Critical Slope in Downhill Timber Skidding

1860
SVEUČILIŠTE U ZAGREBU
ŠUMARSKI FAKULTET
1669

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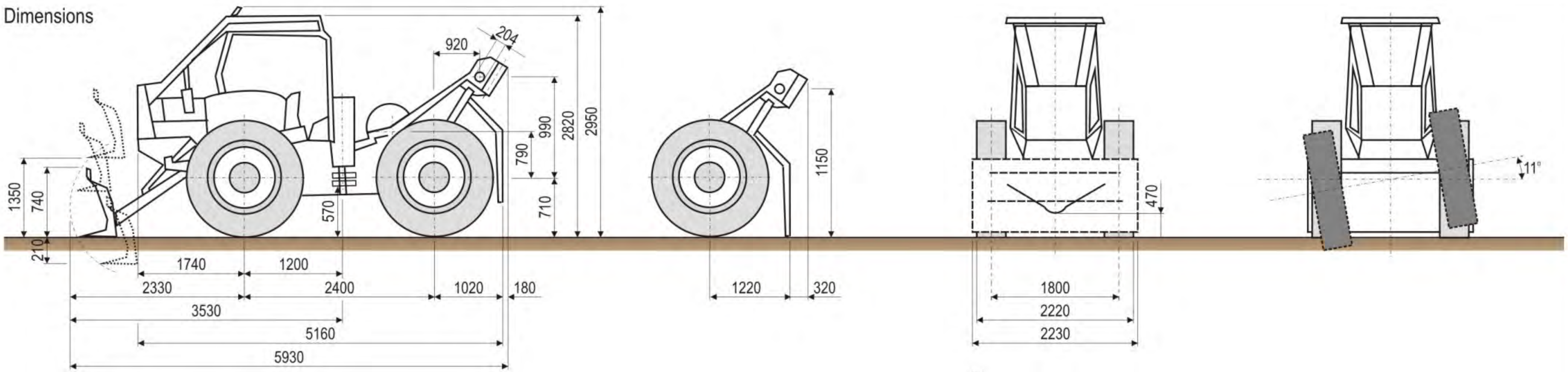
Limiting slopes throught time – wheeled skidder

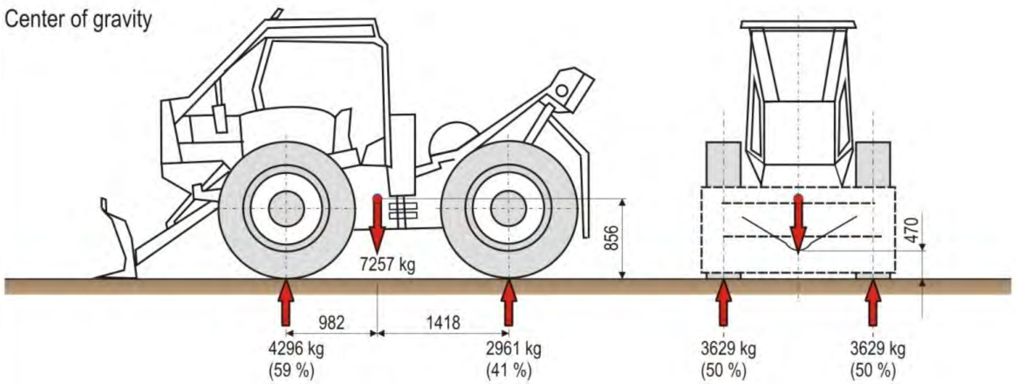
- Rowan (1977) 20 (33)% skidding up the slope and 50% for skidding timber down the slope of terrain.
- MacDonald (1999) boundary slope of 35 (40)% regardless of the slope and timber extraction direction.
- Heinimann (1999) limiting slope is 50%, but on slopes >35% vehicle should stay on secondary forest road infrastructure network.
- Hippoliti and Piegai (2000) empty skidder can overcome maximum 40% of terrain slope, but loaded only up to 20% regardless of slope direction.
- Lubello (2008) states the maximum threshold of 18% in skidding timber up the slope and 23% down the slope of terrain.
- Kühmaier i Stampfer (2010) claim that terrain slope of <30% (regardless of slope direction), but ground obstacles and soil bearing capacity should be taken into account.
- Sauter et all. (2012) define the border slope of 55% for the skidder with crane equipped with the additional winch for anchoring the vehicle.
- Visser and Stampfer (2015) state that guidance on slope limits, based on either science or experience, is rare and few of the major forestry equipment manufacturers provide slope and/or operating limits for their purpose built machinery (for example Komatsu operating guidelines 2015).

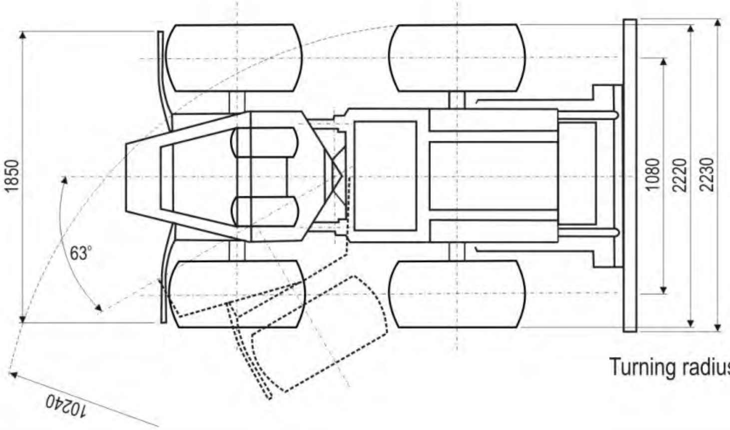
Dimensions and center of gravity

Dimensions



Center of gravity



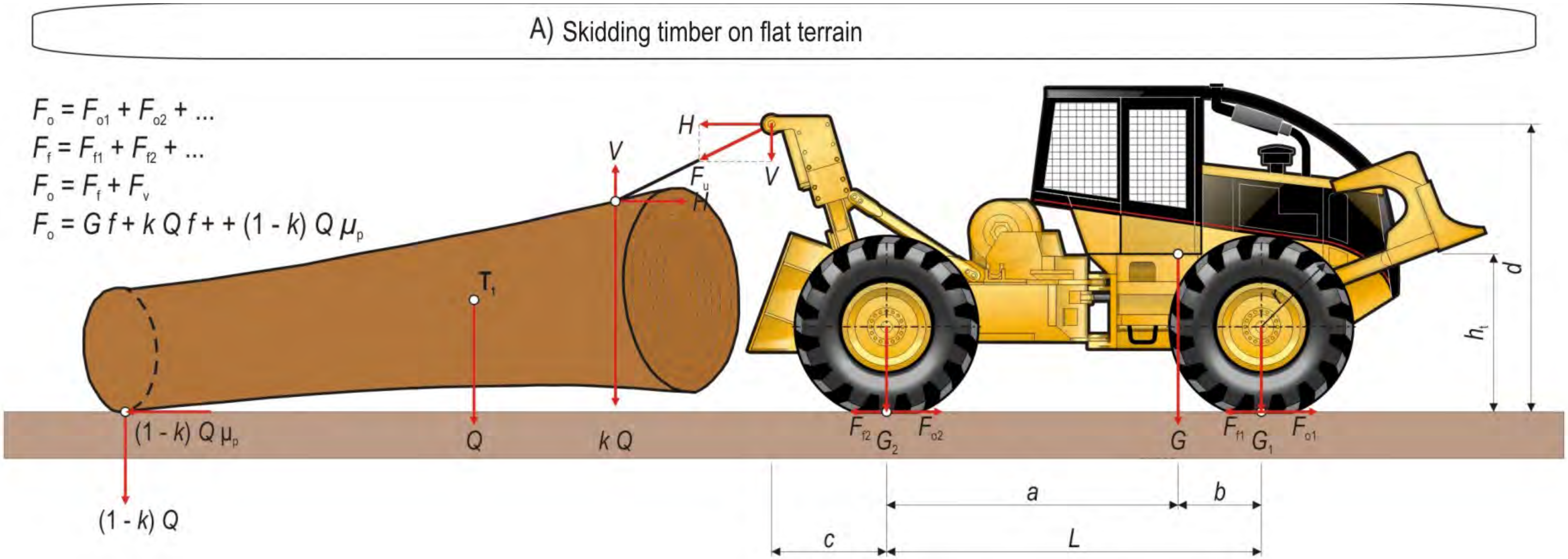


Turning radius

Tyres

16.9 - 30 PR 14		
	Width	429 mm
	Diameter	1485 mm
	Section height	361,5 mm
	Loaded static radius	683 mm
	Max. inflation pressure	260 kPa
	Load capacity	3000 kg

Skidding timber on flat terrain - forces

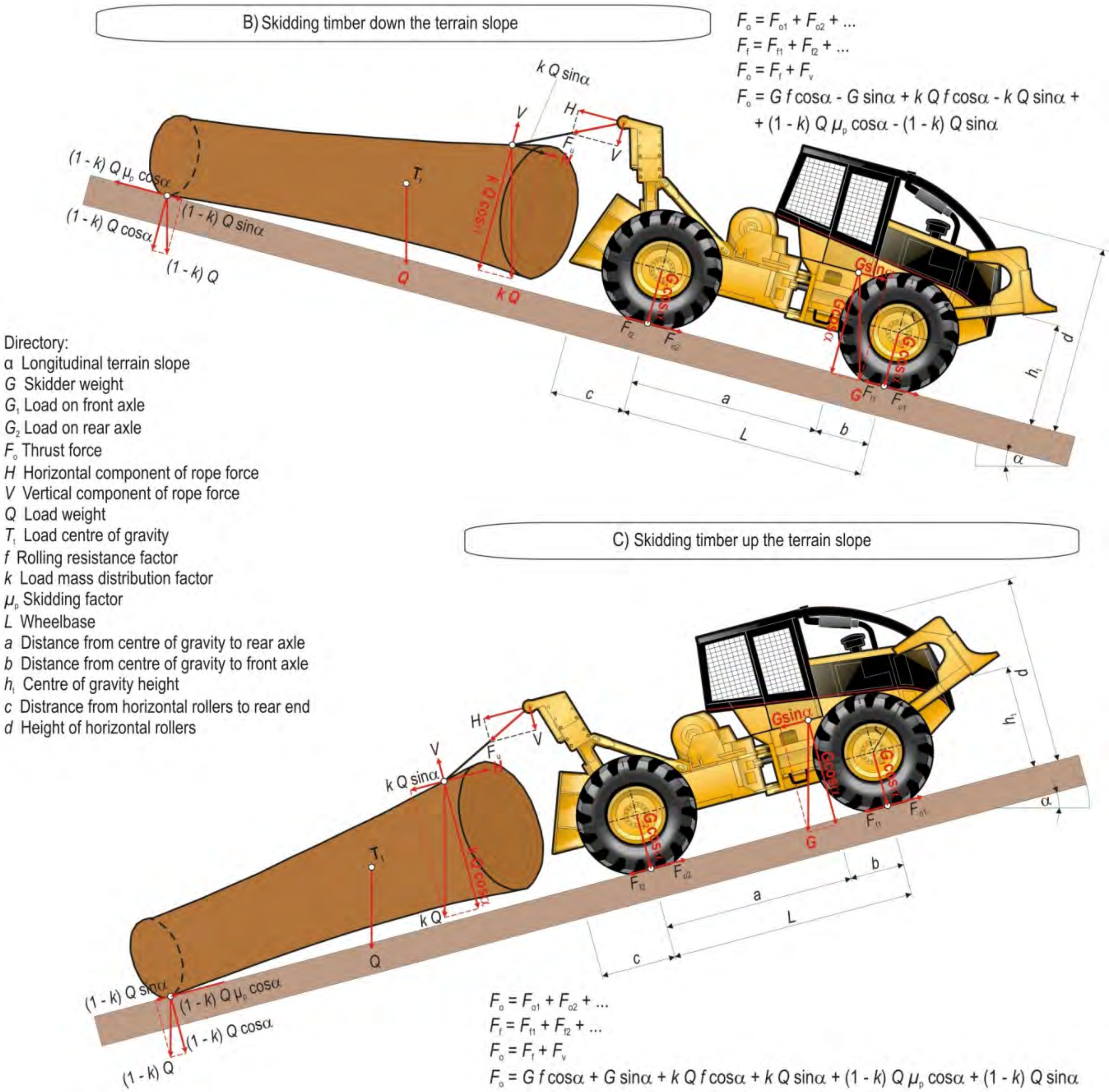


Directory:
- G Skidder weight
- G_1 Load on front axle
- G_2 Load on rear axle
- F_o Thrust force
- H Horizontal component of rope force
- V Vertical component of rope force
- Q Load weight
- T_t Load centre of gravity
- f Rolling resistance factor
- k Load mass distribution factor
- μ_p Skidding factor
- L Wheelbase
- a Distance from centre of gravity to rear axle
- b Distance from centre of gravity to front axle
- h_t Centre of gravity height
- c Distrance from horizontal rollers to rear end
- d Height of horizontal rollers

Skidding timber on flat terrain begins in the moment when thrust force (brought by transmission system to the wheels) begins to overcome resistance forces:

1) Skidder rolling,
2) Rolling of hooked timber,
3) Friction of timber on ground (Sever 1980).

Skidding timber uphill and downhill - forces



Distribution of forces is more complex. Traction begins when thrust force overcome resistance forces:

1) skidder rolling,
2) terrain slope,
3) rolling of hooked timber,
4) overcoming terrain slope of hooked timber,
5) friction of timber on ground,
6) overcoming terrain slope of timber on the ground.

Skidding timber downhill resultants of three forces of resistance (2, 4 and 6) are now in the opposite direction, i. e. direction of the vehicle movement.

Skidding up the slope of terrain, additionally strains rear axle due to the effect of horizontal components of skidder weight ($G \sin \alpha$) and of horizontal components of the rope force (H).
When skidding down the slope load is transferred to the front axle of the vehicle.

Calculation equations

Based on original measurements of Šušnjar (2005) of skidder's (Ecotrac 120V) dimensions and centre of gravity, dependence of load mass distribution factor and skidding factor to affecting parameters (Poršinsky et all. 2012) load distribution during timber extraction on different terrain slopes and five different loads (from 1 to 5 tones) were analyzed.

Load mass distribution factor:

$$k = \frac{V}{Q \cdot \cos\alpha}$$

Skidding factor:

$$\mu_r = \frac{H \pm Q \cdot \sin\alpha}{Q \cdot (1-k) \cdot \cos\alpha}$$

- If k = 0,5 load is a cylinder,
- Idea is to lift as much as possible → vehicle adhesion weight is bigger, soil is less disturbed as well as less tractive force is necessary,
- k depends not just of load mass but of vertex height of rope force,
- Skidding factor – accurse because of dragging part of load on ground, H overcomes resistances between load and soil.

Calculation equations

The first »turning point«:

$$tg\alpha = \frac{G\cdot f + Q\cdot k\cdot f + (1-k)\cdot Q\cdot \mu_p}{G+Q}$$

The second »turning point«:

$$tg\alpha = (1-k)\mu_p$$

Load distribution consisted of calculation and analyses of these parameters:
Adhesion weight:

$$G_a = G\cdot\cos\alpha + V$$

Vertical component of rope force:

$$V = k\cdot Q\cdot\cos\alpha$$

Horizontal component of rope force:

$$H = Q\cdot(1-k)\cdot\cos\alpha\cdot\mu_p - Q\cdot\sin\alpha$$

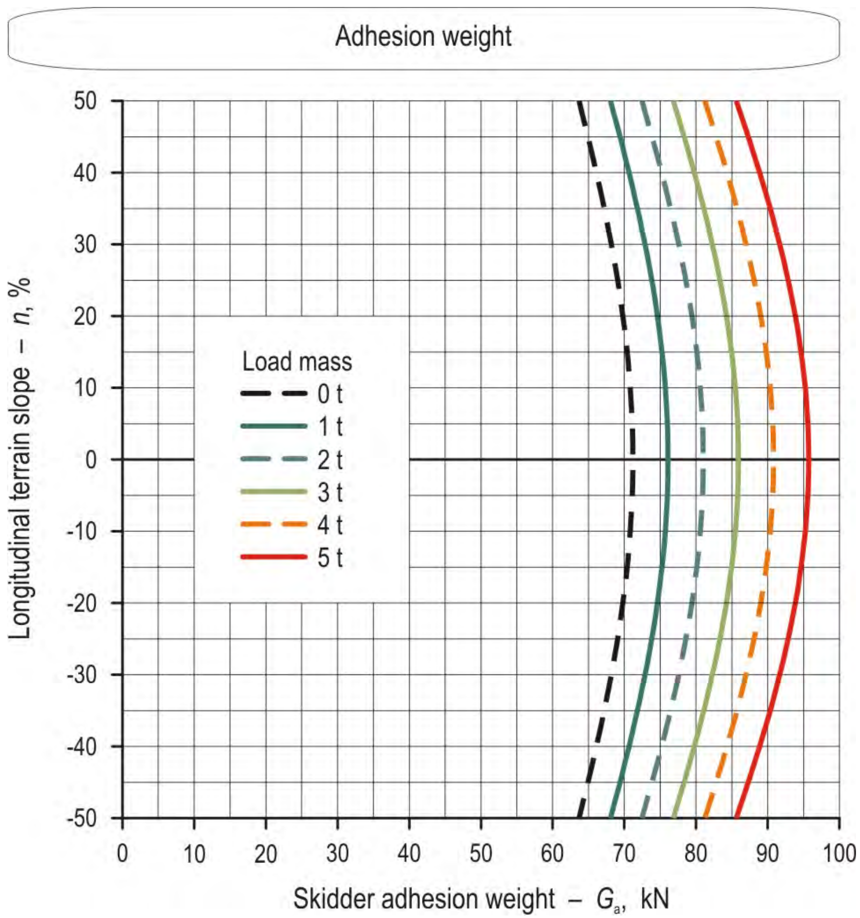
Load distribution on front axle:

$$G_1 = \frac{G\cdot\cos\alpha\cdot a + G\cdot\sin\alpha\cdot h_t - H\cdot d - V\cdot c}{L}$$

Load distribution on rear axle:

$$G_2 = \frac{G\cdot\cos\alpha\cdot b - G\cdot\sin\alpha\cdot h_t + H\cdot d + V\cdot(L+c)}{L}$$

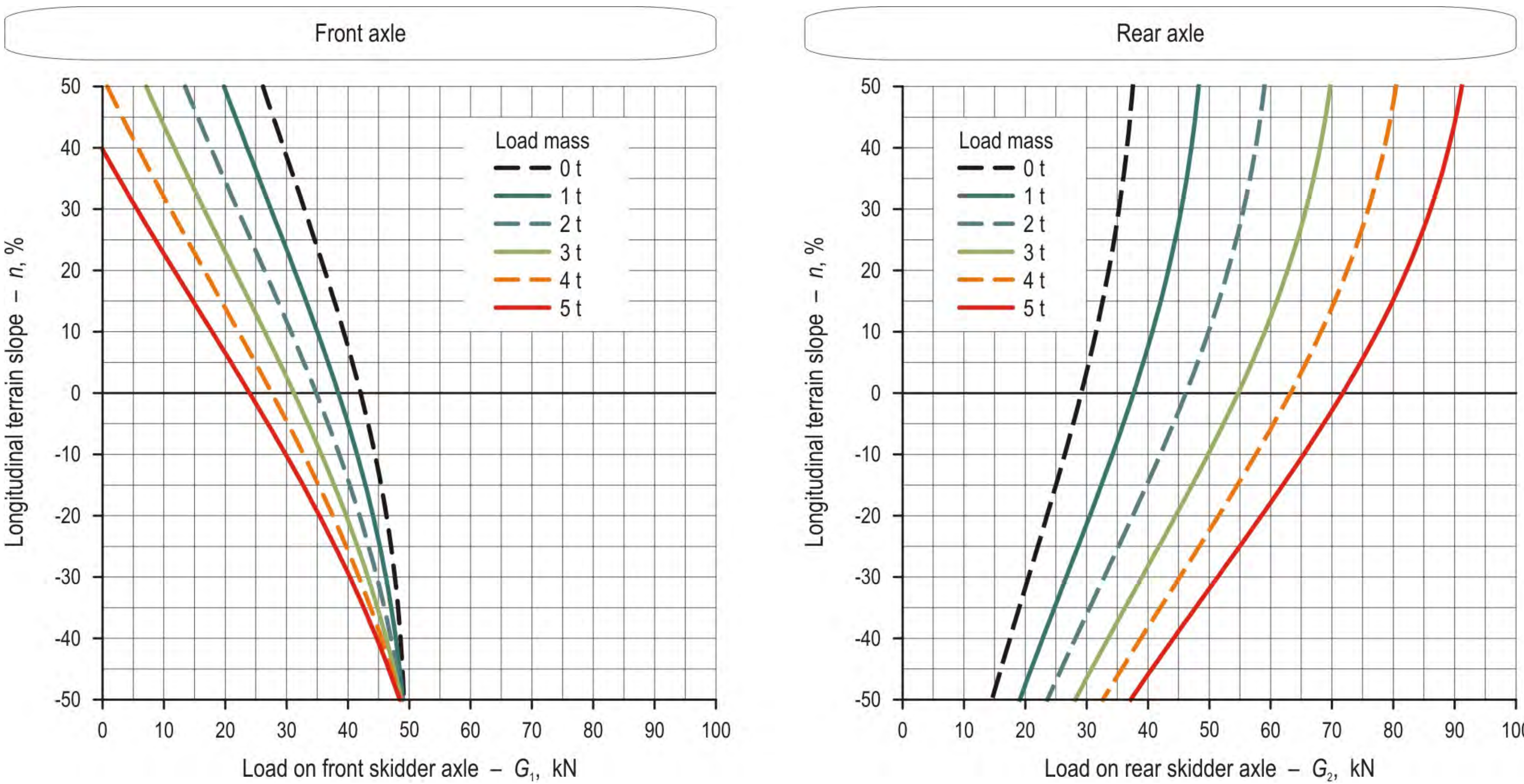
Results – adhesion weight



Adhesion weight represents **the sum of vertical loads** on driving wheels during skidding.

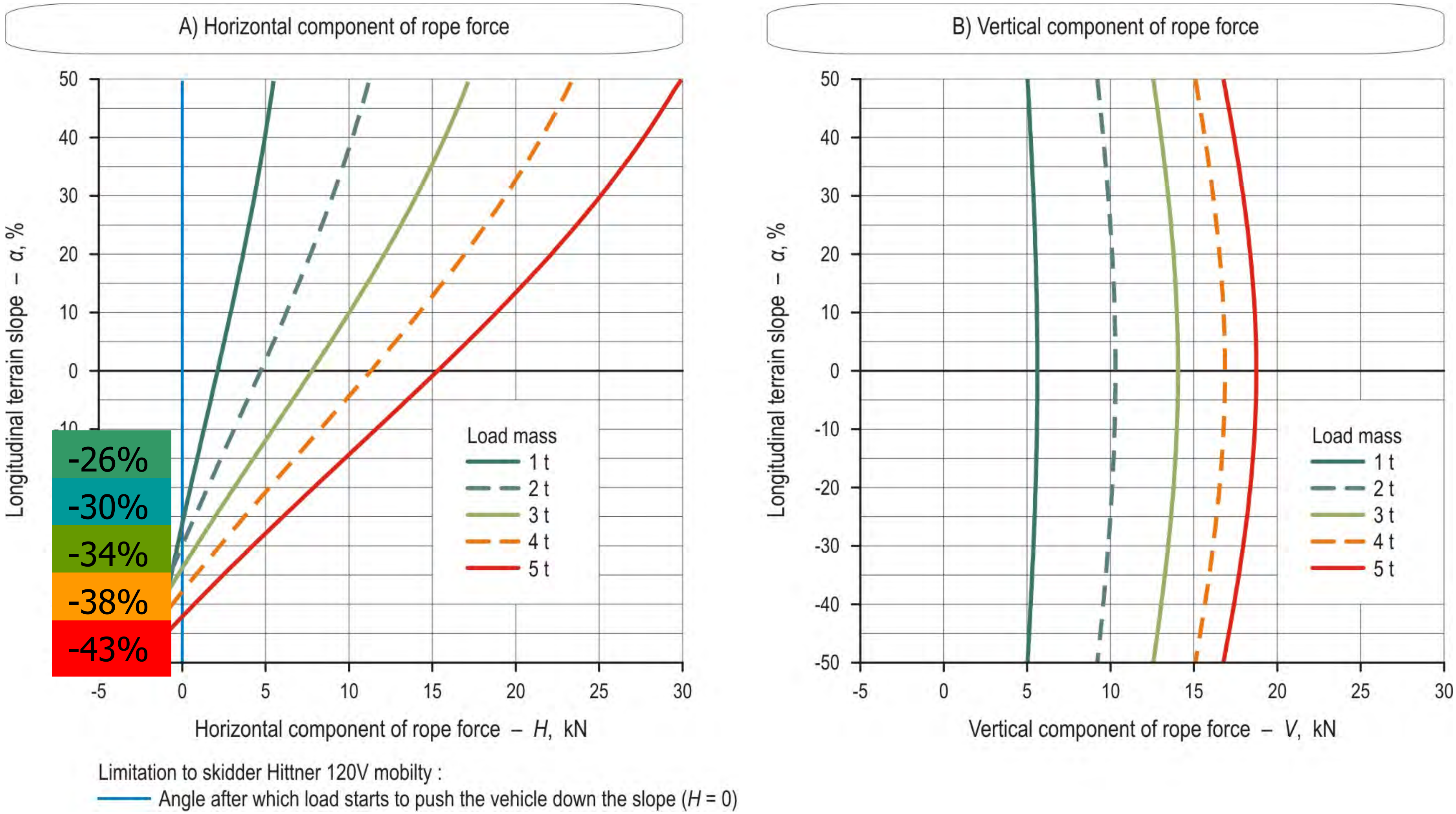
Depends on:
1. skidder weight (*G*),
2. longitudinal terrain slope (*α*),
3. the size of vertical rope force component (*V*), is influenced by load weight (*Q*).

Results – adhesion weight on each axle



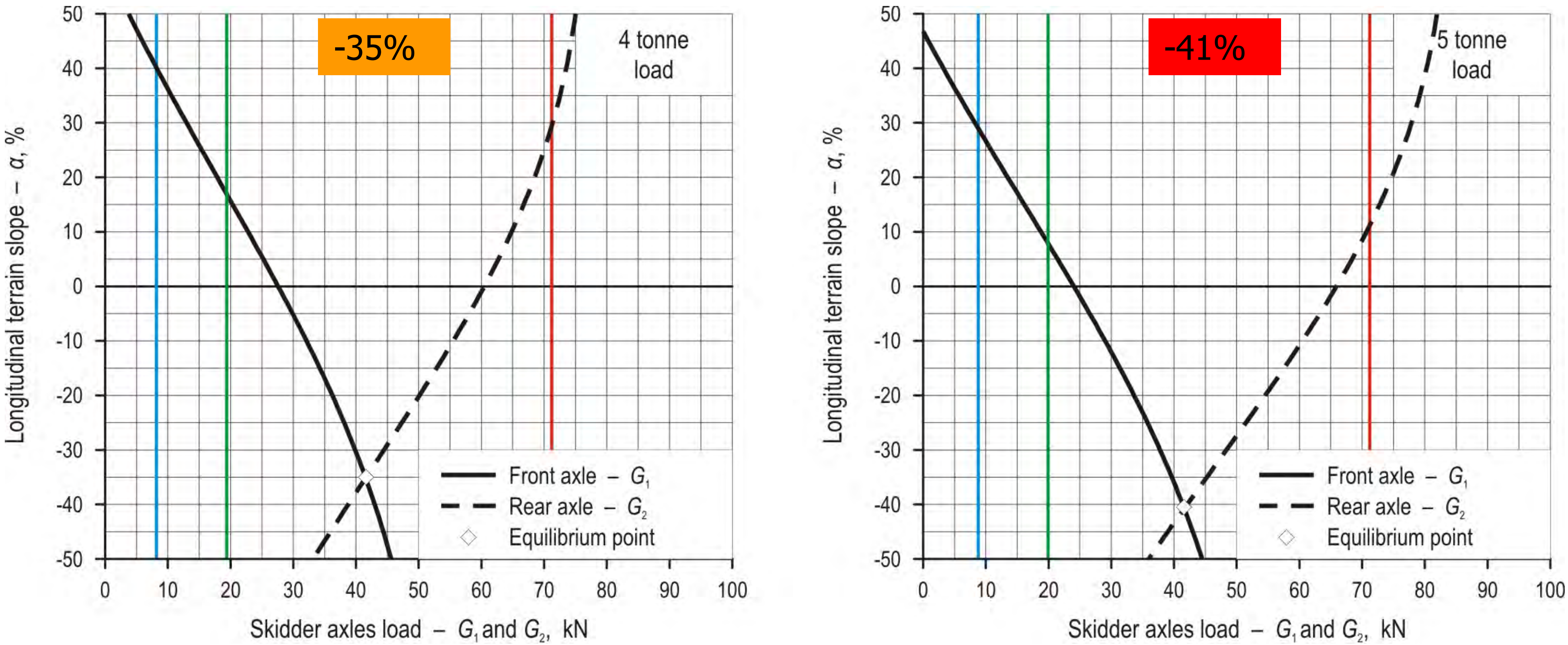
Adhesion weight is different than empty skidder weight (*G*) because the rear axle is additionally loaded with the full amount of vertical rope force component (*V*) that is dispersed to rear wheels thru horizontal rollers of winch.

Load and slope influence on horizontal and vertical components of rope force



During timber extraction downhill H decreases with the increase of terrain slope and load reduction, and V is greater than H → timber (logs) are approaching skidder's rear end, less part of load mass is on ground.
H = 0 is an important criterion for working safety → material fatigue, negative effect on the driver, loss of stearing control etc.

Load and slope influence on axle load distribution



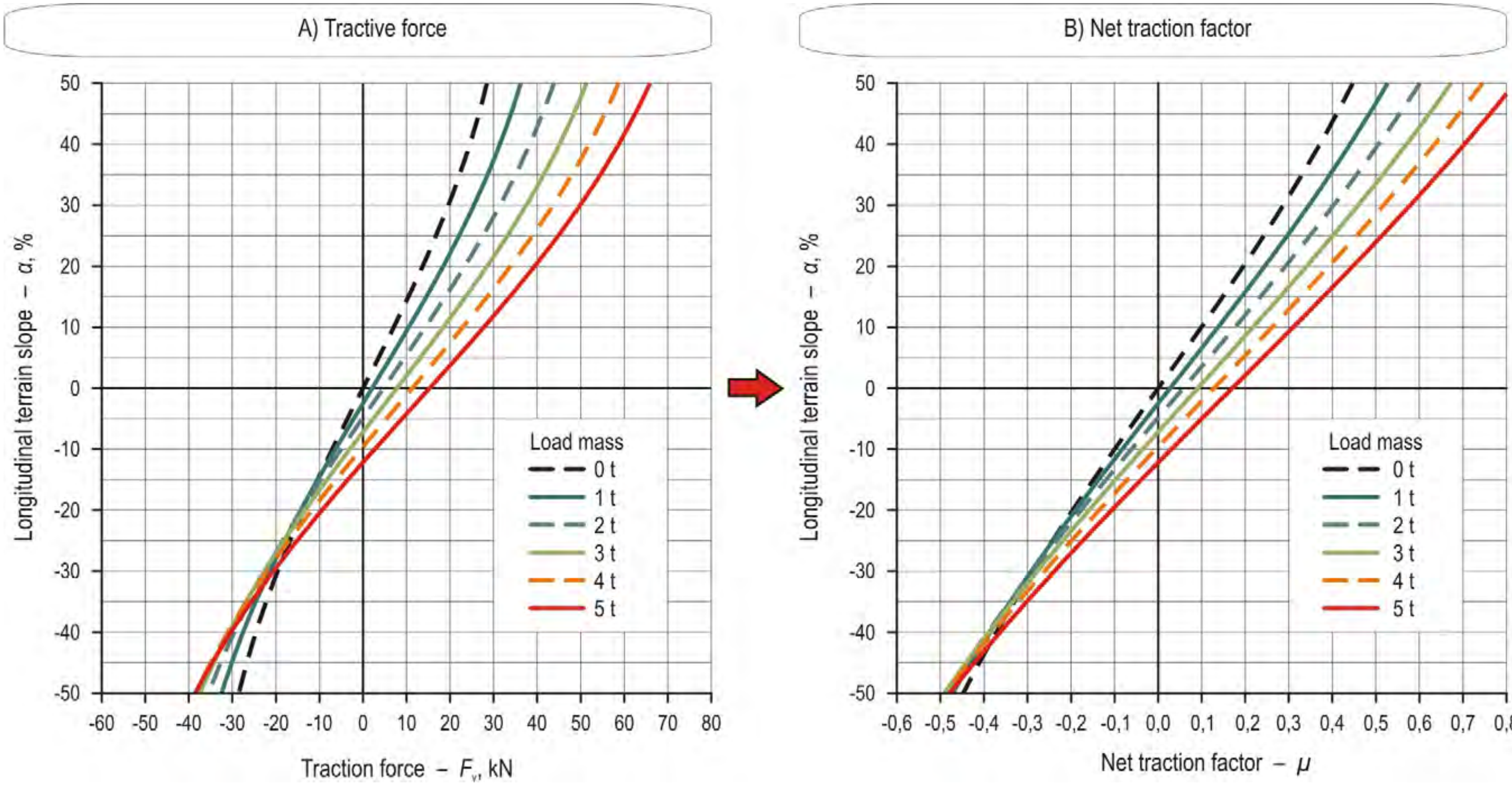
The least load on front skidder axle (0.1 G_a) according to Weise and Nick (2003)

Axle ratio $G_1 : G_2 > 1 : 3.5$ according to Sever (1980)

Maximal load on rear skidder axle (71.19 kN) according to Horvat (1990)

Given limits and most of research today is focused on uphill skidding, while downhill skidding (and vehicle mobility limits) remain fairly unknown.

Traction force



For timber skidding down the slope, traction force needs to overcome the resistance of the load on ground (*H*), but also resistance of horizontal component of skidder weight (*G* sin *α*), which pulls the vehicle in the opposite direction.

With the growth of the inclination angle, grows traction force with increasing of load weight, due to an increase in the value of the horizontal component of rope force (traction resistance) and the weight of a skidder that traction force needs to overcome.

Conclusions

• During skidding timber down the terrain slope one cannot talk about achieving real traction force (torque is used for braking) because skidder pulls the load by its own weight.

• The transfer of power from the motor to the wheels is used for braking due to the large impact of parallel component of skidder weight.

• Skidding is possible on even greater slope angles than stated above, the most important in downhill skidding, is to avoid blocking of the wheels, which will lead to a complete vehicle slippage.

• When load pushes the vehicle down the slope, due to the constant thrust of the timber at the back end of a skidder, one can conclude that such performance in a due time will result in fatigue of the material and early damage to the vehicle as well as the negative influence on psycho-physical state of the driver.


Thank you for your attention!