DIFFERENT METHODS IN DAM 3D MEASUREMENTS AND EVALUATING CAPIBILITY OF PHOTOGRAMMETRY ON DAMS
(CASE STUDY: MARUN DAM)

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Abstract:

Dams are massive all-purpose structures that maintenance and monitoring of them are so critical and must be done with maximum care, so in this paper we focus our attention to different dam 3D measurements methods. Until now, in Iran due to high accuracy needed in dam 3D measurements (around 3 mm), combination of surveying method and geotechnical instruments have been used. Until now a complement method which reduces these limitations has not been involved. Limitations such as mountainous of dams, huge mass of observations and computations are the most difficulties in using surveying methods in dams. As other methods in 3D measurements we can mention to photogrammetry and laser scanners, which are widely used in many branches of engineering sciences. In this paper after all the commercial methods in dam monitoring has been defined, the capability of photogrammetry in combination of surveying methods on spill over of Marun dam (245.7 by 62.8 m) has been examined. During the experience the accuracy of 4.25 mm has been achieved. Although this accuracy are not full satisfactory in concrete dams but bye the results it is clear that we can use this methods on embankment dams which the accuracy of 5 mm on them are needed.

Keywords: Dams, 3D measurements, Geotechnical instruments, Surveying, GPS, Laser scanner, photogrammetry.

1. Introduction

The most important problem refers to dam is dam safety, which may have grave incidents such as dam fracture. Therefore, Protection, maintenance and precise measurement are so critical and must do with maximum care in dams. Precise measurement in dams can be dividing in two categories:

- physical measurements
- Geometrical measurements

Physical measurements can be determined with geotechnical instrumentations such as Inclinometers, Extensometers, Telemeters and piezometers in any critical points on dams. The geometrical measurement can be obtained by involving proper surveying methods. In this paper, we have focused our attention on external measurements, in order to use it in dam 3D measurements. The geometrical measurements methods are as follows:

- Conventional surveying methods
- GPS method
- Laser scan
- Photogrammetry

Subsequently in the following sections, all above procedures represent in detail.

2. Conventional surveying method

In this method observations can be done by involving proper network around the object and reading all the lengths and angles of this network and at last by several processing the position of object points can be determined precisely. Basically on dams due to high accuracy about 3 mm in concrete dams this method in combination of geotechnical methods have been used in dams, and this is the most important reason to use this method beside its difficulties and limitations such as mountainous of dams.

The main disadvantage of most dam geotechnical measuring systems is the observations are restricted to the pre-designed locations where the instrumentation has been installed. The same locations must be measured separately in horizontal and vertical components. Geotechnical monitoring techniques can be especially effective in areas on a slope where the mode of deformation motion has been previously identified. However, for general stability monitoring, where potential regions of failure on steep slopes or structures may not be evident, geotechnical methods are limited (eg Green and Mikkelson, 1986). It is infeasible to install a large number of geotechnical sensors over all parts of a potentially unstable dam structures.

In dam monitoring regions, commonly used surveying techniques are: levelling for detection of changes in elevation of monitoring points, lateral displacement determination by offset measurement from a line of sight (theodolite), and measurement of large changes between known observation pillars or targets (EDM). Optical levelingusually requires second or third order accuracy in dam monitoring. As a rule of thumb, errors for these levelling orders are $4\sqrt{km}$ and $12\sqrt{km}$ mm respectively, where km is the length of traverse in kilometers. First order levelling may be required where a high degree of accuracy is needed, for example the measurement of settlement of a dam. Digital levelling is capable of achieving such accuracies with instrumentation having resolution between 0.4-3 mm for 1 km double run. The measurement of lateral movement from offsets between points is usually performed by locating permanent targets at two ends of a line of sight. Theodolites with a resolution of 1 second of arc are in common use for offset measurements. The sensitivity of the instrument is highly dependent on the type of target being used and sighting distances involved. EDM devices can measure to targets at distances up to several hundred meters. Providing the complete ranges of atmospheric and instrumental corrections are applied, resolution is in the order of 1-2mm± 1ppm (Rueger, 1996). Fully automated robotic total stations can be installed on dams to monitor the position of a number of reflectors with varying elevations at resolution between 0.5-7 seconds of arc and 1-2mm in range. Recent advantages in this technology include motorized reflectorless total stations and theodolites with accuracies between 1.5-5 seconds of arc (eg Katowski, 1993).

All conventional survey activities rely on optical techniques to make measurements to known points. In dam monitoring, as in any type of monitoring activity, a number of reference (control) points or benchmarks located well away from the zone of the ground movements are required. Otherwise, the control points themselves may also be affected by surface motion. The degree of sophistication of reference points or benchmark construction depends heavily on the accuracy required and the permanency of installation. For these reasons the most usual practice is to locate any reference points in sound bedrock.

The requirement for ‘line-of-sight’ observation from stable reference points to monitoring points cannot always be satisfied in all monitoring environments and can be a problem for the surveyors. In addition, extreme conditions, such as temperature changes, atmospheric refraction and fluctuations, and the presence of dust, can alter the optical properties of the environment, thus inhibiting the operation of the equipment. This issue is practically pertinent in monitoring regimes where different observation conditions between surveys may cause systematic errors which manifest themselves as apparent motion.

Surface monitoring has the advantage that, in principle, many points can be accurately monitored throughout the lifetime of the dam structure. The spatial density of monitoring points can be increased relatively easily if any critical areas on the structure are identified. However, in practice, time limitations and pressure of finance restrict the total number of points that can be monitored on the structure. In spite of modern development, such as robotic total stations, a conventional dam monitoring survey can be a time consuming process.

3. GPS method

Since its inception in the early 1970s, GPS has become a widely used surveying tool. Today, accuracies at the centimeter level or better are routinely achieved using a variety of relative positioning techniques.These techniques range from near-instantaneous positioning over relatively short reference receiver to unknown receiver distances, to solutions requiring many hours of data and advanced modeling for distances between receivers of up to several kilometers. Removal of the line-of-sight dependency for survey observation has directly altered the practices of the survey community, allowing larger areas and more points to be measured.

Relative GPS also lends itself naturally to deformation monitoring and GPS has been widely used for a number of monitoring applications. Nowadays, regional GPS surveys are used for measurement of plate tectonic motions and characterize the kinematics and geodynamics of active lithosphere areas for earthquake and volcano hazards (eg McClusky, 2000). In small scale deformation monitoring application, GPS is now used to observe structures which, in the past, may have been monitored using traditional surveying techniques or using inclinometers or extensometers.

With GPS having the capability to provide 3D position information over time, it has much to offer as a tool for the direct measurement of deformation fields. However, as in any deformation monitoring application, the design of optimal GPs system requires an understanding of the expected deformation signal. Depending on the application and accuracy requirements, monitoring strategies can vary from continuous collection of data recorded by permanently installed GPS receivers to sporadic (known as episodic) occupation of monitoring points.

Recent hardware and software developments have led to the development of fast or rapid techniques, which use a combination of lightweight GPS receivers and shorter observation spans. With occupation time of 30 minutes or less, a fast-static is now the most widely used GPS surveying techniques for high precision positioning. This technique is ideally suited to episodic monitoring and fast-static GPS surveys can be significantly quicker to complete than their traditional surveying counterparts, which are of limited range and rely on line-of-sight.

As stated above, routinely achievable accuracies with GPS are in the order of 1cm. there are however two main causes for the degradation of GPS solutions to centimeter level accuracies from raw observations of millimeter level precision: satellite geometry and unmodelled error. Although individual phase observations from different satellites may be very precise, the geometrical distribution (and number) of satellites in the sky may limit the precision of the final compute position. This so-called 'dilution of precision' (DOP) effect is minified when parts of the sky are obstructed by man-made structures.

Whilst phase observations are very precise, they are contaminated by errors which cause them not to be particularly accurate. All error sources must be modeled or removed before millimeter (or lower) accuracies can be achieved with GPS. The main sources of unmodelled error pertain to unwanted reflected of diffracted signals traveling different paths to the direct path from the satellite to the antenna (the so-called multipath effect). Such multipathing effects are accentuated close to man-made structures. Unfortunately, both satellite geometry and unmodelled noises are a problem in dam monitoring, where monitoring points tend to be adjacent to dam walls, restricting satellite visibility and magnifying multipath (eg Eissfeller and Winkel, 1996).

4. Laser scanner

Nowadays, terrestrial laser scanning has become an additional technique for geodetic applications. The use of laser scanners is continuously increasing. Different laser scanners of several companies are available. However, a classification of the laser scanner is quite problematical: on which point of view should the classification be based? Conceivable classifications concern the range or the principle of the distance measurement system or the point density or the point accuracy or the field of view.

Based on the raised question, a classification of terrestrial laser scanners wil be discussed. Fires of all there is no one universal laser scanner for all conceivable application. One scanner is more suitable for indoor use and medium ranges (up to max 100 m). So the decision which laser scanner is the right on depends on the application.

Classification of the laser scanners are as follows:

1- classification by principal of distance measurement system:
    - Time of flight principle
    - Phase principle
    - Optical triangulation principle

2- Classification by instrumental properties :
    - The way of scanning (360 degree scans, scanning specific sections because of limited fields of view, scanning of profiles etc.)
    - The deflection system (sweeping or rotating mirrors)
    - The combination with other devices, mounted on the laser scanner (eg. Camera, GPS)

Therefore the laser scanner must be selected depends on the accuracy and the application of the project. Due to dimension in dams and high accuracy needed on them proper laser scanners must be used. In table (1) classification of laser scanners are shown as follow (Schulz, 2004):

Table 1: classification of laser scanners by measurement system and their accuracies

Measurement system	Range (m)	Range accuracy (mm)
Time of flight	~1000	>10
Phase measurements	<100	<10
Optical triangulation, laser radar	<10	<1

Due table (1), by high precision needed in dam deformation monitoring, above scanners has not used in dams. As mentioned the most important reasons are the dimension of dams and limitation of the accuracies of laser scanners.

As the application of laser scanner in large structure we can mention to using laser scanner in surface deformation of hydropower station during the filling and emptying process. For the first time such a multipoint sampling approach allows the visualization of deformation with an accuracy of about 1 centimeter over whole area of gates during different settings of constant liquid levels (Schafer and Weber, 2002).

5. Photogrammetry

Photogrammetry is the science and art of determining the size and shape of objects as a consequence of analyzing images recorded on film or electronic media. The word science is important, as it implies the laws of mathematics, physics and chemistry and knowledge of their practical applications (Atkinson, 1996).

In recent years by the improvements in high resolution digital cameras and their advantages to analogue cameras, photogrammetry has been widely used in many different engineering sciences. Other reasons in choosing photogrammetry are cost, speed and precision of photogrametry projects. In this case we can mention to projects such as measurements of turbine motor in a size of 8 by 6 meter by Lasseuer and Gayde (1998) and the precision of 0.03 mm, or deformation measurements of Industrial disk (14 by 8 m) by Lasseur and Behren (2004) and the precision pf 0.12 mm.

It is important to say the entire above precision are for Laboratorial sampled without any limitations and other working difficulties. By the advantages of photogrammetry in order to determine capabilities of photogrammetry in large civil structures, we test it on a spillover of Marun dam, 245.7 by 62.8 m) in Iran (figure 1). As we have no knowledge on limitations of using this method in Iran all previous working with their limitations are listed in table (2) as follows:

Table 2: photogrammtry limitations on dams

Photogranmnmetry on dams	Dam	Year	Used camera	Precision (mm)	Limitations of photogrammetry
Fryer	**Chichester** *(Australia)* 254 by 43 m	1989	*Wild p31 Metric*	20.8	Weakness of the camera geometry, network design
Kersten and Maas	**Luzzone** *(Switzerland)* 630 by 208 m	1995	*Kodak DCS200 (1.5 mp) / wild p31 Metric*	14.8/18.6	Camera resolution
Maas	**Nalps** *(Switzerland)* 480 by 100 m	1997	*Kodak DCS460 (6mp)*	5.2	Target size, resolution, weakness of geometry

As has shown in table (2), the results are so far to high precision needed in 3D measurements of dams. So in this paper by high resolution digital camera (8 mega pixel) we have tested the ability of photogrammetry beside the photogrammetrics limitations on Iran dams. Further more we discuss on it.

Figure 1: Spillover of Marun dam

5.1 Inspection of environmental and limitations in Iran dams

Whereas photogrammtry has not been involved in 3D dam measurement in Iran until now, before discussing on main study of this research, it is necessary to evaluate all the existent limitations and difficulties of using this method in Iran. In contrast to other researches that have made by Kersten (1995) and Maas (1997), the workspace and environmental situations in Iran are so different. Videlicet we can mention to high temperature (around 50^{oc} in summer seasons) and topographic characteristics of Iran dam (mountainous situation of dams) especially southern dams (Marun, Dez, Karkheh, Karoon). Therefore, besides instrumental limitations and network design, other environmental and workspace limitations must be concerned widely. The photogrammetric limitations are as follows:

- Impossibility of using common targets used in industrial and architectural photogrammetry, according to severe environmental limitations (high humidity, high temperature and sun consecutive sun radiation).
- Impossibility of using any imagery sensor especially CCD sensors according to their working range (mostly between 0^{oc} to 30^{oc}).

In dam deformation monitoring projects, which all the measurement process must be repeated at least twice a year (in first five years of shelf time of dam), It is necessary to use targets, with maximum performance and resistance against all above limitations.

After targeting, the photogrammetric imagery must perform. This part is the basis of photogrammetry and accurate measurements directly depends on this part. Therefore, choosing proper camera by considering the environmental difficulties such as high temperature in Iran dams, can be considered as one of the most effective elements that can terminate other process.

Digital camera sensors can be divided in two categories: CCD[1] sensors and CMOS[2] sensors. In each project according to their advantages and considering all working situations it is necessary to use proper camera. In this project because of lower energy consumption of CMOS sensors (1/10 CCD sensors at the same size), a CMOS camera has been used. Unlike CMOS sensors, in CCD sensors signal enforcement must be done for each CCD in computational units restricted from main circuit, which increases the

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[1] Charged Couple Device

[2] Complimentary Metal Oxide Semiconductor

temperature and energy in CCDs (Mostofi, 2005). So, using a CCD camera by concerning their advantages (low noise, high sensibility, and high image quality) has not become possible. Today by advances in production of CMOS sensors, these cameras have been used widely besides CCD cameras. and their noises and image quality have been developed (Mostofi, 2005).

Finally, to reach maximum possible accuracy, all above limitations have to be considered, and a proper solution must be involved. By concerning above gleanings, in this study the high-resolution digital camera “Canon EOS 30D” (figure 2) by specifications such as 3504 by 2336 pixels, pixel size: 0.0064 mm and sensor size: 22.5 by 15 cm have been used. This camera has been produced since 2006 and is known as one of the professional cameras of Canon Company.

Figure 2: Canon EOS 30D

5.2 Result of photogrammetry on Spillover of Marun dam

As mentioned before, the main aim of this research was to evaluate the capabilities of photogranmmetry in 3D measurements of dams to monitor any deformations. By noticing, the advantages such as direct measurement of non-contact points on spillover due to safety problems and total time (time of targeting and imagery 4 hour and time of processing about 3 days) photogrammetry can be used as an acceptable measurement tool. In this project, we obtained a total accuracy of 4.2175 mm and a precision of 1.8877 mm. In optimum case (using 8 control points) maximum difference between photogrammetry and geodesy are 2.801, 2.946 and 0.664 mm in X,Y,Z direction. Therefore, this method can be used to monitor any deformation above this range and it is not acceptable as standard 3D Dam measurement in Iran (2-3 mm) but this method can be used after shelf time of dams.

In this project, different cases have been tested. Result showed that geometry strength of network beside number of images, number of image rays for each target point and selecting proper camera positions in the network design are the most effective elements on precision of measurements and have to be considered during executive phase of any similar projects. Therefore, to reach maximum possible accuracy, these elements must be considered in detail. Today, by using digital cameras, there is no problem in taking number of images, and choosing camera stations and the entire images can be achieved in minimum possible time, correspond to analogue cameras.

One of the effective elements in using this method is dam construction. On embankment dams because of their characteristics and their surfaces (filling with rocks and soils) this method cannot be involved. For further studies on embankment dams, this must be noticed and design of special targets is recommended.

As seen in the project, by considering camera to object distance (80-100m), target diameter is so important. By looking in images, it is clear that in edges of entire images respect to far distance to camera and the characteristics of the camera lens (28 mm), targets diameter are small so it is better to use targets with diameter 2 times larger than the one which have been computed in network design.

Other effective parameter on this method is the instrumental limitations, for example by using platform in front of the spillover, network geometry may be improved and, better result can be achieved.

Finally, photogrammetry at least can be used in combination of surveying techniques especially when a fast and not necessarily too accurate analysis is required.

6 Results

Dams are massive all-purpose structures that maintenance and monitoring of them are so important and must be done with maximum care. In Iran due to high accuracy needed in dam 3D measurements (around 3 mm), despite of difficulties and working limitations, the surveying method has been used. Until now a complement method which reduces these limitations has not been involved. Limitations such as mountainous of dams, huge mass of observations and computations are the most difficulties in using surveying methods in dams.

Besides surveying method, in 3D measurements and monitoring structures we can mention to photogrammetry. Nowadays by the technology and instrumental improvements, this method has been used widely in many different sciences. The most advantages of photogrammetry are high precision, rapidity and time of measurements. Therefore by these advantages we have decided to use photogrammetry for the first time in 3D measurements of dam in Iran which has called Marun Dam. In this project, surveying method has been chosen as an evaluating unit and we have focused our attention on evaluating the capabilities of photogrammetry besides surveying methods in 3D measurements of Marun Dam.

until now by considering that no other method have been used in dam 3D measurements besides surveying methods in Iran, in order to evaluate all the difficulties and limitations of this method, all the previous methods have been studied, and after that by visiting Marun dam, the initial research have been started on a experimental sample, on a 30 by 20 meter wall without all the existence limitations on dam, And all the effective elements on precision of the measurements have been tested and figured out. So during the rest of the project by considering all the tests which have been done on experimental sample; the capabilities of photogrammetry on spillover of Marun dam (245.7 by 62.8 meter) have been tested.

By involving photogrammetry method in 3D measurement of Spillover of Marun dam, the accuracy of 4.2 mm has been achieved. Although this accuracy is not satisfactory due to accuracy of 3 mm in concrete dams, but this method can be used on embankment dams which the acceptable accuracy on them are around 5 mm. Also by considering all the tests in this project, by using high resolution individual photogrammetric cameras, improving the network geometry of the cameras situation and by using bigger targets, better results can be obtained and photogrammetry can be used with all its advantages beside surveying methods in 3D measurements of concrete dams.

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