Landslide Susceptibility in the Colorado Springs Area – Geology and History

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Landslide Hazards of Colorado Springs: What the General Public Needs to Know
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Presentation Outline

- Colorado Springs physiographic and geologic setting
  - Why areas of Colorado Springs are susceptible to landslides
- 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 its 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)
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
General Geologic Map

Geology modified from Tweto, 1979
Cheyenne Mountain Front

- Zone of Expansive Steeply Dipping Bedrock
- Precambrian rocks
- Thick surficial deposits
- Pierre Shale
- Fountain Formation

Modified from Finlay, 1916
Cheyenne Mountain Front

Cheyenne Mountain

Photo by Mark Squire
Pediment Gravels - “Mesas”
Laramie and Dawson Fms.
(Pulpit Rock, Austin Bluffs,
and Palmer Park)
Zone of Expansive
Steeply Dipping Bedrock
Piedemt Gravels - “Mesas”
Pierre Shale
Fountain Formation
Precambrian rocks

Modified from Finlay, 1916
Hogbacks between Garden of the Gods and Mountain Shadows area

Dakota and Purgatoire Fm.
hogbacks

Rampart Range
Pikes Peak Granite
“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
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 buy-out 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
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

- 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

1999 embankment landslide

Broadmoor Bluffs Dr. Landslide scarp

1999 Danceglen and Kettleglen landslide
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
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 GIS-based system

Flow Chart

- HISTORY: Are there mapped or historic landslides in the area?
  - Yes: Digitize slide in inventory coverage.
  - No: Map slide in inventory coverage.
- GEOMORPHOLOGY: Is there geomorphic evidence supporting landsliding?
  - Yes: Include area in susceptible zone.
  - No: Not landslide susceptible.
- GEOLOGY: Is the geology favorable for landsliding?
  - Yes: Identify clay-rich geologic formations, create new GIS theme.
  - No: No
- TOPOGRAPHY: Is the topography favorable for landsliding?
  - Yes: Create slope aspect and slope gradient grid coverages based on 2 ft contour data. Include as grid themes in ARCVIEW project.
  - No: Not landslide susceptible.
- Final Landslide Susceptibility Coverage

Project Steps

- Transfer (digitize) known landslides to ARCVIEW themes (coverages) in GIS project.
- Perform air photo reconnaissance and interpretation, digitize boundaries of new landslides to new theme in GIS project.
- Identify clay-rich geologic formations, create new GIS theme.
- Create slope aspect and slope gradient grid coverages based on 2 ft contour data. Include as grid themes in ARCVIEW project.
- Analyze and compare overlapping project coverages. Evaluate effects of water, drainage, geologic structure, and slope conditions on areas that could potentially be affected by slope movement.
- Construct preliminary draft GIS landslide susceptibility coverage.
- Peer review of map
- Edit coverage by field check and stereo photo analyses.
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

- Slump blocks and intermediary scarps (step-and-bench morphology)
- Tension cracks
- Main scarp
- Earth flow toe
- Dip slope
- Rotational slip plane
- Surface of separation where landslide material has overridden intact soil or bedrock

Mod. from Varnes (1978)
Hofstead Slide, 1999

Grading excavation into ancient landslide toe
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

From Noe, 1996
Landslide deposits in home excavation
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.
Topography

- **Slope Grade**
  - GIS grid files, based on 5-ft pixel DEM, were developed for various slope grade intervals. In clay-rich 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

- Slump blocks and intermediary scarps (step-and-bench morphology)
- Earth flow toe
- Surface of separation where landslide material has overridden intact soil or bedrock
- Tension cracks
- Main scarp
- Rotational slip plane

Mod. from Varnes (1978)
A Closer Look: The Mesa

Geology by CGS

Grid basemap © FIMS

DEM basemap © FIMS
Colorado Springs Landslide Susceptibility Map
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 placed within ancient landslide or near slope break (the scarp remnant of the ancient landslide)
    - Slope edge restriction not fully understood
Broadmoor Bluffs Drive

Approximate head scarp location

General direction of movement

Caisson shear-key

Google earth
© 2016 Google
Broadmoor Bluffs Drive

2015 Broadmoor Bluffs Dr.
Landslide scarp

1999 Danceglen and Kettleglen landslide

1999 embankment landslide

Legend

- 2015 landslide scarps
- slides_consultants
- slides_interp
- slides_published
- susceptible

Source: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, ADE, Getmapping, Aerogrid, IGN, USFWS, and the GIS User Community
2015 Constellation-Zodiac Landslide
(reactivation of an ancient landslide)
3 new homes built 1999 - 2015

New Home built 2015
Home built in 1015

3 new homes since 1999

Legend
- 2015 Colorado Springs landslides
- slides_consultants
- slides_interp
- slides_published
- susceptible

Source: Earl, R.G.S. 2303 College, Geospatial Geomatics, USGS/AES Geo, USG, USGS, USA
Surveying, Remote, ES, CT, cartography, and the GIS User Community

Colorado School of Mines
Earth, Energy, Environment
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
Recent ground movements

Inclinometer in 1998 showing movement at 75' below surf.
New slide (2015) between golf course and residential areas
New scarps (2015) above golf course in residential areas

- **Slump at caisson shear-key below Stone Manor Heights**
- **Charles Grove Scarp**
Mountain golf course susceptibility map

Legend

- 2015 landslide scarps
- slides_consultants
- slides_interp
- slides_published
- susceptible

- Two townhomes enrolled in 2001 FEMA buyout program
- 1999 inclinometer showing lateral movement at 75' depth
- 2015 landslide scarps
- 1998 - Tension cracks Threatening Stone Manor Road
- 2015 Home damage

Cheyenne Mountain Zoo

Regency landslide
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

Heavy black line is extent of ancient landslide
Purple lines are recent 2015 scarps

GIS point data from NHAZCA (2017)
Velocity LOS (mm/year)

- < -10.0
- -10.0 to -5.0
- -5.0 to -1.5
- -3.0 to -1.5
- -1.5 to 1.5 (no movement)

For interval 2011 to 2016
1 inch = 25 mm
Purple lines are recent 2015 scarps

1995 Regency Landslide

Heavy black line is approx. extent of ancient landslide

Two townhomes demolished in 2001 FEMA buyout program

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 will always be present
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
Thank you