Steep Slope Harvesting: Understanding Soil-Machine Interaction through Ground Pressures

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Mechanized Steep Slope Harvesting

- Tethered, Steep Slope Harvesting is a promising new technology.
- Possibility to reduce soil impacts, improve safety but site-specific and must consider some physics.
- Namely, gravity and ground pressure.
The Considerations

Safety Considerations
• Pros
  – Less exposure to falling trees, protected in cab
  – More productivity
• Cons
  – Potential sliding, toppling hazard
  – Need experienced operator

Soil Considerations
• Pros
  – Potential to reduce soil impacts through reduced ground pressures
  – Potential to improve mobility
• Cons
  – Heavy equipment on slopes can result in disturbance if not careful
How do we prioritize?

• Use of a cable winch provides potential to have the best of both worlds:
  – Increased stability
  – Increased mobility
  – Reduced ground pressures
  – Reduced soil disturbance

*BUT, How much cable tension is enough?*

*What soil conditions are optimal for operation?*
The typical engineer’s answer:

*It depends!*
Why the engineering answer?

• Equipment operation dependent on several critical factors:
  • How much cable tension is available?
  • How is the machine oriented (Downhill? Uphill? Leveled? Is the boom in or out? Is a tree being handled or cut?)
  • What soil is present? What are the moisture conditions?
The Physics - Gravity

Center of Gravity

Weight

Ground Pressure
The Physics – Ground Pressures
The Physics – Soil Disturbance

Sliding/Slip

Rutting/Bearing Capacity

Compaction

All dependent on ground pressures…
Tether Tension Affects Ground Pressures
Field Testing – Real Ground Pressures

Series of field tests performed, monitored ground pressures. Research is ongoing…
No Cable Tension

- Facing Downhill, Boom In
- Facing Uphill, Boom In
- Facing Downhill, Boom Out
- Facing Uphill, Boom Out

High pressure at base, increases likelihood of sliding

Low pressure, little contact with ground
9,000 lbs of Cable Tension

- Facing Downhill, Boom In
- Facing Uphill, Boom In
- Facing Uphill, Boom Out
- Facing Downhill, Boom Out

Front pressures effectively reduced
Rear pressures increase, tracks are fully engaged
20,000 lbs of Cable Tension

- Facing Downhill, Boom In
- Facing Uphill, Boom In
- Facing Uphill, Boom Out
- Facing Downhill, Boom Out

Pressure (PSI)

Legend:
- Bottom
- Mid-Bottom
- Mid-Top
- Top
Pressure Distributions - Downhill

![Graph showing pressure distributions with different tension levels.](image-url)
Pressure Distributions - Uphill

Base of tracks see lower pressures.

Rear tracks engage.
What does this mean?

- Tracks are better engaged throughout their entire length cable tensions (better mobility)
- Ground pressures decrease (less soil disturbance, more stable)
- Downhill operation is improved by reducing maximum track pressures.
- Uphill operation is improved by better distributing ground pressures.
Soil Interaction

- Stability considerations:
  - Sliding
- Soil Considerations:
  - Sinkage (Bearing Capacity)
  - Slip (Displacement)
  - Compaction
- Function of Soil Types
Soil Types

- **Fine-Grained (Fine-Textured)** – stays wet, slippery at higher moistures, clumps on your shoes, in your hands – (has **cohesion**, not much frictional strength)

**Cohesion:**
- Like glue.
- Slip does not care about pressure but **track contact**.
- Rutting and compaction very sensitive to pressure.
Soil Types

- **Coarse-Grained (Coarse-Textured)** – dries and wets quickly, falls apart after squeezed,
- **Has a bit of cohesion depending on water**
- **Mainly frictional strength**

**Frictional Strength:**
- Slip does care about pressure.
- Rutting and compaction less sensitive to pressure.
Coarse Soils

- Sandy Soils have larger pore sizes, exhibit some “cohesion” from water surface tension when not saturated or dry.
- When saturated or dry, this apparent “cohesion” disappears.
Why?

• Let’s take a unwanted trip back to chemistry class.
• Remember the meniscus in the test tube?
• This is due to water’s surface tension. It occurs in the small “test tubes” – same as soil pores!
• This is how you build a sand castle! It also helps prevent disturbance in sandy soils.
This suction increases sliding stability marginally, but has a great impact on bearing pressure and sinkage.

*Water can help in sandy soils – to a certain extent!*
Soil Displacement

• One common means of soil disturbance is displacement.
• Can be from rutting (bearing capacity) or “slip”.
• Slip requirements makes a major difference for required cable tensions, especially for dry or saturated sands (below).
Soil Displacement

- When some suction or “apparent cohesion is present, slip is less likely. Below is 50% saturated.
- Cable tensions can reduce slippage and displacement.
Fine-Grained, Clay Soils

- Clay soils often provide cohesive strength for movement and sinkage.
- This cohesion decreases rapidly with increasing saturation.
Saturation in clay soils greatly affects sliding stability and sinkage/bearing capacity.

*Water is not your friend in Clay soils.*

110 PSI  
21 PSI  
7.5 PSI
Soil Displacement

- One common means of soil disturbance is displacement.
- Can be from rutting (bearing capacity) or “slip”.
- Slip requirements makes a major difference for required cable tensions.
Practical Implications

• One test included harvester on 48% slope with **no tether**.
• Machine could not remain stable on slope of saturated clay soils. It went skiing!
• Thankfully, a tree and bench on the slope stopped the machine.
• Let’s analyze the situation – soil disturbance and safety concerns could have been avoided with a tether.
Slip n’ Slide

No Name Brand
Actual Case – Downhill Orientation
What if the boom and machine were facing uphill?
Compaction

• Compaction is a common form of soil disturbance.
• Occurs when the soil is not too dry, not too wet (Goldilocks problem)
• Coarse-textured soils not prone to as much compaction (except from vibration), prone to displacement when dry.
• Finer-textured soils prone to more compaction, particularly in that moisture “sweet spot” (Optimum Moisture Content)
Max Dry Density

Optimum MC
Challenges

• Certain soils maintain high moistures year round (Clay)
• Operating on very wet clay soils may reduce compaction potential, but may increase displacements.
• Operating on dryer sandy materials may reduce compaction potential, but may increase displacements.
Harvester – No Tether Tension

![Graph showing the relationship between dry density and moisture content for different numbers of blows at various slope percentages.](image-url)
Harvester – No Tether Tension

![Graph showing the relationship between Dry Density (kg/m³) and Moisture Content (%) for different blow counts and slopes: 25 Blows, 15 Blows, 5 Blows, 5 Blows. The slopes are indicated for 80%, 50%, and 30%.]
Take-Away Messages

• **Soils are Complicated!**
• Ground pressures affect machine stability and soil disturbance.
• Coarse soils are best operated on when there is a bit of moisture. Stability does not vary much with moisture, but displacement does.
• Fine soils are best operated on when they tend to be less saturated. Stability and displacement varies greatly!
Take-Away Messages

• Use of cable assistance is useful at all slopes!
• Enables reduced ground pressures which provides:
  – Less soil displacement (slip and rutting)
  – Access to steeper slopes
  – Improved mobility
  – Improved stability
  – Less compaction (potentially)
• Uphill operation may be beneficial from a soil perspective due to better distribution of ground pressures.
• Every soil is different: know your site conditions, know your soil conditions.
Thanks for your Time!

Questions?