NEW MODE ON CONSTRUCTION SURVEYING

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ABSTRACT

This paper introduces a new mode for establishing the position of new stations adopted for construction purposes, especially by using modern instrumentation as Total Stations and others. The present technique can be performed utilizing predetermined angles and distances to locate new stations. This paper is mainly divided into two sections, the first is concerned with establishing horizontal control work according to the system of working from the whole to the part. The second section illustrates the optimum location of the instrument for determination the heights of the building. Moreover the best location of the traverse relative to be builded area is thoroughly investigated. The construction with its three dimension namely X,Y,X can be locally determined.

Keywords: Construction surveying, Modern instrumentation, Establishing horizontal control work, Optimum location, Best location

INTRODUCTION

Cadastral surveying is one of the basic branches of plane surveying in which the details within a small area of the earth's surface are measured and then plotted on a map with a reasonable scale. The most precise cadastral maps are produced with computed coordinates relative to a desired plane coordinate system. These maps are very essential tools for the design, setting out and execution of all important engineering projects such as access roads, highways, railways, tunnelling, bridges, buildings, ...,etc.

Once the map is available, detailed plans for the construction of a project can be completed. The main job of the surveyor is to mark out the exact locations and the important dimensions of the project according to these final plans. To accomplish such work the surveyor must mark horizontal positions and elevations of the planned construction a process that is begun before the work is started and usually will be continued throughout the entire construction period.

In order to establish a location, there is a large family of instruments that can be used for linear and angular measurements with varieties into their acquired precision.

Also, the field circumstances of the area to be located have significant contribution to the choice and precision of the location.
Naturally a high accuracy requirement is essentially devoted for locations produced by any traverse, to meet the rapid advance into the recent technology of instrumentation and methodology of computations.

The main objective of this paper is to find some answers to some of the questions which facing the practical surveyor during the execution of any location.

ELEMENTARY THEORY

The sides of the control network around and outlined the site can to taken base lines for setting out purposes Figures 1-a and 1-b. Subsidiary lines can be set off from the base line to establish new points. It is generally required to obtained the location of a new point "P" from the coordinates of fixed stations A and B.

Since the positions of the new points will be in terms of the site fixed coordinates, the setting out can be achieved as shown in Figure 1.

Figures 1-a and 1-b shows a baseline AB and a new point "P". Suppose the secondary point P' is established along the baseline AB where the distance AP' equal S (Equation 1-a) or S' (Equation 1-b). The secondary point P' can be established by polar coordinates from the fixed station A. In addition, assume that P'P parallel to x-axis or Y-axis as shown in Figures 1-a and 1-b, respectively. The distances S and S' can be computed using the following formulae:

$$S = \frac{y_P - y_A}{\cos\alpha_{AB}} \tag{1-a}$$

and

$$S' = \frac{x_P - x_A}{\sin\alpha_{AB}} \tag{1-b}$$

where

X_p and Y_P are the coordinates of the new point P,

X_A and y_A are the coordinates of the fixed point A,

α_{AB} is the reduced (quadrant) bearing of baseline AB, where α_{AB} is smaller than 45° in Figure 1-a and α_{AB} is greater than 45° in Figure 1-b.

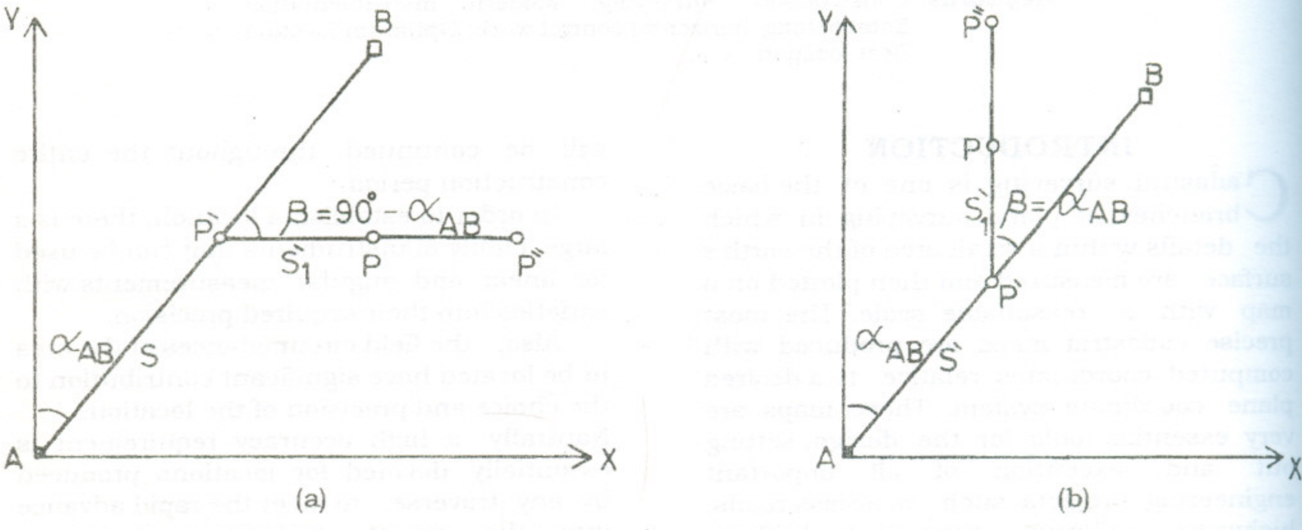

Figure 1 Sketch illustrates the baseline AB and the stations "P" a) α_{AB} < 45° b) α_{AB} > 45°

The distances S_1, and S'_1, can be obtained as follows:

$$S_1 = (X_P - X_A) - S.\sin\alpha_{AB} \tag{2-a}$$

and

$$S'_1 = (Y_P - Y_A) - S'.\cos\alpha_{AB} \tag{2-b}$$

To check the whole work the following formula can be used:

$$S.\sin\alpha_{AB} - (Y_P - Y_A)\ \tan\alpha_{AB} = 0 \tag{3-a}$$

$$S'.\cos\alpha_{AB} - (X_P - X_A)\ \cot\alpha_{AB} = 0 \tag{3-b}$$

Such double check is highly requested especially in case of large difference between the two parts in Equations 3-a, 3-b must be allowable.

POSITION DETERMINATION OF THE NEW POINT IN THE FILED

After establishing the control network in the main site the following procedure has to be followed to locate the design points of the proposed structure. Generally, the following method can be used.

1) Along the baseline AB, the location of point P' can be determined from the fixed control point A using the predetermined distance S or S'. Locating P' on AB can be performed either by EDM or most easily by steel tape.
2) Next, the theodolite can be moved to the already located P'. The angle β can then be measured from the direction P'B. The angle β can be computed as follows:

   $\beta = 90° - \alpha_{AB}$ (Figure 1-a) or

   $\beta = \alpha_{AB}$ (Figure 1-b)

   The direction P'P" can be already obtained.
3) Using any distance measurement device the position of point P can be located along P'P" utilizing either S_1, or S_1', (see Equations 2-a and 2-b).

From the above procedure the position of the new point P can be easily at hand. The baseline AB may be of any arbitrary orientation as shown in Figure 2.

Applying the above-mentioned simple method to those different cases, the design points of the proposed structure, can be located.

The modern technique in distances and angles measuring instruments which used nowadays are the Total Stations instruments. These instruments are the most precise manufactured in measuring long distance. Also the angular and linear measurements were accomplished, by using a Total Station quickly and easily. The results of the different four cases are illustrated in Table 1.

Table 1 Results for the different four cases

No. of Quadrant	Position of point P related a baseline AB	
	AB < 45°	AB > 45°
I (N-E)	Right-hand	Left –hand
II (S-E)	Left -hand	Right-hand
III (S-W)	Right-hand	Left-hand
IV (N-W)	Left -hand	Right-hand

PRECISION AND ACCURACY

To evaluate the positioning accuracy of the new established station, with the assumption that point A is of error free coordinates the following formula can be used [1,2]:

$$\sigma_p = \sqrt{\sigma_o^2 (S^2 + S_1^2) + \left(\frac{\sigma\beta - S_1}{\rho}\right)^2 + 2\sigma_\phi^2} \qquad (4)$$

where σ_o is the probable error of distances S (S') and S_1 (S_1'); σ_β is the probable error of angle β; σ_ϕ is the probable error in position point P'; and $\rho = 206265$.

And, we have [1,2]:

$$\sigma_o = \frac{\sigma}{2\sqrt{2(S^2 + S_1^2)}} \qquad (5)$$

and

$$\sigma_\beta = \frac{\sigma.\rho}{2\sqrt{2}S_1} \qquad (6)$$

where σ is the allowable error for any distance.

ON HEIGHT DETERMINATION OF BUILDINGS

Figure 3 shows the height of the building "H", the distance "S" between the building and theodolite and the vertical angle θ as well.

The height of the building "H" can be calculated by using the formula:

$$H = S. \tan\theta \qquad (7)$$

By error propagation the (M.S.E) of the height can be estimated, namely:

$$\sigma_H^2 = \tan^2\theta \, . \, \sigma_s^2 + S. \, \sigma_\theta^2 / (\rho^2 \, . \, \cos^4\alpha) \qquad (8)$$

where

σ_H , σ_s and $\sigma\theta$ are the Mean Square Error (M.S.E) for the values H_1 S and θ, respectively.

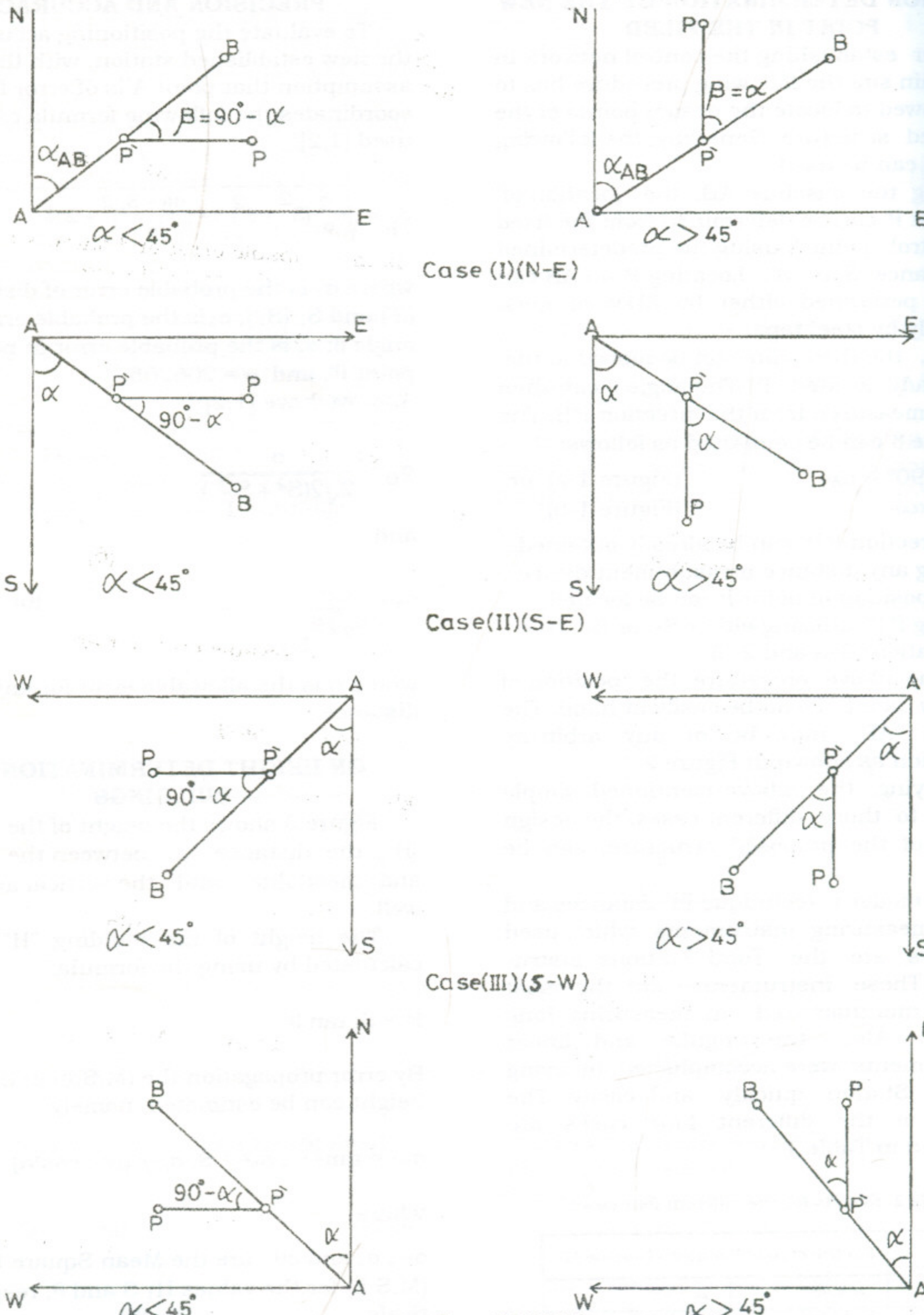

Figure 2 Sketch illustrates the baseline AB in four cases

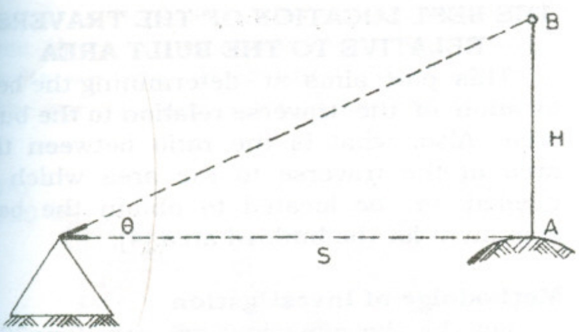

Figure 3 Sketch illustrates the position of the theodolite (case one angle θ

Figure 4 illustrated the relation between σ_H and S_i provided that (H= 1m, σ_s = 0.001 H, σ_θ=1'). Noting that the minimum value of σ_H is at the distance "S_o" where S_o = 1.9H.

It is very obvious that the optimum position of the theodolite is at a distance 1.9 times the height of the building. For more accurate position of the theodolite the value σ_θ and σ_s must be taken.

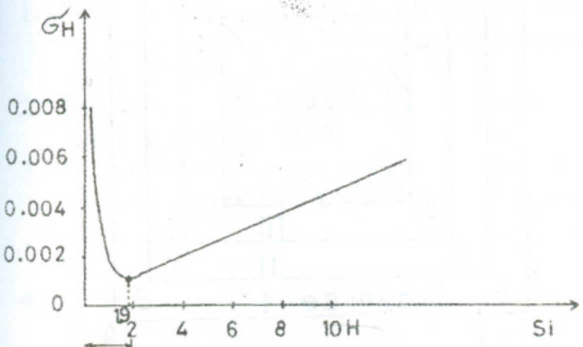

Figure 4 Relation between M.S.E. (H) and Distance (Si)

On the basis of the Equation 8 the following Equation can be set up to obtain S_o [3].

$$S_o = \sqrt[4]{\frac{H^2\rho^2\sigma_s^2 + H^4\sigma_\theta^2}{\sigma_\theta^2}} \qquad (9)$$

In this Equation let $\sigma_s \to 0$ and $\sigma_\theta \to 0$. Referring to Figure 3 we can noted that H S_o ∞.

Let H = 100m, σ_s = 0.01 m, σ_θ = 1' we can obtain the optimum distance S_o equal to 103 m. Let σ_s = 0.01m then, S_o = 189 m. From this we noted that the relation between the σ_θ, σ_s and the optimum distance S_o.

Equation 9 arises from least squares principle. But we can use, by approximate method, the following formula [3]:

$$S'_o = \sqrt[y]{\frac{H\rho\sigma^2 + H^2\sigma\theta}{\sigma_\theta}} \qquad (9')$$

Let H = 100 m, σ_s = 0.01 m, σ_θ =1', by using Equation 9' we can obtain the S'_o=16m.

From the previous discussion, we note that the difference between S_o = 103 m. and S'_o = 116 m is 13%. In the general case, it will be noted that two vertical angles θ_1 and θ_2 as shown in Figure 5. From this figure we can writte

$$H = S(\tan\theta_1 + \tan\theta_2) \qquad (10)$$

From Equation 10, we have

$$\sigma_H^2 = (\tan\theta_1 + \tan\theta_2)^2\sigma_s^2 + \frac{S^2 \cdot \sigma_\theta^2}{\rho^2}\left(\frac{1}{\cos^4\theta_1} + \frac{1}{\cos^4\theta_2}\right) \qquad (11)$$

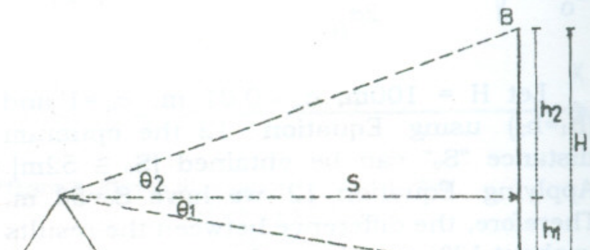

Figure 5 Illustrating the position of the theodlite (case two angle (θ_1, θ_2)

The optimum distance S_o can be obtained from the following formula [3]:

$$S_o = \sqrt{\frac{H^2\rho^2\sigma_s^{\,2} + (h_1^4 + h_2^4)\sigma_\theta^2}{2\sigma_\theta^2}} \qquad (12)$$

where: h_1 and h_2 are the vertical distances

From the horizontal plane for a theodolite between points A and B we have $h_1 + h_2 = H$; and the horizontal plane is lower than point A or higher than point B we have $|h_1 + h_2| > H$. In Equation 12 and by taking $\sigma_s \rightarrow 0$ and $\sigma_\theta \rightarrow 0$ with reference to Figure 5, we have the relation:

$0.5\,H \quad S_o \quad \infty$

In this case if ($\theta_1 = \theta_2$ or $\theta_1 = 0$ or $\theta_2 = 0$), the formula given by Equation 12 can be written in another form as follows:

$$S_o = \sqrt{\frac{H^2\rho^2\sigma_s^2 + H^4\sigma_\theta^2}{2\sigma_\theta^2}} \qquad (13)$$

As mentioned in the first case the following formula can be used instead of Equation 12

$$S_o' = \sqrt{\frac{H.\rho.\sigma_s + (h_1^2 + h_2^2)\sigma_\theta}{2\sigma_\theta}} \qquad (12')$$

Let $H = 100$m, $\sigma_s = 0.01$ m, $\sigma_\theta = 1'$ and ($h_1 = h_2$) using Equation 12 the optimum distance "S_o" can be obtained [$S_o \cong 52$m]. Applying Equation 12' we have $S_o = 58$ m. Therefore, the difference between the results is about 13%. From the previous study we note that the Equations 9 and 12 arises from least squares principle but the Equation 9' and 12' are approximate. It will be noted that the difference between optimum distance in two cases is 13%. A significant progressing in that phase can be achieved.

THE BEST LOCATION OF THE TRAVERSE RELATIVE TO THE BUILT AREA

This part aims at determining the best location of the traverse relation to the built area. Also, what is the ratio between the area of the traverse to the area which is needed to be located to obtain the best alignment for the builded area [4].

Methodolgy of Investigation

For the above purpose an area 30mx30m was chosen with a relatively rigid region, to afford an unyeilding support for the tripods and pegs. Surrounding this block three squared traverses were established with side lengths from 50 m to 90 m with increment of 20 m. The four stations of each traverse is numbered according a serial numbering system common to all these traverses as, seen in Figure 6.

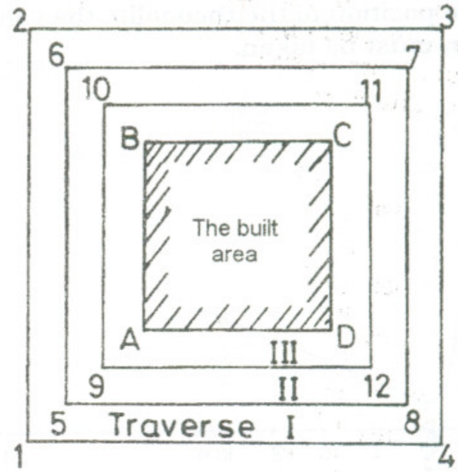

Figure 6 The choice of both the built area and the traverses

The angular measurements were done by using the theodolite one second. And the linear measurements were done by using a 30m steel tape. Every side length was measured two times. The concept here is to measure the sides of each traverse and measure all possible angles to the corners of the block ABCD from each traverse station then adjusting the interior angles of each traverse and use them to compute the coordinates of points A,B,C and D by intersection. The block ABCD can be then treated as a closed traverse and computed three times in our case. From the obtained results we can determine the best position of the surrounding traverse (see Figure 7).

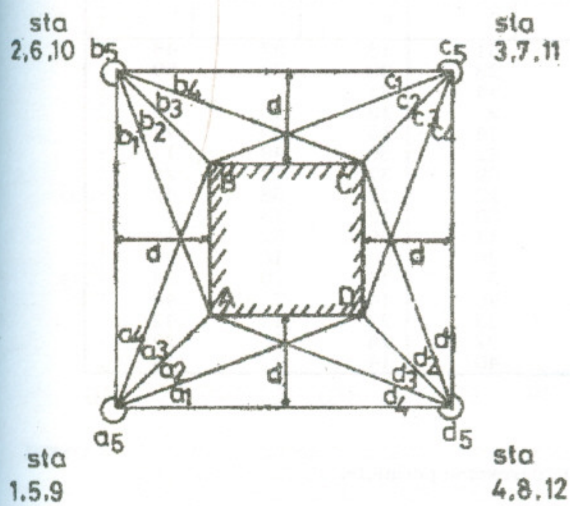

Figure 7 Sample traverse of the three tested cases

The Computational Procedures

1. For all five horizontal angles measured at each traverse station, the mean value of four arcs was taken.
2. The adjusted values for all angles were shown at Table 2.
3. Compute the bearings and differences in x,y components for relative to the horizontal bottom side as the horizontal axes.
4. Compute the linear closing error and then compute the adjusted components of each side according to the transit rule.
5. The coordinates of the points A,B,C and D computed by using the two main formula for intersection (see Figure 8).

DISCUSSION OF RESULTS

The final obtained result can be visualized either numerically or graphically. For our purpose here we are going to follow both approaches.

Table 3 summarizing the final of the three outside traverses especially from the point of view of positional and angular closing errors as varying the perimeter of the traverse.

From this table it can be seen that the most precise traverse (which produce the minimum closing errors for both angular and positional) is that one whose perimeter is ranging between.

Table 4 illustrates the variation of the positional closing error of the inner block according to the position of the used outside traverse. The examination of this table reveals that the best position of the outer traverse relative to the project inner block is located at a lateral distance within the range.

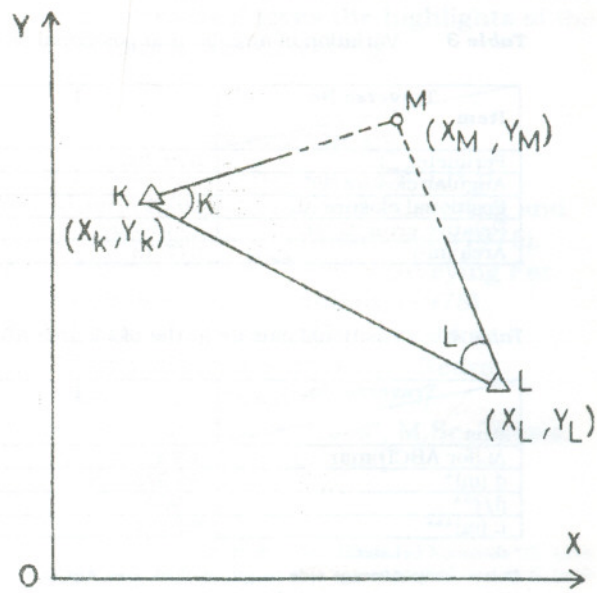

Figure 8 Sketch illustrates the intersection

$$X_M = \frac{X_k.\cot L + x_L.\cot K + (Y_k - Y_L)}{(\cot K + \cot L)}$$

$$X_M = \frac{y_k.\cot L + Y_L.\cot K + X_L Yk)}{(\cot K + \cot L)}$$

Where M represents intersection point (A,B,C and D); K, L represent any two adjacent points with known coordinates; (X_M, Y_M) coordinates of station M.

Table 2 The adjusted angles

Angle	Traverse I			Traverse II			Traverse III		
	o	'	"	o	'	"	o	'	'
α_1	26	7	16	21	23	51	13	37	48
α_2	18	-	40	22	47	23	30	22	59
α_3	17	29	26	22	26	44	31	-	11
α_4	29	30	55	24	39	2	13	58	45
b_1	29	8	47	24	14	14	15	59	23
b_2	17	29	5	22	25	42	30	48	1
b_3	16	50	46	21	19	39	32	12	24
b_4	26	9	22	21	38	27	12	58	42
C_1	26	20	16	21	49	50	13	13	2
C_2	16	42	20	21	12	11	29	52	1
C_3	18	41	18	23	51	26	34	16	24
C_4	28	21	58	23	23	5	15	20	34
d_1	28	51	8	24	1	46	14	7	48
d_2	16	55	1	22	9	23	29	14	42
d_1	17	1	31	20	56	37	28	56	22
d_2	26	20	12	21	40	40	14	1	13

Table 3 Variation of angular and positional closers with outer traverse perimeter

Item \ Traverse No.	I	II	III
Perimeter $\sum L$	329.485	244.719	159.070
Angular closure $\Delta\theta$"	36"	4"	79.5"
Positional closure ΔL	20.09	8.036	5.002
Relative error ΔL /L	1/16400	1/130450	1/ 31800
Area (m²)	677.18	3738.44	1579.58

Table 4 Positional closure in the block area ABCD versus lateral distance of outside traverse

Item \ Traverse No.	I	II	III
ΔL(for ABCD)mm	1.03	0.37	1.07
d (m)*	26.575	15.979	5.273
d/ℓ**	0.909	0.546	0.180
L (m)***	82.371	61.179	39.767

* d: Lateral distance in m.
** ℓ: average side length of block area ABCD
*** L: average side length of outer traverse in m

Figure 9 depicts the relationship between the positional closing error for inner block and the percentage lateral distance of the length of inner block. From this relationship we can deduce that the best position of outer traverse will be located at a distance approximately 40% of the corresponding side of the project. This percentage makes the area of outer traverse is 3.5 times as the inner area. In such a case the perimeter will be double the inner. The relative accuracy positional misclosure (P.M.) of positioning a builded area varing approximately parabolic with the lateral distance (d) of the used traverse for the area of project. In other words, the (P.M.) decrease with the increase of d, the minimum value of (P.M.) is locate at d of about 40% of the respective side of the area of the project then it starts to increase again.

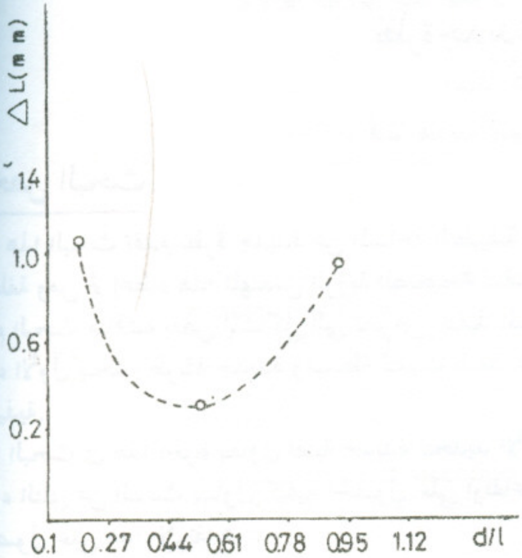

Figure 9 Relation between the positional closing error for inner block (ΔL) and the percentage lateral distance of the length of inner block (d/l)

CONCLUSION

Construction surveying problems have many new aspects and advanced instrumentation, the following conclusions and recommendation can be drawn in this phase.

1. Establishing horizontal control is one of working from the whole to the part. This entails the use of a major control network enclosing the whole area.
2. Using the data illustrated in Table 1 and Figures 1 and 2 establishing horizontal control in the field becomes easy quickly and name more precisely.
3. The approximate method, to determine the optimum position of theodolite for the determine the height of the buildings, can be successfully applied.
4. The best location of the traverse relative to the built area is at a lateral distance of about 40% of the corresponding side of the area of project.
5. This paper is devoted to be a study to improve the interpretability of modern instrumentation by using them with modern technique in phase of construction surveying work. A procedure is already developed for carrying out the construction surveying according to new technique.
6. Finally, this paper illustrates a procedure for a better construction surveying scope adopted for execution of sites as it gives the highlights of the construction surveying.

REFERENCES

1. A.L. Allan, J.R. Hallway and J.H.B. Maynes, "Practical Field Surveying and Computations", LTD, London, (1975).
2. J. Uren and W.F. Price", Surveying For Engineers", LTD, London, (1978).
3. V.D. Bolshkova and G.P. Levshka "Practical Field Surveying", Nedra, Moscow, (in Russian), (1980).
4. S.A. Salem, "Transverses", M.Sc. Thesis, Al-Azhar University, 1981.

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نظرة جديدة عن المساحة التطبيقية

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ملخص البحث

هذا البحث يقدم نظرة جديدة عن المساحة التطبيقية وكيفية التغلب على المشاكل التى تقابل المهندس أثناء تنفيذ المشروعات المختلفة ومن ثم إعطاء هذا المهندس الرؤية الصحيحة لتنفيذ الأعمال بدقة وبطريقة سهلة التطبيق .
يقدم البحث مناقشة بعض المشاكل التى تعترض تنفيذ المشروعات وذلك فى جزئين منفصلين.
الجزء الأول يبحث طريقة جديدة ومبسطة لتثبيت النقط فى الموقع أثناء التنفيذ من واقع الإحداثيات والأبعاد المبينة فى الرسومات التنفيذية.

البحث فى هذا الجزء يتناول تقنية جديدة لتحديد الأماكن أثناء التنفيذ وخاصة مع استعمال الأجهزة المساحية الحديثة.
الجزء الثانى من البحث يتناول كيفية الحصول على ارتفاعات المبانى وبذلك يمكن تحديد المكان الأمثل لوضع الجهاز المساحى للحصول على هذا الإرتفاع.
يتناول الجزء الثانى أيضا من البحث استنتاج عملى لإختبار أفضل مضلع (ترافرس) يحيط بأى مبنى أو أى منشأة لكى يتم تنفيذ هذا العمل وذلك لتسهيل ودقة العمل أثناء التنفيذ.
نخلص من هذا البحث التطبيقى إلى إلقاء نظرة جديدة باستعمال الأجهزة المساحية المتقدمة على المنشأت المختلفة أثناء تنفيذها وذلك بتحديد الأبعاد الثلاثة لهذا المنشأ.