Tethered Equipment on Steep Slopes: Soil-Machine Interaction

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Steep Slope Harvesting

- Steep slope harvesting with tethered machinery a promising new technology.
- Provides alternative to conventional manual falling – a dangerous job on wet, steep slopes.
- However, equipment operation on steep slopes incurs new hazards and potential site disturbances that must also be considered.

A Balancing Act of Priorities

SAFETY CONSIDERATIONS

- **Pros**
  - Less exposure to falling trees, protected in cab.
  - More access to steep terrain and improved productivity (possibly).
- **Cons**
  - Potential sliding, toppling hazard.
  - Need experienced operator.

SOIL AND SITE CONDITIONS

- **Pros**
  - Potential to reduce soil impacts with cable assistance.
  - Potential to improve equipment mobility.
- **Cons**
  - Heavy equipment on slopes can result in more disturbance, compaction and rutting if not careful.

How do we choose?

- Recent addition of a cable winch to heavy equipment provides potential to have the best of both worlds:
  - Increased stability
  - Increased mobility
  - Reduced peak ground pressures
  - Reduced soil disturbance

How much cable tension is enough?

What soil conditions are optimal for operation?

IT DEPENDS!

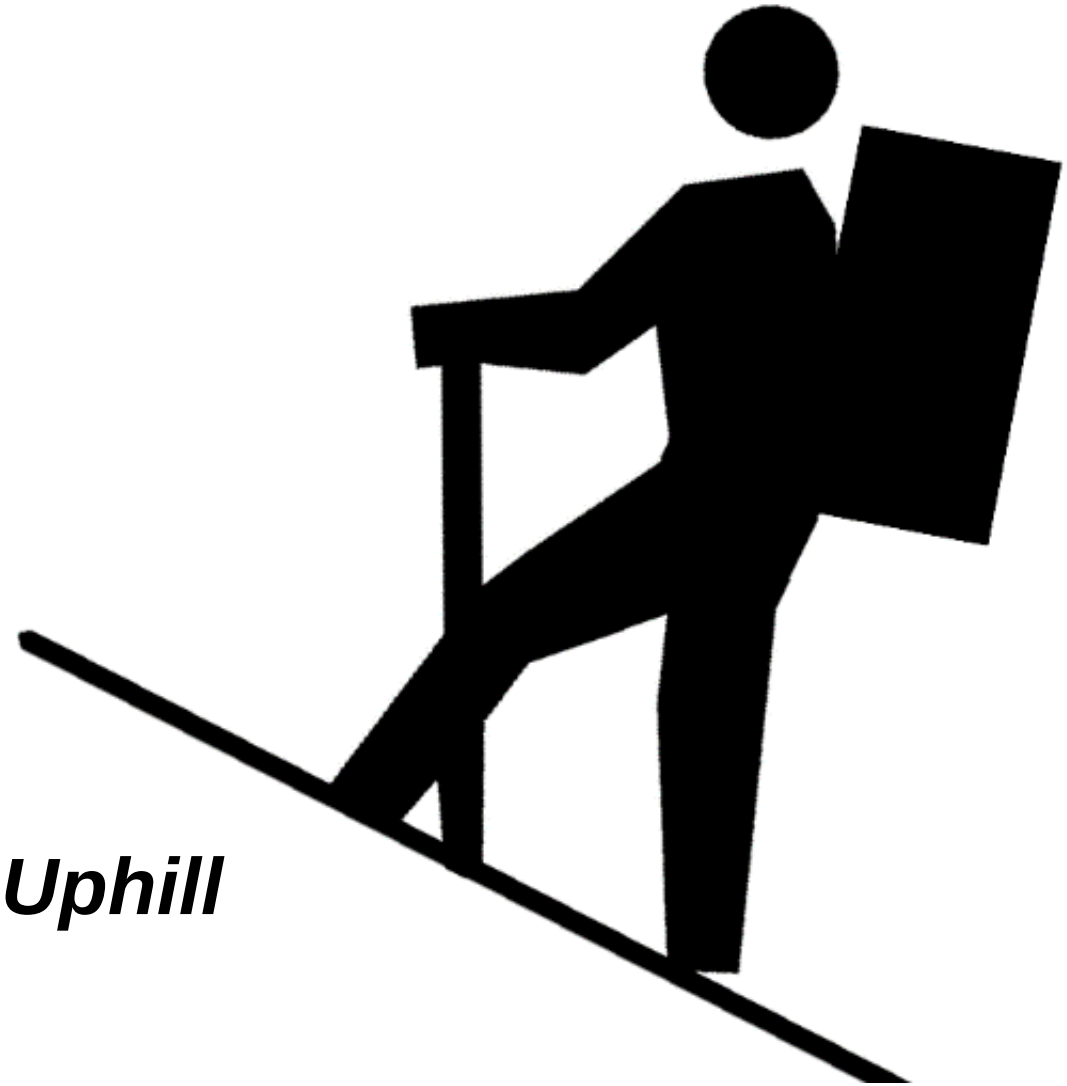
Why does “it depend”?

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

How does cable assist *actually* help?

- It is all based on a simple concept we all intuitively understand.
- Let’s think about walking on steep terrain.

You are hiking either uphill or downhill.



Uphill

Downhill

Think about your balance.

Let’s think about center of gravity.

Uphill
Balanced

Downhill
Imbalanced

Think about your traction.

What about your traction?

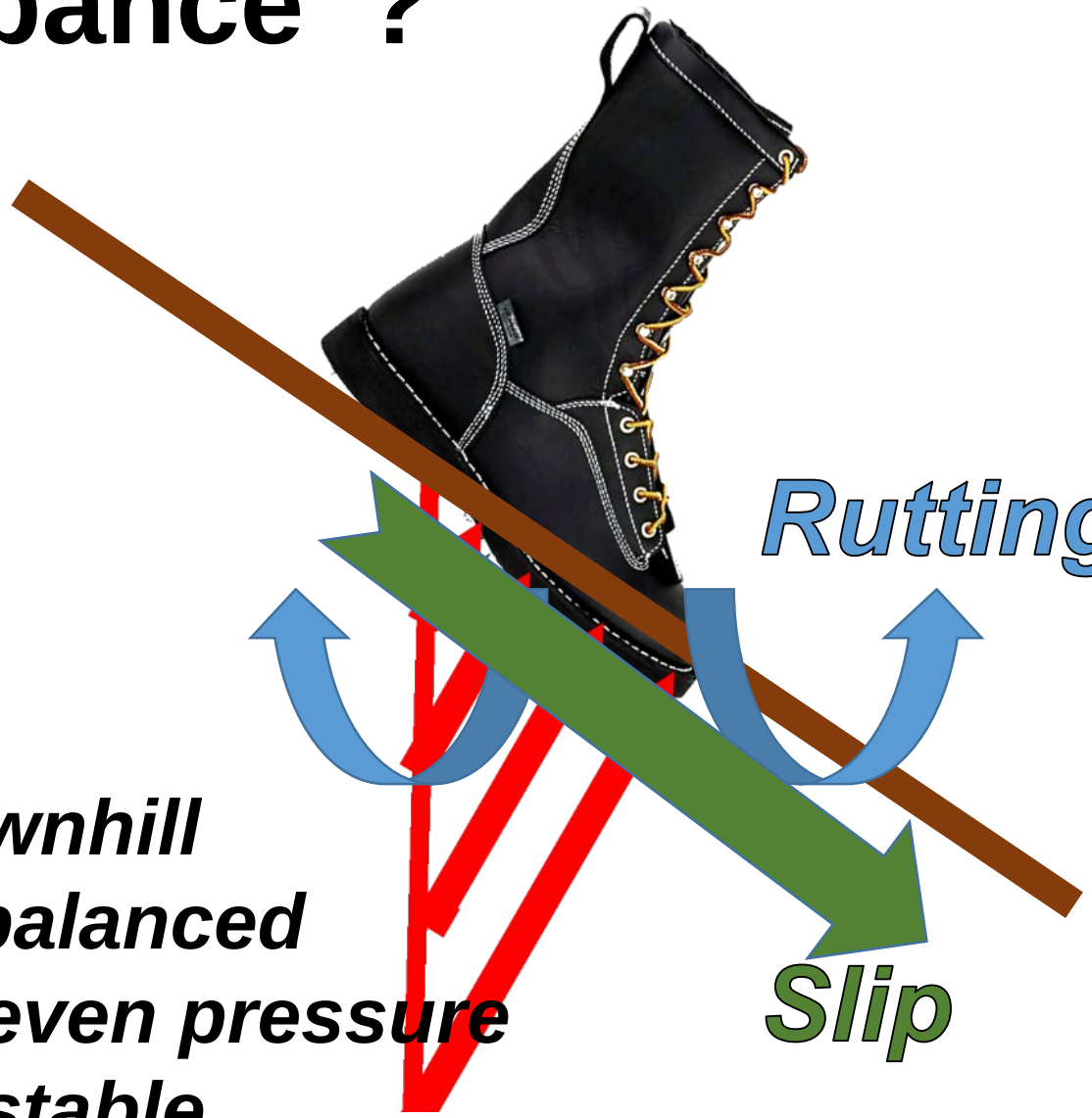
Uphill
Balanced
Even pressure

Downhill
Imbalanced
Uneven pressure

Think about what is more stable.

Stability and “disturbance”?

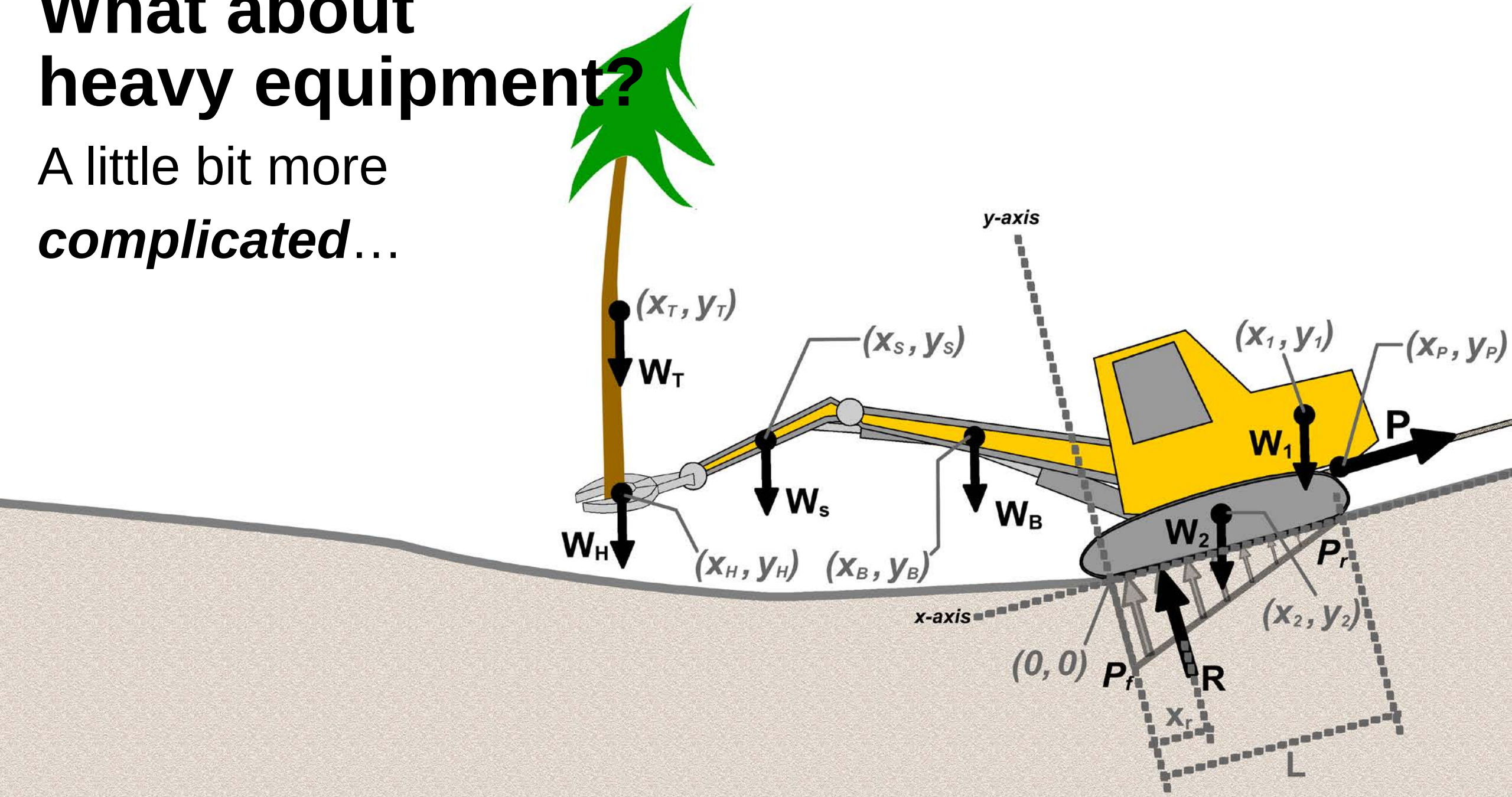
Uphill
Balanced
Even pressure
Stable



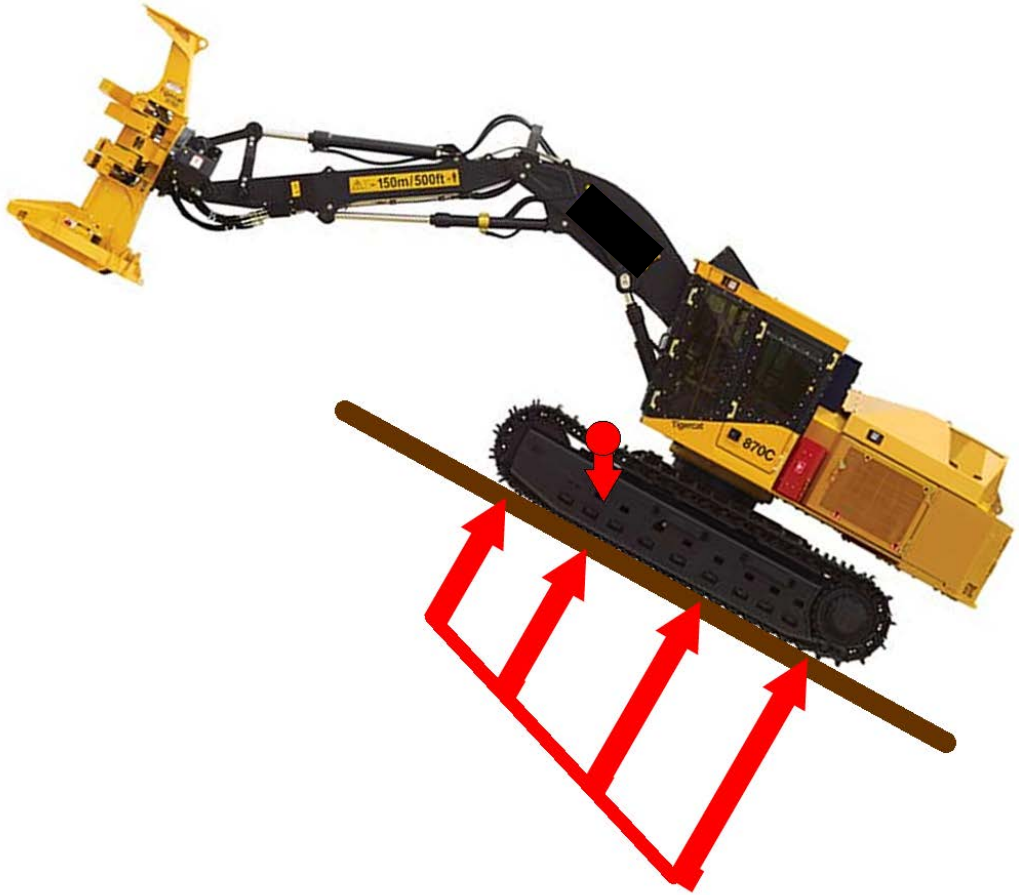
Downhill
Imbalanced
Uneven pressure
Unstable

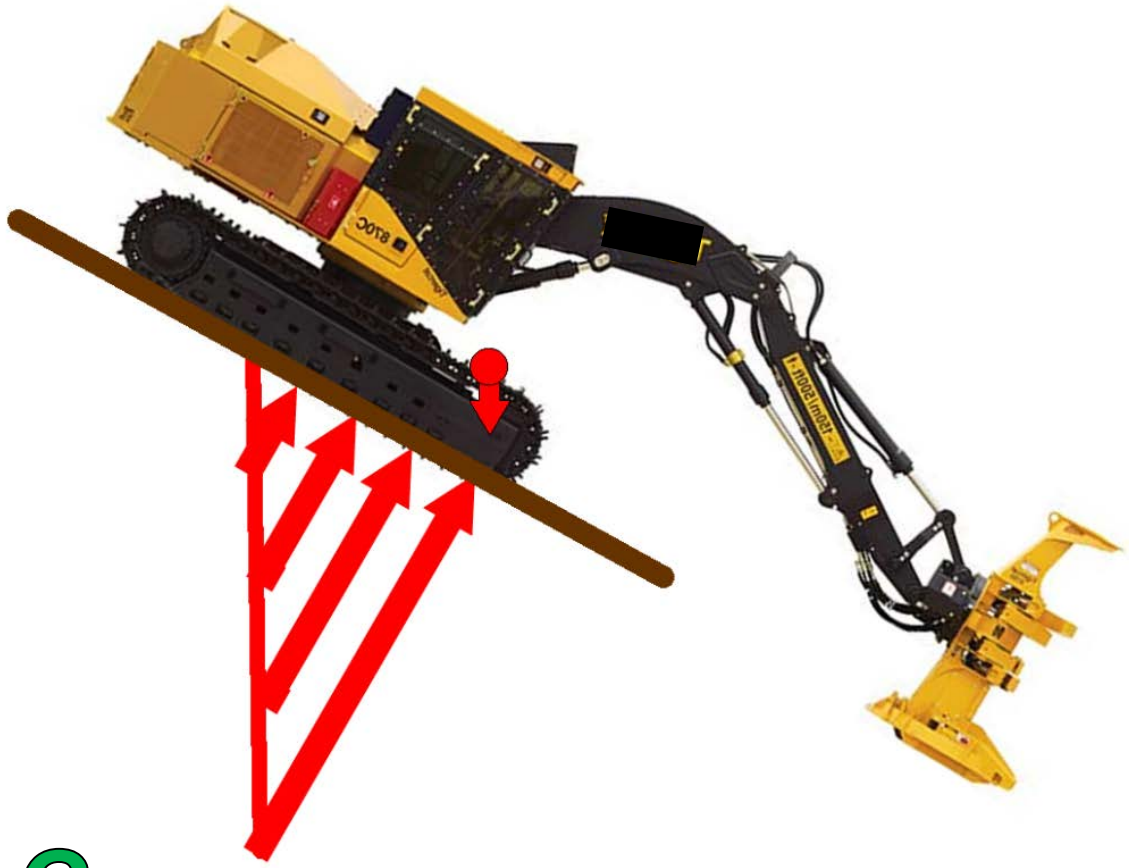
What about heavy equipment?

A little bit more ***complicated***…



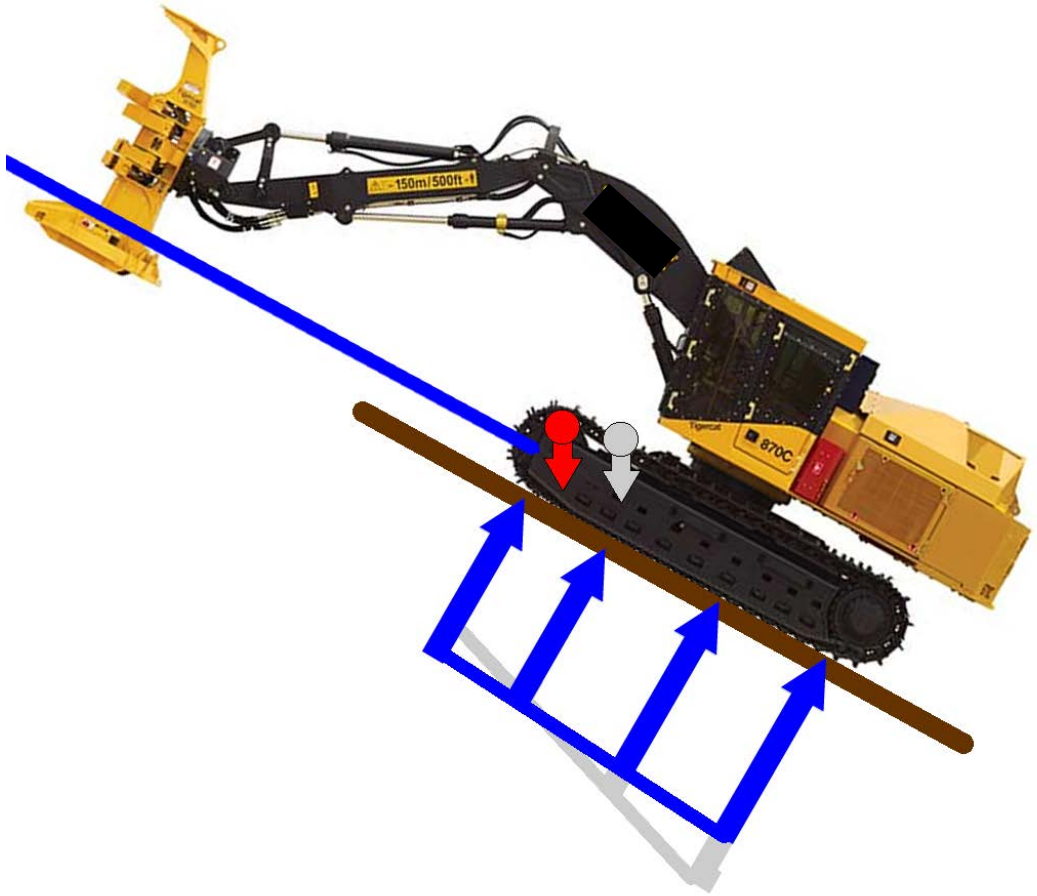
However, the same concepts hold.

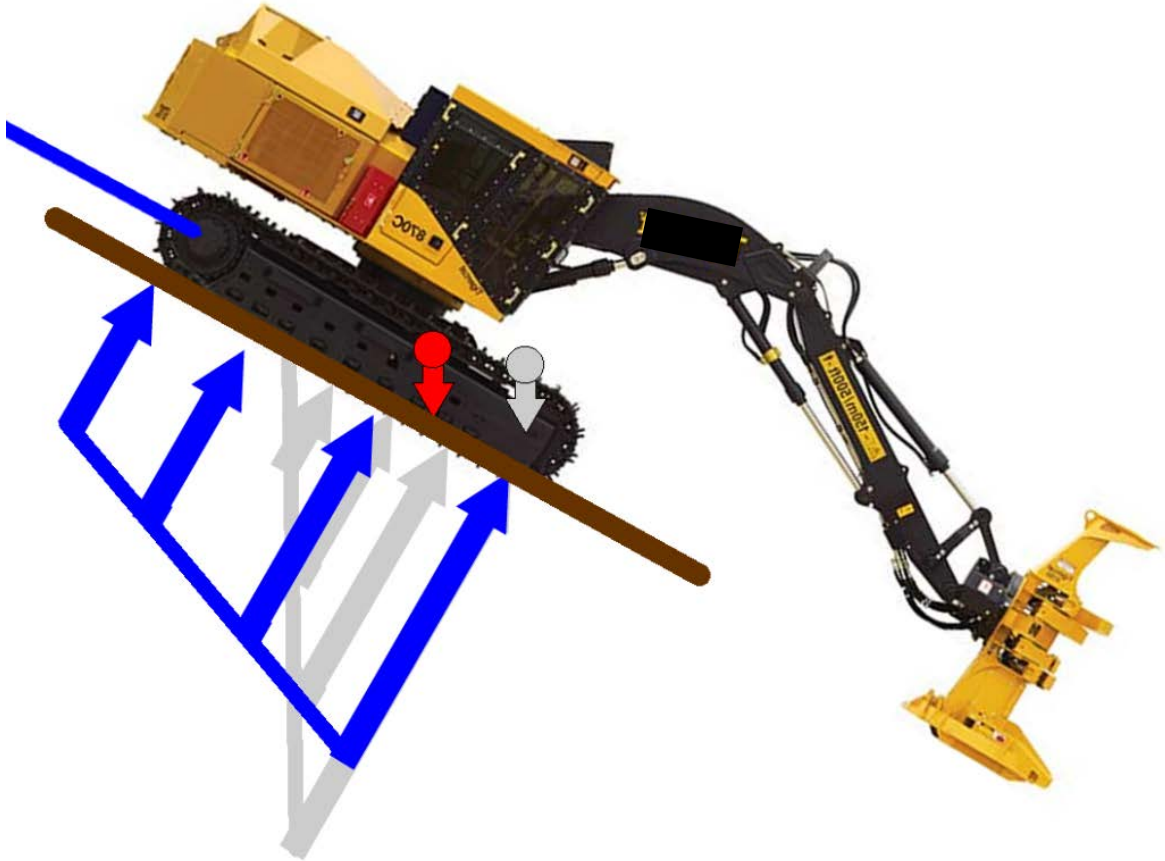




What about the tether?

The tether may shift the center of gravity, possibly to be more stable.



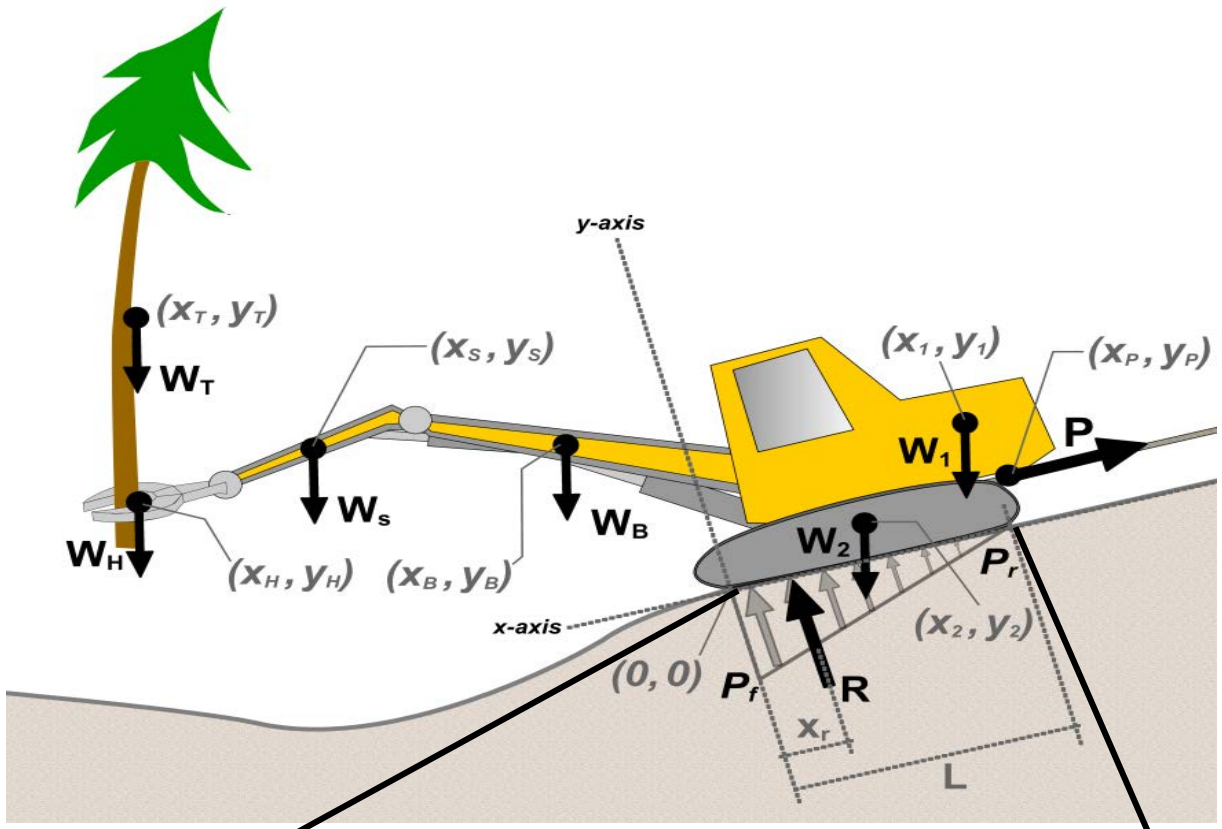


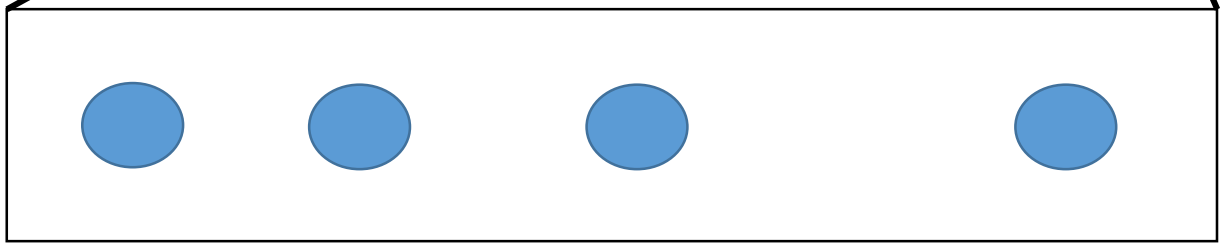
What are the implications?

- Increased stability.
- Decreased ground pressures.
- Less slip during movement.
- Decreased potential for soil disturbance under certain site conditions.

Let’s look at real ground pressures from field tests.

Series of field tests performed, monitored ground pressures.



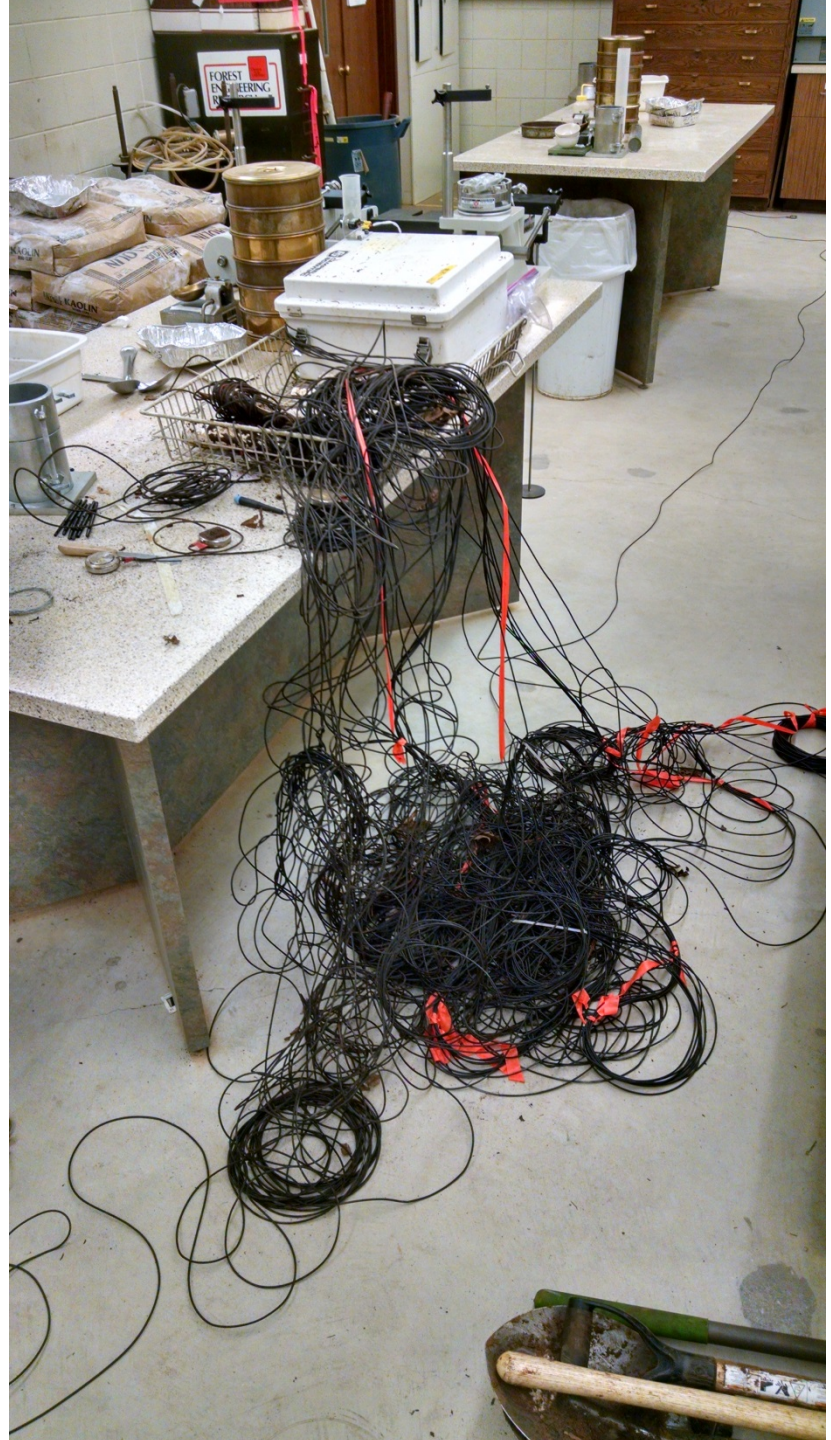


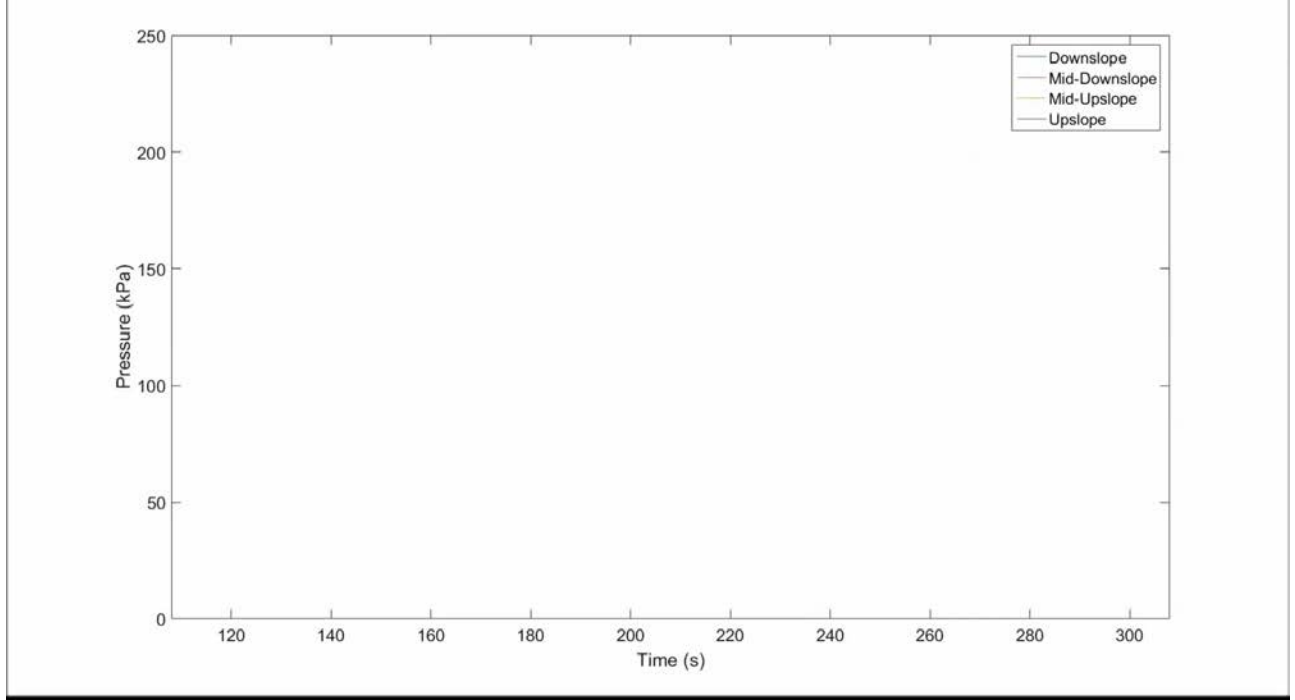
Bottom

Mid-Top

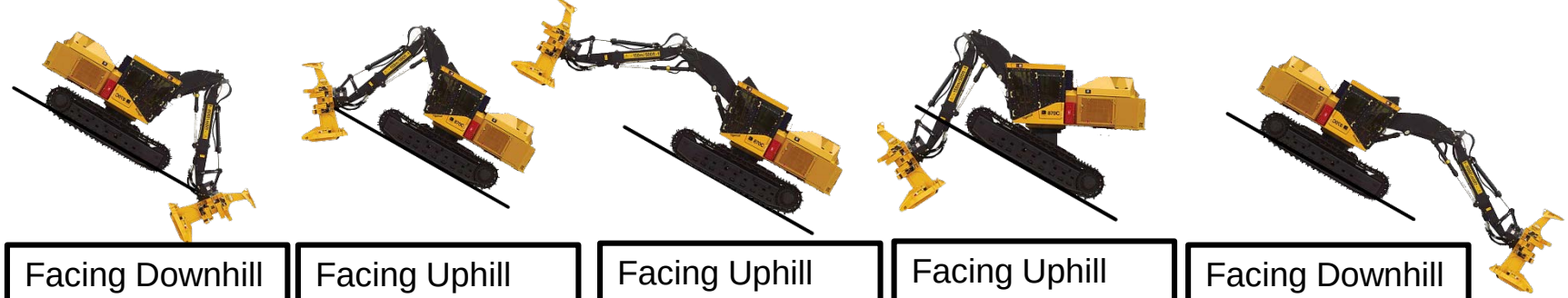
Mid-Bottom

Top


FOREST
KAOLIN


Downslope
Mid-Downslope
Mid-Upslope
Upslope
Pressure (kPa)
0
50
100
150
200
250
120
140
160
180
200
220
240
260
280
300
Time (s)

No Tension



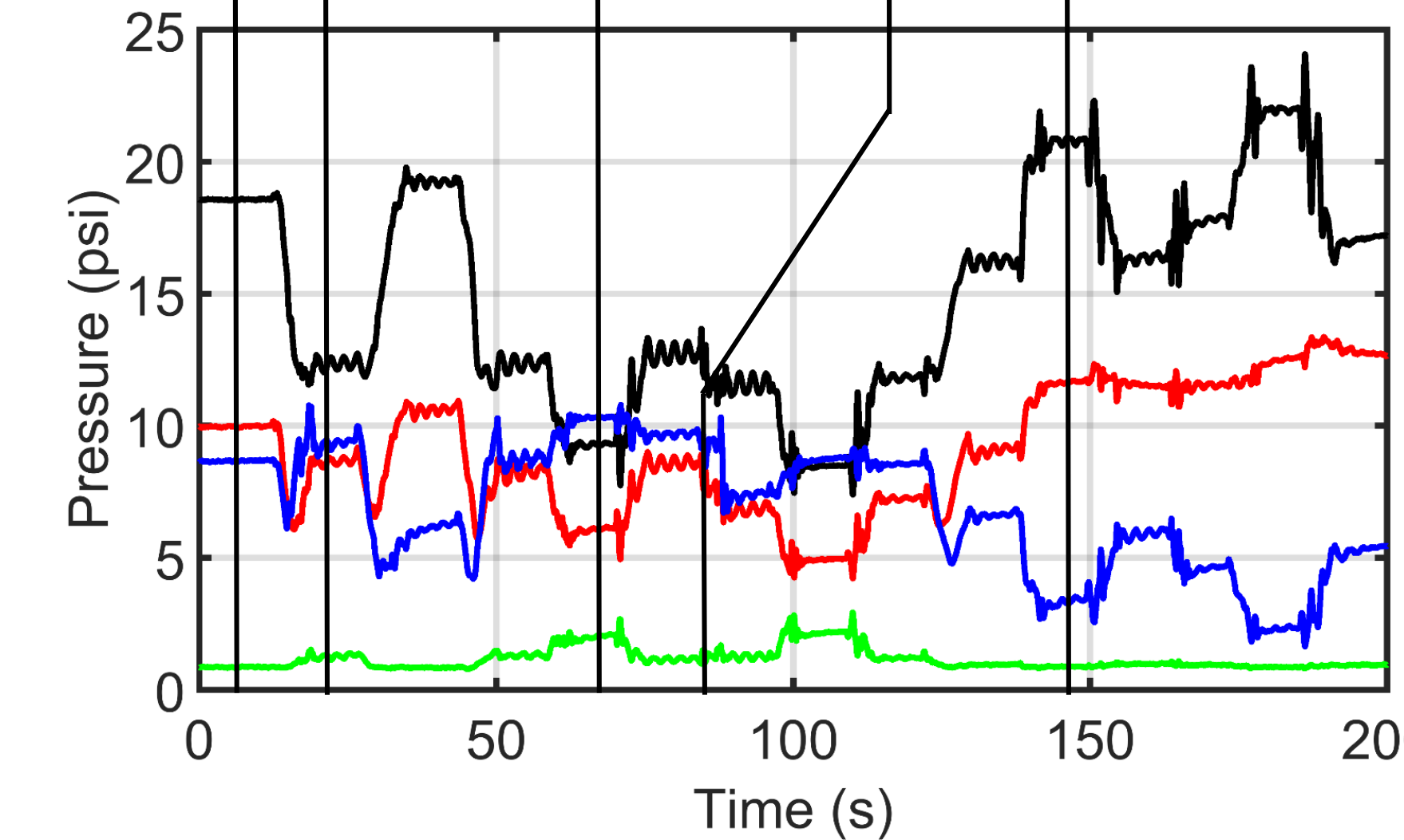
Facing Downhill Boom In

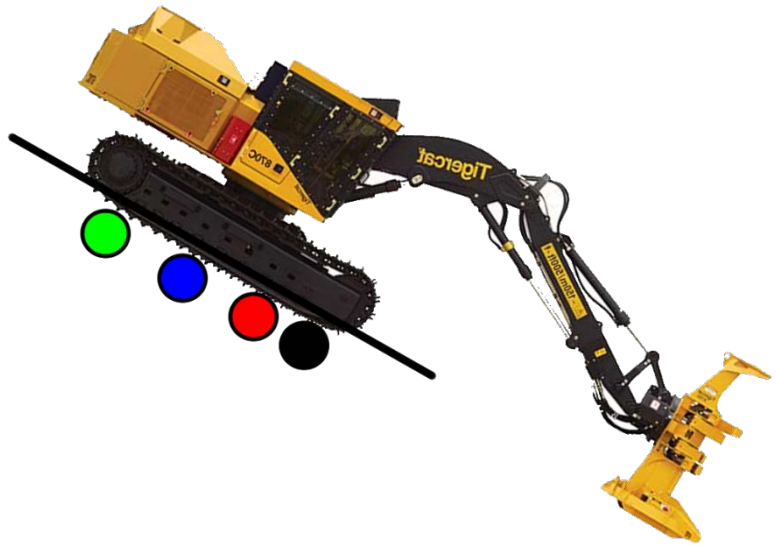
Facing Uphill Boom In

Facing Uphill Boom Out

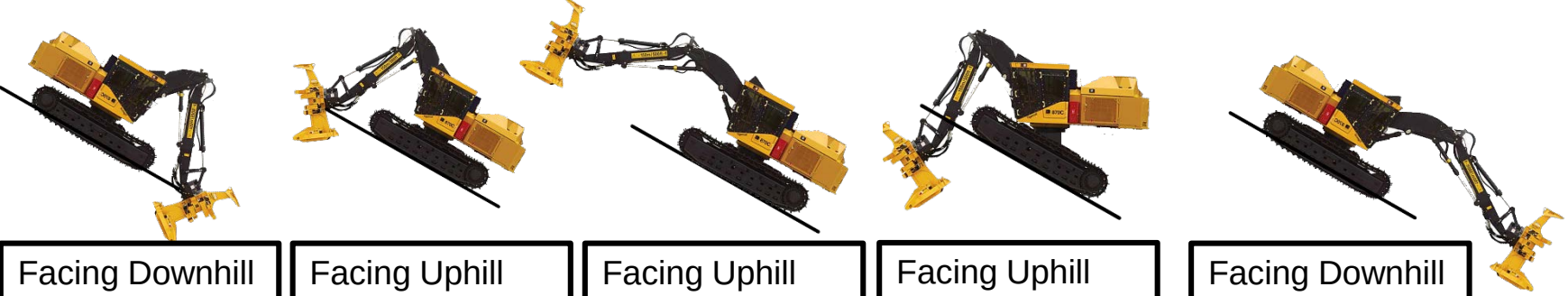
Facing Uphill Leveling

Facing Downhill Boom Out





10 Tons of Tension



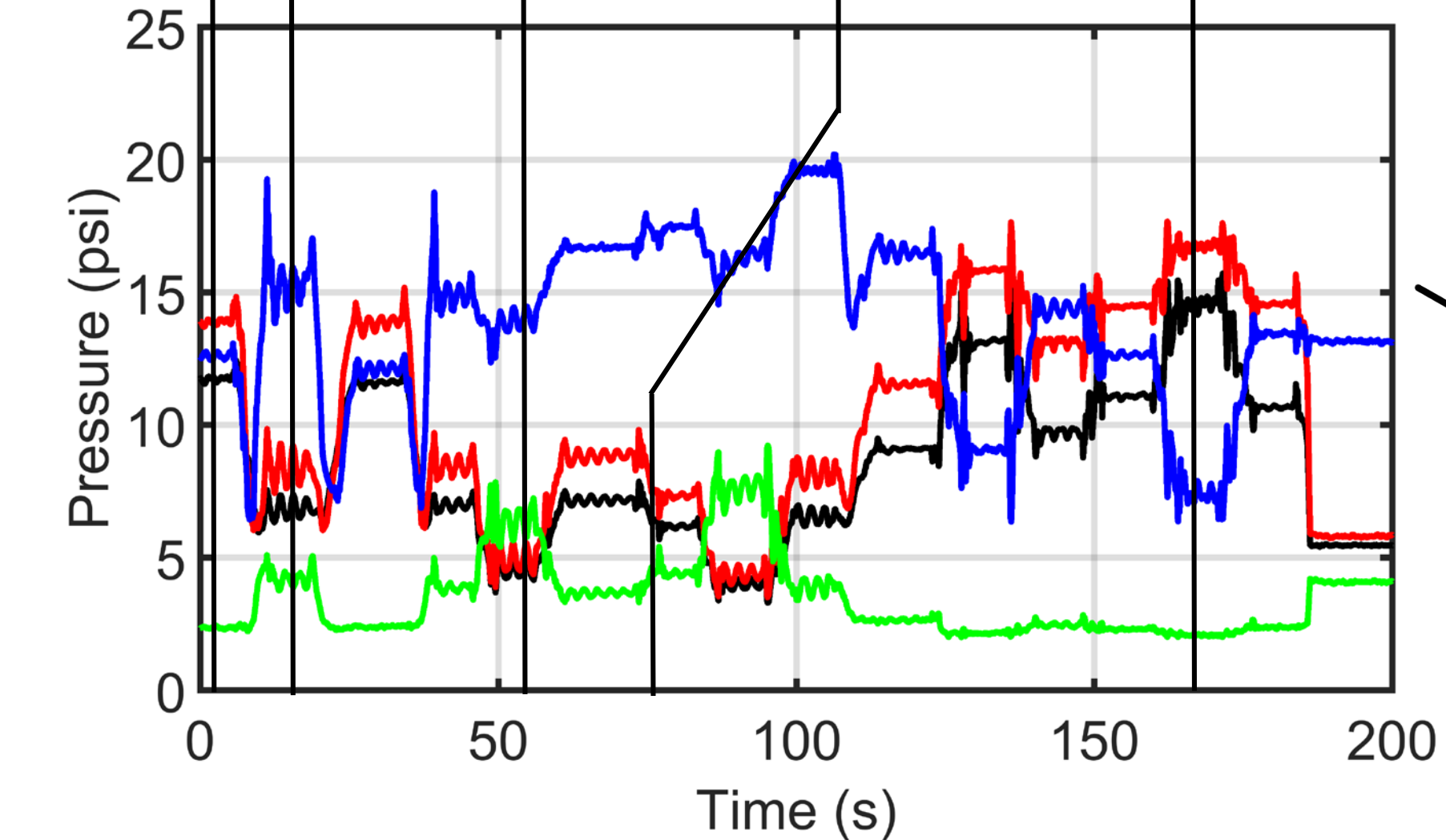
Facing Downhill Boom In

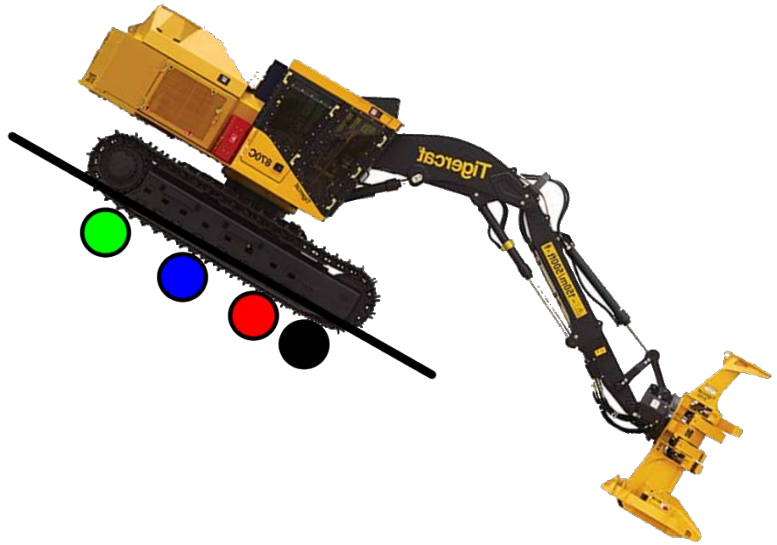
Facing Uphill Boom In

Facing Uphill Boom Out

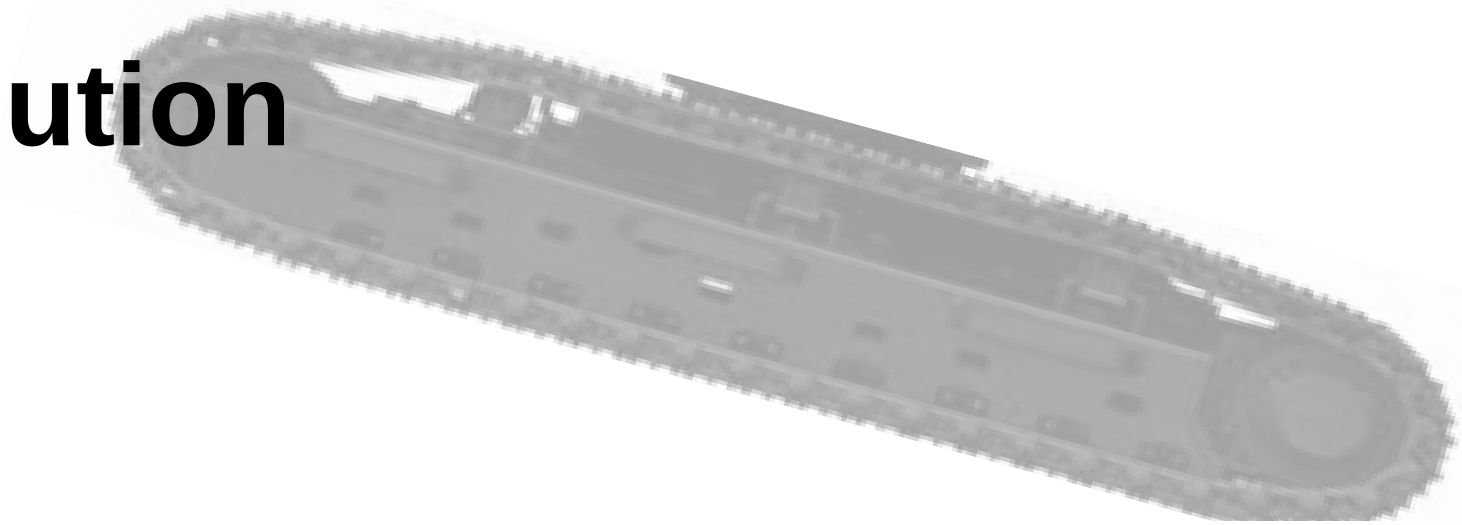
Facing Uphill Leveling

Facing Downhill Boom Out

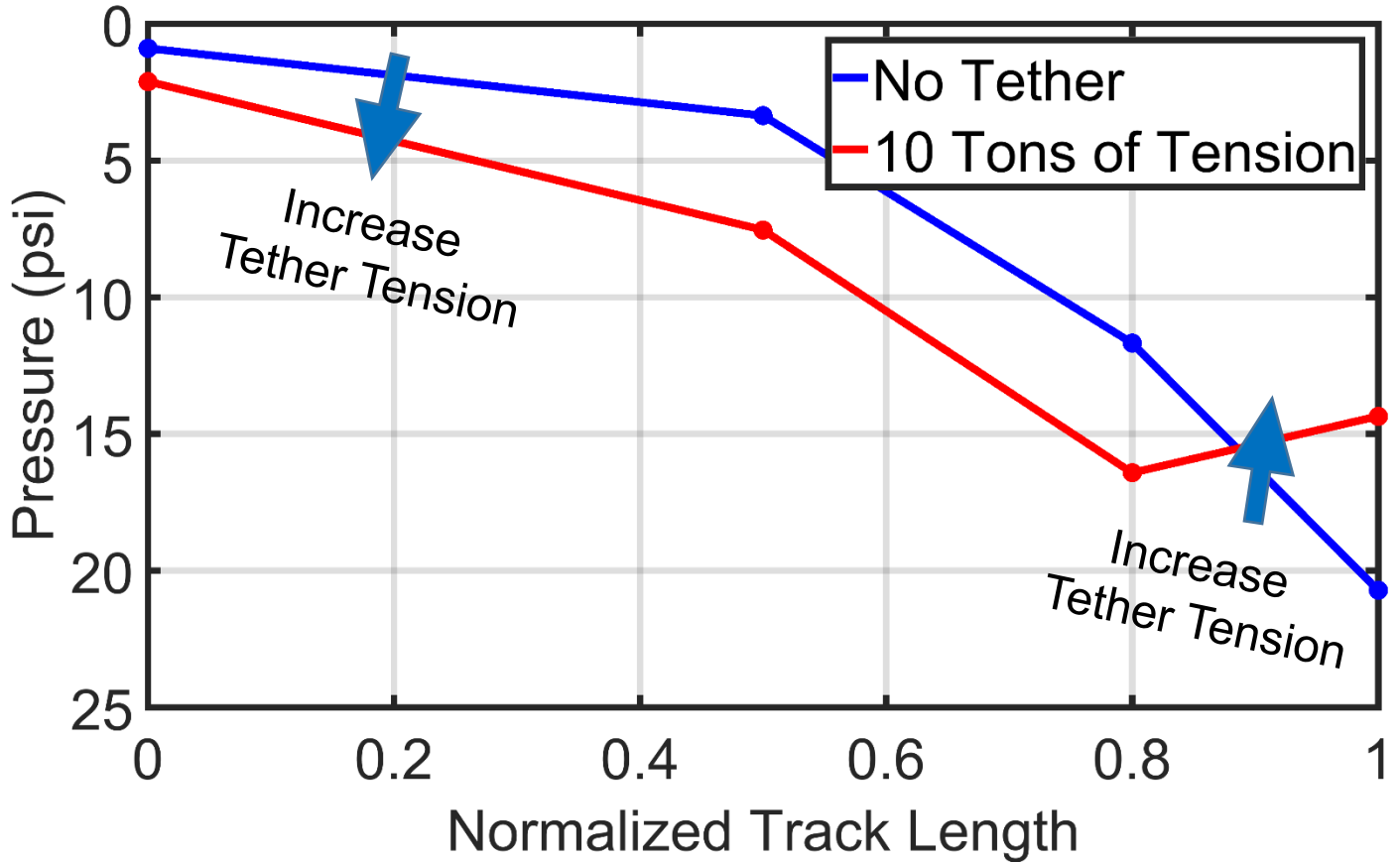




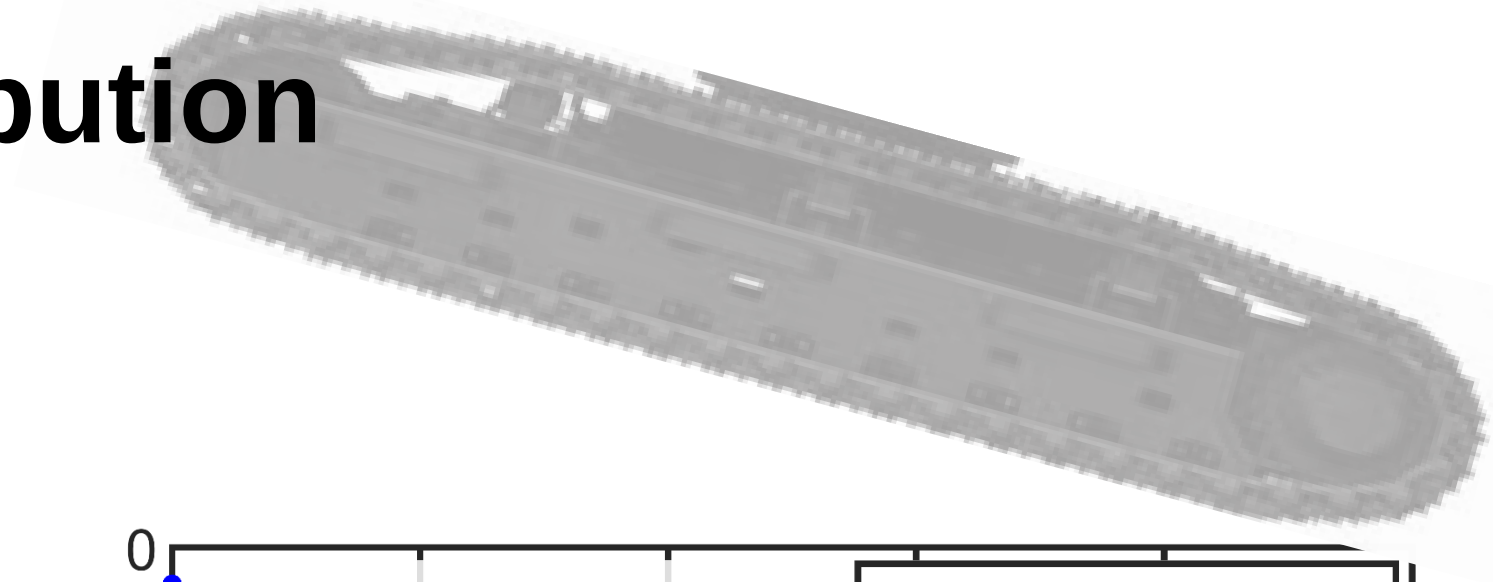
Pressure Distribution Facing Downhill



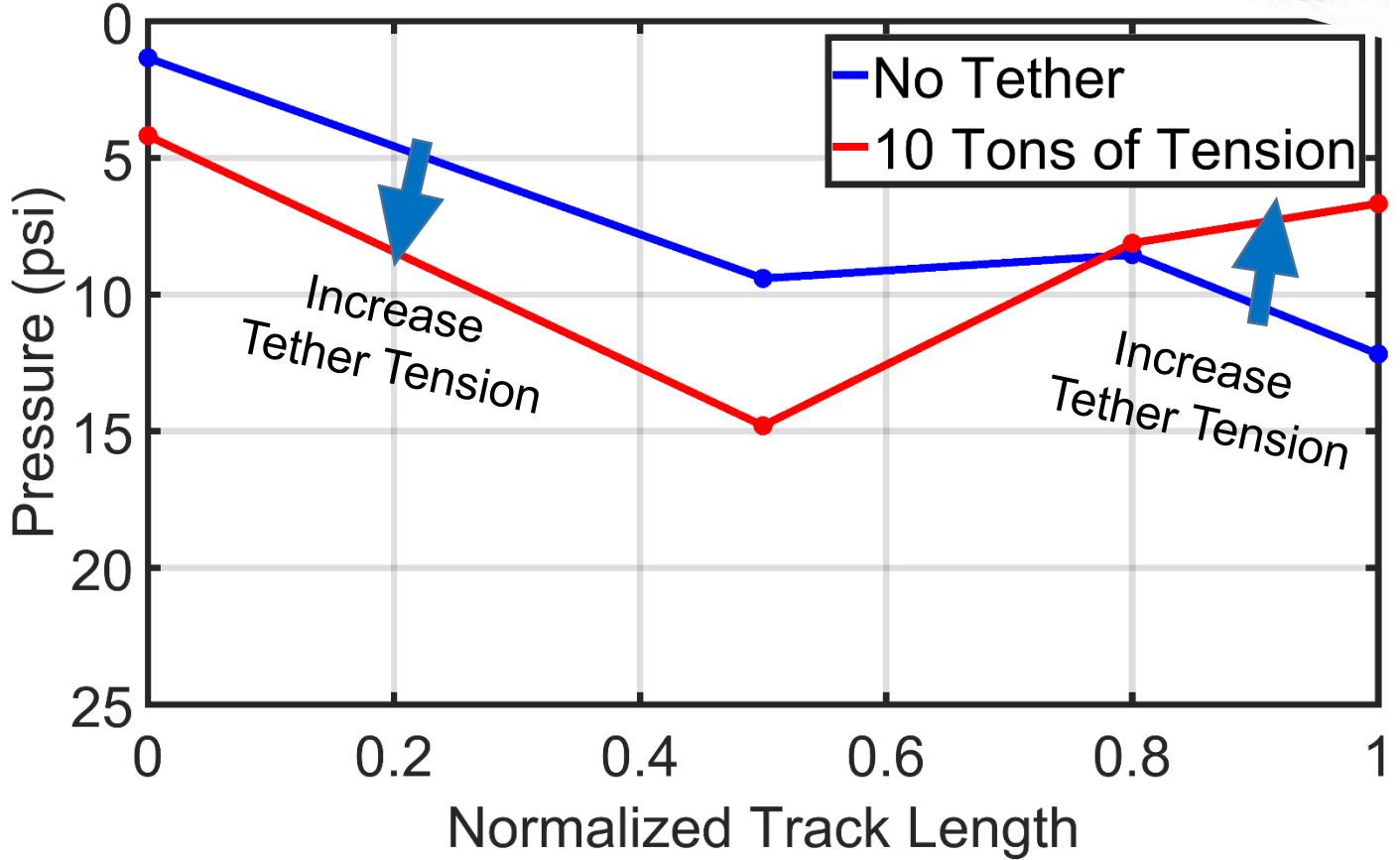
- Increased tension results in more even pressure.
- Better traction, more stability, less slip.
- Possibly less disturbance.



Pressure Distribution Facing Uphill

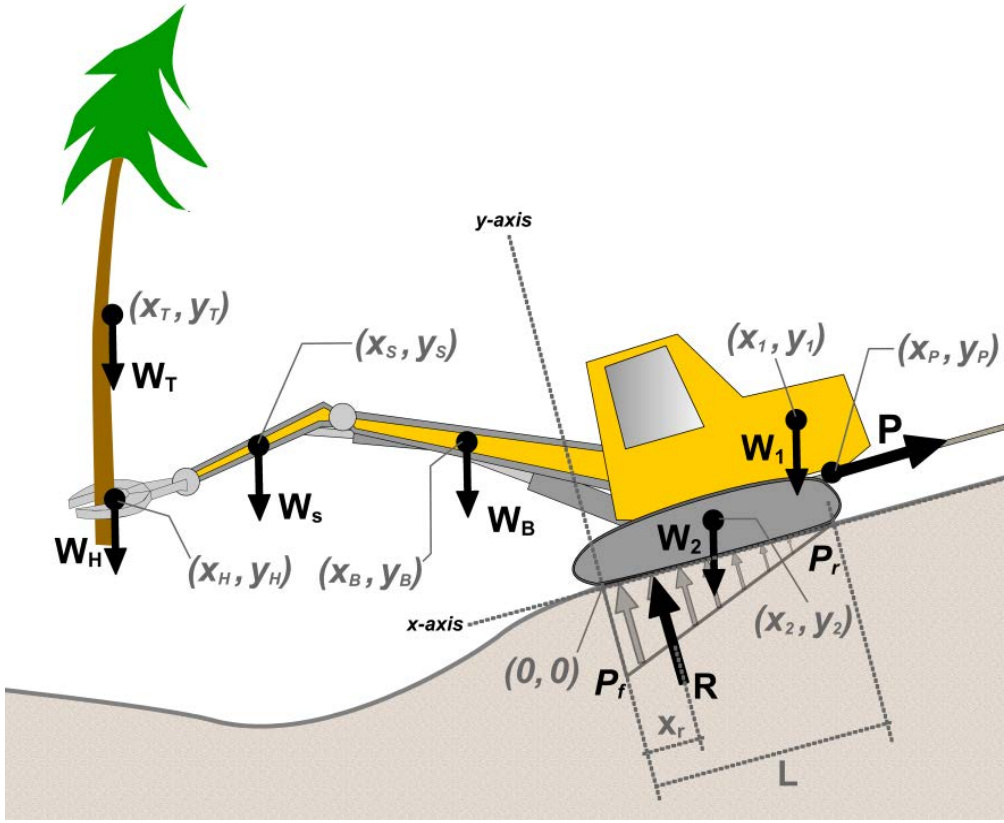


- More even pressure distribution.
- Best traction, most stability, less slip.



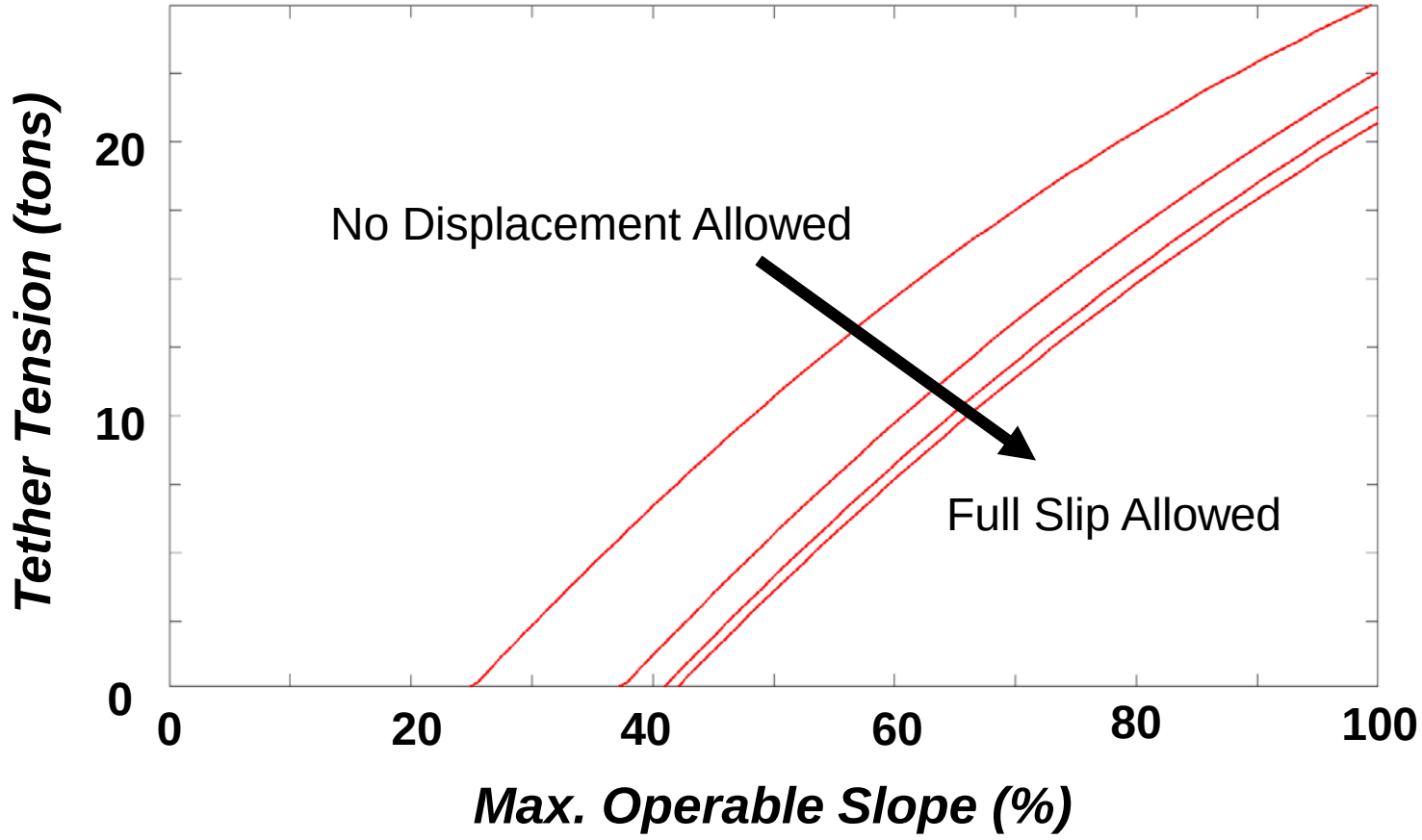
Defining What We See with Physics

- Developed soil mechanics-based approach to assess sliding and overturning stability through ground pressures.
- May define center of gravity, then ground pressure, then stability.
- Incorporate allowable slip, various soils properties, wet or dry.



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

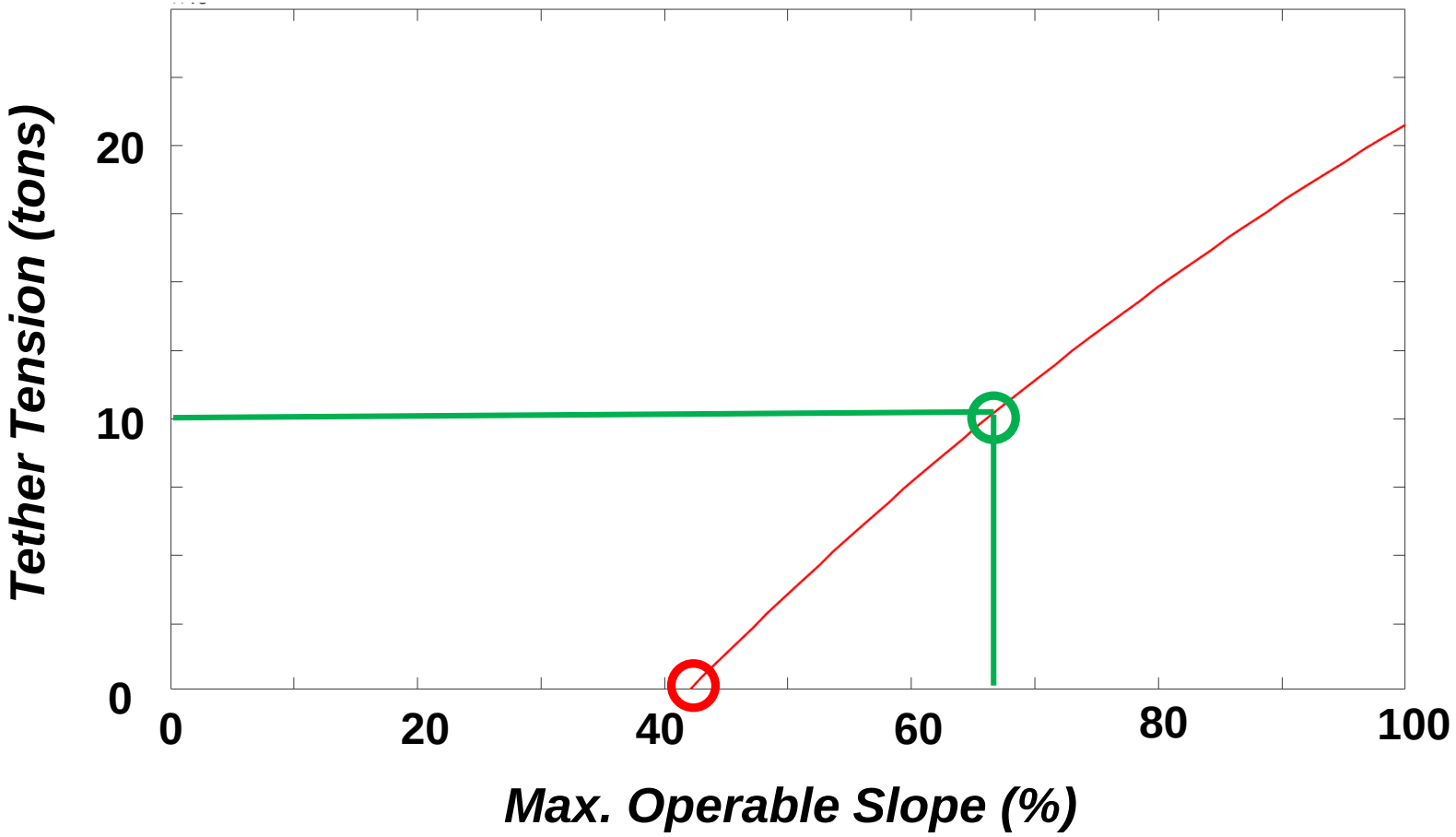
- One test included harvester on 48% slope with no tether.
- Machine could not remain stable on slope of saturated clay soils. It went skiing!
- Thankfully, a tree and hillslope bench stopped the machine.
- Let’s analyze the situation.

The Aftermath

The Aftermath

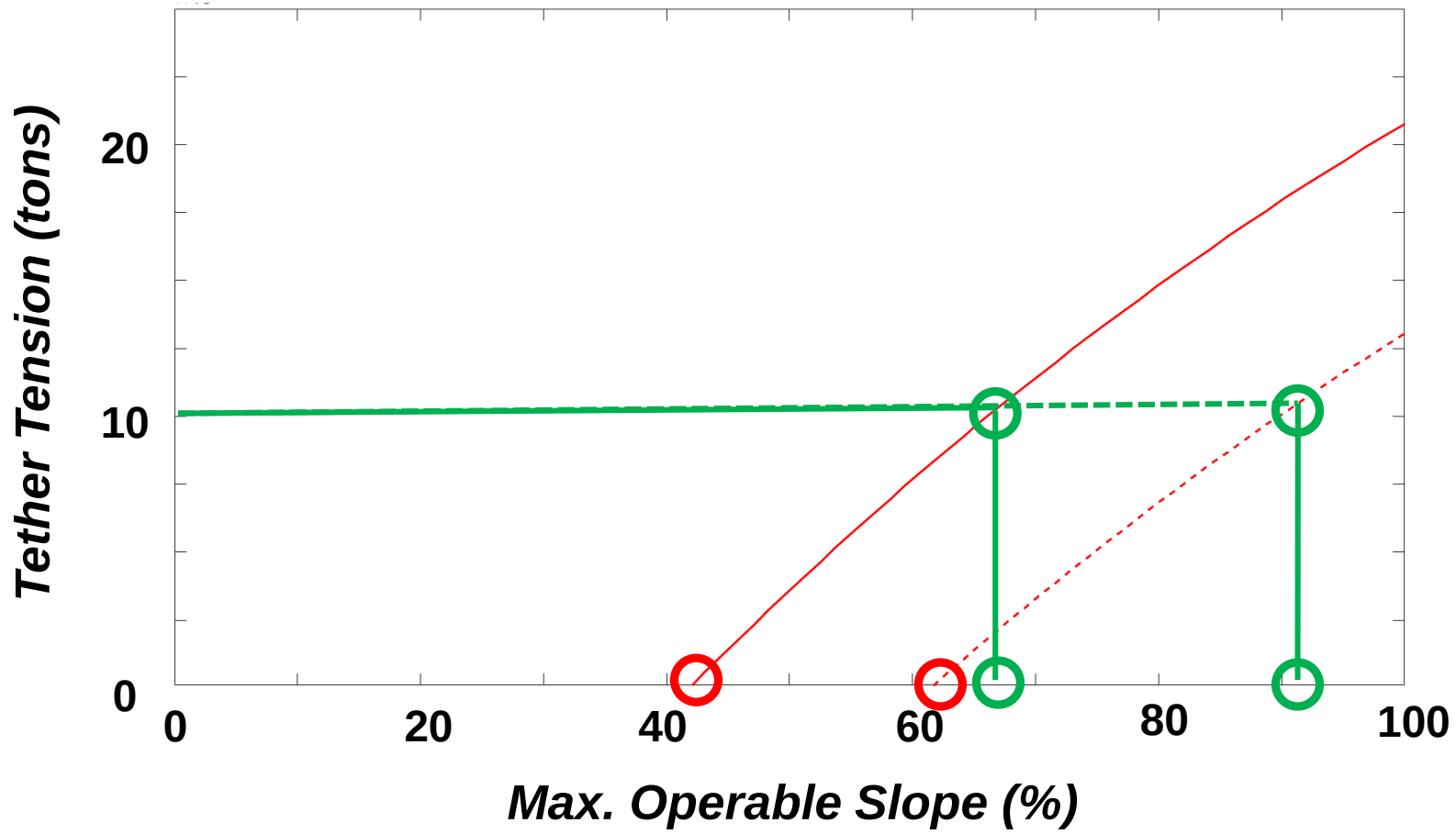
Actual Case – Downhill Orientation

- From soil testing in the field, we calc'ed a max. stable slope of about 42% without a tether. Reality: 48%
- If 10 tons of tension, almost 68% would have been operable.
- Significant increase in accessibility on poor soils.



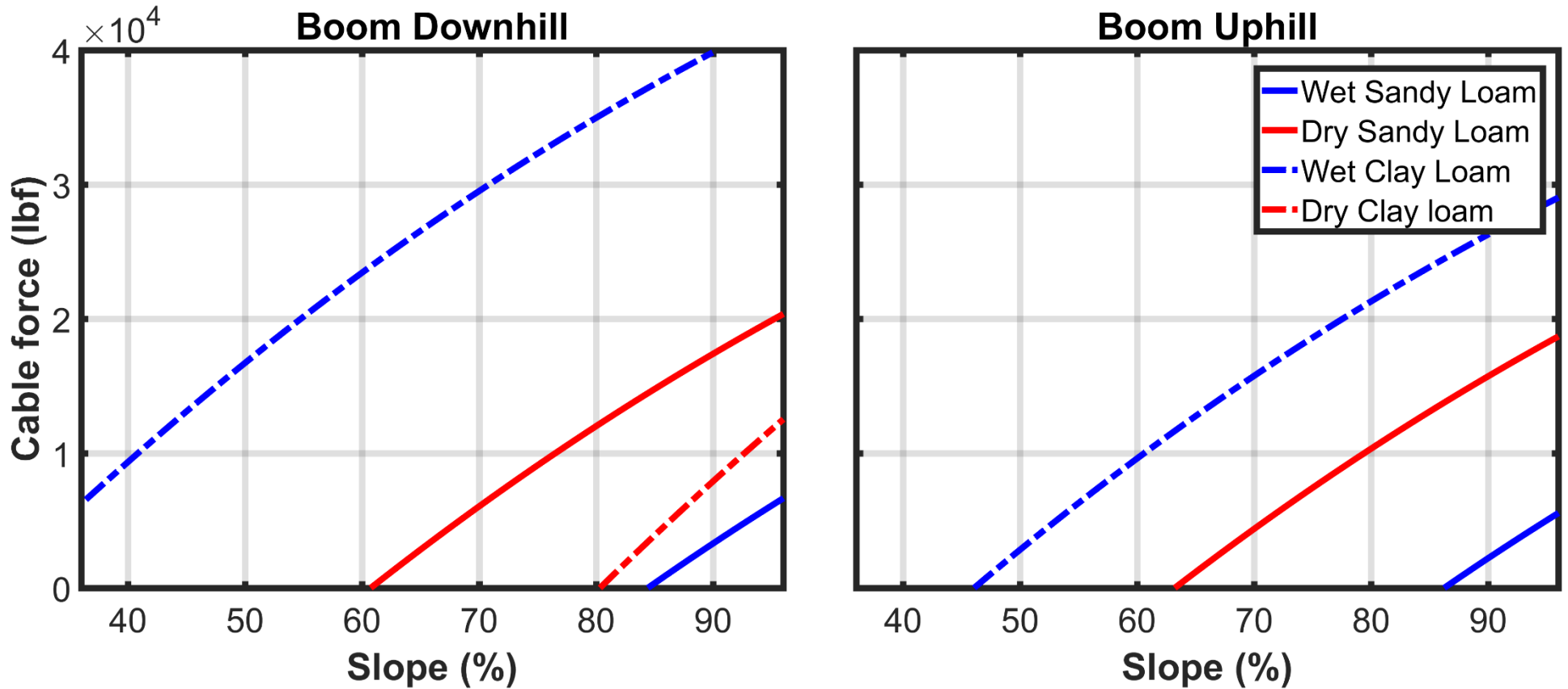
What if the boom and machine were facing uphill?

- If boom was uphill, tether unnecessary at 62%.
- If 10 tons of tension, up to 90% slope is operable when facing uphill.



Varying Soil Types and Moisture

- Wet sandy soils tend to be more operable with a bit of moisture.
- Clays are quite the opposite.



Compaction

- Compaction is one form of soil disturbance.
- Occurs when the soil is not too dry, not too wet.
- Sandy soils more prone to displacement and slip.
- Finer-textured soils prone to more compaction, particularly in that moisture “sweet spot” (Optimum Moisture Content)

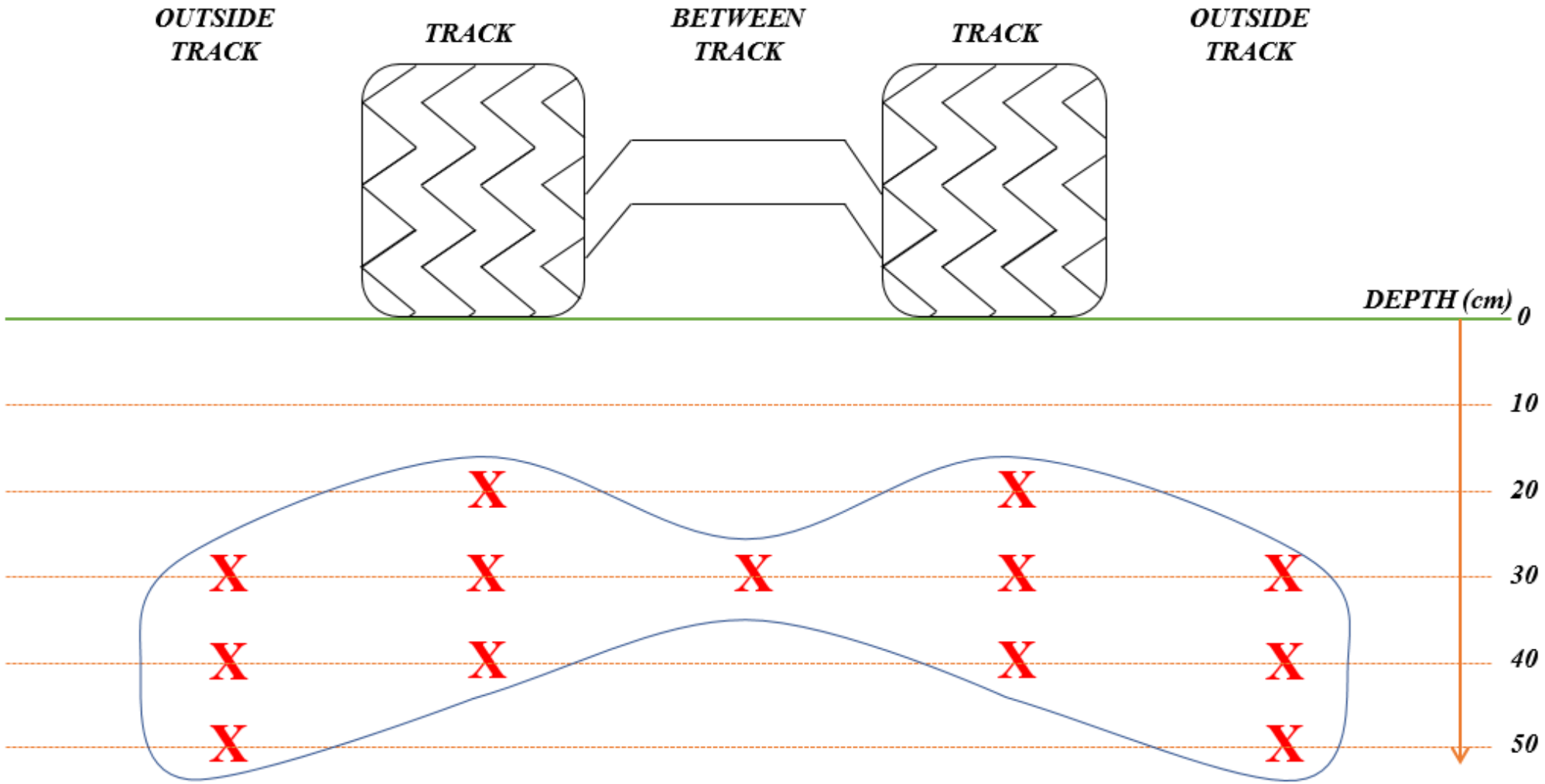
Challenges

- Certain soils maintain high moistures year round (Clay)
- Operating on very wet clay soils may reduce compaction potential, but may increase displacements (slip and bearing)

Observed Compaction Profiles

- Relatively dry clay loams
- Made observations about compaction via penetrometer testing.
- Tested wheeled harvester and forwarder.
- Saw minimal compaction, especially when a tether was used.
- Compaction dispersed in depth.
- Tillage and loosening occurred at surface. Good for planting, but may be prone to erosion if not controlled.

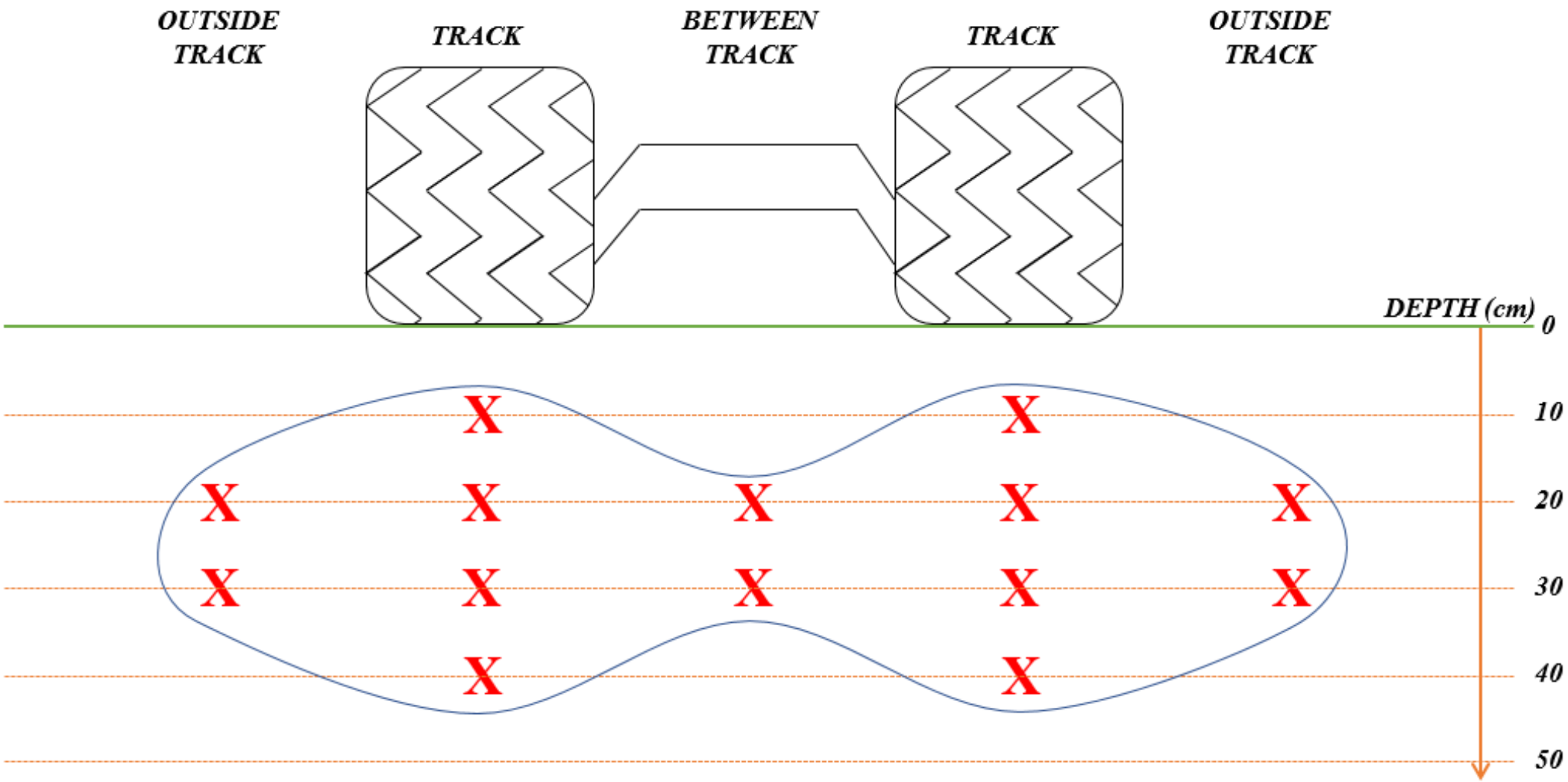
UNTETHERED, POST-HARVESTER



Legend:

X = statistically significant ***increase***.

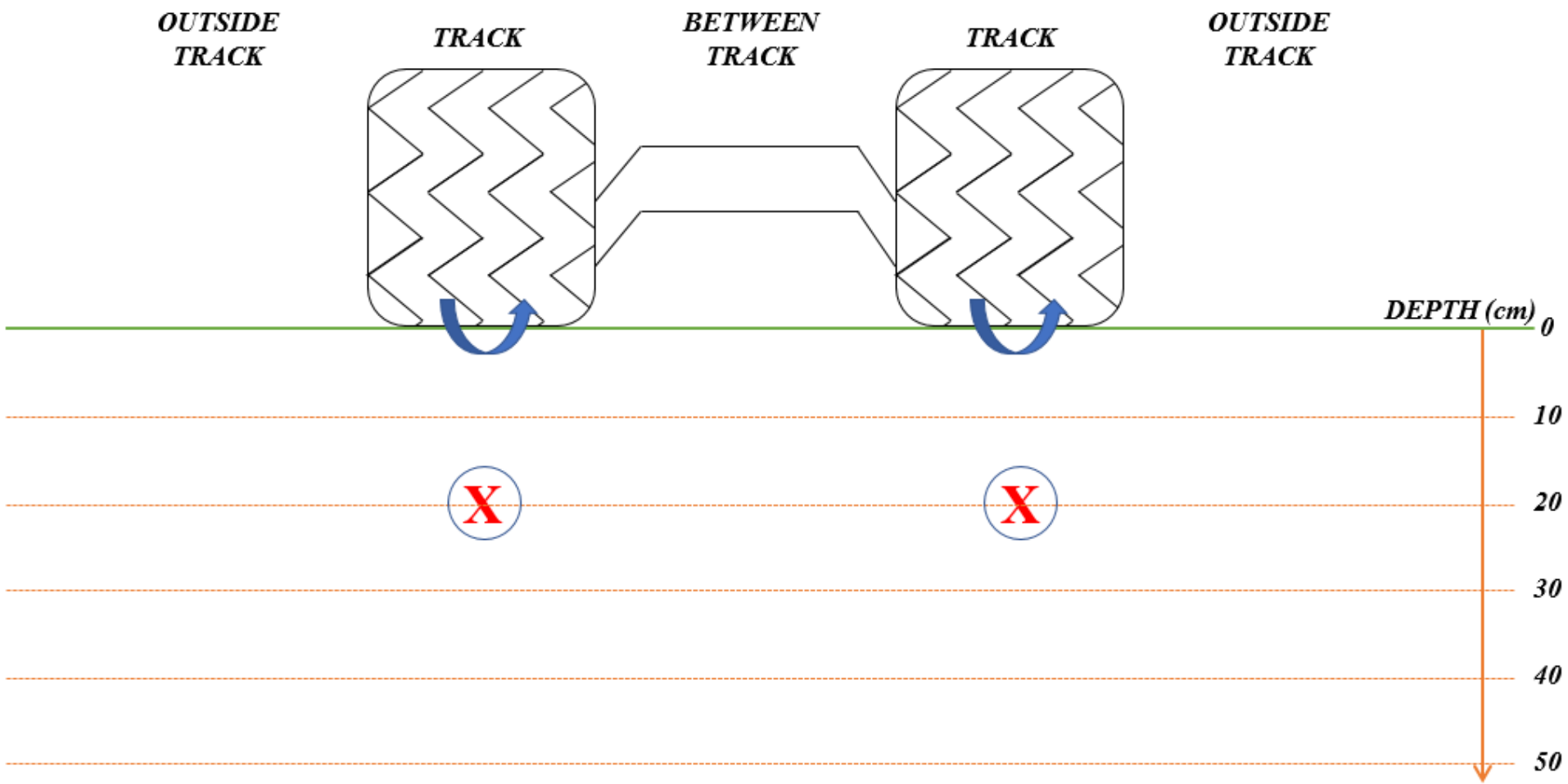
UNTETHERED, POST-FORWARDER



Legend:

X = statistically significant ***increase***.

TETHERED, POST-HARVESTER

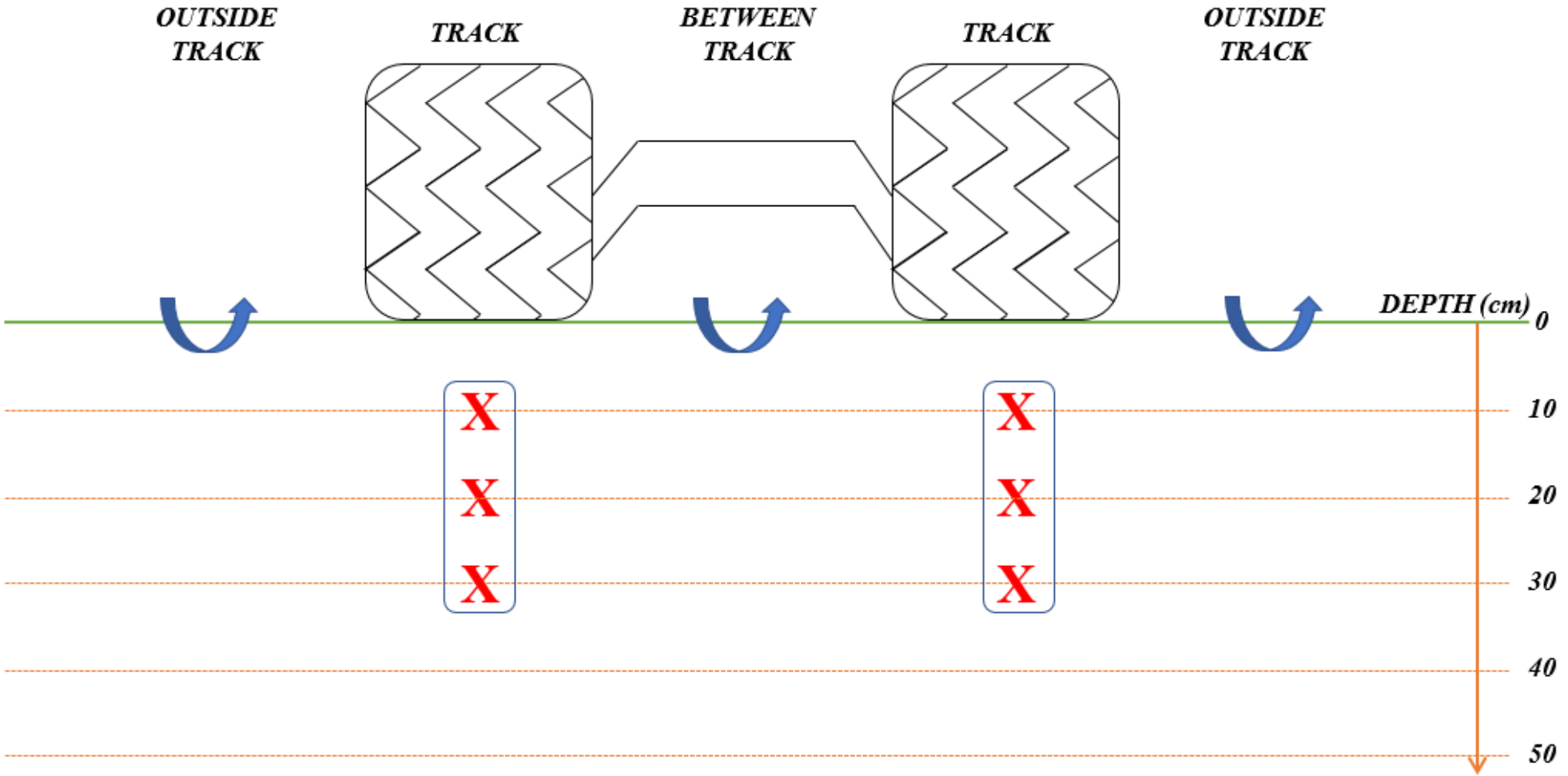


Legend:

X = statistically significant ***increase***.

= statistically significant ***decrease***.

TETHERED, POST-FORWARDER



Legend:

X = statistically significant ***increase***.

= statistically significant ***decrease***.

Take-Away Messages

- ***Soils are complicated!***
- Ground pressures affect machine stability and in turn, soil disturbance and safe operation.
- Use of cable assistance enables reduced ground pressures which provides:
  - Less soil displacement (slip and rutting)
  - Access to steeper slopes
  - Improved mobility
  - Improved stability

Take-Away Messages

- Sandy soils are best operated on when there is a bit of moisture.
- Clay soils are best operated on when they tend to be less saturated. Stability and displacement varies greatly!
- Uphill operation may be beneficial from a soil perspective due to better distribution of ground pressures.
- Compaction noted from preliminary studies are not significant, but slip may matter.
- Slip, however, may be reduced by increasing cable assistance.

Use of a tether potentially provides better safety and operational conditions when soil is considered.

Thanks for your Time!

Questions?

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