Impact Of European Size And Weight Policies On The Characteristics Of Heavy Vehicles

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ABSTRACT

The transportation of volume goods is increasing and this calls for an increase in the space available for the payload. If the permitted length of the vehicle is short, this may lead to vehicles with inferior characteristics. The dynamic stability of vehicle combinations is one of the factors which is affected. Longer vehicle combinations, implying longer trailer wheelbase, significantly increase the dynamic stability. Small tyres, a consequence of low chassis designed for volume-goods, have a negative influence on stability because of their reduced cornering capability. Reduced spring travel of the suspension, which too is a consequence of low chassis, may cause a substantial increase in dynamic wheel forces.

HISTORIC BACKGROUND

As the need for more transportation of goods has developed, both the size and the weight of the heavy vehicles have increased in all European countries.

By tradition the countries in northern Europe have allowed lower axle loads than countries in southern Europe. In some Nordic countries there is also a tradition of using long vehicle combinations. In Sweden, for instance, the maximum allowed length is 24 m and the maximum GCW 60 t for all types of combinations. Another difference is that the northern countries have used bridge formulas in order to protect the bridges.

European length restrictions also encouraged the transition from conventional, bonneted vehicles to forward control vehicles. This change took place during the sixties and today forward control vehicles are virtually exclusively used.

Up to 1985 all requirements with respect to weights and dimensions were based on national regulations. International traffic had to apply to the worst case principle. This is of course no ideal situation for rational transports or for making optimal vehicles, because among other things it creates a need for a wide variety of bogies with different weight distribution, capacity and axle distance.

In 1985 the European Community (now the European Union) adopted a directive which regulated weights and dimensions for international traffic, ie traffic between the countries belonging to the EC (now EU). Many non-EU members later adopted these weights in their national legislation, while some EU members did not approve of them and obtained derogations. The table in Figure 1 shows some of the traditional weights and the international EU weights.

	North Europe	EU	South Europe
Drive axle	10	11.5	13
Bogie	16	18/19	21
GVW 2 axl.	16	18	19
GVW 3 axl.	22	25/26	26

Figure 1. Examples of Axle and Gross Vehicle Weights (tonne)

This EU directive implied an increase of the drive axle load for many countries. At one stage this increase was coupled to the demand that the suspension of that axle should be "road-friendly", ie the stiffness shall be low and the damping sufficient in order to keep the dynamic wheel loads at a low level, which has a positive effect for the roads. This demand is technically justified but due to political difficulties in reaching an agreement it was cut out. One of the bonuses which remains if the drive axle has a "road-friendly" suspension, is that the trailer in four-axle articulated vehicles may have an extra two tonnes load. This type of configuration however is rare. Another bonus is that the GVW of a three-axle truck is 1t higher.

Another requirement which was introduced, in order to improve traction, is that at least 25 % of the weight of the vehicle shall be carried by driven axles.

POLICY TRENDS

WEIGHT

The EU axle weights for international traffic are widely accepted in the national legislations and no further increases are expected.

There is a large variation between permitted GCW in different European countries. It is likely that there will eventually be an increase from 40 to 44 t for international traffic. For combi traffic this is already the case. Further increases for new types of vehicle configuration are also discussed. Regional differences will probably be retained.

Even if the bonus of road-friendly suspensions now is small, there is an interest in many countries in increasing the incentives to use them not only on driven axles. These may be tax benefits just as well as weight benefits.

LENGTH

The overall vehicle length will probably increase in the long run even if it is a diffcult political question in densely populated regions. One reason for this is that the GCW has increased over the years. Another reason is that the density of the goods has decreased. In order to be able to utilize the load capacity it is therefore necessary to increase the space of the payload as much as possible. If the total length is given, other spaces will have to be reduced. Such other spaces are the length of the cab and the length of the gap between the vehicle units. This effort led to the development of short cabs.

The state of the art used to be cabs with a sleeping compartment behind the driver's seat, but trucks for long haul operations started to be ordered with so called day cabs, ie cabs with no sleeping compartment. They were then supplemented with a sleeper box mounted on top of the cab. To further increase the space for the payload, the cab was cut off just behind the doors, the engine was moved forward and the radiator was sometimes moved to the side of the engine. These modifications were often made by specialist companies. The negative consequences for both safety and the driver comfort are obvious. This development was however stopped in 1990 when the EU adopted new regulations, which restricted not only the total length of the vehicle but also the length of the load carrier including the gap between the vehicle units. This regulation gives a reasonable space for cabs with a sleeping compartment.

The gap between a truck and trailer may be reduced to 0.35 m. It is then only possible to drive more or less straight forward without using a special short coupling device which extends the drawbar when cornering. This regulation is likely to be changed so that the total length and the minimum gap are increased.

HEIGHT

The free height under bridges in many European countries does not allow higher vehicles than 4 m. This is also the general EU requirement. Some countries, like Sweden, have no limit at all. The UK has a 4.2 m height limit for vehicles heavier than 35t and no limit for others. There is a discussion going on in the UK about removing the limits. Changing the EU limits however is not on the agenda.

Because of the large quantities of volume goods there is a demand to increase the volume of the payload. Since the length is limited, the only way to achieve that is to increase the height downwards, ie to lower the chassis. However this has implications for the characteristics of the suspension and the tyres.

There are discussions going on concerning a maximum payload height limit.

WIDTH

Most European countries have a maximum permitted vehicle width of 2.5 m, although refrigerated superstructures may be 2.6 m. An increase to 2.55 m has won broad acceptance and is expected to be introduced shortly.

MODULAR TRANSPORTATION SYSTEMS

The EU directive for weights and dimensions is created around one 7.82 m long load module for truck-trailer combinations and another one for semitrailers, about 13.6 m long. These two modules have started to set a standard, especially for the manufacture of standardized semitrailers.

There is a desire within the EU to harmonize the national regulations with respect to vehicle dimensions and Gross Combination and Vehicle Weights. This would at the present stage mean that many countries would have to drastically reduce the length and the weight of vehicle combinations used in national traffic. There is, however, strong opposition to this since it would have a serious negative impact on the transport economy.

A way out of this is a new approach, which allows longer and heavier vehicle combinations based on the existing load modules, 7.82 and 13.6 m, to be driven on roads with a standard corresponding to that of motorways. The combinations would be decoupled at break points before going onto smaller roads. The classification of the road network will be done nationally or regionally. This modular system has gained considerable support among hauliers, vehicle manufacturers and various officials. There are both economic and environmental advantages to this system. For example if the GCW is increased from 40 to 60 tonnes and the conditions are identical, the fuel consumption is reduced by 20% for each transported tonne and at the same time the emission of NOx is reduced by 17%.

IMPACT ON THE DYNAMIC STABILITY

The lateral stability of vehicle combinations is to a large extent determined by how the combination is configured, ie type and number of vehicle units, lengths of the different units, number of axles, axle loads etc. Most of these parameters are chosen in order to optimize transport economy within the framework of current legislation. If the regulations and directives concerning size and weight do not take stability aspects into account, this may very well result in vehicle combinations with far from optimal stability characteristics.

The type of vehicle configuration chosen by the operator is largely affected by existing size and weight regulations. Wheelbases of the vehicle units, overhang, drawbar length and weight distribution are more or less direct consequences of these regulations. Tyre characteristics are also indirectly influenced because they are related to the size of the tyres. Steered axles is another parameter which may be a consequence of the directives.

The influence of these parameters on dynamic stability is studied in the following for the most frequent types of vehicle combinations.

Stability criteria Dynamic stability in this context means oscillatory stability. It may be expressed in terms of how much the lateral acceleration or the yaw velocity of the first vehicle unit is amplified to the last vehicle unit, the rearward amplification. The stability can also be expressed by the yaw damping of the oscillating system. Should the damping be zero or below zero, the system is unstable, ie the oscillations continue with an increasing amplitude without any steering input. The damping measure may be supplemented by the mode shape of the oscillations, ie how the vehicle units move in relation to each other.

High damping is no guarantee of good dynamic stability, because even then the rearward amplification could be large.

The consequence of poor dynamic stability is considerable offtracking, which may be disastrous for other traffic, or a rollover, usually starting with the last vehicle unit, due to an excessive lateral acceleration.

Test methods The damping of the vehicle combination can be measured from the freely oscillating system. The system is excited by a short steering pulse and the damping is obtained from the logaritmic decrement of the amplitudes of articulation angles of subsequent oscillations.

The rearward amplification is obtained by measuring the maximum amplitudes of the lateral acceleration or the yaw velocity of the last and the first vehicle units and by taking the ratio between them during some kind of steering input. This input can be such that a defined single lane change manoeuvre is performed. Different manoeuvres give different results depending on the frequency content of the steering input. From an analysis pont of view the best is to use a pseudo random steer input and to calculate the frequency responses. In this way the rearward amplification as a function of the frequency is obtained. The maximum rearward amplification with a pseudo random steer input is always larger than for lane change manoeuvres.

In the following study linear mathematical models with yaw and lateral degrees of freedom were used. They were excited with pseudo random steer inputs at a test speed of 90 km/h. The tyres were in all cases identical with single tyres on the front axle of the first vehicle unit and twin tyres on all other axles.

TRACTOR AND SEMITRAILER

This is in many European countries the most frequent type of vehicle combination. The number of axles may vary, but there are usually at least five axles. The basic weight and dimensions for the baseline vehicle appear in Figures 26 and 31.

This type of combination is basically very stable with respect to oscillatory stability. The rearward amplification is low and the damping high. In order to fulfil offtracking demands or to avoid wheel scrubbing, steered axles are sometimes used on the trailer. There are two types of steering, self-steering and forced or positive steering. If the wheels are self-steered the tyres do not generate any lateral forces at all.

The rearward amplification versus the frequency (Hz) of yaw velocity and lateral acceleration of the baseline are shown in Figure 2 and Figure 3. It appears that the peak is at approx. 0.3 Hz and well damped.

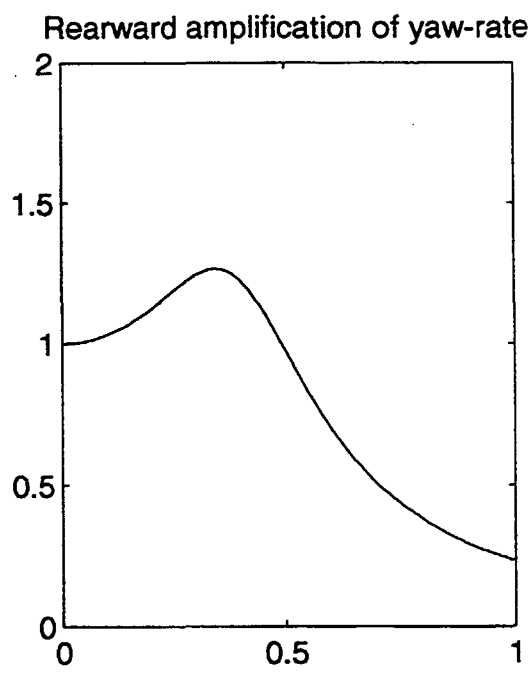

Figure 2. Tractor and semitrailer, baseline. Rearward amplification of yaw velocity vs frequency.

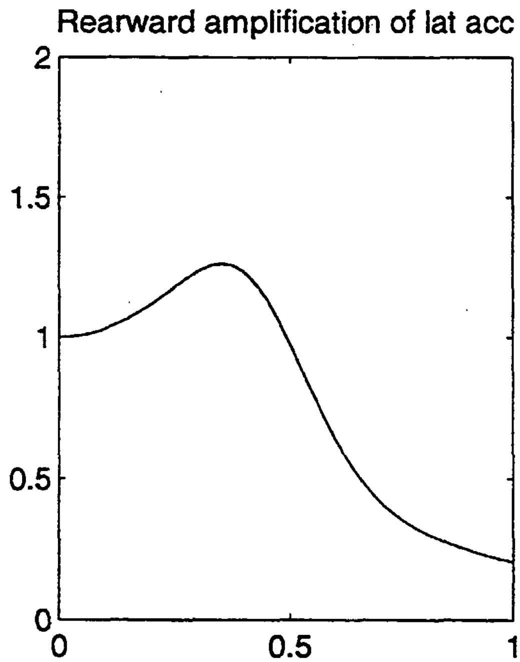

Figure 3. Tractor and semitrailer, baseline. Rearward amplification of lateral acceleration vs frequency.

The maximum rearward amplification (RA) and the relative damping for various alternatives of steered trailer axles are shown in the table in Figure 4. When one axle is steered, it is the last axle. When two are steered, they are the two last ones. It can be seen that self-steered axles have quite a large impact on dynamic behaviour. The rearward amplification increases and the damping decreases..

	RA lat acc	RA yaw	Rel. damp.
Baseline	1.26	1.27	0.41
1 axle self-steered	1.40	2.44	0.21
2 axles self-steered	1.83	7.62	0.07
1 axle pos steered	1.37	1.33	0.39
2 axles pos steered	1.51	1.38	0.38

Figure 4. Tractor and semitrailer. Various alternatives of steered axles.

Positive steering has not at all the same negative influence. If self-steered axles are used they should be locked above a certain low speed.

The damping of the baseline is high, as can be seen in the table, and the tractor is not much affected by the trailer. This appears from the mode shape which is such that the yaw velocity of the tractor is 7% of that of the trailer

TRUCK AND CENTRE AXLE TRAILER

Vehicle combinations with heavy central axle trailers with two or three axle bogies have gained considerable popularity in many European countries. They are most frequently used in the Netherlands. Central axle trailers are characterized by the fact that they, like semitrailers, cannot stand by themselves. The centre of gravity is located close to the centre of the bogie, however, and no roll-moment is transferred through the hitch. Weight and dimensions for a baseline truck and centre axle trailer combination are shown in Figures 27 and 31.

The reason for this popularity is the large amount of volume-goods in the transportations. The total length of the payload can be maximized with a truck and centre axle trailer. It is possible to load two 8.2 m modules within a total vehicle length of 18.35 m if short-couplings are used. Another advantage is the good manoeuvrability.

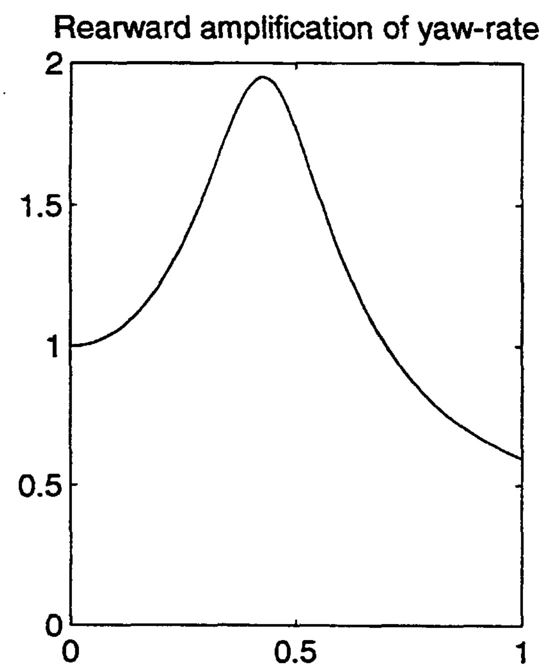

Figure 5. Truck and centre axle trailer, baseline. Rearward amplification of yaw velocity vs frequency.

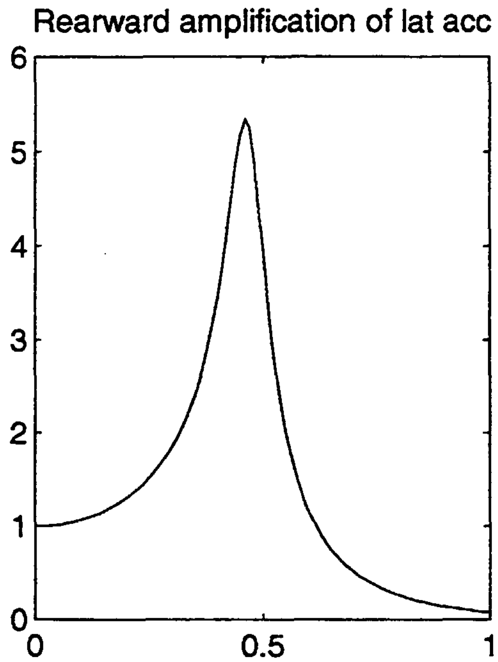

Figure 6. Truck and centre axle trailer, baseline. Rearward amplification of lat acc vs frequency.

From a stability point of view there are disadvantages. The relative damping of this combination is low and because of that there is a risk for dynamic instability if it is not carefully designed. The damping of the baseline is 0.15 and the interaction between truck and trailer is large. The yaw velocity of the truck is 36% of the yaw velocity of the trailer for free oscillations.

The rearward amplification of the yaw-velocity for the baseline appears from Figure 5. The maximum rearward amplification is below two and occurs at 0.4 Hz.

The rearward amplification for the lateral acceleration can be seen in Figure 6. The maximum of this is much higher than for the yaw-velocity. This is however a little misleading because the lateral acceleration of the truck at the frequency where the peak occurs is very low. Consequently the rearward amplification of the lateral acceleration for a realistic manoeuvre, which has a broad-band frequency content, would be much lower.

The sensitivity to variations in various parameters was studied. The results are expressed in terms of relative damping and maximum rearward amplification of the yaw velocity.

The first parameter is the overhang to the hitch. Figures 7 and 8 show that the damping decreases and the rearward amplification increases when the distance to the hitch is increased. The hitch shall thus be located as far forward as possible on the truck.

The next parameter is the wheelbase of the trailer, ie the distance between the hitch and the centre of the trailer bogie. If the wheelbase decreases the damping is quickly reduced and at the same time the rearward amplification increases as can be seen in Figures 9 and 10. A longer wheelbase consequently increases the stability.

Figures 11 and 12 show that the characteristics of the tyres have a very large influence. If the cornering stiffness of the trailer tyres is reduced, this has a very negative influence on stability, with decreased damping and increased rearward amplification. This is one of the consequences of low chassis as they require small wheels and small tyres which usually have a reduced cornering capability.

The distribution of the mass between the truck and the trailer is another parameter which has a major influence on the damping of the vehicle. The more of the mass that is carried by the trailer the lower the damping. See Figure 13. The rearward amplification, on the other hand, is not affected, as appears in Figure 14.

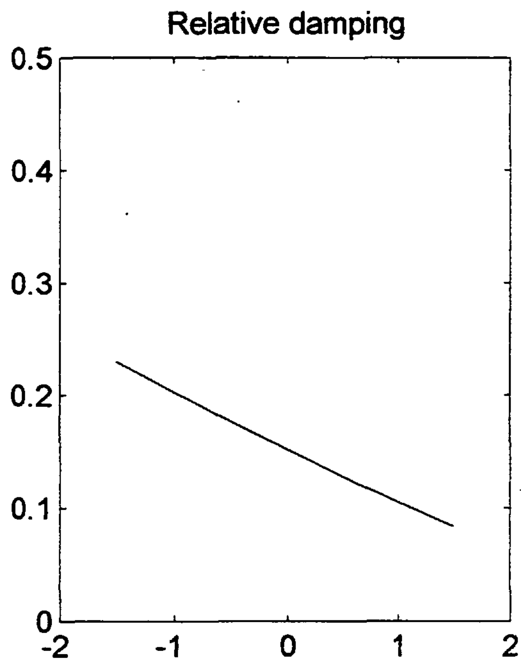

Figure 7. Truck and centre axle trailer. Influence of changes [m] of the overhang to the hitch on the relative damping.

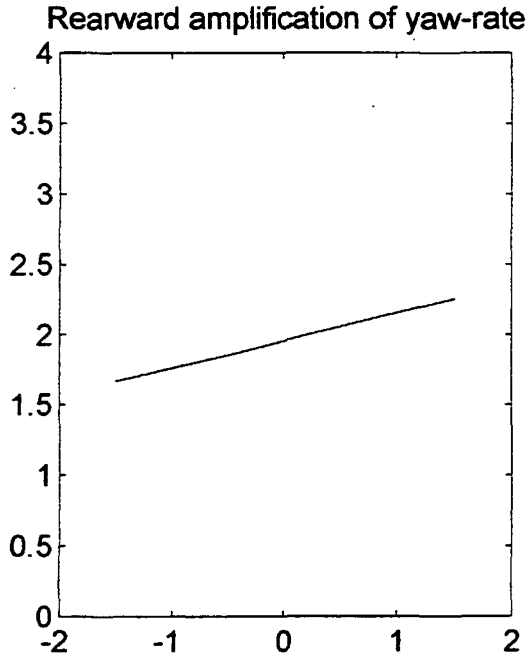

Figure 8. Truck and centre axle trailer. Influence of changes [m] of the overhang to the hitch.

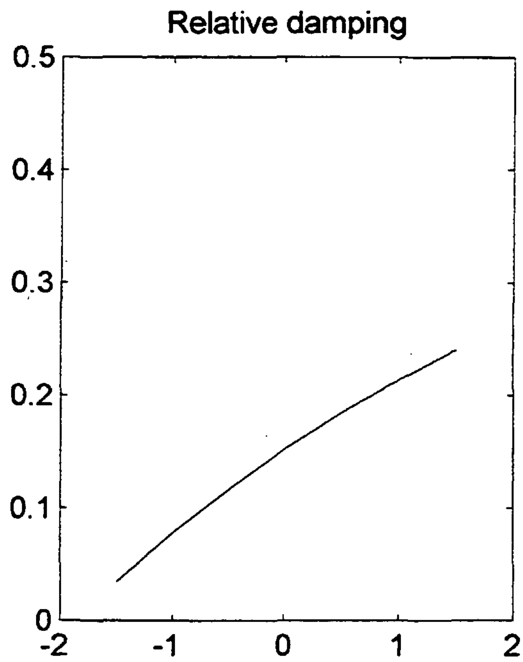

Figure 9. Truck and centre axle trailer. Influence of changes [m] of the trailer wheelbase [m].

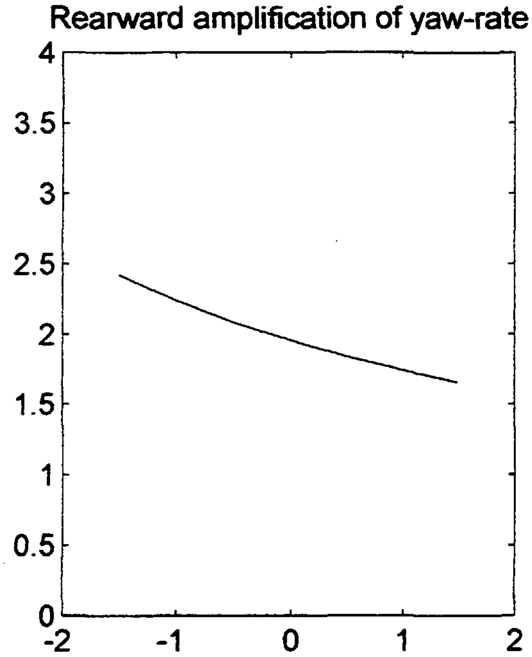

Figure 10. Truck and centre axle trailer. Influence of changes [m] of the trailer wheelbase .

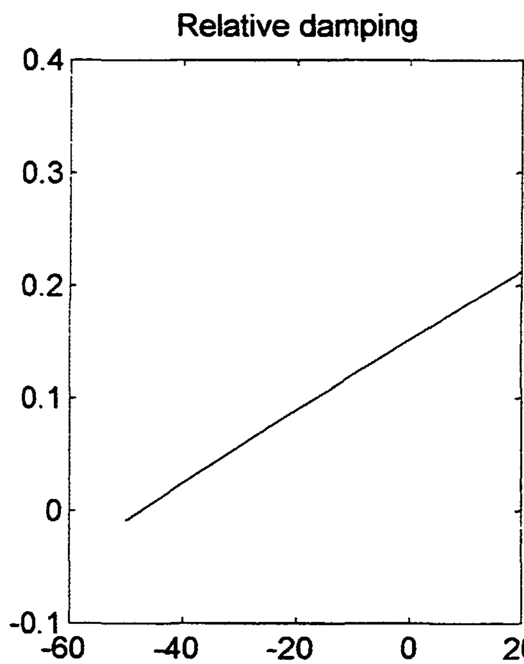

Figure 11. Truck and centre axle trailer. Influence of changes [%] of the cornering stiffness of the trailer tyres.

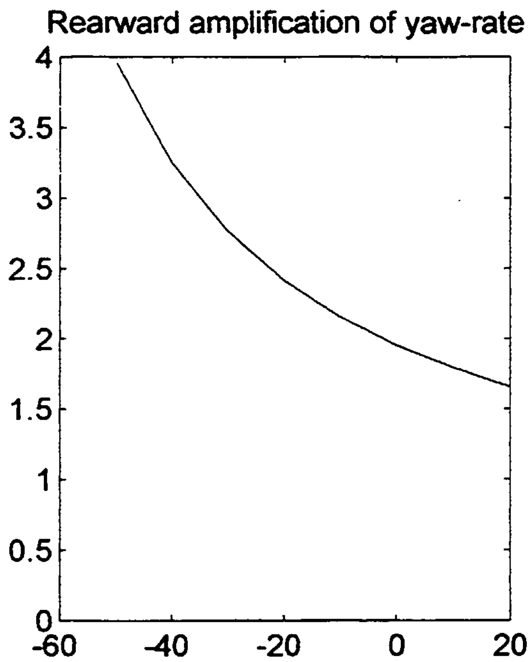

Figure 12. Truck and centre axle trailer. Influence of changes [%] of the cornering stiffness of trailer tyres.

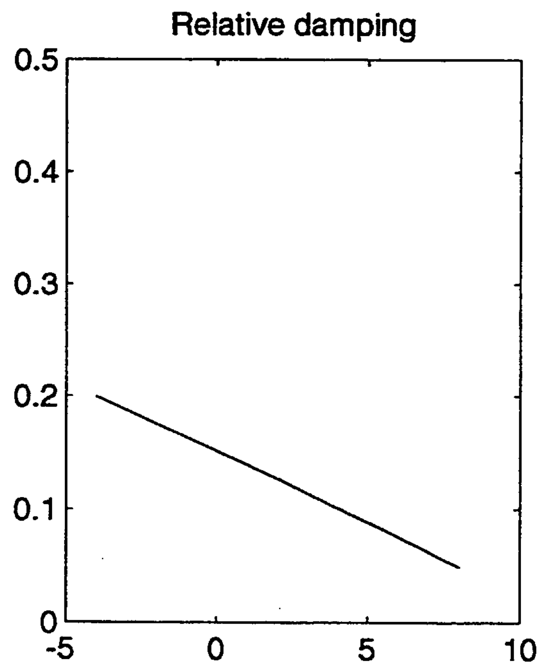

Figure 13. Truck and centre axle trailer. Influence of moving mass to the trailer [tonne].

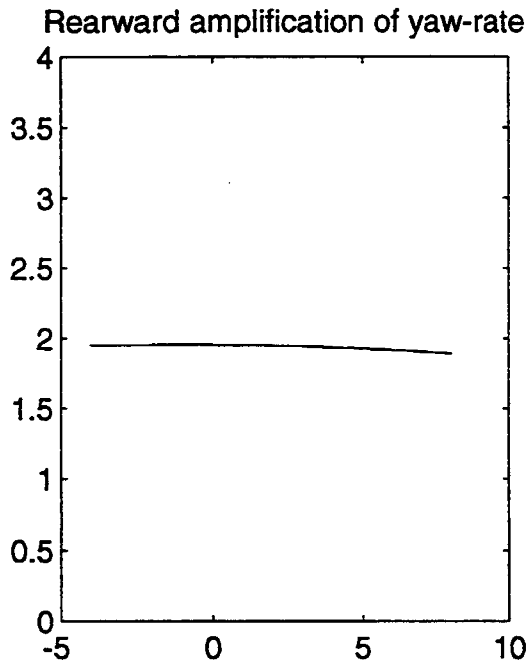

Figure 14. Truck and centre axle trailer. Influence of moving mass to the trailer [tonne].

TRUCK AND DRAWBAR TRAILER

This type of combination is extensively used in countries which allow long vehicles. One of the advantages compared with a tractor semitrailer combination is that the offtracking is much smaller. It is dynamically very well damped and there is a very low degree of coupling between the truck and trailer. The baseline vehicle shown in Figures 28 and 31 has a relative damping of 43%, and at free oscillations the yaw velocity of the truck is not more than 0.4% of that of the trailer. The rearward amplification of both yaw velocity and lateral acceleration is on the other hand high as can be seen in Figures 15 and 16.

The sensitivity to a number of parameters was also studied for this vehicle combination. The stability is expressed as the rearward amplification of the yaw velocity. Using the lateral acceleration would give the same result.

The position of the hitch has the same influence as for the combination with the centre axle trailer. As appears from Figure 17, the rearward amplification is reduced by a more forward position of the hitch.

Increasing the wheelbase of the trailer gives a significant reduction of rearward amplification. This is shown in Figure 18. Especially if the wheelbase of the trailer is small, as it is when the total length is limited to 18.35 m, the reduction of the rearward amplification is large.

Figure 19 shows that tyre choice is very important.

Also a moderate decrease in the cornering stiffness of the trailer tyres gives a significant increase in the rearward amplification.

Figure 20 shows that the mass of the trailer has no influence at all on rearward amplification .

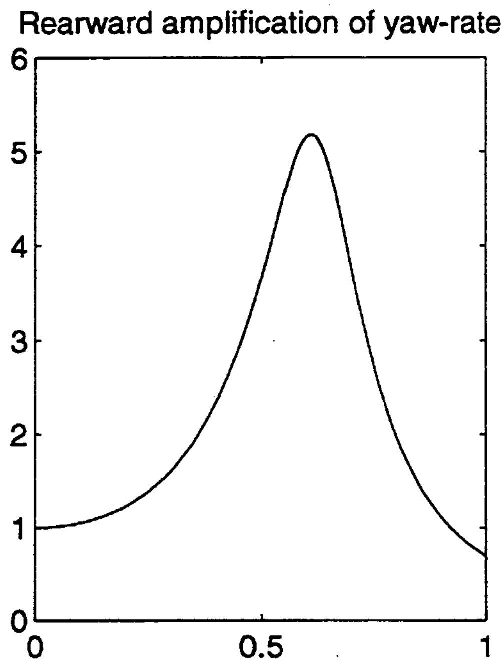

Figure 15. Truck and drawbar trailer, baseline. Rearward amplification of yaw velocity vs frequency.

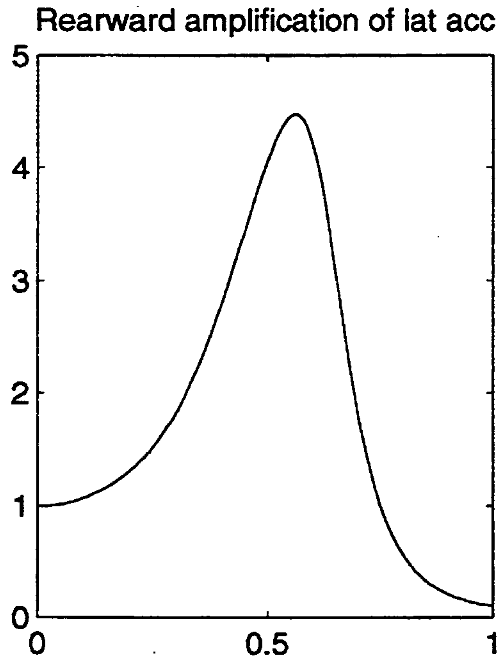

Figure 16. Truck and drawbar trailer, baseline. Rearward amplification of lat acc vs frequency.

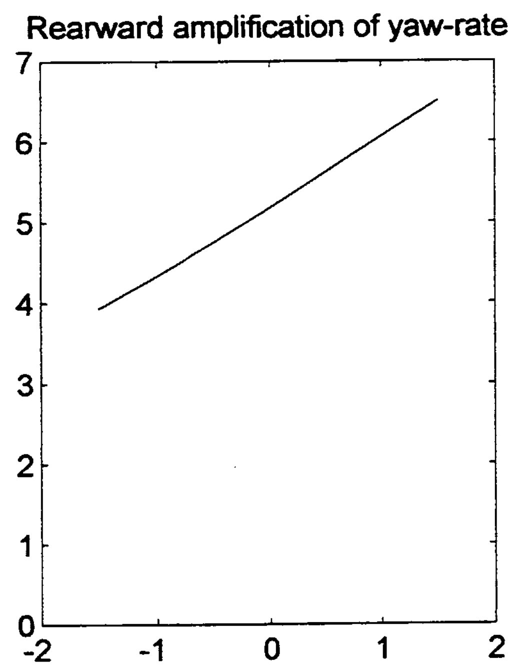

Figure 17. Truck and drawbar trailer. Influence of changes [m] of the overhang to the hitch.

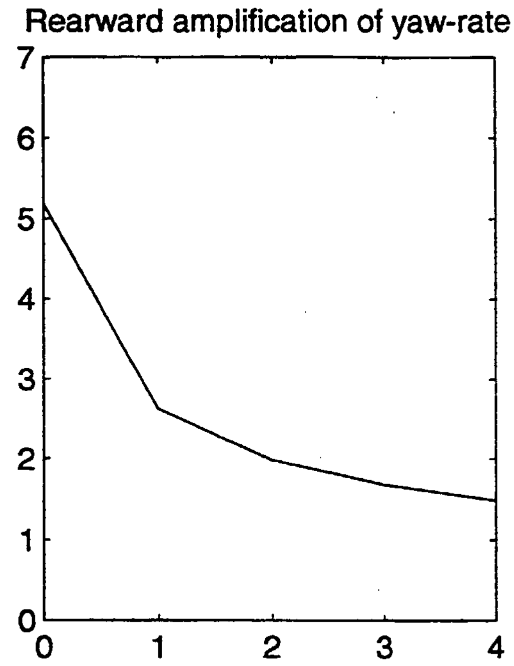

Figure 18. Truck and drawbar trailer. Influence of changes [m] of the trailer wheelbase.

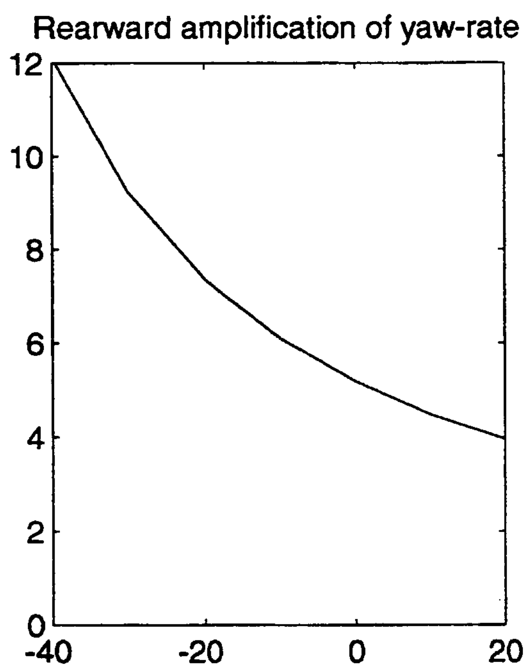

Figure 19. Truck and drawbar trailer. Influence of changes [%] of the cornering stiffness of trailer tyres.

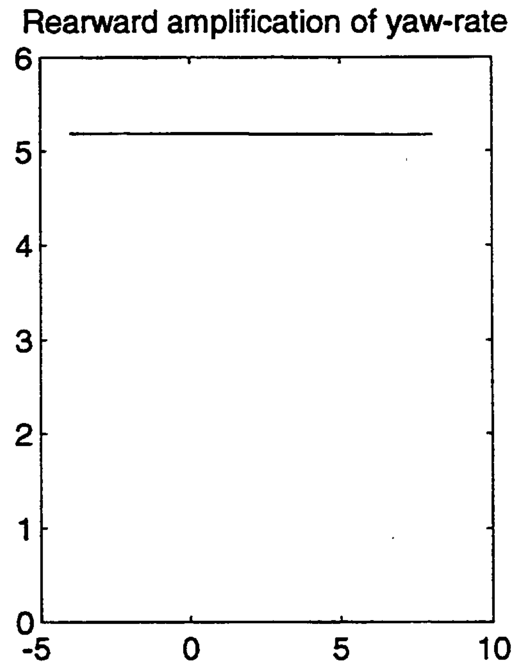

Figure 20. Truck and drawbar trailer. Influence of changes of the mass of the trailer [tonne].

MODULAR COMBINATIONS

Modular combinations based upon 7.82 m and 13.6 m modules are so far only used with special permits as their length exceeds the maximum permitted length. The length of these combinations will be between 25 and 25.5 m.

The combination with truck and dolly and semitrailer according to Figures 29 and 31 is similar to a typical Swedish long haul vehicle, both with respect to length and weight, so there is already considerable experience from this type of vehicle. The rearward amplification for yaw velocity and lateral acceleration is shown in Figure 21 and 22. As could be expected it is much lower than for the previously investigated 18.35 m truck and drawbar trailer. The reason for this reduction of more than 50% is due to the longer wheelbase of the trailer. The damping is high, 39%, and the dynamic coupling between the truck and the trailer is very low.

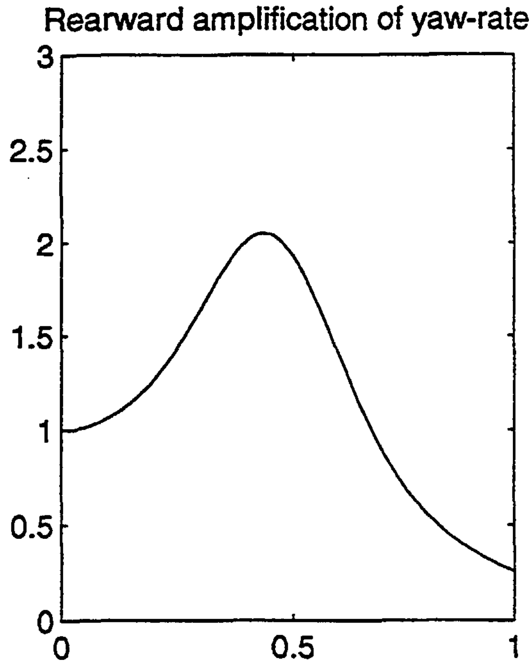

Figure 21. Truck and dolly and semitrailer, baseline. Rearward amplification of yaw velocity vs frequency.

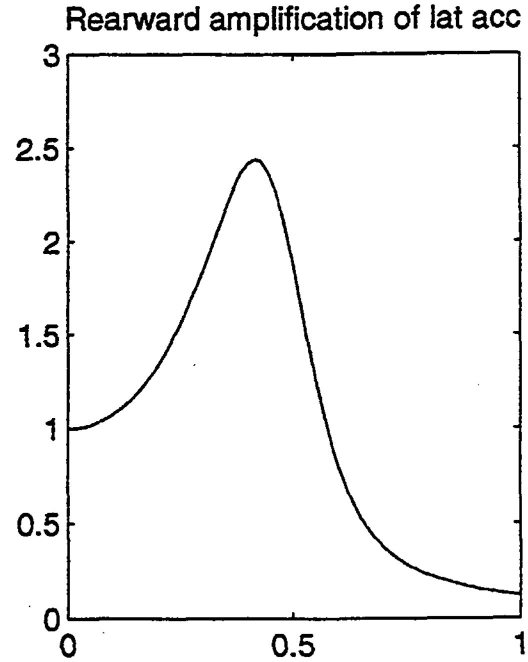

Figure 22. Truck and dolly and semitrailer, baseline. Rearward amplification of lat acc vs frequency.

The other modular combination with tractor and semitrailer and centre axle trailer in Figures 30 and 31 has not yet been widely used, so practical experience is limited. Dynamically it has the same disadvantages as a truck and centre axle trailer combination. The damping is only 11% but the dynamic coupling between the tractor and the last trailer is lower than for the 18.35 m truck and centre axle trailer combination. At free oscillations the yaw velocity of the tractor is 6% of that of the last trailer. The rearward amplification, as appears from Figure 23 and 24, is higher than for the first modular combination but lower than for the 18.35 m truck and drawbar trailer combination.

IMPLICATIONS FOR SUSPENSION CHARACTERISTICS

The increasing demands on lower chassis in order to increase the height of the payload has consequences for suspension characteristics. An inevitable effect of lower chassis is a reduction in spring travel. It is then not possible to retain low suspension stiffness. The consequences of this are a deterioration of the vibration environment in the vehicle and higher dynamic wheel forces on the road. Even more serious is the fact that the short spring travel increases the inclination for frequent bottomings of the suspension. This creates large peak forces both in the vehicle and on the road.

In Figure 25 the dynamic wheel forces for two different suspensions are compared in a simulation where the vehicle is passing an eight m long and 60 mm deep dip with a speed of 20 m/s. The static axle load is 11.5 tonnes and the stiffness of the chassis springs is 250 N/mm. One of the suspensions has a total spring travel including bump stop of 130 mm and the other has 60 mm. The graph shows that the maximum dynamic compression force is more than twice as high with the short spring travel.

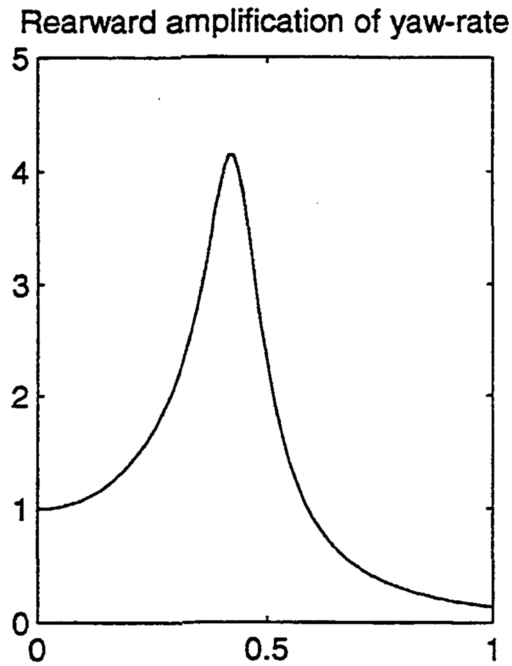

Figure 23. Tractor and semitrailer and centre axle trailer, baseline. Rearward amplification of yaw vel.

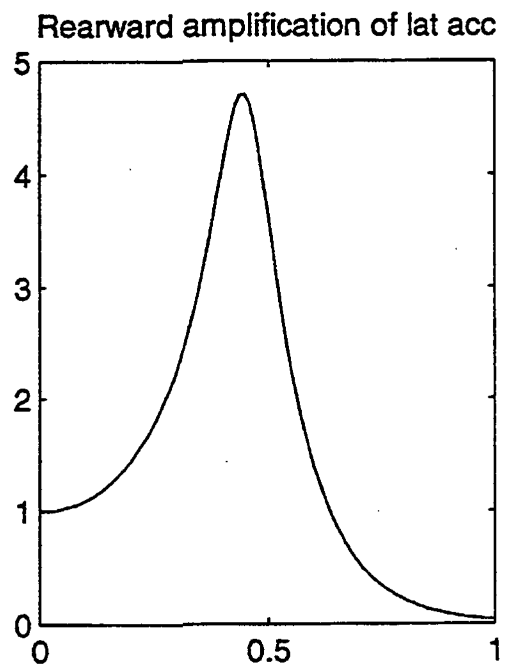

Figure 24. Tractor and semitrailer and centre axle trailer, baseline. Rearward amplification of lat acc.

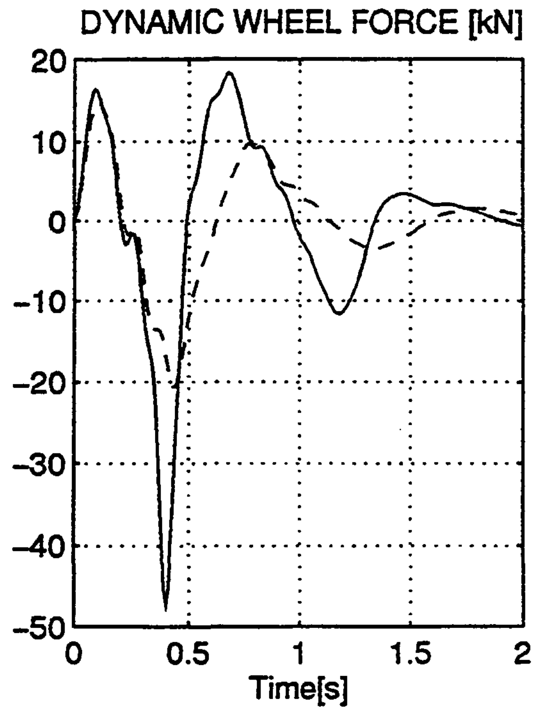

Figure 25. Dynamic wheel forces obtained when passing a 60 mm deep dip for two spring travels. [_________ 60 mm spring travel, _ _ _ _ _ _ _ 130 mm spring travel].

CONCLUSIONS

Regulations and directives have a major impact on the design of vehicles and on the configuration of vehicle combinations. Many vehicle characteristics will therefore be affected by regulations concerning size and weight. The dynamic stability of a vehicle combination is one of the factors which is mostly dependent on weights and dimensions. Longer vehicle combinations, implying longer trailer wheelbase, significantly, increase the dynamic stability. Small tyres, which is a consequence of low chassis for volume goods, have a negative influence on stability because of their reduced cornering capability. Reduced spring travel, which is also a consequence of low chassis, may cause a substantial increase in dynamic wheel forces.

REFERENCES

1. EC DIRECTIVE 85/3 on the weights,. dimensions and certain other technical characteristics of certain road vehicles

2. ISO/TC22/SC9/WG6 N14 - Road vehicles-Heavy commercial vehicle combinations and articulated buses - Lateral stability test procedures.

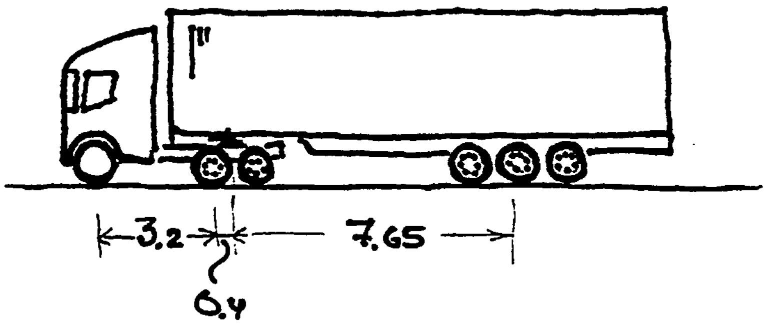

Figure 26. Tractor and semitrailer. GCW = 44 t.

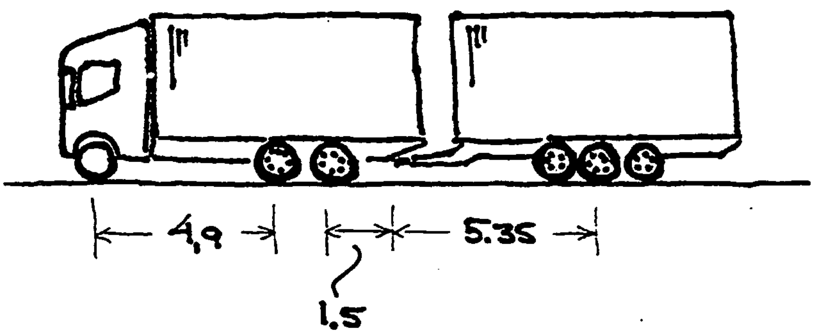

Figure 27. Truck and centre axle trailer. GCW = 44 t.

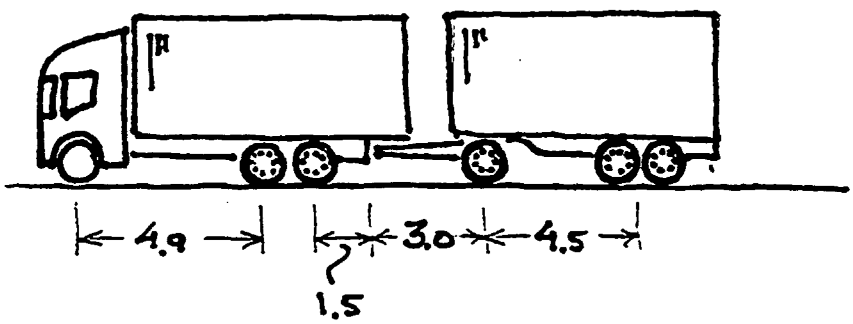

Figure 28. Truck and drawbar trailer. GCW = 44 t.

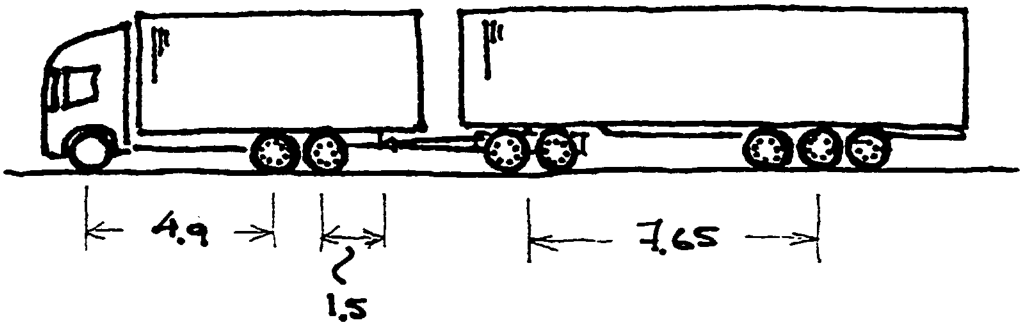

Figure 29. Truck and dolly and semitrailer. GCW = 62 t.

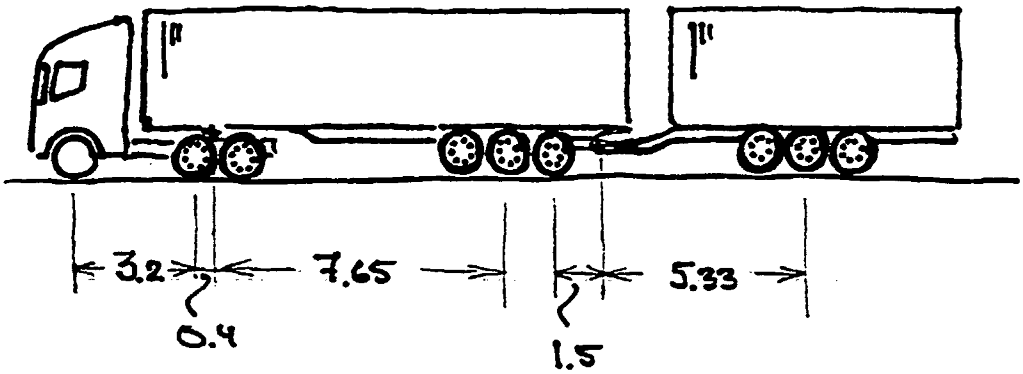

Figure 30. Tractor and semitrailer and centre axle trailer. GCW = 64 t.

	Tractor and Semitrailer	Truck and Centre Axle Trailer	Truck and Drawbar Trailer	Truck and Dolly and Semitrailer	Tractor and Semitrailer and Centre Axle Trailer
Weight, axle 1 (kg)	6000	7000	7000	7000	6000
Weight, axle 2 (kg)	8500	8500	8500	8500	8500
Weight, axle 3 (kg)	8500	8500	8500	8500	8500
Weight, axle 4 (kg)	7000	6667	6667	8500	7000
Weight, axle 5 (kg)	7000	6667	6667	8500	7000
Weight, axle 6 (kg)	7000	6667	6667	7000	7000
Weight, axle 7 (kg)				7000	6667
Weight, axle 8 (kg)				7000	6667
Weight, axle 9 (kg)					6667
Cornering stiffness axle 1 (kN/rad)	270	300	300	400	270
Cornering stiffness axle 2 (kN/rad)	540	540	540	540	540
Cornering stiffness axle 3 (kN/rad)	540	540	540	540	540
Cornering stiffness axle 4 (kN/rad)	450	430	430	540	450
Cornering stiffness axle 5 (kN/rad)	450	430	430	540	450
Cornering stiffness axle 6 (kN/rad)	450	430	430	450	450
Cornering stiffness axle 7 (kN/rad)				450	430
Cornering stiffness axle 8 (kN/rad)				450	430
Cornering stiffness axle 9 (kN/rad)					430
I_z unit 1 (kgm^2)	20000	125000	125000	125000	20000
I_z unit 2 (kgm^2)	550000	100000	1000	2500	550000
I_z unit 3 (kgm^2)			100000	550000	100000

Figure 31. Vehicle data of the combinations in Figures 26-30