BRAKING PERFORMANCE OF AIR SUSPENDED CONVERTER DOLLIES

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ABSTRACT

In 1996 the National Road Transport Committee (NRTC) released a national heavy vehicle axle Mass Limit Review (MLR). The MLR recommended an axle mass increase for axle groups suspended by road-friendly air-suspension. For an air-suspension to be classified as Road Friendly it is required to have a bounce frequency below 2.0Hz and have damping greater than 20% of critical. It is also a requirement that the suspension group achieves load sharing within 5%.

Air suspended converter dollies have become popular in Australia, particularly the triaxle type. Triaxle dollies offer a productivity benefit of between 2.5 and 4.5 tonne when compared to a tandem converter dolly.

There was concern that the increased mass offered to air-suspended dollies would significantly affect the performance of road trains under braking. The Roaduser Autosim Truck Engineering Dynamics (RATED) computer simulation models were used to simulate the performance of hinged and rigid drawbar tandem and triaxle dollies under braking.

The results from the simulation showed that an air-suspended tandem converter dolly could pitch significantly under braking when compared to mechanically suspended dollies. Triaxle air suspended dollies were found to pitch somewhat less than the tandem air-suspended dolly and generated a lower longitudinal force in the coupling. This indicated that the triaxle dolly has better brake balance and should be encouraged by allowing the weight increase. Rigid drawbars on converter dollies reduce the amount of dolly pitch and hence have better brake balance. It was found that tandem axle air-suspended converter dollies perform significantly better if they use a rigid drawbar.

This paper presents the results of the braking performance conducted with the RATED system, briefly compares these results with test data and discusses how key results can be transferred into practice.

INTRODUCTION

Roadtrains in Australia commonly use tandem mechanically-suspended converter dollies to connect trailers to their hauling units. However air-suspended converter dollies are now becoming more popular in Australia, particularly the triaxle type. Triaxle dollies offer a productivity benefit

of 2.5 - 4.5 tonnes when compared to tandem dollies. Triaxle dollies are also seen to have stability and tracking advantages over the tandem dolly.

A converter dolly consists of a chassis supported by two or three axles with either air or mechanical suspension. The chassis has a fifth wheel placed over the centre of the axle group and a hinged drawbar is usually attached to the front of the dolly chassis. Converter dollies traditionally use a hinged drawbar to negotiate obstacles in the roadway without introducing large stresses into the chassis of the dolly. However, this also removes the means by which brake moments can be reacted.

The introduction of air suspension into the dolly design further complicated braking performance. Air-suspensions are typically fitted with a single ride-height control value. However, the transport industry found tandem dollies fitted with a single ride-height control valve tend to pitch about the axle to which the ride height control value is connected. This was of concern to operators and regulators, particularly with the prospect of axle group mass limit increases under the National Road Transport Commission's (NRTC's) Mass Limit Review (MLR).

This paper looks at some aspects of the braking performance of roadtrains equipped with dollies with tandem and triaxle groups, air and mechanical suspensions and with rigid and pivoted drawbars. This work formed part of the NRTC's investigation of the effects of mass limit increases on roadtrain dollies.

SIMULATED BRAKING PERFORMANCE

The Roaduser Autosim Truck Engineering Dynamics (RATED) Braking Model was used to simulate the braking performance of a double roadtrain with tandem and triaxle dollies and with hinged and rigid drawbars.

Simulated Vehicle

The double roadtrain simulated (**Fig 1**) consisted of a 3-axle prime mover, two triaxle trailers and a dolly, which was simulated with the following design variations:

- mechanical suspension (tandem only)
- air suspension
- tandem axles
- triaxles
- reduced brake gain on the rear axle of the triaxle dolly
- pivoted drawbar
- rigid drawbar

The vehicles were simulated under the following axle mass limits:

- current limits of 6t, 16.5t and 20t on steer, tandem and triaxle groups respectively
- MLR Option F limits of 6t, 17.0t and 22.5t on steer, tandem and triaxle groups respectively
- MLR Option F limits of 6t, 17.0t and 22.5t on steer, tandem and triaxle groups and the dolly axle loads remained at Current Limits of 16.5t and 20t for tandem and triaxle dollies respectively

The vehicles were simulated in an emergency straight-line braking manoeuvre similar in severity to Australian Design Rule emergency braking requirements for heavy trucks. The simulation involved stopping from a speed of 90 km/h with a deceleration in the range 0.4 - 0.45 g. The simulated brake line pressure was the same for all vehicles and was set at a level to produce

incipient wheel lock in most of the vehicles investigated. The effects of dolly suspension type, drawbar type and axle group load on the following performance parameters were investigated:

- stopping distance (m) - this provides a fundamental measure of braking performance

- peak longitudinal force applied to the pin coupling on the rear of the first trailer (kN) - this provides a measure of the braking balance between the two trailers

- peak vertical force applied to the pin coupling on the rear of the first trailer (kN) - this provides an indication of the vertical load capacity required at the pin coupling

- maximum dolly pitch angle (deg) - this provides some guide to the stability of the dolly under braking and was included because visual impressions of dolly behaviour may be influenced by direct observation of dolly pitch

- peak axle load on the lead axle of the dolly (t).

    Fig 2 shows an animation frame from the vehicle simulation.

BRAKING PERFORMANCE OF ROADTRAINS

When a roadtrain brakes, the dolly is required to react the moment that is produced from the brake torque and the horizontal force that is applied at the fifth wheel from the trailer it carries. The forces and moments that are applied to the dolly during braking cause the dolly to pitch, as shown in **Fig 3**.

When the dolly pitches, the load on the leading axle increases, while the load on the trailing axle decreases. The load on the centre axle in a triaxle dolly increases by only approximately one third of the load that is transferred from the rear trailer axle group to the dolly group (ie: it is affected little by the brake moments occurring in the dolly). Because the dolly pitches when it is braked and transfers a significant amount of load between axles, it may appear that the suspension on the dolly is brake-reactive even though this is not the case for air suspension.

The results in Table 1 show the minimum stable stopping distance, peak longitudinal and vertical coupling forces, the maximum dolly pitch angle and the peak axle load occurring on the front axle of the dolly. Some of these characteristics are identified in **Fig 4**.

TABLE 1. BRAKING ANALYSIS RESULTS

Vehicle	Loading Condition	Minimum Stable Stopping Distance (m)	Peak Longitudinal Coupling Force (kN)	Peak Vertical Coupling Force (kN)	Maximum Dolly Pitch Angle (deg)	Peak Lead Axle Load (t)	Static Lead Axle Load (t)
Triaxle Dolly (air suspension)							
Hinged Drawbar	Current Weights	76.6	41	0	2.4	10.9	6.67
	MLR Option F (no increase on dolly)	76.3	38	0	2.7	11.5	6.67
	MLR Option F (increase on dolly)	81.0	40	0	2.9	12.6	7.5
	MLR Option F (increase on dolly) (reduction of brake gain)	74.6	51	0	2.9	12.6	7.5
Rigid Drawbar	Current Weights	73.9	10.2	19.7	1.3	9.2	6.67
	MLR Option F (no increase on dolly)	76.1	15.0	19.5	1.3	9.3	6.67
	MLR Option F (increase on dolly)	76.2	17.3	21.6	1.5	10.3	7.5
Tandem Dolly (air suspension except where indicated)							
Hinged Drawbar	Current Weights	79.4	70	0	8.7	15.5	8.25
	Current Weights (mech. suspension)	78.1	53	0	1.5	14.7	8.25
	MLR Option F (no increase on dolly)	84.5	70	0	8.7	15.5	8.25
	MLR Option F (increase on dolly)	85.3	72	0	8.9	16.0	8.5
Rigid Drawbar	Current Weights	74.0	8.6	15.9	1.9	10.2	8.25
	MLR Option F (no increase on dolly)	79.0	8.0	16.5	2.0	10.4	8.25
	MLR Option F (increase on dolly)	79.4	9.6	16.8	2.1	10.6	8.5

The results in Table 1show that, with conventional hinged drawbars in double roadtrains:

- air-suspended triaxle dollies improve the stopping distance by approximately 2%, compared to current mechanical tandem dollies

- under MLR Option F, the stopping distance of the air-suspended triaxle dolly vehicle increases by approximately 6%; if the mass increase is not allowed on the dolly, this degradation in stopping distance is completely avoided

- adjustment of the brake gain on the rear axle of the dolly can improve stopping distance by approximately 9% and this would more than compensate for the effects of the mass limit increase on the dolly.

Further insights gained into dolly braking performance with hinged drawbars include:

- longitudinal coupling loads are much less with triaxle dollies than with tandem dollies, indicating improved balance of braking effort between the vehicle units; the peak coupling forces are 40% lower for the triaxle dolly when compared to the air-suspended tandem dolly. Peak coupling forces under braking have recently been measured for a triaxle dolly (1). The range of measured coupling loads under braking was 36-71 kN for a triple roadtrain. This indicates that the peak coupling forces as determined in the simulation are realistic.

- the pitch angle of the air-suspended triaxle dolly is approximately 3.5 times less than that of the air-suspended tandem dolly. The triaxle dolly pitch is approximately twice that of a mechanically-suspended tandem dolly.

- the peak axle load occurring under the air-suspended triaxle dolly, with increased mass limits applied, is approximately 14% less than that occurring under current mechanical tandem dollies

- tandem dollies with air suspension suffer from a high degree of dolly pitch, high longitudinal coupling loads and high axle loads during braking.

The results in Table 1 also show that the use of rigid drawbars, in place of hinged drawbars, leads to:

- a stopping distance improvement of approximately 7% for air tandem dollies and of up to 6% for air triaxle dollies

- significant reductions in longitudinal coupling loads and dolly pitch angles

- significant reductions in axle loads during braking: compared to the mechanical tandem dolly with hinged drawbar under current limits, the air dolly with rigid drawbar under increased limits reduces the peak axle load by 28% for tandem dollies and by 14% for triaxle dollies.

RIGID VS PIVOTED DRAWBARS

A rigid drawbar dolly has the distinct advantage that during braking the brake moments are reacted through the forward hitch. **Fig 5** illustrates the difference between a rigid and pivoting type drawbar under heavy braking. This also illustrates the difference in dynamic axle loads for the two types of drawbar systems under braking.

Fig 6 shows the axle load time history (for axles 1, 2 and 3) for rigid and pivoted drawbar triaxle dollies under braking. The results show that the dynamic axle loads are somewhat lower for the rigid drawbar than for the pivoted drawbar.

Fig 7 shows the forward speed of the prime mover for rigid and pivoted drawbar triaxle dolly equipped vehicles under braking.

Fig 8 shows the longitudinal acceleration of the rigid and pivoted drawbar triaxle dolly equipped vehicles under braking. The results show that the pivoted drawbar dolly has an oscillation in the acceleration time history due to the rear axle of the dolly locking up under braking. A rapid pitching of the dolly as the vehicle stops follows this. This is not present with the rigid drawbar dolly.

OUTCOMES FOR INDUSTRY

The results from the simulation show that rigid drawbar dollies can improve the braking performance of roadtrains and need to be considered for operation on routes where the terrain is suitable, such as on-highway operations. Routes such as this will not generate unduly high stresses in the dolly chassis.

The results also show that triaxle dollies with pivoted drawbars can also improve the braking performance of a road train and need to be considered for operation in both on-highway and off-highway environments.

CONCLUSIONS

This paper has attempted to demonstrate the use of simulation modelling to determine braking performance of double roadtrains with a variety of converter dolly design characteristics.

The simulation modelling has shown that:
1) the use of rigid drawbars improves braking performance of double roadtrains, especially for air-suspended tandem dollies, and should be encouraged.
2) triaxle dollies also improve braking performance and should also be encouraged.
3) couplings for rigid drawbar dollies should be checked for adequate strength rating when specifying equipment.
4) reduction of the brake gain on the rear axle of a triaxle dollies with pivoted drawbars can improve the braking performance of the dolly.
5) dynamic axle load variations for pivoted drawbar dollies under braking can be large and can be significantly reduced by the using rigid drawbars.

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1. SIMMS, ME (1996) Dynamic tests conducted on two road-trains fitted with triaxle converter dollies, 1175-SJD-2

AUTHOR BIOGRAPHIES

Scott McFarlane (Project Engineer)

Mr Scott McFarlane plays a leading role in advancing Roaduser's worldclass developments in computer simulation of heavy road vehicle systems. His accomplishments include computer simulation, assessment and evaluation of the dynamic performance of heavy vehicle configurations, investigations into stability, braking, safety, design and road effects of heavy vehicle configurations, accident analysis, reconstruction and investigation.

His ability to develop complex, cost-effective models of heavy vehicles has significantly contributed to Roaduser's understanding of how vehicle size and weight interact with the transportation infrastructure. Mr McFarlane is recognised as a world leader in the use of the powerful AUTOSIM™ simulation tool for creating dynamic simulation models and advanced modelling and animation of heavy road vehicle dynamics. He recently completed the MADYMO training course at TNO in The Netherlands and has begun to develop models of complex road vehicle systems with this versatile simulation tool.

A regular attendee at international conferences concerned with the investigation of heavy road and rail vehicle dynamic systems, he is also a member of the International Society of Automotive Engineers (SAE).

A graduate of Royal Melbourne Institute of Technology, Mr McFarlane earned a Bachelor's degree of Engineering (Aerospace) with Honours.

Dr Peter Sweatman (Founder and Managing Director of Roaduser Research)

Dr Peter Sweatman is an acknowledged world leader in the scientific field of heavy vehicle interaction with infrastructure. Dr Sweatman's research has crossed the boundaries of traditional engineering disciplines and his work has been widely recognised in the fields of vehicle design and engineering, vehicle safety, road safety, highway condition monitoring, heavy vehicle standards and regulations and transport economics and policy.

Dr Sweatman was elected a Fellow of the Australian Academy of Technological Sciences and Engineering in 1997.

Dr Sweatman founded Roaduser Research in 1989 and has built it into an internationally successful research organisation, with clients in both the private and public sectors.

During his career, Dr Sweatman has been honoured to play a key role in major industry associations and committees. He is a frequent speaker at international industry events, as well as a regular columnist for the magazine Truck & Bus Transportation. A Fellow of the Society of Automotive Engineers of Australia (SAE-A), he has served on the SAE-A National Council & Executive and chaired the SAE-A National Conference Committee. He is currently Vice-President (Asia-Pacific) of the International Forum for Road Transport Technology. Dr Sweatman also chairs the OECD Road Transport Research Scientific Expert Group (IR6 – DIVINE Project), having the honour of being the first Australian to hold such a post.

Dr Sweatman was selected by the US Federal Highway Administration (FHWA) to author a worldwide review of the Highway/Commercial Vehicle Interaction, including technologies

recommended for consideration in the US. He is also a member of the US Transportation Research Board's Vehicle Size and Weight Committee.

A graduate of the University of Melbourne, Dr Sweatman earned his PhD in Mechanical Engineering for research into the handling of passenger cars. He served as Chief Scientist at the Australian Road Research Board from 1984-89 and founded and developed ARRB's heavy vehicle research from 1976-89.
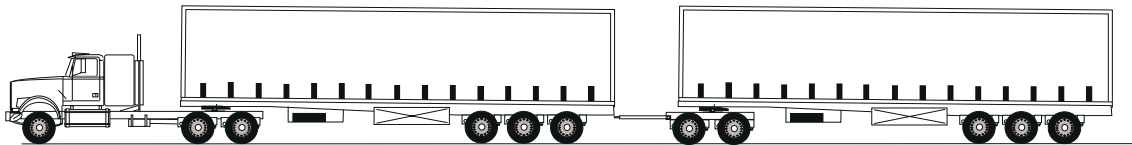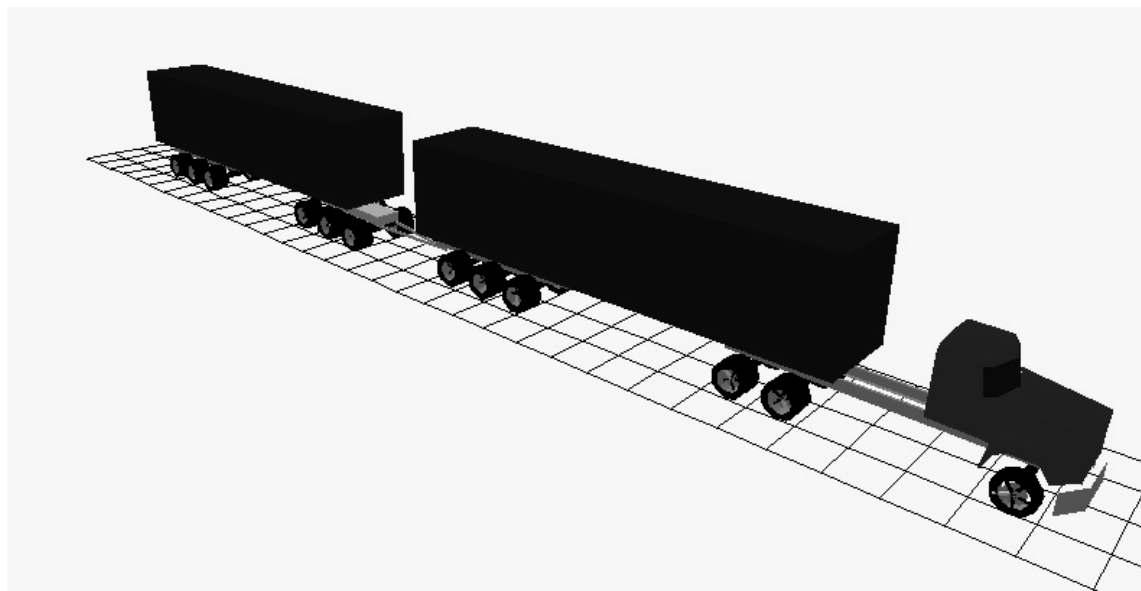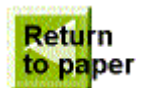
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Figure 1 Double roadtrain simulated

Figure 2 Animation frame of RATED braking model
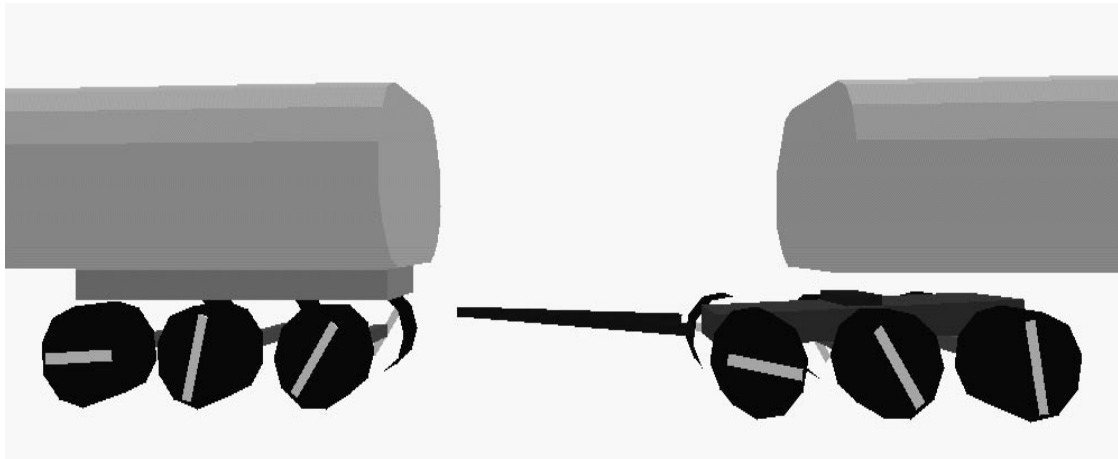
Figure 3 Animation frame of dolly pitch under braking

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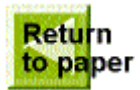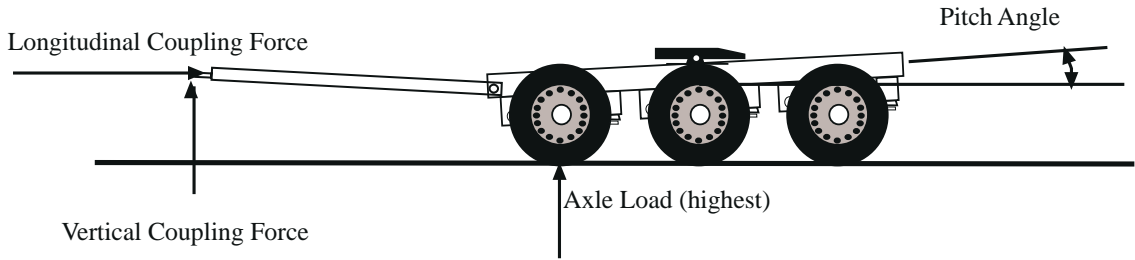
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Figure 4 Dolly performance characteristics
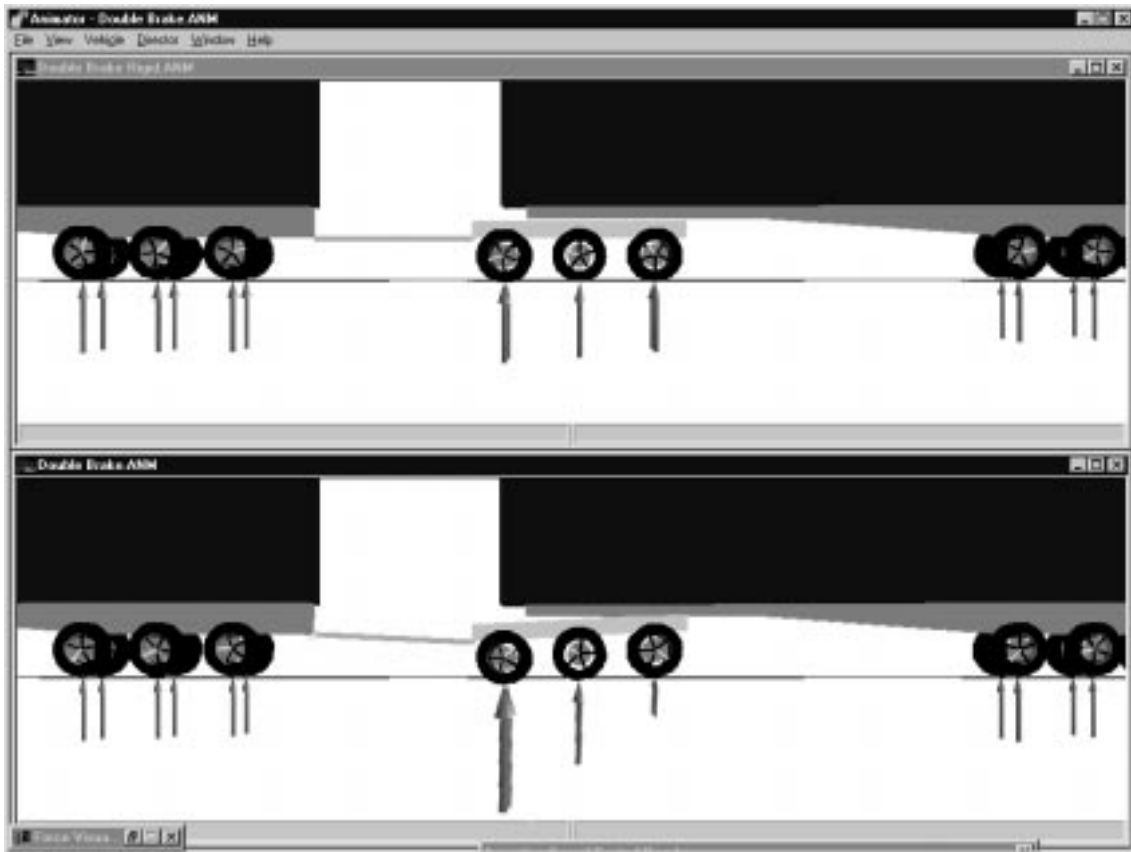
Figure 5 Rigid vs Pivoted drawbar triaxle dolly under braking

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Axle Load (kN)

Rigid

Axle Load (kN)
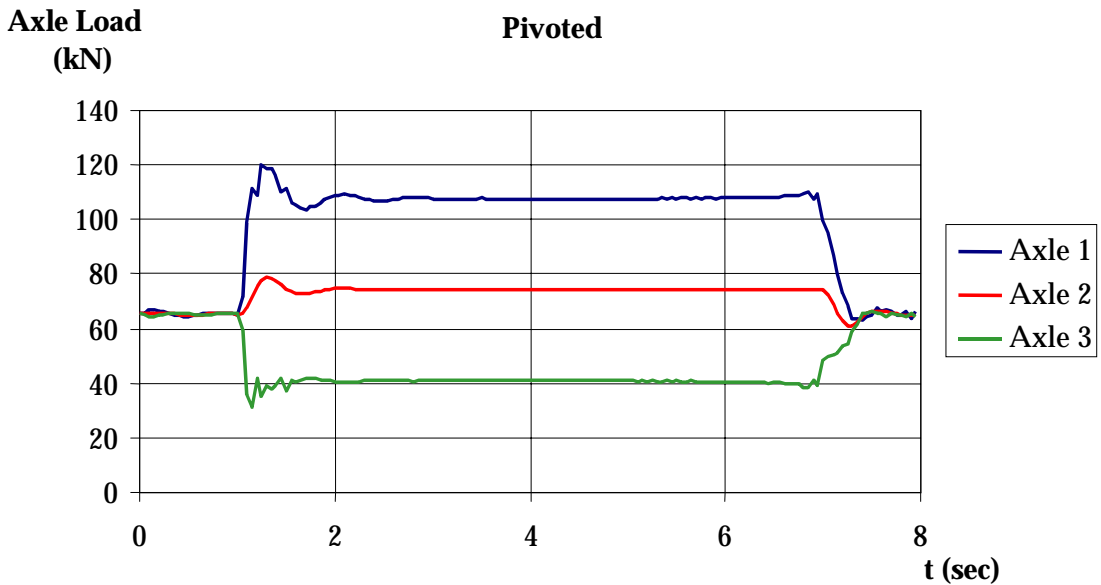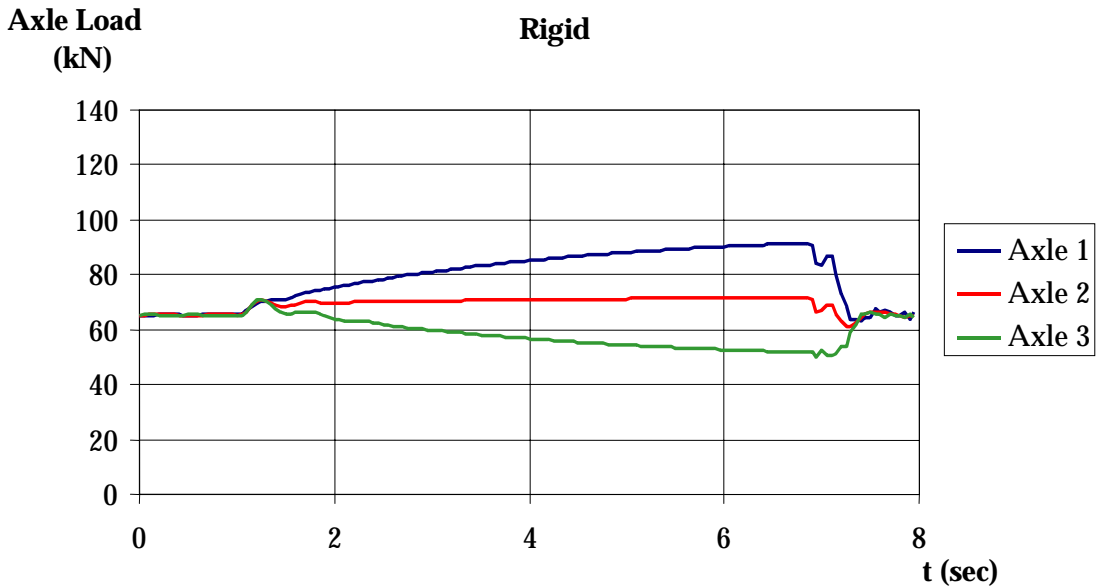
Pivoted

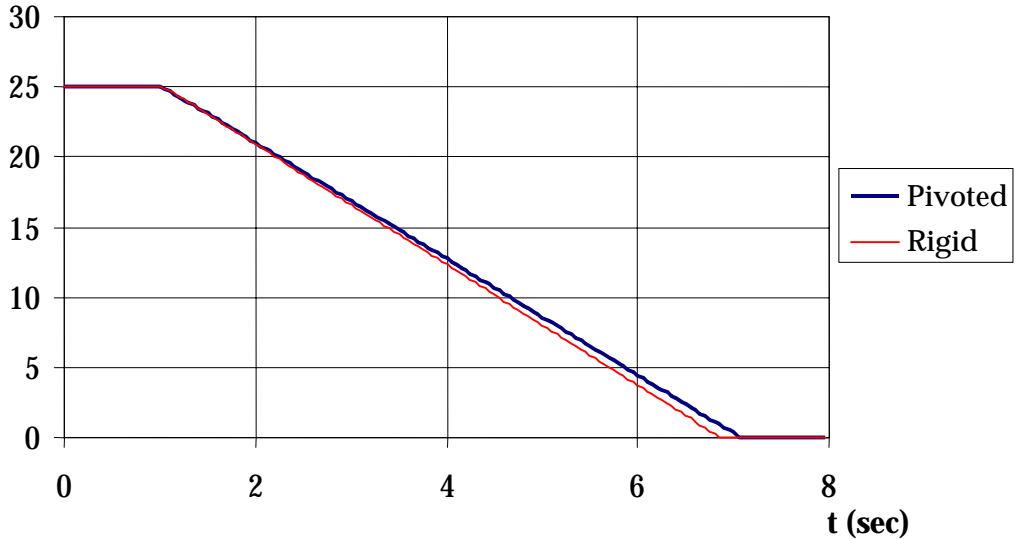**Figure 6 Effect of drawbar (rigid vs pivoted) on dynamic loads of dolly axles**

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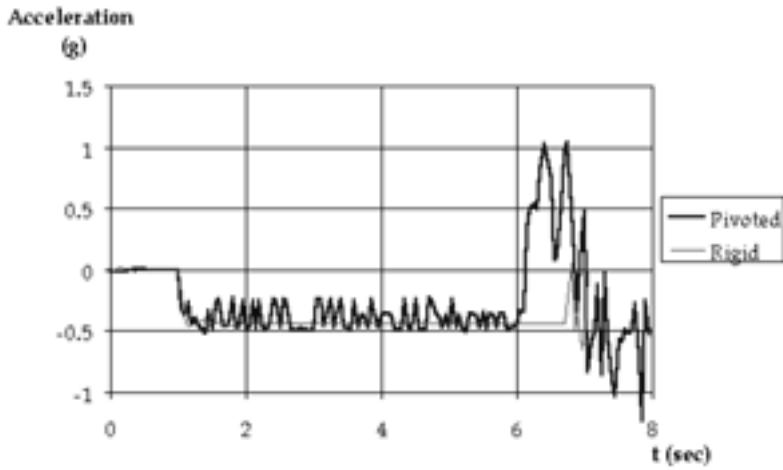**Figure 7 Effect of drawbar (rigid vs pivoted) on forward speed**

Figure 8 Effect of Drawbar (rigid vs pivoted) on longitudinal acceleration of dolly

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