GROUND-BASED LiDAR
Rock Slope Mapping and Assessment

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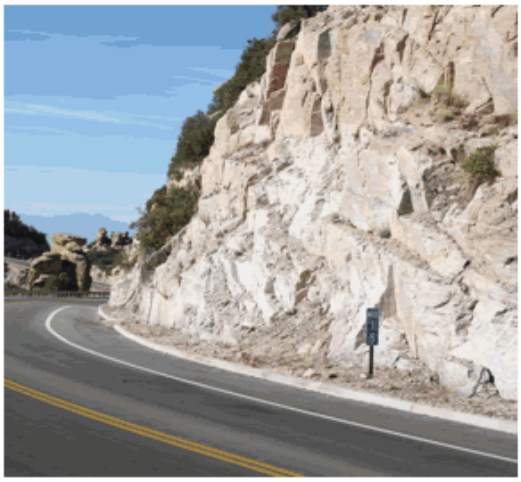

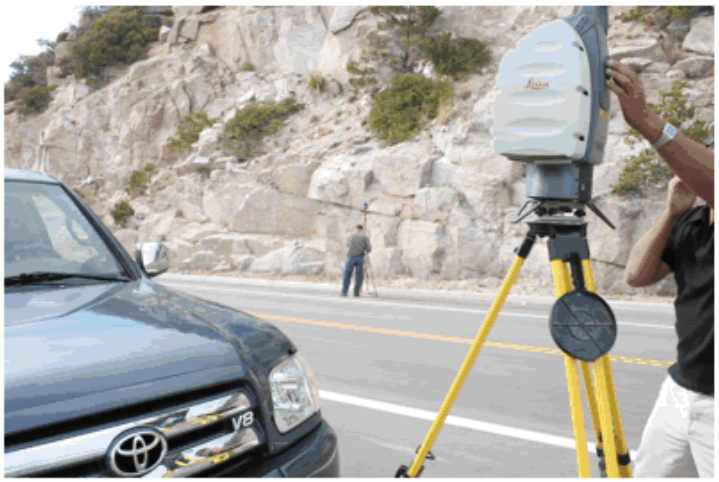

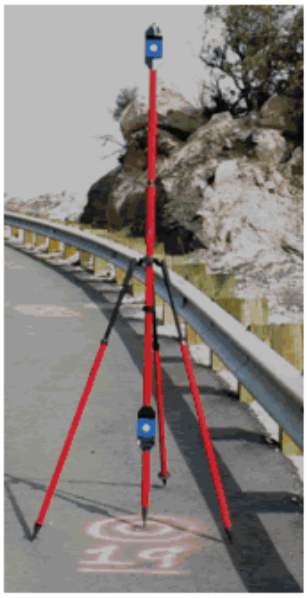

U.S. Department of Transportation
Federal Highway Administration

Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
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FOREWORD

The Federal Lands Highway (FLH) of the Federal Highway Administration (FHWA) promotes development and deployment of applied research and technology applicable to solving transportation related issues on Federal Lands. The FLH provides technology delivery, innovative solutions, recommended best practices, and related information and knowledge sharing to Federal agencies, Tribal governments, and other offices within the FHWA.

The FLH has an interest in using new technology to assist in designing and constructing roads more efficiently. One emerging three-dimensional mapping technology is terrestrial or ground-based LiDAR. LiDAR (Light Detection and Ranging), also often referred to as "3D laser scanning", 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.

This project shows how the new technology of ground-based LiDAR could assist FHWA with highway rock slope stability. Site characterization for rock slope stability involves the collection of geotechnical data, and in the current practice, much of this data is collected by hand directly at exposed highway slopes and rock outcrops. There are many issues with the collection of this data in the field, including issues of safety, slope access, and human bias. It is shown in this report that some of the most important types of geotechnical information for rock slope stability can be acquired using LiDAR at a safe distance from the slope. In many cases, this information can also be automatically extracted from LiDAR point clouds using currently available point cloud processing software, reducing human bias issues. This report concludes that indeed there are benefits available when ground-based LiDAR is employed.

F. David Zanetell, P.E., Director of Project Delivery
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15. Supplementary Notes

COTR: Justin Henwood, FHWA-CFLHD. Advisory Panel Members: Alan Blair, Matt DeMarco, and Roger Surdahl, FHWA-CFLHD; and Scott Anderson, FHWA-FLH. This project was funded under the Federal Lands Highway Technology Deployment Initiatives and Partnership Program (TDIPP.)

16. Abstract

LiDAR (Light Detection and Ranging), 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 purpose of this report was to determine whether the new technology of ground-based LiDAR could assist FHWA with highway rock slope stability. This report includes discussions of currently available LiDAR hardware and software, the current state of LiDAR for highway geotechnical applications (rock mass characterization, rockfall characterization, as-built 3D measurements), best-practices for field scanning and for point cloud data processing, and expected trends in the industry in the near future. It is shown in this report that some of the most important types of geotechnical information for rock slope stability that is currently being collected by hand can be acquired from LiDAR point clouds and associated digital images. This includes detailed information about rock discontinuity orientation, roughness, length, spacing and block size. In many cases, this information can be automatically acquired using currently available point cloud processing software. There are advantages to using LiDAR for collecting this information, including improved safety, accuracy, slope access, and speed of analysis. It is recommended that LiDAR be utilized for future highway slope stability projects.

17. Key Words	18. Distribution Statement
LiDAR, SLOPE STABILITY, ROCK MASS CHARACTERIZATION, DISCONTINUITY, 3D, LASER SCANNING, ROCKFALL	No restriction. This document is available to the public from the sponsoring agency at the website http://www.cflhd.gov.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	km
		AREA		
in^2	square inches	645.2	Square millimeters	mm^2
ft^2	square feet	0.093	Square meters	m^2
yd^2	square yard	0.836	Square meters	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	Square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	Inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	Acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	Ounces	oz
kg	kilograms	2.202	Pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	Poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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- Undergraduate students Brianna Muhlenkamp and Gwynneth Smith, who completed their senior design project on the Mt. Lemmon Highway near milepost 15, comparing LiDAR with traditional methods for rock mass characterization.
- Mehul Patel, a graduate student investigating interoperability between point cloud software and CAD software such as Bentley Microstation and Autodesk AutoCAD.

Also noted with appreciation is Mr. Justin Henwood, P.E., who was the FHWA-CFLHD's Contracting Officer's Technical Representative (COTR) for this work. This report also benefited from the review provided by the FHWA's Technical Advisory Panel members of Scott Anderson, Alan Blair, Matt Demarco, and Roger Surdahl.

This project was funded under the FHWA's Federal Lands Highway Technology Deployment Initiatives and Partnership Program (TDIPP).