



## Vehicle assistance on steep grades

“If the grade or condition of the travel surface may result in a piece of mobile equipment having insufficient braking capability to maintain adequate control the equipment must be snubbed by a cable, or a suitable vehicle must be used to ensure safety when negotiating the grade.”

– Section 16.38 of the Occupational Health and Safety Regulation

The ability of a vehicle to climb or descend a slope depends on several factors, including the following:

- Type and condition of the slope surface
- Type of tire or track
- Engine operating angle limits
- Weight distribution
- Operator skill

Operators should be aware of vehicle limitations and ensure that a slope is within the vehicle capabilities before moving onto the slope.

This document explains how to determine when a slope is beyond the braking ability of a vehicle, and describes what constitutes a “suitable vehicle” for assisting vehicles on a grade.

### Ratings and standards

Vehicle manufacturers provide ratings for maximum operating slope. The maximum operating slope is often listed in the vehicle’s specifications.

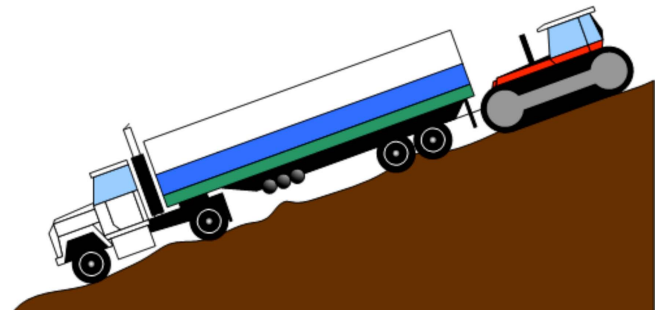
Most manufacturers of construction and industrial mobile equipment meet the standards published by the Society of Automotive Engineers (SAE). Among other things, these standards specify minimum performance requirements for holding slope and stopping ability.

### Holding slope and stopping ability

*Holding slope* is the steepest slope upon which the brakes of a vehicle are capable of holding the vehicle stationary. This assumes that the surface of the slope has enough traction for the vehicle’s tracks or tires to grip.

*Stopping ability* is the rate of deceleration – how quickly the vehicle can come to a stop. Stopping ability slope indicates the steepest slope on which a vehicle can travel. On slopes that exceed a vehicle’s stopping ability, the vehicle’s brakes will not be able to prevent the vehicle from running away.

If the holding slope or stopping ability slope is exceeded, the vehicle is no longer in complete control and requires assistance. A vehicle must not be operated without assistance on any slope that exceeds its holding slope or stopping ability slope.



### Maximum slope requirements

Table 1 describes some of the performance requirements listed in the SAE standards for various vehicle classes. The values shown are based on vehicle weight, using typical weights for each type of vehicle.

Table 1 has been simplified so it only shows either the holding slope or stopping ability slope, whichever value is lower. If a vehicle is to be used near the maximum operating slope, the vehicle operator should confirm with the manufacturer that the vehicle meets the SAE requirement.

**Table 1: Maximum slope\***

Vehicle type	Design slope	Holding force as % of weight
Truck or bus (less than 4500 kg)	20%	20%
Truck or bus (4500 kg or greater)	20%	20%
Agricultural tractors	18%	18%
Wheeled off-road earth-moving equipment	25%	24%
Wheeled loaders, scrapers, and graders	25%	24%
Wheeled off-road dumpers	18%	18%
Crawler tractors and crawler loaders	100%	71%
Roller compactors	20%	20%
Wheeled off-road mobile cranes and excavators	25%	24%
Wheeled skidders	40%	37%

\* These are suggested values only. A vehicle manufacturer may exceed requirements, and list a higher holding slope value in the vehicle specifications.

The “Holding force as % of weight” column shows the percentage of the vehicle weight that attempts to pull the vehicle down the slope. The vehicle must have enough brake force and traction to counter this pull.

Before moving onto a slope, the vehicle operator should determine if the slope is too steep for the vehicle to stop or hold its position using its brakes. To do this, compare the actual slope to either of the following:

- The value listed in the “Design slope” column of Table 1 for the appropriate vehicle
- The maximum slope listed by the manufacturer in the vehicle specifications

If the slope is too great for the vehicle (referred to as the *main vehicle*), a “suitable vehicle” must be used to help the main vehicle maintain control. If the slope is relatively short in length, the suitable vehicle can be placed on a flat area at the top of the slope, and use a winch to help the main vehicle up or down the slope.

### Factors when choosing a suitable vehicle

When choosing a suitable vehicle to assist a main vehicle on a steep grade, consider the following points for both vehicles:

- Weight
- Traction

- Braking ability
- Operating grade

A suitable vehicle must not depend on engine power alone to hold its position while assisting the main vehicle because a stalled engine or drivetrain failure would result in a runaway situation for both vehicles.

Relative vehicle weight is an important factor. Braking ability depends on traction, which in turn depends on the weight and weight distribution of the vehicles. Tracked vehicles are preferable as assisting machines because of their superior traction on most surfaces. Traction for rubber-tired machines can be improved on soft ground or snow by using tire chains on all wheels used for braking.

Two vehicles of the same type but of different weights will develop similar deceleration rates, but the actual braking force developed by the heavier vehicle will be greater.

Properly sized chains, wire cables, or towing bars must be used to snub vehicles together. If cables or chains are used, they must be rigged according to the requirements in Part 15 of the Regulation.

For the combination of vehicles to work, the brake force needed must be less than the brake force available, assuming that the ground surface on the slope can provide enough traction for both vehicles.

### Calculating holding force

Taking the above factors into account, one way to determine whether a vehicle can be used to assist a main vehicle on a slope is to calculate how much brake force is needed and how much brake force is available for the combination of vehicles. To do this, use the following formula:

$$W_t > W_m \frac{(S_{am} - S_m)}{(S_t - S_{at})}$$

Where:

$W_t$  = actual weight of assisting vehicle

$W_m$  = actual weight of main vehicle

$S_t$  = assisting vehicle holding force as % of weight (%wt)

$S_m$  = holding force of main vehicle (%wt)

$S_{at}$  = actual slope for assisting vehicle (%wt)

$S_{am}$  = actual slope for main vehicle (%wt)

Note that the holding force and actual slope values are expressed as percentages of vehicle weight. Look for the holding force values in the “Holding force as % of weight”

column of Table 1. (If the vehicle specifications indicate the maximum slope for the vehicle, use Table 2.)

The percentage weight value for the actual slope is also from the “Holding force as % of weight” column of Table 2. If a slope value falls between two of the values listed in Table 2, use the larger slope for the calculation. Weight values can be in pounds or kilograms, as long as the same unit is used throughout the calculation.

To use the formula, look up the necessary values in the “Holding force as % of weight” columns and insert them into the formula. The actual weight of the assisting vehicle must be greater than the value calculated on the right side of the equation. Slopes that fall between two values on Table 2 should be rounded up to the next highest value.

**Table 2: Conversion chart**

Actual slope in %	Actual slope in degrees	Holding force as % of weight
0%	0.0	0.0%
5%	2.9	5.0%
10%	5.7	10.0%
15%	8.5	14.8%
20%	11.3	19.6%
25%	14.0	24.3%
30%	16.7	28.7%
35%	19.3	33.0%
40%	21.8	37.1%
45%	24.2	41.0%
50%	26.6	44.7%
55%	28.8	48.2%
60%	31.0	51.4%
65%	33.0	54.5%
70%	35.0	57.3%
75%	36.9	60.0%
80%	38.7	62.5%
85%	40.4	64.8%
90%	42.0	66.9%
95%	43.5	68.9%
100%	45.0	70.7%

## Example for calculating brake force

*A 25,000 kg off-road mobile crane needs to be assisted up a 31% slope. The surface of the slope is crushed gravel. An 8000 kg crawler tractor is available, as well as an 8000 kg wheeled off-road loader. Can either of these vehicles be used to assist the crane?*

According to Table 1, the mobile crane is capable of braking to a stop on any slope of 25% or less. The crawler tractor is capable of stopping on a 100% slope. The wheeled loader is capable of any slope 25% or less. The actual slope is 31%, so the loader cannot be used; the crawler tractor is a possible choice.

*Will the crawler be suitable for the task?*

Convert the percentage slopes into percentage weights by referring to Table 2. Use the “Actual slope in %” column, and round 31% up to the next highest value, which is 35%. The actual slope is as follows:

At 35% slope:  $S_{at} = S_{am} = 33\% \text{ wt}$

For the main vehicle, the maximum slope it is capable of is as follows:

At 25% slope:  $S_m = 24\% \text{ wt}$

The maximum braking capability of the assisting vehicle is:

At 100% slope:  $S_t = 71\% \text{ wt}$

Using these values, the formula gives the following:

$$8000 > 25000 \cdot \frac{(33 - 24)}{(71 - 33)}$$

$$8000 > 5921$$

Therefore, the crawler is capable of assisting the mobile crane. If the crawler had not been sufficient for the task, we would need to find another crawler with greater braking capability. This implies a heavier machine.