CHAPTER 1 – INTRODUCTION AND BACKGROUND

Ensuring rock slope stability is a major safety goal along highways. Rock slope instability can occur in many forms, including rapid large-scale rock instability, rockfall, and time-dependent slope degradation and failure. Unstable rock slopes pose a safety hazard that results in accidents and fatalities along U.S. highways every year (Badger and Lowell, 1992; Schuster and Fleming, 1986). Unstable slopes also require costly ongoing maintenance and design improvements such as the installation of rockfall barriers to mitigate rockfall or highway realignments to avoid major unstable rock slopes.

Site characterization is required initially to determine the potential for highway slope instability and to engineer appropriate mitigation methods, which can include catch basins, rockfall fences, ground support, drainage systems, rock sheds, tunnels, etc. Site characterization is also periodically required over the life of the highway because changes in the stability of rock slopes can occur as highway slopes weather and deteriorate. Rock mass site characterization involves the collection of geotechnical data, including information about rock structure, geology, intact rock strength, hydrology, climate, and earthquakes. (Priest, 1993, Hudson and Harrison, 2000). In the current practice, much of this data is collected by hand directly at exposed highway slopes and rock outcrops, including measurements of discontinuity orientation, roughness, fill, length, and spacing. There are many issues with the collection of data in the field, including:

- Safety hazards associated with the collection of this data
- Difficulties in accessing rock outcrops on large slopes or cliffs
- Human bias and accuracy issues associated with selecting areas for measurement and the accuracy of the hand-collected measurements themselves
- Relatively slow data collection and manpower intensive
- Because of the issue above, slope stability calculations with relatively small data sets
- The lack of three dimensional information about the slope (other than surveyed points) that could be used for comparison as slopes weather and deteriorate

To address these issues, new technologies are needed that provide the following benefits:

- Automatic data acquisition over entire slope
- Remote data acquisition for improved safety
- Rapid data collection
- New technologies for data collection and processing easy to learn and operate
- Able to provide a high-resolution 3D Digital Terrain Model (DTM) of a highway slope or rock outcrop that could be compared with future DTMs as the slope ages and deteriorates
- Cost effective

The purpose of this report was to determine whether the new technology of ground-based LiDAR (Light Detection and Ranging) could assist FHWA with highway rock slope stability as described in the list above. LiDAR, also often referred to as “3D laser scanning”, is an emerging three-dimensional mapping technology that employs a laser and a rotating mirror or housing to rapidly scan and image volumes and surficial areas such as rock slopes and outcrops, buildings, bridges and other natural and man-made objects. Ground-based or terrestrial LiDAR refers to tripod-based measurements, as opposed to airborne LiDAR measurements made from airplanes or helicopters.

The output from ground-based LiDAR is a point cloud consisting of millions of laser distance measurements representing the three-dimensional scanned scene. The point clouds are then processed to extract geotechnical information, which includes discontinuity orientation, length, spacing, roughness, and block size. High-resolution digital images are also taken of the scanned scene, and these images can be "draped" onto the point cloud using texture-mapping techniques (Blythe, 1999) to provide a 3D color DTM of the scanned scene. Additional geological and geotechnical information can be extracted from the DTM that would be difficult to observe in the point cloud.

The primary goals of this 18-month study were to:

1. Investigate LiDAR hardware currently available for highway rock slope stability;
2. Investigate point cloud processing software currently available for highway rock slope stability;
3. Evaluate the current state of the technology for providing useful benefits (as discussed in the list above) and compare with other technologies such as photogrammetry;
4. Identify best-practices to be used when conducting field scanning, and also when using software for processing data;
5. Recommend standards for using LiDAR in highway rock slope stability projects; and
6. Investigate likely improvements in LiDAR hardware and software in the next few years.

The list above roughly correlates with the chapters to follow. Chapter 2 of this report provides an overview of LiDAR hardware, and the basic procedure involved in conducting a LiDAR scan in the field. Chapter 3 describes the software used in processing data from LiDAR scans, including point cloud processing software and the interoperability with CADD and other highway design software packages. Chapter 4 describes the primary highway geotechnical applications for LiDAR, including rock mass characterization, rockfall, and detailed 3D surveying. It also includes a section on the accuracy of LiDAR-generated data, and a section comparing LiDAR with ground-based photogrammetry. In Chapter 5, the "best practices" for conducting LiDAR surveys in the field and processing the data are given, based on experiences in a number of different rock and engineering environments in the past several years. Chapter 6 discusses expected advances in LiDAR hardware and software in the next five or so years. Finally, conclusions and recommendations are presented in Chapter 7.

This report concludes that indeed there are benefits available when ground-based LiDAR is employed.