional signs.*

SECTION IV

METHOD OF WORK

RECTANGULATION

34. *Methods.* Main rectangles are demarcated by fixing their corners with reference to triangulation or traverse stations located as near them as possible. The work is carried out in four successive operations.

(*a*) Triangulation or traversing to fix stations near corner stones of main rectangles (with preliminary traversing or triangulation, where necessary to form connection with G. T. Stations), and its computation.

(*b*) Location of corner stones of main rectangles by measurement of distance and bearing from stations.

As a check on the accuracy of the work the traverser should connect each stone by traverse with one of his other stations and send the observed angle and distance to the computing section which should, by computation, ascertain whether the stone has been laid correctly.

(*c*) Exterior rectangulation.

(*d*) Interior rectangulation.

35. *Triangulation or traversing.* Traversing is the more usual and satisfactory method, as the fixing of corner stones from one traverse station and closing on another gives an immediate check on the accuracy of the work. Moreover triangulation, in flat ground, usually necessitates the use of high signals which do not give satisfactory results, whereas for traversing these are not required. Under exceptional circumstances, however, such as very open ground with mounds or low hills, triangulation may be resorted to, if it results in greater cheapness and rapidity of execution. Triangulation might also be advantageous in country too cut up to admit of accurate chaining.

36. *Triangulation.* Triangulation should consist of parallel series of quadrilateral figures running in the direction of the rectangulation, their stations being as close as possible to the theoretical positions of the main rectangle corners. The stations of every fourth series are observed, the remainder being intersected. These series should be joined at intervals of about 20 miles by parallel series running at right angles to them, the whole being tied to a continuous series skirting the outer limit of the area (see plate IV).

Before starting observations, the triangulator should carry out his reconnaissance with a plane table mounted with a 1 inch map with main rectangles shown on it. This consists of locating on the ground, by interpolation from such detail as is available, positions for his stations and intersected points as near as possible to the actual

corners of the rectangles. Having reconnoitred and fixed at least 8 stations in this way, he proceeds to observe the net work thus formed, using signals and ladders as described below. (See plate VII). 36. *(Contd.)*

As rectangulation is usually confined to high ground not liable to inundation, it is desirable to fix, by intersection, prominent points in low ground along river banks, to form a basis for detail survey where there are no stones.

Where triangulation is carried out a season ahead, stations must be semi-permanently marked by stakes, which may be creosoted, 30 inches long and 3 inches square in section, and pointed at one end, as was the case in the Sind Sagar area. These were driven into the ground, 9 inches being left exposed. With a view to the recovery of the stakes in the case of their being obscured by drifts of sand and as a precaution against damage or removal, clods of earth were piled round them, and tripods made of stout branches of trees were erected over them and firmly fixed into the ground. All stakes were placed under the custody of lumbardars of villages, receipt being taken for the number made over to them. 37. *Marks.*

Where computation proceeds *pari passu* and demarcation of main rectangles follows immediately, rough temporary marks only are required, to last until the rectangle concerned has been demarcated and proved. Where, however, location of corners follows immediately, but demarcation of rectangles is left till the following season, semi-permanent marks should be erected, with the same precautions as regards loss.

Signals (see plate VII) were 20 and 30 feet high, made of chir wood poles 10 feet long, with single or double joints, according to the height of the signal, surmounted by a strong white cloth top and held in position by means of four guy ropes fixed to the lower ring of the top. From experience it was found that the ropes soon became loose and the poles sagged out of the vertical. This was due to the insecure hold for pegs in the sand. The 30 feet, or double jointed signals were useful to overcome obstacles such as trees or hamlets. The double joint had however a tendency to weaken the pole which could not always sustain the strain imposed on it. The great disadvantage of this signal was that it did not keep vertical and was liable to oscillation. 38. *Signals.*

In triangulation of this nature, where high signals are a necessity, care should be exercised in their design so that these difficulties can be overcome as far as possible. Three pegs instead of four would facilitate erection of the signals. Plummets are supplied, but a convenient and rapid way of plumbing the signals would be as follows. Guy ropes, could be made all exactly the same length and pegs driven in at equal distances from the mark, so that the point of attachment of the guy ropes to the signals, *i.e.* the base of the signal top, would be directly over the mark.

39. *Ladders.* Ladders were also used for reconnaissance purposes (see plate VII) consisting of a chir wood pole on a base in the shape of a cross. The pole carried seven circular iron bars pierced through it at intervals of 1 foot, and was supported by three guy ropes.

40. *Traversing.* To ensure accurate work, in addition to such traverses or triangulation as may be necessary along the perimeter of the area, and to connect with G.T. work, a net work of main traverse circuits is run along the sides of blocks, with tie lines bisecting the blocks in both directions. Points should be fixed by intersection in low ground as laid down in para 36 sub-para 3.

Parallel sub-circuits are then run, conforming as near as possible to the rectangulation lines as plotted on the maps, stations being located near the theoretical positions of the corners of main rectangles. As the latter are fixed by measurement from one traverse station and checked by closing on another, a second station should be made at no great distance.

Computations should always proceed *pari passu* and corners should be located as soon as possible, so that only temporary marks are required for traverse stations.

41. *Location of corner stones.* Where computation is carried out *pari passu* with triangulation or traversing, which should always be done if possible, and invariably in the case of traversing, location of corner stones should be carried out by the triangulators or traversers. Failing this, the work would have to be done by the exterior rectangulators the following season. This would be very unsatisfactory owing to the possiblity of obliteration of stations and the fact that rectangulators would be required to possess higher qualifications than are expected of them when employed on their ordinary duties. In the following discussion it is therefore assumed that this is the case.

42. *Fixing corners.* As soon as computations are complete, triangulators or traversers must be supplied with khakas showing the distances and bearings of the corners which they have to locate, relative to the nearest stations, and must fix them accordingly, numbering the stones as soon as embedded.

Hitherto it has been considered sufficient for the triangulators or traversers to demarcate the corners only, and it has been necessary for the exterior rectangulators to obtain their initial direction by means of a theodolite set at the computed angle between their forward stone and the nearest triangulation or traverse station. It should be possible to avoid the use of the theodolite by rectangulators altogether if the triangulators or traversers, when embedding stones, were to place stones or marks in the directions of the adjacent corner stones, to give rectangulators their initial direction, and this method will be given a trial. (Also see notes on the new instrument in para 48).

METHOD OF WORK

As a check on the accuracy of the work the traverser should connect each stone by traverse with one of his other stations and send the observed angle and distance to the computing section which should, by computation, ascertain whether the stone has been laid correctly. 42. *(Contd.)*

Before proceeding to his work each exterior rectangulator receives the khakas from the traversers, on which are shown the bearings and distances of each of his corner stones with reference to adjacent triangulation or traverse stations. (He would not need this information if a mark had previously been placed when the corners were located, as suggested in para 42 sub-para 2). He should also be given a copy of the portion of the stone depôt chart which affects him. 43. *Exterior rectangulation.*

On arrival at his camp he should calculate the number of stones which he intends to embed from it and send for them from the correct depôt or depôts as shown on the chart. 44. *Stones.*

Before starting each day's work he should decide the maximum number of stones he can embed during the day and give instructions to his camel-man to follow him with these and to drop them at a prescribed time, one at each of the approximate positions of the stones, as marked by flags and pegs along the line he is demarcating.

On proceeding to his initial corner he should, if the forward line has not already been indicated by a mark, obtain his initial direction by setting off the angle between his forward corner stone and adjacent triangulation or traverse station and plant a flag in the direction obtained. Having erected a signal on the starting stone, he should proceed to demarcate the line in successive operations as follows. 45. *Procedure.*

(*a*) He should prolong his line by aligning flags by means of his theodolite and, by measurement with a long chain, put in pegs and erect flags at the correct distances between stones until he reaches the forward corner stone, where he should erect a second signal. As an alternative method, the procedure may be varied in open country and work very much simplified. It may be possible to erect a signal at the forward corner stone before commencing demarcation, thus facilitating alignment and eliminating lateral error and the necessity of clearing a second line when correcting it. It must however be remembered that the stone is some miles away and may be difficult to find, and much time may be wasted in locating it under unfavourable conditions.

(*b*) After measuring his closing error in distance and alignment, the latter at right angles to his chain line, return along the line and distribute the error at each stone, clearing the line where necessary and erecting flags at the new positions. Tables of corrections to be applied can conveniently be prepared (see plate VI).

45. (*Contd.*) (*c*) Check the alignment by erecting his theodolite at one or more commanding positions on it and testing the correctness of his position by measuring the angle between the two signals. If this is not exactly 180° he moves his theodolite until it is so, thereby placing himself on the correct line. He can now check and finally align his flags.

(*d*) Having carried out operations (*b*) and (*c*), either separately or together according to circumstances, and finally satisfied himself as to the correctness of the sites, he should embed and number the stones, entering the numbers on his khaka. Great care must be observed in embedding stones that the correct position is maintained. To ensure this, it is useful to place pegs at a measured distance in either direction along the line, from which the final position of the stone can be checked by measurement. Stones are embedded with their tops 10 inches above ground and should face the adjacent stones, thus indicating their direction.

The maximum closing error which is usually allowed is 1 in 1000, laterally or in distance. If the error is greater than this, the line must be re-demarcated and, if error persists, the presumption is that the forward corner stone is wrong in position. If this is found to be so, the camp officer should be informed and the stone can be corrected, under his orders, by measurement from the three adjacent main corner stones, the mean position obtained being accepted.

46. *Interior rectangulation.* This consists of the final sub-division of the main rectangles into their component rectangles by running lines between the intermediate stones, as fixed by the exterior rectangulators, and embedding stones at the correct intervals along them.

The general method of work is the same as that adopted by the exterior men, except that interior men do not use theodolites. The initial direction is obtained by laying off a right angle with an optical square. (Also see note on new instrument in para 48). This is usually done by aligning two flags one in either direction, along the exterior line and placing a third flag at right angles by taking the mean of the two positions obtained with the optical square from these two flags. This initial line is prolonged as before and subsequent operations are similar. Having no theodolite, the interior demarcator cannot check his alignment by the 180° method, but can do so by aligning two flags on one signal and checking the correctness of their alignment on the other.

47. *Alternative methods.* In very open country alternative methods may sometimes be adopted in subdividing a main rectangle. Where each flag along the main rectangle is visible from its opposite flag, interior stones may be placed in their correct positions by erecting flags at the intersections of the lines joining them, thus eliminating all chaining and adjustment of closing errors. Every opportunity should be taken to speed up the work by taking advantage of favourable conditions.

METHOD OF WORK

48. *New instrument.*

A new instrument has been devised for laying out right angles and other operations connected with rectangulation. A rectangular prism is employed which, it is claimed, enables a right angle to be laid out accurately to within a minute. It cannot go out of adjustment, as can an optical square, and, being on a stand, is far more accurate and convenient to use. It is also fitted with a sight vane usable in both directions so that it can be utilized for aligning flags, etc. It will be given a trial and, if successful, should replace the optical square and, it is hoped, the theodolite for rectangulators.

49. *Khakas.*

The same work khaka is utilized throughout when locating corner stones and carrying out exterior and interior rectangulation. In addition to the numbers of stones, rectangulators should enter on khakas the distances between them, as first measured, (see plate V) and the final distances after distribution of the closing errors. Partal khakas are dealt with under partalling.

50. *Partals.*

The work should be rigorously checked by measurement with a crinoline chain, and it has been customary for partallers to check 50% of the lines. One partaller is provided for 4 or 5 rectangulators, who may either be ordered by the camp officer to check certain lines or be attached to a group of rectangulators with general orders to partal 50% of the work.

Every partaller is given a partal khaka for each rectangle and first measures the distances between stones and enters them on it. He then distributes the errors and re-embeds the stones in their correct positions, noting the final measurements in red. It is not necessary to move stones to adjust any small errors below 1 foot. When he alters a stone, he draws an open circle on the khaka on that side of the original stone symbol towards which he moves it.

The partal khakas should be sent to camp officers on completion, who should take necessary steps to punish rectangulators whose work is bad. It should however be remembered that partallers cannot always be trusted and rectangulators should not be condemned until their work has been checked by their camp officers. Camp officers should test partallers as well as rectangulators.

In order to avoid the necessity of realignment of interior rectangulation owing to shifting of exterior stones, exterior work should always be partalled before interior work is commenced.

LEVELLING

51. *Ground levels required.*

The object of levelling, as carried out for irrigation projects, is to provide ground levels for corner stones of rectangles, and at intermediate points. This is qualified by the proviso that the levels should not be taken on inirrigable mounds or artificial features but should

51. (Contd.) give the true height of the natural ground. This is very difficult to apply in practice and special orders should be given on the point. In the Sutlej Valley, the orders have been that, where stones are placed on either mounds or depressions, the levels should be taken on the natural surface nearby, provided the distance of the staff from the stone is not more than 15 yards. In most cases this system is fairly satisfactory as the resultant contouring, based on the levels, shows the natural ground and ignores inirrigable features. It is a point however on which there are differences of opinion and the wishes of the Irrigation Department should always be ascertained before orders are issued.

An alternative to the above system would be, always to obtain ground levels at the actual stones and to denote on level charts, either by underlining or printing in a different way, which levels are not on natural ground and should be ignored when contouring. In the Haveli Project a compromise has been asked for, *i.e.* that the Sutlej Valley procedure should be continued where the difference in level concerned is not more than 2 feet, but that, for differences greater than this, the alternative method suggested above should be adopted.

52. *Secondary double levelling* Levelling in the Sutlej Valley, which may be taken as a type of such work, was carried out as follows :—

Secondary double levelling.—This was conducted on exactly the same lines, with observance of the same precautions, as "simultaneous double levelling" of the Department, except that greater latitude was allowed as regards permissible difference between levellers at each station which, in the Sutlej Valley, was ·007 feet. Recording was done on Departmental forms 2 or 12 Levelling.

53. *Tertiary double levelling.* *Tertiary double levelling.*—This differed from secondary double levelling as follows :—

Both the levellers used the same set of staves and observed by placing their instruments side by side. Telescopic staves, Roorkee pattern, were used which were not guyed but held by khalasis. They were placed on tops of stones or, for ground levels, on specially designed plates consisting of two cross pieces of iron each 6½ inches long, section 1 inch by ⅛ inch, rivetted in the centre, an inch from each end being bent downwards and pointed. No staff comparisons and corrections were made. Small Zeiss levels were sometimes used in place of larger instruments. Work was carried out throughout the day and the discrepancy allowed between the mean and middle wire was ·005 feet, and that between two levellers at any one station ·010 feet. Measurements were sometimes made by pacing and not chaining. No recorders were allowed.

METHOD OF WORK

Sides of circuits parallel to tertiary single levelling lines were treated as such in every respect (see para 54), ground heights only being observed. Top heights of stones were observed on other sides of circuits and ground heights of intermediate points. A cross mark was cut on the top of every stone of which the top height was observed, to indicate to single levellers stones from which they could start and on which they could close their work. 53. *(Contd.)*

If one connection in each circuit was impossible, at least two connections in each block were made with adjacent secondary bench marks, mean sea levels of tops of double-levelled stones being thus determined. Each bench mark was connected to two stones and, if the difference between the levels of these, as obtained by the bench mark connectors, and that obtained by circuit-levellers, differed by more than ·05 feet, a third was connected to ascertain whether stones had been disturbed.

Recording was done on special form 13 (Plate XIV) 100 feet being adopted as the datum throughout. On completion, field sheets were sent to section officers who checked the means, rise and fall and reduced levels. As soon as all field sheets of the circuit were received form (Plate XIII) was completed by the section officer and the circuit error found. This is either the difference between final and initial levels in a closed circuit or the difference between relative heights as previously and now obtained for the initial and terminal pillars. Adjustment of error was done by distributing the closing error between reduced levels of all stones, disregarding intermediate points which did not appear on the adjustment form. Mean sea levels were worked out during recess or by a field computing section.

Tertiary single levelling.—This was practically similar to tertiary double levelling, but carried out by one man. The permissible closing error was 0·3 feet in the distance of 6¼ miles. Single levellers read only to two places of decimals of a foot no difference being allowed between the mean and middle wires. 54. *Tertiary single levelling.*

Levelling was carried out from one double-levelled stone to another, ground heights being observed throughout, including those of terminal stones. If a terminal stone was missing, the nearest stone whose top height was known was connected.

In addition to points on the line, levels of points lying off it at right angles were taken (see plate X). The right angle was only approximate, but it is desirable that levellers should be given some instrument to enable them to obtain it more accurately. Distances were usually obtained by pacing. If this is not considered sufficiently accurate, some other form of measurement must be adopted. The most convenient would be a line of rope cut to the required length, a similar rope being used for measurement along the lines of levelling.

54. *(Contd.)* The following detailed description of the running of an East and West line along the side of a 25 acre rectangle (see plate X) illustrates the method employed. The back staff is placed on the top of the first pillar on the line, the instrument being 275 feet from it, the forward staff on the first intermediate point. The back staff is read, first on the stone and then on the ground. The forward staff is then read. The instrument is then set up midway between the intermediate point and the next stone and the back and forward staves read. The level is then shifted 247½ feet south of the forward stone, and the back staff to a point 495 feet south of the stone, the staves being read. The rise and fall and the relative heights obtained for North and South points are written in brackets, to show that the value is not included in the East and West line. This routine is continued until the terminal stone is reached. If a day's work has to be closed at an intermediate stone, the staff is first placed on the ground plate and then on to the top of the closing stone.

55. *Distribution of error.* Recording is done on form 13 as already described under double levelling, and is similar to that of secondary double levelling. As each line is completed the field sheets are taken over by the section officer, who has the means, rise or fall, and reduced levels checked. The terminal error is then determined by taking the differences of level of the closing and starting pillar by double levelling and by single levelling, the difference between the two giving the error.

The following example will illustrate the method :—

Height of terminal stone by double levelling ...	107·323	
Height of starting stone by double levelling ...	102·879	
	4·444	(a)
Height of terminal stone by single levelling ...	104·58	
Height of starting stone by single levelling ...	100·00	
	4·58	(b)

Error (a − b) = 0·14 feet.

Correction to be applied to the line is ½ (a − b) or −0·07 feet. Double levelled heights of terminal stones are accepted and above correction applied to all other levels. This correction is calculated and noted during the field season, and passed if within permissible limits. It is actually applied to mean sea levels by a field computing section or during recess.

56. *Computation.* This consists of finally computing mean sea levels of all stones and points, entering in level books, and preparing rough spot level charts (see plate XI).

56. *(Contd).* The mean sea levels of tertiary double levelled stones are first determined, from the known mean sea level of a secondary levelling bench mark as below :—

Mean sea level of bench mark	...	377·295 ft.
Reduced level of stone from B. M. connection	...	—8·421 „
Mean sea level of stone	...	368·874 ft.

From this mean sea level of the stone and its adjusted reduced level of double levelling, the true value of the datum line of the circuit is determined as below :—

Mean sea level of stone	...	368·874 ft.
Reduced level (height in circuit)	...	96·362 „
Datum line	...	272·512 ft.

The value of the datum line thus obtained is added to the adjusted reduced level of each stone to obtain its mean sea level.

The mean sea level of single levelled stones and other points in single lines are obtained as below :—

Mean sea level of starting stone (from double levelling abstract)	...	372·72 ft.
Value accepted for it by single leveller	...	100·00 „
Value of datum	...	272·72 „
½ the line correction (vide para 55)	...	+0·04 „
Datum	...	272·76 ft.

This last value is added to each reduced level of single line points.

Mean sea levels of all points are thus obtained.

57. *Level Books.* The preparation of level books is illustrated in plate XII which is self explanatory. Mean sea levels of tops of pillars are entered in red to 3 places of decimals, and ground levels in black to two places.

58. *Level charts.* On the spot level charts top heights are not entered, only ground levels to 2 places of decimals. Methods of entering levels and preparing blue prints are illustrated in plate XI.

DETAIL SURVEY

59. *Fixed points* The survey being based on rectangulation stones, stone numbers should be written in light blue on the plane table sections before taking the field.

60. *Conventional signs.* As the final maps are to be reproduced in black only, the conventional signs should be altered so as to give as great a diversity as possible. If a conventional sign, normally in use in the Department,

60. (*Contd.*) depends upon colour only to distinguish it from another, one or other must be changed. The conventional sign table at the foot of the specimen sheet (plate XIX) has been devised with this object in view.

61. *Hill features.* Country for irrigation usually consists largely of desert in which there are no streams, but which contains many depressions of various shapes and depths. These are very important and should not be omitted, however shallow. It is convenient to show them with a cliff symbol where their sides are vertical, with a firm line where well defined, but sloping, and with a broken line where vague and ill-defined. Relative heights should be frequent. As discussed under contouring, it is impossible to show sufficient contours to depict these depressions, or abrupt changes of slope, and both should be shown conventionally by an appropriate symbol.

All well defined hills should be shown, and, where ridges are prominent, form lines might be entered on traces to assist in contouring. The extent to which contouring can be facilitated by temporary form lines indicating the slope of the ground must depend on circumstances, and more especially on the expertness of the surveyors available for the work.

62. *Sand hills* Sand-hills present special difficulties, both from the survey point of view and from that of contouring. They are usually inirrigable and only their limits need be shown, contours being confined to irrigable ground. This is exceedingly difficult to carry out in practice, especially where sand-hills do not rise abruptly, but are bordered by low sand undulations merging into level ground. Special orders should be issued as to how such ground should be dealt with, both by levellers and surveyors, after inspection of the ground by the officer in charge and, if necessary, consultation with the Irrigation Engineers. The principle should be borne in mind that contours are required in irrigable, but not in inirrigable ground, the latter being shown conventionally by the detail surveyors.

63. *Village boundaries* The method of dealing with village boundaries will depend on their accuracy, as taken from village maps, and on the clearness with which they are demarcated on the ground. It has been found that the most suitable method is to survey the trijunctions of one village and, roughly to indicate from village map reductions the positions with reference to them, of those of all other villages on the same plane table section. Trijunctions must then be surveyed ahead of the work, and village boundaries put on in blue by adjustment between them. Thus, when ground is surveyed, village boundaries will already be shown with considerable accuracy, and there should generally be no difficulty in locating them on the ground without having to make exhaustive enquiries from local officials. Boundaries are often clearly demarcated in cultivated country but not at all in waste land.

METHOD OF WORK

Where boundaries are not demarcated, but can be shown, as was the case in the Sutlej Valley, from village maps which have been found accurate, it is probably better to accept them than to endeavour to check or resurvey from local information which is not always reliable. In other words, when boundaries are found accurate when demarcated, they can generally be accepted where undemarcated. Where village maps are based on an inaccurate framework and are quite unreliable, which is not the case in the Punjab, the survey of village boundaries would be a more formidable undertaking and a great deal of co-operation would have to be obtained from the local Revenue Staff. 63. (*Contd.*)

It is possible to have rectangulation stones shown on village maps by the Revenue Staff, and in this way a compilation of village boundaries can be made and put on the plane table sections before taking the field. The disadvantage is that stones are not always shown correctly, and it is doubtful if this method is worth while.

Riverain data should be collected prior to survey, and the positions of stones roughly indicated to enable the surveyors to locate and survey them. It would be possible to compute and plot these, but it is not worth while owing to the abundance of other fixed stones. 64. *Riverain data.*

The usual field traces should be kept up and, as field sections are all in black, it is desirable to elaborate the traces more fully than is usual, mainly with a view to the maps being used later as a basis for 1 inch survey. In the Sutlej Valley Project, traces were prepared which were practically coloured editions of the plane table sections, with the addition of reference numbers for names, the same traces being used in recess as typers' guides. These traces can, if desired, be sent to the Irrigation Department as advance copies of the maps, to be returned on receipt of published copies. This was done in the case of the Sutlej Valley, and was appreciated. In addition to detail actually on the plane table sections, any further information likely to help in contouring should be shown, and also any detail necessary for future 1 inch maps, which has been omitted from the irrigation plans. 65. *Field traces.*

The above refers especially to ornamentation. It must, however, be remembered that, by the time 1 inch maps are prepared, waste land will be under irrigation, and thus it is not desirable to spend time surveying the limits between cultivation and waste land, or on ornamentation of the latter, unless required for the Irrigation Project. 66 *Ornamentation.*

Names are dealt with in the usual way, but the number shown should be the minimum required by the Irrigation Department. All villages and hamlets should be named but very few names of wells should be shown. The names of wells are seldom permanent, and vary with 67. *Names.*

67. (*Contd.*) the temporary owners. As they are very numerous, their omission results in a great saving of time, and permission to omit them should be sought. This does not refer to names of isolated wells in waste land, which may be important.

RECESS WORK

68. *Completion of plane table sections in recess and in the field.* In order to accelerate the submission of field sections for publication, it is desirable to start a typing and contouring section in the field. Each plane tabler should complete three or four sections during the field season, which should begin to reach head-quarters at about the end of the second month. It should be possible to send the first batch for publication before returning to recess and to make considerable headway with the second.

69. *Preparation of small scale maps.* Where small scale, say 1 inch to 1 mile, maps are required in addition to the ordinary sheets, these must either be drawn on blue print reductions of the detail sheets, or be produced direct by photography from them. If the former method is adopted, a good deal of detail can probably be omitted. Whether contours are possible on the reduced maps must depend on circumstances. Each small scale map would probably cover one block. A specimen redrawn 1 inch sheet appears in plate XXI.

For the Panjnad Weir Site of the Sutlej Valley Project, a 1 inch index map, was prepared by photographic reduction from the eleven 4 inch maps, and the result appears in plate XXII. With a view to this, names on the detailed sheet were handprinted a great deal larger than usual. One of the component 4 inch maps appears in plate XX.

70. *Compilation of contour sheets combined with detail.* There are various ways of carrying out the compilation and the method adopted will vary with circumstances. Where a good deal of contouring is to be done on the ground it might be desirable, before taking the field, to print spot levels on plane table sections in blue, but this method has not been tried. In this case contouring might be done on the plane table sections in pencil, either in recess or the field, and traced. A disadvantage of this would be that typing and contouring could not proceed simultaneously and work would be delayed. In the average sheet the amount of detail which actually affects the contouring is not great, and the method employed has been to trace the detail on to the rough compilation sheets before starting the contouring.

Where all work is done in recess, the best procedure is as follows. A grid is prepared for preparation of level charts (see plate XI) and two copies of the grid are printed in blue for each sheet. One copy

is utilized by the levelling party for preparation of the rough compilation of level charts, which rough compilations, having the levels entered in blue, are sent to the party preparing the contour sheets. Details affecting contouring are then transferred on to the blue prints and rough compilations of the contour sheets carried out on them. The remaining copy of the grid is utilized for fair level charts. 70. *(Contd.)*

The following points should be observed when carrying out the work. Contours are only required in irrigable ground, and the higher ground is the most important. No attempt should be made to contour inirrigable hill features which have been shown conventionally on the field sections, but contours should merely be taken up to them. The country for irrigation is normally a confusion of undulations and depressions, there being no regular water features, except large rivers. The depressions may be either isolated and small, or the beds of old rivers and so more or less continuous. Usually the highest ground is along the banks of old river beds, consisting of silt which has been deposited in the past, during periodical overflowing of their banks by the rivers. As even the smallest depressions are normally too deep to permit of the requisite number of contours at 1 foot interval being drawn on the scale of survey, it is sufficient to take the contours up to the banks and stop them there. Actual contouring of depressions is not important as they are bound to be commanded by neighbouring water channels. In the case of sudden changes of slope it is also frequently impossible to show a sufficient number of contours, and a change having been shown conventionally as described under detail survey (para 59), contours both above and below should be run into the symbol and stopped. 71. *Delineation of hill features.*

Contours should be kept as continuous as possible for the sake of clearness and to economise contour values. For instance, where the levels show two rises of height at some distance apart, in the absence of any intermediate level showing the contrary, it would be assumed that the rise is continuous and the feature should be shown by one contour surrounding both levels, rather than by two ring contours.

Owing to the absence of water features contouring consists mainly of ring contours, and it is difficult to differentiate at a glance between those showing rises and those showing depressions. To facilitate this, it is a very useful convention to show contour values, not breaking the contour as is usually done, but on the higher sides of them. Thus, not only are the contours in general made far easier to follow, but the doubts as to rises and depressions are removed because the contour value will always be inside a ring contour showing a rise, and outside that showing a depression. It should be remembered that, owing to the absence of regular water features, contours are far more difficult to follow than in the case of normal ground, and contour values should be exceedingly numerous.

FAIR DRAWING AND REPRODUCTION

72. *Level, contour and detail sheets.* It is not proposed to discuss details of this work, as the methods employed would depend on the form of prints required and other circumstances. The importance of good registration is emphasized. The spot level and contour sheets, which can be vandyked, are unlikely to be much distorted, having been dealt with under office conditions. The field detail sheets however are certain to suffer from a good deal of distortion. As these have to be photographed, being on drawing paper mounted on cloth, the distortion can be corrected and the dimensions made to conform to those of the other sheets.

SECTION V

ORGANIZATION AND PERSONNEL

GENERAL

73. *Sections.* Organization will be dealt with under the following heads, as these have hitherto been carried out by separate parties or offices.

(*a*) Rectangulation.
(*b*) Levelling, including rough compilation of level charts.
(*c*) Detail survey, including rough compilation of contour sheets.
(*d*) Fair drawing of level charts and contour sheets.
(*e*) Reproduction.

It is probable that it will be found more economical and convenient for the same agency to carry out (c) and (d), but this would depend on circumstances and the personnel available.

74. *Officer in charge.* It is necessary that all activities should be co-ordinated under one head who should be responsible for the planning and organization of the work, in consultation with the Irrigation and Revenue Departments. This can either be done by an officer appointed to administer without executive charge, or by the officer in charge of one of the parties concerned. In the latter case, as all other work is dependent on rectangulation, and is preceded by it, the officer in charge of rectangulation should be selected if possible, and the rectangulation party should be responsible for preliminary work affecting the whole project, as well as that in connection with rectangulation itself. Levelling and detail survey parties would deal only with their own work.

RECTANGULATION PARTY

75. *Rectangulators.* The technical personnel of a rectangulation party in the field consists of triangulators or traversers or both, rectangulators and computers.

Rectangulators, who should be designated as such and not called traversers, are divided into exterior and interior. The former require higher qualifications than the latter, owing to the necessity of their having a moderate knowledge of the use of a theodolite. This distinction may be abolished under conditions discussed in para 42.

As work of this nature is not the normal work of the Department, personnel will usually be purely temporary, and rules for their entertainment and terms of service are drawn up for the Department. Pay of rectangulators has been Rs. 30/- (rising after 3 months to 35/-) to 40/-.

75. (*Contd.*) The duties of interior rectangulators are very elementary, and as the pay is considered too high, these men will be recruited in future on Rs. 20/-, if only expected to run one interior line. (See below).

The following proposal for employing menials to do interior rectangulation has been sanctioned as an experiment and, if found satisfactory, will result in a good deal of saving of cost in travelling allowances, tentage etc.

(*i*) Interior rectangulators to have 2 squads and run two lines, receiving the same pay as exterior men.

(*ii*) The head tindal of each squad to be in charge of the running of a line under the rectangulator, and to receive Rs. 5/- temporary allowance, whilst so doing.

76. *Employment of rectangulators.* Rectangulators can be employed either in groups or independently, the former system being preferable where there are difficulties as regards water and supplies. A group consists of about 4 rectangulators and 1 partaller, who all camp together and are given part of a block to deal with. They usually start work on four rectangles in one line and run parallel with each other. A disadvantage of this system is that partallers and rectangulators are too well known to each other, and there is a danger that the former will not show up bad work. Independent rectangulators are given a line to sub-divide, and partallers are used to partal any line under the orders of the camp officer or his assistant.

77. *Camps.* A camp officer, with 1 assistant, should be able to look after a camp of 20 traversers and the required number of computers.

Rectangulation camps should be large, it being preferable to limit the number of camps and to give each camp officer a number of assistants for partalling. The proportion of exterior to interior men being taken to be about 3 to 5, a camp officer, with 2 assistants, should be able to control 24 exterior and 40 interior rectangulators. It would usually be preferable to give all the exterior men to one assistant and all the interior to the other.

78. *Transport and khalasis.* Permanent camel transport has hitherto been used in all work of this nature and it has been necessary to allot 5 camels to each traverser, 5 to each exterior and 1 to each interior rectangulator.

Owing to the necessity of much jungle clearing, and little deviation from the rectangle line being allowed, it has been necessary to allot 12 khalasis to each traverser, though under favourable circumstances the number might be reduced. Nine khalasis have been allowed for each exterior and 6 for each interior rectangulator, including personal khalasis.

Rectangulation work gives very little employment during recess and, unless the staff is required for other work, the greater part of it will normally be sent on Departmental leave or employed elsewhere, only a sufficient number being retained to complete any necessary computation, to prepare any records which may be required of the previous season's work, and to make preparations for the following season. 79. *Recess.*

LEVELLING

As work in connection with irrigation projects is outside the normal programme of the Department, levellers will generally be purely temporary. In the Sutlej Valley, levellers were entertained on Rs. 30/- or 35/-, rising by annual increments of Rs. 2/8/- to Rs. 5/-, to Rs. 50/-. 80. *Pay and distribution of levellers.*

In the Sutlej Valley all levellers including single levellers worked in pairs to save transport, etc. Secondary double levellers worked directly under the O.C. detachment. They were provided with recorders. Tertiary double levellers were under section officers and their work preceded, as far as possible, that of the single levellers. Tertiary single levellers were given from 16 to 20 twentyfive-acre lines or 8 to 10 hundred-acre lines to be worked from each camp.

A camp officer, who should be an Upper Subordinate, with 2 recorders, can look after about 15 levellers. 81. *Camps and transport.*

Permanent camel transport will usually be necessary and, in the Sutlej Valley, camels were allowed at the rate of 1 load camel for each leveller. These camels were not allotted permanently to levellers but were at the disposal of section officers. One extra camel for each pair of levellers was allowed in desert areas to convey water and provisions.

In normal country 28 men were allowed to a pair of secondary double levellers, and 6 men each to tertiary double, or single, levellers. In desert areas 1 extra man was allowed for each pair of levellers. 82. *Khalasis.*

Work in recess was organized into 3 sections, whose duties were as follows:— 83. *Recess.*

(*a*) *Computing Section.*—Adjustment of double levelling circuits (done by O.C. section) and computations of mean sea levels.

(*b*) *Book Section.*—Recording of mean sea levels in book form.

(*c*) *Chart Section.*—Copying of values from books on to charts.

The average number of levellers employed in the Sutlej Valley for field seasons of 6 months was 70, and recess strength to deal with their out-turn, 28 computers, etc. These would be organized approximately as follows:—

Computing Section ..	16
Book Section	6
Chart Section	6

IRRIGATION SURVEYS

DETAIL SURVEY

84. (*a*) *In the field.*—This calls for no special comment as the work is normal to the Department.

(*b*) *In recess.*—Work in recess normally consists of completing and typing plane table sections, rough compilation of contour sheets, and village map reduction, if any, for the following field season. Five typers might be required to type 100 plane table sections in 3 months, and 6 or 7 draftsmen might contour the same number of sheets in the same time. It is preferable for camp officers to complete their own sheets, both as regards typing and contouring. The time taken over recess work depends on the urgency with which the sheets are required. They should usually be completed as rapidly as possible, in which case there would not be work for the whole recess for the staff employed, and arrangements should be made to employ them elsewhere or on the fair drawing of contour sheets (see para 71).

FAIR DRAWING OF LEVEL AND CONTOUR SHEETS

85. In the case of the Sutlej Valley work, this was carried out in No. 2 Drawing Office, Dehra Dūn, most of the draftsmen employed being purely temporary. This was due to the fact that, when contouring was started detail survey had not been asked for, and consequently there was no party available to undertake the work. In future, when contour sheets are combined with detail, the fair drawing might well be carried out by the party doing the detail survey. When no detail survey is carried out and contour sheets are required, they must be drawn by the Drawing Office, or a special staff may be raised by the rectangulation party to do the work. A fair draftsman should draw an average contour sheet in 3 or 4 days, and a level chart in 2 or 3 days.

MAP REPRODUCTION

86. It is not proposed to deal with the question of reproduction which is the normal work of the offices concerned, and the organization for which depends entirely on circumstances.

SECTION VI

OUTTURN AND COST RATES

87. Tabular statements are appended, giving approximate actual and estimated cost rates, and outturn to be expected. Actual cost rates are chiefly based on experience in the Sutlej Valley, where, for the first time, rectangulation, levelling and detail survey have been carried out by the Survey of India Department. These figures must be considered very approximate, and detailed estimates, based on local conditions, should always be prepared.

COST RATES

Cost rates in rupees per sq. mile

	100 acre	64 acre	25 acre	16 acre
	Rs.	Rs.	Rs.	Rs.
Rectangulation, including triangulation and traversing and cost of stones ...	115/-	135/-	170/-	215/-
Levelling, including computations and rough compilation of level charts ...	22/-	32/-	44/-	64/-
Detail survey, including rough compilation of contour sheets	50/-	50/-	50/-	50/-
Drawing of level charts	-/6/-	-/8/-	-/12/-	1/-
Drawing of contour sheets... ...	-/6/-	-/8/-	-/12/-	1/-
Printing and provision of 50 copies of each of the plans referred to in para 20	8/-	8/-	8/-	8/-

NOTE.—Above cost rates do not include instrument and supervision charges. It is usual to add 4% for cost of instruments and 10% for supervision. The latter charge has however been waived in the case of rectangulation and detail survey undertaken for the Punjab Government, on the strength of their utility to the Survey of India. It has however been charged in the case of levelling.

IRRIGATION SURVEYS

OUTTURN

87. *(Contd.)*

Outturn per man per month

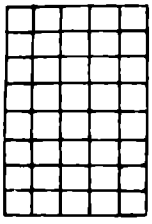
	100 acre			64 acre			25 acre			16 acre		
	Stones fixed	Area Sq. miles	Linear miles	Stones fixed	Area Sq. miles	Linear miles	Stones fixed	Area Sq. miles	Linear miles	Stones fixed	Area Sq. miles	Linear miles
Traversing and location of corners of main rectangles, dimensions about 2½ miles by 1½ miles	..	..	25	...	...	25	...		25	...	...	25
Exterior rectangulation ...	50	24	...	70	23	...	90	20	...	120	18	...
Interior rectangulation ...	45	11	...	50	8	..	80	4	..	90	3	...
Secondary double levelling ...	...	...	100	...	...	100	...	..	100	...	...	100
Tertiary „ „ ...	...	...	140	...	..	140	...	...	140	...	...	140
Tertiary single levelling ...	...	...	140	..	...	140	...	..	140	...	...	140
Detail Survey, not including any contouring in the field. (This work was done almost entirely by pupils so can be considered minimum)	..	12	..	..	12	...	...	12	...	...	12	...

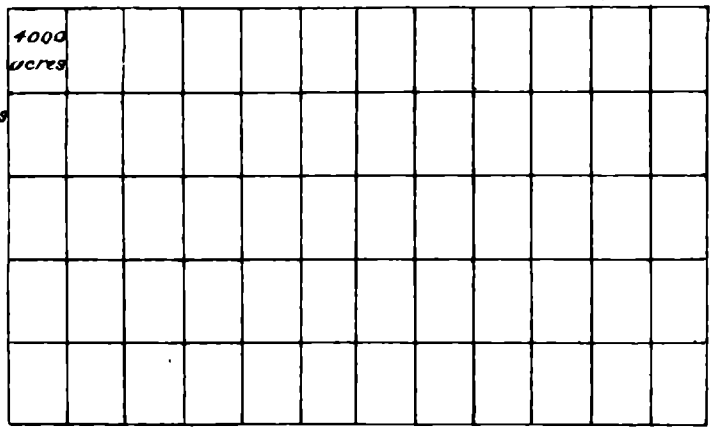
BLOCK DIAGRAMS

Sind Sagar Doab Rectangulation **PLATE I**

Block 25 m x 15 m (240,000 acres)
Subdivided into main rectangles

Main Rectangle 3½ m x 3 m Showing subdivisions to 100 acres



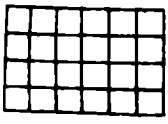


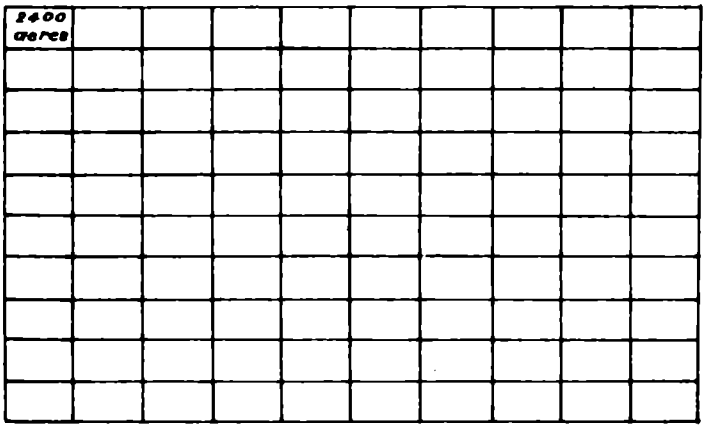
Acre
220'
198'

Sutlej Valley Rectangulation

Block 25 m x 15 m (240,000 acres)

Main Rectangle 2½ m x 1½ m Showing subdivision to 100 acres



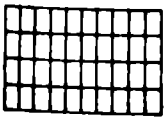


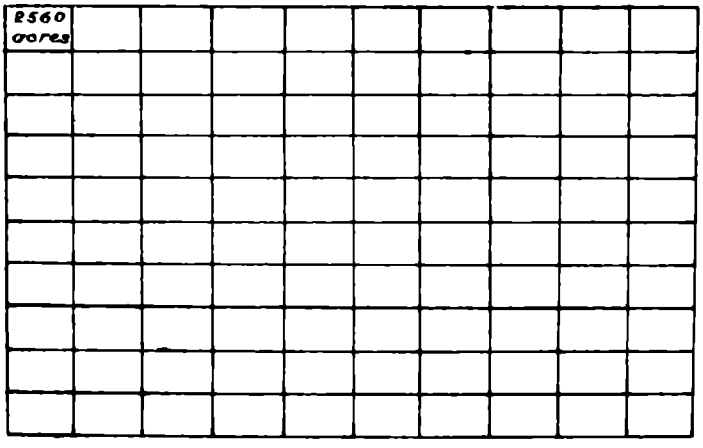
Acre
220'
198'

Sukkur Rectangulation

Block 25 m x 16 m (256,000 acres)

Main Rectangle 2½ m x 1⅝ m Showing subdivision to 64 acres





Acre
2½ ch-165'
40 ch = 264'

PLATE II a.

Diagram showing method of numbering of stones in a 240,000 acre block, stones down to 25 acres being numbered Divisions into Topo Sheets and charts also shown

BLOCK A

1	21	41	61	81	101	121	141	161	181	201	221	241	261	281	301	321	341	361	381	401	421	441	461	481	501	521	541	561	581
2	22	42	62	82	102	122	142	162	182	202	222	242	262	282	302	322	342	362	382	402	422	442	462	482	502	522	542	562	582
3	23	43	63	83	103	123	143	163	183	203	223	243	263	283	303	323	343	363	383	403	423	443	463	483	503	523	543	563	583
4	24	44	64	84	104	124	144	164	184	204	224	244	264	284	304	324	344	364	384	404	424	444	464	484	504	524	544	564	584
5	25	45	65	85	105	125	145	165	185	205	225	245	265	285	305	325	345	365	385	405	425	445	465	485	505	525	545	565	585
6	26	46	66	86	106	126	146	166	186	206	226	246	266	286	306	326	346	366	386	406	426	446	466	486	506	526	546	566	586
7	27	47	67	87	107	127	147	167	187	207	227	247	267	287	307	327	347	367	387	407	427	447	467	487	507	527	547	567	587
8	28	48	68	88	108	128	148	168	188	208	228	248	268	288	308	328	348	368	388	408	428	448	468	488	508	528	548	568	588
9	29	49	69	89	109	129	149	169	189	209	229	249	269	289	309	329	349	369	389	409	429	449	469	489	509	529	549	569	589
10	30	50	70	90	110	130	150	170	190	210	230	250	270	290	310	330	350	370	390	410	430	450	470	490	510	530	550	570	590
11	31	51	71	91	111	131	151	171	191	211	231	251	271	291	311	331	351	371	391	411	431	451	471	491	511	531	551	571	591
12	32	52	72	92	112	132	152	172	192	212	232	252	272	292	312	332	352	372	392	412	432	452	472	492	512	532	552	572	592
13	33	53	73	93	113	133	153	173	193	213	233	253	273	293	313	333	353	373	393	413	433	453	473	493	513	533	553	573	593
14	34	54	74	94	114	134	154	174	194	214	234	254	274	294	314	334	354	374	394	414	434	454	474	494	514	534	554	574	594
15	35	55	75	95	115	135	155	175	195	215	235	255	275	295	315	335	355	375	395	415	435	455	475	495	515	535	555	575	595
16	36	56	76	96	116	136	156	176	196	216	236	256	276	296	316	336	356	376	396	416	436	456	476	496	516	536	556	576	596
17	37	57	77	97	117	137	157	177	197	217	237	257	277	297	317	337	357	377	397	417	437	457	477	497	517	537	557	577	597
18	38	58	78	98	118	138	158	178	198	218	238	258	278	298	318	338	358	378	398	418	438	458	478	498	518	538	558	578	598
19	39	59	79	99	119	139	159	179	199	219	239	259	279	299	319	339	359	379	399	419	439	459	479	499	519	539	559	579	599
20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600

Continuation Block B

400 acre rectangle
Subdivided to 25 acres

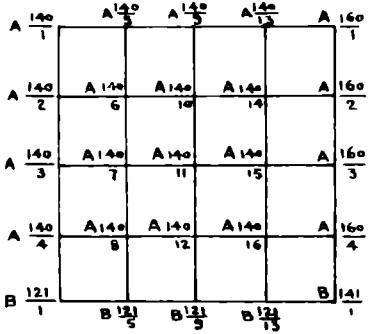


PLATE II b.

Alternative system of stone numbering by main rectangles

(Only to be used when an exact number of main rectangles fall in a sheet)

Block 25×16 m

Subdivided into Sheets & main rectangles Block B

1	9	17	25	33	41	49	57	65	73
1		2		3		4		5	
2	10	18	26	34	42	50	58	66	74
3	11	19	27	35	43	51	59	67	75
6		7		8		9		10	
4	12	20	28	36	44	52	60	68	76
5	13	21	29	37	45	53	61	69	77
11		12		13		14		15	
6	14	22	30	38	46	54	62	70	78
7	15	23	31	39	47	55	63	71	79
16		17		18		19		20	
8	16	24	32	40	48	56	64	72	80

Main rectangle 2½×2 m

Containing 50-64 acre rectangles

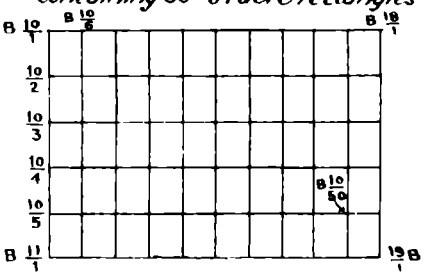


PLATE IIc

Alternative system of stone numbering by sheets

Block 25×16 m

Subdivided into sheets

Block B

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20

Sheet 5×4 m

Containing 200-64 acre rectangles

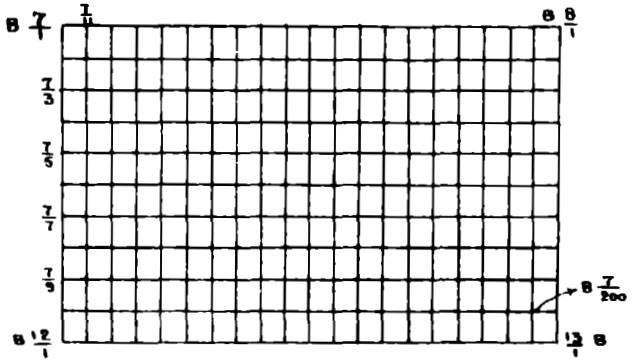


PLATE III

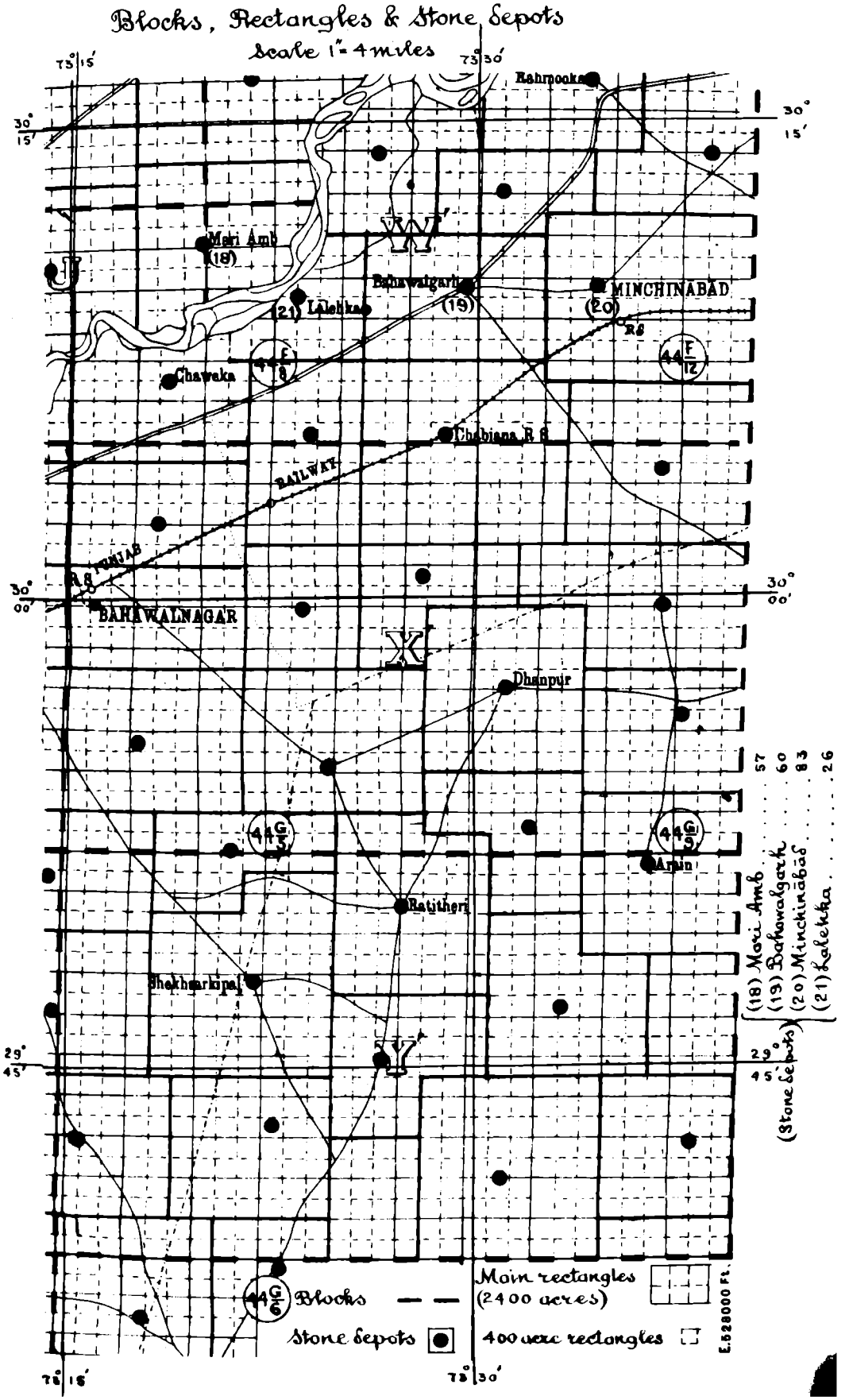
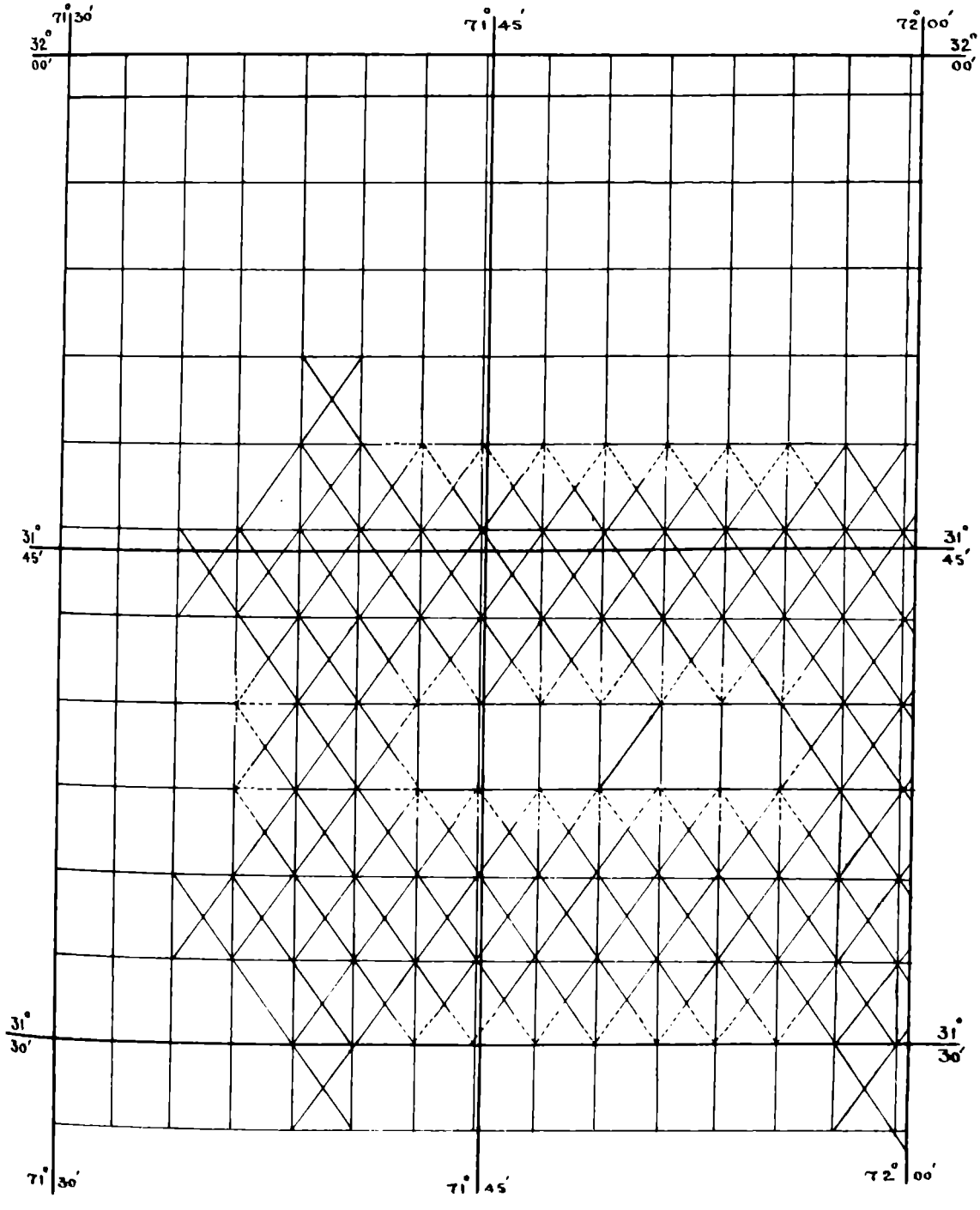

Index plan for Project showing
Blocks, Rectangles & Stone Depots
Scale 1" = 4 miles
75° 15'
75° 30'
30° 15'
30° 00'
29° 45'
Rahmoonka
Mari Amb (18)
Bahawalgarh (19)
MINCHINABAD (20)
Lalekka (21)
Chaweka
Chabiana R S
RAILWAY
PUNJAB
R S
BAHAWALNAGAR
Dhanpur
Ratitheri
Shekhankipal
Arpin
44 F/8
44 F/12
44 G/5
44 G/6
W
X
Y
(18) Mari Amb 57
(19) Bahawalgarh 60
(20) Minchinabad 83
(21) Lalekka 26
(Stone depots)
Blocks
Stone depots
Main rectangles (2400 acres)
400 acre rectangles
E. 528000 Ft.

PLATE IV

Diagram showing network of Triangles

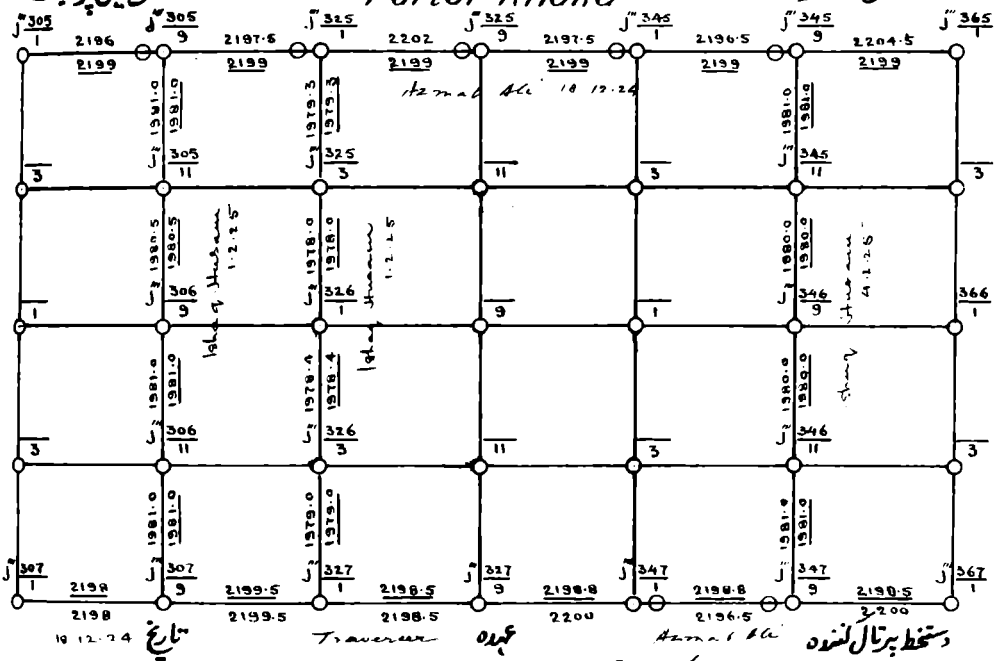
for fixing corners of main rectangles



Diagrams showing Partal & work Khakas

نمبر ۲۳ پارٹی

Partal Khaka

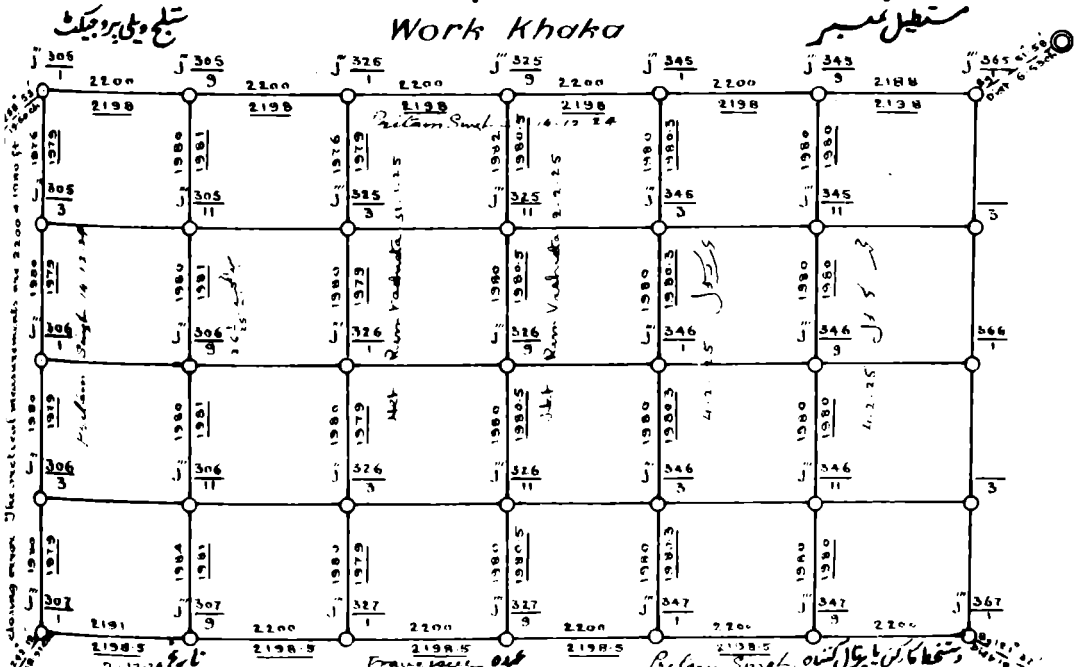


نوٹ: فاصلے جو بوقت پرتال نصب شدہ پتھروں کے درمیان برآمد ہوئے بقلم سیاہی وہ فاصلے جو پرتال کے بعد موقعہ پر صحیح کئے گئے بقلم سرخی درج کئے گئے ہیں

Figures which are not underlined denote partallers measurements of rectangulators work
Those underlined denote measurements after correction by partaller

Rect No 305 Block No J‴ سندھ ساگر پارٹی Sheet No 39 L/10 Line No 29

Work Khaka



نوٹ: فاصلے جو بوقت پرتال نصب شدہ پتھروں کے درمیان برآمد ہوئے بقلم سیاہی وہ فاصلے جو پرتال کے بعد موقعہ پر صحیح کئے گئے۔ بقلم سرخی درج کئے گئے ہیں

Table of corrections to be applied when adjusting closing errors

Closing error on courses in feet	Corrections in feet for sides divided into 8 parts							Corrections in feet for sides divided into 4 parts		
	1/8	2/8	3/8	4/8	5/8	6/8	7/8	1/4	2/4	3/4
1	·1	·3	·4	·5	·6	·8	·9	·3	·5	·8
2	·3	·5	·8	1·0	1·3	1·5	1·8	·5	1·0	1·5
3	·4	·8	1·1	1·5	1·9	2·3	2·6	·8	1·5	2·3
4	·5	1·0	1·5	2·0	2·5	3·0	3·5	1·0	2·0	3·0
5	·6	1·3	1·9	2·5	3·1	3·8	4·4	1·3	2·5	3·8
6	·8	1·5	2·3	3·0	3·8	4·5	5·3	1·5	3·0	4·5
7	·9	1·8	2·6	3·5	4·4	5·3	6·1	1·8	3·5	5·3
8	1·0	2·0	3·0	4·0	5·0	6·0	7·0	2·0	4·0	6·0
9	1·1	2·3	3·4	4·5	5·6	6·8	7·9	2·3	4·5	6·8
10	1·3	2·5	3·8	5·0	6·3	7·5	8·8	2·5	5·0	7·5
11	1·4	2·8	4·1	5·5	6·9	8·3	9·6	2·8	5·5	8·3
12	1·5	3·0	4·5	6·0	7·5	9·0	10·5	3·0	6·0	9·0
13	1·6	3·3	4·9	6·5	8·1	9·8	11·4	3·3	6·5	9·8
14	1·8	3·5	5·3	7·0	8·8	10·5	12·3	3·5	7·0	10·5
15	1·9	3·8	5·6	7·5	9·4	11·3	13·1	3·8	7·5	11·3

Method of application

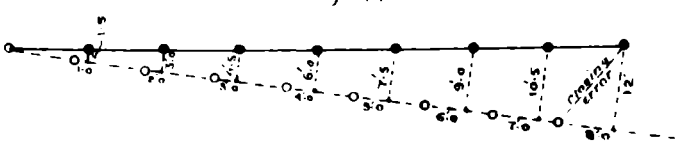


PLATE VII

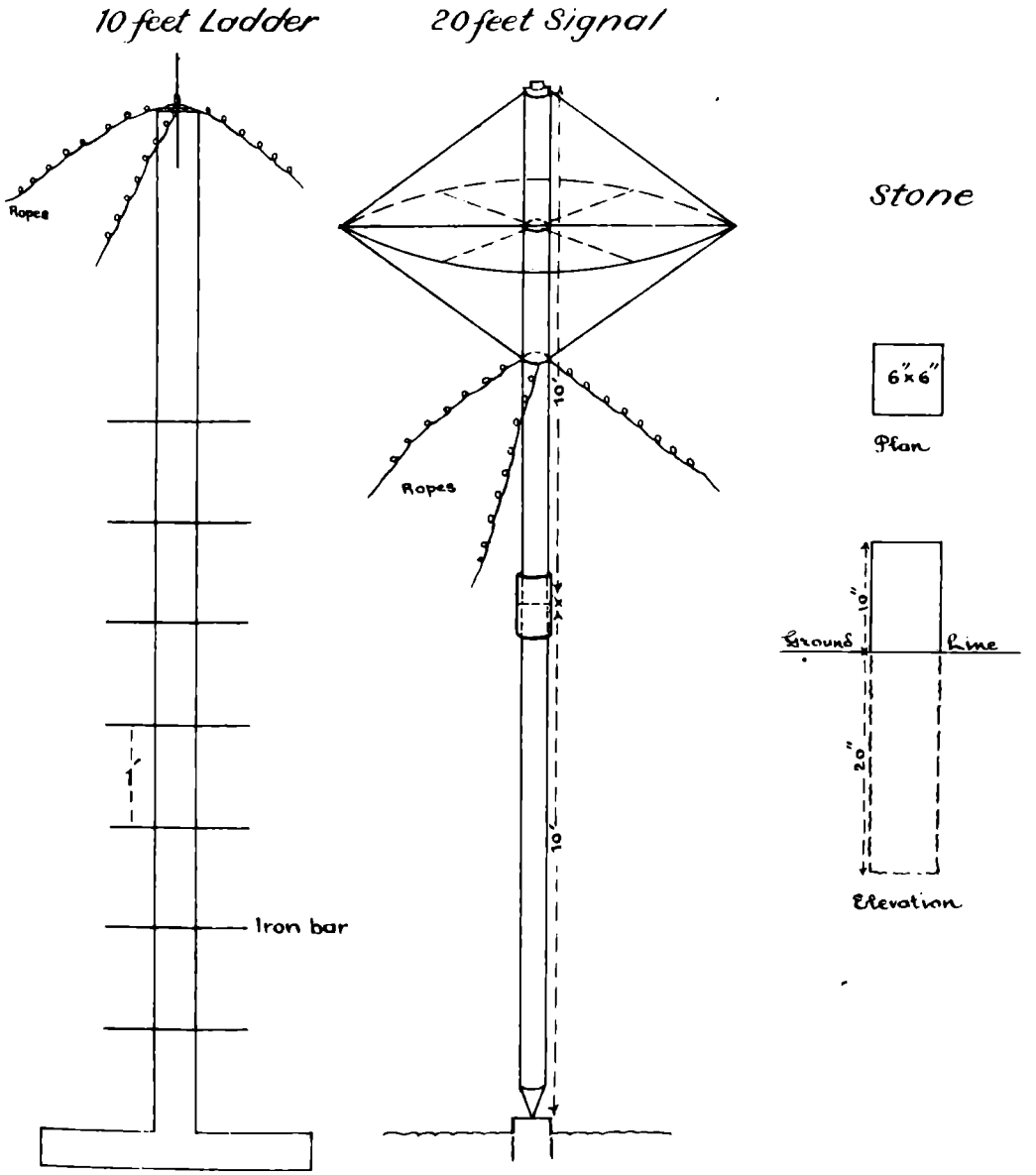
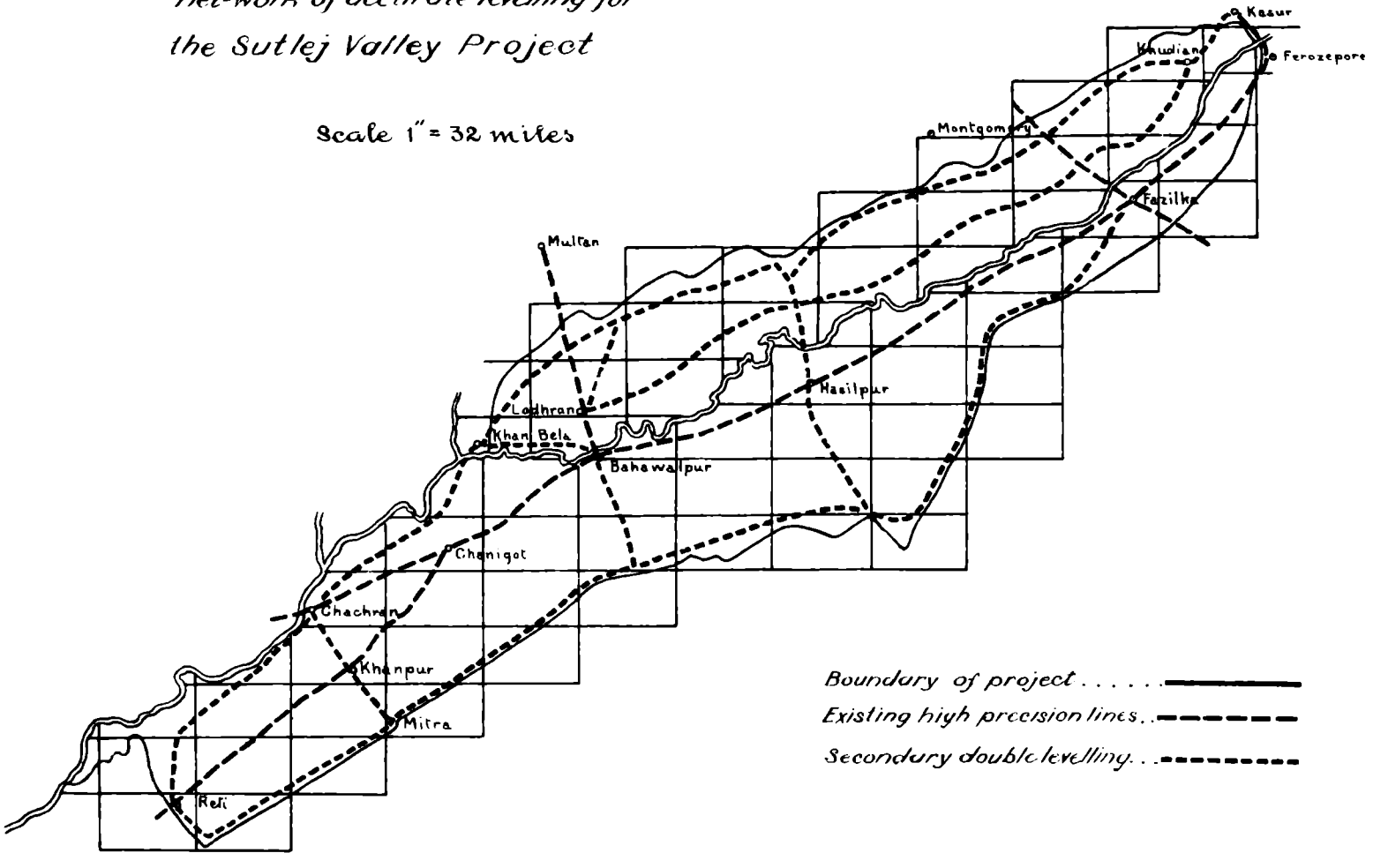
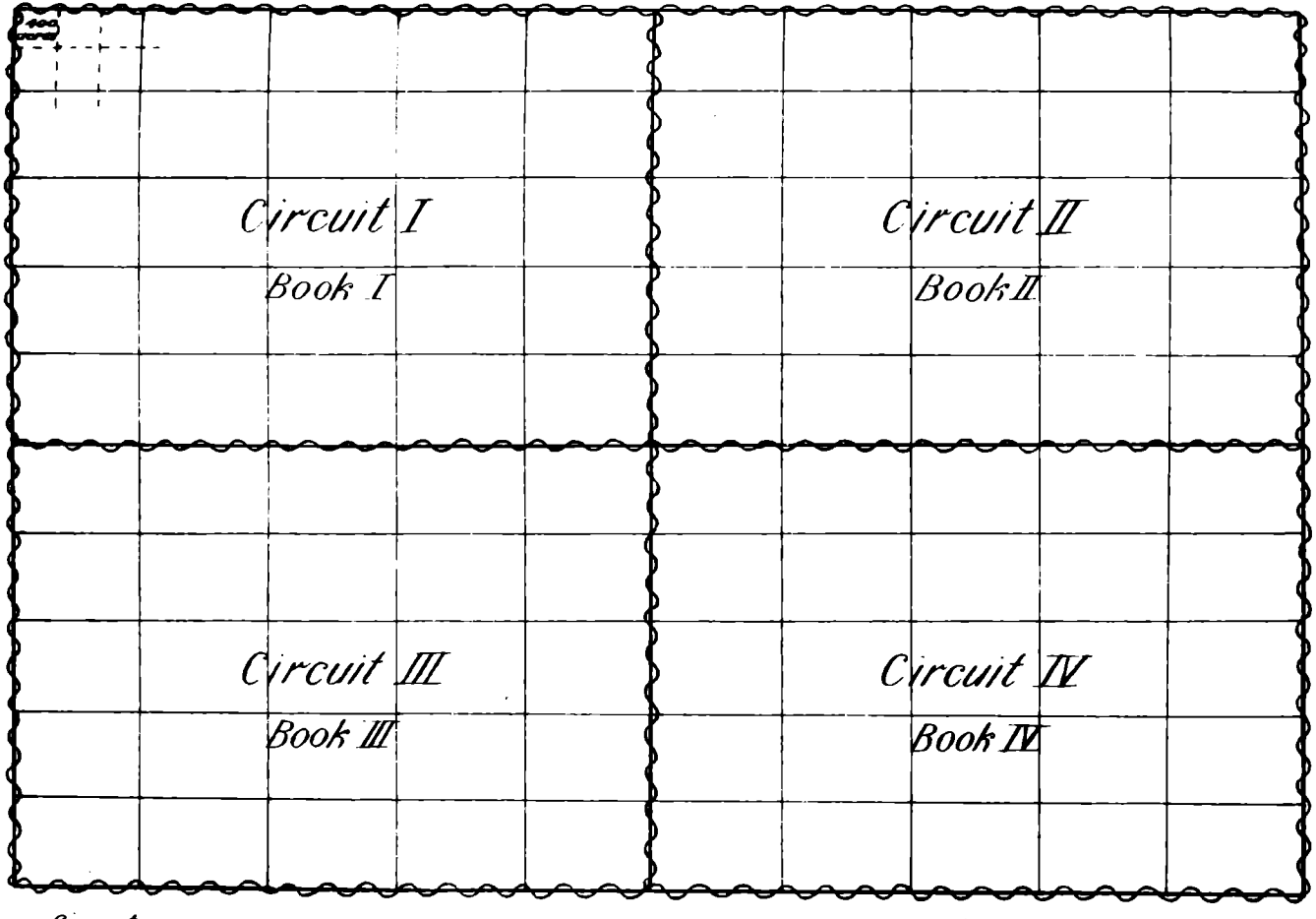

10 feet Ladder
20 feet Signal
Ropes
Ropes
1'
Iron bar
10'
10'
Stone
6"×6"
Plan
10"
Ground
Line
20"
Elevation

Diagram showing blocks and net-work of accurate levelling for the Sutlej Valley Project

Scale 1" = 32 miles



Tertiary levelling to run north & south



and books, tertiary levelling to run East and West

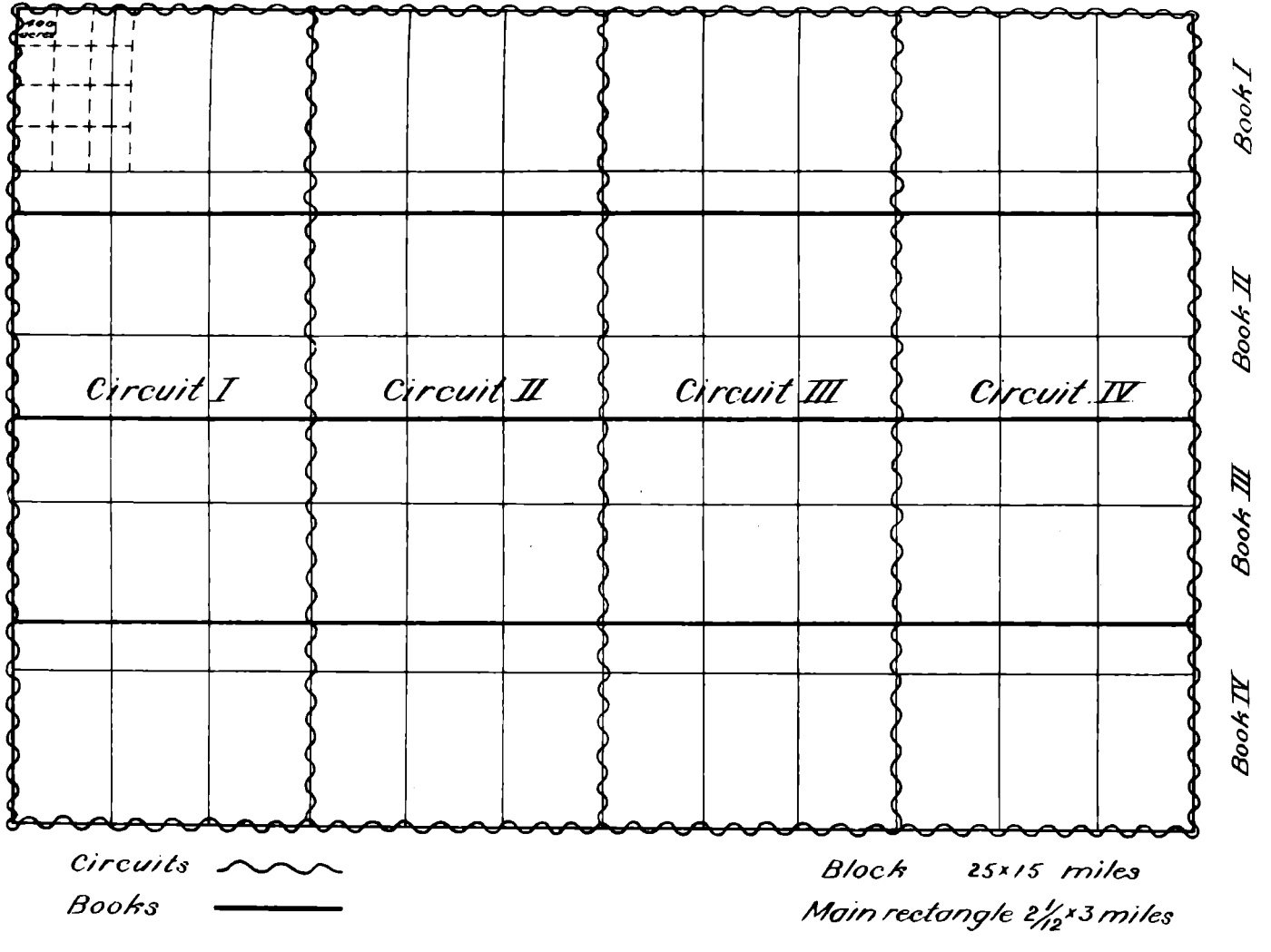
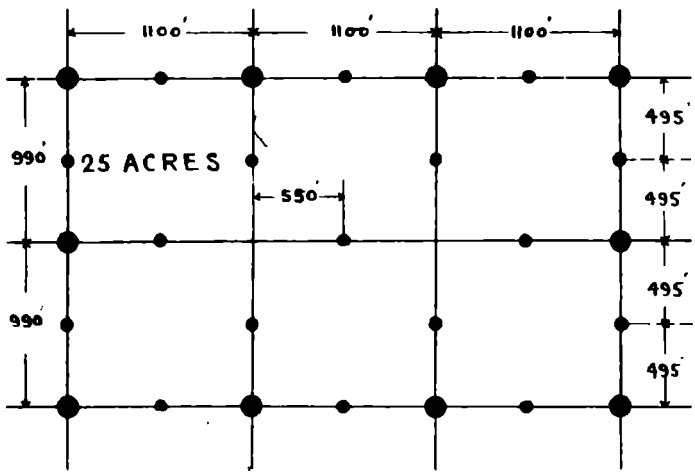
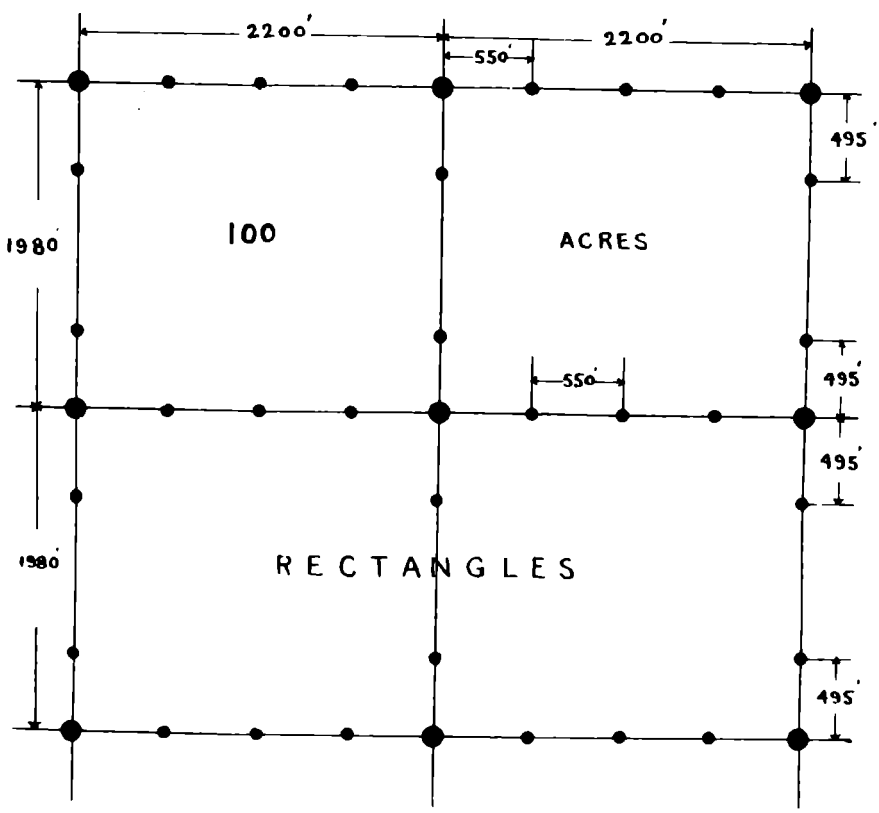


Diagram showing position of levels for 25 & 100 acre rectangles in the Sutlej Valley

Levels run along East & West lines, other levels obtained by off-sets



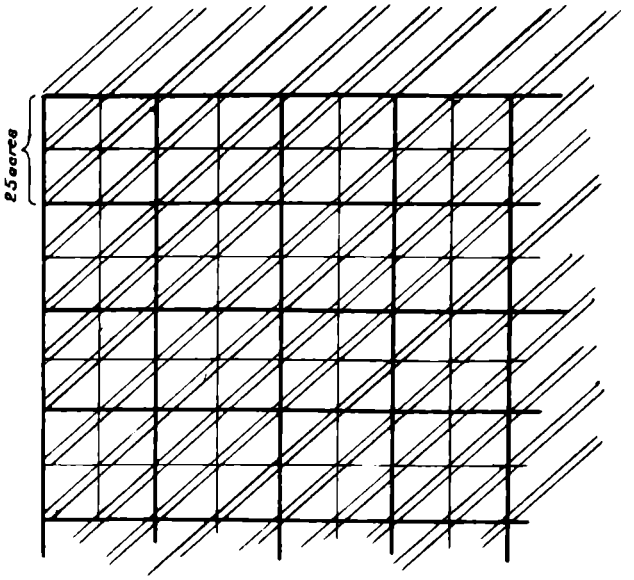


Levelled stone . . . . . ●

Intermediate Levels . . . . . •

PLATE XI

Diagram showing 25 acre grid printed in blue, for Level charts, with guide lines for values



Survey

BLOCK "D"

Specimen page of a level book
(with part of chart inset)
The lay out is that of a chart, the scale distorted

Sutlej Valley

Final level

400-acre rectangle number	Pillar No	Height above Mean Sea Level			Pillar No	Height above Mean Sea Level			Pillar No	Height above Mean Sea Level			Pillar No	Height above Mean Sea Level		
1	1	485 25	E	484 1	5	482 6	E	483 6	9	483 6	E	483 9	13	484 0	E	483 8
	S	483 5			S	482 8			S	482 8			S	483 9		
	2	484 71	E	483 9	6	483 4	E	483 8	10	483 9	E	483 5	14	483 3	E	483 8
	S	485 1			S	483 6			S	483 2			S	482 8		
	3	483 77	E	483 2	7	483 3	E	483 3	11	483 2	E	483 2	15	482 7	E	480 8
	S	483 7			S	483 3			S	483 6			S	480 7		
	4	485 97	E	483 2	8	483 3	E	483 0	12	482 8	E	483 7	16	480 3	E	479 4
	S	483 1			S	483 3			S	482 9			S	479 7		
2	1		E		5		E		9		E		13		E	
	S				S				S				S			
	2		E		6		E		10		E		14		E	
	S				S				S				S			
	3		E		7		E		11		E		15		E	
	S				S				S				S			
	4		E		8		E		12		E		16		E	
	S				S				S				S			
3	1		E		5		E		9		E		13		E	
	S				S				S				S			
	2		E		6		E		10		E		14		E	
	S				S				S				S			
	3		E		7		E		11		E		15		E	
	S				S				S				S			
	4		E		8		E		12		E		16		E	
	S				S				S				S			
4	1		E		5		E		9		E		13		E	
	S				S				S				S			
	2		E		6		E		10		E		14		E	
	S				S				S				S			
	3		E		7		E		11		E		15		E	
	S				S				S				S			
	4		E		8		E		12		E		16		E	
	S				S				S				S			
5	1		E		5		E		9		E		13		E	
	S				S				S				S			
	2		E		6		E		10		E		14		E	
	S				S				S				S			
	3		E		7		E		11		E		15		E	
	S				S				S				S			
	4		E		8		E		12		E		16		E	
	S				S				S				S			

Note.—Heights of ground levels are shown in black.
Heights of bench-marks on tops of pillars are shown in red.

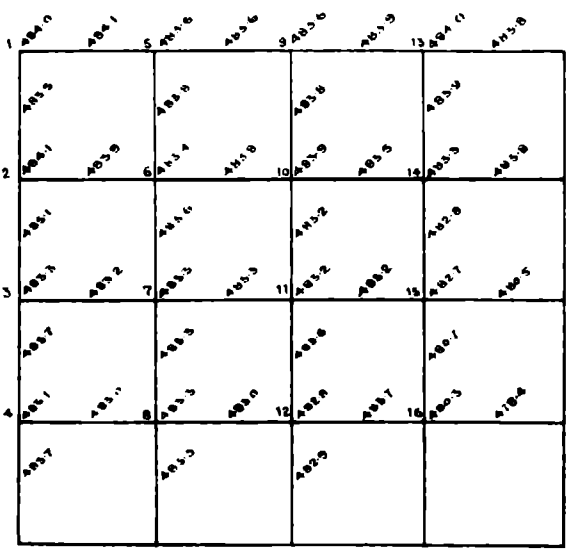
Reduced by ⅓

Rectangulation.

Values.

400 acre rectangle number	Pillar No.	Height above Mean Sea Level			Pillar No.	Height above Mean Sea Level			Pillar No.	Height above Mean Sea Level			Pillar No.	Height above Mean Sea Level		
21	1		E		5		E		9		E		13		E	
	S				S				S				S			
	2		E		6		E		10		E		14		E	
	S				S				S				S			
	3		E		7		E		11		E		15		E	
	S				S				S				S			
	4		E		8		E		12		E		16		E	
	S				S				8				S			
22	1		E		5		E		9		E		13		E	
	S				S				S				S			
	2		E		6		E		10		E		14		E	
	S															
	3														E	
	S															
	4														E	
	S															
23	1														E	
	S															
	2														E	
	S															
	3														E	
	S															
	4														E	
	S															
14	1														E	
	S															
	2														E	
	S				8				S				S			
	3		E		7		E		11		E		15		E	
	S				S				S				S			
	4		E		8		E		12		E		16		E	
	S				S				S				S			
15	1		E		5		E		9		E		13		E	
	S				8				S				S			
	2		E		6		E		10		E		14		E	
	S				8				S				S			
	3		E		7		E		11		E		15		E	
	S				S				S				S			
	4		E		8		E		12		E		16		E	
	S				8				S				S			

400 acre rectangle N.W. Corner Block D
Levelled to 25 acres



Entered by

Checked by

Sutlej Valley Levelling.

Block No. S‴ *Section No.* 5

Adjustment of Circuit No. 3

Computed by
Checked by

M.S.L. of + on Pillar No. = 246·829
Adjusted R.L of .do. = 107·779
Difference = Correction to reduce to M.S.L. = +139·050

Serial No.	Pillar No. S‴	Observed height			Circuit correction	Adjusted height	Final height above M.S.L. +130·050	Remarks.
		1st leveller	2nd leveller	Mean				
1	326/3	100·000	100·000	100·000		100·000	239·050	
2	2							
3	1	98·850	98·850	98·850	+ 4	98·854	237·904	
4	325/4							
5	3	100·200	100·210	100·205	6	100·211	239·261	
6	2							
7	1	101·770	101·770	101·770	9	101·779	240·829	
8	324/4							
9	3	102·810	102·790	102·800	11	102·811	241·861	
10	2							
11	1	98·890	98·870	98·880	14	98·894	237·944	
12	323/4							
13	3	103·670	103·640	103·655	16	103·671	242·721	
14	2							
15	1	107·490	107·470	107·480	18	107·498	246·548	
16	322/4							
17	3	105·860	105·830	105·845	21	105·866	244·916	
18	2							
19	1	104·620	104·600	104·610	23	104·633	243·683	
20	321/4							
21	3	107·110	107·090	107·100	26	107·126	246·176	
22	2							
23	1	106·690	106·670	106·680	28	106·708	245·758	
24	301/13							
25	5							
26	5							
27	1	108·010	108·000	108·005	33	108·038	247·088	
28	2							
29	3	108·280	108·270	108·275	36	108·311	247·361	
30	4							
31	302/1	105·420	105·420	105·420	38	105·458	244·508	
32	282/13							

Circuit adjusted by M. Yasuf *Checked by* D. S. Negi *Date* 17·2·26

M.S.L. computed by M. Yasuf *Checked by* D. S Negi *Date* 26·8·26

Sutlej Valley Levelling.

Block No. S″ *Section No.* 5

Adjustment of Circuit No. 3

Computed by
Checked by

M.S.L. of + on Pillar No. =
Adjusted R.L. of -do- =
Difference = Correction to reduce to M.S.L. =+

Serial No.	Pillar No. S″	Observed height			Circuit correction	Adjusted height	Final height above M.S.L.	Remarks.
		1st leveller	2nd leveller	Mean				
33	282/9	107·250	107·230	107·240	41	107·281	246·331	
34	10							
35	11	103·840	103·810	103·825	43	103·868	242·918	
36	12							
37	283/9	98·140	98·130	98·135	46	98·181	237·231	
38	5							
39	1	106·330	106·320	106·325	48	106·373	245·423	
40	2							
41	3	105·970	105·960	105·965	50	106·015	245·065	
42	263/15							
43	11	107·730	107·750	107·740	53	107·793	246·843	
44	12							
45	264/9	107·960	107·960	107·960	55	108·015	247·065	
46	5							
47	1							
48	244/13							
49	9	104·660	104·660	104·660	60	104·720	243·770	
50	243/12							
51	11	106·980	106·990	106·985	63	107·048	246·098	
52	7							
53	3	106·370	106·390	106·380	65	106·445	245·495	

Circuit adjusted by M. Yasub *Checked by* D. S. Negi *Date* 17.2.26

M.S.L. computed by M. Yasub *Checked by* D. S. Negi *Date* 26.8.26

PLATE XIV

13 Lev.

Date 29-12

Sutlej Tertiary Rebelling

Level No. 16511 Staves Nos. 80-96

Line from S 301·3 / 3 to S 321 / 3

Double Levelled Circuit No. III

Computed by M. Yasub

Checked by D. S. Negi

M.S.L. of starting pillar = 247·36
R.L. of do. = 100·00
Difference = +147·36
Mean line correction = + 0·04
Sum = correction to R. L. = -147·40

Station Number / Staff Distance	Staff Readings: Back	Intermediate	Forward	Differences of Level: Rise +	Fall −	Level Reduced to Origin	M.S.L. Height	Pillar No.	Remarks.
	Brought forward G.L.			100.00		100.00	247.36	S 301/3	
							246.68		
1	4.78	5.46	5.48						
	5.91	6.59	6.99	(0.68)					
	7.04	7.72	8.50						
Sum	17.73	19.72	20.97						
Mean	5.91	6.59	6.99		1.08	98.92	246.32	E	
2	2.08		4.81						
	3.52		6.21						
	4.96		7.61						
Sum	10.56		18.63						
Mean	3.52		6.21		2.69	96.23	243.63	S 301/2	
S	1.84		3.59						
	3.10		4.52						
	4.36		5.45						
Sum	9.30		13.56						
Mean	3.10		4.52		(1.42)	94.81	242.21	S	
3	2.11		3.23						
	3.51		4.59						
	4.91		5.95						
Sum	10.53		13.77						
Mean	3.51		4.59		1.08	95.15	242.55	E	
4	3.52		3.17						
	4.99		4.47						
	6.46		5.77						
Sum	14.97		13.41						
Mean	4.99		4.47	0.52		95.67	243.07	S 301/4	
S	3.95		3.05						
	5.17		4.16						
	6.39		5.27						
Sum	15.51		12.48						
Mean	5.17		4.16	(1.01)		(96.68)	244.08	S	
5	3.86		2.91						
	5.29		4.30						
	6.72		5.69						
Sum	15.87		12.90						
Mean	5.29		4.30	0.99		96.66	244.06	E	
6	4.00								
	5.45		0.38						
	6.90		4.73						
Sum	16.35								
Mean	5.45		3.38	2.07		98.73	246.13	S 301/15	
S	3.57		2.81						
	4.78		4.03						
	5.99		5.26						
Sum	14.34		12.09						
Mean	4.78		4.03	(0.75)		(99.48)	246.88	S	
7	3.52		3.73						
	4.91		5.35						
	6.30		6.97						
Sum	14.73		16.05						
Mean	4.91		5.35		0.44	98.29	245.69	E	
8	4.07		4.47						
	5.05		5.25						
	6.03		6.05						
Sum	15.15		15.75						
Mean	5.05		5.25		0.20	98.09			Extra Sta
			Totals...	103.58	5.43	98.09			

Observed and recorded by A. Din. Examined by R. K. Saxena

M. S. L. Computed by M. Yasub. Checked by D. S. Negi.

Survey of India.

PLATE XV

No. 17 Party.

Sutlej Valley Tertiary Levelling.

Monthly diary.

Name of leveller R. K. Saxena

Month October

Entries made by O. C. Detachment.

Number of working days (actual) 9

Average total outturn per day 61·6 stations

useful " " 6·6 "

Date	Number of stations	New lines: Pillar Number at commencement	New lines: Pillar Number at end	Revision: Pillar Number at commencement	Revision: Pillar Number at end	Remarks. State whether SL or DL, give reasons for no work or small outturn; bad weather, sickness, length of marches etc.
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						Reached Rel. Rly Stn
19						Pillar searching & training Khalasis
20	48	T‴ 491/9	T‴ 534/1			
21	50	534/1	567/11			
22	58	567/11	U‴ 10/1			Double levelling
23	38	U‴ 10/1	6/1			
24	74	T‴ 546/4	6/4			Single levelling, also line U‴ 6/3 to T‴ 546/3
25	-	-	-			Sunday
26	68	T‴ 567/3	U‴ 7/3			also lines U‴ 7/4 to T‴ 567/4 & T‴ 588/9 to U‴ 8/1
27	-	-	-			Sick
28	-	-	-			Marching from U‴ 10/4 to S‴ 529/12
29	74	S‴ 490/5	P‴ 10/5			Thick Jungle
30	72	P‴ 10/3	S‴ 490/4			" "
31	72	P‴ 9/1	S‴ 489/1			" "

Total number of stations 554

Number of rejected stations —

Number of useful stations 554

Signature of leveller R. K. Saxena

Remarks by O.C. Section. A fast & accurate leveller

Y. K. Ramaiya

S.O

13 Lev.

Sutlej Tertiary Levelling

Date 29-12

Level No. 1651 II Staves No. 80-96

Line from S 301/3 to S 321/3

Double Levelled Circuit No. III

Computed by M. Yasub

Checked by D. S. Negi

M.S.L. of starting pillar =
R.L. of do. = 100·00
Difference = +
Mean line correction = –
Sum = correction to R Ls = +

Station Number	Staff Distance	Staff Readings: Back	Intermediate	Forward	Differences of Level: Rise +	Fall –	Level Reduced to Origin	M.S.L. Height	Pillar No.	Remarks
Brought forward					103·58	5·49	98·09			
9		4 66		4·45						
		5·21		5 00						
		5·76		5·55						
Sum		15·63		15 00						
Mean		5·21	G.L.	5·00	0·21		98·30			Extra Stn
10		3 43	3·56	3·15						
		4 71	4·70	4·28						
		5 99	5 84	5·41						
Sum		14·13	14 10	12 84						
Mean		4·71	4·70	4·28	0 43		98·73	246·13	S 321/3	Line completed
					104 22	5·49	98·73			
Sum										
Mean										
Sum										
Mean										
Sum										
Mean										
Sum										
Mean					R.L. of the starting pillar				108·311	
					" " " closing pillar				107·126	
Sum					Difference of Double Levelling				-1·185	
Mean					" " Single				-1·230	
									Error -0·045	
Sum										
Mean									Passed	
									I.K.P.	
									S.O.	
Sum										
Mean										
Sum										
Mean										
Sum										
Mean										
Totals										

Observed and recorded by A. Din Examined by R. K. Saxena

M. S. L. Computed by M Yasub Checked by D. S. Negi

Survey of India.

PLATE XV

No. 17 Party.

Sutlej Valley Tertiary Levelling.

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Name of leveller R. K. Saxena

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Date	Number of stations	New lines: Pillar Number at commencement	New lines: Pillar Number at end	Revision: Pillar Number at commencement	Revision: Pillar Number at end	Remarks. State whether SL or DL, give reasons for no work or small outturn; bad weather, sickness, length of marches etc.
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						Reached Reli Rly Stn
19						Pillar searching & Farming Khalaris
20	48	T" 491/9	T' 524/1			
21	50	524/1	567/11			
22	58	567/11	U" 10/1			Double levelling
23	38	U" 10/1	6/1			
24	74	T" 526/4	6/4			Single levelling, also line U" 6/3 to T" 526/5
25	-	-	-			Sunday
26	68	T" 567/3	U" 7/3			also lines U" 2/4 to T" 567/4 & T" 585/9 to U" 8/1
27	-	-	-			Sick
28	-	-	-			Marching from U" 10/1 to S" 529/12
29	74	S" 490/3	P" 10/3			Thick Jungle
30	72	P" 10/3	S" 490/4			" "
31	72	P" 9/1	S" 489/1			" "

Total number of stations 554

Number of rejected stations —

Number of useful stations 554

Signature of leveller R. K. Saxena

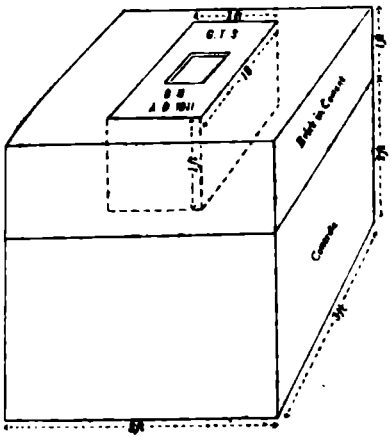
Remarks by O.C. Section. A fast & accurate leveller

Y. K. Ramappa

S.O

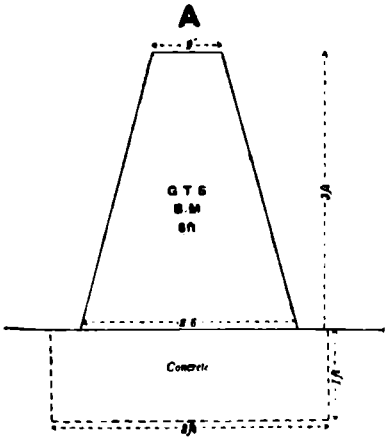
TYPE "B"

Description of an Interred Bench-mark and its referring pillar.

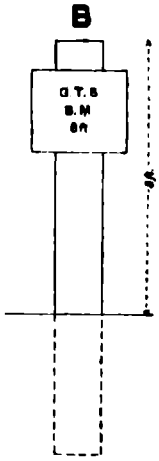


The Bench Mark consists of a dressed stone $1\frac{1}{2}' \times 1' \times 1'$. In the centre of the stone on one side is a sunken square of 5 inch sides and $\frac{1}{4}$ inch deep, with the inscription $\frac{\text{G.T.S}}{\text{B.M}}$, and the year, as shown in the sketch in the margin.

The stone should be laid on a bed of concrete 3 feet square and 2 feet deep, and it should then be surrounded by brickwork set in cement. The upper surface of the stone is to be flush with the masonry and 2 feet below ground level.



A referring pillar of *pakka* masonry $2\frac{1}{2}$ feet square at base, 3 feet high and tapering to 9 inches square at top should be built above ground facing the Bench Mark, and near it, *but not over it*. This pillar should be white washed, and the letters $\frac{\text{G.T.S}}{\text{B.M.}}$ and the distance to the Bench Mark, which should generally be about 6 feet, should be neatly and carefully cut on the side which faces it. (*Vide* sketch A).



If available a post made of a piece of a rail, with an iron plate bearing the letters $\frac{\text{G.T.S.}}{\text{B.M.}}$, and the distance to the Bench Mark may be substituted for the masonry pillar. The rail should be fixed as firmly as possible in the ground with the plate facing the Bench Mark. It should project about 3 feet above ground (*Vide* sketch B).

PLATE XVII

PLATES XVII-XXII