Mapping the inaccessible with LiDAR and gigapixel photography: a case study from Norway

Lato M.
RockSense GeoSolutions Inc., Ottawa, ON Canada
Smebye H., Kveldsvik V.
Norwegian Geotechnical Institute, Oslo, Norway

ABSTRACT
Norway is a topographically rugged country; a large percentage of the land is mountainous terrain with a high rockfall hazard potential. The mountainous regions of Norway currently exploit the extreme topography as a means to generate hydroelectric power. With aggressive plans for further exploitation, these installations are and will be inherently exposed to rock fall and snow avalanches. The Norwegian Geotechnical Institute (NGI) has numerous demanding tasks to assess rock fall hazards from clients operating in these regions. Evaluating the risk associated with a rock fall hazard is a process with several inputs leading to a conclusion or recommendation. The most important inputs are: site evaluation, identification of release areas, simulations and statistics of historical events. The identification of potential release areas and the ability to quantify it and register the location relative to other elements such as industrial installations is challenging. NGI currently uses Gigapan and LiDAR technologies to assist in site investigation and rock fall hazard mapping. Gigapan photography enables visualization of the terrain with extremely high resolution allowing in depth evaluation of regions inaccessible by other means. The LiDAR data can be mapped for structural discontinuities, potential rock fall volume calculation, and run out simulations. Samples from current work in Lysebotten, a 500 m high fjord wall near a construction site for a hydroelectric power electric plant will be used to demonstrate the application of LiDAR and Gigapan for assessing rock fall hazards.

RÉSUMÉ
La Norvège est un pays topographie accidentée , un grand pourcentage de la terre est un terrain montagneux avec un potentiel de risque élevé de chutes de pierres . Les régions montagneuses de la Norvège exploitent actuellement la topographie extrême comme un moyen de produire de l'énergie hydroélectrique . Avec des plans ambitieux pour une exploitation ultérieure , ces installations sont et seront intrinsèquement exposés à la chute de roches et les avalanches de neige . L'Institut géotechnique norvégien (IGN) a de nombreuses tâches exigeantes pour évaluer les risques d'éboulis de clients opérant dans ces régions . L'évaluation du risque associé à un risque d'éboulement est un processus à plusieurs entrées menant à une conclusion ou recommandation . L' apport le plus important sont : l'évaluation du site , l'identification de zones de dégagement , des simulations et des statistiques des événements historiques . L'identification des zones de rejet possibles et la capacité à quantifier et d'enregistrer l'emplacement par rapport à d'autres éléments tels que les installations industrielles est un défi. IGN utilise actuellement les technologies Gigapan et LiDAR pour aider à l'enquête du site et la cartographie des risques de chute de pierres . Photographie Gigapan permet la visualisation du terrain avec une très haute résolution permettant l'évaluation de la profondeur des régions inaccessibles par d'autres moyens . Les données LiDAR peuvent être mappées à des discontinuités structurales, calcul du volume potentiel de chute de pierres , et d'exécuter des simulations . Les échantillons provenant de travaux en cours dans Lysebotten , un mur de 500 m fjord près d'un chantier de construction d'une centrale électrique électrique hydroélectrique seront utilisés pour démontrer l'application de LiDAR et Gigapan pour évaluer les risques de chute de roche .

1 INTRODUCTION

Norway is a rugged country extensively covered by mountainous terrain. The topography lends much of the country vulnerable to natural threats including landslides, rockfalls, tsunamis, and snow avalanches. The mountainous regions of Norway currently exploit this extreme topography as a means to generate hydroelectric power. With aggressive plans for future development and exploitation, these installations are and will be inherently exposed to natural threats. The Norwegian Geotechnical Institute (NGI) has numerous demanding tasks to assess rockfall hazards from clients operating and expanding in these regions. An example of such a task is NGI's ongoing work for Lyse, who is building a new power plant in Lysebotten (Figure 1).

In an early phase of the project, rockfall was identified as a threat to the security of the project. Lyse hired NGI to assess the hazard, estimate the risk and propose mitigation measures. Traditionally this kind of rockfall hazard mapping is done by manual access to the potential rockfall sources together with helicopter inspection. Because of the very steep and hazardous rockface, manual access was nearly impossible.

The unique data collected from with Gigapan Photo and Terrestrial Laser Scanning (TLS) methodology convinced Lyse that a campaign in Lysebotten was necessary to get the results required (Derron et al. 2013; Oppikofer et al. 2009; Stock et al. 2011; Sturzenegger and Stead 2009a, Sturzenegger and Stead 2009b). The remote 2D and 3D imaging technologies provided the most accurate and full coverage method of evaluating the slope for zone of high hazard.

This paper presents a case study on the the field work and data analysis performed in order to assess the slope for potential rockfall hazard source zones.

Figure 1. Lysebotten, outlined in red, is located in south-west Norway.

1.1 Site characterization

Lysefjord is a typical Norwegian fjord shaped by glacial advance during the last ice age. The polishing from the ice and the quality of the rock has led to a smoothly curved rockface. The fjord walls extend vertically many hundreds of meters from sea level and are covered by minimal vegetation.

The construction planned on site is to consist of building a new road, a tunnel, a cavern, and penstocks inside the fjord walls. Typically in Norway, hydroelectric power stations are built within the mountain and all penstocks are tunneled, not constructed as surface pipes, in contrast to, for example, the Niagara hydroelectric generating stations in Canada and the USA. The approximate location of the planned construction is outlined in Figure 2 superimposed on a 3D rectified orthophoto of the fjord mouth.

Figure 2. Orthophoto of the Lysebotten fjord valley. The red circle outlines the tunnel portal, green line is the new road to be constructed, the numbers 1-3 represent TLS and gigapan imaging locations (imagery from http://www.norgei3d.no/).

2 DATA COLLECTION

Data collection at the Lysebotten site combined traditional field investigations, 2D gigapixel photography, and 3-dimensional (3D) terrestrial LiDAR data collection. The combination of various techniques enabled the generation of a spatially accurate and detailed assessment of rockfall activity and potential source zones. All equipment used in this project was ferried to site by helicopter.

2.1 Terrestrial LiDAR

Terrestrial LiDAR Scanning (TLS) is a 3D imaging technique that creates a high-resolution surface model of the scanned area. TLS data was collected from three locations (Figure 2), which enabled the merging of the datasets into a single model to minimize occlusion in the surface model (Lato et al. 2010). The TLS scanner using in this project is an Optech IIRIS-LR scanner with a range of over 2000 m, allowing the entire slope to be scanned at a high resolution. The 3D model was referenced using visible objects in the model, such as houses that were surveyed using dGPS. The transportation of the TLS equipment was done using helicopter as the survey sites are inaccessible by foot or car.

The TLS data was collected across the entire fjord wall above the proposed location of the tunnel portal and surface road construction sites. The data was collected at a minimum resolution of 100 points per square meter. The data from scan location 3 (Figure 2) was unusable as the TLS equipment was exposed to extreme winds at the top of the mountain; the winds caused the equipment to vibrate, which resulted in highly inaccurate data. Fortunately the data from scan locations 1 and 2 provided optimal results.

Figure 4. Optech Ilris LR terrestrial scanner.

2.2 Gigapixel photography

Gigapixel photography is a term referring to the generation of 2D photographs with gigapixel resolution (over one billion pixels), as opposed to the common megapixel resolution images produced by standard digital cameras and photography techniques. The GigaPan head used in this project robotically controls any DSLR camera to optimally collect individual photos, which are later combined into a single gigapixel panoramic photo. The robot pans and rotates the mounted DSLR camera at specific intervals determined by the camera body and focal length of the lens in order to produce images with minimal offset distortion.


Figure 5. Gigapan robot with Canon 5D MkII and a 135mm f/2.0 L prime lens at data collection location 3 (Figure 2).

The individual photographs captured by the robotically controlled camera are automatically stitched together by proprietary software that accompanies the purchase of the GigaPan robot head. The result is a super high resolution photography with no stitching errors or misalignments that are common with hand held panoramic methods and manual stitching procedures.

The camera used in this project is a Canon 5D MkII fit with a 135 mm f/2.0 lens. The photographs were collected at ISO 200, f/8.0, and 1/400th of a second. The most critical component of generating a high quality gigapixel image is in the quality of the individual input images.

The resolution of a gigapixel image for a given site can be increased by using a lens with a longer focal length or a camera body with a greater number of megapixels. This setup results in an average ground pixel size of 10 cm (Lato et al. 2012).

3 DATA PROCESSING METHOLOGY

The identification of potential rockfall source zones was conducted using traditional field-based visual inspections as well as digital analysis of remotely collected imagery. The remote sensing methods used in this project are 3-dimensional (3D) Terrestrial LiDAR Scanning (TLS) and gigapixel photography.

The panoramic gigapixel images, once created, enable the visualization of the entire slope in great detail with the ability to zoom into the image to see individual blocks. The gigapixel images are an excellent tool for mapping active rockfall source zones through the identification of unweathered rock surfaces, which are generally indicative of recent rockfall activity.

Terrestrial LiDAR Scanning (TLS) is a 3D imaging technique that creates a high-resolution surface model of the scanned area. The georeferenced 3D surface model can subsequently be used in combination with the gigapixel image analysis to measure structural orientations, fracture spacing, and volume of recent failures as well as potential failures. All TLS georeferencing and data processing was conducted using PolyWorks V12.1 (InnovMetric, 2014).

The two remote sensing techniques, TLS and gigapixel photography enable detailed mapping of potential rockfall source zones not possible using conventional tools.

3.1 Source zone mapping

The calculation of recent rockfall volumes is a subjective process in which the gigapixel photography data is inspected to delineate source zones. The delineated regions are then mapped onto the TLS data in 3D, the source zone dimensions are measured, and a volume is approximately calculated. The process of determining past failure volumes is a subjective approach that involves careful examination of the 3D TLS data, the 2D gigapixel data and sound judgement on the part of the evaluating engineer. It is not possible to positively determine if the failure was numerous individual rock block failures over a short time span, versus a single large even involving numerous blocks.

3.2 Limitations of employed methodology

The analysis conducted using TLS and gigapixel photographic data have two sources of computational error. The first is geolocation: the georeferencing of the TLS data is conducted using rough markings, not traditional survey control markers. The global alignment error is estimated between 5-10 meters. As such, the true location of the rockfall source zones should be perceived as a general region, and not an exact location.

The second source of computational error is the TLS data itself. The 3D data that comprises the surface model has an accuracy of approximately 0.1 meters. This source of error will have minor implications for the calculation of potential rockfall volume and does not affect the analysis performed using the TLS data.

4 RESULTS

The analysis of the TLS data and gigapixel photographs for potential rockfall source zones and active rockfall source zones resulted in the identification of 10 source zones with potential failure volumes greater than $50m^3$ and 10 source zones with failure volumes less than $50m^3$.

The 10 source zones with potential failure volumes greater than $50m^3$ are outlined in Figure 6 and the UTM coordinates, kinematic failure mode, and potential failure volume of these 10 source zones are reported in Table 1. The volume assessed for each of the source zones is calculated by estimating the location and orientation of the failure surface and integrating the volume between the present day surface with the potential failure surface. This method does not account for stepped or irregular failure surfaces.

The assessment of recent rockfall activity is used alongside kinematic stability assessment to rate the hazard level of the individual source zones. Temporal TLS data is not presently available to conduct change detection analyses and recent activity can only be assessed through identification of unweathered rock surfaces in the gigapixel imagery.

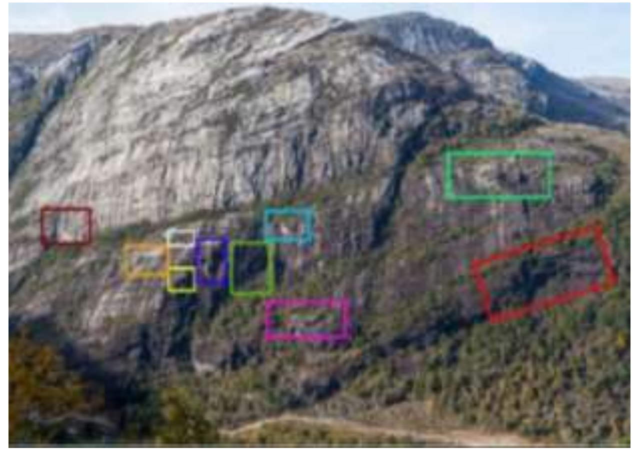

Figure 6. Identification of 10 primary source zones mapped on a gigapixel photograph.

Table 1: Potential rockfall source zone location and geotechnical information

Easting	Northing	Failure mode	Volume (m^3)	Colour
365105	6548845	Topple	7000	Burgundy
365357	6548887	Sliding	4000	Purple
365223	6548849	Sliding	1000	Royal Blue
365289	6548912	Sliding	1200	Light blue
365506	6549135	Sliding	500	Light green
365250	6548877	Topple	50	Green
365214	6548826	Sliding	300	Yellow
365117	6548794	Sliding	5000	Orange
365553	6549120	Sliding	500	Red
365172	6548842	Ravel	200	White

4.1 Example analyses

The two rockfall source zones that pose the greatest hazard to the construction project are outlined in purple and blue boxes in Figure 6; specific details are listed on line 2 and 4 of Table 1, respectively. Both source zones are located within the vicinity of the planned tunnel portal.

4.1.1 Example analyses 1

The source zone outlined in the purple box is a planar sliding wedge type failure characterized by a sliding surface approximately 60 m wide dipping at an angle of 35^o. The source zone is illustrated in Figure 7 (gigapan image).

Figure 7. Source zone visualized in the gigapixel photograph, purple outline in Figure 6.

If the mass were to fail as a single event the approximate volume would be 4000 m^3. This potential sliding failure source zone exhibits no signs of recent movement or active failures. Directly to the right of the potential hazard is what appears to be the sliding surface of a historical failure; this further suggests the potential for future failure.

4.1.2 Example analyses 2

The source zone outlined in the blue box is a planar sliding wedge type failure characterized by a sliding surface approximately 25 m wide dipping at an angle of 60^o. The source zone is located directly to the left of the proposed tunnel portal. The estimated volume of the source zone that has not yet failed is 1200 m^3. The source zone is illustrated in Figure 8 (gigapan image). The left side of the source zone has failed in the recent past as can be identified by the unaltered white rock surface along the sliding plane. The potential source zone appears fractured and it could be expected that smaller individual failures may precede a larger event.

Figure 8. Source zone visualized in the gigapixel photograph, light blue outline in Figure 6.

The size, location, and orientation of the potential source zone makes mitigating against the hazard extremely challenging. The rockmass in both instances cannot be supported without extreme measures, and the tunnel portal cannot be protected by standard systems such as rockfall fences or rockfall sheds due to the large mass of the potential failure volumes.

4.2 Mapped results

The zones identified in the 2D and 3D analyses were plotted in ArcGIS and their spatial relationship with the construction of the road and tunnel portal were examined (Figure 9).

Figure 9. Topographical map with all mapped rockfall hazard locations on the slope face and ranked zones of hazard impact marked along the planned road construction route.

5 CONCLUSION

The information derived from the 2D and 3D analysis provided an accurate and reliable method to assess the spatially extensive slope for rockfall hazards. The TLS analysis enabled the calculation of potential volumes and kinematic failure windows. There are limitations in this analysis that must be incorporated into the larger hazard analysis; however, given the challenges of this project the results generated from the investigation of the remote sensing data provided worthwhile information to the project engineers.

Future work on this project will be the integration of rockfall hazard levels into a risk matrix and the development of protective measures and risk reduction efforts. The authors hope the monitoring work continues and over time differential change maps can be generated to directly assess the slope for zones of activity.

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