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Determination of Vertical Deformations on Dams: Obruk Dam Sample

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ABSTRACT

Changes in the earth's crust or natural/artificial structures are often referred as "deformation". Those changes can be monitored in both vertical and horizontal positions. Specifically, vertical deformation is usually detected with high-precision leveling. In that method, the area is covered with reference and object points surrounding the possible deformation region. Object points are established directly to the sectors where deformation is expected, while reference positions are selected to the position where there is no vertical or horizontal movement. The results of the observations at certain time intervals are evaluated by the least-squares method using the free-network adjustment and the vertical displacements for the object points are estimated according to the time difference. This study was carried out to determine possible vertical deformation in Obruk Dam, Çorum. A local leveling network consisting of 58 points (44 objects and 14 references) were established. For evaluation, 0.6 mm/km precision electronic levelling equipment with round trip observations is used within this ~22 km network. Observations in the field were organized considering the time intervals when the water level in the dam is at the maximum and the minimum throughout the year. With the DEFANA module in PANDA deformation analysis software, the observations of four campaigns between 2016 and 2017 were analyzed. Results indicate significant deformations at the object points ranging from ±2 – ±5 mm in comparison between campaigns 1 and 4, but there is no clear evidence of deformation that could compromise the integrity of the dam.

Barajlarda Düşey Deformasyonların Belirlenmesi: Obruk Baraj Örneği

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ÖZET

Yerkabuğunda veya doğal/yapay yapılarda meydana gelen değişiklikler genellikle "deformasyon" olarak adlandırılır. Bu değişiklikler hem düşey hem de yatay konumlarda izlenebilir. Özellikle düşey deformasyon, genellikle yüksek hassasiyetli nivelman yöntemiyle belirlenir. Bu yöntemde, olası deformasyon bölgesini çevreleyecek şekilde referans ve obje noktalarından oluşan bir ağ kurulur. Obje noktaları, deformasyonun meydana gelmesi beklenen alanlara doğrudan yerleştirilirken; referans noktaları, düşey veya yatay hareketin olmadığı kabul edilen konumlara seçilir. Belirli zaman aralıklarında yapılan gözlemlerin sonuçları, serbest ağ dengelemesi kullanılarak en küçük kareler yöntemiyle değerlendirilir ve obje noktalarına ait düşey yer değiştirmeler zaman farkına göre tahmin edilir. Bu çalışma, Çorum'daki Obruk Barajı'nda olası düşey deformasyonları belirlemek amacıyla gerçekleştirilmiştir. Çalışma kapsamında, 44'ü obje ve 14'ü referans olmak üzere toplam 58 noktadan oluşan yerel bir nivelman ağı kurulmuştur. Yaklaşık 22 km uzunluğundaki bu ağda, çift yönlü gözlemlerle 0.6 mm/km hassasiyetinde elektronik nivelman ekipmanı kullanılmıştır. Arazi gözlemleri, barajdaki su seviyesinin yıl içerisindeki maksimum ve minimum olduğu zaman aralıkları dikkate alınarak organize edilmiştir. 2016 ve 2017 yılları arasında yapılan dört ölçü kampanyasının gözlemleri, PANDA deformasyon analiz yazılımındaki DEFANA modülü ile değerlendirilmiştir. Sonuçlar, 1. ve 4. kampanyalar arasındaki karşılaştırmada obje noktalarında ±2 ila ±5 mm arasında değişen anlamlı deformasyonlar olduğunu göstermektedir. Ancak, barajın bütünlüğünü tehlikeye atabilecek bir deformasyonun varlığına dair açık bir bulgu tespit edilmemiştir.

1. Introduction

The natural balance and high living standards that have been disrupted during the increasing trend of the world population have increased the need for water. This is especially significant for the developing countries with limited resources, such as Turkey (Kalkan et al., 2010; Kalkan, 2014; Yiğit et al., 2016). Efficient use of water resources can only be sustainable with the control of wasted rivers and long-term realistic planning. For this purpose, the establishment of structures such as dams and ponds are necessary initiatives worldwide. Engineering structures such as dams are used to store and regulate water to perform additional functions such as drinking, irrigation, energy generation and even tourism (Kalkan, 2014; Lin et al., 2019; Yiğit et al., 2016; Yavaşoğlu et al., 2018). For a multitude of variations, the construction of those structures can be dated around 3000 years ago, which has been modified over time by the needs of human beings (Li & Wang, 2011; Ponseti & López-Pujol, 2006).

Dams are one of the critical engineering structures under different loads. They usually control the flow of the river and/or the surrounding area, and over time such deformations can occur for many other reasons. Factors such as dam structure, water weight and pressure, temperature and pressure alterations in the body, landslides and movement in the earth's crust might cause such deformations (Ponseti & López-Pujol, 2006; Taşcı, 2008; Yiğit et al., 2016; Liu et al., 2016; Yavaşoğlu et al., 2018). Those effects can cause the structure to collapse. In fact, there have been several examples of that scenario throughout the history (Kalkan, 2014; Lin et al., 2019; Su et al., 2018; Ren et al., 2020).

While the construction of such structures involves a potential hazard to living creatures (the main focus is human life) and economic losses, deformation observations should be conducted periodically in dams to prevent such situations and maintain their regular operations. Those movements can be observed as vertical or horizontal displacements due to constantly changing internal or external loads in and around the dam body with or without linearity and time dependent. And for monitoring and predicting those vector quantities, such precise observations can be made using conventional geodetic methods: Global Navigation Satellite System (GNSS), 3D laser scanning, radar interferometry observations, synthetic aperture radar and level. Specifically, vertical deformation in such structures is usually estimated using high precision leveling methods (Manake & Kulkarni, 2002; Taşcı, 2008; Li & Wang, 2011; Yiğit et al., 2016; Dai et al., 2018; Scaioni et al., 2018; Ren et al., 2020; Yavaşoğlu et al., 2018, 2020; Zhou et al., 2021).

In order to conduct a precise leveling observation, a local network of an object and reference points is established covering the area of the deformation zone and its surroundings. While the position of the object points is selected within the deformation area, the positions of the reference points are around the target zone with no expected deformation. Observations in the network are repeated at certain time intervals to evaluate the deformation. Those intervals are determined by the magnitude of the possible deformation and the amount of time it takes to occur (Ünver, 1988; Setan & Singh, 2001; Taşcı & Gökalp, 2004; Kalkan & Alkan, 2005; Yavaşoğlu et al., 2018). The main purpose of this study is to determine vertical deformations that may occur in the Obruk Dam and its vicinity by using the high precision leveling method.

2. Material and Method

2.1. Project area

Obruk Dam is located in the Oğuzlar district of the Çorum Province, Turkey. It was established on the Kızılırmak River for irrigation and energy generation purposes and was completed in 2007 (Alkan et al., 2016) (Fig. 1).

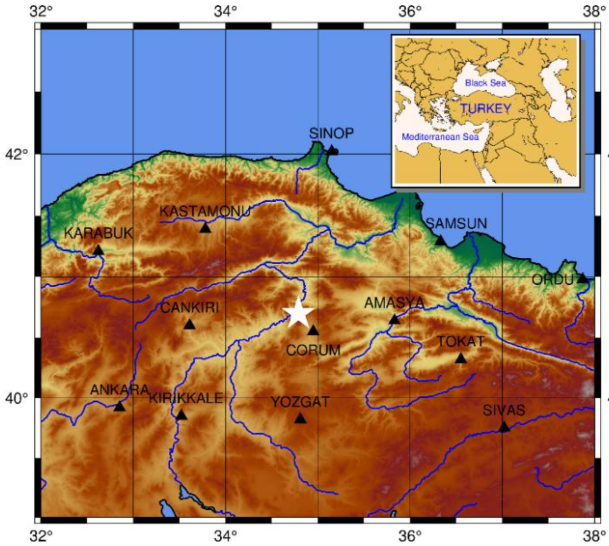

Figure 1. The location of the study in Turkey (white star) (Wessel et al., 2019). Black triangles represent the provinces around the zone, including Çorum.
Şekil 1. Çalışmanın Türkiye'deki yeri (beyaz yıldız) (Wessel vd., 2019). Siyah üçgenler, Çorum da dahil olmak üzere bölgeyi çevreleyen illeri temsil etmektedir.

Table 1. Specifications of the Obruk Dam (Alkan et al., 2016)
Tablo 1. Obruk Barajı'nın Özellikleri (Alkan vd., 2016)

Specification	Quantity
Purpose	Energy + Irrigation
Body embankment type	Semi-permeable soil fill with clay core
Height from talweg	67 m
Height from foundation	125 m
Lake volume at the mean level of water	661 hm3
Lake surface area at the mean level of water	50 km2
Irrigation area	7179 ha
Power	203 MW
Annual power production	473 GWh

Two of the existing pillars (N5 and N6) used in the construction of the dam that were installed by Turkey General Directorate of State Hydraulic Works (DSİ) were selected as reference points and added to the network. In addition, 6 new reference points (N1-N4, N7, N8) which are expected to have zero movement around the dam like N5 and N6 were established (Fig. 2). Bronze leveling apparatus and facilities attached to pillars for precision leveling and preliminary evaluation were completed in November 2015. A total of 44 object points were established, 9 points on the upstream side and 35 points on the downstream side of the dam embankment, with 4 rows of points, the first three include 9 and the last 8 points starting from the upper body (Fig. 3). Force centering equipment was used on those points to conduct GNSS and distance measurements, and a new apparatus was installed on the edges of the object points for precise leveling (Fig. 4).

Figure 2. The new reference point N1 (left) and existing observation point N5 (right). Apparatus is shown inside the red circles for precise leveling.
Şekil 2. Yeni referans noktası N1 (solda) ve mevcut gözlem noktası N5 (sağda). Hassas nivelman için kullanılan düzenek kırmızı daireler içinde gösterilmiştir.

Figure 3. Locations of 8 references and 44 object points around the study area (Alkan et al., 2016)
Şekil 3. Çalışma alanı çevresindeki 8 referans ve 44 nesne noktasının konumları (Alkan vd., 2016)

Figure 4. One of the object's points the downstream (left). The white apparatus was used for GNSS and distance observations, while the other add-on (upper right corner) was used for precise leveling.
Şekil 4. Nesnenin noktalarından biri aşağı yönde (solda). Beyaz aparat GNSS ve mesafe ölçümleri için kullanılırken, diğer ek parça (sağ üst köşe) hassas nivelman için kullanılmıştır.

Loops were created for leveling network, starting from one reference point and ending at another (Fig. 5). Due to the observations made at higher slopes on the dam body, the loop lines were kept as short as possible. Local reference height was used in observation and analysis; therefore, no elevation transfers were made from the national networks. Four campaigns were completed as planned from April 2016 to May 2017 (Table 2). High precise equipment and attachments were used during all the observations (Fig. 6).

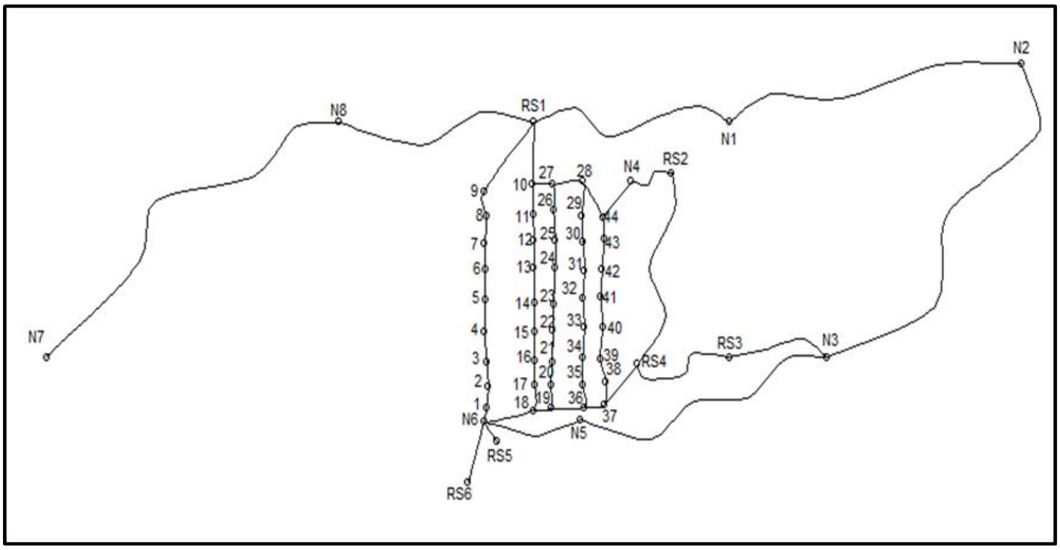

Figure 5. Leveling canvas was created by using all reference and object points in the study area.
Şekil 5. Nivelman ağı (kanvası), çalışma alanındaki tüm referans ve obje noktaları kullanılarak oluşturulmuştur.

Table 2. Campaign dates and mean water level at the time of each observation
Tablo 2. Kampanya tarihleri ve her gözlem anındaki ortalama su seviyesi

# Campaign	Campaign date	Mean water level (m)
1	April 2016	507.68
2	July 2016	508.16
3	November 2016	509.06
4	May 2017	509.44

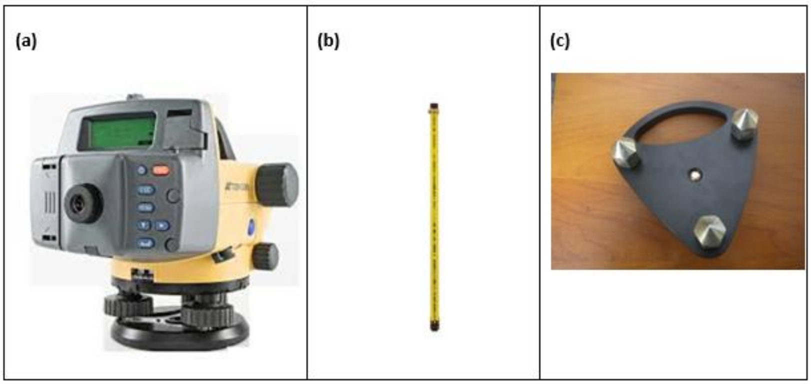

Figure 6. Instruments used during the observations. Topcon DL-503 digital level with 0.6 mm/km vertical leveling precision (a), 2 m unfold leveling rod (b), rod base (c)
Şekil 6. Gözlemler sırasında kullanılan aletler. 0.6 mm/km dikey nivelman hassasiyetine sahip Topcon DL-503 dijital nivelman aleti (a), 2 m açılır nivelman çubuğu (b), çubuk tabanı (c)

Campaigns were carried out as round-trip leveling with "Backward – Forward – Forward – Backward" (BFFB) observations. Each measurement is repeated 3 times and the average values are considered as the result for that part. The height difference between the outbound and return observations was evaluated with the approval of Turkey regulations (30) and elevations were calculated for 14 reference and 44 object points for each period of the campaigns. The average water level in the dam obtained from DSİ (Table 2) and variances in those quantities can be considered as the main reason for the deformations around the area.

2.2. Methodology

Main data source for this study is geodetic observations, thus deformation analysis for that kind can be defined as Conventional Deformation Analysis (CDA) method and is based on the comparison of at least 2 observations at different epochs (Hekimoglu et al., 2010; Yavaşoğlu et al., 2018). For that purpose, the DEFANA module in the PANDA software was used for the evaluation of all the observations and the deformation analysis. In this module, the geodetic network is divided into two classes as the reference and the object points, and an F-test is used to evaluate the inconsistent results between them. Deformation analysis is performed between two different campaigns. The basis of the deformation analysis is the global approach test, which determines the displacements between the target points. The test transforms observations into a new datum using the appropriate covariance S matrix for the displacements to avoid the datum effect (Alisic et al., 2011; Niemeier & Tengen, 1990).

Deformation can be considered as significant movements between independent periods of the observations (1). If two consecutive sets of observations indicate zero deformation, then null hypothesis (Ho) can be written as:

$$H_0: E(d)=x_2-x_1=d=0 \qquad (1)$$

where x1 and x2 are coordinate vectors for each observation period. But if there are changes in those vectors then:

$$H_a : E(d)\neq 0 \qquad (2)$$

And linear hypothesis test can be written as follows:

$$Q_{dd}=Q_{x1x1}+Q_{x2x2} \qquad (3)$$

$$R=d^T Q_{dd}^{+}.d \qquad (4)$$

$$s_0^2=(v_1^T P_1 v_1+v_2^T P_2 v_2)/(f_1+f_2) \qquad (5)$$

$$T=R/(s_0^2.h) \qquad (6)$$

where:

Q_{x1x1}, Q_{x2x2} : Cofactor matrices for each observation epochs

Q_{dd} : Cofactor matrix of displacement vector between epochs

Q_{dd}^{+} : Pseudo-inverse of Q_{dd}

s_0^2 : Estimated variance of the displacement vector

T : Test statistic (Hekimoglu et al., 2014; Yigit et al., 2016; Yavaşoğlu et al., 2018).

The T value can be accepted as the limit value for the deformation vector and can be compared with the value of the F-test. If the limit value of the F distribution exceeds T-test statistics ($T > F_{h, f, 1-\alpha}$), then the null hypothesis is rejected and the difference between the coordinate vectors of the evaluated periods indicates a significant deformation within the network (Doğanalp et al., 2007; Doğanalp & Turgut, 2009; Kalın, 2010; Yigit et al., 2016; Yavaşoğlu et al., 2018).

3. Data Acquisition

After entering all data from the network, it is tested for incompatible measurements and adjusted with the aforementioned software. As a result, four adjusted values were evaluated for each campaign. After the basic evaluation, deformation analysis was performed to detect significant movements between all campaigns and the points exceeding the standard deviation values in the network were considered to have deformation.

Six different deformation analyzes were conducted with different pairwise variations of the observations using the data campaigns given in Table 2 (1-2, 1-3, 1-4, 2-3, 2-4 and 3-4) and the results indicate a certain behavior in each period.

All the figures and the values for the observed deformation of the points are given below (Fig. 7-12) (Table 3-7).

The first analysis between 1st and 2nd campaigns indicates movements at the reference points N1, N2, N3, N7, Rs3 and Rs4. No significant change in the object points was detected (Fig. 7, Table 3).

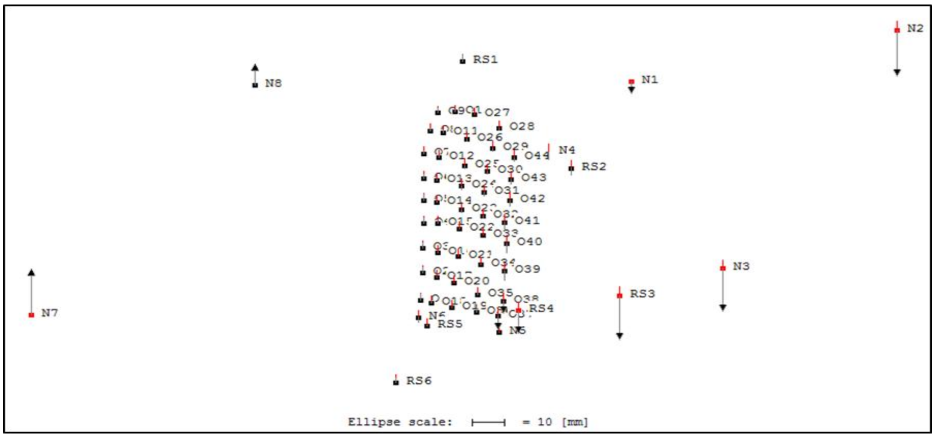

Figure 7. Deformation analysis between 1st and 2nd periods
Şekil 7. 1. ve 2. dönemler arasındaki deformasyon analizi

Table 3. Deformation values between 1st and 2nd periods
Tablo 3. 1. ve 2. dönemler arasındaki deformasyon değerleri

Point	N1	N2	N3	N7	Rs3	Rs4
Deformation (mm)	-3.58	-13.46	-12.49	13.29	-12.90	-6.69

The deformation analysis between the 1st and 3rd periods indicates movements over the N1, N2, N3, N7, Rs1 reference points and object point O40.

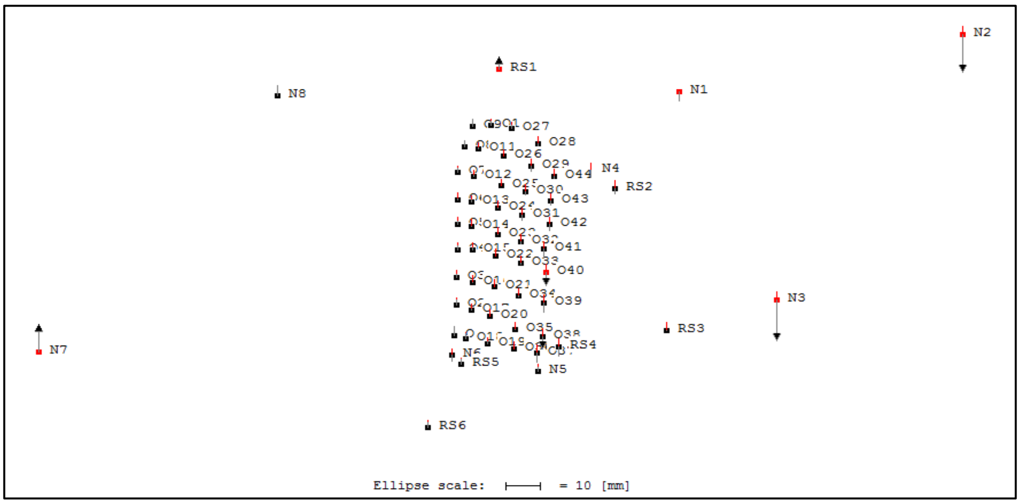

Figure 8. Deformation analysis between 1st and 3rd periods
Şekil 8. 1. ve 3. dönemler arasındaki deformasyon analizi

Table 4. Deformation values between 1st and 3rd periods
Tablo 4. 1. ve 3. dönemler arasındaki deformasyon değerleri

Point	N1	N2	N3	N7	Rs1	O40
Deformation (mm)	-2.75	-9.93	-10.71	7.30	3.41	-3.63

The longest period within the scope of the project is the comparison of the 1st and the 4th periods. The result of the analysis indicates that almost all the object points above the mean water level have a deformation between +2 – 5 mm upwards.

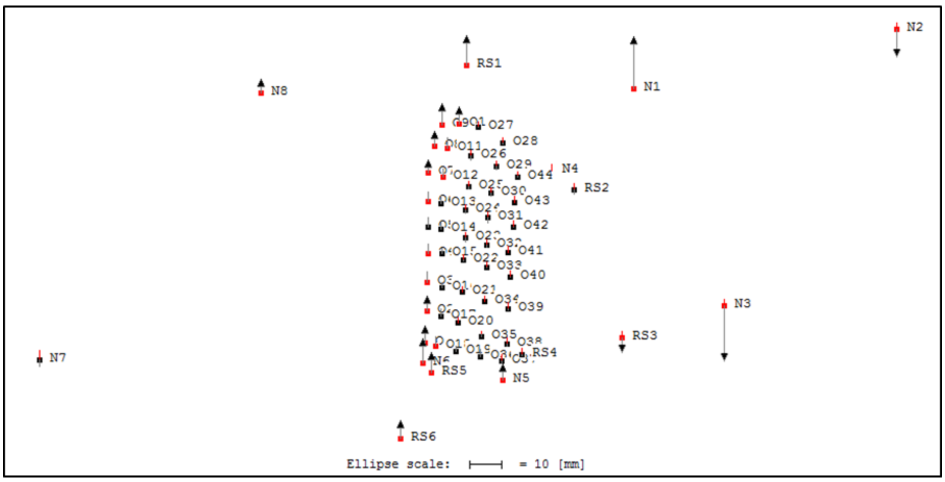

Figure 9. Deformation analysis between 1st and 4th periods
Şekil 9. 1. ve 4. dönemler arasındaki deformasyon analizi

Table 5. Deformation values between 1st and 4th periods
Tablo 5. 1. ve 4. dönemler arasındaki deformasyon değerleri

Point	Deformation (mm)	Point	Deformation (mm)	Point	Deformation (mm)
N1	13.2	Rs5	5.27	O8	3.96
N2	-7.01	Rs6	4.57	O9	5.36
N3	-13.85	O1	4.3	O10	4.33
N5	4.1	O2	3.85	O11	2.94
N6	6.17	O3	3.05	O12	2.65
N8	3.69	O4	2.7	O18	2.72
Rs1	7.54	O6	2.71		
Rs3	-3.87	O7	3.21		

On the other hand, no significant deformation was observed between the 2nd and 3rd periods.

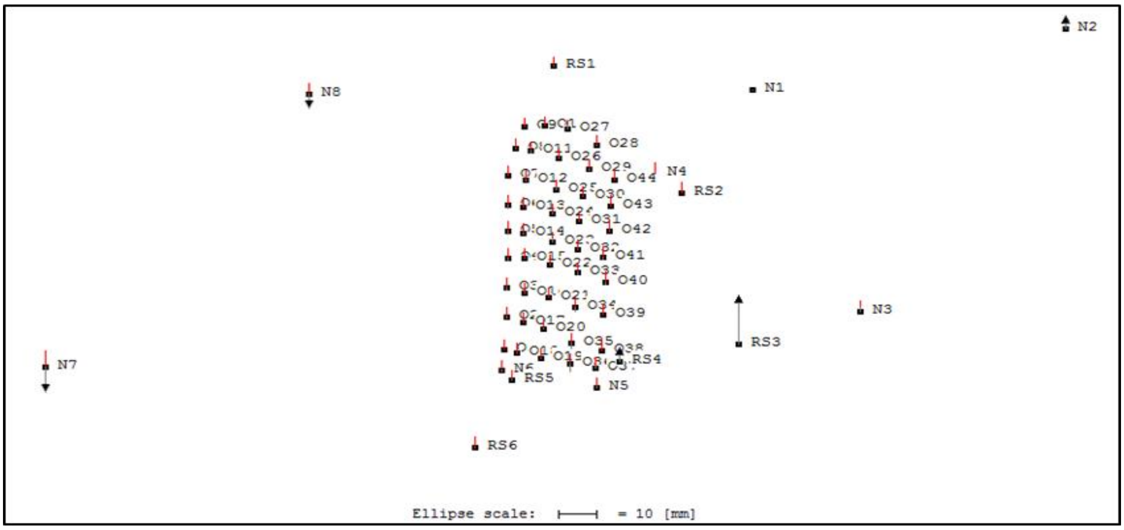

Figure 10. Deformation analysis between 2nd and 3rd periods
Şekil 10. 2. ve 3. dönemler arasındaki deformasyon analizi

Analysis between periods 2 and 4 indicates deformations at the reference points N1, N6, N7 and Rs3, but no significant movements at the object points.

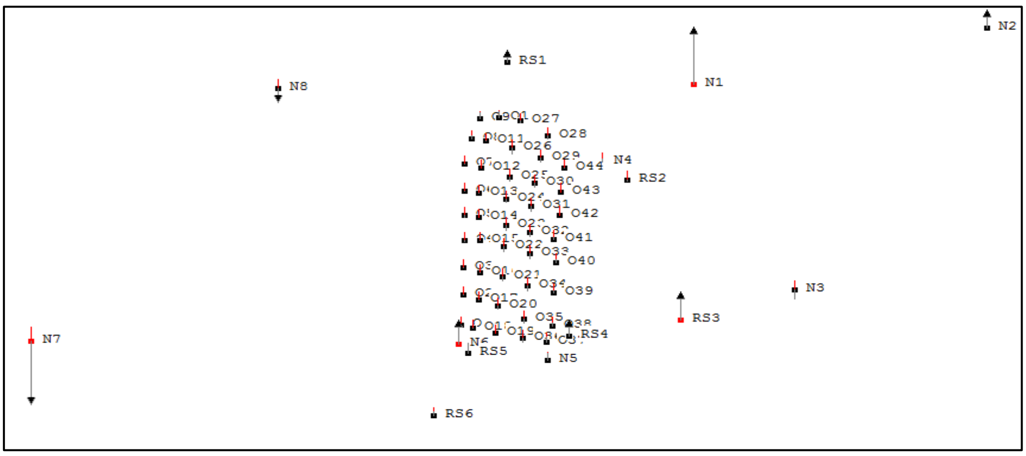

Figure 11. Deformation analysis between 2nd and 4th periods
Şekil 11. 2. ve 4. dönemler arasındaki deformasyon analizi

Table 6. Deformation values between 1st and 4th periods
Tablo 6. 1. ve 4. dönemler arasındaki deformasyon değerleri

Point	N1	N6	N7	Rs3
Deformation (mm)	15.32	6.43	-16.71	7.56

And finally, the analysis between periods 3 and 4 indicates deformations only at points N1, N6, N7 and Rs3, as in the analysis between periods 2 and 4.

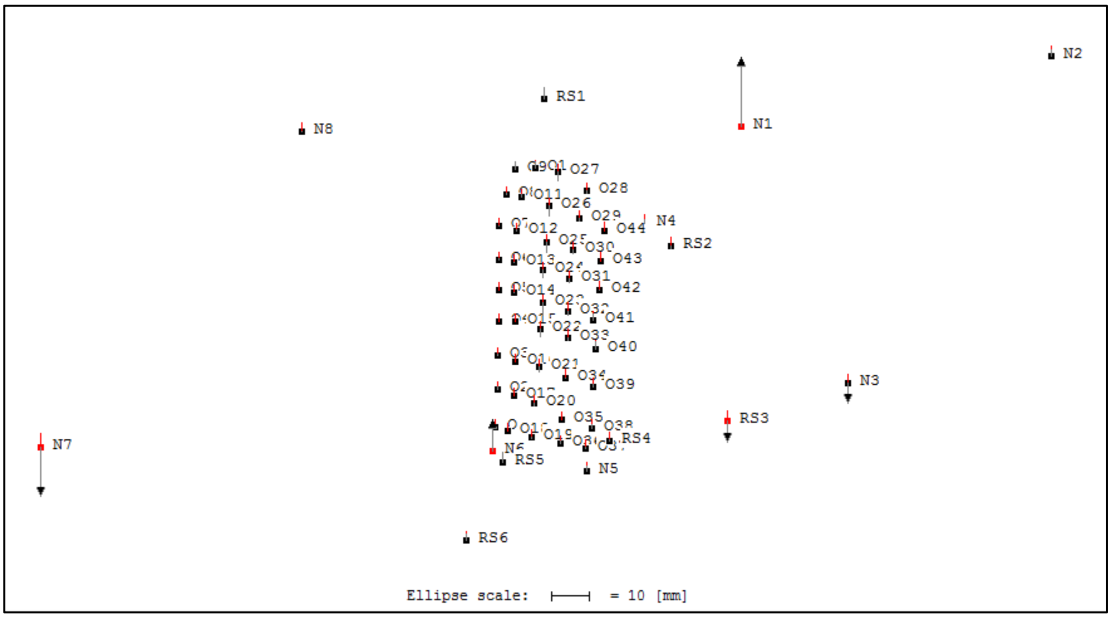

Figure 12. Deformation analysis between 3rd and 4th periods
Şekil 12. 3. ve 4. dönemler arasındaki deformasyon analizi

Table 7. Deformation values between 3rd and 4th periods
Tablo 7. 3. ve 4. dönemler arasındaki deformasyon değerleri

Point	N1	N6	N7	Rs3
Deformation (mm)	14.72	6.86	-10.50	-4.67

4. Discussion and Conclusion

In this study, a network was designed by establishing a total of 58 points (14 reference and 44 object points) to monitor the vertical deformations in the Obruk Dam in Çorum province, Turkey. Observations were completed in 4 different periods between 2016-2017 and the deformation analysis was conducted using PANDA software. It has been observed that the evaluations (adjustment, deformation analysis, etc.) made using this software are quite comprehensible. The software, and specifically the DEFANA module, increase the ability to determine, interpret and make decisions using statistical tests.

The standard deviation of the network is calculated as ±0.4 mm with the free network adjustment for the April, July and November campaigns, and ±0.3 mm for the May campaign. Those values support the applicability of the high precision leveling method to deformation observations.

The campaign was planned considering the maximum and the minimum water levels in the dam. Those changes in the water level given in Table 2 are used to interpret the movements and the deformations at the object points. Throughout the project, the observations on the dam were completed at 3-months and/or 6-months periods and 6 different analyzes of the results of all campaigns and campaign pairs are given in the previous sections.

Considering Table 4, while no significant movement was observed at the object points between the 1st and the 2nd periods, significant deformations varying between +2 – 5 mm occurred at the points above the water level between the 1st and the 4th periods. During that period, the water level changes by +1.76 m and can increase the pressure on the body, causing movement at the object points. This may indicate that the causes of deformation observed in different dams in the literature may be valid in this study as well (Ünver, 1988; Taşcı et al., 2004; Kalkan & Alkan, 2005; Yavaşoğlu et al., 2018).

At the beginning of the project, the reference points were established outside the dam's impact area and on the solid ground. According to the results, a vertical movement of about -13 mm was observed around point N3. That is considered as the cause of the local deformation, as some construction was done near the point. In addition, a significant vertical movement was observed at the N7 point between 1st and 2nd (+13 mm), 1st and 3rd (+7 mm), and 2nd and 4th (-10 mm) campaigns. Those movements may be due to seasonal water level changes. However, all the deformation analyzes demonstrate that the activities observed during the project should not compromise the integrity of the structure.

Monitoring the deformations around large engineering structures such as dams over time is an important issue in terms of preventing life threatening scenarios. Therefore, it is highly recommended to continue making deformation observations at Obruk Dam. If those studies cover the 6 month periods, that may reduce the cost of further activities.

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Author contributions

Zafer Köse: Conceptualization, Methodology, Software, Field study, Writing-Original draft preparation Tamer Baybura, Mehmet Nurullah Alkan, Kayhan Aladoğan, Veli İlçi, İbrahim Murat Ozulu, Fazlı Engin Tombuş, Vahap Engin Gülal, Murat Şahin: Conceptualization, Methodology, Field study

Conflict of Interest Statement

Author of the present study does not have any conflicts of interest.

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