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STRENGTH REQUIREMENTS FOR FIFTH WHEEL COUPLINGS IN ROAD TRAINS AND GENERAL ARTICULATED VEHICLES

by

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Project 400 — Strength Requirements for Fifth Wheel Couplings

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I. INTRODUCTION

Road trains consist of articulated vehicles hauling one or two trailers, or alternatively, rigid trucks hauling two or three trailers. They are permitted to operate in all parts of the Northern Territory and in restricted areas of other States, with the exception of New South Wales, Victoria and Tasmania.

Following a NAASRA study of the operation of road trains (NAASRA 1978), dimensional, mechanical and operational requirements were introduced under the States' legislation. NAASRA had recommended that fifth wheels, turntables and king pins meet the relevant Australian Standards and, in addition, that certain turntable types not be allowed. The NAASRA study had noted, however, that the relevant Australian Standards (AS 1771-1773) do not include a strength rating scheme based on the hauling and hauled masses, as used in the European "D-rating" scheme. ARRB was therefore requested to carry out the necessary research to develop strength standards for fifth wheel couplings, turntables and king pins used under typical Australian operating conditions. The scope of the research was widened to include general transport vehicles (semi-trailers), as well as road trains, because there are currently no effective controls on fifth wheel strength.

It was realised that enforcement of AS 1771-1773 would not solve the problem because it is essentially a standard for interchangeability and includes only a cursory strength requirement. AS 1771-1773 is currently being revised and this report is a direct input to SAA Committee ME/53 - Semi Trailer and Heavy Trailer Couplings to assist in that revision. A survey of fifth wheel manufacturers carried out by ME/53 found that most favoured the introduction of a D-rating concept and the ARRB research has been directed to that end. This is also in line with Australian Government thinking because ATAC has a policy of harmonisation of Australian Design Rules with ECE requirements. The relevant ECE regulation no.55 (Uniform Provisions Concerning the Approval of Mechanical Coupling Components of Combinations of Vehicles) embodies a D-rating concept, and the ARRB research has attempted to follow the ECE 55 format wherever possible.

Similar research had previously been carried out by ARRB (Sweatman 1980), into strength requirements for the pin-couplings used in road trains and the Results are now embodied in AS 2213-1984 (50 mm Pin-Type Couplings and Drawback Eyes for Trailers). A fundamental distinction between that research and the present research is that the pin-couplings themselves were already rated according to a valid standard test, and it was necessary only to determine application formulae for vehicle combinations, based on the masses of the units. However, in the case of fifth wheels, both the vehicle application formulae and the component rating test need to be determined.

While it is desirable that vehicle standards closely follow the laws of physics, experience has shown that the need to

(a) cover a wide range of vehicle types,

(b) accommodate existing (for example, ECE) standards and,

(c) maintain a high degree of simplicity.

(d) mitigates against the direct use of complex vehicle mechanics formulations in standards.

The emphasis in the research was therefore on measuring maximum coupling loadings under real operating conditions, rather than the more contrived type of experimentation needed to fully explore the vehicle dynamics involved. There is, therefore, considerable engineering judgement used in this report. However, unlike standards developed in other parts of the world, at least the assumptions and initiutive aspects are contained in a single document!

2. MEASUREMENT OF FIFTH WHEEL FORCES

Measurements of in-service fifth wheel forces were obtained using an instrumented fifth wheel fitted to a road train prime mover belonging to Parnell Transport of Orrorroo, SA. Tests were undertaken on a journey from Port Augusta, SA, to Docker River, NT. The test vehicle was operated in triple, double and semi-trailer configurations, on both sealed and unsealed roads.

2.1 INSTRUMENTED FIFTH WHEEL

An instrumented fifth wheel capable of measuring the vertical, longitudinal and lateral forces and the overturning moment (Fig 1) was developed by Paccar Inc., US. It was brought to Australia by Kenworth Aust. and made available to ARRB

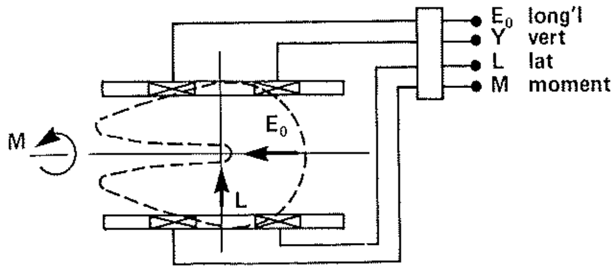


Fig. 1 — Instrumented fifth wheel coupling on loan from Paccar Inc.

through the Australian Institute of Petroleum (AIP). The fifth wheel itself was manufactured by Holland Hitch, US and is mounted on load cells produced by Evergreen Weigh Inc, US. For road train use, a new mounting plate rated for 115t GCM was fitted by Holland Hitch Aust and the fifth wheel slide was blocked, in accordance with advice from Holland Hitch, US. No ballrace turntable was fitted.

The load cells had been accurately calibrated in the US and these calibrations were used in the present tests. The fifth wheel had been previously used by ARRB in P323 - Articulated Vehicle Stability and, for that purpose, the overturning moment calibration had been checked.

2.2 VEHICLE CONFIGURATION

The road train consisted of a prime mover, three tanker trailers (two steel skeletals and one conventional aluminium) and two converter dollies. Fig 2 shows the three configurations tested (triple, double, semi) and their axle loads. For the triple, one slightly downloaded condition was also tested (download on the leading trailer). The GCM's tested were 112t and 105t (triple), 77t (double) and 42t (semi). These are close to the legal maxima of 115t, 78t and 42t respectively.

The prime mover was a Mack Super Liner 6 x 4 unit with EM9 - 400(R) engine and 5-speed transmission with auxiliary overdrive, with an effective drive ratio of 4.08:1 for top gear operation. Tare weight was 10.5t unfuelled. The fifth wheel setting was 230 mm ahead of the tandem suspension centre line.

The suspension was a 6-rod single-point "Camelback" and 11R 22.5 radial tyres in dual configuration were fitted.

The two skeletal tanker trailers and the conventional aluminium tanker trailer were triaxle units fitted with six-spring suspensions and 11R 22.5 radial tyres in dual configuration.
The converter dollies were Type C dollies, with hinged drawbars and fixed-base fifth wheels hinging in the pitch mode, but restrained in oscillation by rubber pads. Four-spring suspensions and 11R 22.5 dual radials were used. The drawbars were connected to the towing vehicle using Ringfeeder 50 m pin-type couplings.

Essential dimensions of the road train units are given in Fig 2.

2.3 INSTRUMENTATION

Signal-conditioning amplifiers, power supplies, etc. were built at ARRB to suit the Paccar fifth wheel transducers. Data was recorded on a Racal 7-track FM analog tape recorder, previously used in ARRB truck research projects and described fully by George (1980).

A sensor was fitted to the truck speedometer and data recorded on the tape recorder.

A voice track was used to describe the terrain and to locate significant events in the recorded data.

2.4 TEST PROCEDURE

The three trailers were loaded with fuel at Port Pirie, SA and towed separately to Port Augusta where all configurations were assembled and weighed on a weighbridge.

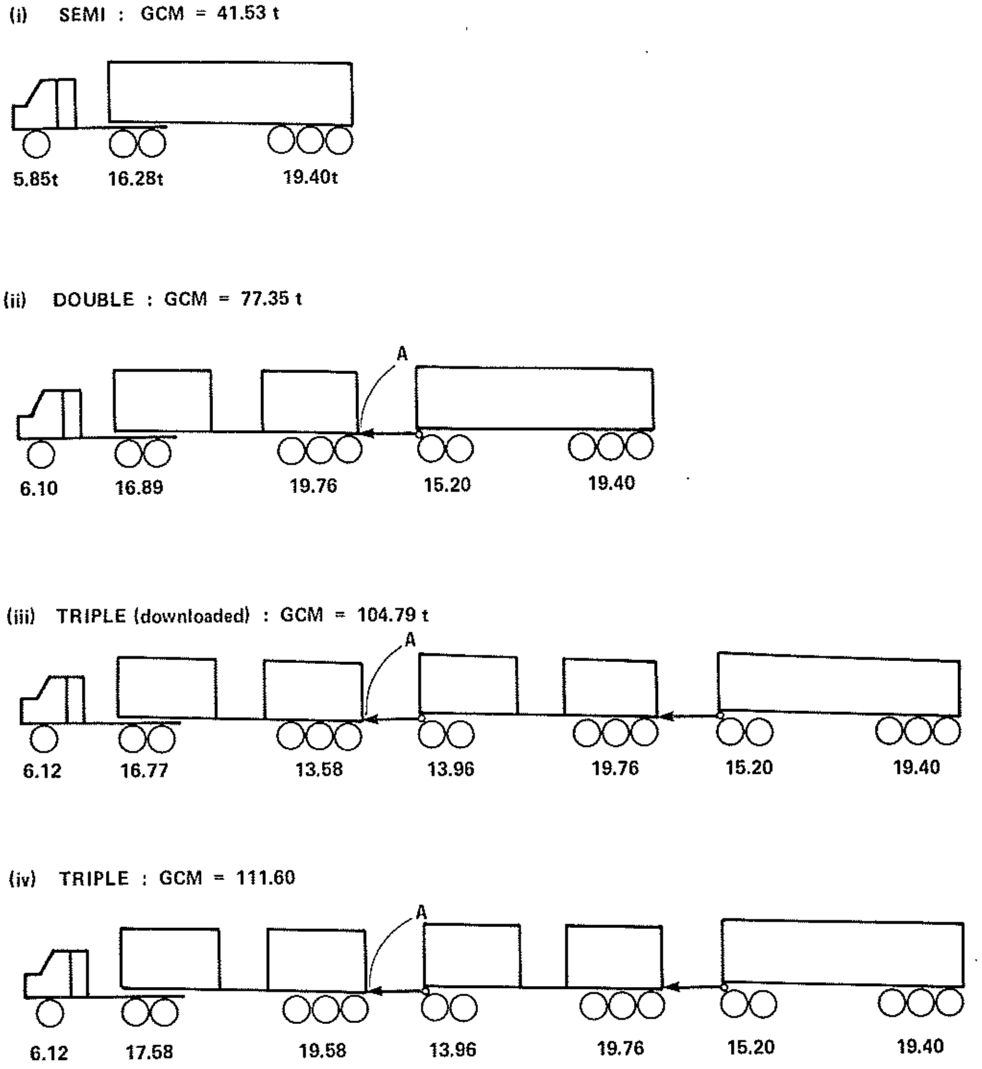
The Stuart Highway was subject to a major reconstruction project in the years immediately preceding and following these tests (carried out in 1983) and no longer contains the unsealed sections referred to in this report. However, the data obtained on these sections is considered representative of unsealed road operations in other parts of Australia.

The test route followed the Stuart Highway north through Pimba on a sealed road and onwards to Coober Pedy on an unsealed road. The road north of Coober Pedy was sealed for approximately 30 km and was unsealed through Mt Willoughby and Marla to the Northern Territory border where we took the Victory Downs turnoff (unsealed) via Mulga Park to Curtin Springs, some 80 km east of Ayres Rock. The road is then sealed to Ayres Rock and unsealed onwards to Docker River, an aboriginal community near the Western Australian border.

Table 1 shows the vehicle configuration, road type and approximate distance involved with each section of the test. A total of approximately 1600 km travel, with each configuration traversing both sealed and unsealed sections, was involved in the test. Experience had shown that, where the most severe loading conditions are needed to be captured in such tests, it is necessary to accompany an operator on his full route. While drivers tend to drive more carefully than they otherwise might when a vehicle is instrumented for a short road test, the normal pressures of a long journey, plus fatigue, tend to produce more representative driving behaviour. The long unsealed sections from Mt Eba to Coober Pedy (250 km) in the triple and from Marla to Curtin Springs (420 km) in the double were considered to be particularly useful in this regard.

Data was recorded continuously through each "log", which consisted of the driver's normal journey segment before stopping to check tyres, lights etc. These logs were approximately 60 km in length and there were 31 logs in the entire test.

The vehicle left Port Augusta on the morning of Aug 2 1983 and arrived at Docker River on the afternoon of Aug 6 1983. The test therefore occupied four consecutive days with overnight stops at Coober Pedy, Marla, and Curtin Springs.



Note : overall length of each trailer = 12.5 m
distance kingpin to centre of rear axle group = 8.5 m
drawbar length (drawbar eye to centreline of fifth wheel) = 4.66 m

Fig. 2 — Vehicle configurations tested

TABLE I

TEST DETAILS

Configuration	GCM (t)	Road Type	Distance (km)
Double	78	sealed	150
Triple	112	sealed	170
Triple	112	unsealed	250
Triple	112	sealed	30
Triple	112	unsealed	120
Triple	105	unsealed	130
Double	78	unsealed	420
Semi	42	sealed	80
Semi	42	unsealed	220
	Total		1570

2.5 RESULTS

Data was analysed for each log, determining the amplitude distribution, mean, standard deviation, and maximum and minimum of each data channel (longitudinal, vertical and lateral forces and the overturning moment). Typical examples of each distribution are given in Fig 3. Selected parameters of all such distributions are given in Tables II and III.

Longitudinal Force

```
Force (kN)     Percentage     Histogram
**********     **********     *********
(interval midpoint)

 -5.5         0.3        $
 -2.4         0.6        $
  0.8         1.1        $$
  3.9         1.7        $$$
  7.0         2.4        $$$$$
 10.1         4.1        $$$$$$$$
 13.3         6.1        $$$$$$$$$$$$
 16.4         8.3        $$$$$$$$$$$$$$$$$
 19.5        11.2        $$$$$$$$$$$$$$$$$$$$$$
 22.6        13.1        $$$$$$$$$$$$$$$$$$$$$$$$$$
 25.8        13.5        $$$$$$$$$$$$$$$$$$$$$$$$$$$
 28.9        11.8        $$$$$$$$$$$$$$$$$$$$$$$$
 32.0         9.0        $$$$$$$$$$$$$$$$$$
 35.1         6.3        $$$$$$$$$$$$$
 38.3         4.1        $$$$$$$$
 41.4         2.5        $$$$$
 44.5         1.5        $$$
 47.6         0.9        $$
 50.8         0.5        $
 53.9         0.3        $
```

Fig 3(a)

Lateral Force

```
Force (kN)     Percentage     Histogram
**********     **********     *********
(interval midpoint)

-12.1         0.3        $
-11.2         0.4        $
-10.4         0.6        $
 -9.5         0.8        $$
 -8.7         1.0        $$
 -7.8         1.5        $$$
 -7.0         2.0        $$$$
 -6.1         2.7        $$$$$
 -5.2         3.6        $$$$$$$
 -4.4         4.5        $$$$$$$$$
 -3.5         5.8        $$$$$$$$$$$$
 -2.7         7.0        $$$$$$$$$$$$$$
 -1.8         8.2        $$$$$$$$$$$$$$$$
 -1.0         8.7        $$$$$$$$$$$$$$$$$
 -0.1         9.0        $$$$$$$$$$$$$$$$$$
  0.8         8.5        $$$$$$$$$$$$$$$$$
  1.6         7.7        $$$$$$$$$$$$$$$
  2.5         6.4        $$$$$$$$$$$$$
  3.3         5.2        $$$$$$$$$$
  4.2         4.1        $$$$$$$$
  5.0         3.1        $$$$$$
  5.9         2.3        $$$$$
  6.8         1.7        $$$
  7.6         1.2        $$
  8.5         0.9        $$
  9.3         0.6        $
 10.2         0.4        $
 11.0         0.3        $
```

Fig 3(c)

Vertical Force

```
Force (kN)     Percentage     Histogram
**********     **********     *********
(interval midpoint)

  64.9        0.6        &
  70.4        1.0        &
  75.9        1.6        &&
  81.3        2.3        &&
  86.8        3.4        &&&
  92.3        4.7        &&&&&
  97.7        6.6        &&&&&&&
 103.2        8.9        &&&&&&&&&
 108.6       11.8        &&&&&&&&&&&&
 114.1       14.7        6&&&&&&&&&&&&&&&
 119.6       12.3        &&&&&&&&&&&&
 125.0        9.2        &&&&&&&&&
 130.5        6.7        &&&&&&&
 136.0        4.8        &&&&&
 141.4        3.5        &&&
 146.9        2.4        &&
 152.4        1.7        &&
 157.8        1.1        &
 163.3        0.8        &
```

Fig 3(b)

Overturning Moment

```
Moment (kNm)    Percentage     Histogram
************    **********     *********
(interval midpoint)

-28.1         0.3        $
-27.3         0.3        $
-26.4         0.4        $
-25.5         0.5        $
-24.7         0.6        $
-23.8         0.7        $
-23.0         0.8        $$
-22.1         1.0        $$
-21.2         1.0        $$
-20.4         1.3        $$$
-19.5         1.5        $$$
-18.7         1.7        $$$
-17.8         1.9        $$$$
-17.0         2.2        $$$$
-16.1         2.4        $$$$$
-15.2         2.7        $$$$$
-14.4         2.9        $$$$$$
-13.5         3.3        $$$$$$$
-12.7         3.5        $$$$$$$
-11.8         3.9        $$$$$$$$
-10.9         4.0        $$$$$$$$
-10.1         4.1        $$$$$$$$
 -9.2         4.2        $$$$$$$$
 -8.4         4.3        $$$$$$$$$
 -7.5         4.2        $$$$$$$$
 -6.6         4.1        $$$$$$$$
 -5.8         4.1        $$$$$$$$
 -4.9         3.9        $$$$$$$$
 -4.1         3.6        $$$$$$$
 -3.2         3.4        $$$$$$$
 -2.4         3.2        $$$$$$
 -1.5         3.0        $$$$$$
 -0.6         2.6        $$$$$
  0.2         2.4        $$$$$
  1.1         2.1        $$$$
  2.0         2.0        $$$$
  2.8         1.6        $$$
  3.7         1.4        $$$
  4.5         1.2        $$
  5.4         1.0        $$
  6.2         0.9        $$
  7.1         0.8        $$
  8.0         0.7        $
  8.8         0.5        $
  9.7         0.5        $
 10.4         0.4        $
 11.4         0.3        $
 12.3         0.3        $
```

Fig. 3(d)

Fig. 3 — Probability distribution of fifth wheel loadings for a triple road train on an unsealed road (log 16) for forces and moments in the following axes:
(a) longitudinal, (b) vertical, (c) lateral, (d) overturning

TABLE II

RESULTS FOR LONGITUDINAL AND VERTICAL FIFTH WHEEL FORCES

Log	Config	Road	Vertical Force (kN)				Longitudinal Force (kN)			
			mean	s.d.	min	max	mean	s.d.	min	max
1	N/A									
2	double	sealed	111	24	37	201	10	8	-36	61
3	triple	sealed	119	14	63	195	14	9	-22	65
4	triple	sealed	121	20	57	227	19	7	-19	87
5	triple	sealed	119	19	70	185	17	7	-16	68
6	triple	unsealed	116	30	-9	248	22	12	-47	118
7	triple	unsealed	119	26	15	234	26	10	-26	90
8	triple	unsealed	120	22	21	239	25	9	-26	71
9	triple	unsealed	120	33	-6	316	26	11	-34	94
10	triple	unsealed	114	35	-42	253	22	11	-45	93
11	triple	sealed	113	27	-73	222	14	12	-72	85
12	triple	unsealed	117	33	-85	260	24	11	-58	89
13	triple	unsealed	115	27	-3	254	21	11	-38	78
14	triple	unsealed	110	24	-39	355	26	13	-46	110
15	triple	unsealed	108	23	7	225	23	10	-32	80
16	triple	unsealed	110	23	-21	253	20	10	-26	77
17	double	unsealed	107	24	23	258	10	9	-48	64
18	double	unsealed	116	15	35	221	14	10	-37	67
19	double	unsealed	112	17	-3	216	13	9	-41	63
20	double	unsealed	114	28	-4	297	17	11	-43	86
21	double	unsealed	111	23	-4	248	15	11	-51	81
22	double	unsealed	-	-	-1	266	-	-	-32	81
23	double	unsealed	113	26	-21	290	18	9	-38	84
24	double	unsealed	112	22	-9	324	14	10	-41	87
25	double	unsealed	113	13	14	265	16	10	-32	96
26	double	unsealed	116	21	-2	255	19	12	-32	81
26A	semi	sealed	115	20	20	217	8	4	-36	48
27	semi	unsealed	114	27	-19	325	11	9	-41	74
28	N/A									
29	semi	unsealed	114	28	1	317	14	10	-44	62
30	semi	unsealed	115	27	6	246	15	10	-38	69
31	semi	unsealed	116	26	6	268	15	9	-38	69

In addition, power spectra were determined using a dual-input HP 3582A Spectrum Analyser. Data channels were entered in pairs (longitudinal with vertical force and lateral force with overturning moment) and the following were determined: amplitude spectrum, coherence, and the phase relationship between the two variables. Fig 4 shows typical results for the triple, with one definite spectral peak for the vertical force (around 3 Hz) and a broader band of response between 10 Hz and 25 Hz, some of which could be related to transducer resonance. The characteristic for the longitudinal force shows peaks in the range 6 Hz to 12 Hz. The two variables show fairly high coherence around the higher frequency vertical force peak While it is tempting to attribute this to the existence of a dynamic mode involving pitching of the prime mover, it could well be an artifact of the transducer. Dixon (1970) obtained a similar result with a transducer of similar design. As neither the Paccar not the Dixon transducer was calibrated dynamically for multi-axis excitation, it is impossible to deduce the mechanism behind the considerable vertical fifth wheel loading in the higher (10 Hz to 25 Hz) frequency range. Other possible mechanisms aside from rigid-body modes (unlikely in this frequency range) are chassis beaming modes in prime mover or trailer. The overturning moment shows a fairly broad band of response in the range 10 Hz to 20 Hz, and the lateral force peaks around 10 Hz and has fairly high coherence with the moment at that frequency. Therefore, at least part of the moment loading on the fifth wheel may be related to the lateral force. As a check, the vertical force and overturning moment were paired into the spectrum analyser and showed no coherence, and therefore may be assumed to be independent.

The maximum loading conditions for each vehicle configuration and road condition are given in Table IV.

Two observations follow without further analysis:

(i) vertical loadings are high and exceed the AS 1773 requirement for fifth wheels with 50 mm kingpins.

(ii) longitudinal forces are higher in the double or triple than the semi, as would be expected.

TABLE III

RESULTS FOR FIFTH WHEEL
LATERAL FORCE AND OVERTURNING MOMENT

Log	Config	Road	Lateral Force (kN)				Overturning Moment (kN m)			
			mean	s.d.	min	max	mean	s.d.	min	max
1	N/A									
2	double	sealed	-6	4	-27	14	-7	10	-43	33
3	triple	sealed	-3	3	-16	10	-5	6	-32	27
4	triple	sealed	-3	3	-16	12	-6	6	-31	24
5										
6	triple	unsealed	1	6	-49	40	-3	11	-51	54
7										
8	triple	unsealed	-1	4	-27	25	-7	8	-50	36
9	triple	unsealed	1	5	-28	28	-5	10	-50	43
10	triple	unsealed	1	5	-41	43	-6	9	-50	39
11	triple	sealed	2	5	-30	34	-5	10	-54	49
12	triple	unsealed	0	5	-31	32	-7	9	-53	51
13	triple	unsealed	-1	5	-32	33	-8	9	-52	45
14	triple	unsealed	-1	4	-27	33	-8	8	50	43
15	N/A									
16	triple	unsealed	0	4	-37	32	-8	9	-50	41
17	double	unsealed	-2	4	-31	24	-12	9	-53	45
18	double	unsealed	0	4	-25	22	-11	8	-48	31
19	double	unsealed	0	4	-29	25	-11	8	-51	33
20	double	unsealed	-1	5	-42	37	-11	11	-51	52
21	double	unsealed	-2	5	-43	41	-11	10	-50	44
22	double	unsealed	-1	4	-40	38	-11	8	-51	55
23	double	unsealed	-1	4	-30	29	-10	9	-51	41
24	N/A									
26	double	unsealed	-2	4	-41	36	-11	10	-51	37
26A	semi	sealed	-3	3	-27	19	-11	6	-40	29
27	semi	unsealed	0	6	-51	48	-9	11	-52	48
28	semi	unsealed	-1	4	-24	29	-9	9	-48	38
29	semi	unsealed	-1	7	-38	46	-9	12	-51	54
30	semi	unsealed	N/A							
31	semi	unsealed	N/A							

3. VEHICLE APPLICATION FORMULAE

It is usually assumed that, of the three forces and one moment acting on the fifth wheel, only the longitudinal force depends on the entire vehicle configuration. Therefore, D-ratings, taking into account the masses of all units, apply only to longitudinal forces. While it has not been necessary to make this assumption in the present study, it has been confirmed that the vertical and lateral forces and the overturning moment are essentially independent of the gross combination mass (GCM). This section therefore concentrates on the longitudinal forces.

The approach taken follows that previously developed for pin couplings (Sweatman 1980) in that separate steady-state and dynamic components are derived and then combined in the overall D-rating. This approach was formulated on the basis that part of the loading is related to acceleration, rolling loss, wind resistance and grade arrects, and is supplied by the tractive effort of the prime mover, while part consists of dynamic effects related to road condition. Reasonable maximum values for the steady state and dynamic components are calculated separately and then added together to give the maximum possible calculated loading conditions.

3.1 STEADY-STATE COMPONENTS

Based on the earlier work (Sweatman 1980), the calculated maximum steady-state components developed under traction for the articulated vehicle (semi), double and triple are:

$$E_{oss} = \frac{0.4d(M_1 - M_0)}{M_1} \qquad \text{(semi)} \qquad (1)$$

$$E_{oss} = \frac{0.4d(M_1 - M_0 + M_2)}{M_1 + M_2} \qquad \text{(double)} \qquad (2)$$

$$E_{oss} = \frac{0.4d(M_1 - M_0 + M_2 + M_3)}{M_1 + M_2 + M_3} + 0.81 \qquad \text{(triple)} \qquad (3)$$

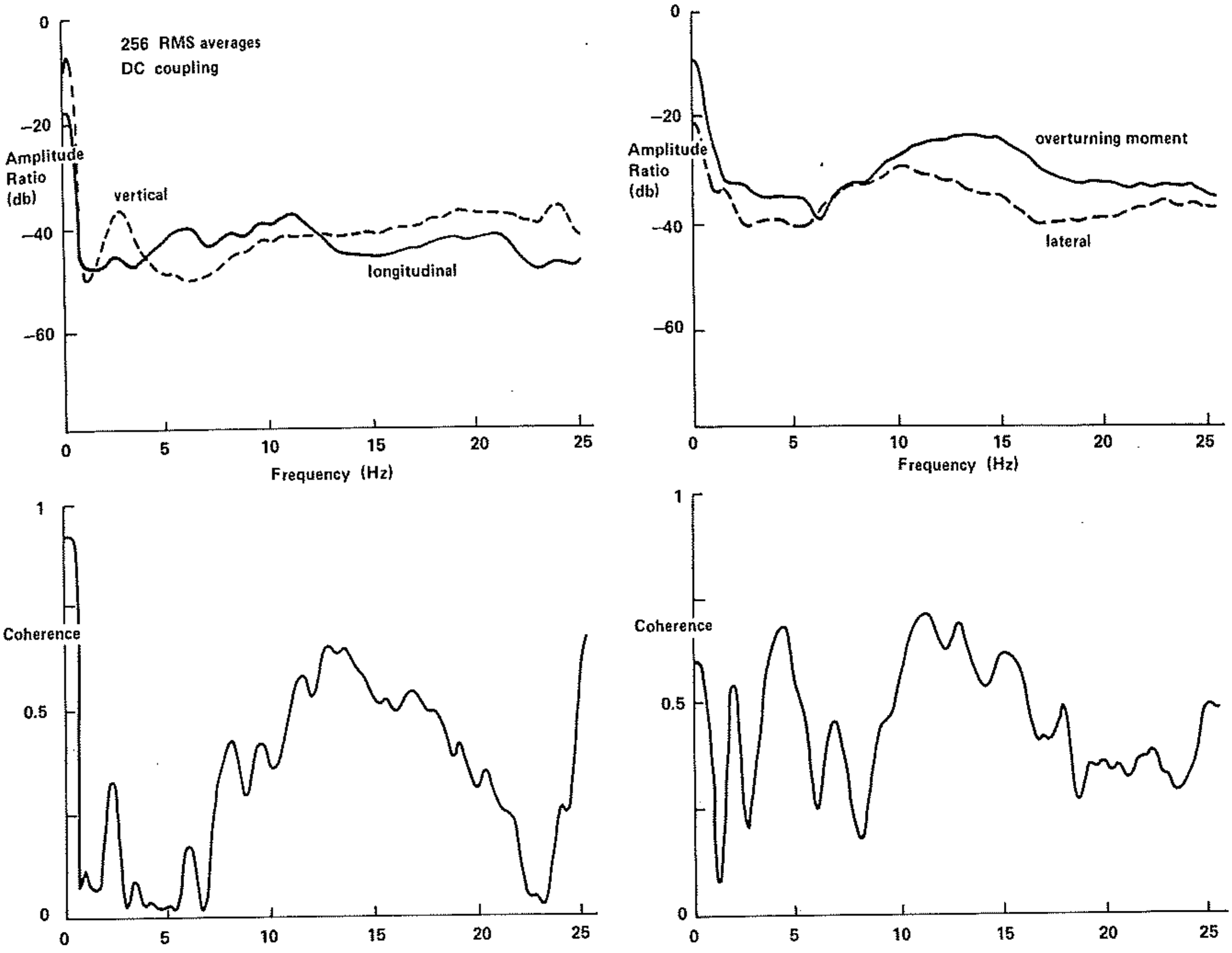


Fig.4 (a)

Fig. 4 (b)

Fig. 4 — Spectrum analysis of fifth wheel loadings for a triple road train on an unsealed road (log 16) for the following pairs of forces and moments: (a) vertical and longitudinal, (b) lateral and overturning

TABLE IV

MAXIMUM FIFTH WHEEL LOADINGS BY VEHICLE CONFIGURATION AND ROAD CONDITION

Vehicle Configuration	Road Type	Maximum Fifth Wheel Loadings[1]			
		Y (kN)	E_O (kN)	L (kN)	M (kN m)
Semi	sealed	258	78	27	40
	unsealed	325	74	51	54
Double	sealed	201	61	27	43
	unsealed	324	96	43	55
Triple	sealed	227	87	34	54
	unsealed	355	110	43	54
AS 1773 requirements		270	270	-	100

[1] Symbols are defined as:
Y = Vertical force
E_O = Longitudinal force
L = Lateral force
M = Overturning moment

Where E_{oss} = max steady-state longitudinal force applied to fifth wheel on prime mover.

M_o = tare mass of prime mover

d = drive axle group load

M_1 = mass of articulated vehicle (prime mover plus first trailer)

M_2 = mass of second trailer

M_3 = mass of third trailer

Two points should be noted:

(i) Eqns 1 to 3 are expressed in mass units, as is customary;

(ii) Eqns 1 to 3 are based on measurements undertaken with a lower-capacity Mack R600 prime mover (Sweatman 1980). Perusal of Table II shows that the mean longitudinal forces for the triple are considerably higher than those for the double and semi-configurations: the highest mean forces were 26 kN, 18 kN and 17 kN for the triple, double and semi-respectively. On this basis, eqn 3 includes an additional component of 8 kN (0.81 t) to allow for added tractive capacity in the larger prime movers used in triple road trains.

The above equations apply only to fifth wheels mounted on prime movers. Similar expressions developed for fifth wheels on converter dollies are:

$$E_{1ss} = \frac{0.4d\ M_2}{M_1 + M_2} \qquad \text{(double)(4)}$$

$$E_{1ss} = \frac{(0.4d+0.81)(M_2+M_3)}{M_1+M_2+M_3} \qquad \text{(triple)(5)}$$

Where E_1 = max steady-state longitudinal force applied to fifth wheel on dolly

and d, M_1, M_2, M_3 are as defined above.

3.2 DYNAMIC COMPONENT

In the earlier road train pin-coupling research a simple approach to calculating dynamic forces occurring between the units, and resulting from relative movement between the units, was developed. While not attempting to model the complex behaviour of a road train, the earlier approach was based on some insights into such behaviour and employed some assumptions which seemed reasonable.

A similar, but separate, approach to directly calculating the dynamic forces acting on the prime mover fifth wheel was considered, but not pursued because of great uncertainties in representing the effect of the drive-axles-to-ground contribution in a dynamic context. This would be a good subject for research in its own right.

Rather, it was decided to investigate whether there was a robust relationship between the **measured** dynamic component at the fifth wheel (prime mover) and the **calculated** dynamic component between the articulated vehicle and the first towed trailer (point A in Fig. 2). This would lead to an indirect calculation of the dynamic forces acting on the prime mover fifth wheel, at least for the double and triple, and would mean that a unique approach would be needed only for the case of the articulated vehicle.

The formulae derived for calculating the dynamic pin-coupling forces (Sweatman 1980) are reproduced here:

$$E_d = \frac{0.5\ M_1M_2}{M_1+M_2} \qquad \text{(double)(6)}$$

$$E_d = \frac{1.2\ M_1M_2M_3}{M_2(M_1+M_3)+2M_1M_3} \qquad \text{(triple)(7)}$$

Measured dynamic components at the fifth wheel (prime mover) were extracted from the data of Table II as ½(max - min) and were averaged for the cases of triple, downloaded triple, double and semi. The calculated and measured dynamic components are:

Vehicle	Measured Dynamic Fifth Wheel Component (kN)	(t)	Calculated Dynamic Pin Coupling Component (kN)	(t)
Semi	54.3	5.54	NA	
Double	59.4	6.06	93.8	9.56
Triple(Download)	62.0	6.32	101.8	10.38
Triple	64.7	6.60	105.8	10.78

These values are plotted in Fig 5 and show a fairly linear relationship represented by the equation:

$$E_{od} = 0.42\ E_d + 1.99 \qquad (8)$$

Where E_{od} = max dynamic longitudinal force applied to prime mover fifth wheel

E_d = max dynamic longitudinal force applied between the articulated vehicle and first towed trailer

and E_d is given by eqns (6) and (7) for the double and triple respectively.

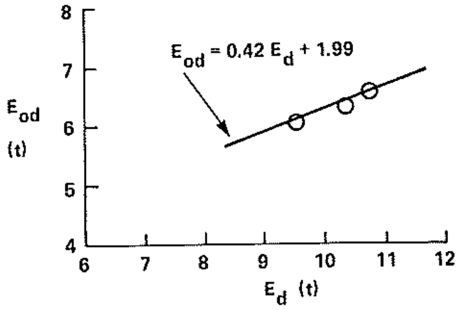


Fig. 5 — Measured dynamic fifth wheel component (E_{od}) versus calculated dynamic pin coupling component (E_d)

For the case of the articulated vehicle, the following form is postulated:

$$E_{od} = \frac{kM_o(M_1-M_o)}{M_1} \qquad (9)$$

Where M_o, M_1 are as defined previously and k is a constant. To fit the measured value of 5.54t, k = 0.7 and

$$E_{od} = \frac{0.7M_o(M_1-M_o)}{M_1} \qquad (10)$$

Note that this is a somewhat unsatisfactory approach as it is based on one data point only.

Fifth wheels used on dollies also need to be covered and it is reasonable to assume that the same dynamic loading is applied to the fifth wheel as the pin-coupling because they are separated only by the mass of the drawbar and part of the dolly frame ie. eqns (6) and (7) apply for the double and triple respectively.

3.3 D-RATINGS

3.3.1. Articulated Vehicles

Combining the maximum steady state and dynamic components (eqns (10 and (1)) yields

$$E_o = \frac{(M_1-M_2)(0.7M_o+0.4d)}{M_1} \qquad (11)$$

Where E_o = max longitudinal fifth wheel force

In order to study eqn (11) with respect to the provisions of ECE 55, it is necessary to evaluate a range of typical articulated vehicles. Table V shows such a range, with legal maximum axle loads, prime mover tare weights and fifth wheel static (vertical) load. The D-rating in ECE 55 is given by

$$D = \frac{0.6\ T.R}{T+R-U} \qquad (12)$$

Where T = max mass of prime mover including the load on the fifth wheel

R = max mass of semi-trailer

U = static (vertical) fifth wheel load

Perusal of Table V indicates that, with the exception of minor under-representation for the lightest (and least common) vehicles, the ECE 55 D-rating agrees quite well with the research-based formula. It is proposed, in the interests of international harmonisation, to adopt the ECE 55 formula as given in eqn 12 for the case of the articulated vehicle.

3.3.2. Road Trains

Combining the maximum steady-state and dynamic components (eqns 2, 3 and 8) yields

$$E_o = \frac{M_1(0.4d+0.21M_2)+0.4d(M_2-M_o)}{M_1+M_2} + 1.99 \qquad \text{(double) (13)}$$

$$E_1 = \frac{M_2(0.4d+0.5M_1)}{M_1+M_2} \qquad \text{(double) (14)}$$

$$E_o = \frac{0.50\ M_1M_2M_3}{M_2(M_1+M_3)+2M_1M_3} + \frac{0.4d(M_1-M_0-M_2+M_3)}{M_1+M_2+M_3} + 2.80 \qquad \text{(triple) (15)}$$

$$E_1 = \frac{1.2M_1M_2M_3}{M_2(M_1+M_3)+2M_1M_3} + \frac{(0.4d+0.81)(M_2+M_3)}{M_1+M_2+M_3} \qquad \text{(triple) (16)}$$

Where E_o = max longitudinal fifth wheel force (on prime mover)

E_1 = max longitudinal fifth wheel force (on dolly)

In order to study eqns 13 - 16 with a view to a simplified calculation procedure, it is necessary to evaluate a range of typical road trains. Table VI shows such a range, with legal maximum axle loads. Other data for the articulated vehicle are as in Table V. Note that longitudinal strength values for fifth wheels on dollies need to be higher than those on prime movers.

In order to simplify calculations and to cast the formulae in the ECE 55 style, a relationship of the form

$$D_o = \frac{K\ (T+k_2R)R}{T+R-U} \qquad (17)$$

TABLE V

TYPICAL FIFTH WHEEL STRENGTH VALUES FOR ARTICULATED VEHICLES

Vehicle					eqn (11)				eqn (12)
			M_o (t)	M_1 (t)	E_o (t)	T (t)	R (t)	U (t)	D (t)
0 5.4	0 8.5	0 8.5	8.0 (4/4)	22.4	5.79	13.9	14.4	5.9	5.36
0 5.4	0 8.5	00 16.5	8.0 (4/4)	30.4	6.63	13.9	22.4	5.9	6.15
0 5.4	00 16.5	00 16.5	9.5 (4.5/5)	38.4	9.97	21.9	28.9	12.4	9.89
0 5.4	00 16.5	000 20	9.5 (4.5/5)	41.9	10.24	21.9	32.4	12.4	10.16
0 6.5	00 16.5	000 21	10.5 (5.5/5)	44.0	10.62	23.0	33.5	12.5	10.51

was examined for fifth wheels on prime movers and a relationship of the form

$$D_1 = \frac{k_2(R + k_4 T)T}{T + R - U} \qquad (18)$$

was tried for fifth wheels on dollies. It was found that reasonable agreement between E_o and D_o was obtained with $k_1 = 0.5$ and $k_2 = 0.08$; similarly, seasonable agreement between E_1 and D_1 was obtained with $k_3 = 0.5$ and $k_4 = 0.08$. Thus the D-rating formulae proposed are

$$D_1 = \frac{0.05(T + 0.08R)R}{T + R - U} \qquad \text{(prime mover)} (19)$$

$$\text{and } D_1 = \frac{0.05(R + 0.08T)T}{T + R - U} \qquad \text{(dolly)} (20)$$

Where U = static (vertical) fifth wheel load

T = sum of prime mover axle loads (for fifth wheel on prime mover)

T = max mass of towing articulated vehicle plus dolly tare weight (for fifth wheel on dolly)

R = total mass towed by fifth wheel

Typical values of D_o and D_1 obtained with eqns 19 and 20 are given in Table VI and V constitute a good, slightly conservative, representation of E_o and E_1 respectively, as illustrated in Fig 6.

3.4 OTHER RATINGS

3.4.1 Vertical Loadings

Dynamic vertical loadings on the fifth wheel were extracted from the data of Table II, expressed as ½ (max - min) once again and averaged for each vehicle configuration on unsealed roads. Results are as follows:

Vehicle	Vertical Dynamic Component		Vertical Mean Value	
	(kN)	(t)	(kN)	(t)
Semi	146	14.9	115	11.7
Double	131	13.4	112	11.4
Triple (Download)	148	15.1	110	11.2
Triple	137	14.0	117	11.9

As would be expected, these vertical loadings indicate no systematic vehicle configuration effect. For an average quasi-static vertical fifth wheel load of 11.55t, the average dynamic component is 14.28t, or 1.24 times the static load.

It is therefore proposed that a V-rating for vertical loading be introduced with

$$V = 1.25\,U \qquad (21)$$

3.4.2 Lateral Loadings

Dynamic lateral loadings in the form of lateral force and overturning moment were extracted from the data of Table III, expressed as ½(max - min) and averaged for each vehicle configuration on unsealed roads.

TABLE VI

TYPICAL FIFTH WHEEL STRENGTH VALUES FOR ROAD TRAINS

Vehicle							E_0 (t)	E_1 (t)	D_0 (t)	D_1 (t)
0 5.4	00 16.5	00 16.5	00 16.5	00 16.5			11.44	11.92	11.64	12.06
0 5.4	00 16.5	000 20	00 16.5	000 20			11.87	12.83	12.05	12.63
0 5.4	00 16.5	00 16.5	00 16.5	00 16.5	00 16.5	00 16.5	13.07	14.95	13.40	15.11
0 5.4	00 16.5	000 20	00 16.5	000 20	00 16.5	000 20	13.57	16.02	13.91	16.29
0 6.5	00 16.5	000 21	00 16.5	000 21	00 16.5	000 21	13.68	16.35	14.45	16.89

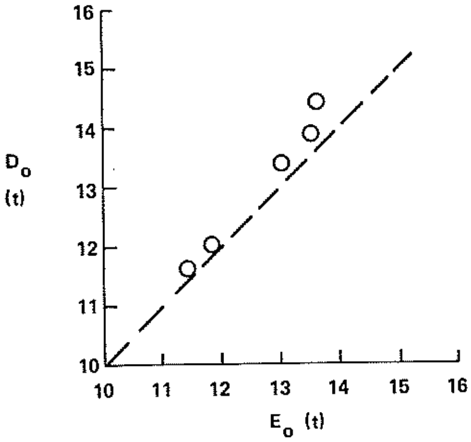


Fig. 6(a)

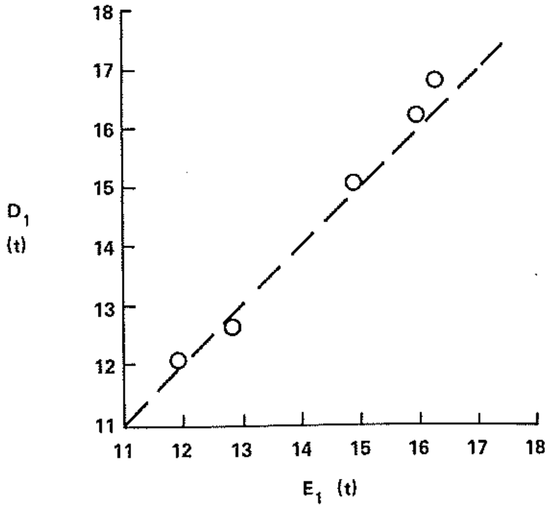


Fig. 6 (b)

Fig. 6 — Road train fifth wheel D-rating versus maximum longitudinal fifth wheel force for:
(a) fifth wheel on prime mover (E_0), and
(b) fifth wheel on converter dolly (E_1)

Results are as follows:

Vehicle	Lateral Dynamic Component (kN)	(t)	Overturning Dynamic Component (kN m)
Semi	39.3	4.01	48.5
Double	33.3	3.39	46.7
Triple(download)	32.4	3.29	46.2
Triple	34.0	3.47	47.9

Once again, the results do not appear to be vehicle-specific, but the lateral and overturning components could be related (see Section 2.5). It is proposed to define an M-rating of the form

$$M = 5\,U \qquad (22)$$

Note that it is proposed to introduce engineering units here, with M in kN m, while U remains in conventional units of t. (Note further that the data indicates a rating of the form $M = 4.15\,U$, and this was multiplied by the ratio $^{2.6}/_{2.2}$ to allow for the highest likely centre-of-gravity location (2.6 m) as compared to that of the test vehicle - estimated to be 2.2 m).

The lateral dynamic component is relatively large (from 50% to 70% of the longitudinal dynamic component, depending on the vehicle configuration). For an average quasi-static vertical fifth wheel load of 11.55t, the average lateral dynamic component is 3.54t, or 0.31 times the vertical load. It is therefore proposed to define an L-rating of the form

$$L = 0.3\,U \qquad (23)$$

Note that, because the tare weight of a dolly is somewhat less than a prime mover, the fifth wheel vertical load U is potentially higher on the dolly, and so highest lateral loadings would occur on fifth wheels mounted on dollies.

4. COMPONENT RATING TESTS

4.1 LONGITUDINAL AND VERTICAL TEST

In Annex 4, Section 3.2.2. of ECE 55 a dynamic fifth wheel test is specified. It involves the application of alternating longitudinal (± 0.6 D) and vertical (U ± 0.2U) forces, whether simultaneously or separately.

While the longitudinal test is consistent with the results of the present study, the vertical test is considered inadequate. This should relate to the V-rating, with an alternating application of ± 0.6V about the datum value U. This amounts to a test of U ± 0.75U, considerably more demanding than the ECE 55 test. Nevertheless, it is believed that the more severe test of U ± 0.75 U is needed for Australian conditions.

The results of the present study have no particular significance as to whether these forces are applied simultaneously or separately, or at any particular frequency.

4.2 LATERAL TEST

ECE 55 has no provisions for the application of lateral forces or overturning moment. There does appear to have been some discussion of the need for a static overturning moment test in ISO (Document ISO/TC 22/SC 15/WG 4 N 53 Rev.2), but this was not introduced.

It is believed that a lateral dynamic test is needed for Australian conditions and should be based on the alternating application of a lateral force of ± 0.6L and an overturning moment of ± 0.6M. This amounts to a lateral force of ± 0.18U and a moment of ± 3U. The moment test could be combined with either the lateral or vertical test. The results of the present study do indicate some justification for combining the moment and lateral tests.

5. EFFECT OF VEHICLE MASS INCREASES

The effects of various axle load increases on D-, V-, L- and M-ratings are illustrated in Table VII(a) for articulated vehicles and Table VII(b) for road trains. These ratings are indicative only, as prime mover and trailer tare weights and fifth wheel longitudinal locations would be expected to vary with mass limit increases of the magnitude considered in Table VII. It is assumed that road train prime movers would tend to have a higher tare weight than those used in general articulated vehicles. Hence the 41.9t GCM vehicle #4 in Table VII(a) assumes a fifth wheel load U = 12.4t, while the baseline vehicle #8 in Table VII(b) assumes a fifth wheel load (on the prime mover) of U = 11.5t. These effects are illustrated in Fig. 7.

It is believed that some D-rated fifth wheels are available currently in Australia, with the most typical rating around 15 t with heavier duty units rated at 17.4 t. Clearly, mass increases should not present a problem with rated fifth wheels on articulated vehicles because, even at 51 t gross mass, a D-rating of 13 t is adequate. However, mass increases could create problems with triple road trains, where D-ratings up to 20 t would be required.

As no fifth wheels are adequately V-rated, and L- and M-ratings have not previously been considered, there are potential problems in those areas with any mass increases.

6. KINGPINS, TURNTABLES AND SKID PLATES

All components associated with the fifth wheel are subject to loadings similar to the fifth wheel and therefore similar vehicle application formulae and component rating tests should apply, although not all tests in each case. The following scheme for including these components is suggested:

Component	Vehicle Application Formulae	Component Rating Tests
Fifth Wheel	D, V, L, M	±0.6D, U±0.6V, ±0.6L, ±0.6M
Kingpin	D	±0.6D
Turntable	D, V, M	±0.6D, U±0.6V, ±0.6M
Skid Plate	D,V, M	± 0.6D, U±0.6V, ±0.6M

7. CONCLUSIONS

1. Test results indicate that fifth wheel dynamic vertical forces are high and that dynamic longitudinal and lateral forces and the overturning moment acting on fifth wheels are substantial.
2. Fifth wheels and associated components should be subject to dynamic tests and rated for their longitudinal, vertical and lateral capacities.
3. Vehicle application formulae should be used in selecting fifth wheels and associated components for use in articulated vehicles and road trains.
4. Test results align with ECE requirements for longitudinal forces, but show that such

TABLE VII(a)

FIFTH WHEEL RATINGS WITH VEHICLE MASS INCREASES
(ARTICULATED VEHICLES)

Vehicle/Axle Loads (t)			U (t)	GCM (t)	D (t)	V (t)	L (t)	M (kN m)
1								
0	0	0						
5.4	8.5	8.5	5.9	22.4	5.4	7.4	1.8	30
6.5	10	10	7.4	26.5	6.5	9.3	2.2	37
2								
0	0	00						
5.4	8.5	15	5.9	28.9	6.0	7.4	1.8	30
5.4	8.5	16.5	5.9	30.4	6.1	7.4	1.8	30
6.5	10	18	7.5	34.5	7.3	9.4	2.3	38
7.0	11	20	9.0	38.0	8.2	11.3	2.7	45
3								
0	00	00						
5.4	15	15	10.9	35.4	9.0	13.6	3.3	55
5.4	16.5	16.5	12.4	38.4	9.9	15.5	3.7	62
6.5	18	18	14.0	42.5	11.1	17.5	4.2	70
7.0	20	20	16.5	47.0	12.6	20.6	5.0	83
4								
0	00	000						
5.4	15	18	10.9	38.4	9.2	13.6	3.3	55
5.4	16.5	20	12.4	41.9	10.2	15.5	3.7	62
6.5	18	22	14.0	46.5	11.4	17.5	4.2	70
7.0	20	24	16.5	51.0	12.9	10.6	5.0	83

existing requirements for vertical forces are inadequate. (ECE requirements relate to articulated vehicles, but not to Australian road trains).

5. Provided that appropriate vehicle application formulae and component tests are introduced, increases in legal load limits should not create problems for these components of articulated vehicles (general transport vehicles) but would create problems with road trains (large combination vehicles).

8. RECOMMENDATIONS

1. Vehicle application formulae as given in eqns 12,19,20,21,22 and 23 should be used to establish the required fifth wheel (and associated component) strength ratings for particular vehicle configurations.

2. Fifth wheels and associated components should be tested and rated according to the tabulation in Section 6 of this report.

3. The implications of increased strength ratings needed on fifth wheels (and associated components), and the lack of such ratings, should be considered by the National Association of Australian State Road Authorities Road Vehicle Limits Group when considering truck size and weight issues.

4. Further research is needed to study fifth wheel requirements in the emerging class of vehicle known as Medium Combination Vehicles, an example of which is the B-double.

TABLE VII(b)

FIFTH WHEEL RATINGS WITH VEHICLE MASS INCREASES (ROAD TRAINS)

Vehicle/Axle Loads (t)								Fifth Wheel on GCM				
								(t)	D (t)	V (t)	L (t)	M (kN m)
5												
	0	00	00	00	00							
	5.4	16.5	16.5	16.5	16.5			71.4	11.2	14.4	3.5	58
	6.5	18	18	18	18			78.5	12.7	16.3	3.9	65
	7.0	20	20	20	20			87.0	14.2	18.8	4.5	75
6												
	0	00	000	00	000							
	5.4	16.5	20	16.5	20			78.4	12.4	14.4	3.5	58
	6.5	18	22	18	22			86.5	13.2	16.3	3.9	65
	7.0	20	24	20	24			95.0	14.7	18.8	4.5	75
7												
	0	00	00	00	00	00	00					
	5.4	16.5	16.5	16.5	16.5	16.5	16.5	104.4	13.3	14.4	3.5	58
	6.5	18	18	18	18	18	18	114.5	14.7	16.3	3.9	65
	7.0	20	20	20	20	20	20	127.0	16.4	18.8	4.5	75
8												
	0	00	000	00	000	00	000					
	5.4	16.5	20	16.5	20	16.5	20	114.9	13.6	14.4	3.5	58
	6.5	18	22	18	22	18	22	126.5	15.3	16.3	3.9	65
	7.0	20	24	20	24	20	24	139.0	17.0	18.8	4.5	75

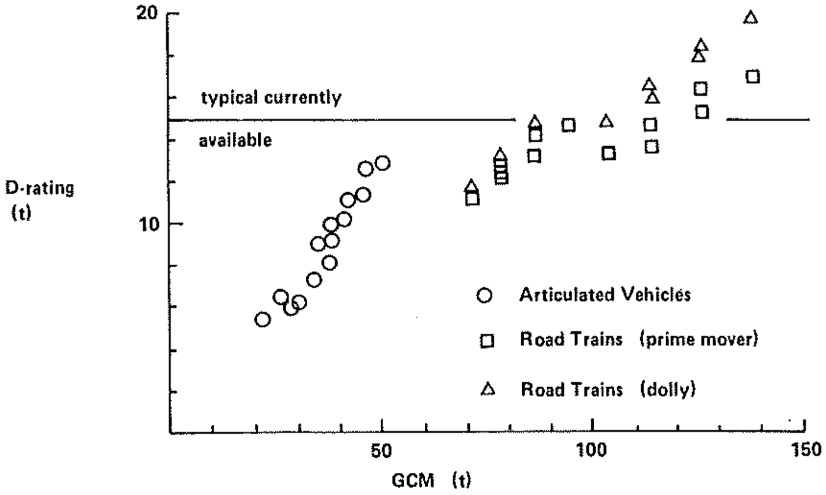


Fig. 7 — Fifth wheel D-rating versus vehicle GCM for articulated vehicles and road trains

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AUSTRALIAN ROAD RESEARCH BOARD

REPORT SUMMARY

THE PURPOSE OF THIS REPORT

To document test results, findings and the development of fifth wheel strength ratings, and to present consequent proposals to SAA Committee ME/53.

THIS REPORT SHOULD INTEREST

Directors, NAASRA RVLG, SAA ME/53, transport equipment manufacturers and suppliers.

THE MAJOR CONCLUSIONS OF THE REPORT ARE

- Test results indicate that fifth wheel dynamic vertical forces are high and that dynamic longitudinal and lateral forces and the overturning moment acting on fifth wheels are substantial.
- Fifth wheels and associated components should be subject to dynamic tests and rated for their longitudinal, vertical and lateral capacities.
- Vehicle application formulae should be used in selecting fifth wheels and associated components for use in articulated vehicles and road trains.
- Test results align with current ECE requirements for longitudinal forces but show that such existing requirements for vertical forces are inadequate. (ECE requirements relate to articulated vehicles, but not to Australian road trains).

AS A CONSEQUENCE OF THE WORK REPORTED, THE FOLLOWING ACTION IS RECOMMENDED

- Vehicle application formulae as given in eqns 12, 19, 20, 21, 22 and 23 should be used to establish the required fifth wheel (and associated component) strength ratings for particular vehicle configurations.
- Fifth wheels and associated components should be tested and rated according to the tabulation in Section 6 of this report.

RELATED ARRB RESEARCH

P437 – Load transfers in multi-axle platforms with gooseneck connections.

CUT OUT INFORMATION RETRIEVAL CARD

SWEATMAN, P.F. (1987) : STRENGTH REQUIREMENTS FOR FIFTH WHEEL COUPLINGS IN ROAD TRAINS AND GENERAL ARTICULATED VEHICLES. Australian Road Research Board. Research Report ARR 149. 15 pages including 7 figures and 7 tables.

KEYWORDS : Articulated vehicle/dynamics/trailer/coupling/strength rating*/road train/ evaluation (assessment)/specification (standard)

ABSTRACT : Following the recommendations of the NAASRA study of the operation of road trains, research was carried out to develop fifth wheel strength ratings to be incorporated in the relevant Australian Standards (AS 1771-1773). The longitudinal, lateral and vertical forces, plus the overturning moment, acting on an instrumented fifth wheel coupling were recorded during typical operation of a triple road train, a double road train and an articulated vehicle on both sealed and unsealed roads in South Australia and the Northern Territory. Data were analysed to determine maximum dynamic and steady state loadings in each axis, to develop generalised formulae to calculate such loadings for each vehicle configuration, and to recommend fifth wheel, kingpin, turntable and skid plate test procedures. It is recommended that dynamic multi-axis test procedures are needed to certify fifth wheels for Australian conditions and that fifth wheel selection be based on a group rating formulae based on a D-rating concept.

*Non IRRD Keywords