Natural Hazards and the Built Environment: a State of Practice Perspective
Waldo Canyon 2012

Gaylon Wamper - AP

Robie Blair - KRDO

Denver Post
Floods follow Fires

Michael Rieger - FEMA
West of Manitou Springs, CO, August 2013

Super-elevated highway curve
K-rail barrier
Rock fall fence
Lower Waldo Canyon Precipitation Gage
+38.8781°, -104.9333°
El 6920 ft

Fountain Creek flow direction
Culvert inlet

+38.8784°, -104.9337°, El 6922 ft

Steel guard rail barrier
US 24 East
US 24 West

Narrow area
Wide area
Construction equipment
Waldo Canyon flow direction
Tributary canyon flow direction

U.S. Department of Transportation
Federal Highway Administration
Old School Reconnaissance
New School: YouTube

- Note the Rockfall Fence
In the week before GEER arrived

When GEER arrived

Sallie Clark, Commissioner
What now?
Nets and U.S. 24 Culvert
Design Considerations

- **Fisher Canyon Debris Dam**
  - Singular hazard design

- **Williams Canyon – Residences**
  - Condemnation

- **Waldo Canyon – 4-lane U.S. Highway 24**
  - Temporary need, risk transfer

- **Downtown Manitou Springs**
  - Partnership and coordination
We’ve had an *implicit* goal of safety

Federal Highway Legislation (MAP-21) has seven *explicit* National Performance Goals

1. **Safety**  
2. Infrastructure Conditions: State of Good Repair  
3. Congestion Reduction  
4. System Reliability - improve efficiency  
5. Freight Movement and Economic Vitality  
6. Environmental Sustainability  
7. Reduced Project Delivery Delays
Mt. Lemmon, Tucson, AZ
The only road serving Mt. Lemmon
Design and repair considerations here address some other goals:

1. Safety
2. Infrastructure **Conditions**: State of Good Repair
3. **Congestion** Reduction
4. System **Reliability**- improve efficiency
5. Freight Movement and **Economic** Vitality
6. Environmental **Sustainability**
7. Reduced Project Delivery Delays

**State of Practice:** A more explicit discussion of performance goals is expected.
A slow-moving cold front stalled over Colorado.

Heavy rains are produced along Colorado's Front Range from Colorado Springs to the Wyoming border.

Parts of Larimer and Boulder Counties received upwards of 20 inches of rain. Federal emergency declaration is issued in 15 counties.

GEER members evaluated social media response.
Road Network Impacts

Highway Status between September 12 - 16, 2013

Highway Status as of September 24, 2013

STATE HIGHWAY CLOSURES
- Closed to all traffic
- Closed - Emergency Only
- Closed - Local Access Only
- Open with Restrictions
- Open to All
- No Reported Damage - Expect Normal Travel
Other Impacts

- 9-10 deaths
- > 11,000 people evacuated
- 1,750 people rescued by air and ground
- 17,322 damaged homes and businesses
- 2055 destroyed homes and businesses
- 486 miles road damage, 118 miles need permanent repair
- $2.89 billion impact
- $450 million FHWA outlay

Denver Post, 09/07/14
Emergency Relief (ER or ERFO) from FHWA

- Catastrophic and from external cause
- Generally within right of way
- In-kind, to standard, or with betterment

What if there is no “standard”?  
When is a betterment justified with ER funds?

Application of ER Program is not easy or routine
RISK

Likelihood x Consequence
RESILIENCE

The capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well being, the economy, and the environment. - USDOT
Standards

• AASHTO “Green book” for geometrics
• AASHTO Guide Specs for Bridges and Structures
• State Specifications
• Rock Slope Standards?
  ▪ Inside ROW, Outside ROW
  ▪ Global Stability
  ▪ Rockfall Hazard

If they exist at all, they have ‘escape clauses’
<table>
<thead>
<tr>
<th>RHRS FACTORS</th>
<th>Primary contribution to risk</th>
<th>RISK</th>
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<tbody>
<tr>
<td>1 Structural Condition</td>
<td>Hazard</td>
<td></td>
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<tr>
<td>2 Strength/Stability</td>
<td>Hazard</td>
<td></td>
</tr>
<tr>
<td>3 Water/Climate</td>
<td>Hazard</td>
<td></td>
</tr>
<tr>
<td>4 Rockfall History</td>
<td>Hazard</td>
<td></td>
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<tr>
<td>5 Ditch Effectiveness</td>
<td>Consequence</td>
<td></td>
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<tr>
<td>6 Vehicle Risk (Exposure)</td>
<td>Consequence</td>
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<tr>
<td>7 Sight Distance</td>
<td>Consequence</td>
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<tr>
<td>8 Roadway Width</td>
<td>Consequence</td>
<td></td>
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<tr>
<td>9 Size/Volume</td>
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<td></td>
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<tr>
<td>10 Slope Height</td>
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<td>A Education/Warning</td>
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<td>B Maintenance Frequency</td>
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<td>C</td>
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<td>D</td>
<td>Consequence</td>
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Post - Construction

Pre - Construction
Oso Landslide
Snohomish County, WA
Location and General Slope
22 March 2014 – What happened?
GEER Reconnaissance

- Two months elapsed
- Last recovery at same time
- Six people, 4 days
- Excellent County support in field
- USGS presence since day one

Some remarkable observations reported…

Understanding that can be applied in practice
Seismic Signals

Pacific Northwest Seismograph Network

[Diagram showing seismic signals and locations]
Jim Creek Wilderness Station – 11 km Away

Pacific Northwest Seismograph Network

03/22/2014 10:37

U.S. Department of Transportation
Federal Highway Administration
Lidar Topography

2006 slide

2013

2014
Impact
WSDOT High-Resolution Mosaic
24 March 2014
Record of Extension

WSDOT High-Resolution Mosaic 24 March 2014
Liquefaction
Veneer
Flow
Prior public view of Risk, Resilience and Standards

- Steelhead Haven subdivision was platted in 1962
- Slide movement every decade since 1950s
- A few building permits were issued after 2006
- All properties complied with hazard ordinances
- Studies were primarily for other purposes

Basically, there is some of each: risk, resilience and standards
Risk (as understood now)

Approximate risk within 5 km of Oso

- California Delta Levees
- New Orleans Levees 2005
- New Orleans Levees 2012
- Stillaguamish Valley
- Green River Valley

Risks considered "Unacceptable" for Existing Slopes in Australia and Hong Kong
SR 530 Reconstruction

- ER eligible: how should it be rebuilt?

Remember:
Risk
Resilience
Standards
Flood Stage

SR 530

WSDOT

U.S. Department of Transportation
Federal Highway Administration
Design Solution
A final concept

Highway departments (and others) are using risk based plans to manage their assets and to achieve performance goals.

The SR 530 embankment on the Oso landslide is now an asset subjected to risks.
Consider a “Risk Cube”
ALL GEOTECHNICAL RISK

Performance Goals

Asset Class

- Safety
- Infrastructure
- Congestion
- Environmental

Risk Source

- Operational Risk
- Physical Failure
- External Agency Impacts
- Natural Hazards

Risk Sources on GEOTECHNICAL Assets with respect to ALL Performance Goals

Can be done for GAM Section, Corridor or entire inventory

Σ of ALL Risk Sources on GEOTECHNICAL Assets with respect to ALL Performance Goals

Retaining Walls
- \( R_{RW,S,NH} \)

Slopes
- \( R_{SL,I,NH} \)

Embankments
- \( R_{EM,C,NH} \)

Subgrade
- \( R_{SB,E,NH} \)
2 Sources are managed separately.

- Operational Risk
- Physical Failure
- External Agency Impacts
- Natural Hazards
- Retaining Walls
- Slopes
- Embankments
- Subgrade

Performance Goals:
- Safety
- Infrastructure
- Congestion
- Environmental

Asset Class:
- RRW,S,NH
- RRW,C,PF
- REM,C,NH
- RSB,E,NH
- RSL,I,NH
- RW,S,NH

Risk Source:
Geotechnical Asset Management (GAM) 
Risks

Performance Goals

Asset Class

Risk Source

Safety
Infrastructure
Congestion
Environmental

Physical Failure
Natural Hazards
Retaining Walls
Slopes
Embankments
Subgrade

RRW,S,NH
REM,C,NH
RSL,I,NH
RWB,S,NH
RRW,C,PF
REM,E,NH
REM,C,NH
REM,E,NH
Physical Failure Risk Source

- Safety
- Infrastructure
- Congestion
- Environmental

Performance Goals

- Retaining Walls
- Slopes
- Embankments
- Subgrade

Physical Failure: $R_{RW,C,PF}$

Safety Condition Performance vs. Time
Natural Hazard Risk Source

Performance Goals

- Retaining Walls: $R_{RW,S,NH}$
- Slopes: $R_{SL,I,NH}$
- Embankments: $R_{EM,C,NH}$
- Subgrade: $R_{SB,E,NH}$

Time

Safety Condition Performance

- Safety
- Infrastructure
- Congestion
- Environmental
My Question for you:
The risk of what? Let’s be clear.

Your Questions for me?