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Horizontal Deformation Monitoring of Kut Barrage-Iraq using High Precision GNSS& Total Station

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Abstract

The modern evaluation and analysis techniques for the horizontal deformation of concrete structures such as barrages depend on a geodetic network, with control points, required to carry out the adjustment for the networks according to the adjustment techniques "Least Squares method". The study included measurement of fourteen point in the downstream side, depending on the global satellite navigation system and using the Adjust program to calculate the amount of displacement resulting. A comparison done between the resulted deformations magnitude for the network points for 2014 epoch with respect to the General Directorate for Survey (GDS) at epoch 2005 the deformation or movement could be verified by applying the statistical techniques to analyze the movement. The analysis shows that the movement displacement systems stable and amount 3.5cm.

Keywords: Kut Barrage, horizontal deformation, least square adjustment, analysis result.

مراقبة التشوه الافقي لناظم الكوت-العراق باستخدام نظام اقمار الملاحة العالمي والمحطة المتكاملة

الخلاصة

التقنيات الحديثة لتقييم وتحليل التشوهات الأفقية لهياكل المنشآت الخرسانية مثل النواظم تعتمد على الشبكات الجيوديسية، مع نقاط المراقبة، اللازمة لتنفيذ عمليات التسوية الشبكية وفقا لأساليب التصحيح "طريقة المربعات الصغرى". لقد تضمنت الدراسة قياس اربعة عشر نقطة من جهة المصب بالاعتماد على نظام اقمار الملاحة العالمي وباستخدام برنامج التصحيح لحساب مقدار الازاحة الناتجة. تمت المقارنة بين حجم التشوهات الناتجة لشبكة النقاط في عام 2014 مع نتائج المديرية العامة للمساحة (GDS) في عام 2005 ومن خلال تطبيق الأساليب الإحصائية لتحليل الحركة يبين التحليل ان حركة الازاحة للناظم مستقرة ومقدارها 3.5سم.

الكلمات الدالة: ناظم الكوت، التشوه الافقي، طريقة المربعات الصغرى، تحليل النتائج.

Introduction

All flood control structures like Dams, locks, levees and embankments are subjected to external loads that cause deformation and permanence of the structure itself, plus its foundations. Any indication of unusual behavior may threaten the safety of the structure. Careful monitoring of the loads on a structure and its response to them can be helpful in determining unusual behavior of that structure. In general, monitoring consists of both measurements and visual inspections. To help ensure the

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safe monitoring of a dam, it should be permanently equipped with proper instrumentation according to the goals of the observation, structure type and size, and site conditions[1]. Deformation survey, for monitoring purposes, has been used in many disciplines for, various applications. Among typical examples is the application of the deformation, monitoring in geodesy to identify the crustal, deformation or tectonic movements at global or regional scale. The deformation survey is also regularly conducted to monitor the, behavior of engineering structures such as barrage, bridges, rail track and etc. The deformation monitoring survey requires acquisition of observation data obtained from more, than one campaign of field, measurements. The type of instruments used in data acquiring depends on the nature, of work and also, on logistical consideration. Normally, for a small network, the use of theodolite and total station seems good enough in measuring the required directions or, horizontal angles and distances[2]. The technique of total least square (TLS) as an alternative technique for the ordinary, leas square LS. In deformation analysis. The applied TLS in solving the similarity transformation, between two different coordinate systems (two epochs) was found to give better results than the one obtained by ordinary LS[3]. The Deformation monitoring system presented here is designed to provide adequate geodetic information of, the structure and surrounding area over a long period of time. However, a continual assessment done, to identify any shortcomings to the scheme and to improve the reliability, accuracy and survey methods used[4]. There are advantages and disadvantages of using a total station for dynamic deformation monitoring. The advantages include the high accuracy as quoted above, the automatic target recognition which provides precise target pointing and the possibility of measuring indoors and in urban canyons[5]. The disadvantages include the low sampling rate, problems with measurement in adverse weather conditions[6], and the fact that a clear line of sight is needed between the total station and the prism. Total stations allow the measurement of many points on a surface being monitored within a short period of time.

Kut Barrage

Kut barrage is a a structure fitted with gates to regulate the water level in the pool behind in order to divert water through a canal for irrigation, power generation, and flow augmentation to another river. The construction is located on the Tigris river of Kut city in eastern, Iraq. It takes five years to construct the barrage between 1934 and 1939. The barrage height is 10.5m and a length of 516m at (32˚29' 51˝, 45˚ 48' 57”) left and (32˚30'00”, 45˚49'11”) right, UTM projection, WGS84 ellipsoid, Figure (1).

Fig. 1. Location Kut barrage on Map

Deformation Survey Techniques

The general procedures to monitor the deformation of a structure and its foundation involve measuring the spatial displacement of the selected object points (i.e., target points) from external control points that are fixed in position. Either terrestrial or satellites positioning methods are used to measure these geospatial displacements (Δx, Δy, Δz). The reference points are located in the structure, only relative deformation determined micrometer joint measurements are relative observations. Absolute deformation or displacement is possible if the control points are located outside the actual structure, in the foundation or surrounding terrain and beyond the area that may be affected by the dam or reservoir. Subsequent periodic observations are then made to be relevant to these absolute control points. Assessment of permanent deformations requires an absolute data[7] .In general, for concrete dams, it is ideal to place the control points in a rock foundation at a depth unaffected by the reservoir. These control points can be easily accessed to perform deformation surveys with simple measurement devises. Fixed control points located within the vicinity of the dam but outside the range of its impact are essential to determination of the deformation behavior of the structure. Thus, monitoring networks in the dam plane should be supplemented by and connected to triangulation networks and vertical control whenever possible. If only two control points were used in the network as fixed points, then the adjustment called (minimal constrained adjustment), while when all the control points used in the adjustment, it's called (fully constrained adjustment)[8].The general operating procedure for the monitoring system of structural deformations could be summarized in the flow chart in Figure (2). A project for specific measurement scheme and its operating procedures should be developed for the monitoring system[7].

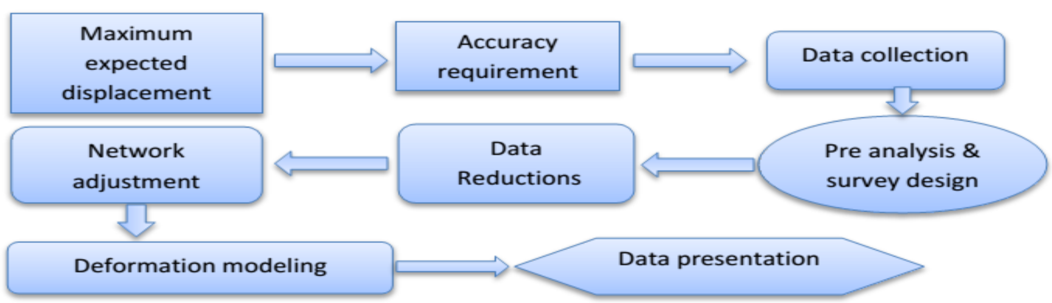

Fig. 2. Deformation survey data flow

Least Squares Adjustment

Least square is a powerful statistical technique that may be used for 'adjusting' or estimating the coordinates in survey control networks. The term adjustment is the one in popular usage but it does not have any proper statistical meaning. A better term is ' least squares estimation ' since nothing, especially observations, are actually adjusted. Rather, coordinates are estimated from the evidence provided by the observations. In practical survey network, it is usual to observe more than the strict minimum number of observations required to solve for the coordinates of the unknown points. The extra observations are' redundant ' and can be used to provide an ' independent check ' but all the observations can be incorporated into the solution of the network if the solution is by least squares[9]. The solution follows a systematic procedure; any system of observation may be represented in matrix from as:

$$mA^{n}\ nX^{1} = mL^{1} + mV^{1} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:
A : Matrix of coefficients of the unknowns.
X: Matrix of unknowns, adjusted quantities.
L : Matrix of observation.
V : Matrix of residuals.
m : Number of unknowns.

$n:$ Number of observation.

$$X = (A^T A)^{-1} A^T L \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For a system of weighted observation:

$$X = (A^T W A)^{-1} A^T W L \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where
W: is a diagonal matrix of weights.

The Precision Analysis

The matrix equation for calculating residuals after adjustment, whether the adjustment is weighted or not, is:

$$V = AX - L \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The standard deviation of unit weight for an unweight adjustment is:

$$\sigma_0 = \sqrt{\frac{V^T V}{r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$r = n - m$

The standard deviation of unit weight for a weighted adjustment is:

$$\sigma_0 = \sqrt{\frac{V W V^T}{r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

In Equations (5) and (6), r is the number of degrees of freedom in an adjustment, which usually equals the number of observations minus the number of unknowns, or:

$$r = m - n$$

Standard deviations of the individual adjusted quantities are:

$$\sigma_{xi} = \sigma_0 \sqrt{q_{xixi}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

(q_{xixi}) the diagonal element in $(A^T W A)^{-1}$ matrix, in the ith row and in the ith column, this matrix is called "covariance matrix" and symbolized by Q_{XX} [10].

Horizontal Geodetic Control Network for Monitoring Purposes

The geodetic horizontal network of Kut barrage consists of four observation pillars distributed about upstream and downstream for the barrage and fourteen points located on the wall barrage with distance 33m as shown in Figure (3). The observation pillars are a concrete cylinder with a diameter of 45cm and a height of 130cm above the ground level as shown in Figure (4). The top of the pillars are protected by a metallic cover. This cover extends down of the observation pillars to cover a concrete stage that is designed to be suitable to the force centering equipment of the field observations.

Fig. 3. Locations the points on the wall of barrage (field work)

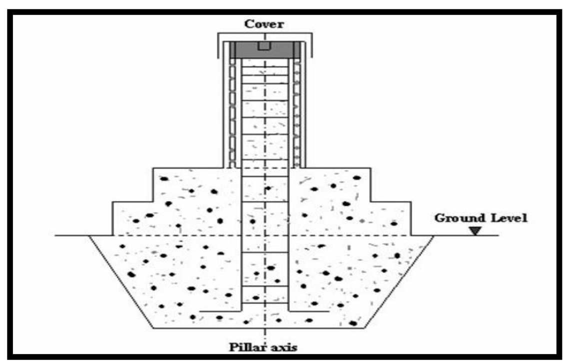

Fig. 4. Standard form for monitoring Pillars (control Point) used in monitoring

The Directorate General of Survey (DGS) is the organization responsible for monitoring of kut barrage. DGS used hybrid network for distance and angles with double observations for year (2005). The design and this type of networks is known as multivariate design of these observations are carried out by (DGS) according to control point which represents the reference points. The new evaluation techniques and the studies of the horizontal structures deformation depends on the geodetic observation network (control point). The adjustment for the networks depends on the techniques of least square. Comparing the occurred deformation for network points at each consecutive observation, the deformation or movement could be verified by an applying the statistical techniques to analyze the movement.

A deformation analysis where done from measuring (3D) control point by GNSS (Global Navigation Satallite System) two points at the downstream as shown in Figure (5).

Fig. 5. GNSS installiation on control point (P4),(field work)

Static method GNSS surveying was applied on two points (P3, P4) of the barrage and the observed period was 90 minute for every point with in interval 15second. Horizontal monitoring points of the 14 points in the downstream of the barrage through total station electronic model imaging station IS 201 (1”), this device belong the center of remote sensing university of technology. There are old data observed from the Kut barrage for 2005 year, measured by angle and distance method, doing by the Directorate General of Survey (DGS) .These data will be compared with our results with analysis. Table (1) shows results the observed GNSS two control point (pillars) that located at downstream direction after process GNSS data by online Positioning User Service (OPUS) from coordinate system UTM, datum WGS 84, zone 38 North (45E), Geoid EGM08.

Table (2), shows the result, points related to horizontal geodetic network, which contains two control points, fourteen monitoring points.

Table 1. Observe by the GNSS for two control point (pillars) that located at downstream direction

ID	Easting (meter)	Northing (meter)	Elevation (meter)
P3	577086.395	3595034.716	21.563
P4	577552.512	3595482.040	20.402

Table 2. Observe fourteen points for epoch 2014

Observe (00)			Observe (01)		DIFF	
P.N	Easting	Northing	Easting	Northing	DX	DY
P3	5777086.518	3595034.820	577086.518	3595034.820	0.00	0.00
P4	577552.527	3595482.121	577552.527	3595482.121	0.00	0.00
15	576658.374	3595871.417	576658.323	3595871.426	-0.051	0.009
16	576684.925	3595892.354	576684.911	3595892.336	-0.014	-0.018
17	576709.378	3595913.260	Not seen	Not seen	Not seen	Not seen
18	576734.932	3595934.179	Not seen	Not seen	Not seen	Not seen
19	576760.426	3595955.112	Not seen	Not seen	Not seen	Not seen
20	576785.948	3595976.066	Not seen	Not seen	Not seen	Not seen
21	576811.470	3595996.990	576811.408	3595996.905	-0.062	-0.085
22	576837.968	3596017.912	576837.922	3596017.928	-0.046	0.016
23	576862.492	3596038.840	576862.443	3596038.888	-0.049	0.048
24	576888.995	3596059.787	576888.907	3596059.796	-0.088	0.009
25	576913.525	3596080.714	576913.576	3596080.725	0.051	0.011
26	576939.030	3596101.652	576939.028	3596101.667	-0.002	0.015
27	576964.571	3596122.586	576964.537	3596122.542	-0.034	-0.044
28	576992.084	3596140.473	576992.089	3596140.479	0.005	0.006

Analysis Adjustment Data

The least squares principle is widely applied to the adjustment of surveying measurements because it defines a consistent set of mathematical and statistical procedures for finding unknown coordinates using redundant observations. During the net adjustment data by software adjust. Monitoring software systems consist of two components, measurement collection and measurement analysis as shown in Figures (6) and (7).

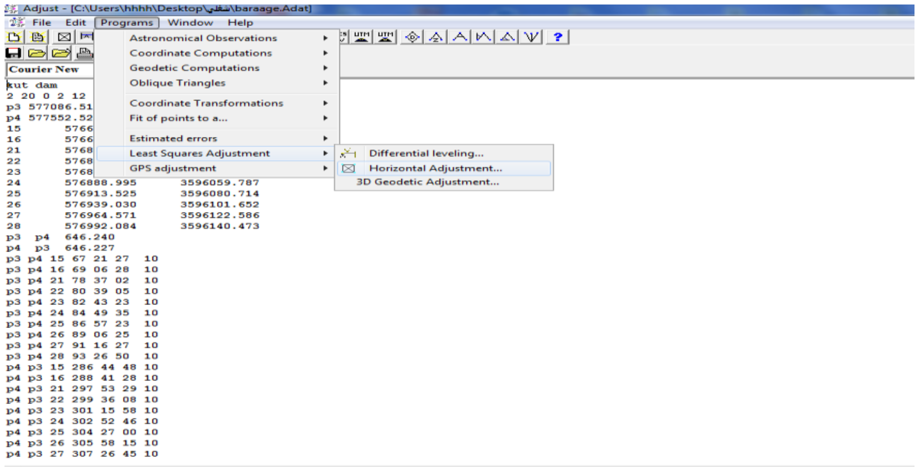

Fig. 6. Adjust software

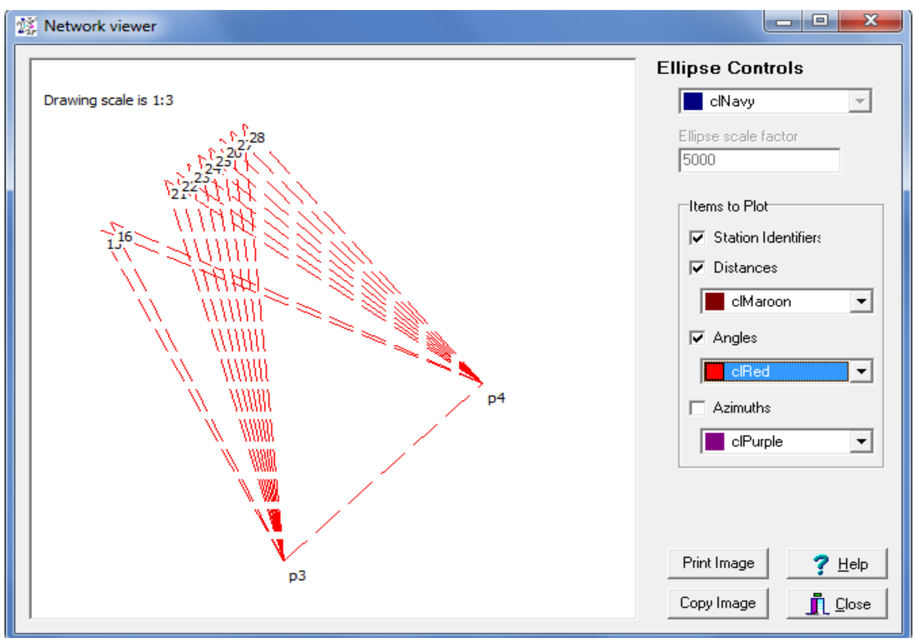

Fig. 7. Measurement analysis

The computation of deformation for epoch 2014. Tables (3) to (9) shows the results analysis as follows:

Number of control station =2

Number of unknown station =12

Number of distance observations =2

Number of angle observations =20

Number of azimuth observations =0

Table (10), shows the result, points related to horizontal geodetic network, which contains two control points, fourteen monitoring points. The computation of deformation for epoch 2014.

Tables (11) to (16) show the results analysis as follows:
Number of control station =2
Number of unknown station =12
Number of distance observations =2
Number of angle observations =20
Number of azimuth observations =0

Table 3. Initial approximations for unknown stations

Station	X	Y
15	576658.374	3595871.417
16	576684.925	3595892.354
21	576811.470	3595996.990
22	576837.968	3596017.912
23	576862.492	3596038.840
24	576888.995	3596059.787
25	576913.525	3596080.714
26	576939.030	3596101.652
27	576964.571	3596122.586
28	576992.084	3596140.473

Table 4. The control stations

Station	X	Y	Δx	Δy
P3	577,086.518	3,595,034.820	0.0010	0.0010
P4	577,552.527	3,595,482.121	0.0010	0.0010

Table 5. The distance observations

Station occupied	Station sighted	Distance (m)	S
P3	P4	646.227	1.000
P4	P3	646.240	1.000

Table 6. The angle observations station back sight (P3) and station occupied (P4)

Station Foresight	Angle	S
15	67°21'27"	10"
16	69°06'28"	10"
21	78°37'02"	10"
22	80°39'05"	10"
23	82°43'23"	10"
24	84°49'35"	10"
25	86°57'23"	10"
26	89°06'25"	10"
27	91°16'27"	10"
28	93°26'50"	10"
15	286°44'48"	10"
16	288°41'28"	10"
21	297°53'29"	10"
22	299°36'08"	10"
23	301°15'58"	10"
24	302°52'46"	10"
25	304°27'00"	10"
26	305°58'15"	10"
27	307°26'45"	10"
28	308°59'07"	10"

Table 7. The adjusted stations

Station	X	Y	Δx	Δy
P3	577,086.518	3,595,034.820	0.0003	0.0003
P4	577,552.527	3,595,482.121	0.0003	0.0003
15	576,658.853	3,595,871.276	0.0215	0.0210
16	576,684.240	3,595,892.211	0.0210	0.0212
21	576,811.880	3,595,996.706	0.0191	0.0231
22	576,837.395	3,596,017.592	0.0188	0.0237
23	576,862.893	3,596,038.516	0.0186	0.0244
24	576,888.322	3,596,059.503	0.0184	0.0252
25	576,913.864	3,596,080.396	0.0182	0.0261
26	576,913.864	3,596,101.308	0.0180	0.0271
27	576,964.919	3,596,122.207	0.0178	0.0282
28	576,992.898	3,596,140.164	0.0175	0.0292

Table 8. The adjusted distance observations

Station occupied	Station sighted	Distance	V	S
P3	P4	645.943	-0.2838	0.0004
P4	P3	645.943	-0.2968	0.0004

Table 9. The adjusted angle observations station backsight (P3) and station occupied (P4)

Station Foresighted	Angle	V	S"
15	67°21'27"	0.0"	2.9
16	69°06'28"	0.0"	2.9
21	78°37'02"	0.0"	2.9
22	80°39'05"	0.0"	2.9
23	82°43'23"	0.0"	2.9
24	84°49'35"	0.0"	2.9
25	86°57'23"	0.0"	2.9
26	89°06'25"	0.0"	2.9
27	91°16'27"	0.0"	2.9
28	93°26'50"	0.0"	2.9
15	286°44'48"	0.0"	2.9
16	288°41'28"	0.0"	2.9
21	297°53'29"	0.0"	2.9
22	299°36'08"	0.0"	2.9
23	301°15'58"	0.0"	2.9
24	302°52'46"	0.0"	2.9
25	304°27'00"	0.0"	2.9
26	305°58'15"	0.0"	2.9
27	307°26'45"	0.0"	2.9
28	308°59'07"	0.0"	2.9

Adjustment Statistics
Iterations = 2 ; Redundancies = 2; Reference Variance = 0.0843 ; Reference so = ±0.29

Table 10. Observe fourteen points for epoch 2005

Observe (00)			Observe (01)		DIFF	
P.N	Easting	Northing	Easting	Northing	DX	DY
P3	5777086.760	3595034.506	577086.760	3595034.506	0.00	0.00
P4	577552.550	3595482.135	577552.550	3595482.135	0.00	0.00
15	576657.736	3595871.368	576657.759	3595871.308	-0.023	0.06
16	576683.287	3595892.267	576683.301	3595892.241	0.014	0.026-
17	576708.804	3595913.177	Not seen	Not seen	Not seen	Not seen
18	576734.372	3595934.041	Not seen	Not seen	Not seen	Not seen
19	576759.905	3595954.965	Not seen	Not seen	Not seen	Not seen
20	576785.442	3595975.855	Not seen	Not seen	Not seen	Not seen
21	576810.971	3595996.782	576810.996	3595996.729	0.025	0.053-
22	576836.522	3596017.648	576836.539	3596017.651	0.017	0.003
23	576862.058	3596038.570	576862.075	3596038.534	0.017	0.036-
24	576887.581	3596059.480	576887.645	3596059.436	0.064	0.044-
25	576913.118	3596080.371	576913.152	3596080.367	0.034	0.004-
26	576938.686	3596101.293	576938.676	3596101.318	-0.01	0.025
27	576964.212	3596122.238	576964.238	3596122.216	0.026	0.022-
28	576989.767	3596143.079	576989.769	3596143.108	0.002	0.029

Table 11. The initial approximations for unknown stations

Station	X	Y
15	576657.736	3595871.368
16	576683.287	3595892.267
21	576810.971	3595996.782
22	576836.522	3596017.648
23	576862.058	3596038.570
24	576887.581	3596059.480
25	576913.118	3596080.371
26	576938.686	3596101.293
27	576964.212	3596122.238
28	576989.767	3596143.079

Table 12: The control stations

Station	X	Y	Δx	Δy
P3	577,086.760	3,595,034.504	0.0010	0.0010
P4	577,552.550	3,595,482.135	0.0010	0.0010

Table 13. The angle observations station back sight (P3) and station occupied (P4)

Station foresight	Angle	S
15	67° 21' 11"	10"
16	69° 06' 25"	10"
21	78° 36' 59"	10"
22	80° 39' 10"	10"
23	82° 43' 23"	10"
24	84° 49' 34"	10"
25	86° 57' 25"	10"
26	89° 06' 33"	10"
27	91° 16' 33"	10"
28	93° 26' 00"	10"
15	286°44' 44"	10"
16	288°41' 49"	10"
21	297°53' 32"	10"
22	299°36' 12"	10"
23	301°16' 01"	10"
24	302°53' 01"	10"
25	304°27' 09"	10"
26	305°58' 22"	10"
27	307°26' 48"	10"
28	308°52' 17"	10"

Table 14. The adjusted stations

Station	X	Y	Sx	Sy
P3	577,086.760	3,595,034.504	0.0002	0.0002
P4	577,552.550	3,595,482.135	0.0002	0.0002
15	576,658.571	3,595,870.699	0.0163	0.0159
16	576,684.067	3,595,891.661	0.0159	0.0160
21	576,811.536	3,595,996.296	0.0145	0.0175
22	576,837.033	3,596,017.248	0.0143	0.0179
23	576,862.524	3,596,038.160	0.0141	0.0185
24	576,888.018	3,596,059.092	0.0139	0.0191
25	576,913.510	3,596,080.052	0.0138	0.0197
26	576,938.989	3,596,101.033	0.0136	0.0205
27	576,964.505	3,596,122.959	0.0135	0.0213
28	576,989.990	3,596,142.881	0.0133	0.0223

Table 15. The adjusted distance observations

Station occupied	Station sighted	Distance (m)	V	S
P3	P4	646.014	-0.2132	0.0003
P4	P3	645.014	-0.2262	0.0003

Table 16. The adjusted angle observations station back sight (P3) and station occupied (P4)

Station foresighted	Angle	V	S"
15	67°21' 21"	0.0"	2.2
16	69°06' 25"	0.0"	2.2
21	78°36' 59"	0.0"	2.2
22	80°39' 10"	0.0"	2.2
23	82°43' 23"	0.0"	2.2
24	84°49' 34"	0.0"	2.2
25	86°57' 25"	0.0"	2.2
26	89°06' 33"	0.0"	2.2
27	91°16' 33"	0.0"	2.2
28	93°26' 00"	0.0"	2.2
15	286°44'44"	0.0"	2.2
16	288°41'49"	0.0"	2.2
21	297°53'32"	0.0"	2.2
22	299°36'12"	0.0"	2.2
23	301°16'01"	0.0"	2.2
24	302°53'01"	0.0"	2.2
25	304°27'09"	0.0"	2.2
26	305°58'22"	0.0"	2.2
27	307°26'48"	0.0"	2.2
28	308°52'17"	0.0"	2.2

Adjustment Statistics
Iterations = 3 Redundancies = 2 Reference Variance = 0.0483 Reference so = ±0.22

Conclusion

The results show that the horizontal deformation value for mark points is less than (3.5cm) for the downstream, therefore our inference is that Kut barrage is stable hydraulic structure according to international standards.

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