Tech Brief

USE OF SMALL UNMANNED AERIAL SYSTEMS FOR RETAINING WALL INSPECTIONS

Introduction

Like every class of assets, retaining walls need to be inspected and assessed periodically to analyze their performance and identify issues to prevent future failure (Gerber, 2012). State Departments of Transportation (State DOTs) must maintain asset management programs, which include the inspection of retaining walls (23 U.S.C. 119 (d)(2)(D)). Many of the structures are constructed in challenging site conditions, including mountainous terrain, soft ground, and sites that are not easily accessible (Brutus and Tauber, 2009).

Key Takeaways

- UAS can assist to access hard-to-reach areas.
- UAS have been used to find defects that could have led to a failure in the structure.
- UAS may assist to provide a safer infrastructure system through more frequent inspections.

The use of specially trained personnel using ropes for accessing steep, highly exposed wall faces may increase the risk for the operation and be cost-prohibitive. Additional hazards regarding wildlife, insects, and poisonous plants can also be a safety factor for inspectors (DeMarco et al., 2010). Unmanned aircraft systems (UAS) have become synonymous with the ability to collect data in challenging site conditions. They can be a helpful tool for retaining wall inspections, condition assessments, and ratings.

Many State DOTs are using UAS for infrastructure inspections, including retaining walls. The ability to deploy UAS without affecting traffic flow can help State DOTs carry out inspection duties without inconveniencing the traveling public. The ability to provide a detailed three-dimensional (3D) model or point cloud may also be advantageous to provide an overall assessment for movement and stability of the site. With advances in advanced analytics, UAS data may also be incorporated into artificial intelligence and machine learning algorithms to analyze and create prediction models for the life cycle of retaining walls.

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UAS for Retaining Wall Inspections

Using UAS for retaining wall inspections can supplement existing tools for condition-based inventory systems (Figure 1). The assessment of the condition of a retaining wall is the most critical part of its inspection record and serves as the basis for decisions about maintenance, repair, the frequency of future inspections, and even possible replacement (Brutus and Tauber, 2009).

Figure 1. MnDOT Retaining Wall Inspection Using UAS (Photo Courtesy MnDOT)

Understanding the goals for the inspection and the environment where the retaining wall is located is the first step when considering which aircraft platform and sensor is best suited for the operation. UAS may be beneficial in data collection efforts for most of the earth-retaining structure (ERS) attributes identified in Figure 2. UAS may also increase the efficiency of the time on-site and the return on investment of the equipment. The ability to process UAS data to create 3D models and georeferenced imagery can be beneficial for many workflows, while the ability to import data collected from UAS into various software provides the means to accurately measure, sketch, and have detailed documentation for the inspection team. Some considerations for UAS collection methods for inspecting retaining walls are illustrated in Figure 3.

- Wall or parts of it, out of plumb, tilting or deflected
- Bulges or distortion in wall facing
- Some elements not fully bearing against load
- Joints between facing units (panels, bricks, etc.) are misaligned
- Joints between panels are too wide or too narrow
- Cracks or spalls in concrete, brick, or stone masonry
- Missing blocks, bricks, or other facing units
- Settlement of wall or visible wall elements
- Settlement behind wall
- Settlement or heaving in front of wall
- Displacement of coping or parapet
- Rust stains or other evidence of corrosion of rebars
- Damage from vehicle impact
- Material from upslope rockfall or landslide adding to load on wall
- Presence of graffiti (slight, moderate, heavy)
- Drainage channels along top of wall not operating properly
- Drainage outlets (pipes/weepholes) not operating properly
- Any excessive ponding of water over backfill
- Any irrigation or watering of landscape plantings above wall
- Root penetration of wall facing
- Trees growing near top of wall

Figure 2. ERS Condition Attributes (Source: Brutus and Tauber, 2009)

Aerial Mapping
- Overall Site Analysis
- Site/Wall Monitoring Over Time
- Deformation Identification

Photo/Video Collection
- Focused Inspection
- Situational Awareness
- Communication

Vertical/Oblique Aerial Mapping
- Wall Face Inspection
- Crack and Defect Identification
- Supplement Inspection

Figure 3. Considerations for UAS Collection Methods for Retaining Walls (Source: FHWA)

Aerial Mapping

Aerial mapping may be helpful for overall site analysis or to monitor a site over time. UAS may be a viable solution for surveying a more extensive site area to provide additional information for geotechnical investigations that are difficult to monitor using conventional methods. Aerial maps and 3D point clouds provide a base model to analyze subsequent data to better understand the site as a whole. As an example, the California DOT (CalTrans) Steep Terrain Group used UAS to find a large hole in the crib wall supporting the toe of the slope below the northern abutment of the Lime Kiln Bridge in Big Sur and initiated emergency repairs, as illustrated in Figure 4.

Figure 4. Lime Kiln Bridge on Highway 1 on the Big Sur Coast (Photo courtesy of Caltrans Steep Terrain UAS Group)

Boreholes provide specific data about the environment, but having supplemental data from UAS to provide an overall understanding of the entire site and boundaries of the wall may also be helpful. Supplementing the inspection by combining UAS and conventional data collection methods may provide additional data to better understand the complex environment surrounding the wall and failure points that may be present in the surrounding topography.

A variety of sensors can be used for the aerial mapping of the walls, but red, green, blue (RGB) cameras or Light Detection and Ranging (LiDAR) are typically used. A passive (RGB or traditional) camera will often be processed using Structure for Motion (SfM) to create a 3D model or point cloud. Passive (RGB) cameras are available at a lower cost and are beneficial for use in environments with minimal vegetation or when including the vegetation in the point cloud will not degrade the data requirements. In situations when a ground-level survey is needed in high vegetation areas, a UAS LiDAR scanner with multiple returns can be helpful because it can penetrate through vegetation. Additionally, when using UAS for aerial mapping, it may be beneficial to incorporate ground control points (GCP) and real-time kinematic (RTK) or post-processing kinematic (PPK) to improve data accuracy and accurately align subsequent flights. Establishing permanent control or reference points outside the walls' boundaries can provide a durable reference point for quality control and establish GCPs for future flights. If the GCPs for the aerial mapping are all established in an area with ground movement, it may help to verify their accuracy prior to flight to determine if they have moved since the last operation. The coordinates will need to be adjusted to prevent errors introduced into the data sets when processing if the points have moved.

Photo and Video

Using UAS for photo and video collection may be helpful due to their ability to rapidly access hard-to-reach areas. Workers can perform the work from a safe location while collecting the data. In addition, using UAS instead of ropes or ladders can substantially increase productivity and improve safety while also providing a collection of higher quality georeferenced data (Lovelace and Wells, 2018).

Vertical Mapping

Using UAS for vertical mapping typically requires an aircraft with the ability to hover (e.g., rotorcraft) in addition to a moveable gimbal, which allows the camera to be rotated perpendicular to the face of the wall. Without these features, it can be difficult to see all the aspects of the wall face. For example, mapping from a nadir direction (directly below, perpendicular to the aircraft) can create anomalies or fail to provide data on vertical faces, as illustrated in red on the missing data on cliff faces in Figure 5 because the vertical faces were obscured from a top-down angle. If the camera is positioned slightly oblique, it can capture more of the surface area. Figure 6 illustrates this phenomenon more simply. The oblique angle can “see” the vertical face of the wall, while the nadir angle obscures it.

Both active (e.g., LiDAR) and passive (e.g., RGB) sensors may be helpful for vertical mapping. Depending on the material or texture of the wall, LiDAR may be favorable if too much noise or ambiguity is introduced through SfM processing. Similarities in the texture of the material may prove difficult for photogrammetry to decipher, leading to ambiguities that create additional data noise. Selecting a quality camera or sensor may help to improve the data quality and reduce data noise when using an RGB camera. For example, a smooth surface may look rough and not uniform if the data set has a high value of noise or ambiguity in an SfM point cloud. For identification of defects and monitoring over time, it is often beneficial to incorporate aerial imagery and point clouds to provide detailed imagery and 3D models to analyze.

Figure 5. Missing Data with nadir angle 3D mapping (Photo courtesy of Utah DOT)

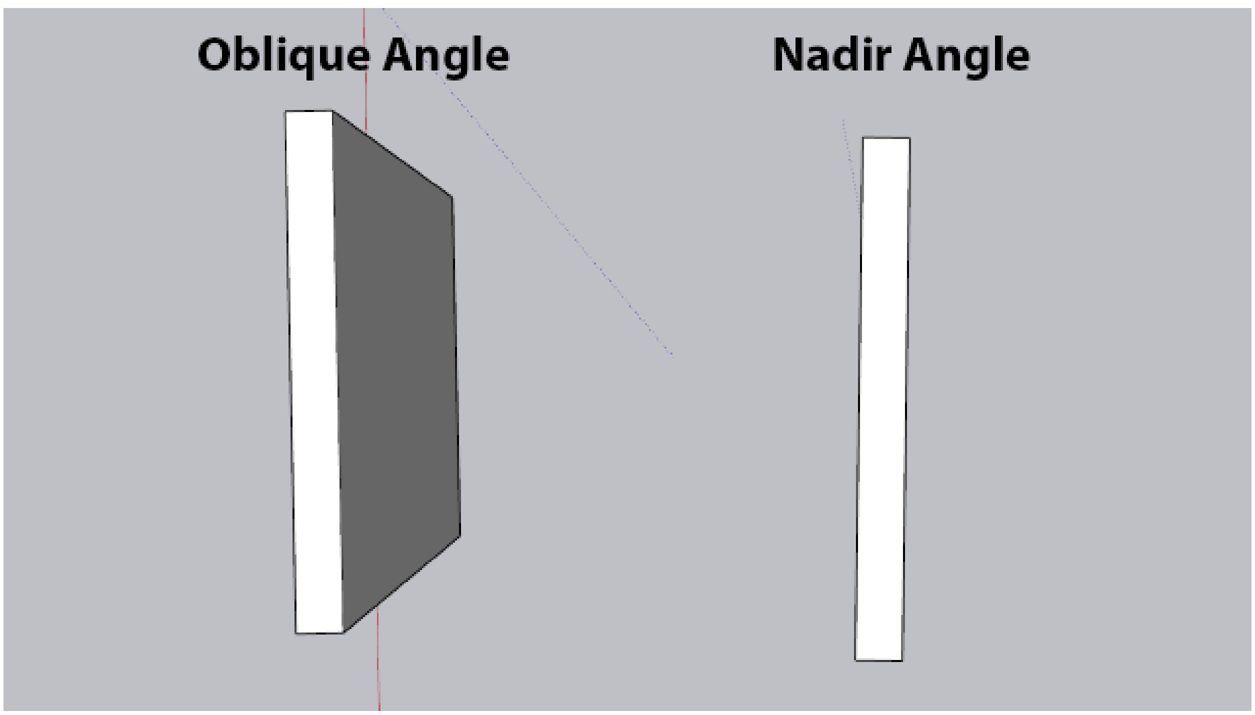

Figure 6. Oblique and nadir angles for walls (Source: WSP)

Caltrans Steep Terrain UAS Group used UAS to create a 3D model to capture and quantify the damage created from the 2020 Meyers Fire, which burned the slopes and damaged the wood lagging retaining walls of highway infrastructure, as illustrated in Figure 7 and Figure 8.

Figure 7. 3D model of post fire response north of Jenner, California (Photo courtesy of Caltrans Steep Terrain UAS Group)

Figure 8. 3D model of post fire response north of Jenner, California (Photo courtesy of Caltrans Steep Terrain UAS Group).

Data Collection Planning

When using UAS for retaining wall inspections, understanding the capabilities of the aircraft, data goals, and deliverables can be important. Having a comprehensive data collection plan before any operation can help optimize each step of the process.

FAA Regulations

UAS operators in both the public and private sectors must also adhere to statutory and regulatory requirements. Public aircraft operations (including UAS operations) are governed under the statutory requirements for public aircraft established in 49 USC § 40102 and § 40125. Additionally, both public and civil UAS operators may operate under the regulations promulgated by the Federal Aviation Administration. The provisions of 14 CFR part 107 apply to most operations of UAS weighing less than 55 lbs. Operators of UAS weighing greater than 55 lbs may request exemptions to the airworthiness requirements of 14 CFR part 91 pursuant to 49 USC §44807. UAS operators should also be aware of the requirements of the airspace in which they wish to fly as well as the requirements for the remote identification of unmanned aircraft. The FAA provides extensive resources and information to help guide UAS operators in determining which laws, rules, and regulations apply to a particular UAS operation. For more information, please see https://www.faa.gov/uas/.

UAS Sensor Considerations

For retaining wall inspections, a quality RGB camera may prove sufficient to gather photos and videos and create point clouds in combination with SfM. For deeper analysis, it may be helpful to use an infrared or thermal camera to see temperature differentials in the wall and surrounding topography, which may help pinpoint issues caused by water. A multispectral camera may prove helpful in gauging the effect of vegetation mitigation or analyzing the surrounding area because it can see additional wavelengths of various spectral regions to interpret physical plant conditions. Multispectral cameras can offer insight on where water may be more prevalent in the ground due to healthy plant growth and to monitor noxious weed mitigation efforts. LiDAR can be useful in areas where lighting conditions do not favor an RGB camera or vegetation is present, and a base map of the bare ground is needed to understand the topography better when assessing sites for movement. Table 1 provides a quick reference guide for sensors and their applications.

Table 1. UAS Sensors

UAS Sensors for Retaining Wall Inspections	
Sensor	**Applications**
RGB camera (fixed focal length and zoom lenses)	Still photos Videos Aerial imagery and mapping
Infrared or thermal	Thermographic analysis Identification of water seepages
Multispectral	Near infrared and short-wave infrared analysis
LiDAR	Detailed 3D mapping with vegetation or poor lighting conditions

Ground Control or Reference Points

Figure 9. GCPs placement (Image courtesy of UDOT)

Ground Control Points (GCPs) may be helpful when absolute accuracy for a map of a retaining wall and its surrounding terrain is necessary for creating orthomosaics and point clouds. GCPs may also prove beneficial when mapping and monitoring a site over time to understand changes in movement across the site. Without GCPs, it may be more difficult to decipher movements in the topography versus errors in the data. It may also be advantageous to create at least two GCPs outside the movement area when using them for monitoring over time. (Figure 9) If all GCPs are located inside the movement area, and the site is moving uniformly, it may be difficult to assess actual movement. Having GCPs outside the reference area can also provide an outside reference to check the internal points for verification, which allows for better site assessment. For vertical mapping, reference points on the wall that act as GCPs can help monitor movement and verify the accuracy of the data. They may also prove helpful for SfM to help reduce data noise or geometric inaccuracies and improve the accuracy of the 3D model solution during processing when the texture and/or features of the wall are similar. The reference points or GCPs should have a high contrast of color so they stand out from the existing surfaces for easier identification in the software (James et al., 2017).

Data Collection and Data Processing

UAS flights for retaining wall inspections may require multiple operations to capture the necessary data of the structure itself and its surrounding area. Consistent flight lines and adequate overlap is key to producing quality data for analysis. Retaining walls are often located in difficult terrain with varying topography. Automated mapping software may assist with ensuring the necessary overlap and consistency in uneven terrain as shown in Figure 10.

Figure 10. Automated mapping software

When crews are new to using UAS for retaining wall inspections, manually analyzing raw photos or videos may be a first step to increasing productivity or safely accessing hard-to-reach retaining walls. However, data processing that creates 3D models, point clouds, and orthomosaics can provide additional value. Minnesota DOT was able to use UAS to collect data and process it to create the colorized 3D point cloud of the retaining wall seen in Figure 11. The colorized point cloud of the retaining wall helped identify defects and enabled advanced analytics of the data. This allowed Minnesota DOT to make data-informed decisions regarding the repair of the retaining wall.

Figure 11. Colorized 3D Point Cloud of MnDOT Retaining Wall Repair Project (Image courtesy of MnDOT)

Conclusion

UAS may prove to be a valuable tool for data collection for retaining wall inspections that helps eliminate risks associated with ground operations in areas that are steep, highly vegetated, or generally unsafe to navigate by foot. While UAS are still relatively new to retaining wall inspections, they have been identified as a resource for inspectors to access hard-to-reach areas, map large sites with ease, gather additional information, and find defects that could lead to a failure in the structure (Lovelace and Wells 2018).

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Online Resources

Federal Aviation Administration (FAA) Unmanned Aircraft Systems (UAS). https://www.faa.gov/uas/.

Federal Highway Administration (FHWA) Unmanned Aerial Systems (UAS). https://www.fhwa.dot.gov/uas/

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