ATTENUATORS FOR CONTROLLING ROCK FALLS

Results of State-of-the-Art, Full-Scale Testing

16th Annual Technical Forum

Geohazards Impacting Transportation in

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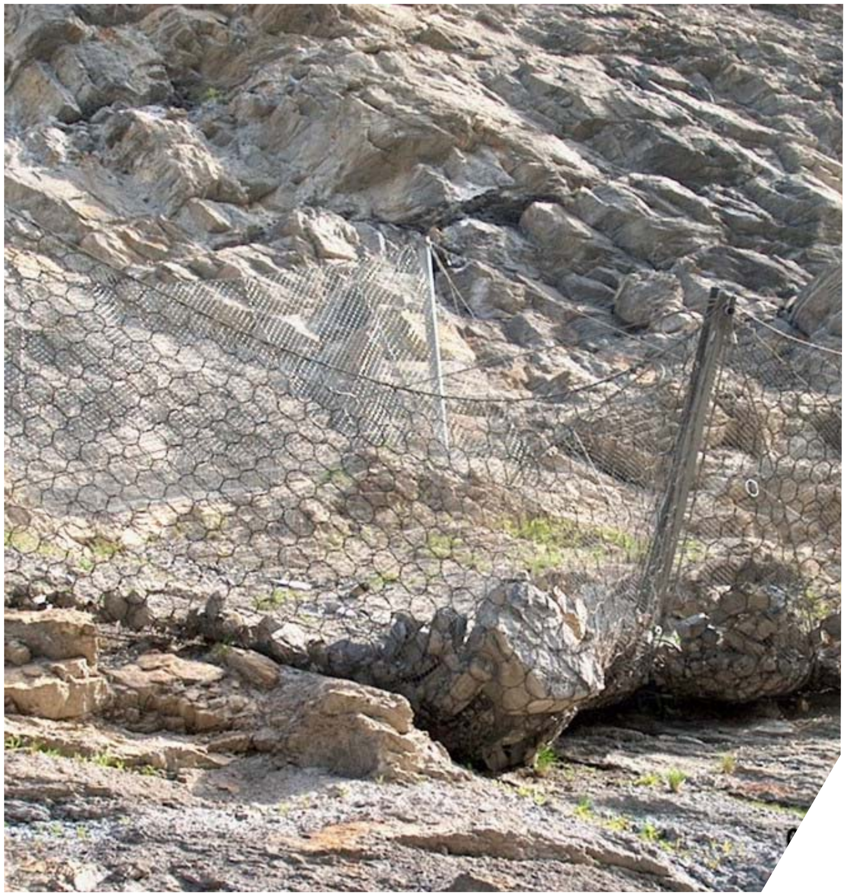
OVERVIEW

1. Attenuation
2. Examples of Attenuator installations
3. Full scale testing of Attenuators
4. Instrumentation of test installation
5. Attenuator response to impact
6. Principal of attenuator function (conservation of momentum)

- Flexible fences absorb ALL impact energy
- Contained rock falls must be cleaned out
- Net deflection requires substantial clearance



- Drop test is standardized, but not true duplication of rock fall impacts

ATTENUATION

- Attenuate:
  to weaken or reduce in force, intensity, effect, quantity, or value.

- Rockfall Impact Attenuation: Oblique impact with the net where the rock is deflected and only a portion of the impact energy is absorbed by the net.

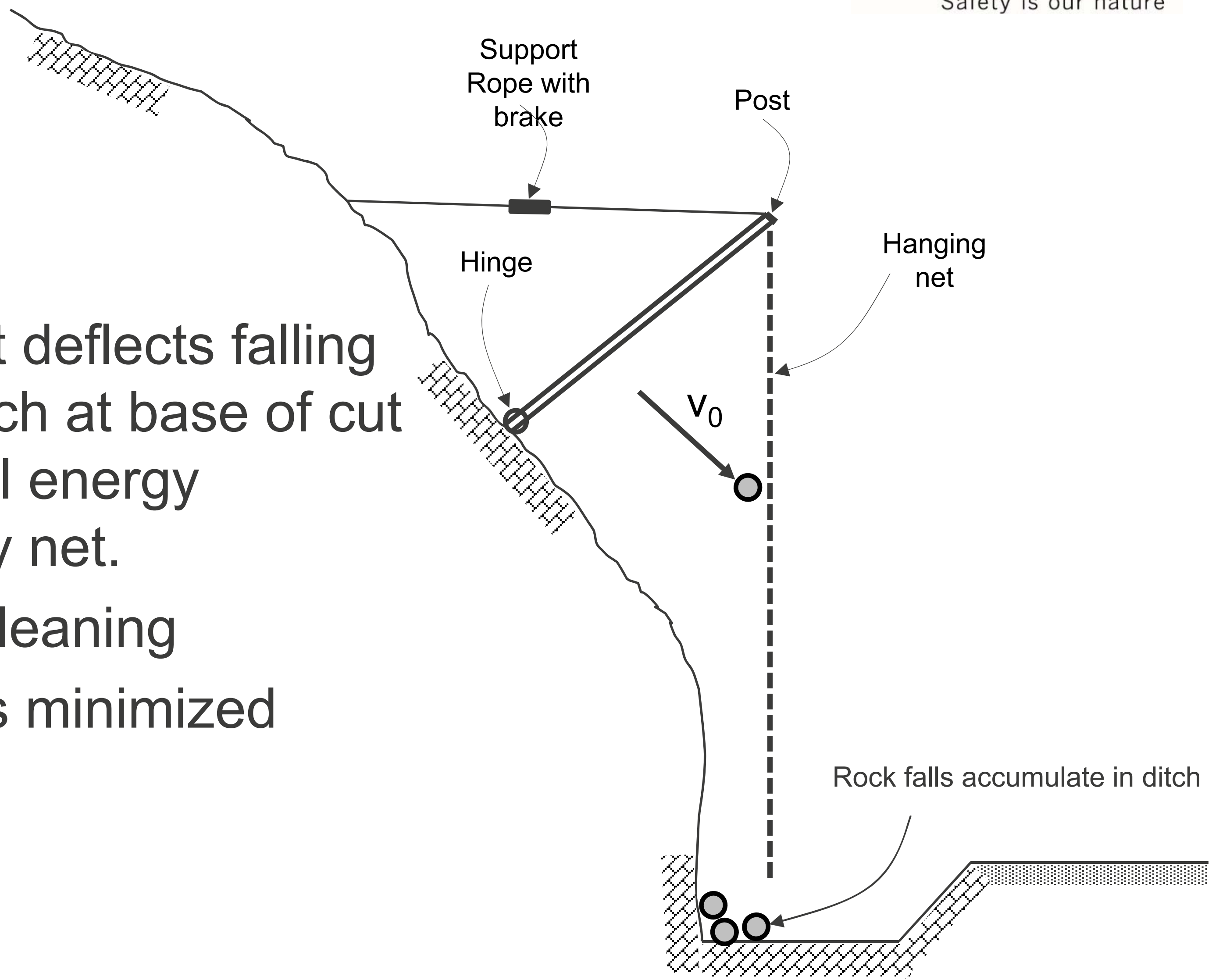
ATTENUATION

A*ttenuator* (also called *Hybrid barrier*) refers to a passive rockfall protection system:

- That consists of a flexible geofabric suspended from a horizontal top support cable that is raised off the ground by posts or anchored across a chute
- Typically there is no internal, side, or bottom anchoring of the fabric allowing for controlled deformation of the fabric.
- Providing either full containment of rock or attenuation of the rockfall trajectory to the base of the installation.

From: Badger et al. - cOF A HYBRID DRAPERY SYSTEM

ATTENUATORS



- Hanging net deflects falling rock into ditch at base of cut with minimal energy absorbed by net.
- Net is self-cleaning
- Deflection is minimized

Wave-shaped nets will deflect rock into the ditch with significant energy absorbed by impact with the ground

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01

MODEL TESTING OF ATTENUATION STRUCTURES

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Attenuator model

Baseball pitching machine - projectile translation velocity and rotation could be varied.

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Velocities during contact with net – projectile is slowed from 11.78 ms-1 at first contact to 8.42 m s-1, and impacts ditch at 9.33 m s-1

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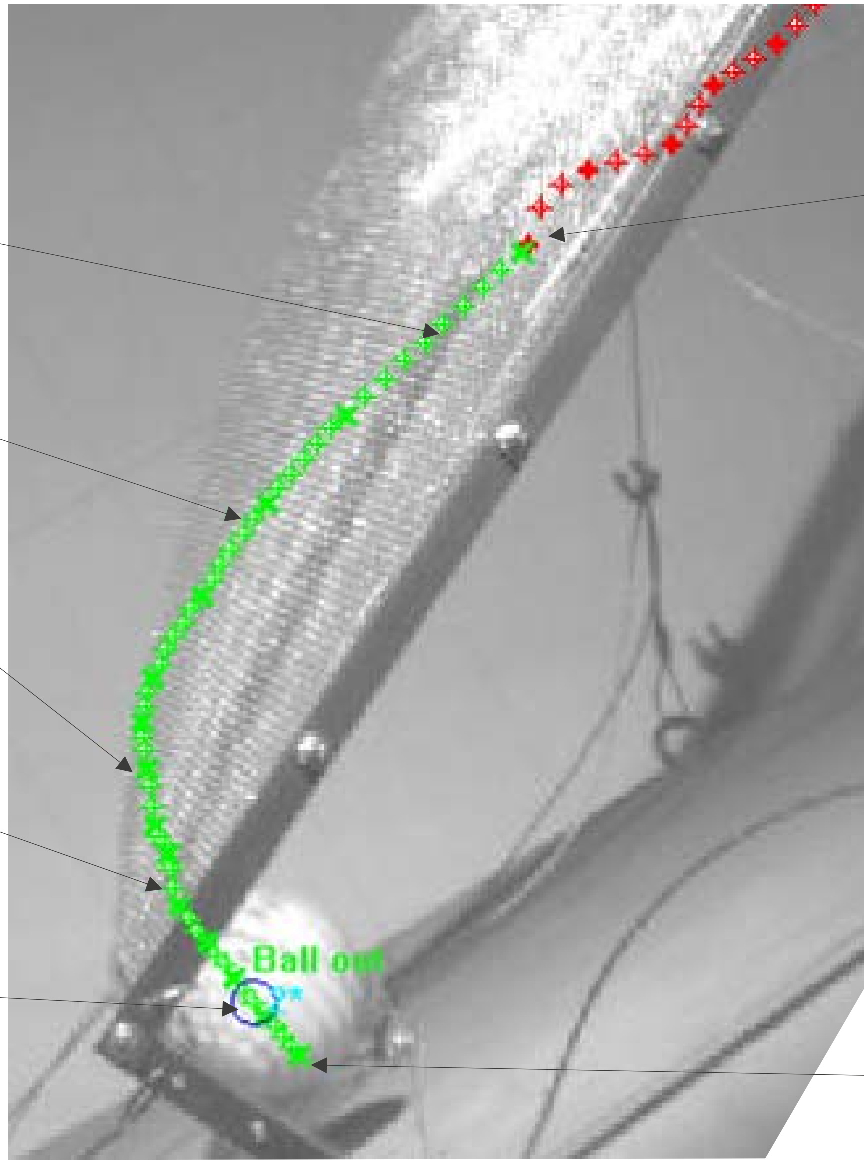

V_{70} = 11.78 m/sec

V_{80} = 10.37 m/sec

V_{90} = 8.42 m/sec

V_{100} = 9.48 m/sec

V_{110} = 9.33 m/sec

Frame 59: ball first contact with net

Frame 115: ball leaves contact with net

56 frames (0.047 s)
in contact with net

Wave net test 34-2

Date: 2012

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02

EXAMPLES OF ATTENUATOR INSTALLATIONS

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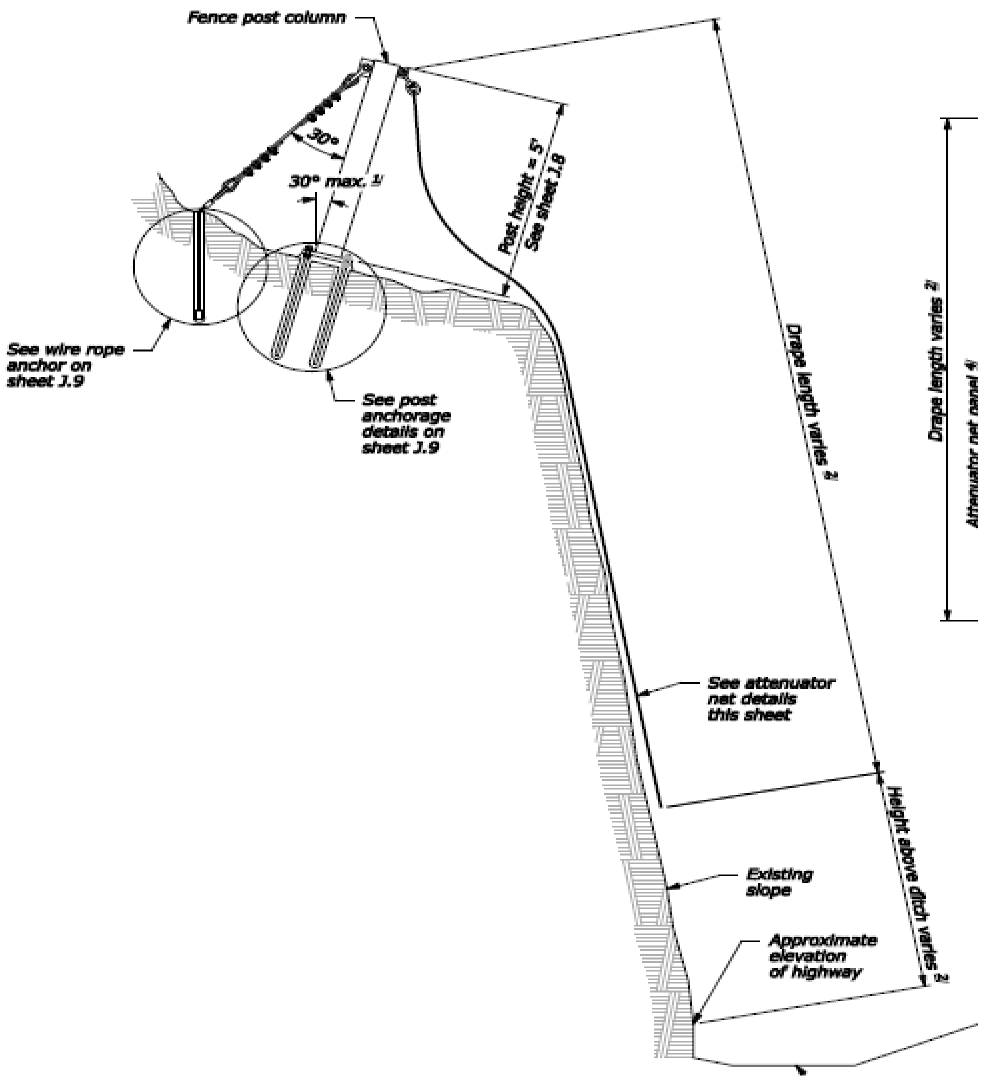
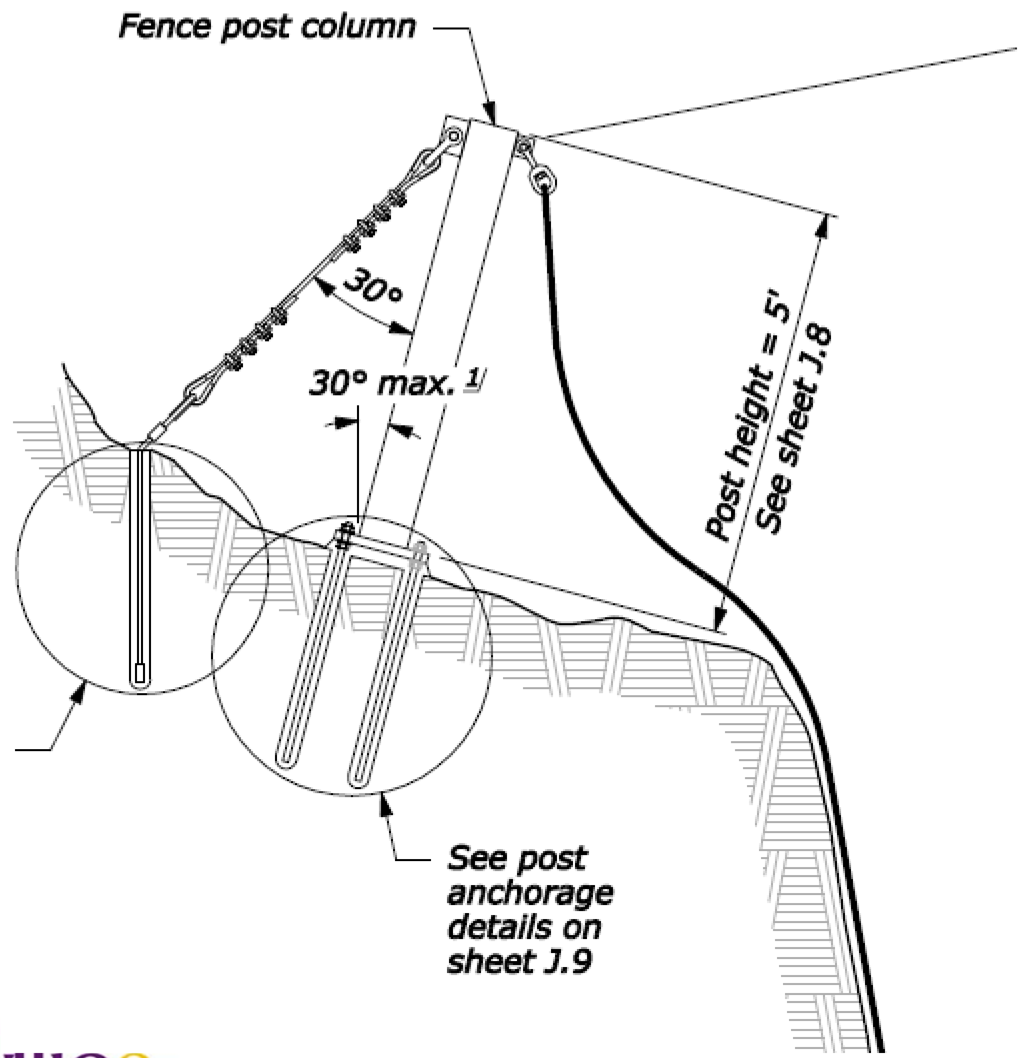
TYPICAL ATTENUATOR FROM WASHINGTON STATE, USA

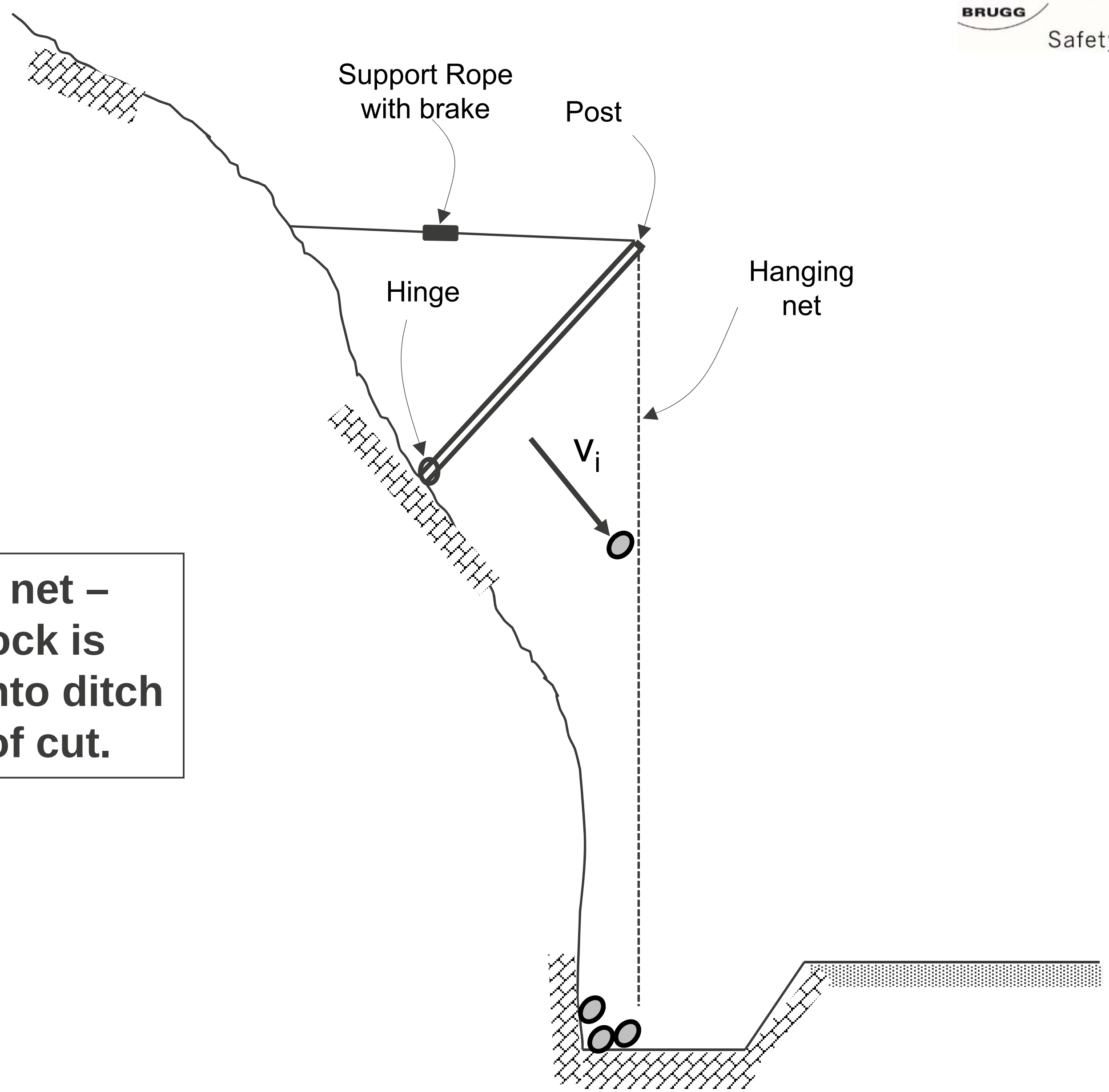


TYPICAL ATTENUATOR FROM WASHINGTON STATE



- The system components are strictly specified
- Structural Design that is not tested
- Anchor and post forces based on calculations
- These forces are very high due to static loads from the mesh and external loads (ice)

TYPICAL NA ATTENUATOR RCN S4-250 KETCHUM-CHALLIS, IDAHO



Hanging net – falling rock is deflected into ditch at base of cut.

ATTENUATION STRUCTURE – HANGING NET

Rock falls from height of 750 ft. contained by net across gully.
Maintenance required after 24 years

Attenuator under construction at base of 780 ft. high slope

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Attenuator spans gully below rock fall source area at height of 1600 ft.

For high energy impact, hinged bases and brakes on guy wires allow Attenuator to deflect with no damage to net components. Repair involves re-standing posts and replacing brakes.

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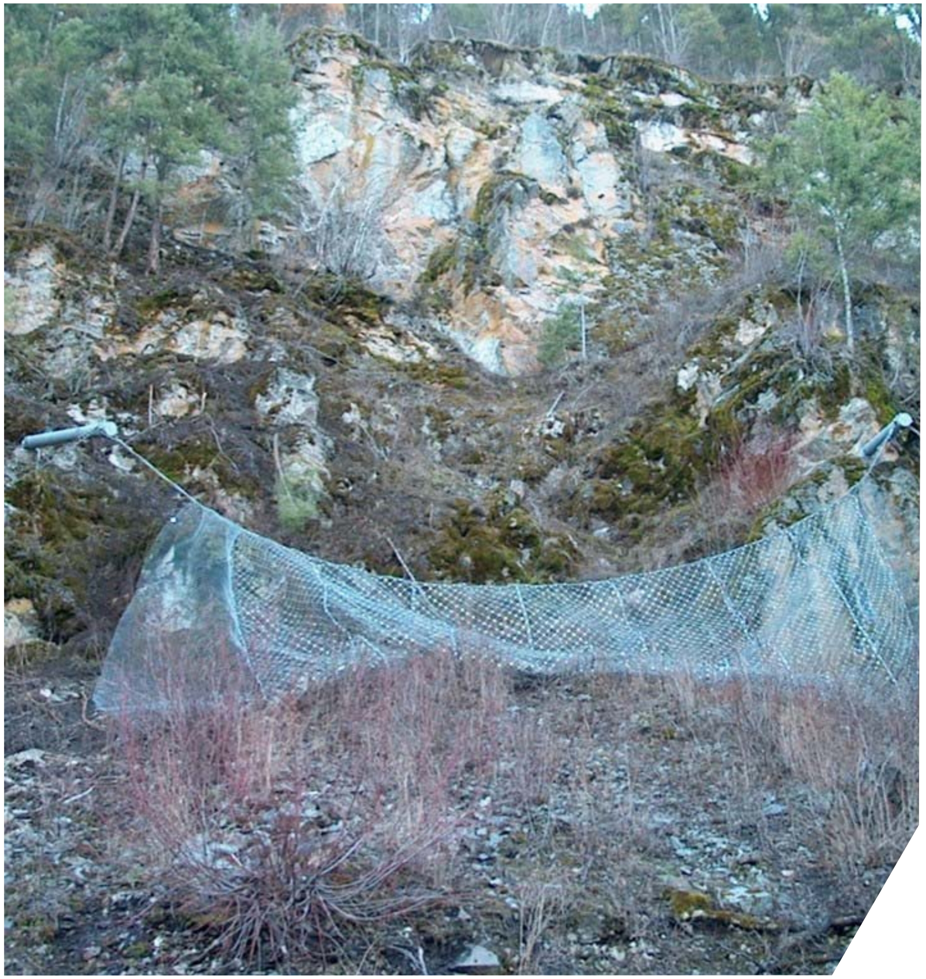

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- CONCRETE BLOCKS (UNCONNECTED) FORM OUTER FACE OF DITCH AT BASE OF ATTENUATOR. ALTERNATIVELY USE GABIONS.

03

FULL SCALE TESTING OF ATTENUATORS

GOALS OF CANADA TESTING

- RXE-1,000 Attenuator System in 1:1 Field Test
  - Acquire deflection and forces
  - Impact energies higher than previously tested:
    - Geobrugg tested SPIDER Attenuator to 200 kJ
    - Other research up ~400 kJ

GOALS OF CANADA TESTING

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- Evaluate impact mechanic theories to produce more efficient rockfall barriers/attenuators
  - Small, efficient systems that will be able to control bigger rockfall events at lower cost
- Collect data to help develop attenuator system designs
  - Design methodology relating attenuation and impact mechanics

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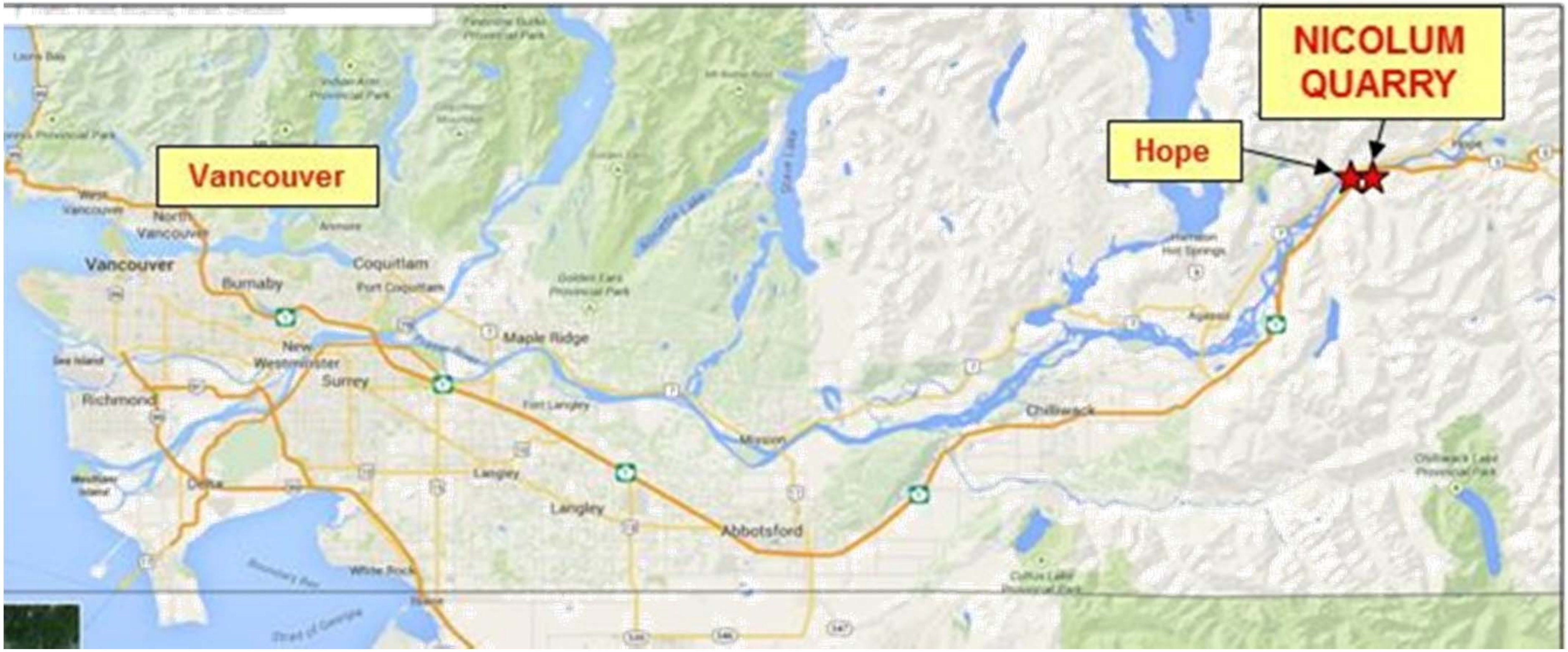
TEST SITE


NICOLUM QUARRY
Hope
Vancouver
Coquitlam
Burnaby
Richmond
Surrey
Maple Ridge
Langley
Abbotsford
Mission
Chilliwack


Nicolum Quarry


Main Haul Road between highway and quarry
Test block drop zone
Highway 3
Attenuator

ATTENUATOR TEST SITE
200 FT. DROP HEIGHT

CONDUCTED PRE-TEST ROCK ROLLING

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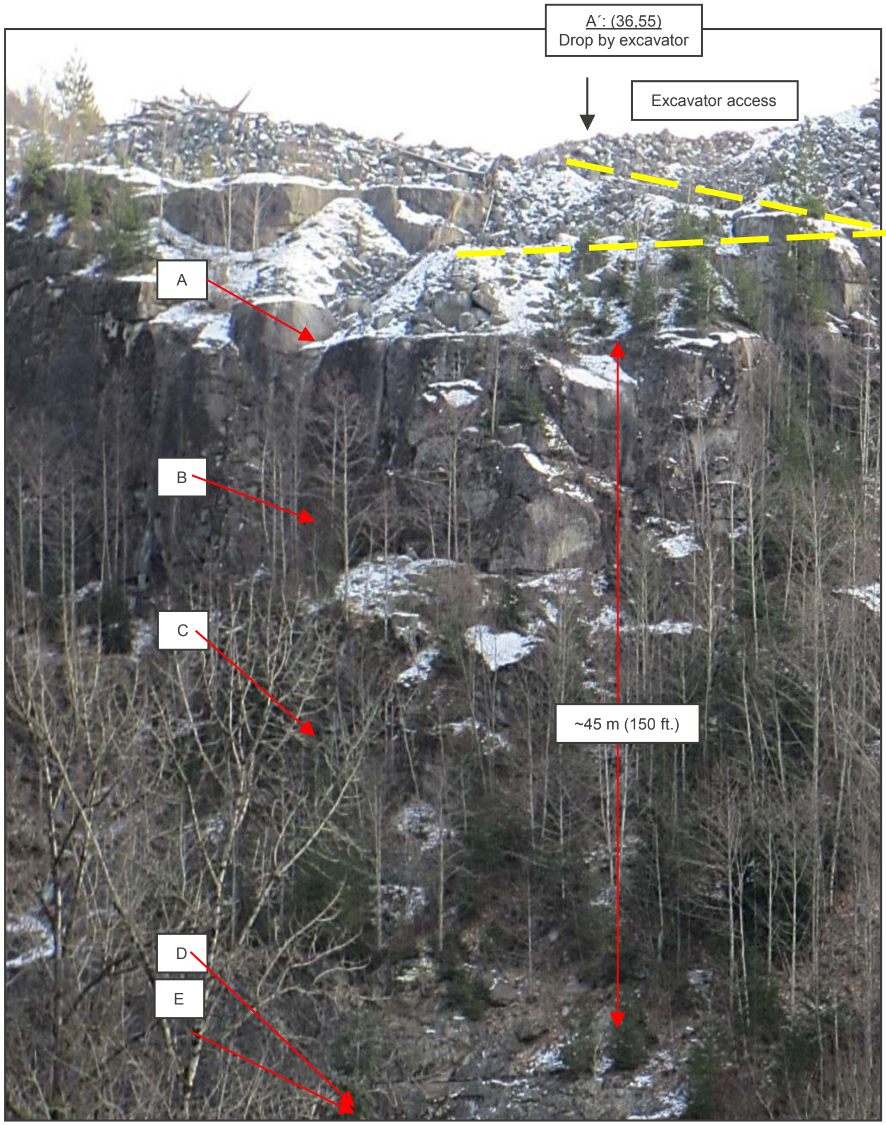

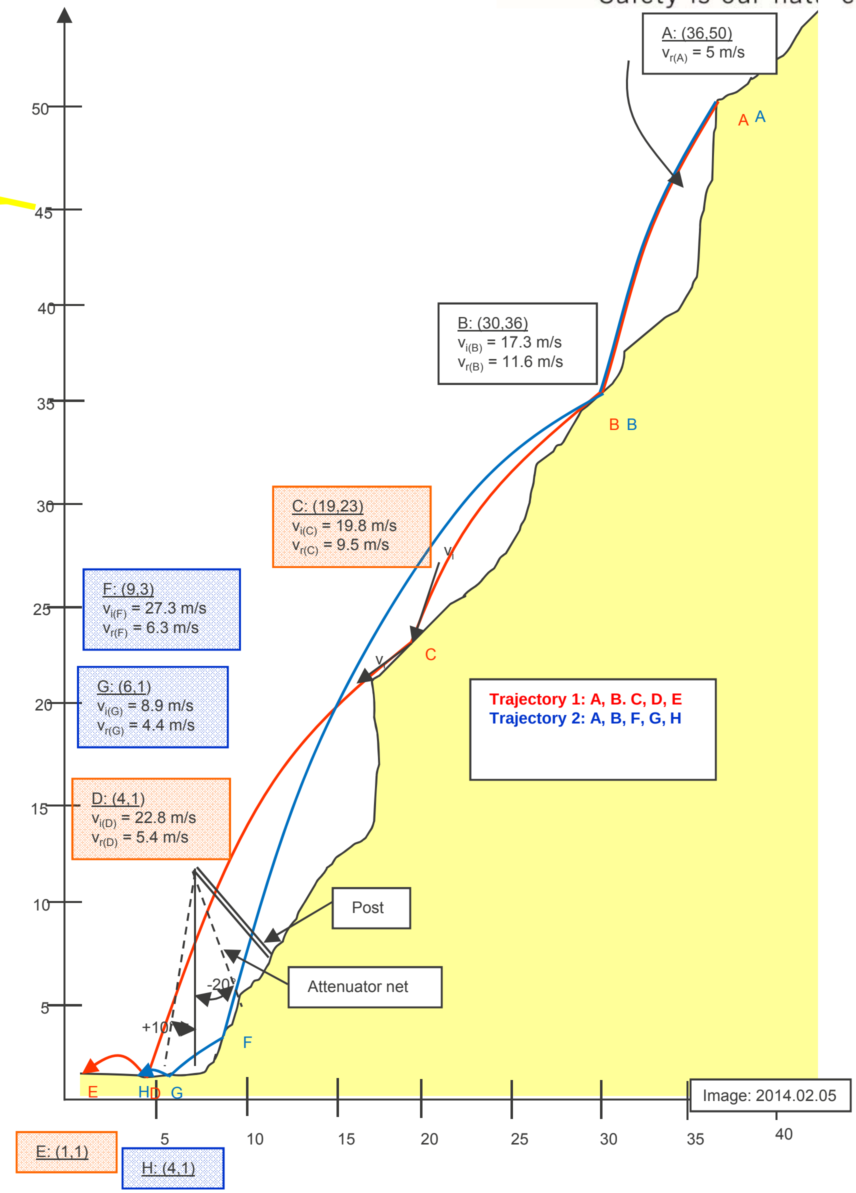

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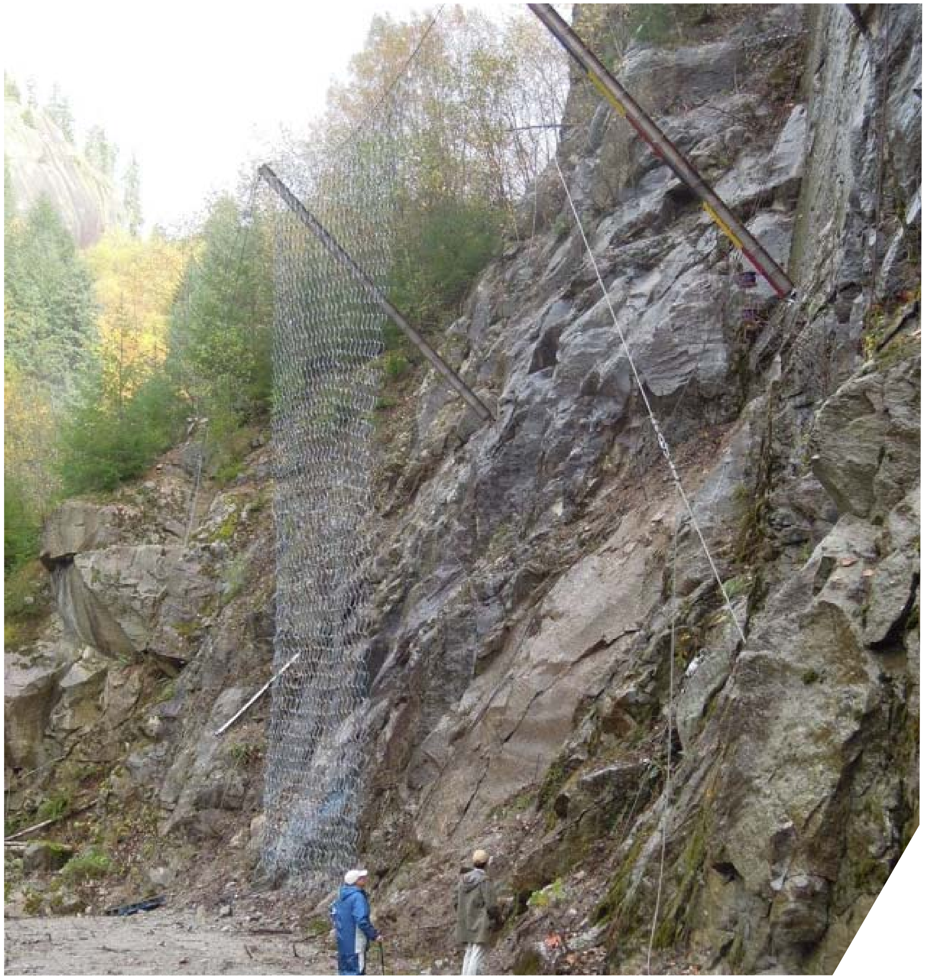
Net dimensions:
36 ft. high by 40 ft. wide
Posts: 25 ft. long.



Drone's-eye view of
attenuator test site

Trim blasting to remove remnant benches and focus rock falls in gully

TEST BLOCKS:
2240 LB. AND 5540 LB.

Blocks heavily reinforced to withstand impact

04

INSTRUMENTATION OF TEST INSTALLATION

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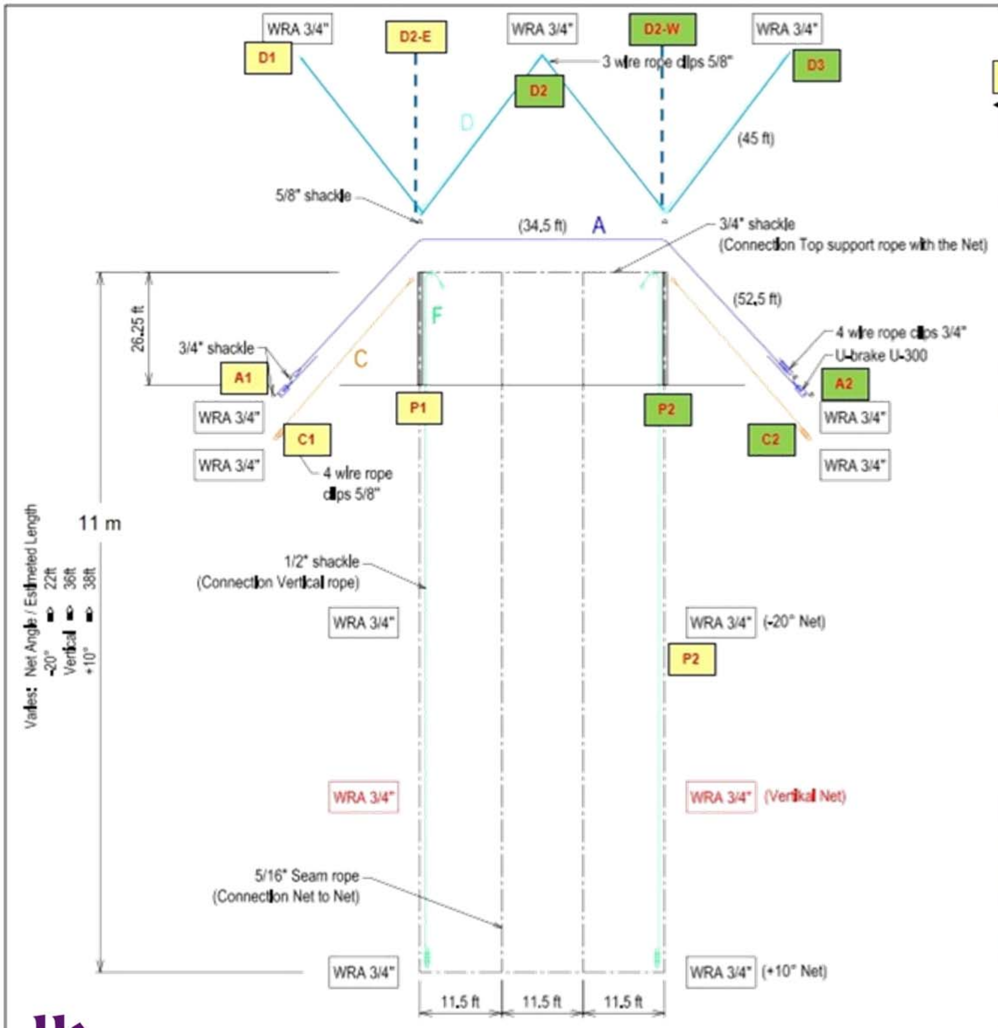

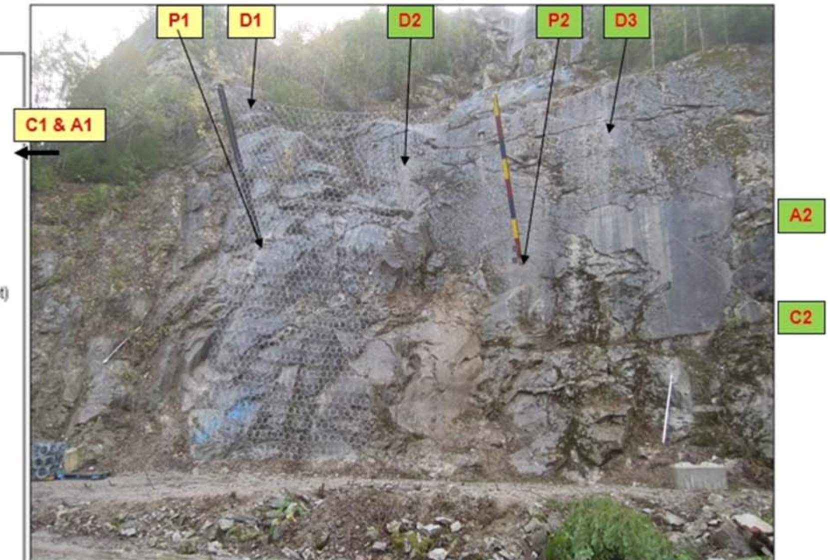

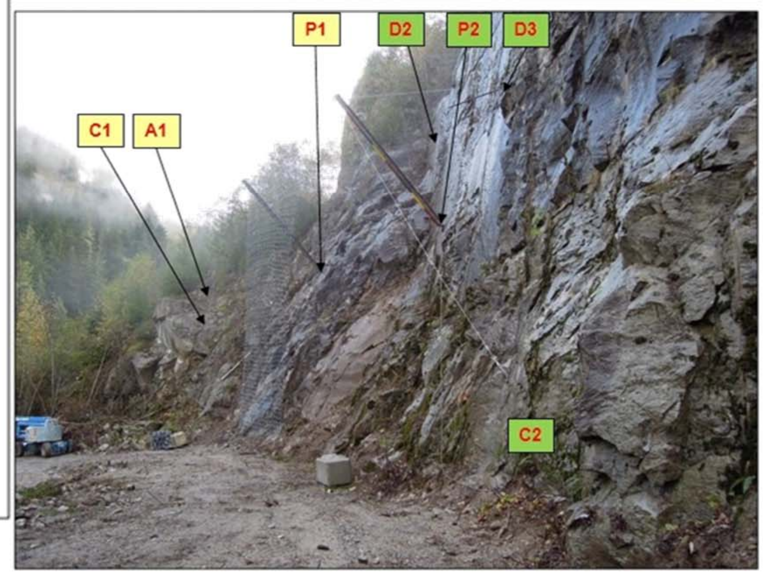

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TEST BLOCKS AND ROCKS WEIGHED WITH CRANE SCALE

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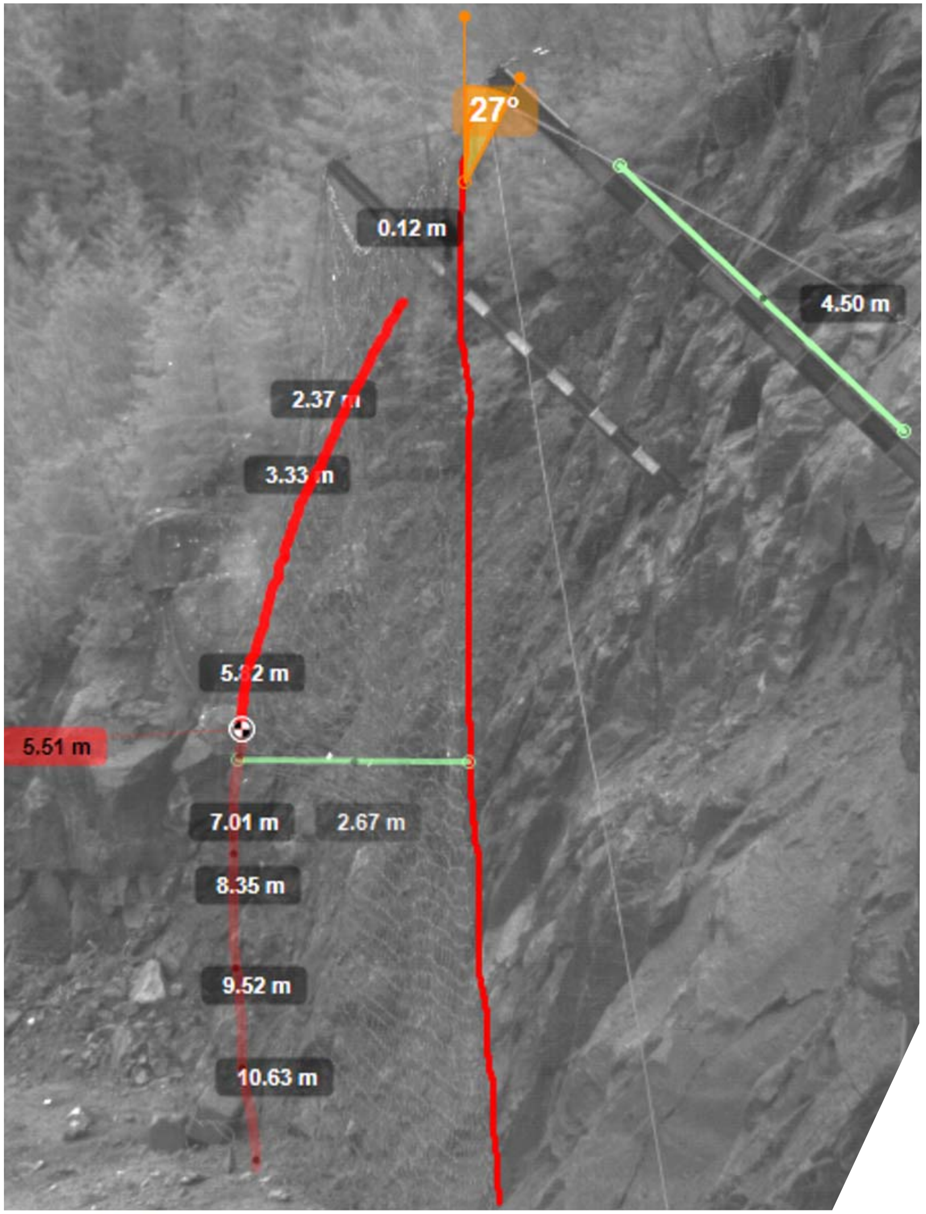
ATTENUATOR CONSTRUCTION

Load cells on guy wires with data acquisition system recording at 2000 Hz.

- Data acquisition system recording at 2000 Hz
- Trigger starts all instrumentation simultaneously



- Trajectories recorded with camera running at 1200 fps
- Velocities measured with video analysis software
- Deflection measured against scale

SMART ROCKS CONTAINED:

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- 3-D accelerometers
- 3-D gyroscopes
- Data acquisition system 2000 Hz

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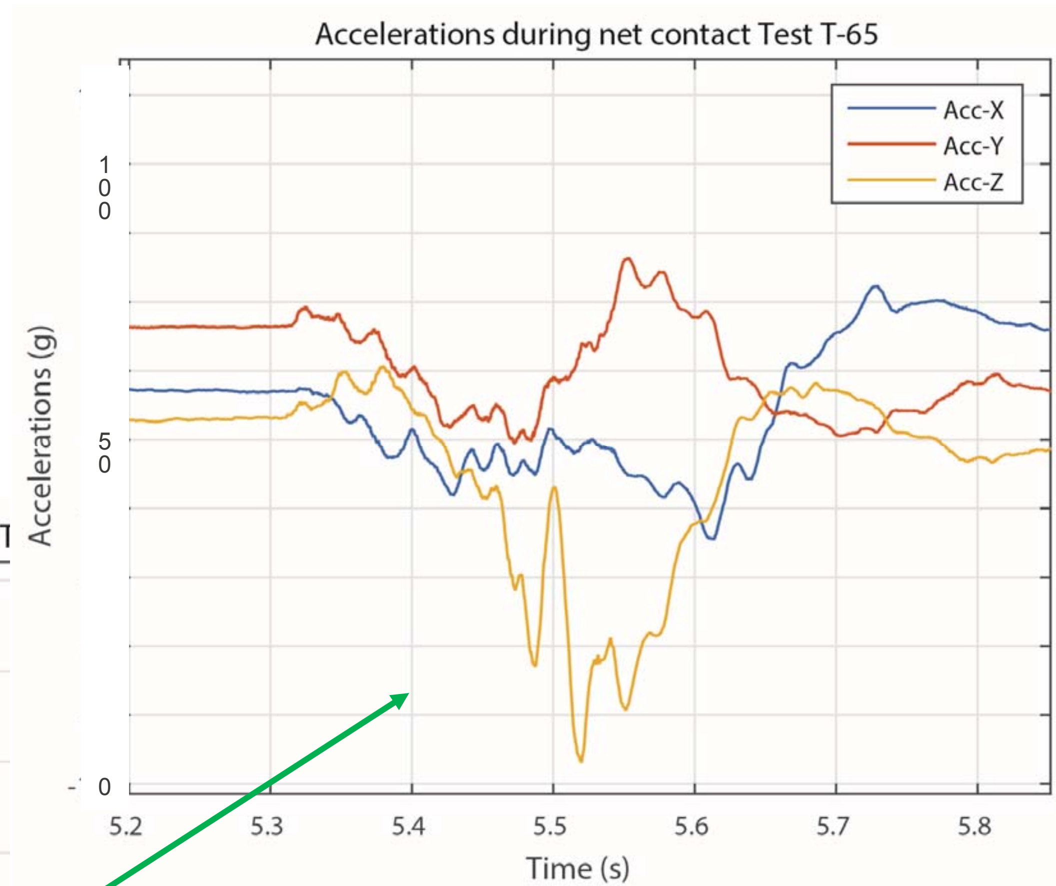
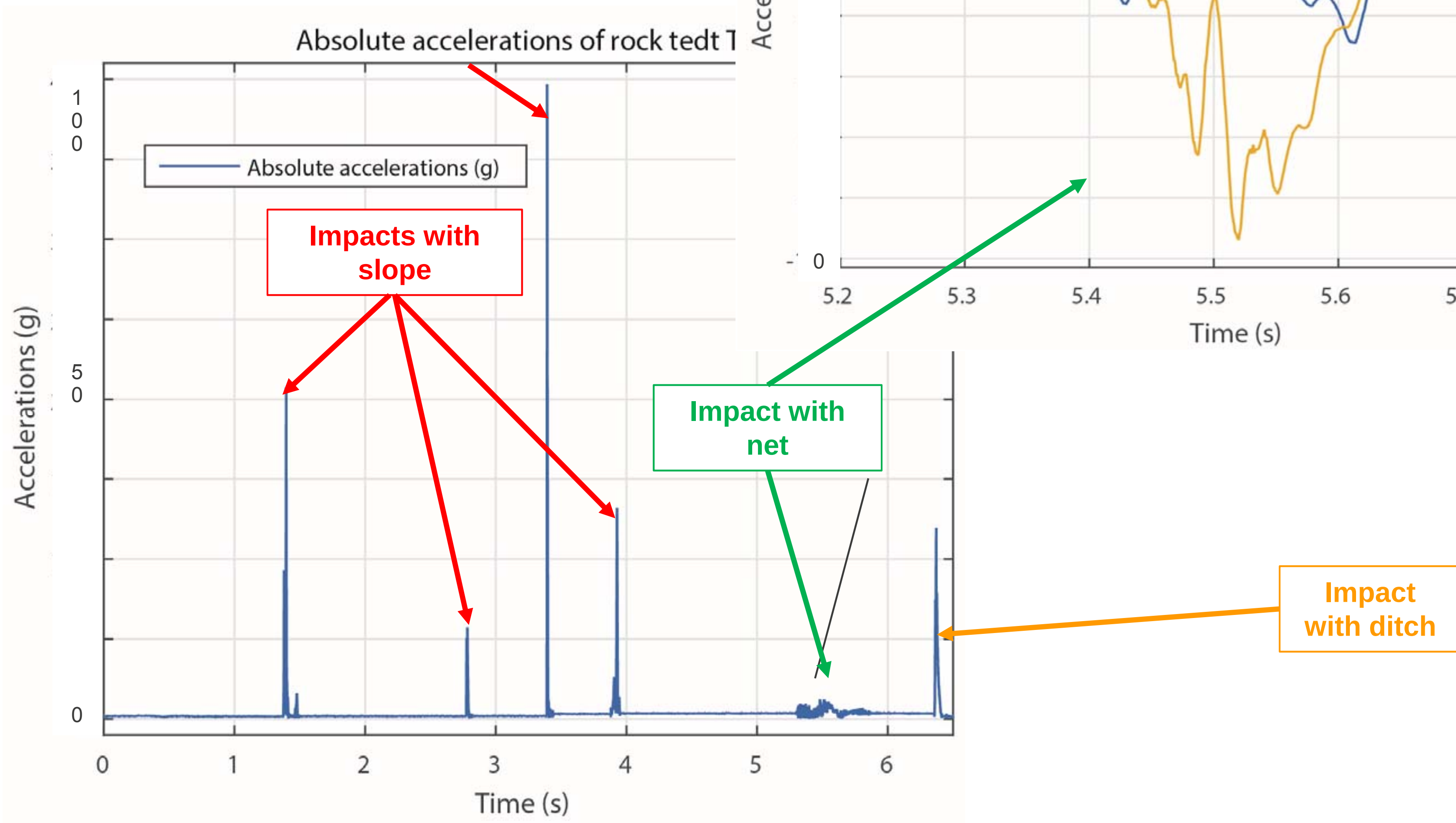
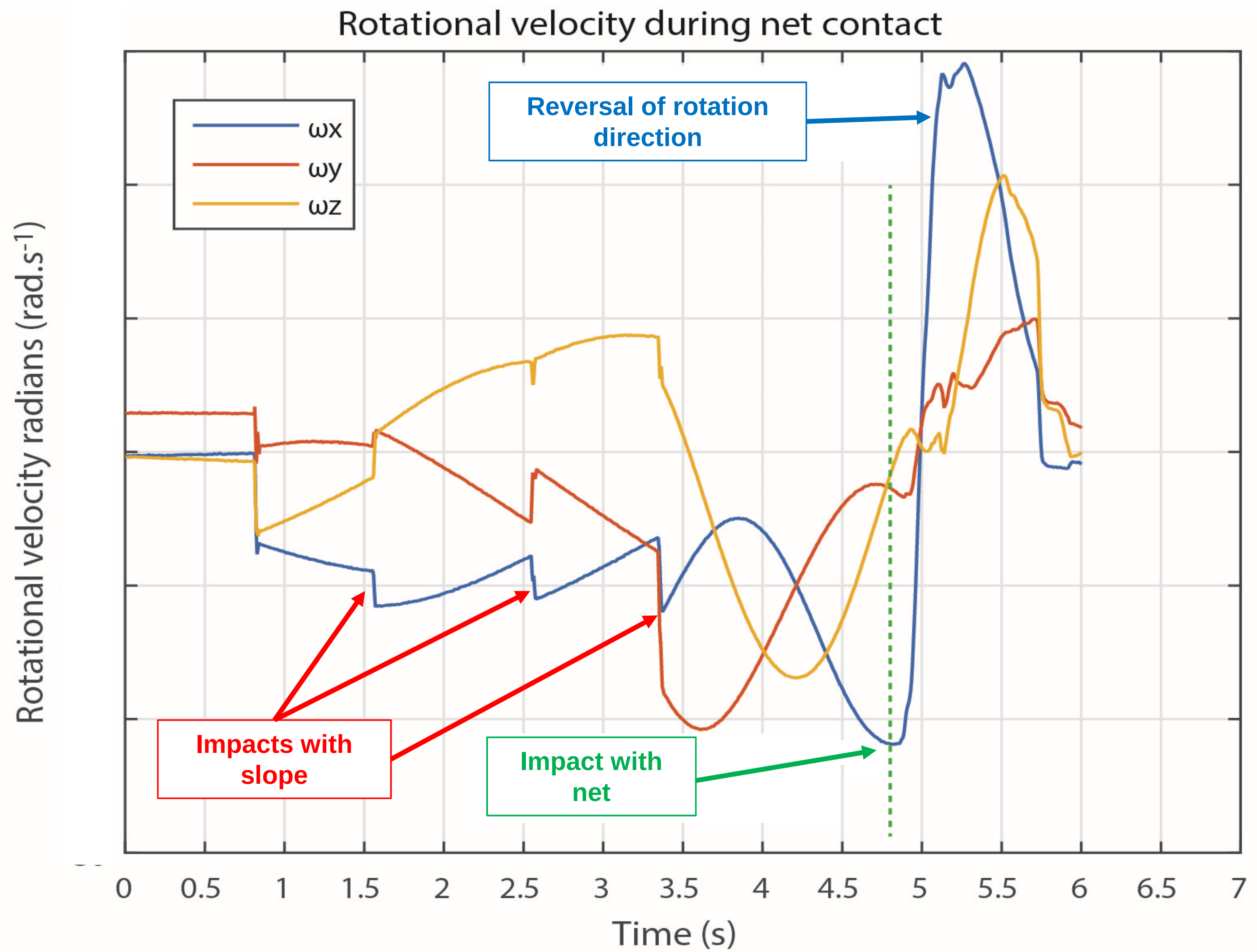
ATTENUATOR RESPONSE TO IMPACT

Accelerometers record G forces at impact

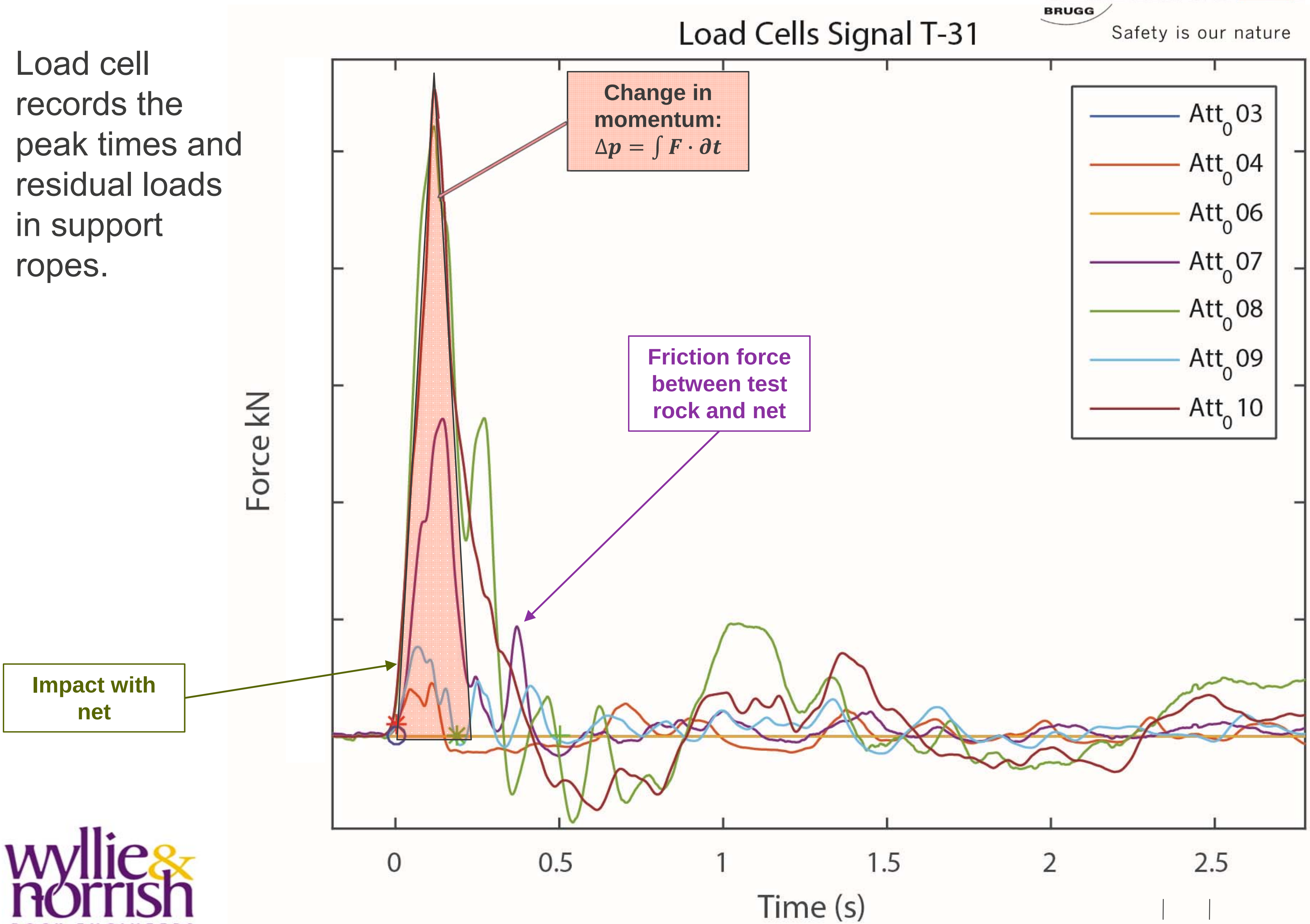




Rotational velocity changes at impact points.
Reverses during impact with net.



Load cell records the peak times and residual loads in support ropes.



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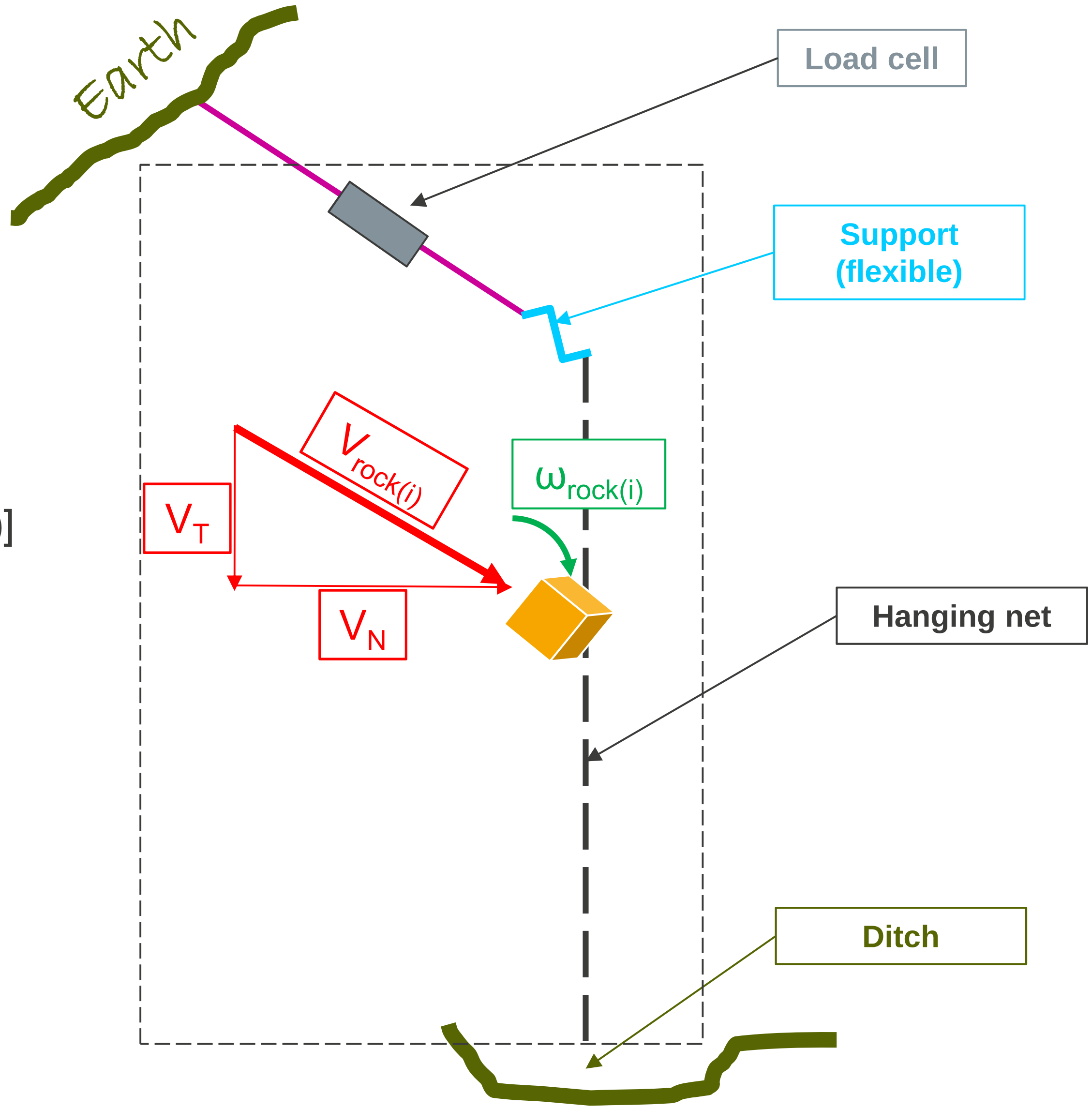
06

PRINCIPLE OF ATTENUATOR FUNCTION

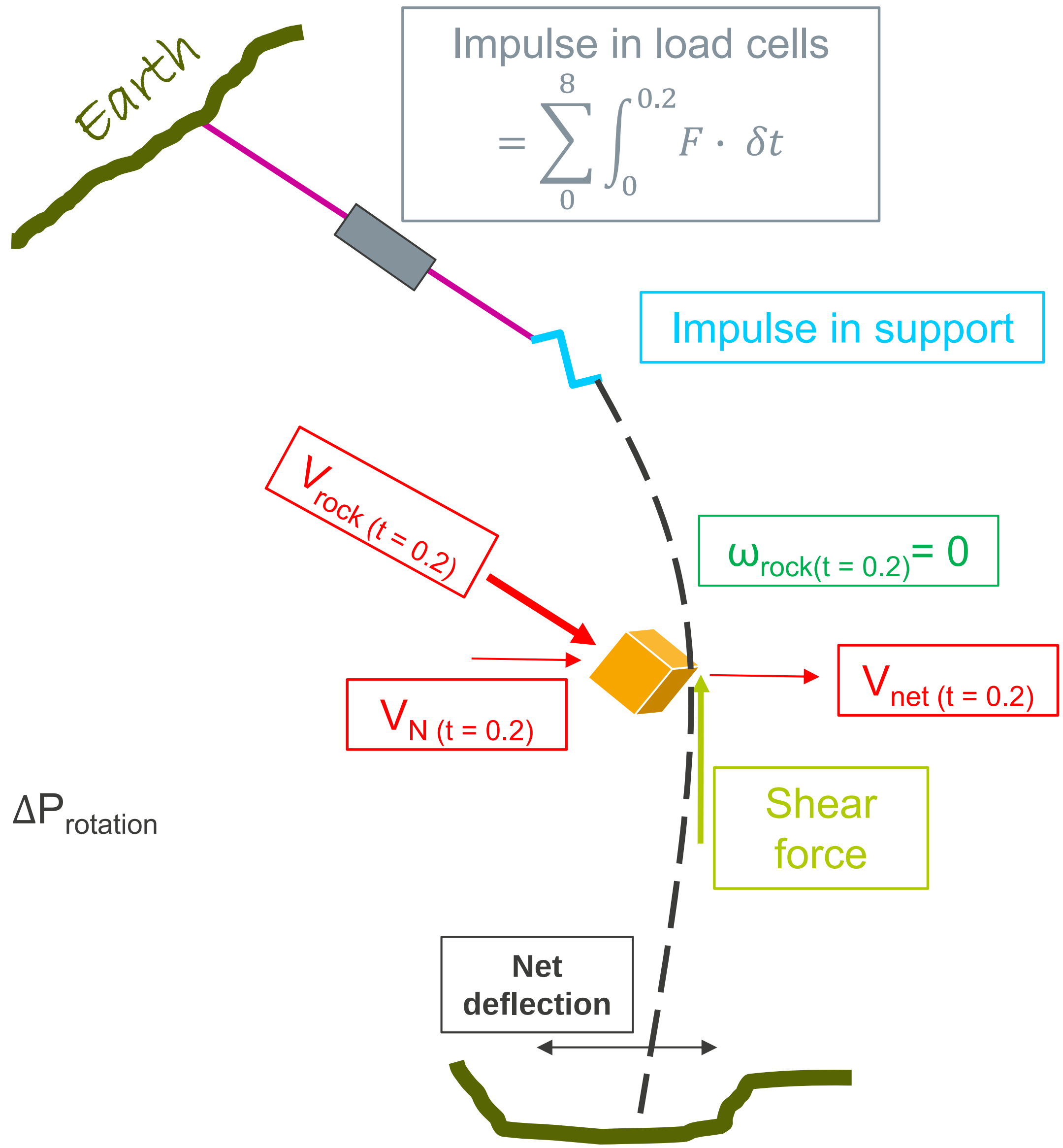
1. Momentum (P) of rock at impact with net, t = 0

Impact momentum

$P_{rock} = [m_{rock} \cdot V_{rock(i)}] + [I \cdot \omega_{rock(i)})]$



2. Momentum (P) of rock at maximum force in net, t = 0.2 s



Conservation of momentum

Momentum at t = 0

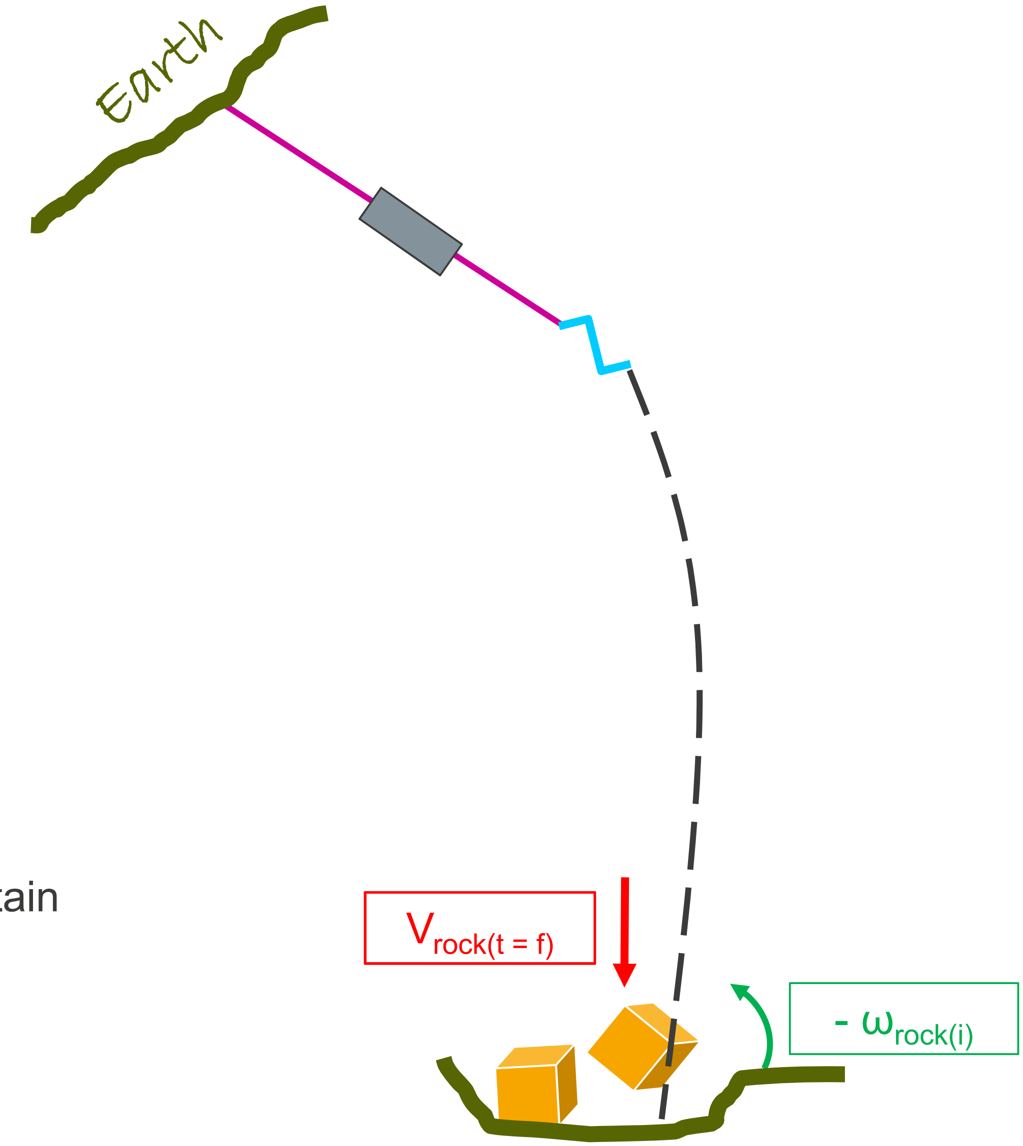
$P_{rock} = [m_{rock} \cdot V_{rock(i)}] + [I \cdot \omega_{rock(i)}]$

$\Delta P_{rock} = \quad \Delta P_{net} + \quad \Delta P_{LC} + \quad \Delta P_{support} + \quad \Delta P_{rotation}$

Momentum at t =0.2 s

$\Delta P_{rock} = [m_{rock} \cdot (V_{rock(i)} - V_{rock\ (t=0.2]})] = [m_{net} \cdot V_{net(t=0.2)}] + [\int_{0}^{0.2} F_{LC} \cdot \delta t] + [\Delta P_{support}] + [I \cdot \omega_{rock(i)})]$

3. MOMENTUM (P) OF ROCK AT IMPACT WITH DITCH



Reverse rotation helps to retain rock fall in ditch

CONCLUSION

1. Model and full-scale testing show that Attenuators redirect falls into the ground without stopping
2. It is possible to design efficient rock fall protection structures that absorb only a portion of the impact energy.
3. Attenuators are self-cleaning, and have limited deflection.

Thank you