Landslide Susceptibility in the Colorado Springs Area – Geology and History

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Presentation Outline

- Colorado Springs physiographic and geologic setting
 - Why areas of Colorado Springs are susceptible to landslides
- Recent Colorado Springs landslide history (1995-1999)
- Development of the Landslide Susceptibility Mapping Program
- 2015 landslides
- Current ground movement trends areas of risk
- Concluding remarks



Physiographic Setting

- The City of Colorado Springs
 - 2nd largest city in Colorado
 - Population 465,000 (2016)
 - City limits elevation range from 5,720 to 9,212 ft
- Lies within the Colorado Piedmont
 - Physiographic transition between the Great Plains and the Rocky Mountains
 - Along mountain front, erosion and downcutting by Fountain Creek and it's tributaries exposes older bedrock



Geologic Setting

- Rampart Range and Cheyenne Mountain Front
- Eastward dipping bedrock, steep near Front
- Cretaceous claystone
 - Underlies most of the city west of I-70
 - At core of dissected foothills
 - Low rock strength, prone to landsliding
- Quaternary deposits (glacial epochs)
 - Mountain-front pediment gravels and debris fans
 - Alluvial river terraces
 - Older to younger landslide deposits
 - colluvium (slope wash)



Geologic Setting, cont.

- Unconsolidated gravelly sand deposits shied from the mountains are more resistant to weathering compared to the underlying claystone
- Continuous erosion, gully down-cutting, and landsliding formed eastward sloping mesas and ridges that are underlain by weathered soft claystone
- Mesa side slopes remain prone to instability



Rampart Range Front





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General Geologic Map



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Cheyenne Mountain Front



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Cheyenne Mountain Front





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GENERALIZED CROSS SECTION OF THE GARDEN OF THE GODS ROAD

EAST





WEST

Hogbacks between Garden of the Gods and Mountain Shadows area





"Recent" Landslide History

- 1993-1994 Mountain Shadows landslide
- □ 1995 wet spring caused several new landslides
- 1996 Colorado Springs enacts geologic hazards ordinance
 - Begins submitting development plans to CGS for review of geologic hazards
- 1997 Additional landslides during another wet spring



Regency Drive Landslide, 1995





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Regency Drive, 1995





1997 Friendship Lane Landslide



Photos courtesy of J. Himmelreich



Same slide after 1999 reactivation



"Recent" Landslide History

- 1999 Heavy spring rains trigger flooding and activated additional landslides. El Paso County and Colorado Springs declared a Presidential Disaster Area
 - FEMA "Unmet Needs Program" authorized for buyout assistance program for owners of impacted or condemned homes
 - 27 homes in 8 landslide locations (Squire, 2006)
 - Validation program by CGS
 - Landslide susceptibility map also funded by FEMA





Hofstead Slide, 1999











Photos by Mark Squire



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Broadmoor Bluffs Drive Area

- Broadmoor Bluffs Drive under construction above Farthing Drive - 1996
- Broadmoor Glen South Development approved – 1997
- 1998 to 2001 Three incidences of landslides in the vicinity



1998-2001 landslides

- 1998-1999 Ground movement at Broadmoor Bluffs Drive home mistaken for settlement: expensive underpinning and foundation reinforcement (ultimately failed in 2015)
- 1999 Small landslide triggered by excavation for Danceglen cul-de-sac below Farthing Dr.
 - Landslide material removed to the slip plane and slope buttressed with engineered fill acting as a shear key
 - 3 houses were later built on reconstructed slope



1998-2001 landslides

- Distress in Broadmoor Bluff Drive embankment (facing south) noted ~1998
 - 2001 City hired geotech and investigation determined embankment settlement was a landslide
 - City approved project to mitigate Broadmoor Bluff Drive landslide by construction of a shear key using drilled-shaft concrete caissons



Broadmoor Bluffs Drive with landslide susceptibility overlay





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Cheyenne Mountain Golf Course

- Hummocky ground of golf course recognized as ancient landslide in 1973 (Scott and Wobus USGS geologic map)
- Several periods of accelerated movement, most active in 1995, 1999, and 2015
- Tension cracks, insipient scarps in golf course below Stone Manor Heights during 1998-1999 development application reviews
 - Geotech reported deep (75') movement above historic landslide within proposed development area



1995 reactivation at golf course







Insipient scarp in 1998 below Stone Manor Heights





Two townhomes on Appian Court within golf course removed in 2001 FEMA buyout program





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Landslide Susceptibility Mapping Program

- Funded by FEMA unmet needs funds, supported by City of Colorado Springs
- August 12, 2002 Presentation of mapping program to City Council, GIS files submitted to city staff
- Published by CGS in 2003



Mapping Methodology

- Landslide history
- Geomorphology
- Geology
- Topography
- Other effects (water, human factors)
- Mapped into a GISbased system



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Landslide Inventory

- Landslide locations were compiled from the following sources
 - Published geologic maps
 - Available USGS maps
 - CGS was concurrently mapping 1:24K quadrangles for STATEMAP program in Colorado Springs
 - Consultant reports
 - John Himmelreich maps
 - Land-use geotech reports submitted to CGS for review
 - Project mapping from analysis of aerial photography and bare earth hillshade images developed from 5-ft pixel DEM. Sites were field checked



Geomorphology – landslide landforms



Hofstead Slide, 1999



Stealth landslides – no visible morphology at ground surface



Uintah Road cut near intersection with Superior Street at transition of Pierre Shale to steeply dipping zone





Disturbed Claystone Landslide deposits in home excavation









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Geology - Weak Claystone Bedrock

Major formation units dip to the east

Pierre Shale

- Predominant bedrock unit underlying Colorado Springs west of I-70, over 3,000 feet thick
- Low shear strength, expansive, overconsolidated claystone with common bentonite seams
 - Weathers to a fat clay, very sticky/greasy when wet
- Glen Eyrie Shale Member of the Fountain Formation

Responsible for instability in Cedar Heights

Other minor units include the Benton Group shales and clay-rich beds of the Laramie and Dawson Fms.



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Topography

Slope Grade

- GIS grid files, based on 5-ft pixel DEM, were developed for various slope grade intervals. In clayrich formations, sustained slope grades that exceeded 12% (8(H):1(V) or 7 degrees) were examined
- Slope Aspect
 - North-facing (shadow) slopes hold more moisture
 - East-facing slopes are in the approximate dip direction of claystone bedrock and may "daylight" weak bedding planes



Other Factors

Ground water

- seeps and spring areas
 - Ground water passes thru overlying gravel to perch on impermeable claystone and migrate towards side slopes
- poor drainage
- Ground modification
 - Cuts and fills can destabilize potentially unstable slopes (e.g., Hofstead Terrace cut slope)
- Vegetation changes
- Marginal Zones



Susceptibility margin zones





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A Closer Look: The Mesa









Colorado Springs Landslide Susceptibility Map



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2001 to 2014 - Extended period of drought and drier weather

- Little landslide activity
- Landslide susceptibility and risk was forgotten
- Much wetter conditions in 2014/2015



2015 Landslide activity

- Tension crack and insipient landslide scarp occurred along north rim of Broadmoor Bluffs Drive
 - Previous underpinning mitigation failed. Insipient scarp occurred at slope break.
 - CGS had earlier recommended that no homes be places within ancient landslide or near slope break (the scarp remnant of the ancient landslide)

Slope edge restriction not fully understood



Broadmoor Bluffs Drive





Broadmoor Bluffs Drive





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2015 Constellation-Zodiac Landslide (reactivation of an ancient landslide)











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2015 reactivation of Mountain Golf Course landslide

- Large complex translational landslide
- Fresh scarps above and extensional ground cracks within golf course
- Active landslide toe
 - Lies in previous developed areas below the golf course within the ancient landslide
 - Homes are being damaged



Cheyenne Mountain Golf course





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Recent ground movements





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New slide (2015) between golf course and residential areas





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New scarps (2015) above golf course in residential areas



Slump at caisson shear-key below Stone Manor Heights

Charles Grove Scarp









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Mountain golf course susceptibility map





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Mountain Golf Course

In Nov. 2016 CGS retained an InSAR consulting firm to evaluate ground movements in the Cheyenne Mtn. vicinity InSAR investigation (NHAZCA, 2017) appears to indicate that movements of the Mountain Golf Course landslide extend from the upper scarps at Stone Manor Heights road to the landslide toe at Childe and Haversham Drives





Image from:

2017, Rocca and Brunetti, eds., A-DinSAR Analysis on the East Flank of Cheyenne Mountain, Colorado (USA) by COSMO-SkyMed Data: Natural Hazards Control and Assessments (NHAZCA) S.R.I.

Full data set 2011-2016



Cheyenne Mountain Golf Course Landslide Preliminary InSAR analysis – 2011-2016





GIS point data from NHAZCA (2017)



Closing comments

- Colorado implemented a revised geologic hazard ordinance in 2017
- Colorado Springs has recently retained a geotechnical consultant to further evaluate ground stability below Cheyenne Mountain
- Potential ground instability and risk of landslides within the landslide susceptibility zones of Colorado Springs <u>will always be present</u>



Closing comments, cont.

- Higher standards of care (i.e., higher costs) are needed in geotechnical investigations in landslide susceptible areas. In sensitive slopes one must discern stealthy landslides, disturbed claystone vs. intact bedrock, and what are the fluctuating ground water levels during periods of high precipitation
- Consider pro-active measures to safe-guard property valuations
 - Certain options may not be politically palatable
 - Shared risk and limited protection with Geologic Hazards Abatement Districts (GHAD) should be further considered



Cheyenne Mountain Area with draped landslide susceptibility overlay





