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THE BEACON SYSTEM: A COMBINED GEODETIC AND BOUNDARY SURVEY*

Submitted by the Government of the Democratic Republic
of the Sudan

(This paper is a continuation of a study started in 1963 on major cadastral surveys in the Sudan. The first paper (E/CN.14/CART/42) was presented in Nairobi in 1963.)

INTRODUCTION

Flat agricultural land in developing countries is the main source of economy. It is required that this land be both mapped and demarcated-divided into agricultural plots. However, most of these countries are in a very bad need of reliable maps; some of them have no maps whatsoever. To perform the conventional surveys and maps in order to demarcate the land would be unrealistic in such case. On the other hand, to demarcate the land in a local system for a particular need and then later have to make a precise national system would be a duplication of work.

The Beacon Survey, discussed herein was introduced in the Sudan in an attempt to best satisfy these two requirements simultaneously (mapping and demarcation) as far as possible.

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The Beacon System

The Beacon System Survey divides agricultural flat lands into squares one minute in longitude and one minute in latitude. The system was first employed in the Sudan in 1907. It was not the product of thorough research and investigation in the field of geodesy and demarcation when it was first adopted. On the contrary, persistent need for some type of quick mapping with minimum cost, that can be done with the staff available, brought the method to life. During the intervening years, the survey staff obtained training in the use of this method. They developed a degree of consistency and a technique for demarcating the land at minimum cost. Approximately 13 years ago, the need arose to subdivide additional areas for agricultural development.

Favourable experience with the earlier Beacon System caused the survey department to again adopt this method for developing two major areas.

It was carried out in both Kenana, in the middle of the Sudan and Khasm el Girba, in the eastern Sudan irrigation schemes.

Although experience has proved its success, yet its accuracy was never investigated. This research is intended to penetrate those unknown conditions and compare it as a type of demarcation to other demarcation methods and especially the Public Land System of the United States of America.

Description of the monuments used

The Beacon

Two types of monuments have been used; both are called the beacon.

- The one used in the earlier part of the work (1907) consists of: an iron base plate 9" in diameter, screwed to a 2" diameter pipe 6 feet long. This entire assembly is sunk 3 feet into the ground with the plate at the bottom. The instrument (theodolite or planetable) could be set over this pipe. A 1-7/8" diameter pipe also 6 feet long is bolted inside the lower pipe. The whole beacon stands 9 feet above ground level. An iron cross vane 27" long, 6" high is fitted with a screw cap at the apex. This vane points in the direction North and East. The latitude and longitude of the point (in degrees and minutes only) are pointed on the vanes. (see Fig. I)

- The latter (1957) concrete beacon, which is more steady consists of: a reinforced concrete pole 10 feet long, with a square x-section 4" x 4" at the top and 6" x 6" at the bottom. A circular concrete disc 9" diameter and 1½" thick is buried under the beacon (buried mark). A bolt B.M. projects 2" from the side of the beacon at one foot elevation from the ground. The three top feet are painted with black and white strips; a cross-vane similar to the earlier one is fitted over the apex. (see Fig. II)

The Pile B.M.

It consists of a 2" diameter pipe 2 metres long, with a 9" square base plate welded at its bottom and a hemispherical cap welded at its top. The whole assembly is sunk into the ground, leaving 0.20 metres projecting above the ground surface which is covered with a concrete pyramid. (see Fig. II).

Description of the method

From an astronomical or geodetic station, a point is established in the vicinity of the area to be surveyed. From this, a point at an even 10 minutes in latitude and longitude is established.

Meridians are established by the method of plunging with a second order theodolite and corrected in azimuth by polaris observation. The parallels of latitudes are established by offsets from the tangents.

Taking the average elevation of the area, the length of the arcs of meridians and parallels and offsets from the tangents are calculated in office using the modified Clarke 1880 Spheroid.

Azimuth checks on meridians were observed every 5 minutes using polaris. After the computation of this azimuth, the line is offset to lie in the true meridian position. A standardized 100 metres steel tape is used for cross-section and an MRA 3 tellurometer is used in control work.

The Contour Survey

A Bolt B.M. is set on every beacon, and a Pile B.M. near every third beacon. Loops of levels of three minutes square are run using a second order level (Wild N2). Spot heights are determined every 150 metres.

The level survey is plotted on a map of scale 1:20,000 with half a metre contour interval. These maps are used by engineers in the design of the scheme with regard to irrigation and by agriculturists with regard to individual plots subdivision.

Applicability of the method

1. Most irrigable areas in developing countries are very flat. Any long line triangulation or traverse would require towers both for observation and later for making use of the points. Even the photogrammetric surveys are not as adaptable as the Beacon system since a type of cadastral survey will still be needed.

2. The equatorial climate and the hot weather makes the survey of longer lines very costly.

3. Frequent azimuth checks are easy using polaris. Low calibre, well-trained personnel will be very much adapted for the azimuth observation.

4. Quick on-the-field survey with no office check is the kind of survey needed in those countries.

5. The mercator projection with its straight meridians and parallels makes these minute squares as real rectangles in the projection sheets.

6. The system is straight forward and not much technical knowledge is needed to perform the actual field work.

Scope of the study

a) To investigate the existing system so as to determine the discrepancies in it as compared to geodetic values obtained by an independent method, and to determine its order of accuracy.

b) To investigate the system, as a type of astronomical traverse to determine the sources of error; then analyse how error propagates through the network.

c) To investigate the adaptability of the Beacon system as a type of boundary survey subdivision over vast flat land for various purposes and users; and to compare it with the existing methods; primarily the US Public Land System.

d) To determine improvements on the system which can be incorporated as inexpensively as possible and which will add extra strength, accuracy, redundancy and convertibility to a longer national network. This network would be used to determine the shape of the earth and best fitting figure at the particular area.

To achieve this, rigorous triangulation connection was surveyed from the second order triangulation. The result, together with the least squares adjustment of these ties, is considered on that paper.

Comparison between the Beacon System and the US Public Land System

The physical fixation of boundary and the elimination of the confusion with regard to title is a far more critical problem than the monumentation of bench marks for vertical control, or traverse and triangulation for horizontal control. But, if we studied the US Public Land System we find that there are some elements that shed as much doubt in the problem of title fixation as the absence of any survey. Considering the date they were surveyed, the hazardous conditions, the poor instrumentation, the natural obstruction and low prices paid by the government for those surveys, the basic land rectangulation of one mile square has served its purpose. (see Figs. III, IV, V and VI)

The Beacon system on the contrary has followed along with most other types of surveys on the path of new mechanization. The adaptation of the new distance measuring techniques has increased its accuracy while decreasing its cost. The new angle measuring equipments and orientation instruments may make it more attractive than it is now. So the Beacon system, which would at least give a third order accuracy as a horizontal control, is a modification of the US Public Land System where "there is no real system of control nor are the measurements made with great accuracy".

While the position of the beacon depends only on the astronomical position which is for all practical purposes fixed, the position of the section corner in the US Public Land System depends on the actual land marks; the measurements themselves cannot be used to hold the position of the corner. They are qualifying terms only.

The Beacon could be considered a fairly accurate geodetic monument; the public land system is only a boundary monument. The attached three sketches (Figs. III, IV, V and VI) show the public land and the beacon systems.

The township-range and sections identifying system in the public land uniquely defines any parcel of land. In the beacon system there is no such identification.

CONCLUSION AND RECOMMENDATIONS

The result of the relative accuracy investigation show that while the errors in angle and azimuth tend to cancel each other, the errors in distance accumulate and shift the entire survey in one direction. This should be expected since the astronomical azimuth check, although it does not bring the points to the same meridian, tend to keep them in a meridianal direction. The North - South advance has no check whatsoever; this is the reason for the unrealistic shift in latitude of all the points.

The test area was so small and the number of points so few that a more concrete conclusion is not justified. It goes without questioning that some type of check on linear measurement is necessary to improve the accuracy. This could be achieved either by tying the Beacon system to higher order triangulation nets, or by latitude observations. How frequently this should be performed depends on the order of accuracy desired.

The Beacon system of subdivision in the first half of the 20th century employed instruments of that period. The use of modern survey instruments will improve the accuracy of this subdivision. For example: the use of some type of gyro-theodolite could eliminate the need for frequent azimuth observations; the use of electronic distance measuring equipment could reduce the error in linear measurement and thereby reduce the need for a large number of ties or latitude observations; the use of optical reading theodolite will expedite the conduct of the survey.

Since this survey (1907) covers a huge area, and the position of the very limited number of beacons evaluation showed errors of 17 metres, it is entirely possible that even larger errors exist. It is recommended that re-evaluation of the horizontal position of the beacons be performed before they are adopted as correct for control purposes. It is recommended that a photogrammetric survey of the whole area be made and correct latitude and longitude be computed for every beacon position using analytic aerotriangulation methods. The Beacon's vertical control as already obtained in the field is to be accepted in this computation.

It should be mentioned that higher accuracy would be expected from the Beacon method of survey if these recommendations be adopted. If a second order accuracy or higher were to be achieved, the Beacon survey could be used to determine the best fitting spheroid for the Sudan or the area in question using special formulae.

As a boundary survey method, all of these improvements might still be needed. One thing that is really needed, however, is a type of identification of the one minute squares. Since the five minute squares already have an identifying name the 25 squares inside could be designated by names or numbers; a modification of the US Public Land System is recommended. It is recommended that the numbers 1 - 5 be subscripts to the latitude and longitude of the South - West corner of the five minute squares. The subscripts should increase going East and North. For example, the $\frac{15^\circ\ 10'\ (1)}{32^\circ\ 40'\ (1)}$ is the one minute square at the southeast corner of the five minute squares in which $\frac{15^\circ\ 10'}{32^\circ\ 40'}$ is the southwest corner. The one minute s quare whose northeast corner three minutes north and two minutes east of this point is designated by $\frac{15^\circ\ 10'\ (3)}{32^\circ\ 40'\ (2)}$.

It is recommended that every beacon position be photographed and/or photo identified by either terrestial or aerial methods of photogrammetry against a background of the most important surrounding natural and artificial features. These photographs should be part of the field notes and an essential part of the legal documents.

Note: This paper is an abstract from a thesis presented to the faculty of the graduate school of Cornell University USA for the Degree of Master of Science in June, 1967 by the author.

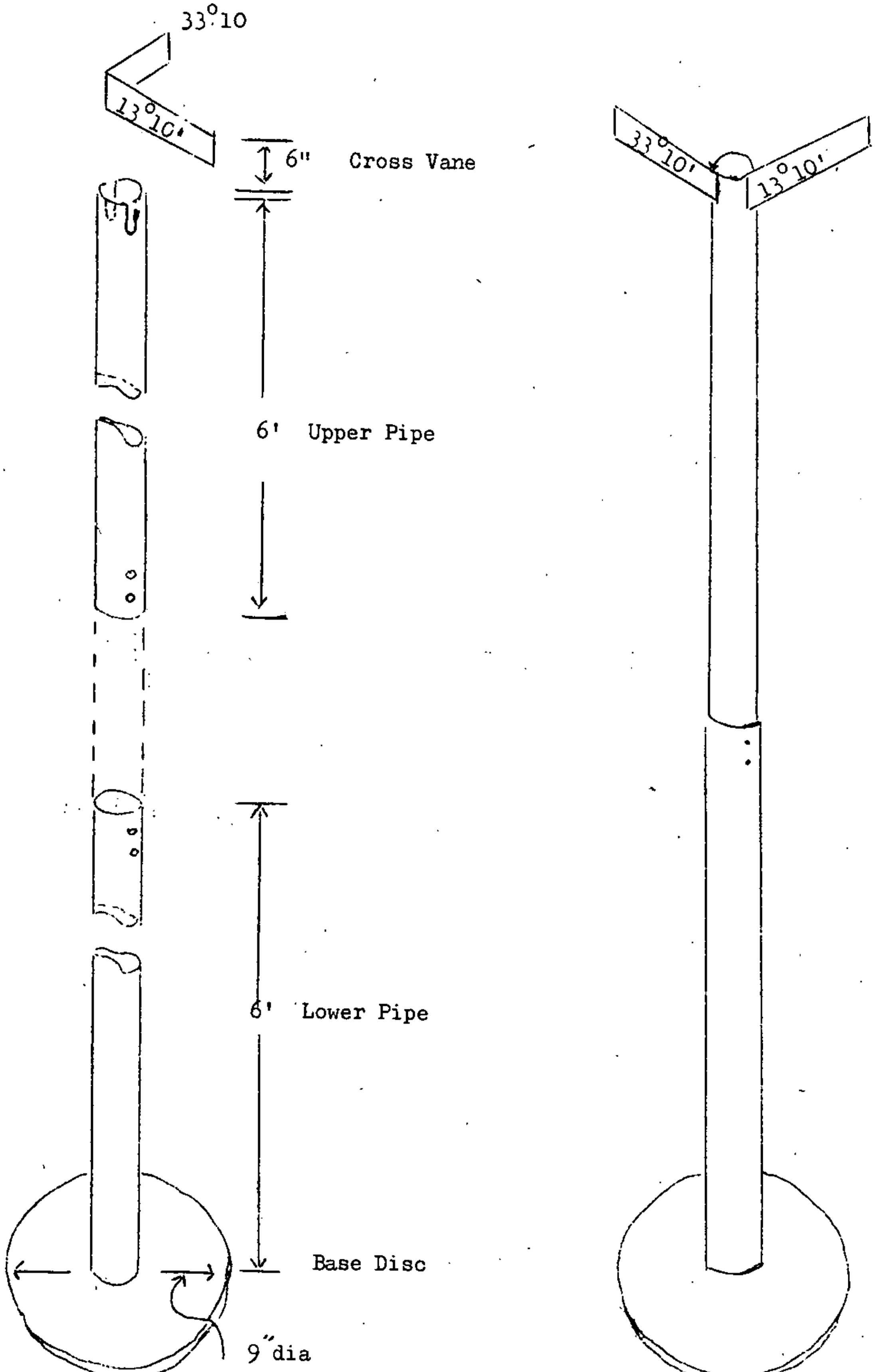
33°10
13°10'
6"
Cross Vane
6'
Upper Pipe
6'
Lower Pipe
Base Disc
9" dia
33°10'
13°10'

Fig. I

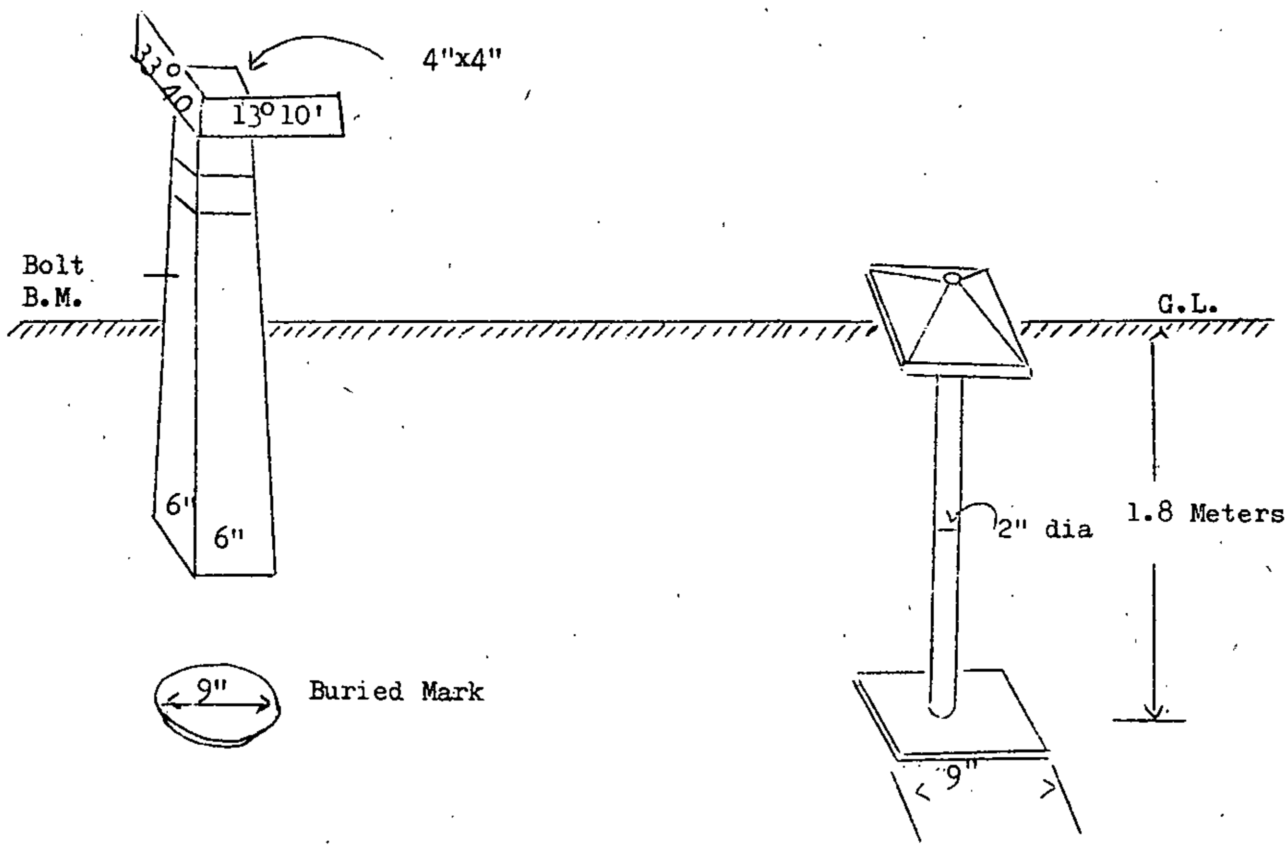

Fig. II Beacon, Bolt and Pile Bench Mark

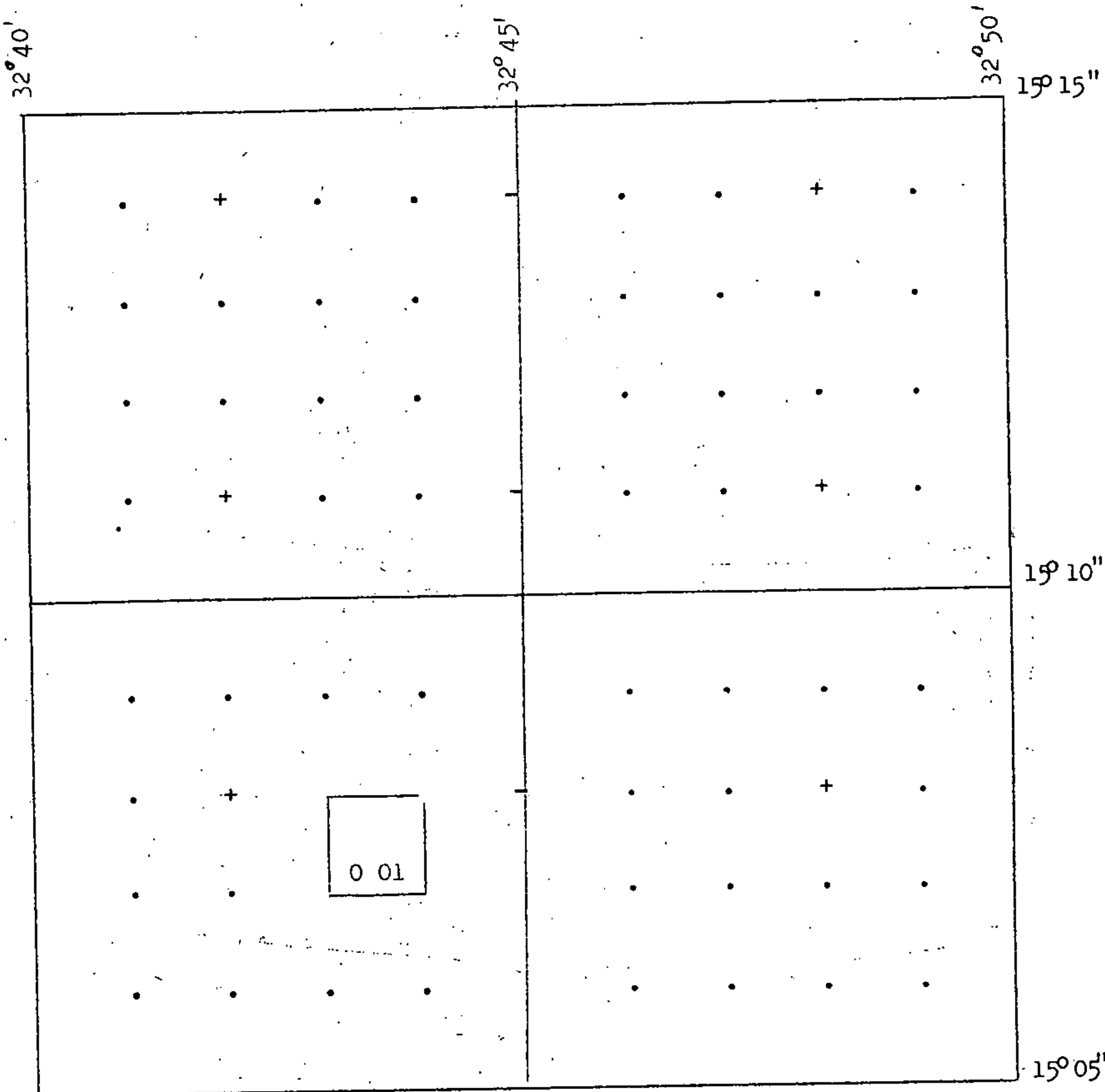

Fig. III Sudan Public Land System Beacon Diagram

. Beacon

+ Beacon with a Pile B.M.

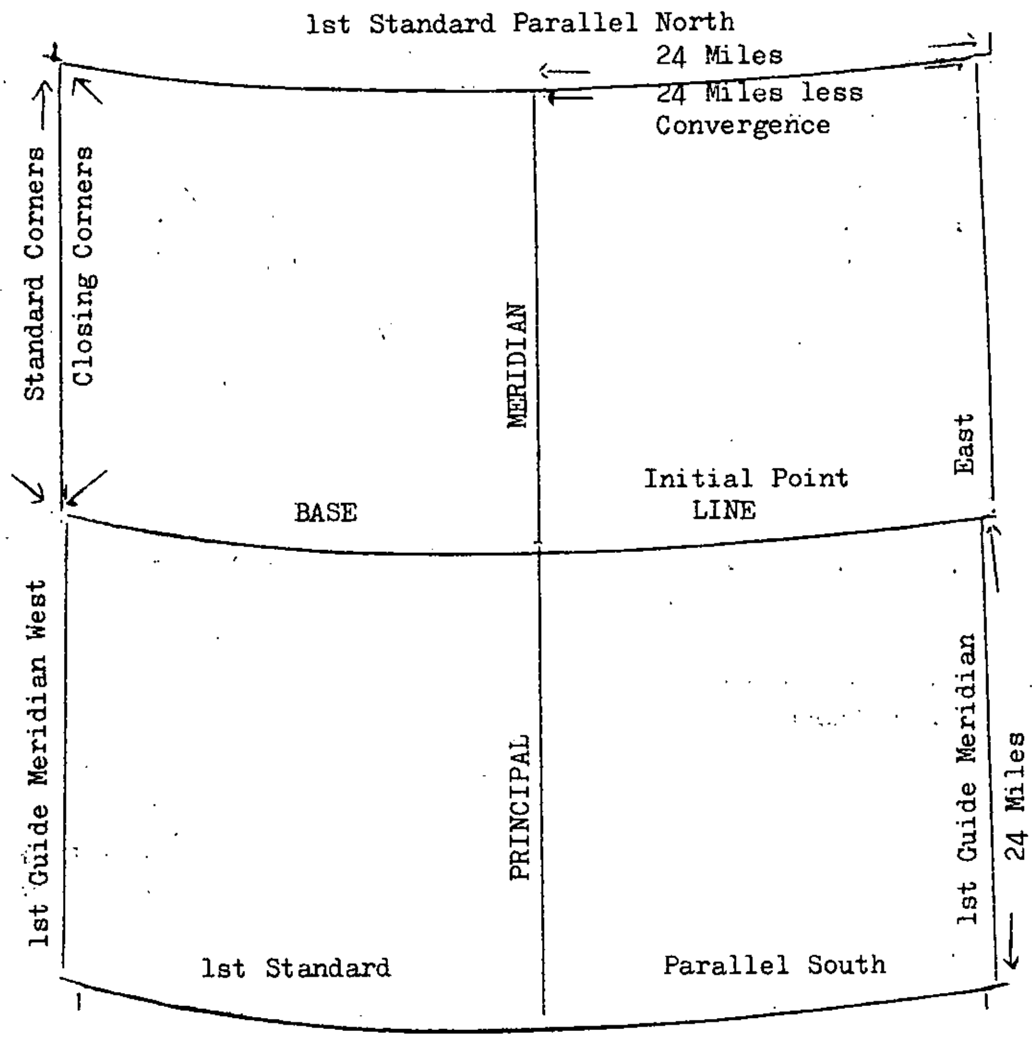

Fig. IV US Public Land System
Division into 24 Mile Tracts

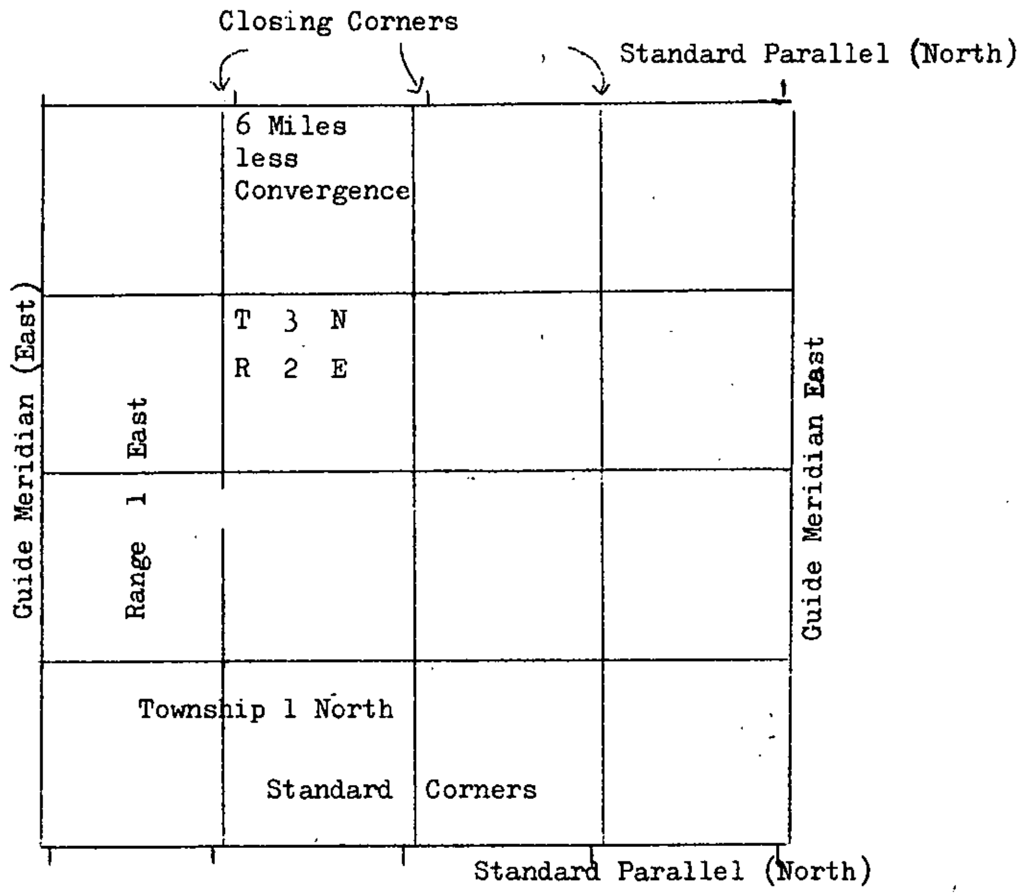

Fig. V US Public Land System
Subdivision A 24 Miles Tract into Townships

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Fig.VI US Public Land System
Subdivision of Township into Sections