RECLAMATION

Managing Water in the West

Photogrammetric Tools for Condition Assessment of Reclamation Structures

Research and Development Office
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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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14. ABSTRACT: Photogrammetry is a low-cost 3D modeling solution that can be used for condition assessment of Reclamation structures. However, using photogrammetry for condition assessment requires specialized, novel and obscure techniques. This report describes some of the techniques researched and applied to projects at Reclamation in FY15. This project was extended into FY16 to continue researching these techniques.		
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Disclaimer

Executive Summary

Reclamation is familiar with using photogrammetry for modeling and describing geologic features. This report focuses on expanding the established techniques to apply to structural analysis, remote monitoring, and condition assessments of Reclamation's structures. Several challenges have been identified and field investigations were conducted to assess possible solutions. From field investigations, photogrammetry has shown benefits for

- Inspections
- Quantifying extent of damage
- Identifying seepage
- Identifying amount of corrosion
- Mapping locations
- Measuring volumes
- Determining movement
- Comparing time-based changes
- Archival record keeping

In short, photogrammetry promises significant improvements for many steps in the inspection and condition assessment process for Reclamation structures. This project had received continued funding for FY16 to continue to advance Reclamation's knowledge and expertise in using photogrammetry for these functions.

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Introduction

The majority of Reclamation's concrete structures were built between 1930 and 1960. Many of these structures are exposed to harsh environments with corrosive soils and water and large temperature variations that can accelerate concrete deterioration. As these structures begin to approach their design life, it is important for Reclamation engineers to accurately inspect and evaluate these concrete elements and perform necessary repairs.

Photogrammetry at Reclamation has been practiced for several years. The basic process has been performed regularly by the geologists at the Technical Service Center with great success. Bryan Simpson, John Earle, Rebecca Heisler (retired 2014), Tim O'Connor and others continue to use the process to model rock structures, calculate volumes and areas, describe discontinuities, and construct stereonets. Challenges arise when photogrammetry is used for other applications such as structural analysis, remote monitoring, and condition assessments of Reclamation's structures.

The objective of this report is to document the progress made in using the latest photogrammetric techniques and technologies to improve condition assessment of Reclamation structures. Several challenges and applications have been identified and implemented into the Concrete, Geotechnical, and Structural Laboratory's (CGSL's) current inspection and condition assessment program. This report describes each of the challenges and focuses on presenting the successful applications of photogrammetry in the field, particularly for condition assessment of concrete structures.

Photogrammetric Tools

4D Analysis

Time-based photogrammetry can be used to monitor changes in structure conditions over time whether it is on the order of seconds or decades. For this process, several digital models over time are generated on a subject and joined to provide an animation of the changes in the model. This process was implemented successfully on the Canal Breach Test performed by Robert Rinehart (86-68530) and Tony Wahl (68-68560) in the summer of 2015.

One of the challenges of applying photogrammetry to Reclamation's needs was the ability to acquire and process data with respect to time. Two software packages have been identified for use in a 4D or time based analysis, PhotoScan Pro and PhotoModeler Motion. Both can generate a 3D model on time-stamped sets of imagery. The sets are then merged based on their time to generate a dynamic 3-D model that can show the differences as the model changes.

Photogrammetry can be used to assist in 4-D modeling in the laboratory. Figure 1 shows the camera set up to capture the internal erosion of a canal embankment. This project was conducted in collaboration with the Hydraulics group of the TSC and the Dam Safety Office.

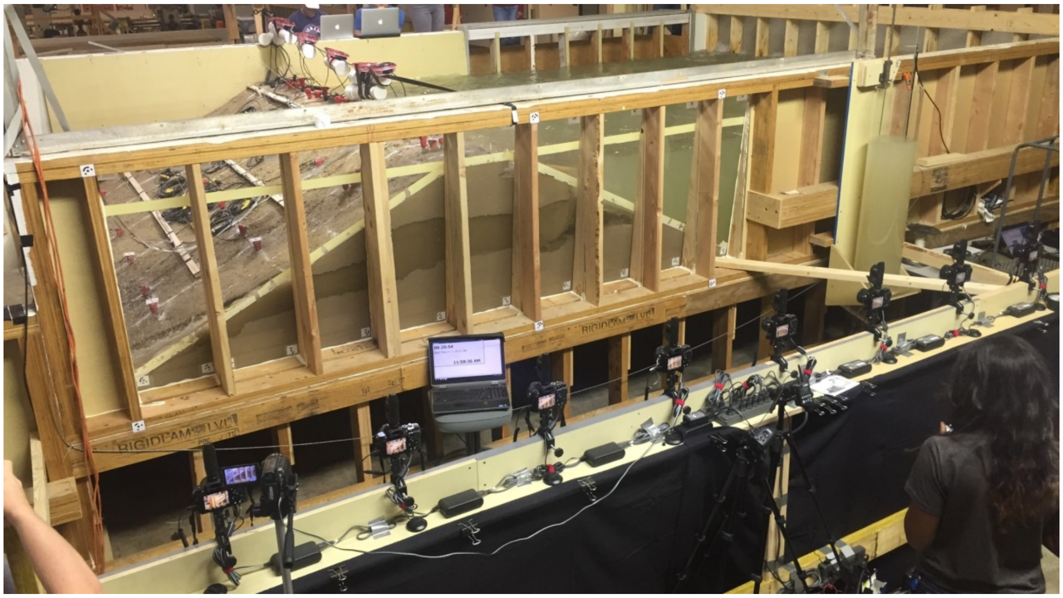


Figure 1: Camera set-up for acquiring data to capture the internal erosion of a canal embankment with respect to time.

Georeferencing

By synchronizing the GPS location of the camera with the image file, the time to solve the model is shortened as well as providing the model an accurate location without the need for separate survey points included in the subject acquisition. Two methods for geotagging the photos include using GPS enabled equipment and synchronizing an external GPS to the image files using software. These alternatives would be used to determine if the model is solved faster and which of the two alternatives provide the best results.

Georeferencing a model has been accomplished by using an X90-OPUS Static GPS receiver to provide ground truthing using a minimum of six targets or ground control points (GCP's) in a project. This receiver occupies the target site for a minimum of 20 minutes and the data that is collected is uploaded to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) system for analyses and corrects the position's error. Thus, the 3D model can be scaled and correct coordinates assigned for a true-to-life representation.

Low Cost Point-and-Shoot and Smartphone Sensor Usage

Lower cost cameras and smartphones use smaller imaging sensors resulting in lower image quality and thus less accurate models. However, recent advances in software technology help reduce the average error and provide similar accuracy to larger sensor, more expensive cameras.

In September 2015, images captured during the Facility Review of Cortes Dam by Stacy Johnson with her government issued iPhone 6S Plus were used to create a model of the downstream face and spillway of the dam (see Figure 2). This demonstrated the capability of the software and hardware for use in collecting data for digital models of Reclamation structures.

Figure 2: The photogrammetric model of Cortes Dam using data collected from a smartphone.

Non-visible Light Photogrammetry

Research has shown that subsurface defects can be detected using other types of light detection such as thermal infrared (IR) and ultra-violet (UV) sensors. This technology can be used in conjunction with photogrammetry to provide additional layer of information on the 3D model. An IR camera was used at Webster Dam in the fall of 2014 to reveal subsurface defects in the concrete. The subsurface defects were revealed because the temperature of the concrete in this area was different than the surrounding concrete.

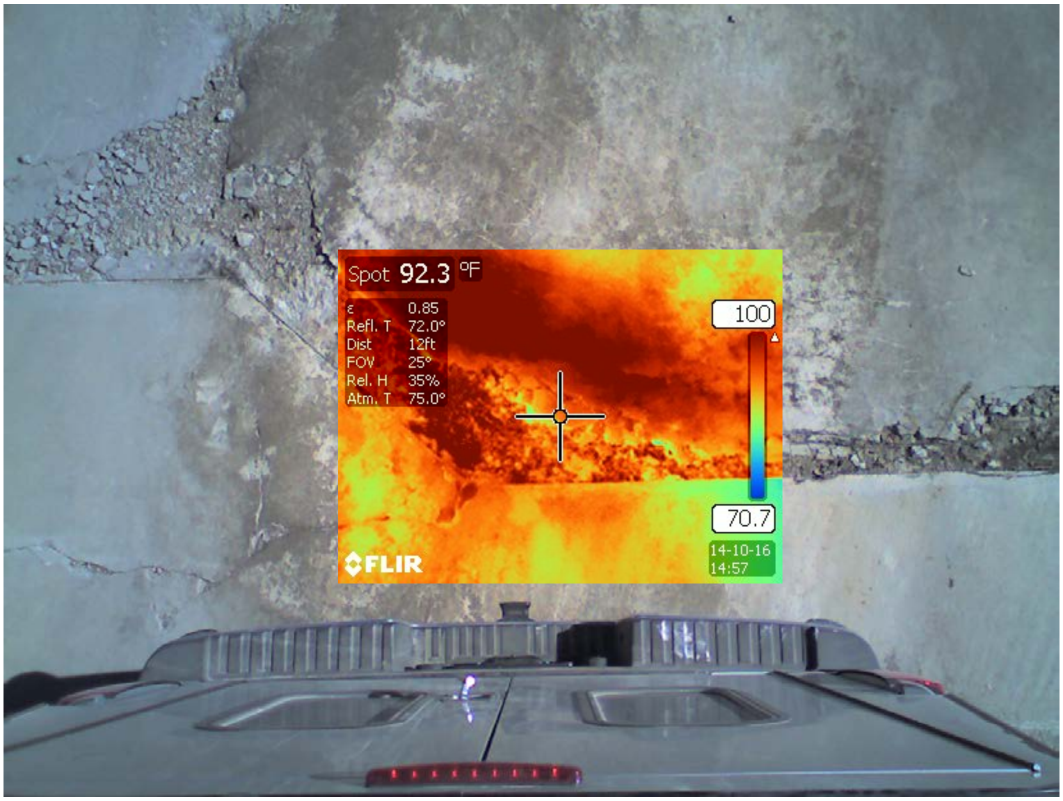


Figure 3: IR image superimposed over a digital image of the damaged spillway at Webster Dam.

Client Software for Viewing 3D Models

Typically the final step in reporting the 3D model involves reducing the model to several 2D images to represent the data in a report or presentation. Many times, however, the client would like access to the same 3D model that was used for the analysis. The ability of the client to purchase the software and hardware required to view the model is often prohibitive. This year, one of the software producers of photogrammetry software used at Reclamation (Agisoft Photoscan), released a free viewer for clients to manipulate and view the resultant model without the need for specialized hardware.

Inspections

Since high-resolution cameras are used in the data acquisition, inspections can be performed by zooming in to and maneuvering around a structure. This is beneficial from a safety standpoint because Reclamation employees do not need to access hard to reach places for a thorough inspection. Figure 4 is an example of a model of a full structure that could be inspected from a computer, with the chances of employee injury greatly reduced. This model was generated from images collected from the Big Thompson Diversion Structure in the fall of 2014.

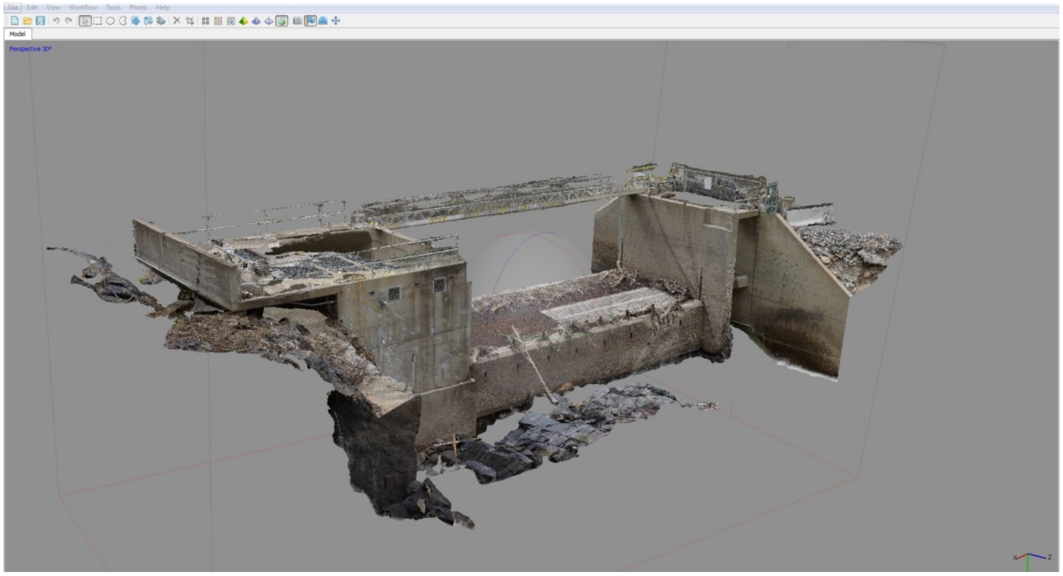
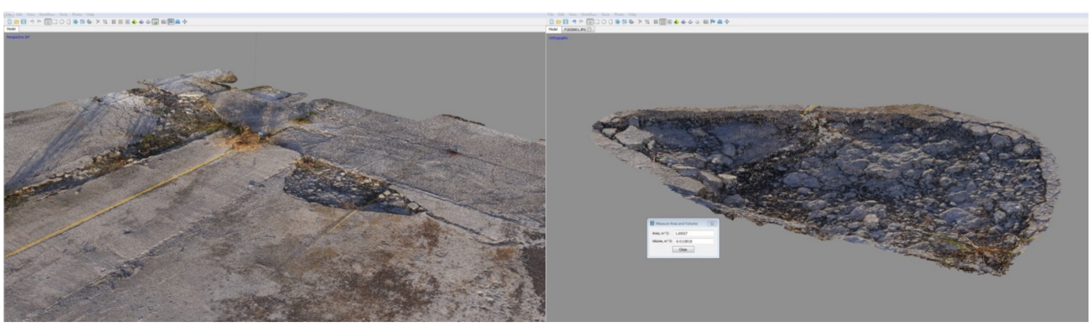


Figure 4: Photogrammetric model of Big Thomson Diversion Structure.

Measuring Extent of Damage

Using scales in the data acquisition process, the resulting model can be used to quantify damage. Length, area, and volume of deterioration can be easily calculated from the photogrammetric model. For example, if there is extensive pitting or spalling in a structure, the area and volume of removed concrete can be determined quickly with accuracy that cannot be achieved using traditional methods such as a tape measure. Figure 5a shows the spillway at Webster Dam with extensive spalling. If the region of interest is selected, such as in Figure 5b, the area and volume of damage can be quickly and accurately determined.



(a) **(b)**

Figure 5.(a) 3D rendering of the concrete spillway damage at Webster Dam (b) Quantification of area (11.8 ft^2) and volume (0.42 ft^3) of damaged material.

Cracks can be mapped and quantified using photogrammetry. Crack length and width can also be measured. Figure 6 shows mapped cracks at Webster Dam collected in the fall of 2014. Additionally, distances can easily and accurately be measured as shown in Figure 7. Here the surveying pins between adjacent canal wall at the Upstream Canal Control Structure at Tunnel #5 near Farmington, NM is measured using photogrammetry.

Figure 6. Crack mapping at Webster Dam using photogrammetry.

(a) (b)

Figure 7. (a) Photo of an offset joint at the Upstream Canal Control Structure at Tunnel #5 near Farmington, NM. (b) Measured distance of 9.149 inches between the two survey points.

Identifying Seepage or Corrosion

A photogrammetric model consists of thousands or millions of points, each with a 3D position and colored from the pixel in the digital image. This collection of points is referred to as the point cloud. Using sophisticated point cloud manipulation software, feature extraction routines can be run on the model to detect trouble areas based on the color of the pixel. This tool was used to identify corrosion and calcium carbonate formations on the downstream face of Hubbart Dam. Figure 8 shows the face of the dam and the areas marked in red are those that were automatically identified as those with corrosion formation on the concrete. By using photogrammetry and images taken from positions on the ground, the locations and areas of the formations are accurately measured. Traditionally, rope team inspectors scale the face of the dam to make these measurements.

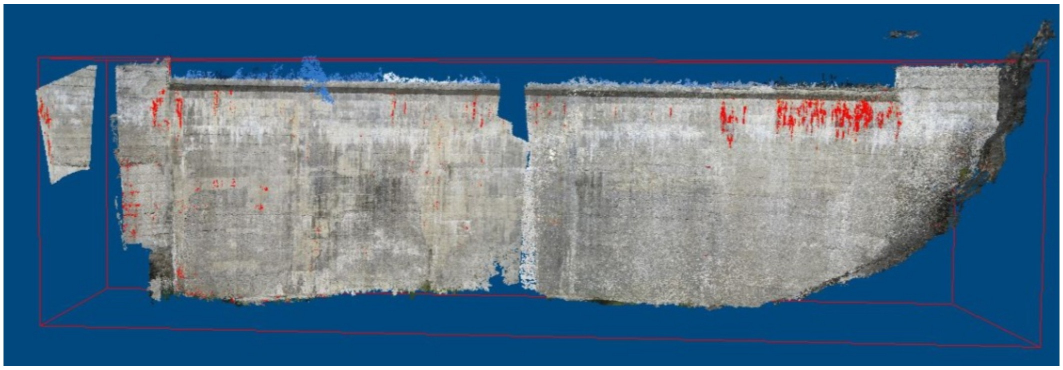


Figure 8. Identification of regions with corrosion (red) on the face of Hubbart Dam.

Conclusions

Using photogrammetric tools for facility reviews and condition assessment shows great promise in improving these activities. Further research aimed at implementing these tools is warranted. The following list is some of the most recent tools to be used in different projects that demonstrate the potential for photogrammetry

- 4D analysis of the Canal Breach Test at the Denver Hydraulics Lab, Summer 2015
- Georeferencing 3D models for scale and coordinate systems
- Application of smartphone imagery at Cortes Dam, Fall 2015
- IR image overlay of spillway delamination at Webster Dam, Fall 2014
- Use of 3D model manipulation and viewing using free photogrammetry viewers on standard issue Reclamation computers
- 3D photogrammetry model inspection including hard to access features at Big Thompson Diversion Structure, Fall 2014
- Using photogrammetric models to measure volumes, areas, widths and lengths of damage at Webster Dam, Fall 2014 and canal wall movement at the Upstream Canal Control Structure at Tunnel #5 near Farmington, NM
- Identifying and measuring corrosion at Hubbart Dam.