RECENT RESEARCH RELATING TO TRUCK SIZE AND WEIGHT LIMITS IN AUSTRALIA

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1. INTRODUCTION

The first IRTE Heavy Vehicle Design Seminar coincided with the completion of the most comprehensive review of Australia's truck size and weight limits for over 10 years. This was of course the National Association of Australian State Road Authorities' Review of Road Vehicle Limits (RORVL - NAASRA 1985). Some of the results of RORVL were discussed at that IRTE seminar, in October 1985. Since that time, research into heavy vehicle issues has continued in Australia, implementation of the RORVL recommendations has been an important issue and the specific issue of suspension design was addressed by a joint Australian Road Research Board/Federal Office of Road Safety Symposium on Truck Suspensions. A great deal of attention has been devoted to the question of cost recovery related to increased truck weight limits. Priority truck design safety issues at the national level have been (and continue to be) truck braking and a review of the design and operational principles of road train use.

This paper aims to provide Seminar participants with a research perspective of these recent developments and latest research findings. The Australian Road Research Board has continued to be active in the fields of suspension and tyre effects on road wear and vehicle stability and has commenced studies of B-double dynamic stability, truck ride comfort (related to the development of a high speed road profilometer), multi-axle load platforms and truck driver braking behaviour. Selected reseach developments are described in this paper.

2. TRUCK WEIGHT LIMITS

RORVL carried out benefit-to-cost analyses for various scenarios of increased truck weight limits, commonly known as Options A to D (see Table I). These options were all considered technically and economically viable and their adoption depended on the financial constraints of road authority budgets and the application of a user-pays principle for increased road wear. The demand for increased productivity in the road transport industry resulted in strong industry involvement in consideration of mechanisms for cost-recovery related to higher road and bridge costs under higher axle load limits.

There are two steps in this process. At a technical level, it is necessary to evaluate pavement, bridge and safety characteristics of truck configurations; at an operational level it is necessary to consider payload characteristics and various economies of scale related to increased limits.

Since the time of the NAASRA Economics of Road Vehicle Limits (ERVL) Study (Fry et al 1975), the 6-axle articulated vehicle has proliferated in Australia and is believed to have acceptable safety characteristics and superior "road efficiency" (ie. tonnes of payload carried per unit road wear generated). Road efficiency for various vehicle configurations is illustrated in Fig. 1. Note that road wear is expressed in Equivalent Standard Axles (ESA's), calculated as follows:

$$\text{ESA's} = \left(\frac{L}{E}\right)^4 \qquad (1)$$

where L = axle group load (t)
E = axle group equivalency (t)

and accepted values of E for Australian practice are:

E =	5.4 t	(single axle/single tyres)
	8.2 t	(single axle/dual tyres)
	13.6 t	(tandem axle/dual tyres)
	18.5 t	(triaxle/dual tyres)
	17.0 t	(triaxle/wide single tyres)

Fig. 1 illustrates the generally superior road efficiency of the 6-axle articulated vehicle and the 8-axle B-double. RORVL therefore concentrated on operational and economic analyses of weight limit scenarios for a truck fleet already dominated by the 6-axle vehicle and actively considered the permit operation of B-doubles.

Since 1985, RORVL Option A weight limits have been introduced by various means in the Australian Eastern States (Western States were already at or above these limits). Some States have introduced concurrent cost recovery measures such as annual permit fees or additional registration charges or other restrictions. Progress with the introduction of B-doubles (at up to 55 t Gross Combination Mass and 23 m in length) on specified routes under permit has been slow in the Eastern States and negotiations are continuing.

One interesting aspect of weight limits for the 6-axle articulated vehicle is that historical constraints can make for sub-optimal distribution of the gross weight between the axle groups. This is illustrated in Fig. 2 where we see that, while the RORVL A (41.5t) distribution of 15 t tandem/20 t triaxle is near-optimal, the RORVL C (42.5t) distribution of 16.5t tandem/20 t triaxle is far from optimal, with 14.5t/22t giving a considerably higher road efficiency. This illustrates the general principle that the ratio of the triaxle to the tandem load limits should be increased for greatest efficiency in Australia. Correction of this is constrained by the already-high tandem limit of 16.5t in some Australian States.

3. SUSPENSION DESIGN

The Australian Road Research Board, in conjunction with the Australian Federal Department of Transport, held a symposium on truck suspension characteristics affecting road loading and safety in Canberra in March 1987. Some 120 delegates represented researchers, vehicle and suspension manufacturers from 5 countries, and Australian vehicle regulators and road transport industry. The overall conclusions of the symposium may be simply stated as:

(i) dynamic suspension-related effects on pavement wear are very significant (at least as important as overloading), are becoming better understood through the efforts of researchers in many countries, and current knowledge is not yet sufficiently focussed to regulate these effects.

(ii) truck stability is a key safety implication and almost enough is known to develop standards for stability.

A working group has been proposed under the Australian Transport Advisory Committee (ATAC) structure to advise on:

* a straightforward test procedure to classify the on-road performance of suspensions.

* a means of implementing an industry performance standard (options include design standards, guidelines to good practice, positive incentives such as axle load and permit concessions, variable charges to cost recover relative road wear and development of a classification of suspensions according to their potential to cause road wear).

Also, having regard to the considerable research effort underway in various countries (Cebon 1985, Mitchell 1987, Woodrooffe and LeBlanc 1987), it was recommended that the OECD Road Transport Research Program be asked to:

* encourage further liaison between researchers on dynamic pavement loads and their effects on pavement damage.

* assist in making results transferable and reproduceable, by use of common measurement schemes and presentation formats.

* co-ordinate an international research program on dynamic pavement loads and their effects on road damage, with a view to developing a widely accepted performance standard.

4. RECENT RESEARCH

4.1 Suspensions and Tyres

Following early measurements of dynamic road loading related to suspension type, speed and road roughness (Sweatman 1983), ARRB has been working with major suspension manufacturers to assess the effects of design changes related to spring rates, friction-levels and the use of hydraulic dampers. Good progress is being made, although the results are not yet able to be published.

Attention has also turned to measurement of pavement responses under moving vehicles and the measurement of longitudinal road profiles which both generate and reflect the effects of dynamic loading through the vehicle suspension/tyre system.

Conventional determination (at creep speed) of the relative pavement wear effects of wide single and dual tyre arrangements (Sharp et al 1986) had confirmed the additional wear associated with wide singles. Further analysis of highway-speed data showed that, although the absolute pavement deflections decrease with increasing speed, the wide single effects increase relative to the duals. This is illustrated in Fig. 3 and is thought to be related to increased bouncing on the (more compliant) wide single tyres. This points to the need to tune suspensions for wide single tyre use. Further investigations of a large body of test data is being carried out.

The newly-developed ARRB high-speed profilometer (Prem 1987) is producing interesting wavelength characteristics as Australian flexible roads wear and become "rougher". The example shown in Fig. 4 shows the development of a definite 2.5m wave which happens to coincide with the wheel hop and bogie pitch frequencies of trucks at highway speeds. As one of many uses of the profilometer, road sections are begin periodically monitored to trace the development of such deformations.

4.2 Stability

The ARRB program of articulated vehicle stability research has progressed from the steady state tilt test results previously reported (Mai and Sweatman 1984) to full-scale dynamic tests (Tso 1987). These dynamic tests have confirmed the validity of the tilt test for steady-state manoeuvres when the following predictable effects are allowed for:

(i) suspension static friction

(ii) lateral tyre restraint on the tilt deck and,

(iii) changing normal load on the tilt deck.

These three effects cause a small and predictable over-estimate of steady-state stability using the tilt deck.

Extensive tilt testing of a range of vehicles and suspension types has now been carried out and Fig. 5 provides a transport operator User's Guide to the level of stability provided by 90 combinations of prime mover and trailer suspensions. If one neglects the older-style torsion bar prime mover suspension, choice of trailer suspension is currently the more powerful determinant of stability. However, the prime mover suspension holds more scope for future improvements in design for stability.

Full-scale dynamic testing for transient situations (such as lane-changing) has not revealed any major factors degrading stability when compared to the steady-state condition. In fact, higher lateral accelerations have been achieved in transient manoeuvres than in the steady state condition for the same vehicle. This occurs because the lateral acceleration pulse is at a maximum at only one point along the length of the vehicle at any given instant, while it is reacted by the whole vehicle. Further testing and analysis is being carried out to determine whether there are potentially adverse transient situations and to better assess the driver's perception of such events. Current indications are that the latter is dangerously inadequate.

Dynamic testing of a B-double combination confirmed the stability benefits of roll coupling between the units and of increased length which further amortises the effects of a lateral acceleration pulse.

4.3 Ride Comfort

While various ride meters and standards have been developed, none have been proven for the complex situation of the articulated vehicle. The most promising approach appeared to be the US National Aeronautical and Space Agency (NASA) ride index developed for aircraft because it combined multi-axis excitation into a single index, had been correlated with subjective ratings obtained in laboratory tests and details had been published (Wood and Leatherwood 1985).

Data is currently being collected in the cab of a 6-axle articulated vehicle under various load, speed, road roughness and suspension conditions. Analysis is proceeding for suspension manufacturers.

Further development of the technique is expected.

4.4 Multi-axle Load Platforms

Australian practice favours the gooseneck style of load platform over the drawbar type because the gooseneck allows higher operating speeds to be sustained safely. This causes difficulties with load transfers between the trailer axles and goosenecks. Some of the load platform styles tested by ARRB are illustrated in Fig. 6. Current indications are that the "two-rows-plus-gooseneck" style minimises dynamic load on the gooseneck and hence the prime mover axles.

5. CONCLUSIONS

1. Increased interest in truck size and weight limits and cost-recovery in Australia is causing a demand for research into pavement wear and deterioration. ARRB is providing tools, such as the high speed profilometer, to respond to this demand.

2. Truck research at ARRB is providing techniques for objective evaluation of the road wear, stability and ride quality characteristics of a wide range of articulated, combination and specialised vehicles.

3. Truck-related research is beginning to become transferable internationally and this is enhanced by increasing industry involvement in research programs.

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DESCRIPTION	**ALLOWABLE AXLE LOAD [a](tonnes)**			
	Option A	Option B	Option C	Option D
Single Axle Single Tyres (b)	6.0	6.0	6.0	6.5
Twin Steer	10.0	10.0	10.0	11.0
Single Axle Dual Tyres	9.0	9.0	9.0	10.0
Tandem Axle 6 Tyres	12.0	13.0	13.0	13.0
Tandem Axle Dual Tyres	15.0(c)	16.0(c)	16.5	16.5
Triaxle	20.0	20.0	20.0	21.0
Gross Combination Mass	41.0	42.0	42.5	44.0

Notes:
(a) Legal Limit, excluding tolerance
(b) 6.6 tonnes in S.A. for each Option
(c) Eastern States only

TABLE I. WEIGHT LIMIT OPTIONS CONSIDERED IN THE RORVL STUDY

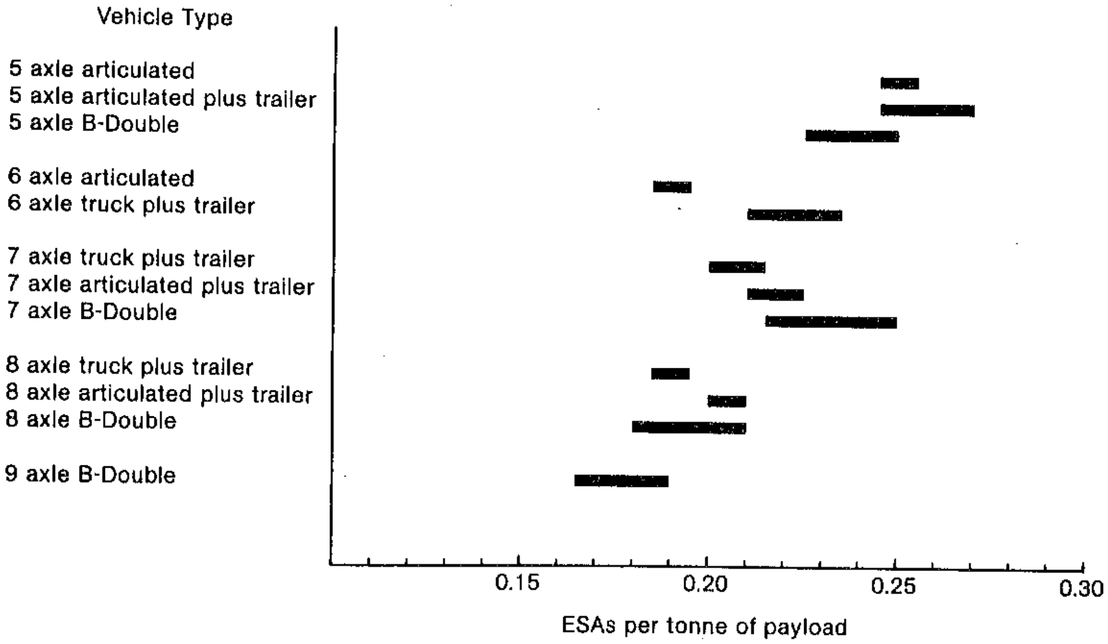

FIG. 1 RATIO OF ROAD WEAR (EXPRESSED IN EQUIVALENT STANDARD AXLES) TO PAYLOAD (t) FOR VARIOUS TRUCK CONFIGURATIONS (SOURCE: NAASRA 1985)

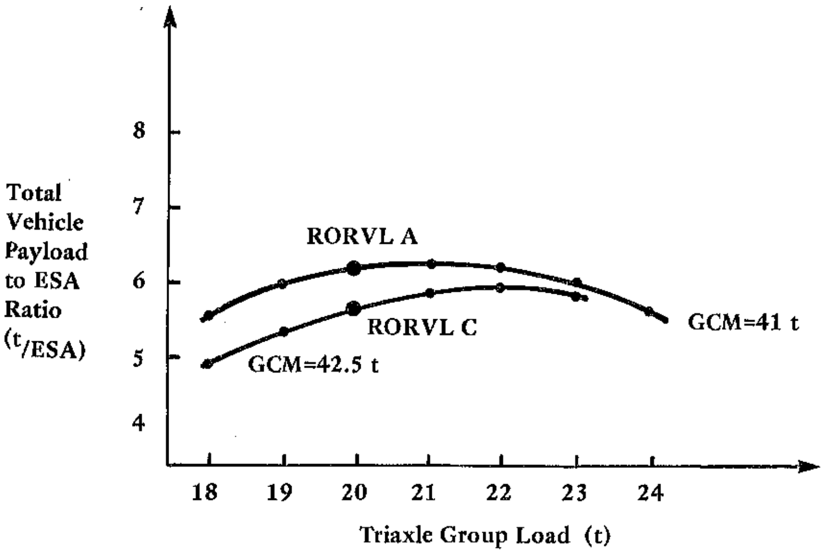

FIG. 2 RATIO OF PAYLOAD TO ESA's FOR 6-AXLE ARTICULATED VEHICLE AS THE GROSS WEIGHT IS RE-DISTRIBUTED BETWEEN THE TANDEM AND TRIAXLE GROUPS.

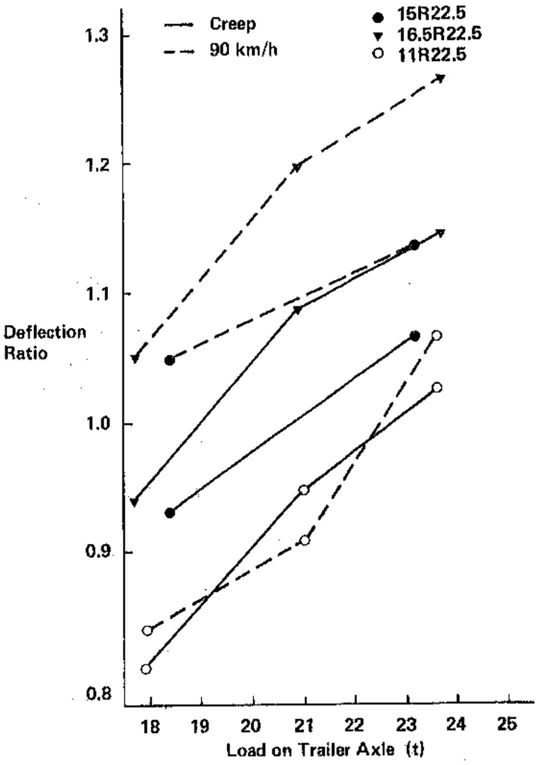

FIG. 3 NORMALISED PAVEMENT DEFLECTIONS AS DEPENDENT ON VEHICLE SPEED, TYRE TYPE AND AXLE LOAD.

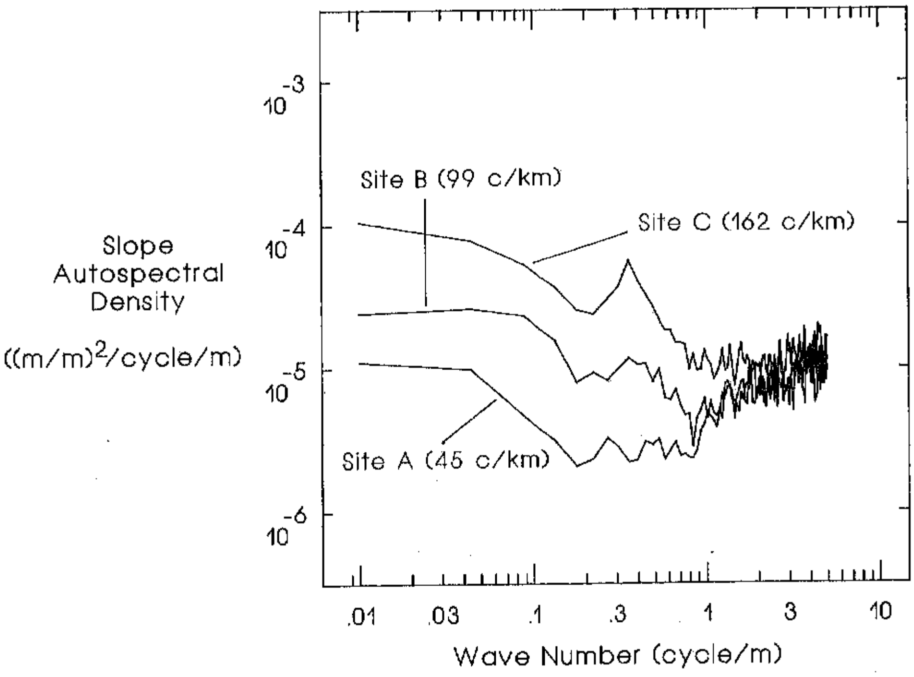

FIG. 4 LONGITUDINAL PROFILE SLOPE POWER SPECTRA FOR AUSTRALIAN ROADS DETERMINED USING THE ARRB PROFILOMETER (SOURCE; PREM 1987).

PRIME MOVER SUSPENSION / SEMI-TRAILER SUSPENSION	IH (Four Spring)	M A C K (Single point 'Camel back')	TBB (Torsion Bar)	TBB 115 (Torsion Bar)	SCANIA (Four Spring)	HENDRICKSON (RT380 Walking Beam)	REYCO (Four Spring)	VOLVO T-RIDE (Single Point)	MERCEDES (Single Point)	A V E R A G E (g)
BPW-VA3 (WIDE)	A .417	C .379	.342	C .375	B .388	B .402	A .426	B .404	C .386	.391
BPW-VA3 (NORMAL)	C .385	.355	.309	.352	.362	C .374	B .391	.368	.352	.361
FREIGHTER (WIDE)	A .419	B .392	.347	B .396	B .406	A .407	A .413	B .405	C .386	.397
FREIGHTER (NORMAL)	C .383	.356	.309	C .369	C .373	C .373	C .370	.367	.346	.361
HALCO AIR	B .394	C .370	.318	C .377	C .385	C .384	C .380	C .385	.367	.373
YORK	C .382	.360	.318	.363	C .370	C .374	C .376	.368	.352	.363
SINCLAIR (WIDE)	A .419	B .389	.341	C .385	B .401	B .404	A .416	B .402	C .385	.394
REYCO (WIDE)	A .421	B .388	.344	C .386	B .399	A .408	A .427	B .405	B .388	.396
BPW (AIR)	C .378	.349	.301	.344	C .360	.363	.375	.360	.346	.353
GOTH (WIDE)	A .422	B .391	.345	B .388	B .404	A .407	A .420	B .405	B .389	.397
AVERAGE	.402	.373	.327	.374	.385	.390	.399	.387	.370	

FIG. 5 USERS' GUIDE TO STABILITY (LATERAL ACCELERATION AT WHEEL LIFT EXPRESSED IN g) RELATED TO SUSPENSION TYPES IN 6-AXLE ARTICULATED VEHICLES.

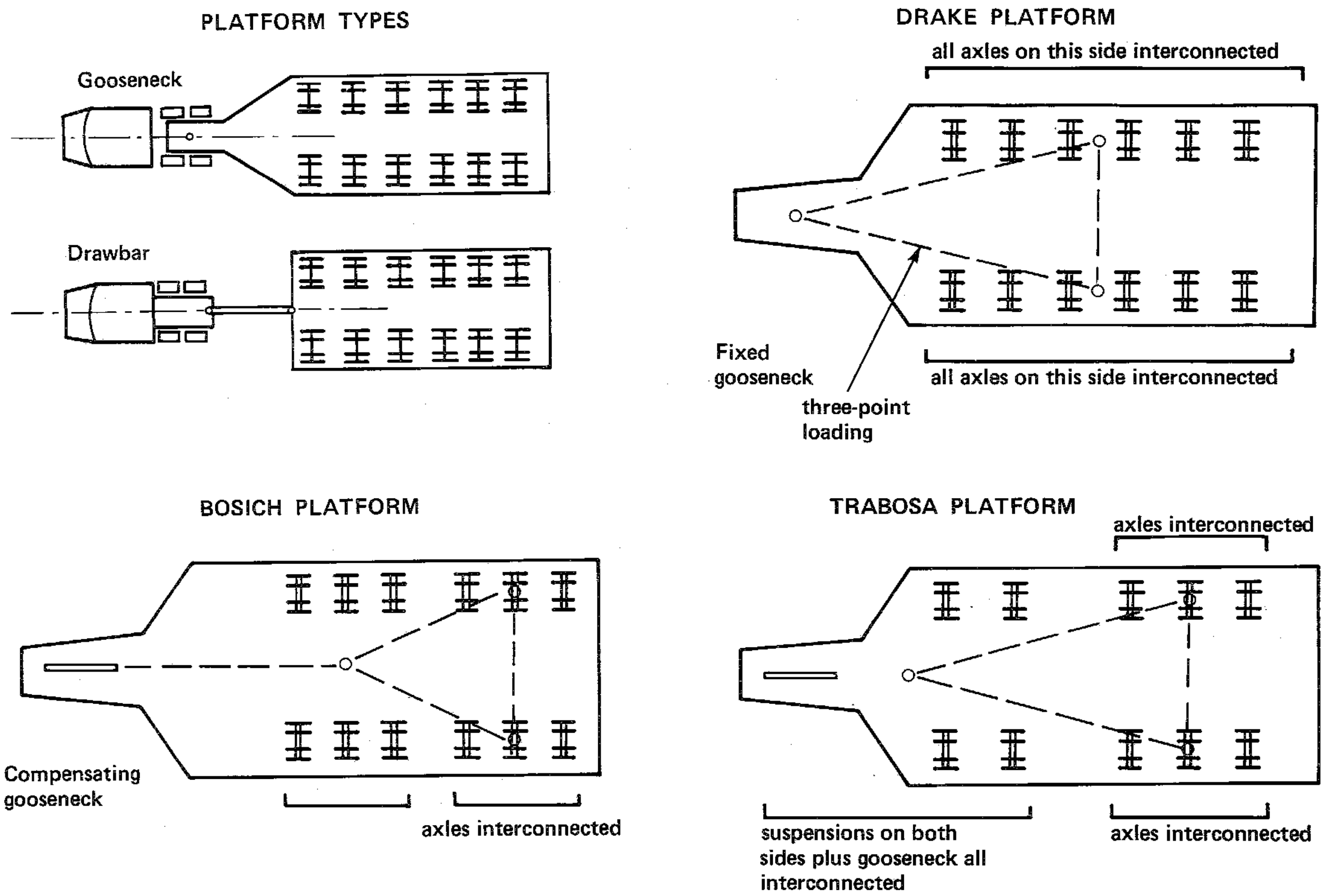

FIG. 6 ILLUSTRATION OF HYDRAULIC INTERCONNECTION AND SUPPORT PRINCIPLES OF GOOSENECK LOAD PLATFORMS.