

## CLEVIS COUPLINGS IN MULTI VEHICLE COMBINATIONS

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### Abstract

This article addresses the issue of dimensioning the coupling equipment in multi vehicle combinations. Extensive measurements have been performed. The measurements are made on the clevis couplings in the combinations. Measurements are made on highways, rural forest roads as well as on test tracks.

A filtering concept that enables the separation of effects from different force generating mechanisms has been developed. Based on observation from the analyses qualitative models are set up for the force generating mechanisms.

The results show that the margin between the measured force magnitudes and the requirements calculated using the Australian rules is wide.

Further results show that there is a strong relation between speed and forces generated in the couplings. In particular this holds true for forces generated by the interaction between the longitudinal unevenness and the geometrical layout of the vehicle combination.

**Keywords:** Clevis Coupling, Coupling Forces, Measurements, Filtering

## 1. Introduction

Over the last decade many trials with multi-vehicle combinations have been carried out in Sweden. The driving force for these trials has been transport efficiency and reduction of CO<sub>2</sub> emissions. The gross combination mass, GCM, of those trial combinations has been between 65 and 90 tonnes. The overall combination length has been between 25 and 33 meters. The number of vehicles in each combination has varied from two to four. While increasing the GCM the axle loads have been kept the same.

The different cargos transported covers, timber, wood chips, iron ore, gravel and general cargo. One of the first combinations put in to operation was a 90 tonnes GCM combination thirty meters long. It comprised one rigid truck, a dolly, a link trailer and a semitrailer. This operation showed a 35% CO<sub>2</sub> reduction as compared to a tractor plus semitrailer common for this kind of transport on the European continent. It encouraged further trials with different combinations in different applications.

The exercises have been supported by the Swedish innovation and development agency. They have also been fully transparent to the Swedish road administration agency. The support from the agency has involved special exemptions to enable these exercises to be run in general everyday traffic.

The interest and support from industry like forest transport companies as well as general cargo logistics companies has been very high. They have also engaged intensively in the trials.

Considering the situation within the European Union where the so called modular vehicle directive [1] applies focus is on validating the application of those combinations included in the European Modular System, EMS. While this is true the implication of the exercises are wider.

While putting those trial combinations together a key issue has been to set some rules for the dimensioning of the coupling equipment used. The UNECE regulation [2] did not at that time encompass vehicle combinations with more than two vehicles. The first option then was to look for the Australian rules applied to road trains. Those rules are based on measurements in Australia during the 1980:s, [3],[4],[5]. They have been used there since then with satisfactory results. During the 1980:s extensive measurements were performed on center axle trailers with different configurations and load conditions, [8]. Detailed measurements on coupling forces have since been very sparse. Recently however University of Oulu in Finland has carried out interesting measurements on heavy timber transport combinations, [9]. Some simulation work is being done that address some of the issues concerning coupling forces in longer and heavier vehicle combinations, [10].

It was decided to verify the applicability of those Australian rules and to enable more combination types to be covered by those rules. In order to do that it was decided to carry out extensive measurements of coupling forces. Focus, for those measurements, was on clevis couplings which was reasonably easy to establish.

## 2. Methodology

### 2.1. Measurement Equipment and Procedures

Drawbar eyes were equipped with strain gages in full bridges to measure forces in three directions, longitudinal, transvers and vertical. The thus prepared drawbar eyes were then calibrated using third party calibrate load cells. The strain gage bridges were monitored using a measurement and data acquisition system, [6],[7] . The sampling frequency was generally set at 200 Hz. That is to say that the measurements catch frequency content up to 30 Hz approximately.

The fact that we just grained away the raw forging surface from the throat of the drawbar eye enables us to keep full performance. I.e. it enabled us to perform measurements in combination running in full production. Hence the same equipment can be used at the test track as well as in the highway and forest roads applications.

During some of the exercises the speed signal from the CAN system was recorded simultaneously.

A measurement officer was always going along sitting in the truck cab having live on a computer screen the different signals measured. That officer also took notes about different sensation experienced such as road bumps or pot holes enabling comparison with abnormal force levels monitored.

### 2.2. Roads and Test Tracks Used

#### ***Track 1: Rural Road of Poor Standard***

This road was used for combinations with rigid truck, three axle dolly and a three axle semitrailer. This road was some 7 meter wide. It was prone to frost heave and had fair amount of bumps and pot holes. This road was some 150 km long one way.

#### ***Track 2: Rural Road of Medium to Good Standard***

This road was used for timber transport with a rigid truck, a dolly, a link semitrailer and a semitrailer. The road is some 150 km long one way. Half of the distance was approximately 7 meter wide with one lane each direction. The other half was approximately 11 meter wide with alternating one lane and two lanes in each direction. Approaching traffic is separated by a wire fence.

#### ***Track 3: Rural Plus Forest Road***

7 meter wide medium standard paved road combined with narrow unpaved forest road. The mix between the two road types varied but overall the mixture was 50/50. This road was used for timber transport from the tree cutting areas to some timber terminal. Speed on the forest roads is of course lower.

#### ***Track 4: Rural Plus Local Road***

7 meter wide medium standard paved road of good standard combined with narrow unpaved road in a gravel pit. The mix between the two road types varied but overall the mixture was 90/10. This road was used for timber transport from the tree cutting areas to some timber terminal. Speed on the forest roads is of course lower.

#### ***Track 5: Rural Dual Carriage Motorway***

This road is a good standard motorway. It includes a passage with a 7% ascent. This road is used with a tractor, a semitrailer, a dolly and a semitrailer. The cargo is general cargo. The road is 300 km long one way.

## **Track 6: Rural Dual Carriage Motorway Plus 1-2-Alternating Lanes**

Good standard motorway and 1-2-alternating lanes wire fence separated approaching traffic. This road is used with a tractor, a semitrailer, a dolly and a semitrailer. The cargo is heavy machine parts. The road is 440 km one way and the mixture is 60/40.

## **Track 7: Handling Track at a Test Site**



**Figure 1 – Overview of test track 7 and 8**

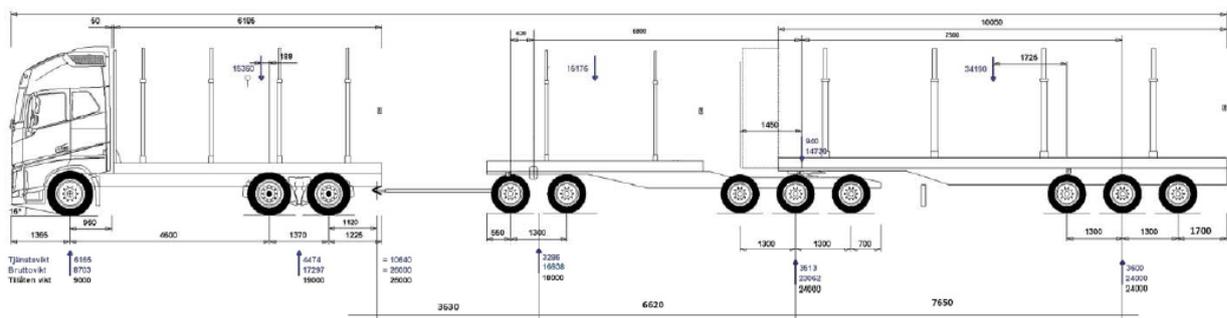
This test track (Figure 1) is an oval track approximately 2 km long. The track has a fair amount of unevenness. It also includes some ascents and descents that trigger tractions and braking efforts.

## **Track 8: Rural Road Track at a Test Site**

This is an approximately 3 km long track including a variety of good and bad paving and also an ascent of 11,7%

### **2.3. Vehicle Combinations Included**

#### **Combination 1: Four Pile Timber Transport 90 Tonnes GCM**



**Figure 2 – Layout of the "One pile more combination"**

This combination (Figure 2) used a rigid truck, a dolly, a link semitrailer and a semitrailer. It is 30 meters long. Axle loads except for steering axle are kept close to 9 tonnes. The dolly has

a rigid drawbar. The combination is running empty one way and fully laden in the other direction. Measurements were made on road/track 2.

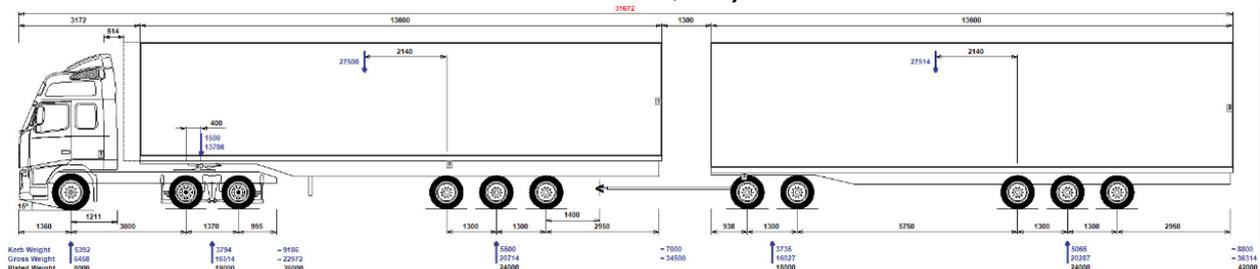
### **Combination 2: Dual Center Axle Trailer Combination 66 Tonnes GCM**



**Figure 3 – A double center axle trailer combination**

This combination (Figure 3) uses a rigid truck and two center axle trailers (CAT). The length of the combination is 27,3 meters. The clevis couplings are installed underslung 1900 mm from the rear extreme of the rigid truck and the first trailer. The axle separation of the trailers is longer than general for center axle trailer. Further adaptations are made to assure combination lateral stability. The cargo is general cargo. The degree of utilization of GCM capacity is ~70%. The utilization is the same each way. Measurements were made on road/track 7 and 8. Severe emergency braking tests were made at the test track with this combination.

### **Combination 3: An A-double Combination, 74/80 Tonnes GCM**



**Figure 4 – Layout of the A-double combination used**

This combination (Figure 4) comprises a tractor, a semitrailer, a dolly and a semitrailer. The length of the combination is 32 meters. The clevis coupling is installed underslung 1600 mm from the rear extreme of the rigid truck and the first trailer. The degree of utilization of GCM capacity is ~70%. The utilization is the same each way. Measurements were made on road/track 6 with 74 tonnes combination and road/track 5, 7 and 8 with the 80 tonnes combination. Severe emergency braking tests were made at the test track with this combination.

### **Combination 4: Rigid Truck Plus Dolly and a Semitrailer, 90 Tonnes GCM**

This combination uses a four axle rigid truck, a three axle dolly and a three axle semitrailer. The combination is running empty one way and fully laden in the other direction. Measurements were made on road/track 1.

### **Combination 5: Rigid Truck Plus Dolly and a Semitrailer, 74 Tonnes GCM**

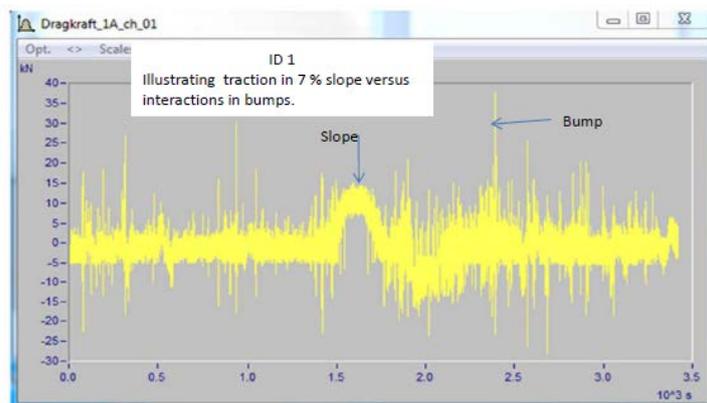
This combination uses a four axle rigid truck, a two axle dolly and a three axle semitrailer. The combination is running empty one way and fully laden in the other direction. Measurements were made on road/track 3.

### **Combination 6: Rigid Truck and Center Axle Trailer, 59 Tonnes GCM**

This combination uses a four axle rigid truck, a three axle center axle trailer. The combination is running empty one way and fully laden in the other direction. Measurements were made on road/track 4.

## **3. Analysis Techniques**

Some of our first trial showed nicely the difference between traction and braking forces on the one hand and interaction forces on the other hand.

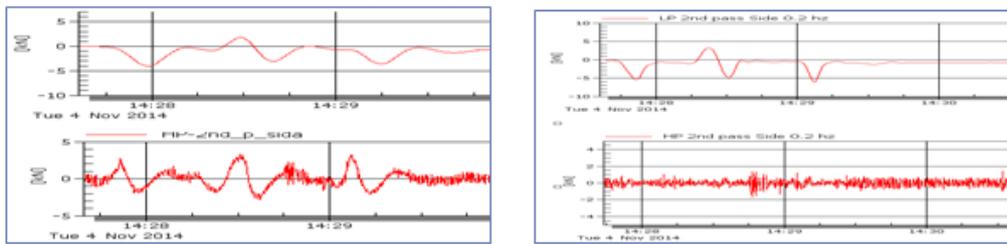


**Figure 5 – Sample signal of longitudinal force in an A-double**

Figure 5 triggered us to look for a separation of traction and braking force generating mechanism from other mechanisms.

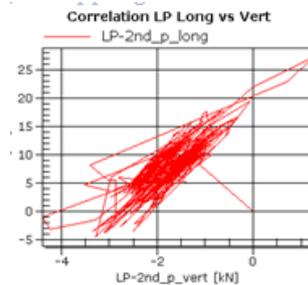
We had also at some very early measurements seen from force distribution graphs that we had at least a bi-modal distribution.

At the test track we used among other tracks an oval track approximately 2 km long. This particular track has a fair amount of unevenness. It also includes some ascents and descents that trigger tractions and braking efforts. Looking at those ascents and descents we found that we could isolate the traction and braking efforts by applying a low-pass filter to the force signals recorded. The cutting frequency 0,05 Hz was found to separate these parts of the force signals. This cutting frequency has proved to work fine with most applications that we have assessed. By visually inspecting the high-pass part of the signals in time space we could judge whether we had managed to eliminate all traction and braking part. This kind of inspection showed us that we had to raise the cutting frequency to 0,2 Hz as we made a close look analysis of the maneuvering forces in an in the progress to a terminal. In figure 6 below we see high-pass signal in the lower line. The left column shows 0,05 Hz cutting frequency and the right column shows 0,2 Hz cutting frequency. We note that at a cutting frequency a good share of the traction and braking signal is left in the high-pass filtered signal.



**Figure 6 – Illustration of filtering with different cutting frequency**

We made a very basic analysis of correlation between the different force signals, i.e. longitudinal, vertical and transvers/side, (Figure 7). This correlation is of course expected as there is a strong coupling between the mechanisms generating dynamic the vertical forces and the dynamic longitudinal forces. See under the discussion section below.



**Figure 7 – Simple illustration of correlated signals**

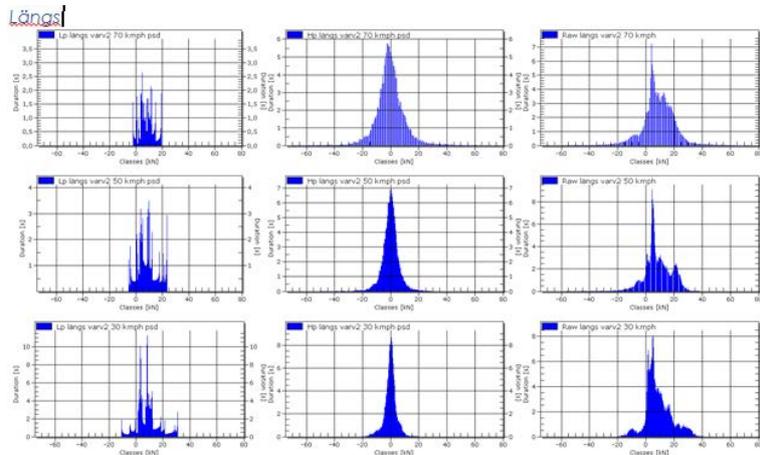
Apart from those signal filtering analyses we also made some detailed examination of local phenomena, like bumps or pot holes.

## 4. Results

The results from the measurements show that the Australian rules can be applied with a good margin of safety. Furthermore the measurements have enabled the outline of a model that explains some of the mechanisms generating the coupling forces. Hence the work has increased the level of understanding. In particular it nicely explains why the long road trains used in Australia works in spite of the fact that extra ordinary heavy couplings need not be applied.

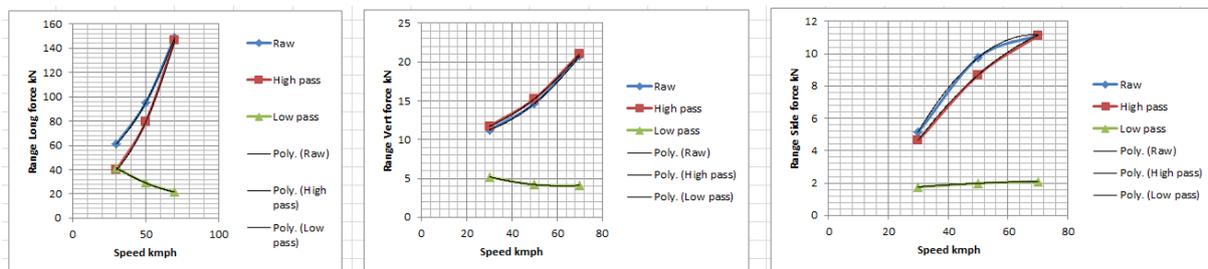
These results have been achieved through filtering the measured signals. Observations during transports in commercial operations led us to try to split the forces emanating from traction and braking out from the rest of the discrete forces observed.

Applying a low-pass filter to the measurements performed at a test track enabled us to develop a low-pass filter that separate traction and braking forces from the rest. The continued observations resulted in a conclusion that the remaining forces are interaction forces.

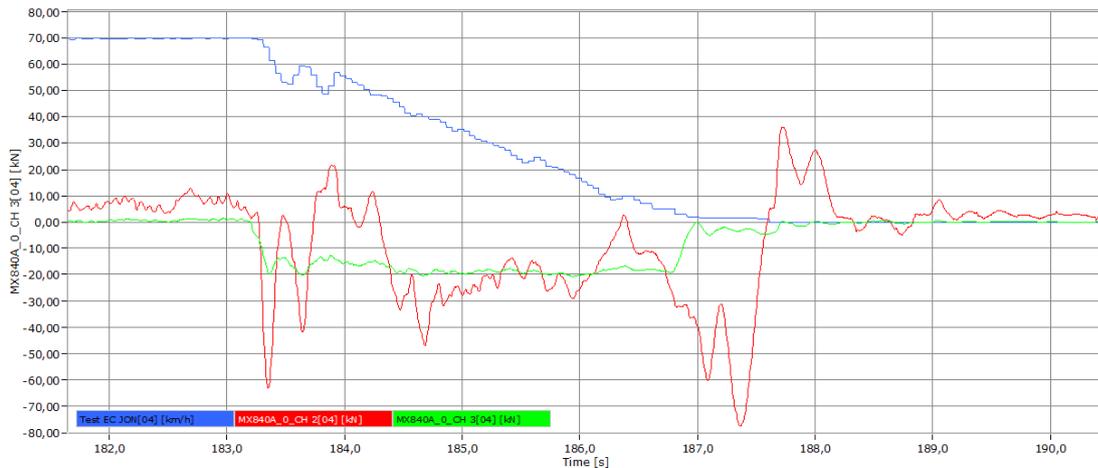


**Figure 8 – Longitudinal forces filtered at different constant speed, 70, 50 and 30 kmph**

Figure 8 illustrate the results of the filtering exercises. From left to right there is low-pass, high-pass and raw signal. Vertically the lines of pictures illustrate the different speeds. Some observations have been made concerning the speed dependence of coupling forces. In particular it may be seen that the high-pass signal show a strong dependence on speed. From figure 9 it can be seen that it is the high pass fraction of the forces that is strongly dependent on speed. The low pass fraction vertical and the longitudinal forces has a weak tendency to increase with lower speed. This is assumed to be due to the tests are run at constant speed with cruise control. At high speed there is enough of kinetic energy that can support the climbing of the ascents.

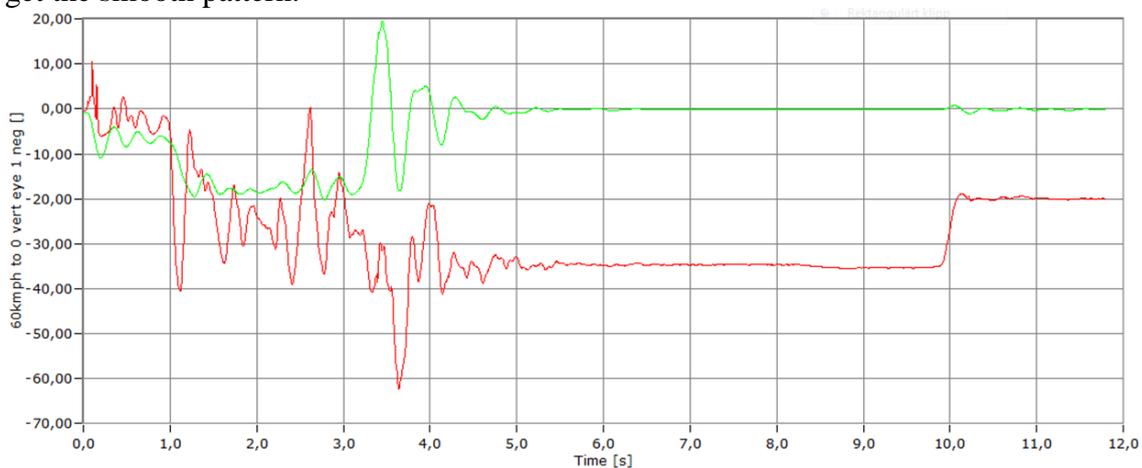


**Figure 9 – Force range as function of speed**



**Figure 10 – Emergency braking A-double, 70 to 0 kmph**

Figure 10 is showing forces measured in a clevis coupling of a dolly of an A-double at a deceleration of 0,57G. The descending line (blue) illustrates speed while the large amplitude line (red) is the longitudinal and the smoother line (green) is the vertical force. Note that the highest longitudinal force is occurring when the combination has come to a full stop. This is due to the out of phase pitching motion of the first and second trailer. It is also worth noting that the vertical force shows smoother pattern. This is the effect of the last trailer pushing forward through the fifth wheel on the dolly. This gets the dolly to pitch forward generating a downwards force in the clevis coupling. There is very little dynamic in this mechanism. Hence we get the smooth pattern.



**Figure 11 – Emergency braking rigid truck and two CAT, 60 to 0 kmph**

Figure 11 shows the longitudinal forces in the lower line and the vertical forces in the upper line. We observe the same high longitudinal force at the end of the braking after full stop. Of course the initial peaks are also worth observing as the onset of the brakes generates a pivoting of the CAT due to the high position of the center of gravity. The vertical force show very pronounced peaks at the end of the braking. This is due to the strong dynamic that we have in a CAT. All three vehicles in the combination continue pivot out of phase after full stop. This

has been seen from video sequences from the tests. This is completely different from what we find with the dolly in the A-double. I.e. there are partially different mechanisms active.

## 5. Discussion

The number of measurements and the filtering developed have made it possible to allocate different mechanisms to different fractions of the forces observed. As this has been done it has been shown that traction and braking forces are low in magnitude.

We have observed that the major fraction of the vertical and longitudinal forces is generated through interaction between the road waviness and the geometry of the vehicle combination, e.g. drawbar length and inclination. An originally horizontal drawbar will be too short as the last axle group of the first trailer passes a bump leaving the drawbar in an inclined position. The two heavy trailers next to such a drawbar then need to be pulled together or is the drawbar elongated. This generates high forces in the drawbar as the trailer masses will not easily moved relative to each other. The faster this process happens the higher the forces generated. It is also observed that the masses of those two trailers in a road train will work as a low pass filter. I.e. high interaction forces will not be transferred to vehicles further away than just next to the coupling under observation.

The mechanism behind the interaction forces are nicely illustrated in the braking tests. (Figure 10; Figure 11) I.e. as the two ends of the “drawbar” moves vertically in relation to each other longitudinal forces are generated. The rear end of a rigid drawbar shall be seen to be the pivoting center of that vehicle.

The observations for the vertical forces in some sense confirm the mechanism behind the calculation model found in regulations. That model presupposes the structure of the CAT being rigid. If you were to account for drawbar flexibility, you would find the vertical forces to be lower. This is observed as measured forces are much lower than predicted by regulations.

## 6. Conclusion

It has been over and over again observed that the traction and braking forces are lower in magnitude than the interaction forces. It has also been observed that the interaction forces mainly concerns the two vehicles directly connecting at the coupling point concerned. Vehicles further away from the coupling point are of subordinate importance.

Applying those observations to the Australian road trains it could be observed:

- Traction forces are limited by the engine power available
- Braking forces are under normal condition to a large extent limited by unbalanced brakes adaptation between vehicles on the one hand and by signal delay on the other hand.
- At full emergency brake the magnitude of the braking forces may come close to the level of the interaction forces.
- The interaction forces are local and hence are not dependent on the length of the road train.

Hence, applying quite ordinary couplings in road trains, works fine.

While the results from our projects are focused on clevis couplings it seems reasonable that the principles may be applicable also for fifth-wheel couplings. In such case a discussion can be driven from the viewpoint that the distance between king-pin and the axle group is to be considered as the “drawbar”. This length is usually longer than that of a full trailer, dolly or center-axle trailer. This gives some reasoning why the force in the fifth wheel often is considered to be lower than in clevis couplings.

In summary we conclude that there are three groups of mechanisms generating coupling forces:

1. Traction and braking forces
2. Interaction forces
3. Terminal maneuvering forces at extreme articulations.

Those three groups are arranged in order of magnitude, i.e. traction and braking generating the lowest forces.

Forces in the third group can be very high. These forces need to be further studied. When more knowledge has been gained on these forces then the regulations might be addressed to incorporate the more detailed knowledge. This could result in the coupling dimensioning being more adapted to the particular application and combination.

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