Additional Information for Senate Enquiry into Road Safety

Air Suspension Dynamic Load Sharing Promotes Heavy Vehicle Road Safety

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Postulate the Adverse Dynamic Load Sharing Characteristics of Standard Air Suspended axle groups is both directly and indirectly the cause of numerous heavy vehicle accidents.

In addition deficient dynamic load sharing of axle groups inflicts considerable unnecessary damage on the road infrastructure.

Introduction

In the extensive investigation by Sweatman[1] conducted in 1983 wherein

'*a wheel force transducer was used to measure dynamic wheel loads in 2- and 3-axle groups for speeds ranging between 40 km/h and 80 km/h over road surfaces ranging from as-new construction (NAASRA Roughness of 20 c/km) to those exceeding the maximum desirable roughness (175 c/km). The effects of tyre inflation pressure and axle group load were taken into account. A factorial experimental design was used to determine dynamic loading, expressed as a dynamic load coefficient (DLC), as a function of speed and roughness for each suspension type. Nine suspensions types were tested comprising five tandem drive suspensions and four trailer suspensions (two tandem groups and two triaxle groups). In addition to the DLC, the load sharing performance of each suspension was examined by determining the ratio of the mean wheel force to the equally-shared static load. This was termed the load-sharing coefficient (LSC).*

…

In addition to controls on suspension systems, the roughness of pavements needs to be limited as does the speed of heavy vehicles in order to reduce dynamic pavement loading. Current conditions imply a higher level of dynamic loading on highways than on urban arterials. It may be desirable for target levels of roughness on various classes of road to take dynamic loading into account. More cognizance should be taken of roughness levels in developing pavement rehabilitation programs.

All axle group suspensions tested were type-approved load-sharing systems. With specific exceptions, they proved capable of maintaining the average wheel load within plus or minus 10 per cent of the desired wheel load share under typical highway operating conditions. … Some improvement to the current requirement for load-sharing is therefore desirable although this is not as pressing a need as the dynamic road loading problems already discussed. Load-sharing requirements should be improved by the addition of a quantitative dynamic test, based on maintaining the average wheel load within plus or minus 10 per cent of an equal share of the axle group load. A requirement for suspensions fitment according to the suspension manufacturer's specification should also be introduced.

Further research is needed to better quantify the response of pavements to dynamic loading, to

1 Sweatman, P. F. (1983) : A Study of Dynamic Wheel Forces In Axle Group Suspensions of Heavy Vehicles. Australian Road Research Board. Special Report SR No 27. 56 pages. (ISBN 0 86910 141 2)

better investigate the load-sharing ability of the six-spring triaxle suspensions and to determine the effects of the vehicle configuration on the dynamic loading generated by suspension systems. '

In this investigation Sweatman took opportunity to examine two trailer air suspensions types. In regard to these trailer air suspension units Sweatman comments '*Air suspension, used most commonly on tandem and triaxle trailer configurations, are usually of the 'trailing arm' type (Fig. 2c). Anti-roll devices are needed, and radius rods are always fitted. Dampers are needed to prevent 'bounce'. Load sharing is provided by interconnecting the air systems on adjacent axles.*'

In summing up this investigation Sweatman concludes in Section 6. of the report:

' *3. Load sharing ability and dynamic loading are separate characteristics of axle group suspensions and need to be determined differently. …*

12. In order protect roads, the current definition of a Load Sharing System in Draft Regulation 101(15) needs to be clarified and enforced with respect to effective damping being provided on each axle and also with respect to the damping status of rubber springs. As a more discriminative alternative, a dynamic test requirement should be introduced and could be based on a DLC of 0.20 or less, under roughness and speed conditions given by $VR^{0.50} = 850$ *when tested using a method similar to that reported here.*

13. The load sharing ability of an axle group suspension is reflected in the mean dynamic wheel forces measured at each axle under normal operating conditions.

…

16. With specific exceptions, most currently-accepted load sharing suspensions maintain the average wheel load share within 10 per cent of the desired equal share under typical operating conditions.

17. An appropriate quantitative load sharing requirement is the ability to maintain the average wheel load within ± 10 per cent of the desired wheel load share under typical highway operating conditions. This would need to be tested dynamically using a method similar to that adopted in the experiments reported here.

18. The load sharing ability of the six-spring triaxle suspension with respect to its leading and trailing axles was not fully investigated in the experiments reported here.'

19. At least in some cases, the method of fitting the suspension to the chassis and the axle group load need to be considered to ensure that type approvals leads to acceptable load-sharing performance on the road. Torque rod location can significantly affect the load-sharing performance of a suspension system.'

Finally Sweatman declares the following recommendations in Section 7:

'*1. Research should be carried out to better quantify the response of pavements to dynamic loading.*

…

4. The definition of Load Sharing System in Draft Regulation 101 (15) should be clarified with respect to effective damping being provided on all axles under all conditions.

…

6. A quantitative dynamic road loading requirement which could be based on limiting the dynamic load coefficient to 0.20 or less under roughness and speed conditions given by $VR^{0.50} = 850$*, should be considered as a Design Rule.*

7. A dynamic quantitative load sharing requirement, based on maintaining the average wheel load within plus or minus 10 per cent of the desired wheel load share, should be considered for inclusion in the Draft Regulations. This should be tested using a method similar to that adopted in the ARRB experiments, with all suspensions attachments fitted according to the suspension manufacturer's specification.

8. A requirement for suspension fitment and torque rod location according to the suspension manufacturer's recommendation should be added to the ACVP Guide to Heavy Vehicle Suspension Systems and Acceptable Axle Groups.

9. Further research into the load sharing ability of the six spring triaxle suspension is needed.

10. Further research into whole-vehicle dynamics affecting dynamic loading over and above known suspension effects is needed.'

Unfortunately in this paramount initial assessment of the load sharing ability of air suspensions Sweatman failed to realize the air flow in the interconnected air bag conduit/s (ref Fig 2c [2]) is a time, conduit internal friction and fitting resistance dependant. In addition at other than extremely low vehicle speed operation the air flows in the connecting conduits involves high speed air flows. In such high speed fluid flow situations inertia effects, extrapolated viscosity properties and orifice flow limiting effects must be considered.

Notably crude laminar flow and typical orifice limiting flow rate theoretical and /or empirical models do not apply. Hence standard air suspensions exhibit static load sharing but exhibit deficient dynamic load sharing. Unfortunately there is no equivalence between static and dynamic load sharing.

Sweatman's investigation also failed to examine air suspended drive axles groups including (single, tandem and tri axle arrangements (with or with lazy axles)) either trailing arm or cradle (parallelogram systems).

An air suspended axle is one that utilises 2 or 4 load bearing air springs to connect to either a flexible or rigid trailing arm or a cradle, respectively. The trailing arms or cradle, in turn, support a axle. In the case of 2 air spring suspensions (per axle) the axle is located longitudinally by either flexible or rigid pivoted load supporting trailing arms. Here the trailing arms are U bolted or in some cases weld connected to the axle casing. In the case of 4 air spring suspensions (per axle) the

2 Ditto

axle is located longitudinally by non load carrying double pivoted links typically arranged in a parallelogram arrangement. In both suspension types the axle is constrained laterally by panhard rods or by a 'Vee' link arrangement. The suspension torsional stiffness may be enhanced by use of a lateral beam cross and/or torsion bar.

The different suspension types utilise different air spring types. Typically the 2 air spring per axle systems utilise rolling lobe type air springs. In comparison cradle or 4 air spring type suspensions typically utilize bellows type air springs. In all cases the working media is compressed air extracted from the vehicle's brake compressed air system.

The ride height of an suspended axle group is controlled by a dedicated ride height control system for each axle group. This ride height system, on standard or stock systems, comprises a feed back link between the connected axle or suspension component and the ride height control valve input link. Such systems are described as axle locked as typically this feedback system receives magnified response from a particular axle in the axle group. Furthermore in those arrangements where ride height control valve/s is attached on or near the rear most chassis cross member the feedback signal may be magnified by chassis flex. The ride height control valve, in turn, controls the ride height by the valve operating in the supply, dwell, exhaust states.

An axle group may be fitted with one or two ride height control valves. Typically on standard systems they are so installed to receive high gain to body lean. On prime movers for maintenance convenience the (typically dual) ride height control valves typically receive feedback from the rear axle of the axle group. In comparison on trailer rear axle groups, particularly tri axle groups, the single ride height control valve is connected to the middle axle.

On undriven axle groups the single ride height control valve should be located laterally biased to the near side. However, on driven axle groups should a single ride height control valve be utilized the same should be located laterally biased to the off side.

Preferably all axle groups should be controlled by a unitary ride height control valve responding to a fractional extent of the axle groups instantaneous ride height. Furthermore the ride height control valve should be located at or near the axle group's geometric centroid.

Due to the use of capillary connected air springs standard air suspensions are grossly deficient in inherent damping. This damping deficiency demands air suspended axle groups be operated with shock absorbers in high state of repair.

Development of Vehicle Standards Bulletin VSB 11[3]

After considerable time effort, and Committee involvement Sweatman's original recommendations for dynamic quantitative load sharing requirement[4] was diluted to a requirement for the static load share between axles in a multiple axle group to be within 5%[5]. So crude is this requirement is that a number of mechanical or metal spring suspensions satisfy the performance standard for road-friendly suspensions. It is recommended the load sharing performance requirement declared in VSB 11 be reverted back to the original plus or minus 10% dynamic load sharing requirement with the suspension carrying its maximum legal load, with the vehicle operating at 100 km/h on paved road surface with a roughness of some 72 c/km. Preferably the road roughness counts should be

3 Certification of Road-Friendly Suspension Systems, Revision 2 July 2004.
4 Refer Recommendation 7 in Reference 1.
5 VSB 11 Performance Requirement (ii) page 8 of 17.

generated by concave surface deviations for air suspended axle groups and convex surface deviations for mechanical suspensions.

VSB 11 is also due for revision noting the need to assess the road friendly status of multi axle groups utilising super single tyres on all axles of the axle group.

As highlighted by the restriction in VSB 11 load sharing, both static or dynamic, is obviously not applicable for single axle axle groups. Whereas,load sharing, particularly dynamic load sharing, between axles of a axle group, becomes increasingly significant with increasing number of axles in the axle group in excess of two.

Prime Mover Pitching Phenomena

The pitching characteristics of prime movers is strongly vehicle configuration dependant.
This discussion can be presented in terms of rigid trucks (including buses / coaches and rigid trucks hauling hitch articulated trailers) and turntable articulated prime movers.

Rigid Trucks

Notably rigid trucks (including buses and coaches) exhibit minimal pitching tendency. This minimal pitching tendency, in terms of both extent and severity, results from the fact the centre of gravity (CoG) of the tare and payload is typically well forward of the rear axle group. Obviously, the extent of rigid vehicle pitching increases with increasing extent of rear end over hang and/or rear end counter load (e.g. rear engined bus).

For rigid trucks the extent of pitching is largely determined by the steer axle contacting a road surface deviation. This extent of steer axle generated pitching is far greater than that caused by the vehicle's rear axle group contacting the same road surface deviation. Furthermore the extent of steer axle generated pitching is allayed somewhat by use of tandem steer axle arrangements.

Turntable Articulated Heavy Vehicles

For turntable articulated heavy vehicles additional vehicle details govern the pitching extent. In particular the number of axles in the rear axle group and the relative location between the fifth wheel and the longitudinal centroid of the rear axle group are paramount variables.

Single drive axle prime movers

Typically for single drive axle turntable articulated heavy vehicles the turntable centreline is located just forward of the drive axle. Hence, for typical trailer rear end overhangs, the CoG of the tare and payload is well forward of the single rear drive axle hence the pitching extent and severity is minimal (in both absolute and relative terms).

Tandem rear axled prime movers

Independent of whether bogie drive, single drive plus lazy (with dual or single tyres, lead or post) it is typical for the turntable to be located longitudinally at a position intermediate between the two axles.

Due to the typical adverse dynamic load sharing between the two rear axles tandem axled turntable articulated prime movers exhibit significant pitching. The extent and severity of this pitching decreases with increasing wheelbase. Conversely it follows the extent and severity of the pitching increases with decreasing wheelbase. Unfortunately there exists a growing trend towards the use of shorter wheel base (SWB) prime movers consistent with their higher productivity.

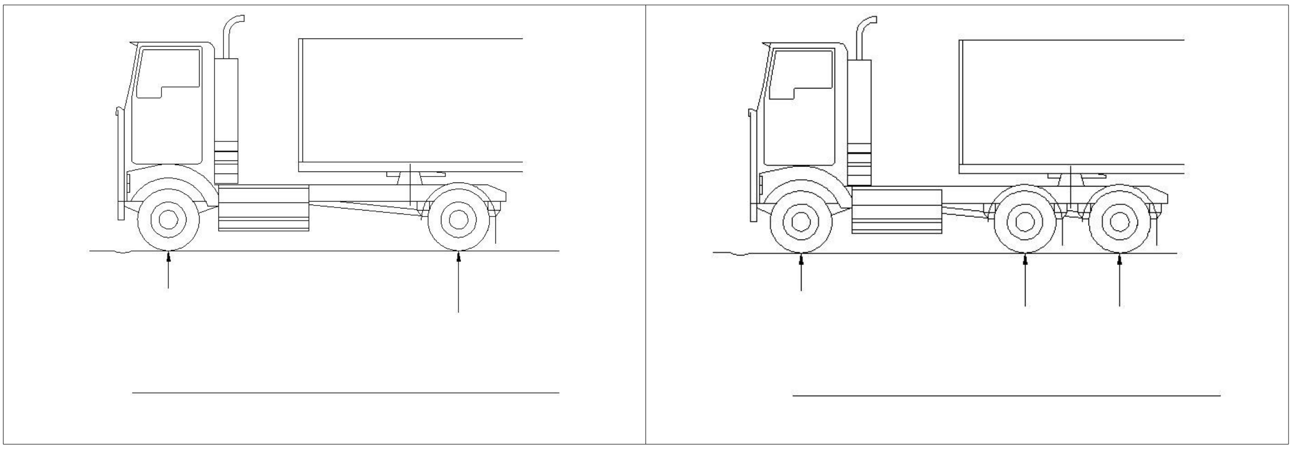


Figure (I) Single Axle (a) and Tandem Rear Axled (b) Prime Mover Approaching Road Depression (Intermediate Wheelbase Prime Movers)

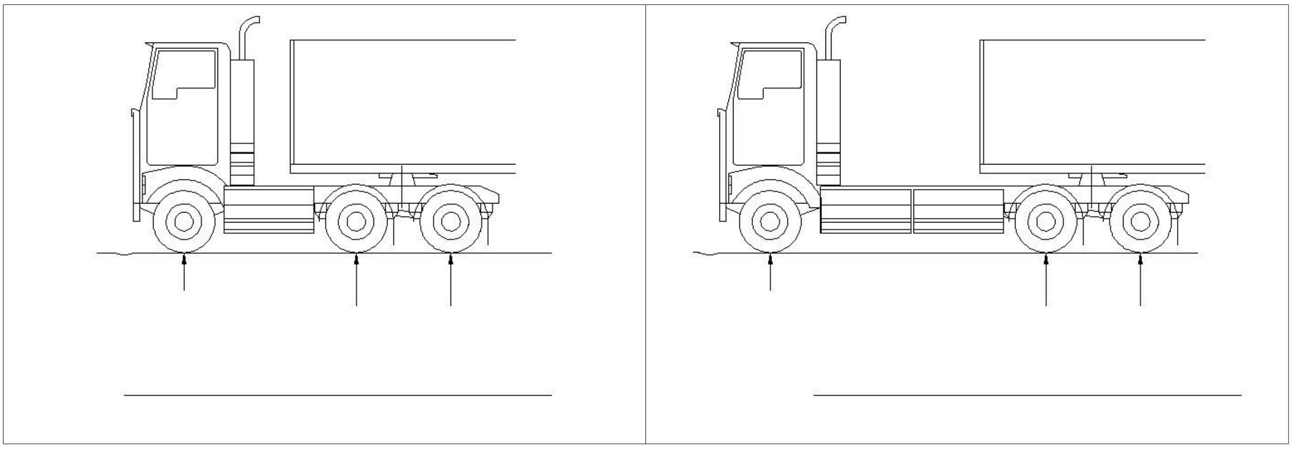


Figure (II)

Comparison of Short (SWB) (a) and Long (LWB) (b) Wheelbase Prime Movers

Due to the pitching characteristics of tandem axled prime movers they attract particularly adverse accident statistics. These adverse accident statistics result from the possibility the steer tyres may unexpectedly and unpredictably loose contact in those instants the load on the steer axle is suppressed. On the other hand significant bump steer may occur at those instants the steer axle load is excessive relative to the time average steer axle load. Obviously the extent of the same is exacerbated should the steer axle load vary significantly.

The significant prime mover pitching and bump steer demands unyielding driver vigilance. Failure of driver vigilance heralds premature driver fatigue. Driver fatigue is known to be a high risk driver condition for accidents.

Tri and Tridem rear axled prime movers

Prime movers installed with rear tri axle groups exhibit minimal pitching. However, significant dynamic variation in axle loads occurs between each axle in the axle group. Tri rear axled prime movers exhibit vastly deteriorated turning circles.

Accident Scenarios

Standard air suspended trucks and prime movers exhibit the following accident signatures.

- high risk of loss of control negotiating the latter sections of long sweeping curves. The risk of roll over and / or loss of control in a long sweeping curve is particularly high if the heavy vehicle drive axle group is fitted with at least one single high gain, to body lean, ride height control valve and/or the curve becomes progressively and increasingly sharper. This risk is exacerbated should the vehicle be hauling a high centre of gravity load and the vehicle is travelling downgrade.
- high risk of loss of control negotiating the exit zone immediately post a long sweeping curve. The risk of loss of control in the exit zone of a long sweeping curve is particularly high if the heavy vehicle drive axle group is fitted with at least one high gain, to body lean, ride height control valves. The risk is exacerbated should the driver not have the opportunity to progressively cancel lock, the steer axle contacts a pavement disturbance and the vehicle is travelling downgrade.
- high risk of loss of control entering the second curve of a close coupled opposite lock curve sequence. This risk is particularly adverse should the lead curve be a long sweeping curve and the second close coupled curve relatively sharper. The risk is exacerbated should the driver not have the opportunity to progressively cancel lock post the apex of the lead curve, the steer axle contacts a pavement disturbance in the transition zone and the vehicle is travelling downgrade.
- high risk of rollover / loss of control in a curve post a high torque application (in some cases assumptions regarding or knowledge of the previous route is necessary). The risk of rollover / loss of control is particularly high if the vehicle drive axle group is fitted with 'axle locked' high gain, to body lean, the steer axle contacts a pavement disturbance in the transition zone and the and the vehicle is travelling downgrade.
- High risk of loss of control of high productivity vehicles (e.g. B doubles hauled by short wheel base prime movers) on seemingly ideal roads particularly on straights. Here the risk of loss of control is exacerbated by the vehicle's pitching, bump and roll steer characteristics; pavement surface (including extent and asymmetry) and edge conditions (such as nearside depressions and edge dropouts), shock absorber status, frame rise extent and sensitivity. In regard the steady state frame rise extent the same rapidly increases with increasing combination size.
- High risk of loss of control contacting adverse pavement conditions (including extent and asymmetry), rapidly changing pavement frictional conditions and wet roads (the latter is particularly adverse should the pavement be severely tramlined with water puddles present). The risk of loss of control is exacerbated should the prime mover's shock absorbers be in poor state of repair.
- Vehicles fitted with bellows type air spring are particularly prone to rollover / loss of control. This tendency is exacerbated should the suspension be operating with shock

absorbers in poor state of repair and the air springs suspend rigid relatively short trailing arms.

Most significant improvement to heavy vehicle suspensions

Air suspended multiple axle groups should be installed with dynamic load sharing mean ride height controlled unitary valved biased orifice flow inherently damped air suspensions. The unitary ride height control valve should be so positioned to be relatively insensitive to body lean and receive no more than 50% feedback from a particular axle in a bogey axle group.

The installation of sub 50% axle ride height feedback controlled unitary valved biased orifice flow inherently damped air suspensions is also particularly strategic for air suspended single axles.

Safety Benefits

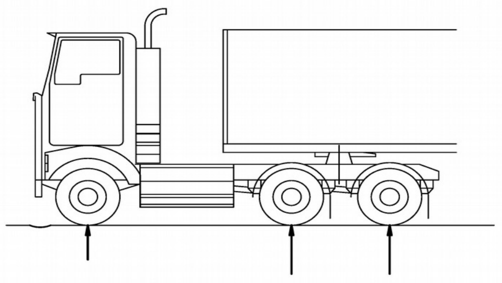
The safety improvements stemming from adopting dynamic load sharing include:

- vastly improved handling and greatly reduced risk of darting
- vastly improved ride
- significantly reduced driver fatigue
- reduced darting correction demands on fatigued drivers
- improved traction
- vastly improved braking yielding vastly reduced braking distances
- improved tolerance to vehicle operation with out of specification shock absorbers
- vastly reduced compressed air consumption (so ensuring supplies to the brake system)
- reduced drive line dynamic loading
- reduced vehicle maintenance requirements
- reduced tyre wear
- reduced road damage yielding, in turn, positive feedback to improved vehicle ride, handling and driver vigilance,
- improved tolerance to operation on adverse roads and/or unsealed roads
- consistent and reliable output from on board load management systems (hence reduced risk of vehicle overloading)
- vastly improved consistent and reliable platform for the operation of on board ABS, ESC and ERP systems
- vastly more stable road train operation when using tandem and tri axle B and C trailer dollies
- improve the ride and handling of multiple axle buses and coaches
- ((futuristic) provide a stable platform for autonomous controlled heavy vehicles).

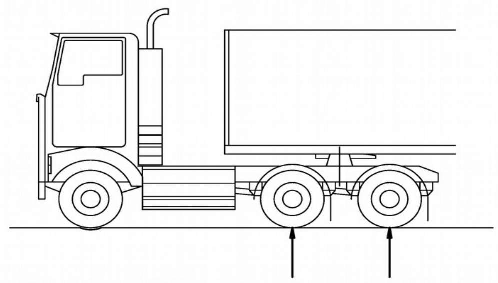
Simulated Air Suspended Axle Group Axle Load Response to Passing over a Road Depression

I) Prime mover response

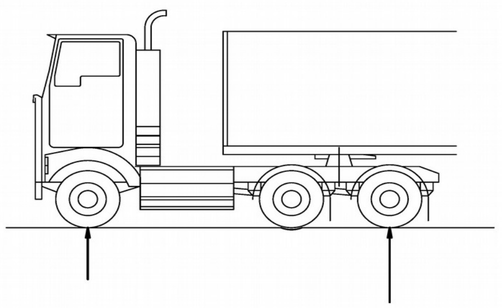
Figures 1 and 2 following present a simplified schematic sequence of a prime mover's axle load response to passing over a road depression. The responses are presented for both a standard air suspended and improved air suspended prime mover in Figures 1 and 2, respectively.



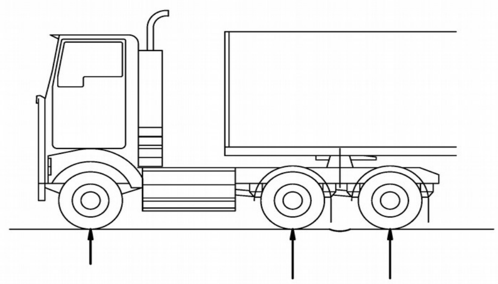
(a) Prime mover axle loads with the steer axle approaching a depression (t = 0 ms)



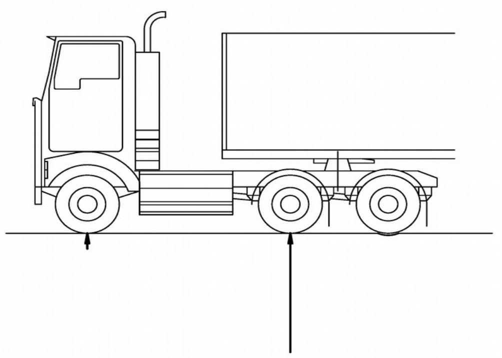
(b) Prime mover axle loads with the steer axle at the depression (t ≈ 20 ms)



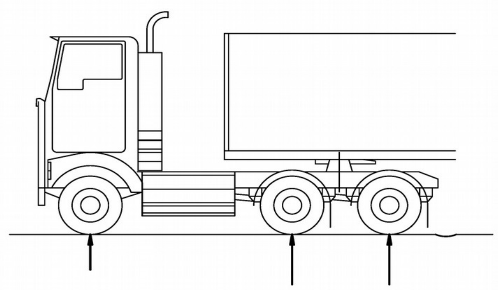
(c) Prime mover axle loads with the lead drive axle at the depression (t ≈ 140 ms)



(d) Prime mover axle loads with the drive axles straddling the depression (t ≈ 165 ms)



(e) Prime mover axle loads with the rear drive axle at the depression (t ≈ 190 ms)



(f) Prime mover axle loads when clear of the depression (t ≈ 210 ms)

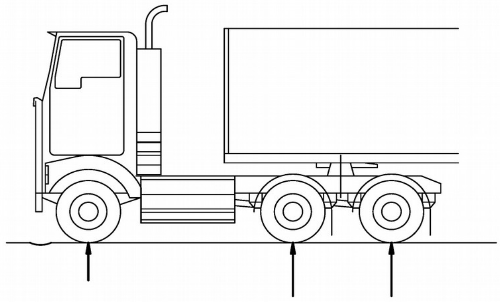
Figure 1   Prime mover axle load response to passing over a road depression – standard or **static load sharing** bogie drive suspension. **Legend** The length of the vertical arrow, underneath each axle, indicates the instantaneous axle load magnitude.

Discussion

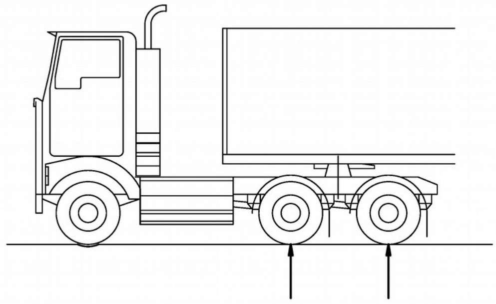
In Figure 1 the simulated 'to the left' prime mover movement simultaneous to passing over a road depression is depicted by the schematic sequence (a) to (f), inclusive. Note the significant axle load oscillations post the event are not depicted. (At 100 kph the event duration between the steer axle passing first contacting the depression (schematic (b)) to the rear drive axle contacting the same depression (schematic (e)) is approximately 200 ms.)

Closer examination of the foregoing sequence, particularly the extremely rapid axle load variation between phases (c) and (e), explains two commonly observed significant road damage phenomena. Notably the growth of road damage, both in the fore and aft direction, from each initial pavement deviation and the formation of corrugations one axle group spacing upstream and downstream from each significant initial road surface deviation. The 'in the direction of travel' corrugation growth dominates in response to time dissipating periodic axle oscillations post each axle contacting a road depression. The corrugation intensity and spatial extent is strongly dependent on the state of repair of each passing vehicle's shock absorbers. In particular should the majority of heavy vehicle traffic be operating with shock absorbers in poor state of repair the resulting corrugation spatial extent, from the road depression, is significant. Should this be the case corrugations may be evident for up to 20 axle oscillations. (If on the other hand the heavy vehicle traffic operated with shock absorbers in high state of repair a maximum of approximately 5 corrugations form.) The growth of the resultant road damage is extremely rapid should the road be subject to frequent upper highway speed heavy vehicle movements. Furthermore the extent and rapidly of the damage is exacerbated when the drive axles are subject to significant torque (i.e maintaining constant speed on a grade; accelerating; ascending or descending (subject to engine braking) long significant grades; pulling up and away from traffic lights, etc., etc.).

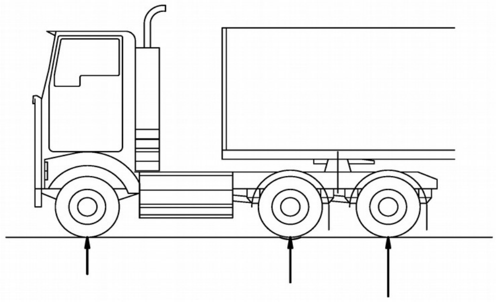
Hence the foregoing schematic sequence highlights it is a **gross misnomer** to refer to standard air suspended axles as road friendly. In fact, as the foregoing sequence reveals, standard air suspended prime movers are **road wreckers**.



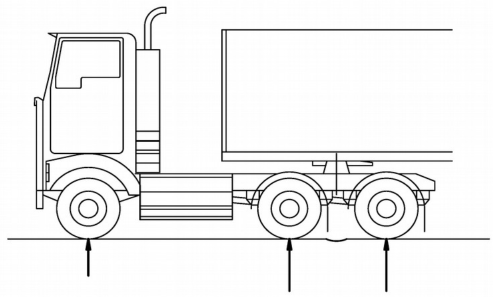
(a) Prime mover steer axle approaching pavement depression (t = 0 ms)



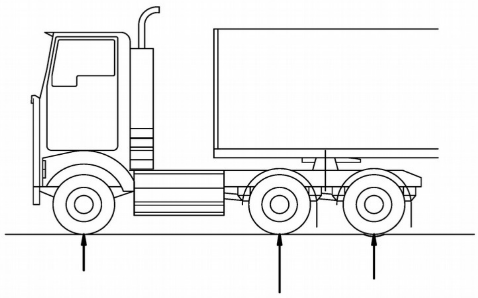
(b) Prime mover steer axle at depression (t ≈ 20 ms)



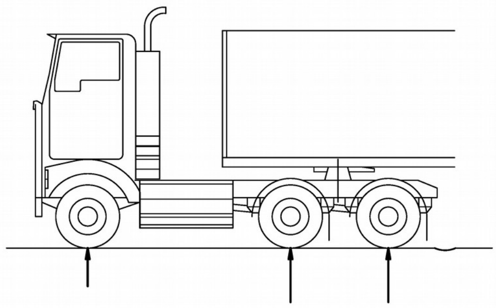
(c) Prime mover lead drive axle at depression (t ≈ 140 ms)



(d) Prime mover drive axles straddling depression (t ≈ 165 ms)



(e) Prime mover rear drive axle at depression (t ≈ 190 ms)



(f) Prime mover past depression (t ≈ 210 ms)

Figure 2 Prime mover axle load response to passing over a road depression – improved or **dynamic load sharing** bogie drive suspension. **Legend** The length of the vertical arrow indicates the instantaneous individual axle load magnitude

Discussion

The simulated 'to the left' prime mover movement simultaneous to passing over a road depression is presented by the schematic sequence (a) to (f), inclusive. Note the axle load oscillations post the event are not depicted. (At 100 kph the event duration between the steer axle passing over a depression (schematic (b)) to the rear drive axle contacting over the same depression (schematic (e)) is approximately 200 ms.)

Examination of the sequence, presented in Figure 2, reveals the near elimination of the upstream and downstream corrugation formation phenomena. Notably heavy vehicle axles supported on dynamic load sharing suspensions are **genuinely and inherently road friendly**.

Comparison of Figures 1 and 2 also reveals prime mover pitching is a major safety hazard for truck drivers and hence all road users.