

Heavy vehicle stability guide

Version 1.0
Land Transport Safety Authority
PO Box 2840
Wellington
New Zealand

Background

New Zealand has a high incidence of rollover and loss-of-control crashes compared with other countries such as the United States and Canada. Rollovers occurred in 29 percent of the heavy vehicle crashes attended by the New Zealand Police Commercial Vehicle Investigation Unit between July 1996 and November 1999.

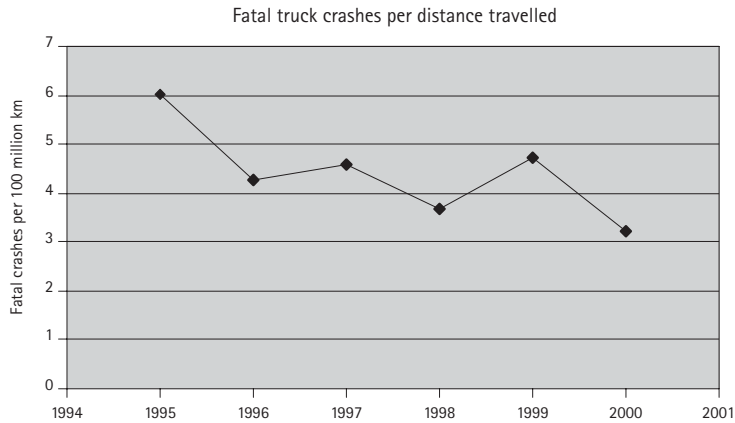


Figure 1: Fatal truck crashes per distance travelled

This high number largely reflects New Zealand’s difficult driving conditions. The country has more bridges, corners and hills per 100 kilometres of road, and fewer divided highways, than most other developed countries.

Drivers of large vehicles have a responsibility to do so considerably and professionally. Rollovers in single-vehicle crashes involving trucks often reflect their poor appreciation of general dynamics and stability issues. And while two-thirds of all fatal truck-versus-car crashes are the car drivers’ fault, drivers must appreciate they sometimes have the power to prevent the crash, even if they are not at fault. This means driving according to the conditions, and having a reasonable understanding of the forces at work on the vehicle and their effects.

A 1999 study¹ showed a clear relationship between rollover crash risk and stability (characterised by the static roll threshold (SRT)). Figure 2 shows the relationship between rollover crash risk and SRT. The poorest-performing vehicles (those with an SRT less than 0.3g) had four times the average rollover crash rate. The study also found that the 15 percent of vehicles with an SRT less than 0.35g were involved in 40 percent of the rollover crashes. It is clear that improving the performance of the poorest-performing vehicles in New Zealand’s fleet should generate a substantial reduction in rollover crashes.

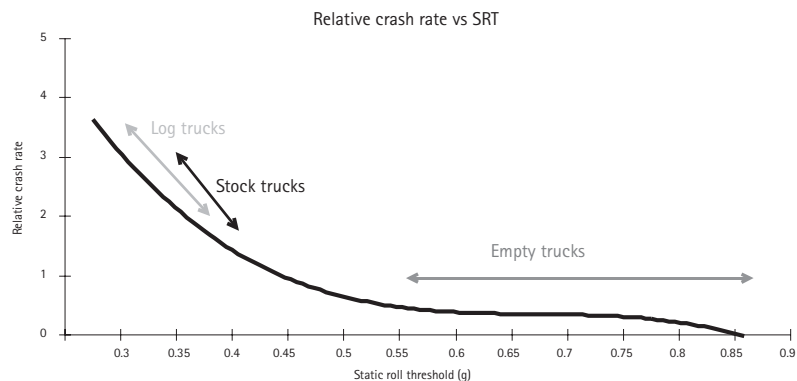


Figure 2: Relationship between rollover and crash risk and SRT

¹Mueller, T.H., de Pont, J.J. and Baas, P.H.(1999) Heavy Vehicle Stability versus Crash Rates. TERNZ Research Report prepared for the LTSA, available online at www.ltsa.govt.nz/publications/docs/Stability.pdf.

The *Vehicle Dimensions and Mass Rule* includes a performance-based stability requirement for heavy vehicles of classes NC (trucks over 12 tonne) and TD (trailers over 10 tonne).

This guide provides information on heavy vehicle stability issues and suggests techniques for minimising the risks of rollover and loss-of-control crashes, therefore improving the current crash trends.

The basics

Like everything around us, we're affected by the laws of nature. These, for example, ensure that:

- we don't fall off the planet
- if we throw something it will keep going in a straight line away from us
- while a man walking into a tree will probably damage himself, a man running into a tree will damage himself more out of all proportion to his increase in speed
- a short, stocky rugby prop will maintain his feet better in a maul or a ruck than a much taller lock
- if you wander onto ice you stand a really good chance of falling over.

These same principles apply to our vehicles and, while they can't be eliminated, they can be controlled.

Speed

The effect of speed on cornering stability, braking distance and impact forces increases at the square of the speed increase. This means, for example, that cornering forces don't just double when the vehicle speed doubles, they increase by four times.

This effect is highlighted in Figure 3. The arrow in the left-most illustration represents the overturning force acting on a truck in a 30 kilometre per hour (km/h) corner. If the same truck is driven through the same corner at 60km/h, the overturning forces will be four times higher ($2 \times 2 = 4$, speed squared effect), represented by the arrow in the middle illustration. If the truck is now driven through the corner at 90km/h the overturning forces will be nine times higher ($3 \times 3 = 9$, speed squared effect) than at 30km/h, as in the third illustration. This speed squared effect has a dramatic impact on vehicle stability and controllability.

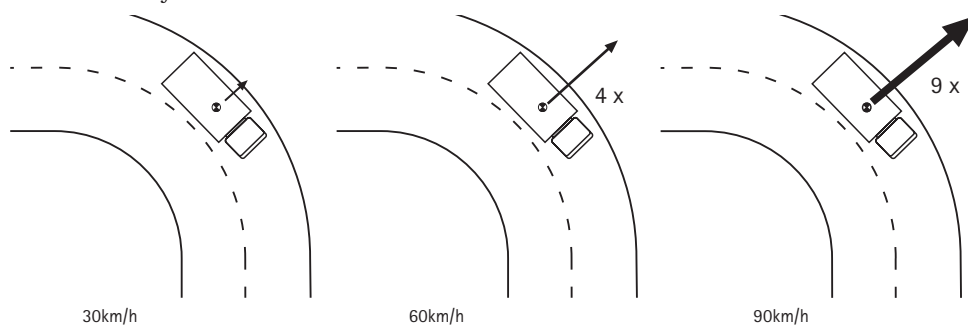


Figure 3: Speed squared effect on cornering forces

Gravity

Gravity creates a force that, in simple terms, attracts everything towards the centre of the earth. The force is measured as weight. A person weighing 90 kilograms (kg) and a truck weighing 15,000kg (Figure 4) are both attracted towards the centre of the earth with the same gravitational acceleration. If both were free to fall they would accelerate at the same rate, called one gravity (accelerate at 1g).

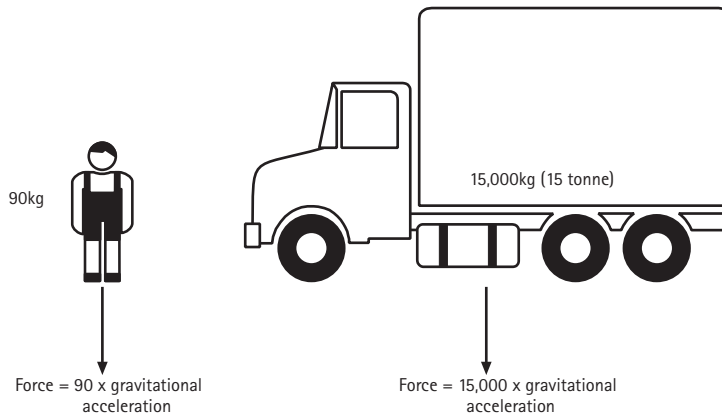
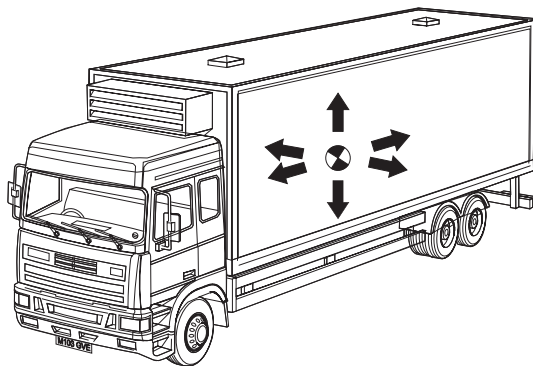


Figure 4: Gravitational acceleration

Centre of gravity

Every object affected by gravity has a centre of gravity (CG): the point around which the object is balanced in all directions (Figure 5). The higher the CG the more unstable the object (such as a truck). The closer to the ground, the more stable the object.



In vehicle terms, if a load is not centred across its width, the stability will be reduced when cornering. If the load is not balanced correctly along its length, wheel lockup during braking becomes more likely.

Figure 5: Centre of gravity

Kinetic energy

Kinetic energy is the energy contained in a moving object. The heavier and/or faster the object, the more energy it will contain.

A bullet, for example, is small but extremely fast and has the potential to do a lot of damage over a small area owing to its kinetic energy. A truck, on the other hand, is relatively slow but is extremely heavy and also has the potential to do a great deal of damage over a greater area for the same reason.

While a bullet's energy is either absorbed by the target or eventually eliminated by friction as it moves through the air, the energy in a vehicle is converted to heat by the friction that occurs in the brakes when the driver activates the brakes. The effects of kinetic energy increase at the square of the speed – and have a major influence on all motor vehicles in three particular situations:

1. **Braking** The faster a vehicle goes, the further it takes to stop. For example, if a truck's speed is doubled, it will take four times the distance to stop it.
2. **Cornering** If a truck enters a corner at 60km/h there will be four times more overturning (side) force on the vehicle than if it had entered the corner at 30km/h.
3. **Impact** The damage to a vehicle (and its driver) at impact in a crash situation will also increase at the square of speed. In other words, double the speed = four times the damage, triple the speed = nine times the damage. A pedestrian knocked down at 60km/h will suffer four times as much damage as one knocked down at 30km/h.

Friction

Friction is the resistance to motion that occurs when one body or surface moves across another. On a vehicle the most common points of friction are the brakes, the tyre contact with the road, air resistance and engine and transmission components.

Friction creates heat. Vehicle braking systems produce large amounts of heat, but the secret to a good braking system is its ability to dissipate, or remove, that heat quickly. The faster a vehicle is travelling, or the heavier it is, the more heat the brakes generate in bringing the vehicle to a stop.

The friction between the tyres and the road is what allows the driving, braking and cornering forces to be transmitted to the road surface.

Centrifugal force (overturning or side force)

Centrifugal force causes passengers to slide across the seat when cornering at high speeds and happens when a moving object, such as a vehicle, changes direction.

The weight of a vehicle means that when travelling in a straight line it will endeavour to continue in that direction, even when the driver turns the steering wheel. Changing direction causes the vehicle's weight to move to the outside of the turn which, unless the driver controls its speed, can lead to rollover or sliding out.

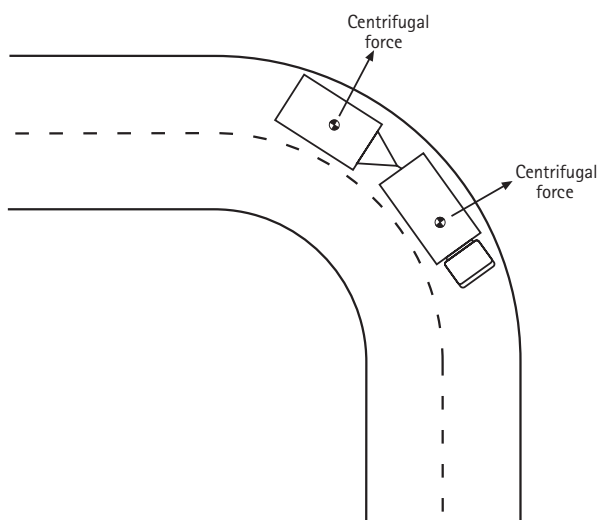


Figure 6: Centrifugal force in a turn

Centrifugal force is affected by the square of vehicle speed and the turn radius. In other words, the faster the vehicle is going and/or the tighter the turn, the more likely the driver is to lose control of the vehicle and for rollover to occur.

Stability

Of the factors that can influence a vehicle's tendency to roll over, the following are the most important:

- speed
- CG height
- track width
- suspension
- tyres.

If all these factors are maintained at acceptable levels, the vehicle will remain stable. The risk of loss of control and rollover will increase if they are not considered.

Rollovers typically happen during cornering (at either high or low speed) and during sudden evasive steering manoeuvres.

Static roll threshold (SRT)

SRT describes the maximum amount of lateral (sideways) acceleration a heavy vehicle can handle without rolling over. This depends on the vehicle's speed and the tightness of the turn.

The centrifugal (side) force created by the lateral acceleration will push a part of the vehicle's weight to the outside of the curve when the driver turns the steering wheel. The SRT is the lateral acceleration required to transfer all the weight to one side of the vehicle, and is a fraction of 1g (Figure 7).

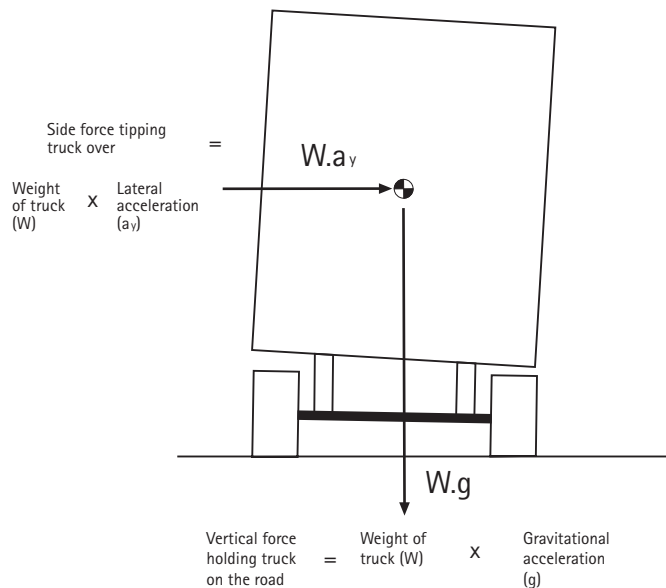
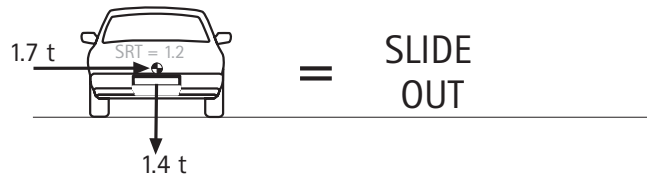


Figure 7: Side force and vertical forces acting on truck during cornering

Figure 8 illustrates the effect of SRT on the level of side force required to cause a vehicle to slide out or roll over. It clearly indicates the importance of CG height.

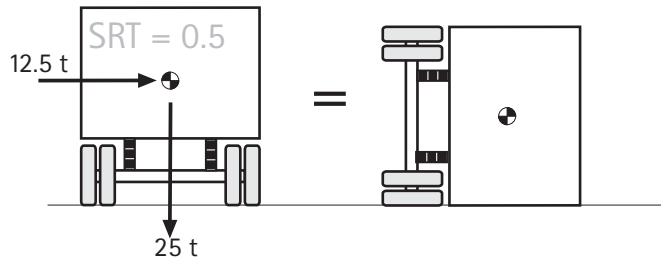
Example 1

If a car has a mass of 1.4 tonnes and an SRT of 1.2g a side force of 1.7 tonnes is required to cause rollover. Generally the car will slide out before rolling over.



Example 2

A 4-axle trailer with a mass of 25 tonne, and an SRT of 0.5g (low CG load) will roll over in a corner if the side force is greater than 12.5 tonne (0.5g).



Example 3

A 4-axle trailer with a mass of 25 tonne and an SRT of 0.3g (high CG load) will rollover in a corner when the side force goes beyond 7.5 tonne (0.3g).

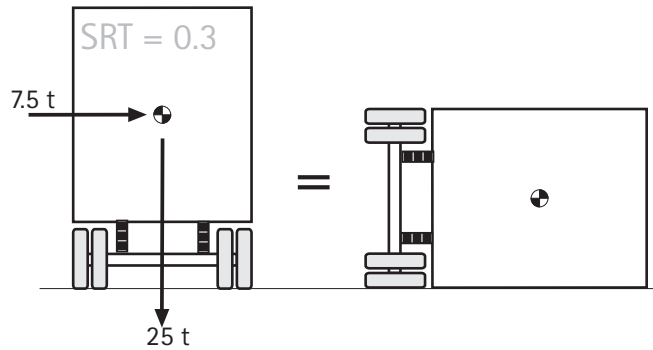


Figure 8: SRTs of different vehicles and loads

The *Vehicle Dimensions and Mass Rule* requires all goods service vehicles of classes NC (trucks exceeding 12 tonne) and TD (trailers exceeding 10 tonne) to meet an SRT performance standard of 0.35g or higher. Because heavy combinations are not rigid in their construction, the effects of tyres, suspension, trailer couplings and load type and height must all be considered when calculating the SRT.

Evasive manoeuvres

Dynamic load transfer ratio, rearward amplification and high-speed off-tracking

Drivers operating heavy vehicle combinations need to make constant steering corrections, whether for simple road undulations and the effects of camber or wind or when negotiating intersections and undertaking evasive manoeuvres to avoid other vehicles or obstacles.

These manoeuvres can be at relatively low speed but involve several directional changes (as in a roundabout) or take place at high speed, as in a steering correction during cornering. In each of these situations there is a dynamic transfer of weight from one side of the vehicle to the other.

Every steering correction is amplified along the length of the combination, so a minor movement of the steering wheel will create a large amount of sideways movement at the rear of the unit. This is known as steering (or rearward) amplification, or “cracking the whip” (Figure 9). The effects can be quite startling, even on straight roads, particularly if the vehicle is transporting “live” loads or those with a high CG. It may also result in the trailer off-tracking outside the path of the prime mover (see Figure 9).

Rearward amplification causes a load transfer from one side of the vehicle to the other. This is quantified with a measure called “dynamic load transfer ratio” (DLTR), which is illustrated in Figure 10. A vehicle with a poor SRT will have a high DLTR, making it unstable not only on corners but also in any steering manoeuvre.

The DLTR is determined using a standard lane change manoeuvre. It uses 0 as the ratio for a vehicle moving down a straight road and 1 for a vehicle that has all its wheels (except the steer wheels) on one side off the ground. An acceptable DLTR is 0.6. At this level 60 percent of the weight has been transferred from one side of the vehicle to the other during the standard lane change.

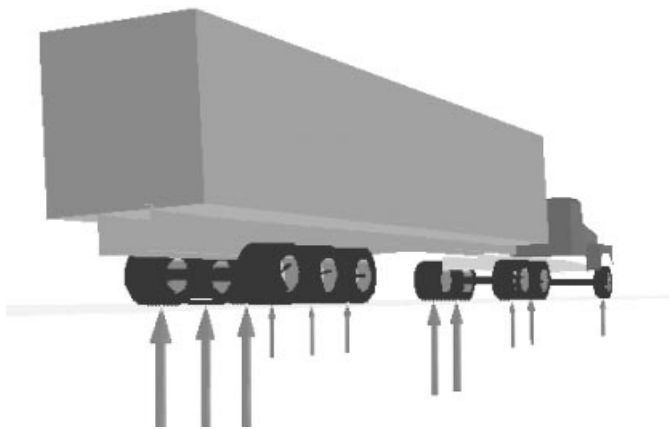


Figure 10: Dynamic load transfer ratio

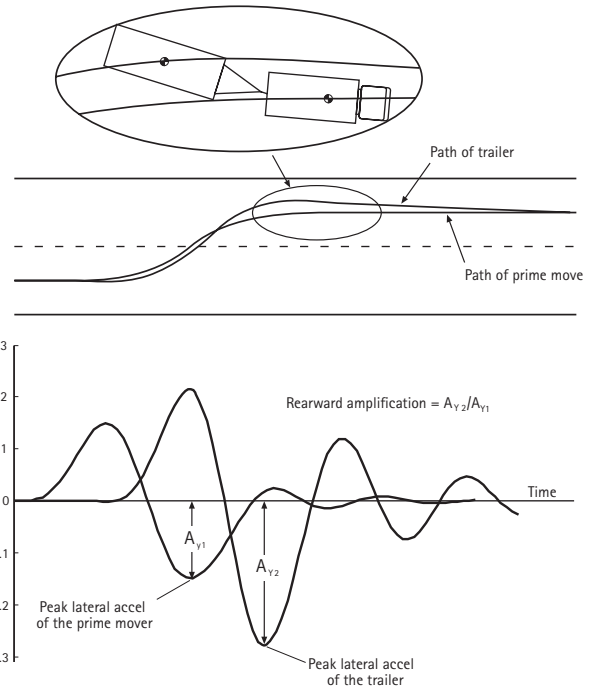


Figure 9: Rearward amplification in lane change

Dynamic load transfer ratio (DLTR)

DLTR is the ratio of the weight on one side of the vehicle to the other. When travelling straight DLTR is 0 as the weights on both sides are equal. At the point of rollover DLTR = 1 as all the weight is on one side of the vehicle.

Vehicle/load factors

Roll coupling

Roll coupling is a key influence on the likelihood of a combination vehicle rolling over. It relates to the way a trailer is attached to its towing vehicle. For example:

- a semi-trailer is coupled to its prime mover in a way that ensures any lateral (side) forces must be sufficient to roll over not only the trailer, but also the tractor unit
- a full (dog) trailer is coupled to the truck via a steerable drawbar that can rotate at the hitch. This means that if the weight transfer is sufficient to roll the trailer over, it will do just that. The truck will normally stay on its wheels unless other factors are involved.

The SRT for the most unstable unit in a truck and trailer combination becomes the performance standard for the whole unit. This will almost invariably be the trailer SRT.

Vehicle inspections

The recommended daily checks on heavy vehicles achieve a number of positive outcomes:

- They ensure that the vehicle meets legal requirements for operating on the road.
- They reduce the risks for both the driver and other road users.
- They play an important part in transport companies' routine maintenance programmes.

The “she’ll be right” attitude has no place in the modern industry and “kicking the tyres” and checking the oil and water are not sufficient to give the operator confidence that the vehicle is safe and ready to carry out its tasks.

A number of the items that must be checked can directly affect stability. For example:

- tyres transmit all the driving, braking, steering and cornering forces from the vehicle to the road. They play a crucial role in maintaining stability and must be checked for compatibility, tread, inflation and damage. Spot checks should be carried out during the shift and pressures checked with a gauge at least weekly
- the suspensions support the vehicle’s weight and isolate it and the load from road shocks. While air suspension can provide superior stability, all suspension components should be checked for damage or distortion
- brakes and steering should be checked when moving off and any problems reported and immediately rectified. Hub temperatures can be checked as a way to identify whether individual brakes are binding or, alternatively, not operating at all. One brake out of adjustment can add metres to the stopping distance.

Load placement

Load placement and security are key factors in many stability-related crashes. Drivers must make sure there is enough weight over all axles to provide adequate brake balance.

The load should be distributed evenly across the vehicle (Figure 11). When offloading freight, it’s important to consider redistributing the remaining cargo.

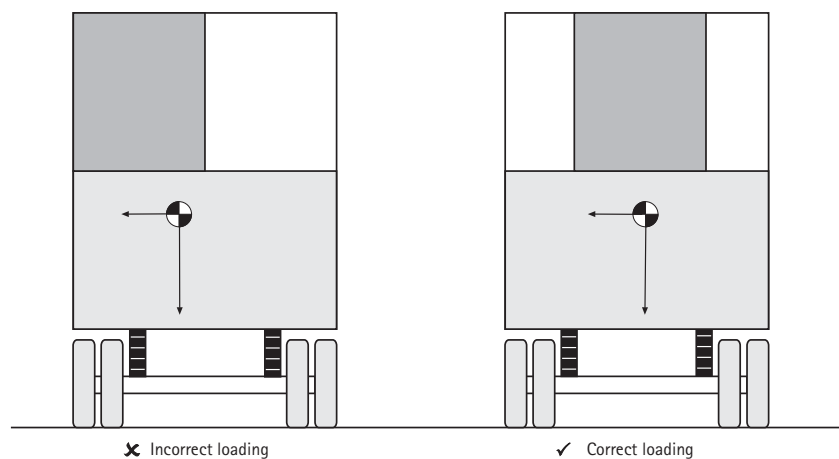


Figure 11: Load placement effect on centre of gravity

Heavy items should be placed to the bottom of the load so that the CG remains as low as possible. “Live” loads (those that by their nature will move, such as livestock, hanging meat, bulk liquids and grain) should be loaded to minimise movement as much as possible (Figure 12).

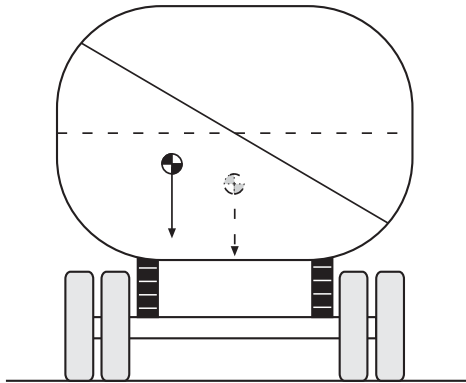


Figure 12: Effect of live loads on centre of gravity position

The LTSA publication *The Truck Loading Code* sets minimum standards for load restraint; operators should familiarise themselves with it. These standards are designed to prevent load shift under normal operating conditions including braking, acceleration, cornering and movement over uneven ground.

Any load shift will decrease stability dramatically, particularly during braking and cornering. Any loads positioned more than 100 millimetres away from the curtains or sides of a vehicle must be restrained in accordance with the Code to prevent the likelihood of load shift during cornering.

Drivers with loads with a high CG must drive more carefully, especially around curves. Their responsibility for loading rests with them and starts at the time of loading. Any loading placement that increases the height of the CG or shifts it off-centre (closer to one side) will reduce the vehicle's stability.

Driver factors

The system of vehicle control

When negotiating intersections, roundabouts and other potential hazards such as road works, railway crossings and crash sites, it's important to control the vehicle's speed and lateral cornering forces before entering the site. Drivers following the system of vehicle control (Figure 13) will be concentrating on potential trouble spots, not on the brakes and shift lever.

1. Course Know where you are going and put the vehicle in the correct place on the road
2. Mirrors Check behind the vehicle and along both sides
3. Signal Indicate your intentions for at least three seconds before you carry out any manoeuvre
4. Brake Adjust your road speed early so you can downshift
5. Gears Change down, and repeat the process if necessary so that you are in the right gear before you manoeuvre
6. Mirrors Check your mirrors again
7. Execute Carry out the manoeuvre
8. Accelerate Accelerate away from the turn or hazard

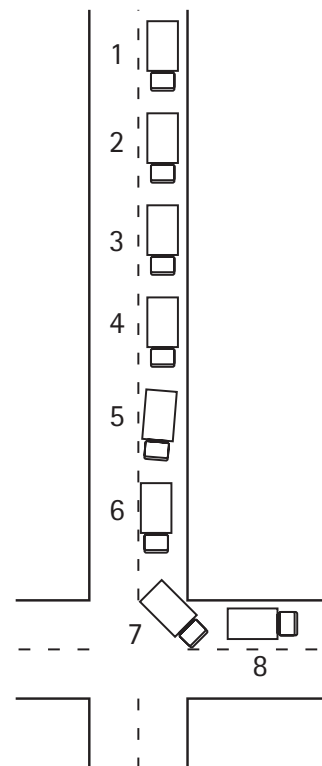


Figure 13: Vehicle control during turns

While this technique does take some getting used to, it produces an unrushed, deliberate driving style that reduces the risks. This is particularly so at intersections and even more so at roundabouts, where three directional changes can occur and vehicles carrying high CG or “live” loads often come to grief. In these situations the combination of road camber and running trailer wheels onto kerbs can make the stability problem even worse and a very cautious approach is necessary.

It is important to maintain two-handed steering whenever possible, not only during turns and cornering but also when travelling on straight roads. A driver who consistently leaves one hand off the wheel responds more frequently to normal vehicle movement than one who adopts a relaxed, two-handed steering style. The dynamic load transfer that occurs as a result of steering amplification and yaw (snaking) should not be underestimated, particularly by those who operate vehicles carrying high CG loads.

Jack-knife and trailer swing

While the two frightening situations of jack-knife and trailer swing are more common with semi-trailer combinations, they can, and do, happen to full trailers.

In a jack-knife the drive axles lock up under braking before the steer axle locks up. Any small side-to-side force imbalance owing to road slope or surface condition will cause the drive axles to move rapidly out of line.

Trailer swing happens when the semi-trailer wheels or rear wheels in a full trailer lock up under braking before the axles on the prime mover or front of the trailer. The trailer’s rear swings out of line and tries to “catch up” to the front.

The main causes of these situations are:

- poor brake balance
- poor load distribution
- harsh braking
- incompatible truck-trailer configurations
- deceleration or braking on corners, particularly on wet or icy roads.

These situations can be avoided by:

- using the right speed for the prevailing conditions
- keeping the correct following distances
- ensuring efficient maintenance
- maintaining correct load distribution.

Cornering

No two corners are exactly the same, and road-controlling authorities try to give some indication of corners’ severity by using advisory signs.

These signs include a recommended speed and a diagram of the corner’s line. The recommended speed reflects a maximum of 0.22g of sideways acceleration on any vehicle following a constant, steady path, at the posted speed, through the corner. If the SRT of a vehicle were 0.22g it would roll over while negotiating the curve at the advisory speed.



The speed squared effect means the difference in speed between 0.22g and 0.35g can be small. For example, a truck driving through a curve with a 25km/h speed advisory sign at the posted speed would experience a 0.22g lateral acceleration. If the truck travelled through the curve at 31.5km/h, the lateral acceleration would be 0.35g, only a 6.5km/h difference.

Empty vehicles have a much higher (safer) SRT but the same basic principles apply.

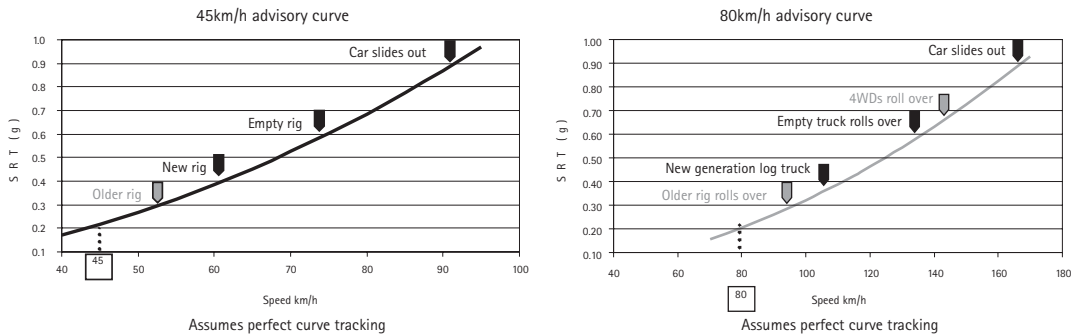


Figure 14: Rollover speeds versus SRT for 45km/h and 80km/h speed advisory turns

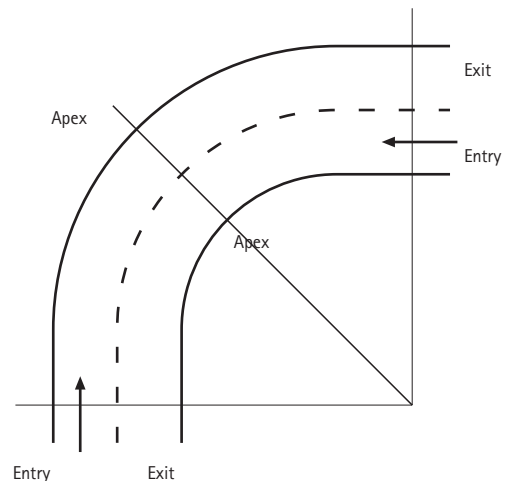
Figure 14 shows the maximum speed possible at different SRT levels for a 45km/h and 80km/h corner before rollover occurs. The actual speed at which rollover happens may be lower owing to the driver having to make steering adjustments through the corner, road undulations or load shifting.

When travelling down a straight road, a vehicle is at 0 percent of rollover. When all the wheels on one side come off the ground during cornering or an evasive manoeuvre, the vehicle is at 100 percent of rollover. Where are you (between 0 and 100 percent) every time you go around a corner? If you are 1km/h below the speed to roll over you might not know, but if you are 1km/h above the speed you really, really will!

Think of this as the “1k factor”.

By far the most important aspect of dynamics control is the driver’s response to corners. While every corner is different, each has three definite points.

1. **Entry** This is where the driver begins to turn the steering wheel to enter the corner. At this point the driver must have completed all deceleration, braking and downshifting. They should be at, and maintaining, the desired speed as they enter the bend.
2. **Apex** This is the point where the vehicle is closest to the inside of the turn. The driver should maintain the entry speed to this point and now start to slowly accelerate. The steering line should now be completed.
3. **Exit** The driver should have accelerated from the apex to this point, which is where the vehicle returns to a straight line.



Vehicle rollovers normally occur between the apex and the exit of a corner as a result of excessive speed or braking. The prime mover should pull the trailer through the bend, not be pushed by it. This can only be achieved with the correct technique. Cornering stability will be improved and the effects of centrifugal force reduced if the correct cornering line is also applied.

“Off-tracking” is another issue to be considered during cornering. While most operators are aware that combinations, particularly semi-trailers, track in dramatically at low speed, the opposite can happen at high speed. Running too close to the centre line through left-hand bends and too close to the road edge through right-hand bends can lead to trailer wheels crossing into the opposing lane or drifting off the road edge with serious consequences.

Summary

While the *Vehicle Dimensions and Mass Rule* introduces new standards for heavy motor vehicles and requires manufacturers and operators to meet these standards, the success of the Rule rests in no small part with drivers.

Drivers need to:

- acquire a basic understanding of vehicle dynamics
- apply the correct driving techniques to manage the forces at work
- ensure their vehicle speed reflects the driving conditions
- consider the effects of loads and the ever-changing road conditions
- familiarise themselves with the effects of speed, weight and cornering dynamics.

This guide will, we hope, offer the first step in improving that knowledge and be a catalyst of discussion.