Creep accuracy assessment of Mosul dam structure as a function of water depths level for the dam reservoir

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Abstract

Periodic monitoring of huge infrastructure such as dams is very important, the phenomenon of creep in earthen dams needs to prepare studies in order to know the most influential factors. The main objective of this research is to determine the values of creep of the Mosul Dam structure both the upstream and downstream sides of the dam's body and make a relations between horizontal displacements (creep) versus the values of water elevations in the dam reservoir in order to predict the values of creep if the water elevation differences are available. The data was obtained by the Ministry of Water Resources (unpublished data).

The instruments used in observation operations are Total Station Topcon 7501 and GPS devices Topcon GR-5 receiver. While the software used in processing the data are (SPSS, GIS, Visual Basic 6,and Excel). Excel program used to specifying the water elevations differences. GIS technology (Arc GIS 10.8) used to find the differences in the horizontal distances for every two sequential years, then rearrangement the differences for both distances and water elevations differences are achieves by the visual basic 6 program algorithms. Finally formulating the mathematical models are done by SPSS software. The average creep for the optimum model to the downstream side of the dam is (8.22mm) and in the upstream side is (6.45mm).The value of the average creep for the optimum model (downstream side) is (8.22mm) and in the upstream side is (6.45mm). The results depicted that the amount of creep on the downstream side of the dam is greater than the upstream side.

The study was able to make a six mathematical models for the horizontal displacements, three mathematical models for upstream side of the dam and three mathematical models for downstream side. The optimum equations was selected on statistical bases after conducting a verifications. The results proved the values of creep increases with the increase in water levels. Therefore, it is possible to considered the value of water depths as a function of creep.

Key word; Mosul dam ,Creep, Upstream**.**

Introduction

The structures of the dams must be continuously monitored in order to detect dam creep. Observations of the creep can be utilized to forecast dam displacement sooner, lowering maintenance costs and improving structural durability and safety. Dams in infrastructure parts can have a direct impact on people's and property's safety. The dam system may fail due to an over-loading condition caused by the disparity in water heights upstream and downstream of the dam. Over-loading can be caused by reservoir water sediments, live water storage, and possibly unintentional loads such as earthquakes, wind forces, and so on [1].

With changing cyclic loading, the structure's stress life may be shortened. In reinforced concrete constructions, fatigue failure commonly manifests itself as cracks. Design standard no.13 embankment dams are examples of standard requirements used in dam construction. Data on structural displacement under operational loads is a useful tool for predicting structural performance [2].

For displacement monitoring, new accurate system identification techniques using low-cost devices are being developed. Remote sensing technology and the use of modern devices (Topcon GR-5) receivers can make an accurate geodetic field surveying the field work can be done by taking spatial coordinates (x,y, z) through the cross sections and longitudinal sections covering the body of the dam in Mosul dam structure (case study). And by repeating these measurements over time, with regular and synchronous changes in water elevations upstream and downstream of the dam reservoir, for many years. As a result, the behavior of the dam structure can be investigated in order to determine horizontal displacement (creep).

Previous studies emphasized the importance of continuous monitoring of large structures, for example an earthfill (Kremasta Dam) and a concrete dam (Ladon Dam), Greece, Spectral analysis of the available data, revealed that movements correlate with the reservoir level fluctuations [3].

The results revealed in Eleonora D’Arborea (Cantoniera) dam, Sardinia. GNSS technology can be conveniently used to monitor dams allowing for a more intense description, both in space and time [4].

The results show that GPS makes it possible to continuously follow the dynamics of geophysical entities with weak and slow displacements (5 mm/day). Alpes-de-Haute-Provence, France [5].

The results demonstrate the feasibility of using the geodetic method as a pattern for the confirmation and improvement of deterministic modeling methods. Arenoso dam, Spain [6].

The current study focuses on the spatial differences as a function of time for the horizontal movement of the Mosul dam structure, which are related to the water heights of the upstream and downstream disparities, based on a literature review. For a certain time period, this study analyses modern relationships for dam creep displacement connected to water heights to upstream and downstream discrepancies. For a more precise study, these relationships can be evaluated for two sides of the longitudinal section of the dam, referred to as the upstream and downstream sides. As a result, the creep relations may be utilized to forecast horizontal displacement for each difference in water height.

Case study location (Mosul dam)

The Mosul Dam is situated on the Tigris River in Iraq's northwestern province of Nineveh, roughly 60 kilometers northwest of Mosul city, between latitudes ($36^\circ38'00'' \ to \ 37^\circ5'00''$) north and longitudes ($42^\circ05'00'' \ to \ 42^\circ52'00''$) east (3.1). The Mosul Dam was completed on January 25th, 1981, and commenced operation on July 7th, 1986 [7].

The dam serves a variety of purposes, including providing water for three irrigation projects, flood control, and hydropower generating. The dam, including the spillway, is 113 meters high and 3650 meters long. The dam is an earth fill type with a mud core and a rock face on the upstream side (Iraqi Ministry of Water Resources 2020), as shown in figure (3.2), with a top width of (10 m) at the (341m M.S.L) crest level. At normal operation, the dam's reservoir water storage capacity is 13.3 billion cubic meters, with 10.37 billion meter cubic meters of living storage and (2.93) meter cubic meters of dead storage.

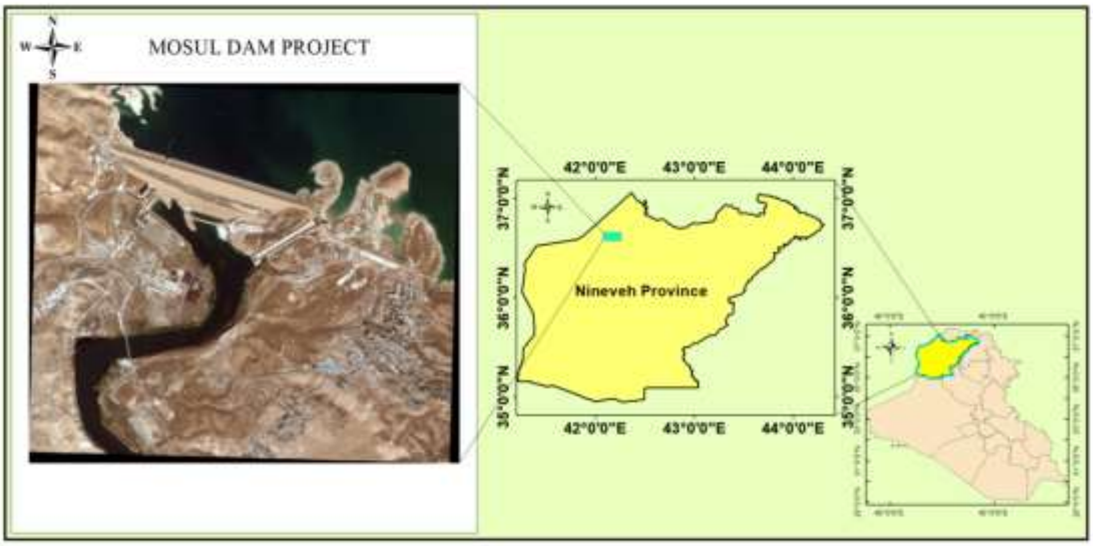


Figure (3.1) Location map of study area

Methodology

The first stage of the work includes the collection of raw data, represented by the Cartesian coordinates of stations that are monitored on the body of the Mosul Dam structure using (GPS) technique by (Topcon GR5 GNSS Receiver) used to observe the (X,Y) coordinates, with accuracy in horizontal (3mm + 0.1 ppm) and vertical (3.5 mm + 0.4 ppm) in static mode, vertical datum (EGM08) geoid of earth gravitational model with WGS84 UTM. Other collected data are the water levels in the upstream and downstream of the Mosul Dam reservoir, for many years. All these raw data are acquired from the Iraqi Ministry of Water Resources,(unpublished data).

Then the storage and maintenance stage are done using GIS technique (10.8) to find the distance differences between every two consecutive years. Visual Basic (6.0) are used to determine the highest values of the distance differences, and the SPSS program (26) edition is used to draw curves and make relationships between distances and water elevations differences. Microsoft Excel program is used to determine differences in water elevation differences for each two sequential years.

Results

Table(4.1) shows the variations in horizontal displacements between two consecutive years vs water elevation head differences between the same two years, where these differences are taken into account for the upstream side of the dam.

Table (4.1): Variations of horizontal distances differences versus water elevations head differences for the period of (2016-2017) within upstream side of the dam

No.	Station	water elev. diff.(m)	Horizontal Dist. Diff. (creep)(mm)	No.	Station	water elev. diff.(m)	Horizontal Dist. Diff. (creep)(mm)
1	BM87	11.90	11.77	13	BM71	7.99	6.09
2	BM61	10.90	11.60	14	BM77	7.99	5.99
3	BM69	10.70	10.49	15	BM78	7.59	5.77
4	BM89	10.29	7.77	16	BM52	6.99	5.41
5	BM53	10.19	7.07	17	BM85	6.79	5.19
6	BM73	9.79	6.84	18	BM57	6.79	5.02
7	BM79	9.29	6.68	19	BM84	6.69	4.84
8	BM51	9.29	6.65	20	BM64	6.59	4.32
9	BM63	9.19	6.53	21	BM100	6.59	3.61
10	BM72	9.09	6.44	22	BM96	6.49	3.13
11	BM58	8.29	6.26	23	BM83	5.89	2.41
12	BM91	8.19	6.11	24	BM95	5.69	1.90
				25	BM90	5.59	1.89
						S.D	2.57
						Av.	5.99
						Sum	149.76

Figure (4.1) depicts the relationships between these variables as shown in the table (4.1), as well as the correlation equation between variables. For the upstream side of the dam, it appears that (R^2=0.94) is a valid determination coefficient between horizontal distance differences and water elevation differences. This behavior can be attributed to an increase in horizontal distance differences with an increase in water elevation differences over the course of two years (2016-2017). This relationship will also be validated by the verification section.

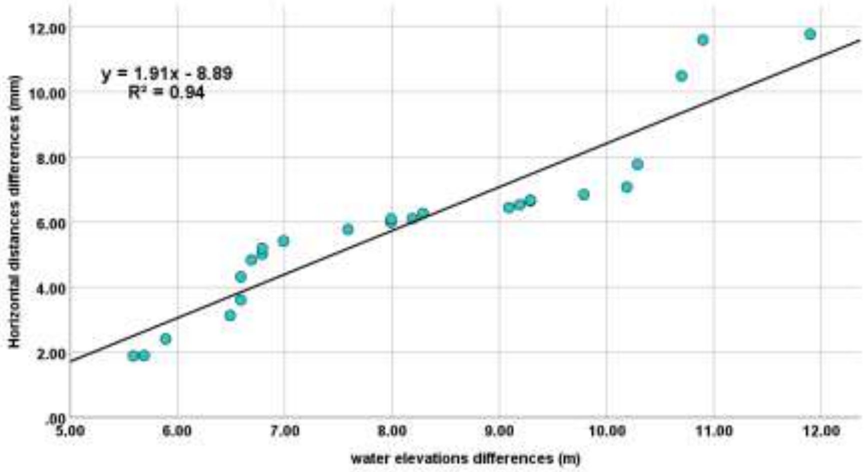


Figure (4.1): Relation model of horizontal distances differences (creep) versus (water elevations head difference) for the period of (2016-2017) within upstream side of the dam

Table (4.2) also shows the relationship between differences in horizontal lengths (creep) and differences in water heights on the downstream side. The average values of the horizontal distance difference (Av.=6.89 mm) on this side of the dam's body (downstream side) show that the differences in the eastern section of the dam are greater than the values of creep in the western part of the dam's body upstream side (Av.=5.99 mm) over the same period. Where the disparity in horizontal distances with the excess of water elevations can be seen for two years in a row (2016-2017).

Table (4.2): Variations of horizontal distances differences versus water elevations head difference for the period of (2016-2017) within downstream side of the dam

No.	Station	water elev. diff.(m)	Horizontal Dist. Diff. (creep)(mm)	No.	Station	water elev. diff.(m)	Horizontal Dist. Diff. (creep)(mm)
1	BM16	11.90	10.02	13	BM45	7.99	6.71
2	BM20	10.90	9.43	14	BM46	7.99	6.71
3	BM34	10.70	8.81	15	BM41	7.59	6.65
4	BM22	10.29	8.62	16	BM28	6.99	6.60
5	BM33	10.19	8.59	17	BM23	6.79	6.60
6	BM27	9.79	8.52	18	BM43	6.79	6.60
7	BM18	9.29	8.46	19	BM47	6.69	6.20
8	BM15	9.29	8.42	20	BM40	6.59	5.83
9	BM13	9.19	7.92	21	BM39	6.59	5.66
10	BM12	9.09	7.40	22	BM29	6.49	3.93
11	BM37	8.29	7.17	23	BM09	5.89	3.88
12	BM10	8.19	7.08	24	BM35	5.69	3.42
				25	BM06	5.59	3.12
						S.D	1.85
						Av.	6.89
						SUM	172.34

Figure 4.2 shows the direct relation between each level of storage and the value of creep, as well as the increase of horizontal distance differences with the increase of water elevation differences for two consecutive years (2016-2017). Significant determination coefficient (R^2=0.94) exists between water elevation changes and horizontal displacements.

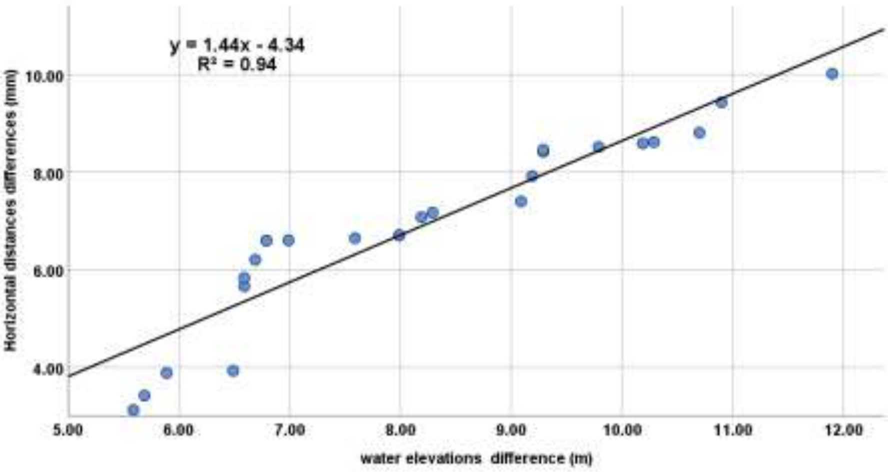
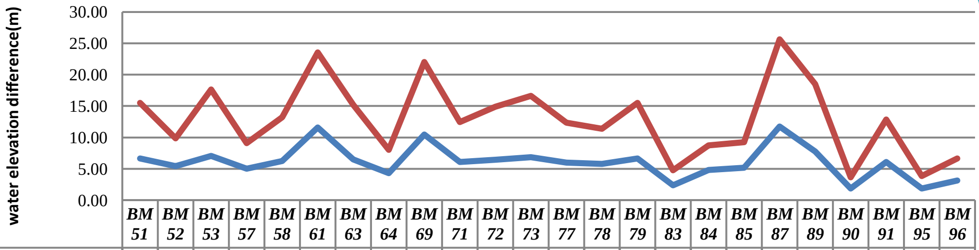


Figure (4.2): Relation model of horizontal distances differences (creep) versus (water elevations head difference) for the period of (2016-2017) within downstream side of the dam

Figure out (4.3) The difference in horizontal displacements (creep) of the observed stations (estimated using GIS technology) for the period of (2016-2017) within the upstream side of the dam are represented by the blue color's curve (X axis).

The red curve depicts the values of the expected horizontal distances disparities to the stations for two consecutive years, determined using the mathematical equations developed in this study, during the period (2016-2017) within the upstream side of the dam. Both curves are drawn with the same difference in water elevations for the period (2016-2017), which represents the (Y axis).

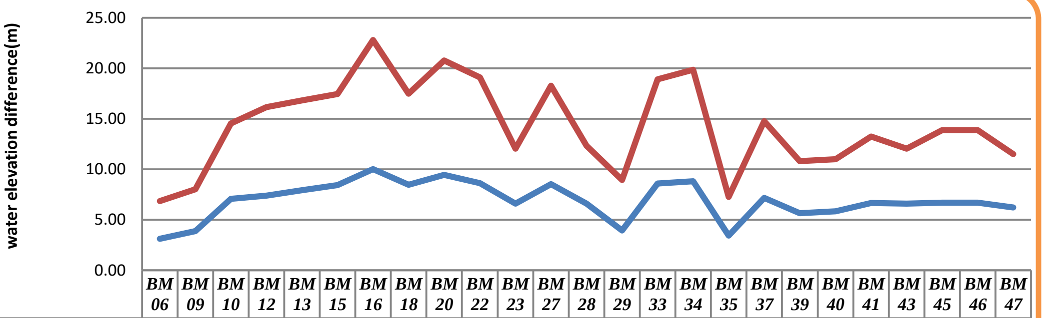
The convergence of the findings between the calculated (predicted values) and observed values may be seen in the drawing.



	BM 51	BM 52	BM 53	BM 57	BM 58	BM 61	BM 63	BM 64	BM 69	BM 71	BM 72	BM 73	BM 77	BM 78	BM 79	BM 83	BM 84	BM 85	BM 87	BM 89	BM 90	BM 91	BM 95	BM 96
predicted (mm)	8.85	4.46	10.5	4.08	6.94	11.9	8.66	3.70	11.5	6.37	8.47	9.81	6.37	5.61	8.85	2.36	3.89	4.08	13.8	10.7	1.79	6.75	1.98	3.51
observed (mm)	6.65	5.41	7.07	5.02	6.26	11.6	6.53	4.32	10.4	6.09	6.44	6.84	5.99	5.77	6.68	2.41	4.84	5.19	11.7	7.77	1.89	6.11	1.90	3.13

Figure (4.3): Variations of the observed and predicted horizontal distances differences for the periods of (2016-2017) within upstream side of the dam in (mm) for each station

The blue color's curve in figure (4.4) represents the expected horizontal distances differences values for the years (2016-2017) within the dam's downstream side, while the red color's curve represents the observed horizontal distances differences values. The observations stations on the dam's body on the downstream side of both curves blue and red colors are on the X axis of this figure. The water elevation differences over the period of time are represented on the Y axis (2016-2017). The variations between expected and observed horizontal distances are acceptable.



	BM 06	BM 09	BM 10	BM 12	BM 13	BM 15	BM 16	BM 18	BM 20	BM 22	BM 23	BM 27	BM 28	BM 29	BM 33	BM 34	BM 35	BM 37	BM 39	BM 40	BM 41	BM 43	BM 45	BM 46	BM 47
predicted(mm)	3.71	4.14	7.45	8.75	8.89	9.04	12.8	9.04	11.3	10.4	5.44	9.76	5.73	5.01	10.3	11.0	3.85	7.60	5.15	5.15	6.59	5.44	7.17	7.17	5.29
observed (mm)	3.12	3.88	7.08	7.40	7.92	8.42	10.0	8.46	9.43	8.62	6.60	8.52	6.60	3.93	8.59	8.81	3.42	7.17	5.66	5.83	6.65	6.60	6.71	6.71	6.20

Figure (4.4): Variations of the observed and predicted horizontal distances differences for the periods of (2016-2017) within downstream side of the dam in (mm) for each station

The results of the calculated and observed horizontal distance differences (creep) values for the stations in the western half of the dam's body (upstream side) and for the time are shown in Figure (4.5). (2016-2017). The blue color represents the computed (predicted) horizontal distances difference values, whereas the red color reflects the observed horizontal distances differences values.

The apparent convergence of the results shows that the relationships proposed in this study are reliable.

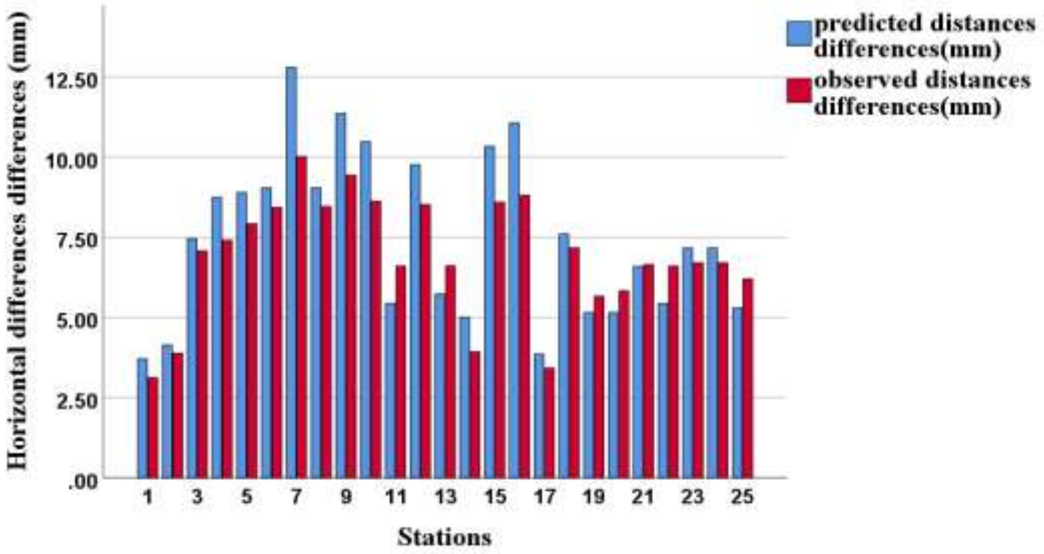


Figure (4.5): The observed and predicted horizontal distances differences histogram for each measured station with the upstream side of the dam during (2016-2017)

The results of the estimated and observed values of horizontal displacement (creep) for the eastern section of the dam's body (the downstream side) and for the period (2016-2017) are shown in the histogram (4.6).

The blue color indicates the estimated horizontal distance discrepancies, whereas the red color represents the observed horizontal displacement values. The histogram's results show a high level of reliability, confirming the study's legitimacy.

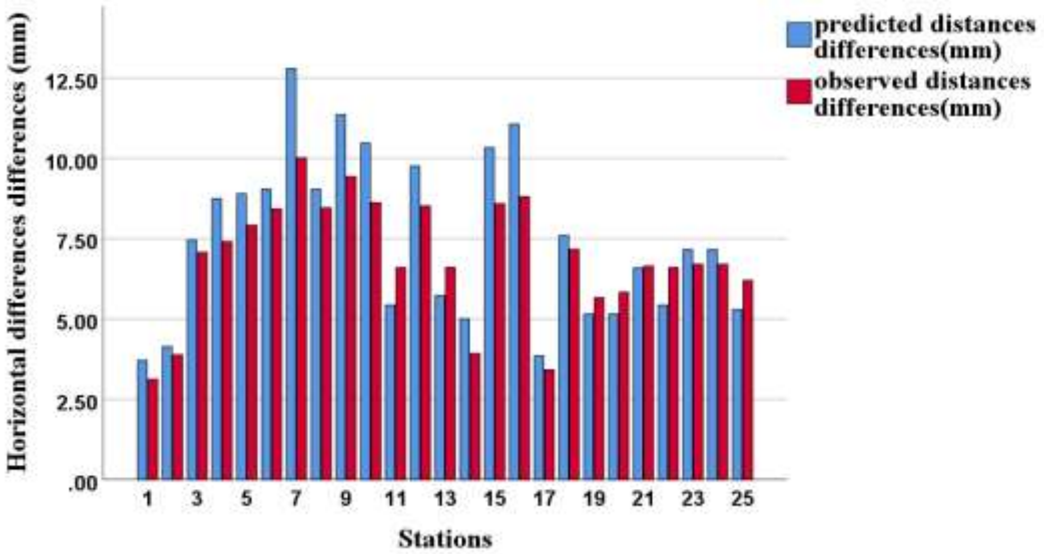


Figure (4.6): The observed and predicted horizontal distances differences histogram for each measured station with the downstream side of the dam during (2016-2017)

Conclusions

Through the results obtained in this study, on both sides of the dam body (upstream and downstream). All values of creep indicates to the clear effect of changes in storage water levels to the behavior of the dam.

Mathematical equations have been formulated on the basis of direct correlation between the values of change in water levels in the dam reservoir and the values of creep for every two successive years.

The results showed strong correlation coefficients between water elevations differences and creep are ranged from (0.94) to (0.97).. With an increase in the value of the change in water levels creep increase within the same time period (for every two successive years).Verifications were able to select the best model among the mathematical models, based on the statistical values obtained for each model.

Recommendations

1-Conduct additional research with broad enough ranges of variables impacting horizontal and vertical distance differences with water elevation differences to allow conclusive conclusions to be formed in the final evaluation.

2- Study of other reasons that affect the behavior of the dam such as the chemical and physical properties of the soil with the dam foundation

3-Using the videogrammetry technique in monitoring operations in addition to the traditional remote sensing techniques (GPS).

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