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STRENGTH REQUIREMENTS FOR TOW COUPLINGS IN ROAD TRAINS

by

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Feasibility Study 1083 Hitch Forces in Road Trains

AUSTRALIAN ROAD RESEARCH BOARD
INTERNAL REPORT

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REPORT SUMMARY

THE PURPOSE OF THIS REPORT

is to propose a strength rating scheme for the couplings used in Australian road trains. The proposed scheme is based on an ad hoc study with specific short-term objectives. The method of calculating the dynamic coupling force component is speculative and may invite comment.

THIS REPORT SHOULD INTEREST

Directors, NAASRA Large Combination Vehicle Working Party, SAA Committee AU/3, Road Users TC, those involved in operation, regulation and equipment supply in the road train industry.

THE MAJOR CONCLUSIONS OF THE REPORT ARE

1. Peak tow coupling forces are caused by dynamic events related to high frequency motions between the road train units and are not directly attributable to the tractive effort of the prime mover.
2. The scheme used for strength rating of road train couplings in Australia should include both dynamic and steady-state factors. A new scheme of this type is proposed.
3. The 40 mm DIN Standard towing eye is undesirable for general road train use and is desirable only for doubles operation up to a Gross Combination Mass of 40 t.

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

Following review of the report by NAASRA, SAA Committee AU/3 should consider the proposed strength rating scheme with a view to its inclusion in Australian Standard 2213.

RELATED ARRB RESEARCH

A830 Assistance to NAASRA Road Train Working Party

CUT OUT INFORMATION RETRIEVAL CARD...........

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ABSTRACT : The National Association of Australian State Road Authorities (NAASRA) has developed regulations for the operation of road trains. Standards for tow coupling strength were based on the DIN D-rating which was intended for two-unit vehicles. An experimentally-based study was carried out to develop a rating scheme for multi-unit vehicles operating under Australian conditions. Coupling forces were measured in an instrumented road train between Port Augusta, South Australia and Alice Springs, Northern Territory. These results were used to develop a strength rating formula based on the units and taking into account both steady-state and dynamic towing forces. A new rating scheme, the E-rating, is proposed. Particular attention was paid to the 40 mm DIN Standard towing eye and it is concluded that it is suitable only for doubles operation up to a Gross Combination Mass of 40 t.

*Non IRRD Keywords

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ABSTRACT

The National Association of Australian State Road Authorities (NAASRA) had developed regulations for the operation of road trains. Standards for tow coupling strength were based on the DIN D-rating which was intended for two-unit vehicles. An experimentally-based study was carried out to develop a rating scheme for multi-unit vehicles operating under Australian conditions. Coupling forces were measured in an instrumented road train between Port Augusta, South Australia and Alice Springs, Northern Territory. These results were used to develop a strength rating formula based on the masses of the units and taking into account both steady-state and dynamic towing forces. A new rating scheme, the E-rating, is proposed. Particular attention was paid to the 40 mm DIN Standard towing eye and it is concluded that it is suitable only for doubles operation up to a Gross Combination Mass of 40 t.

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LIST OF SYMBOLS

a_{rel} - Relative acceleration between towing and towed units (m/sec^2)

b - Longitudinal acceleration of road train (m/sec^2)

g - Gravitational acceleration (m/sec^2)

k - Effective spring constant between road train units (N/m)

$p_{1,2}$ - Natural frequencies of simplified road train triple (rad/s)

x_1 - Displacement co-ordinate of towing unit (m)

x_2 - Displacement co-ordinate of first towed unit (m)

x_3 - Displacement co-ordinate of second towed unit (m)

D - Existing strength rating of coupling (t)

E - Proposed strength rating of coupling (t)

E_d - Dynamic component of coupling force (kN)

E_{1d} - Dynamic component of coupling force between the first two units in a triple (kN)

E_{ss} - Steady-state component of coupling force (kN)

M_1 - Mass of towing unit (t)

M_2 - Mass of first towed unit (t)

M_3 - Mass of second towed unit (t)

M_D - Tandem drive axle group mass (t)

P_1 - Tractive force applied by towing unit (kN)

P_Y - Tensile yeild force for DIN 40 mm drawbar eye (kN)

1. INTRODUCTION

Road trains consist of articulated vehicles hauling one or two trailers, or alternatively, rigid trucks hauling two or three trailers.

Following a general consideration of requirements for road trains by the NAASRA Economics of Road Vehicle Limits (ERVL) Study (Fry *et al.* 1976) a Project Committee and Working Party were set up to review the operation of road trains. Subsequently, the dimensional, mechanical and operational requirements of road trains were recommended in a Working Party Report (NAASRA 1978).

Tow couplings are used to connect additional trailers to the hauling vehicle which may be a rigid truck or articulated vehicle. The NAASRA ERVL Study (Fry *et al.*) had recommended that standards for tow coupling design should be developed and introduced. The NAASRA Working Party considered three general types of tow coupling used in Australia:

(a) the 'European type' (Fig 1) with a close-fitting pin in a towing eye,

(b) the 'American type', or pintle hook, which allows for more 'slack' in the connection, and

(c) simple couplings with two horizontal plates and a 'drop pin'.

The European coupling was considered to be a desirable type for use in road trains.

While the Working Party was carrying out its task, an Australian Standard for 50 mm Pin-Type Couplings for Trailers was being developed. This Standard (AS 2213-1978) was specified in the Working Party's recommendations (NAASRA, 1978). It is based on a 'D-rating' of tow coupling strength derived from DIN and ISO Standards.

There was, however, some doubt as to the applicability of the D-rating scheme to road trains consisting of more than two units. The D-rating was developed originally for truck-trailer combinations. Elements of the road train industry believed that the D-rating formula would require the use of tow couplings of considerably higher strength than those operating successfully on road trains. There was evidence, however, of unusual maintenance procedures being carried out on the smaller 40 mm drawbar eyes and cases of stretching of these eyes were reported.

NAASRA requested the Australian Road Research Board to investigate a strength rating scheme for tow couplings in road trains operating under Australian conditions. A research project was undertaken with the following aims:

(a) to measure in-service hitch force levels on existing road train routes,

(b) to compare in-service hitch force levels with known methods of calculation, and

(c) to recommend a method of calculation for the strength rating of tow couplings.

2. MEASUREMENT OF HITCH FORCES

Measurements of in-service hitch forces were obtained in an instrumented road train operating between Port Augusta (SA) and Alice Springs (NT). A 'triple', consisting of an articulated vehicle towing two trailers, was tested for part of the journey; for comparison purposes, one trailer was removed to produce a 'double' for the remainder of the journey. Conditions on the Stuart Highway represented a wide variety of unsealed surfaces, traversing cattle grids and creek beds, as well as sealed road surfaces. Other road features such as steep sustained grades and 'twisting' terrain, combining climbing with turning, were also encountered.

2.1 TOW COUPLINGS

European pin-type couplings of the type illustrated in Fig 1 were fitted to the road train tested. The major strength-related characteristic of such couplings is the pin diameter. Fifty millimetre couplings, as specified in Australian Standard 2213-1978, were used.

The towing connection consists of the'coupling' (housing the towing pin) which is attached to the towing unit and the 'eye' which is attached to the drawbar of the towed unit. The couplings and eyes used were of Swedish manufacture as follows:

- VBG 800 coupling
- VBG 880 drawbar eye.

They were tested in a new condition.

The coupling, consisting of pin, housing and locking mechanism, is mounted to a rear member of the towing vehicle using a 'sandwich' of rubber blocks which promote a wide angle of drawbar movement and lower vibration levels. The hardened pin is barrel-shaped to allow pitch and roll of the drawbar eye relative to the towing unit. The VBG 880 drawbar eye is designed to provide 0.6 mm clearance on the towing pin when new. It is fitted with a replaceable bearing insert. The drawbar eye is bolted to the drawbar of the towed vehicle.

2.2 VEHICLE CONFIGURATION

The road train consisted of a prime mover, three similar van-type semi-trailers and two 'dollies' . The general configuration of the vehicle is shown in Fig 2 together with axle masses of the loaded vehicle recorded on a weighbridge. The gross combination mass (GCM) was 96.25 t before the prime mover was fuelled. The legal maximum GCM for this vehicle is 104.4 t in the Western States.

The prime mover was a conventional-cab Mack R600 fitted with a 'Camelback' single-point tandem drive rear suspension. The fifth wheel kingpin was set 200 mm ahead of the tandem suspension centre-line. The fifth wheel assembly was of the conventional fixed-base type accepting a 90 mm trailer kingpin.

The van-type trailers carried fibreglass refrigerated units on Fruehauf chassis fitted with 'four-spring' tandem suspensions. The 'dollies' comprised fixed-base fifth wheel assemblies mounted over four-spring tandem suspension units and fitted with hinged drawbars which were rubber-mounted.

The wheels on the road train were fitted with steel radial tyres in conventional dual arrangement.

Dimensions of prime mover, trailers and dollies are given in Fig 3.

2.3 INSTRUMENTATION

Coupling Transducers

Strain gauges applied to the shank of a drawbar eye provided a simple and effective transducer for the measurement of towing forces. After some adjustment of the location of the longitudinally-sensitive gauges along the sides of the drawbar eye it was possible to obtain a force-strain characteristic which was acceptably linear and symmetrical (i.e. equal in sensitivity to tensile and compressive forces). A temperature-compensated arrangement was adopted. A typical transducer calibration characteristic is given in Fig 4. The static calibration was carried out with a Materials Test System (MTS) laboratory machine providing accurately-reproducible force levels.

A simple test showed that the transducer was also sensitive to vertical load applied to the drawbar. This was not considered to be a difficulty because the drawbar was provided with a lateral hinge isolating pitch motions of the trailer from the coupling under test; as noted in 2.1, the coupling pin itself allows for a degree of pitch articulation so that the drawbar was effectively hinged at both ends. Vertical forces at the coupling would be confined to inertia forces acting on the drawbar mass.

Robust strain gauge amplifiers were developed to be drawbar-mounted. Amplified towing force signals were conveyed to the prime mover for conditioning and recording.

Details of the instrumentation system are given by George (1980)

Data Logging

The sleeper cab of the prime mover contained a Racal 7-track FM data-logging tape recorder for continuous analog recording of towing forces. Signals from couplings A and B were recorded on separate channels. A voice track was used to describe the terrain and to locate significant events in the recorded data. Another data channel was used to monitor a truck-speedometer-mounted speed sensor. However, a difficulty with prime mover electrical earth caused the speed sensor to malfunction for most of the journey.

A microprocessor data analyser was also carried in the cab of the prime mover and this enabled the experimenter to obtain progress print-outs of the amplitude distribution of the towing forces at both hitches.

2.4 TEST PROCEDURE

Four refrigerated vans were loaded with food products in Adelaide, South Australia, and were towed separately north to Port Augusta where a road train 'triple' was assembled, as shown in Fig 2.

The selected test route followed the Stuart Highway northwest from Port Augusta, through South Australia and into the Northern Territory, the journey ending at Alice Springs. The route followed is shown in Fig 5. The road train departed Port Augusta mid-morning on 21st June and arrived Alice Springs midday on 23rd June 1979.

The triple was operated over a sealed surface from Port Augusta to Pimba, and over an unsealed surface from Pimba to Welbourne Hill in the north of South Australia. A double (as for Fig 2, but with van number 6 removed) was then operated over unsealed surfaces from Welbourne Hill to the Northern Territory border where the bitumen resumes. The double then continued into Alice Springs on a sealed road.

It was possible, therefore, to test both triple and double over sealed and unsealed surfaces.

The driver of the road train followed his usual procedures and the journey was divided into approximately 20 segments with fairly frequent stops to check tyres, carry out minor repairs, etc. Data was logged in 18 segments totalling 25.4 hours of running time. The separate segments or 'logs' are indicated in Fig 5. Table I indicates the test conditions and duration of each segment or 'log' of the journey.

2.5 RESULTS

Continuous records of hitch forces on analog tape provide time histories of hitch forces during specific events such as starting from rest, ascending steep hills, etc.

Figure 6 shows a typical record of front and rear coupling forces occurring when the triple pulled away from rest on an unsealed road surface. Large oscillations in the towing force at Hitch A occurred; this might be attributed to resonance through the drive train of the prime mover. Hitch B shows smaller amplitude force oscillations which are in phase with those measured at Hitch A. The peak towing force at Hitch A did not exceed 30kN.

A steep sustained grade was encountered in log 5 of the test. Figure 7 shows the towing forces developed as the grade steepened. Gear changes in the prime mover are apparent. The steady towing force experienced by Hitch A did not exceed 50kN.

Typical dynamic hitch forces which can be generated in a triple running over an unsealed corrugated road are shown in Fig 8. This shows high dynamic forces at Hitch A due to train resonance at a frequency of approximately 6 Hz. Lower amplitude oscillations occurred at a similar frequency in Hitch B, and the oscillations at the two hitches appear to be directly out of phase. The dynamic component of the force at Hitch A has an amplitude of approximately 70kN and exceeds the highest steady towing force measured. This type of sustained resonance did not appear to occur with the double.

It is likely that both the rubber mounts of the tow coupling and drawbar hinge contribute to this resonance. A simple calculation shows that, for the tandem axle spacing of 1.24 m in the test vehicle, a 6 Hz disturbance would be produced at a speed of 27 km/h on a corrugated road.

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Amplitude Distributions

The microprocessor analyser determined amplitude distributions of the hitch forces during each segment of the test. Figure 9 shows such distributions for the double operating on

(a) unsealed and

(b) sealed roads.

These distributions are similar, although the sealed-road result is slightly more 'peaked'.

Figure 10 shows the towing force distributions obtained in both hitches of the triple operating on a sealed road. It is noticeable that a relatively high proportion of Hitch A forces occurred in the range 30kN to 40kN. This is probably related to the presence of the sustained grade referred to in Fig 7.

A comparison of the triple's performance on an unsealed road is given in Fig 11. These distributions are surprisingly similar to the sealed-road results of Fig 10.

Peak Coupling Forces

Analog tape recordings of the hitch forces were scanned with a peak detector to determine individual occurrences of unusually high couling forces. Table II summarises the conditions under which these peak forces occurred. The highest coupler forces recorded for each vehicle configuration and road standard are as follows:

(a)	Double (sealed road)	70.5kN
(b)	Double (unsealed road)	85.5kN
(c)	Triple (sealed road)	85.5kN
(d)	Triple (unsealed road)	98.0kN

Cases (a), (c) and (d) all occurred at fixed raised structures.

Figure 12 shows an actual record of the doubles hitch force in a case very similar to (b) above. Figure 13 shows the actual data for case (d). In the latter case it is apparent that the forces occurring in the rear coupling are much lower. However, it must be assumed that the out-of-phase forces at the rear hitch do contribute to the peak loading at the front hitch through dynamic interaction. In all cases of peak coupling force occurrences summarised in Table II, a dynamic rather than a steady state event was responsible.

3. STRENGTH RATINGS OF TOW COUPLINGS

Current rating schemes and regulations for the strength of tow couplings are based simply on the mass of the towed units, or, in the case of the 'D-rating', the masses of the units ahead of and behind the coupling.

3.1 D-RATING SCHEME

The D-rating as specified in DIN 74051 and DIN 74052 is given by

$$D = \frac{M_1\ M_2}{M_1 + M_2} \tag{1}$$

for a truck-trailer combination. Thus the D-value has units of mass and is a single mass value representing the entire combination as it affects the strength required at the coupling. It is difficult to trace the development of the D-rating in the German literature. However, the essence of the argument in a report of unknown origin by Strauchmann (1967) appears to be as follows. The simple concept behind the D-value is a coupled two-mass system subject to a steady driving force and experiencing a steady acceleration. This is illustrated in Fig 14a. For a steady acceleration b,

$$P_1 = b(M_1 + M_2) \tag{2}$$

and $$D = bM_2. \tag{3}$$

These equations (2) and (3) may be combined by eliminating b to yield

$$D = \frac{P_1\ .\ M_2}{M_1 + M_2} \tag{4}$$

The maximum driving force P_1 is then taken to be

$$P_1 = M_1\ g \tag{5}$$

which is equivalent to assuming that the entire truck mass is concentrated over the drive axles, that the vehicle has unlimited engine torque and that a co-efficient of friction of one exists at the road surface. Equations (4) and (5) are then consistent with eqn (1).

It is suggested here that an alternative way of arriving at eqn (1) is to consider the dynamic model shown in Fig 14b, where relative movement is permitted to occur between the units. If the accelerations of the two units are $\ddot{x}_1$ and $\ddot{x}_2$ then the coupling force is given by

$$D = (\ddot{x}_1 - \ddot{x}_2) \cdot \frac{M_1 M_2}{M_1 + M_2} \qquad (6)$$

For a relative acceleration *between* the units of 1 g

$$\text{i.e.} \quad \ddot{x}_1 - \ddot{x}_2 = 1 \text{ g} \qquad (7)$$

eqn (6) reduces to eqn (1).

In practice the coupling force is a combination of steady pull, where there is no relative movement between the units, and a dynamic component caused by movement at the coupling.

It should be noted that the assumption of eqn (5) is unrealistically conservative and allows a wide margin for impact effects in the coupling. However, the D-rating is very much removed from physical reality and it is considered that any scheme aimed at predicting in-service coupling forces would beed to include dynamic as well as steady state components.

3.2 COMPARISON OF MEASURED FORCES WITH D-RATING SCHEME

A modified D-rating scheme was adopted in Australian Standard 2213-1978 '50 mm Pin-Type Couplings for Trailers'.

The formulae used are

$$D = \frac{0.9\, M_1 M_2}{M_1 + M_2} \qquad \text{(articulated vehicle with one trailer)} \qquad (8)$$

and

$$D = \frac{0.75\, M_1\, (M_2 + M_3)}{M_1 + M_2 + M_3} \qquad \text{(articulated vehicle with two trailers)} \qquad (9)$$

while the original form of eqn (1) was adopted for the truck-trailer combination.

There was considerable doubt as to the appropriate means of extending the original scheme (based on two units) to the case involving three units. A modifying factor of 0.75 was introduced in eqn (9) to ensure a practical range of D-values.

Table III shows a comparison of the maximum coupling forces measured during the test for both double and triple operation with the D-ratings determined from the original and modified formulae (for the actual unit masses of the test vehicle). (To facilitate comparison, coupling forces are shown, improperly, in tonnes).

As can be seen in Table III, the maximum coupling forces measured were considerably less than the calculated D-values for both the double and the triple. The maximum forces measured represent 53 per cent and 44 per cent of the original D-values for the double and triple respectively; they represent 59 per cent and 59 per cent respectively of the modified D-values. This indicates that the *relative* modifying factors of 0.9 and 0.75 were well chosen, but the overall level of the D-values is probably too high.

3.3 METHOD FOR PREDICTING MAXIMUM COUPLING FORCES

The intention here is to develop a means of predicting the maximum likely coupling forces based on simple characteristics of the vehicle, including the masses.

As mentioned earlier, such a scheme should take into account both the steady-state and dynamic components of the total coupling force. To avoid confusion with D-values, coupling forces in this scheme will be designated with the letter E.

Steady-State Component

In the style of eqn (4),

$$E_{ss} = P_1 \cdot \frac{M_2}{M_1 + M_2} \tag{10}$$

for a double, and

$$E_{ss} = P_1 \cdot \frac{(M_2 + M_3)}{M_1 + M_2 + M_3} \tag{11}$$

for a triple.

It is assumed that the maximum tractive force, P_1, is proportional to the load on the drive axles. The maximum steady towing force was developed with the triple on a sustained grade in segment 5 of the test. From the data of Fig 7 and the histogram of Fig 10, the maximum steady force at Hitch A was of the order of 40kN. Assuming a retarding force acting on each unit proportional to its mass, the tractive effort generated at the drive axles may be estimated as

$$P_1 = 40 \cdot \frac{(M_1 + M_2 + M_3)}{M_2 + M_3} \tag{12}$$

$$= 64\text{kN}$$

The mass on the drive axles (M_D) was 16.3 t and so the ratio of tractive force to vertical force was

$$\frac{P_1}{M_D\ g} = .40 \tag{13}$$

In view of the possibility of overloading, it is considered that the rated load of the drive axles is a more appropriate basis for estimating the maximum tractive forces than the legal tandem axle mass limit. A common load rating for heavy-duty tandem axles is 44,000 lb (approximately 20 t), so that

$$P_1 = .4 \times 20\ g = 8\ g\ \text{kN} \tag{14}$$

In line with the traditional practice of expressing coupling forces and ratings in mass units, eqns (11) and (10) then become

$$E_{ss} = \frac{8\ (M_2 + M_3)}{M_1 + M_2 + M_3} \qquad (15)$$

for the triple, and

$$E_{ss} = \frac{8\ M_2}{M_1 + M_2} \qquad (16)$$

for the double. In the case of a single drive axle vehicle in a doubles configuration, the vertical load rating is halved and

$$E_{ss} = \frac{4\ M_2}{M_1 + M_2} \qquad (17)$$

Dynamic Component

Equation (6) related the coupling force in a double to the relative acceleration between the two units, assuming that flexibility and movement in the coupling allow the two masses to vibrate against each other. From Table II the maximum doubles coupling force in a dynamic event was 86kN. The mean towing force for that segment of the test is estimated at 8kN and so the amplitude of the dynamic component is estimated to be 78kN.

Now eqn (6) may be re-written in the form

$$E_d = a_{rel} \cdot \frac{M_1\ M_2}{M_1 + M_2} \qquad (18)$$

and substituting the appropriate values for the masses in the test vehicle gives

$$a_{rel} = \frac{(36.1 + 30.6)}{36.1 \times 30.6} \times 78$$

$$= 4.71 \text{ m sec}^{-2} \qquad (19)$$

i.e. $a_{rel} = 0.48\ g$

The calculation for the dynamic component of the coupling force in a double will be based, therefore, on a maximum relative acceleration between the units of 0.5 g and eqn (18) becomes

$$E_d = 0.5 \frac{M_1\ M_2}{M_1 + M_2} \qquad (20)$$

In case of the triple, more complex dynamic behaviour is involved. Although no attempt will be made to explain the detailed dynamic behaviour of such a vehicle, a simple model which is consistent with the general character of the test results will be developed.

Figure 15 shows a simple three-mass system coupled by springs of equal stiffness. The co-ordinates x_1, x_2 and x_3 specify the displacements of the three masses. Such a system has two natural frequencies corresponding to two modes of vibration.

Based on a standard reference (Harris and Crede 1961) it may be shown that the squares of the natural frequencies are given by

$$p^2_{1,2} = \frac{k}{2}\left[\frac{1}{M_1} + \frac{2}{M_2} + \frac{1}{M_3}\right] \pm \frac{k}{2}\sqrt{\left(\frac{1}{M_1} - \frac{2}{M_2}\right)^2 + \frac{2}{M_1M_2} + \frac{1}{M_3^2}} \qquad (21)$$

Perusal of the dynamic coupling force data of Fig 8 indicates a resonance at a frequency of approximately 6 Hz and shows that the two coupling forces are out of phase. This would indicate a predominance of the higher frequency mode, as indicated in Fig 15, where one hitch is acting in tension while the other is in compression. The importance of this out-of-phase mode is also indicated in Fig 13, showing the highest coupling force measured during the test. Note that Hitch A is initially placed in compression, probably caused when the leading unit encounters the obstruction and is momentarily retarded. The resonance then builds until Hitch A experiences a tensile peak at the same time that Hitch B experiences a compressive peak.

Once again using the relative acceleration between the first two units as a criterion, it may be shown that

$$E_{1d} = a_{rel} \cdot \frac{k}{p_2^2} \qquad (22)$$

where p_2 is the larger value given by eqn (21). The application of a series expansion to this expression results in the approximation.

$$E_{1d} = a_{rel} \frac{\dfrac{1.08\, M_1M_2M_3}{M_1M_2 + M_2M_3 + 2M_1M_3}}{1 - \dfrac{M_1M_2M_3(M_1 + M_2 + M_3)}{(M_1M_2 + M_2M_3 + 2M_1M_3)^2}} \qquad (23)$$

As was the case for the double, the maximum dynamic coupling force component is estimated from the peak force measured (98kN) minus the mean towing force (10kN) i.e. a maximum dynamic component of amplitude 88kN. Substituting this value in eqn (22), and using eqn (21) to calculate k/p_2^2 based on the test vehicle masses, gives a_{rel} = 0.87 g. Thus the relative acceleration criterion for the triple is considerably higher than that determined for the double (0.5 g).

A further simplification can be introduced in eqn (23) because the denominator term tends to be a constant for practical road train configurations. In that case, the following approximation is proposed:

$$E_{1d} = \frac{1.2\ M_1M_2M_3}{M_2(M_1 + M_3) + 2M_1M_3} \tag{24}$$

Proposed Strength Rating System

In the previous section simple models have been developed which predict the maximum steady state and dynamic coupling forces for any road train configuration, based on measurements of one double and one triple configuration only. The equations presented are an attempt to independently predict the maximum steady state and dynamic forces, for similar road conditions and driving style, for practical modern road trains of any configurations and gross mass.

In order to take into account both the steady state and dynamic coupling force components, it is proposed to add these two contributions in the rating scheme. That is, the worst case is considered, where the peak steady state and dynamic components occur simultaneously.

The equations for predicting the maximum coupling forces are then determined from

$$E = E_{ss} + E_d \tag{25}$$

so that, using eqns (16) and (20) for the double

$$E = \frac{(8 + .5M_1)\ M_2}{M_1 + M_2} \tag{26}$$

and, using eqns (15) and (24) for the triple,

$$E = \frac{8(M_2 + M_3)}{M_1 + M_2 + M_3} + \frac{1.2\ M_1M_2M_3}{M_2(M_1 + M_3) + 2M_1M_3} \tag{27}$$

In the case of a single drive vehicle (assumed to be practical only for a double) the appropriate expression derives from eqns (17) and (20):

$$E = \frac{(4 + .5\ M_1)\ M_2}{M_1 + M_2} \tag{28}$$

Typical ratings based on eqns (26), (27) and (28) have been calculated for a range of practical road train configurations. These E-values are shown in Fig 16, compared with calculations based on the original and modified D-ratings. It is apparent that, in almost all cases, the E-value is lower than the modified D-value. In one exceptional case, the three axle rigid truck towing two four-axle trailers, the E-value is slightly higher.

Suitability of 40 mm type coupling

It is proposed that the above system should apply to both 40 mm and 50 mm pin-type couplings. However, it is considered that the suitability of the 40 mm coupling should be based on the strength of the eye rather than the coupling and pin assembly: there has been considerable evidence of stretching in 40 mm eyes used in road trains in Australia.

In order to study this more closely, a tensile test was carried out on a 40 mm eye. Twelve strain gauges were attached to a DIN 74054 ISO-Standard standard 40 mm eye, as shown in Fig 17. The outputs of all gauges were monitored as the applied tensile force was increased in 10kN steps up to 150kN. These strains, for the outermost four gauges, are shown in Fig 18. The critical tensile strain occurred at gauge number 4 and rose to $1020\mu\varepsilon$ at a test force of 150kN.

Simple calculations were then carried out related to an assumed yield strain of $1500\mu\varepsilon$. Based on a strain of $1020\mu\varepsilon$ at 150kN, the tensile force to yield the 40 mm eye is estimated to be

$$P_Y = 150 \times \frac{1500}{1020} \qquad (29)$$

$$= 220\text{kN}$$

The maximum coupling force measured in the road test was 98kN, giving a margin of safety of $\frac{220}{98} \doteq 2.24$ in the road test itself.

Based on eqn (27), the E-value for the largest practical triple shown in Fig 16 (of GCM 114 t) is 16.8 t, or 165kN. The margin of safety of the 40 mm eye would then be $\frac{220}{165} = 1.33$.

According to Oberg *et al.* (1976) the recommended factor of safety for a member using reliable materials under difficult loading or environmental conditions is in the range 3 to 4. In the case of a drawbar eye for road train use, the desirable factor of safety might be estimated as follows, taking into account uncertainties caused by coupling wear, more severe driving or road conditions, different spring mounts on the coupling and higher GCM:

Desirable factor of safety

$$\begin{aligned} &= 1.5 \text{ (coupling wear)} \\ &\times 1.5 \text{ (operating conditions)} \\ &\times 1.2 \text{ (spring mounts)} \\ &\times 1.2 \text{ (GCM)} \qquad (30) \\ &= 3.25 \end{aligned}$$

It is concluded that the 40 mm drawbar eye is undesirable, both for the actual road test carried out, and for the projected maximum force which could be generated in a triple of maximum GCM.

Based on the tensile force to yield the 40 mm eye (eqn 29) and the desirable factor of safety (eqn 30), the eye is estimated to be adequate for a tensile force of

$$E = \frac{220}{3.25} \qquad (31)$$

$$= 68\text{kN}$$

which, in the units customarily used in rating couplings, is equivalent to a strength rating of 6.9 t.

Reference to Fig 16 indicates that the DIN Standard 40 mm eye (and hence any 40 mm coupling with which it is used) is adequate only for doubles with single axles.

4. CONCLUSIONS AND RECOMMENDATIONS

(a) Peak tow coupling forces are caused by dynamic events related to high frequency motions between the road train units and are not directly attributable to the tractive effort of the prime mover.

(b) Large dynamic coupling forces are most commonly generated when the road train encounters fixed raised structures such as railway crossings.

(c) The scheme used for strength rating of road train tow couplings in Australia should include both dynamic and steady state factors. A new scheme of this type is proposed (see eqns (26), (27) and (28)). This scheme is an attempt to best and most simply use the limited available data.

(d) The 40 mm DIN Standard drawbar eye is undesirable for general road train use because it has an unsatisfactory margin of safety against yielding of the ring under tensile forces. It is suitable only for doubles with single axles up to a GCM of 40 tonnes.

(e) The road train triple showed a tendency to develop a longitudinal resonance which was not noticeable for the double. The rubber tow coupling mounts, intended to reducer shock effects in doubles, may not have the most suitable stiffness characteristics for use in triples.

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DISTRIBUTION TO INCLUDE: Directors, NAASRA Eng. Sec., Road Users TC.

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TABLE I

TEST CONDITIONS FOR EACH SEGMENT OF ROAD TRAIN TEST

LOG NUMBER	LOCATION	TRAVEL TIME (hr)	ROAD SURFACE	ROAD TRAIN CONFIGURATION
1	Port August to Yorkey's Knob	.52	bitumen with short unsealed sections	triple
2	Yorkey's Knob to Nine-Mile Hill	.16	bitumen	triple
3	Nine-Mile Hill towards Pimba	.89	bitumen	triple
4	Towards Pimba	1.18	unsealed	triple
5	into Pimba	.84	bitumen	triple
6	Pimba to Lake Hart	1.08	unsealed	triple
7	Lake Hart to Kingoonya	2.13	unsealed	triple
9	to Bundy Hill	.99	unsealed	triple
10	from Bundy Hill	2.27	unsealed	triple
11	approaching Coober Pedy	1.16	unsealed	triple
12	into Coober Pedy	.78	unsealed	triple
13	Coober Pedy to Honeymoon Hill	1.92	unsealed	triple
14	Honeymoon Hill to Mt.Willoughby	1.33	unsealed	triple
15	from Mt.Willoughby through Welbourne Hill	2.31	unsealed	triple
16	to Malaga	.58	unsealed	double
17	Malaga to Marla Bore	.10	unsealed	double
18	from Marla Bore	3.42	unsealed	double
19	into Kulgera	.54	bitumen	double
20	Kulgera to Alice Springs	3.21	bitumen	double

TABLE II

PEAK COUPLING FORCE OCCURRENCES

CONFIGURATION	ROAD SURFACE	LOG	PEAK FORCE (kN)	DYNAMIC BEHAVIOUR
Double	Sealed	20	60.5	2.5 Hz oscillation at cattle grid (high speed)
			60.0	2.5 Hz oscillation (high speed)
			70.5	6 Hz oscillation at cattle grid (low speed)
	Unsealed	17	85.5	6 Hz oscillation ascending hill
		18	79.5	6 Hz oscillation at railway crossing (low speed)
			75.5	6 Hz oscillation on corrugated road
			76.5	6 Hz oscillation
			83.0	2.5 Hz oscillation negotiating deep hole at low speed
Triple	Sealed	3	85.5	3 Hz oscillation at cattle grid(high speed)
			70.5	3 Hz oscillation at cattle grid(high speed)
	Unsealed	11	95.0	6 Hz oscillation
		12	93.5	6 Hz oscillation
		13	94.0	6 Hz oscillation
			97.0	6 Hz oscillation at railway crossing(low speed)
			92.0	6 Hz oscillation
		14	98.0	6 Hz oscillation at railway crossing (low speed)
			89.5	6 Hz oscillation
		15	88.0	3 Hz oscillation at large bump (low speed)
			91.5	6 Hz oscillation

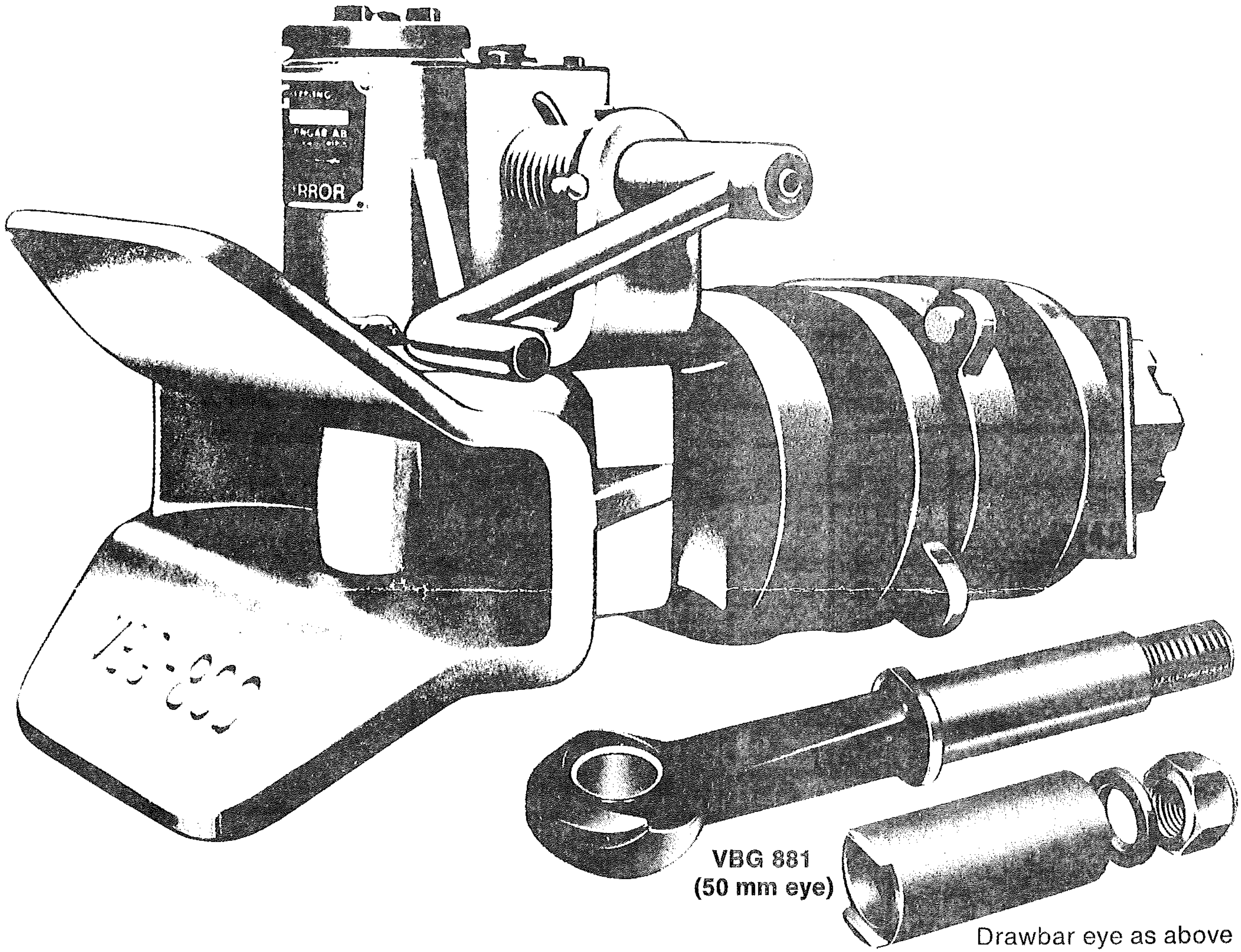
TABLE III

COMPARISON OF MAXIMUM COUPLING FORCES MEASURED WITH THE CALCULATED D-RATINGS

CONFIGURATION	MAXIMUM COUPLING FORCE MEASURED ($\times\frac{1}{9.8}$kN)	D-RATING	
		ORIGINAL (t)	MODIFIED (t)
Double	8.7	16.6	14.9
Triple	10.0	22.6	16.9

AUTOMATIC TRAILER COUPLING

MODEL VBG 800



**VBG 881
(50 mm eye)**

Drawbar eye as above
with square socket
part. no. VBG 882

Fig.-1. European Pin-Type Coupling
as used in road test.

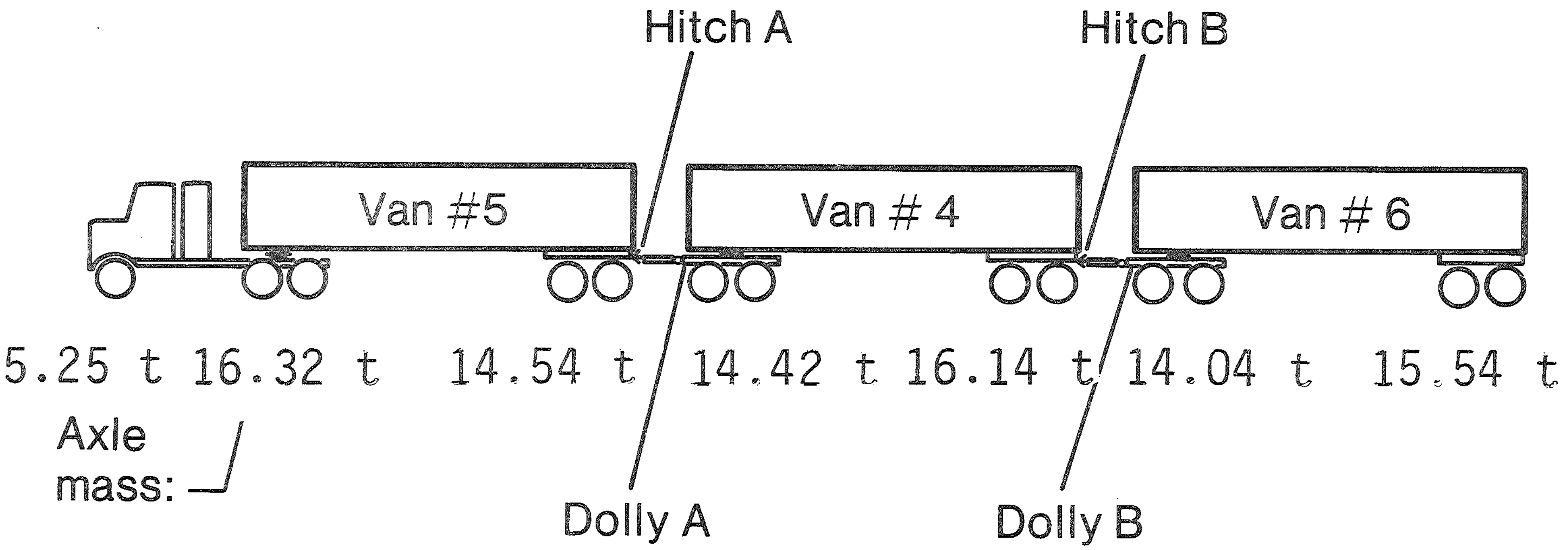


Fig 2 - Road train configuration and axle loads

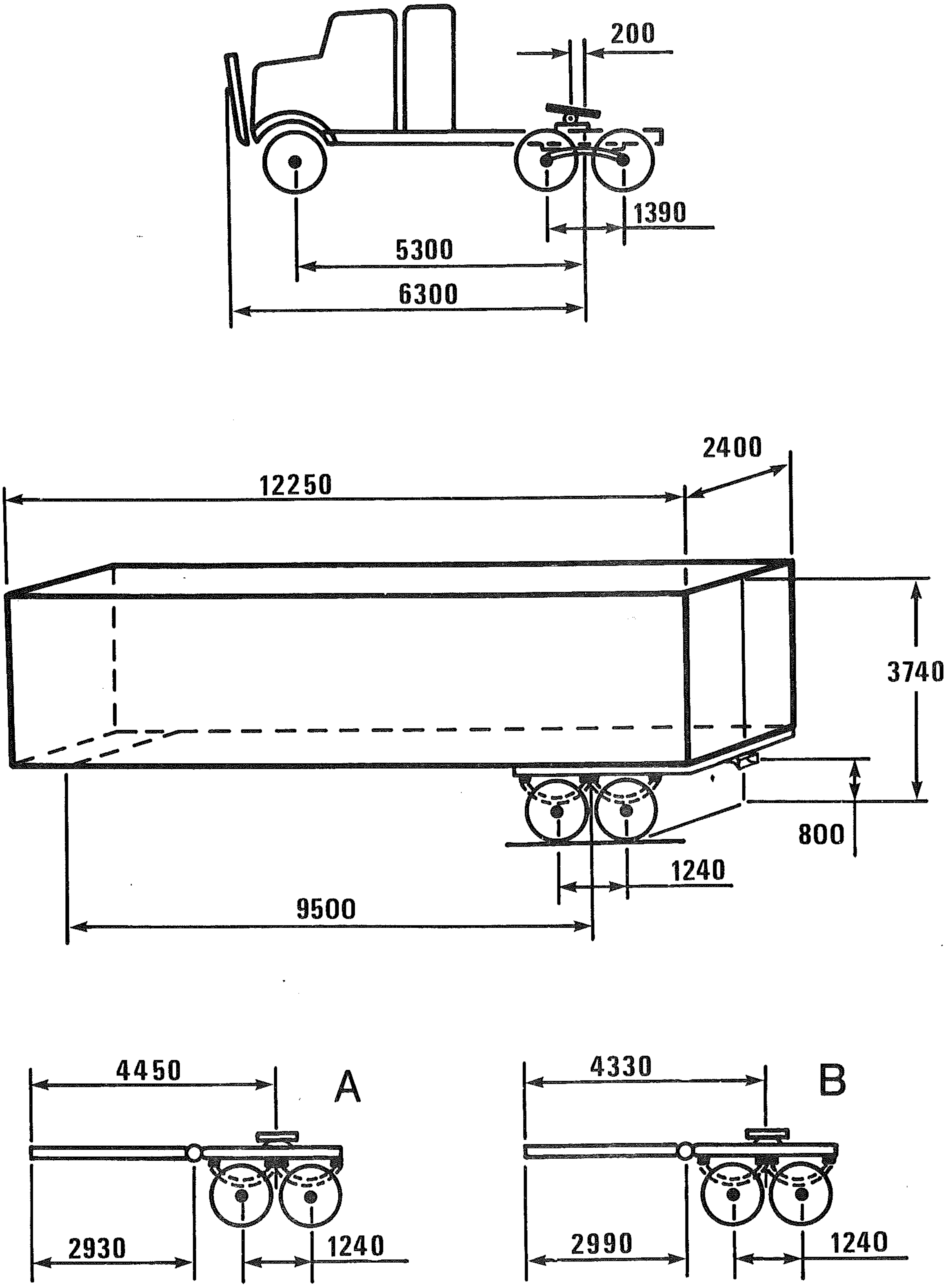


Fig 3 - Dimensions of road train units (in mm)

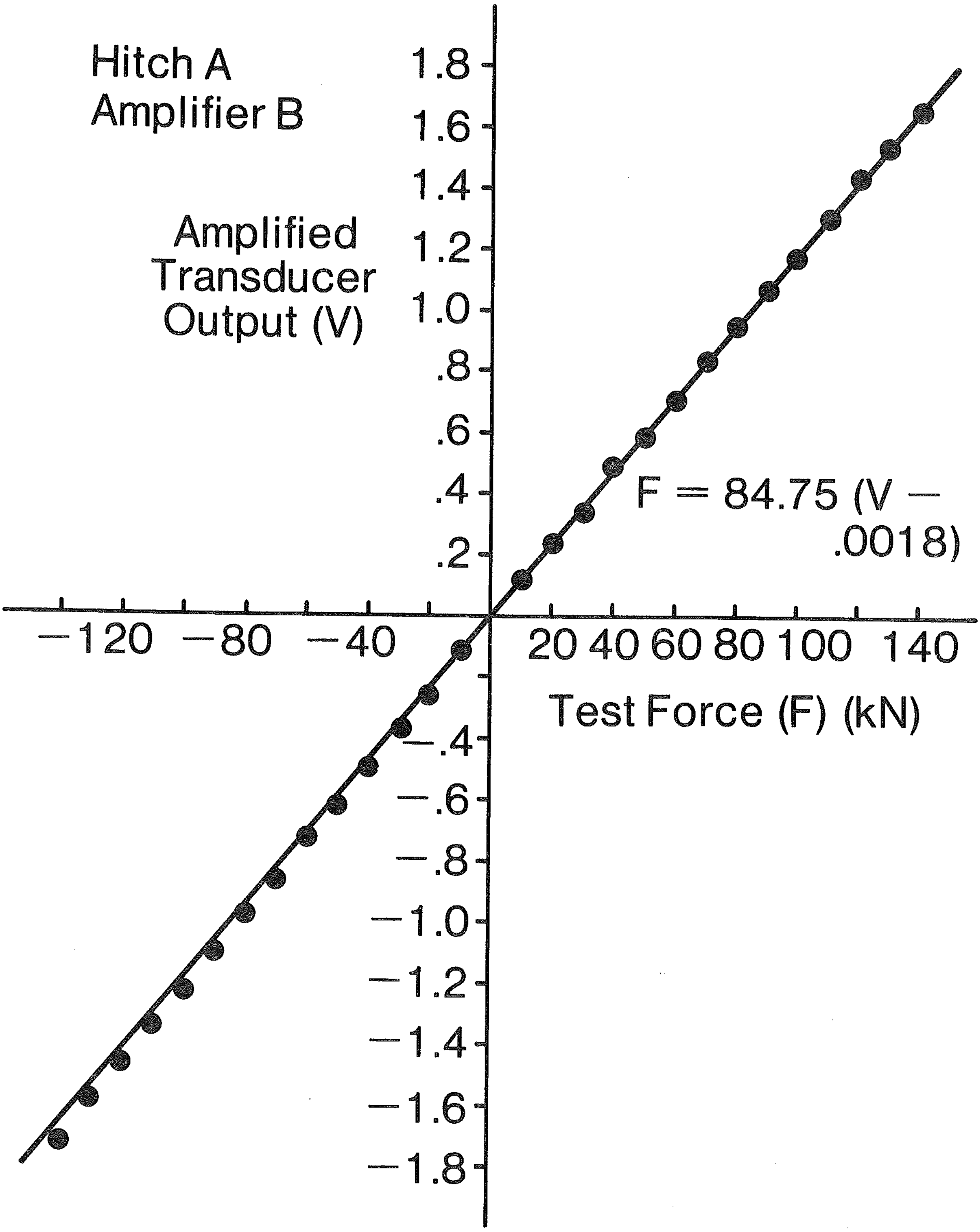
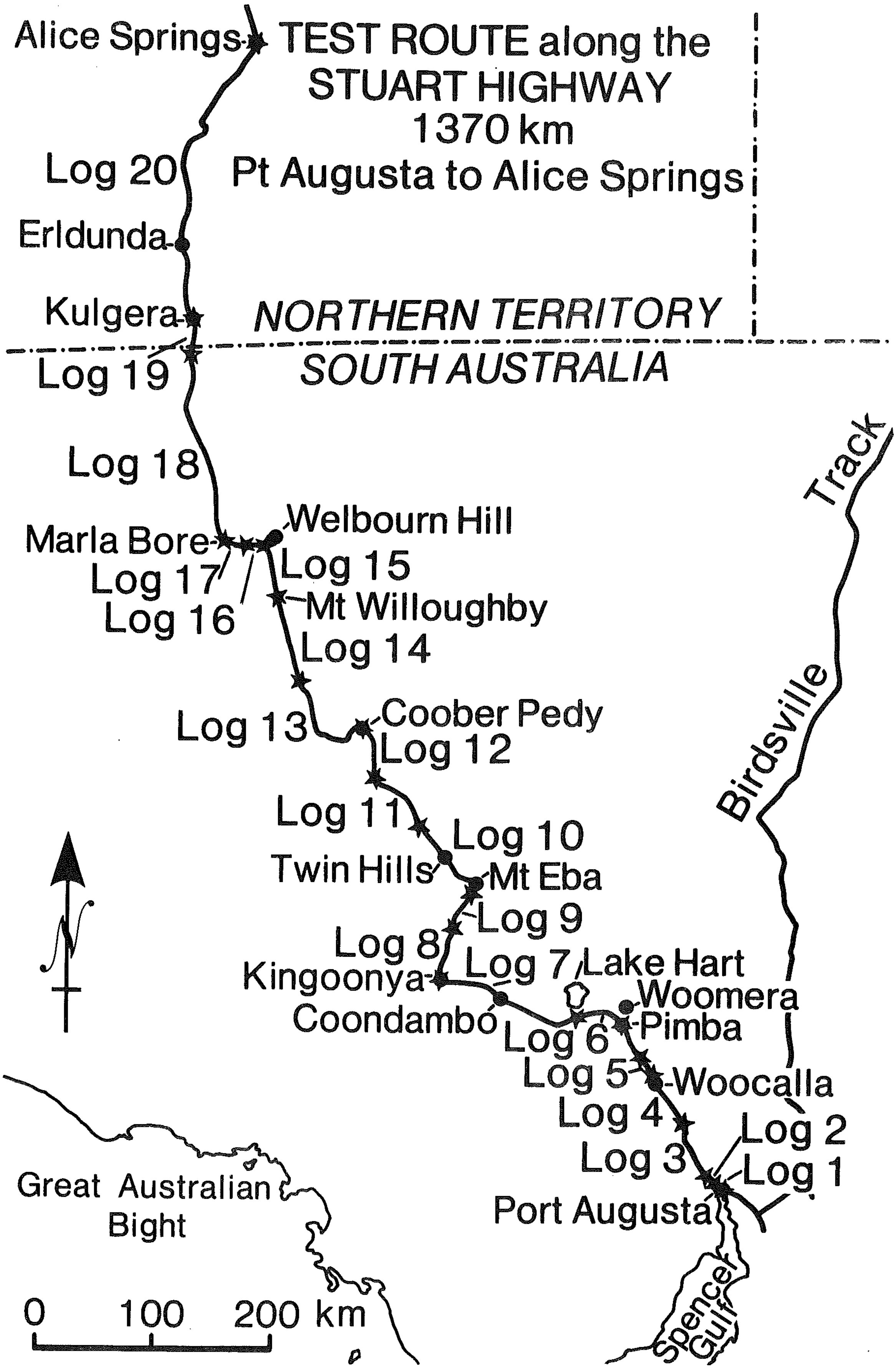


Fig. 4 — Typical calibration of towing force transducer



* indicates stops.

Fig 5 - Road train test route

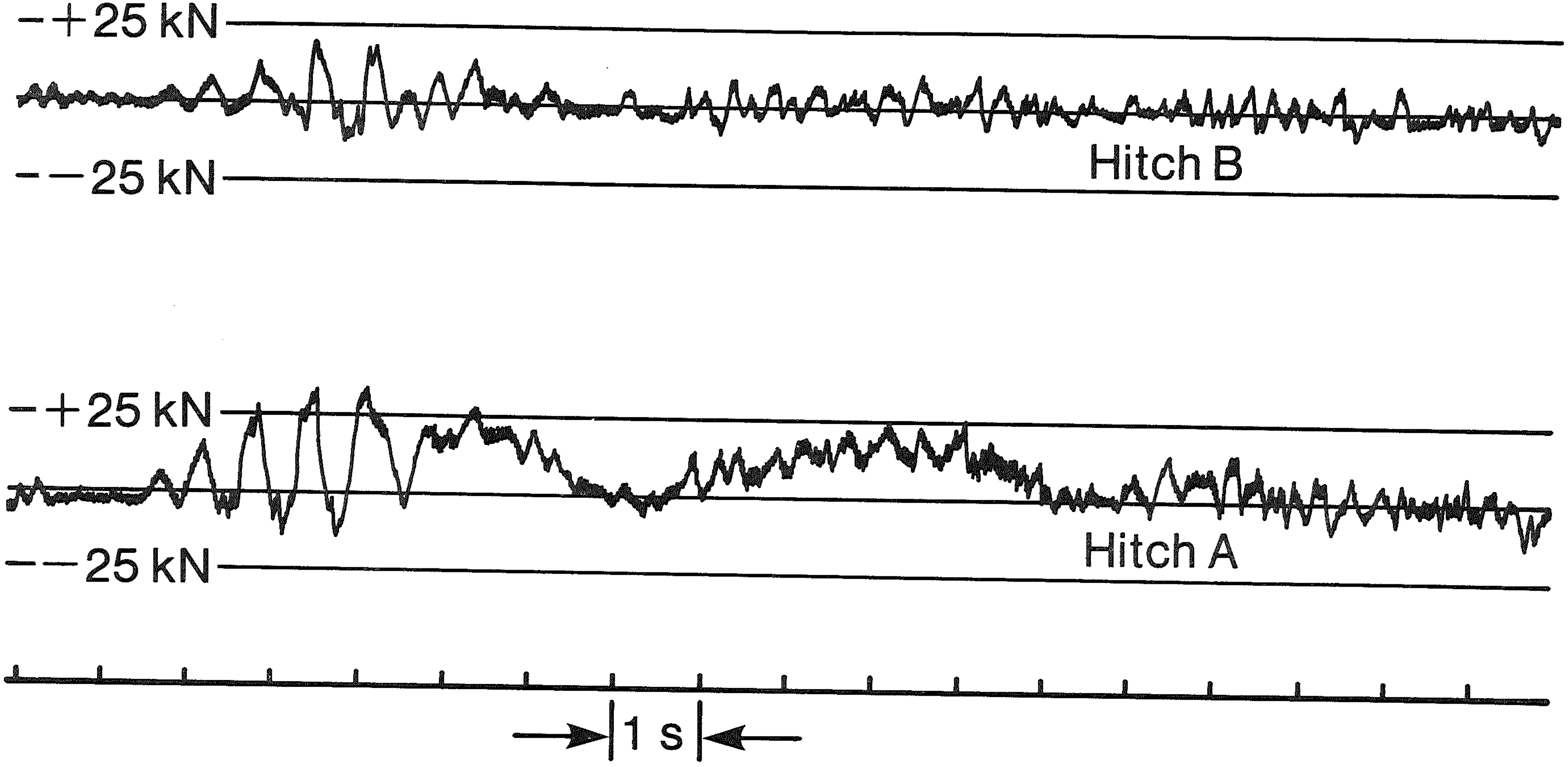


Fig. 6 — Time histories of hitch forces in triple while starting from rest on an unsealed road. (Log 14)

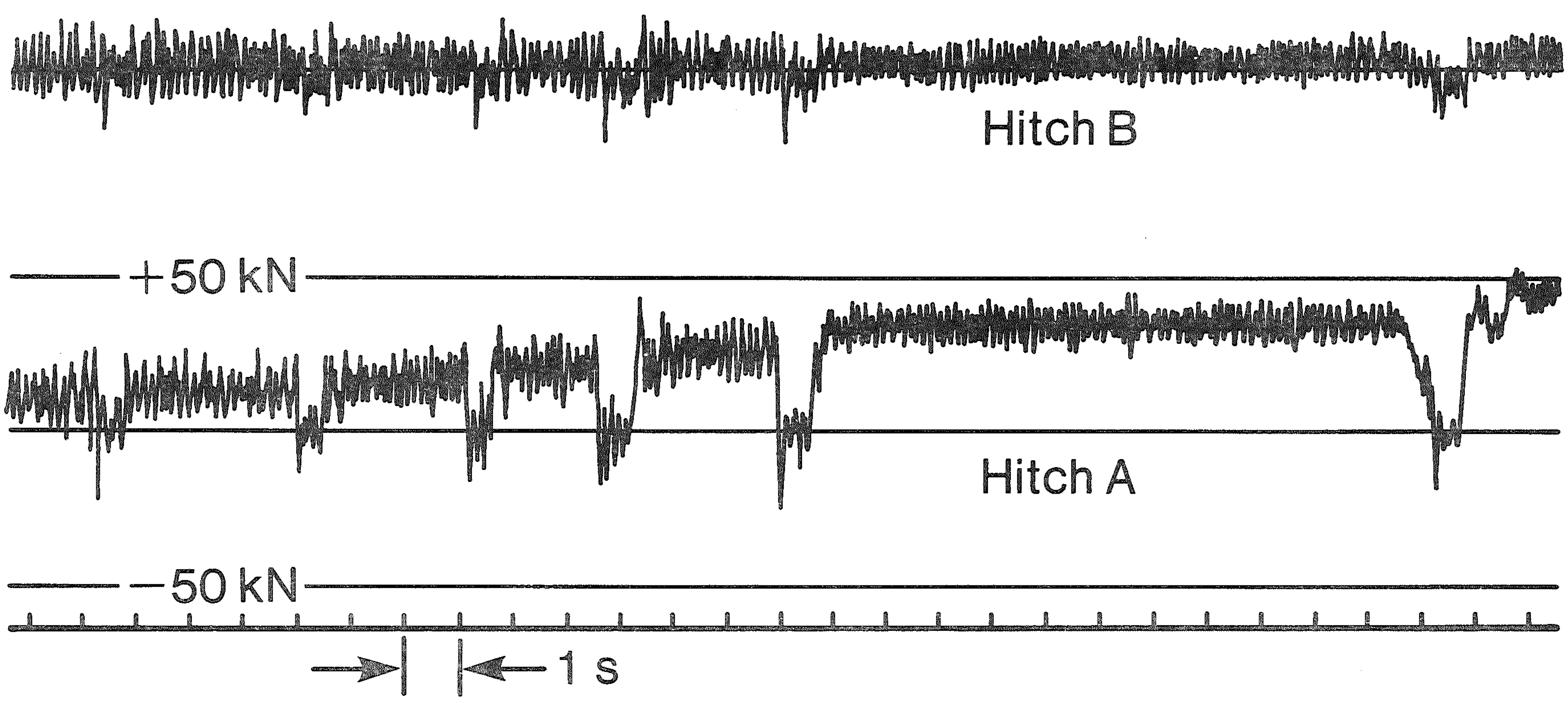


Fig. 7 — Time histories of hitch forces in the triple ascending a steep grade approaching Pimba S.A. on a sealed road. (Log 5)

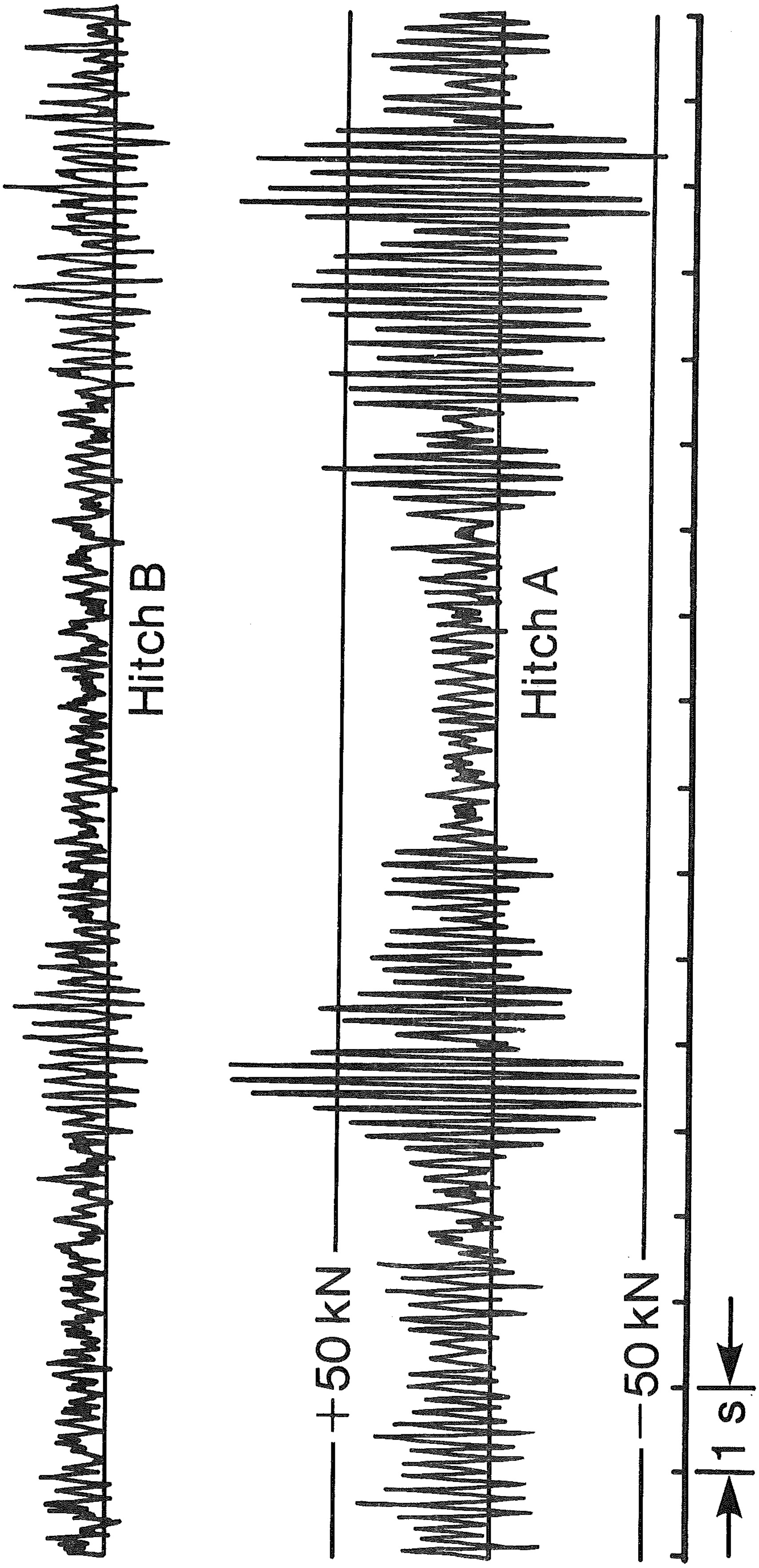


Fig. 8 — Dynamic hitch forces developed by a triple proceeding on an unsealed road near Coober Pedy S.A. (Log 12)

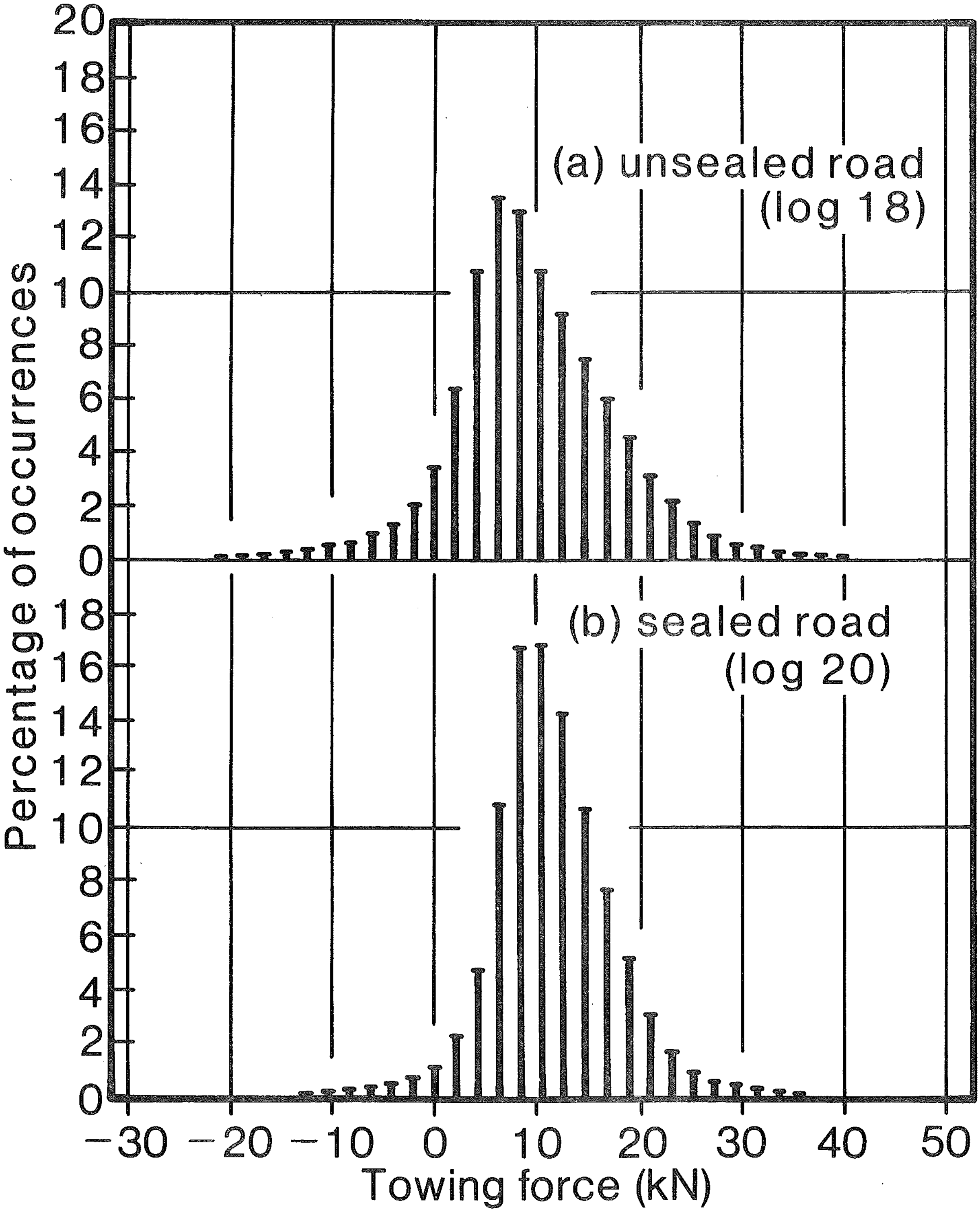


Fig. 9 — Amplitude distributions of towing forces in a double operating on (a) unsealed and (b) sealed roads

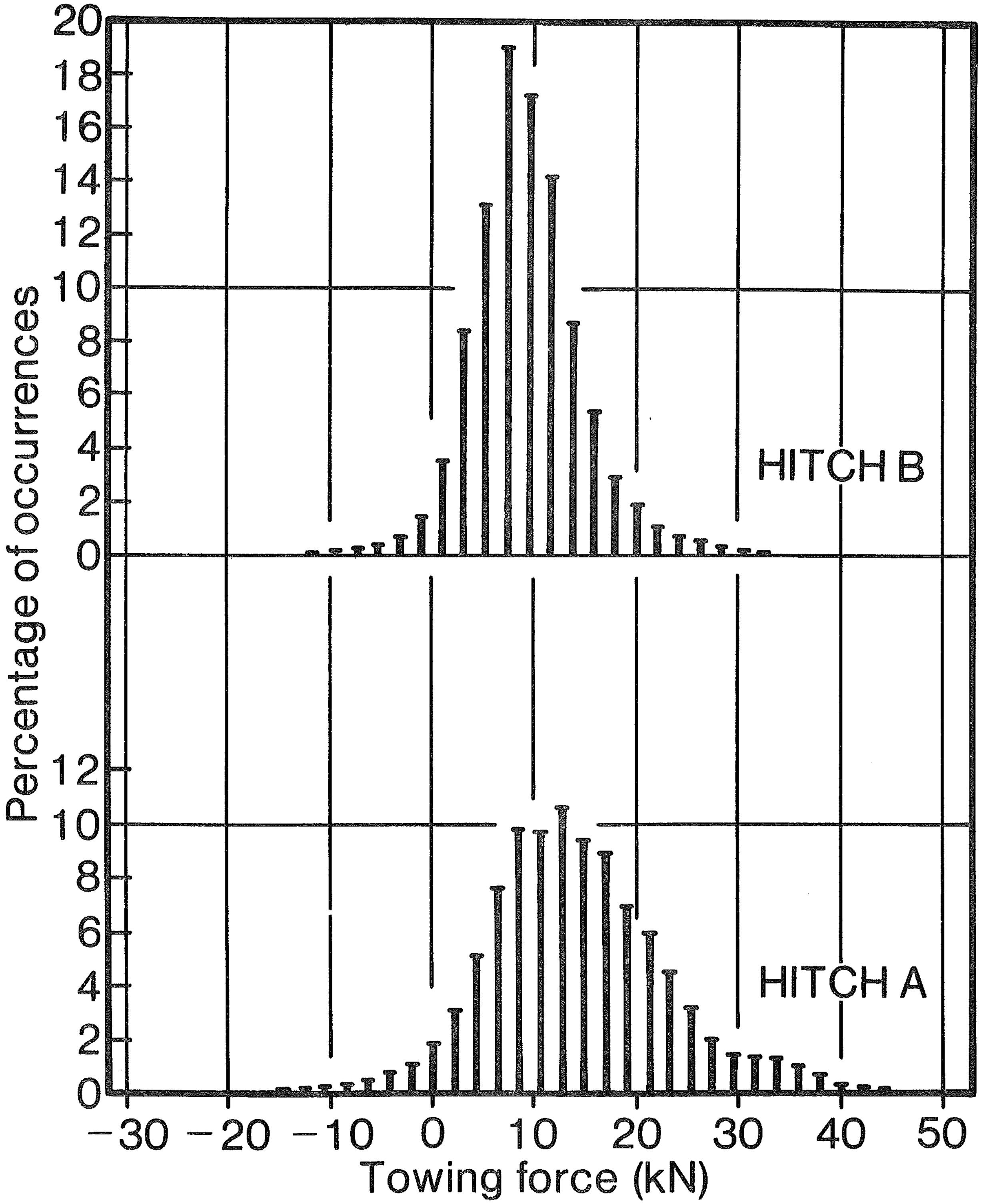


Fig. 10 — Amplitude distributions of towing forces in a triple operating on a sealed road (log 5)

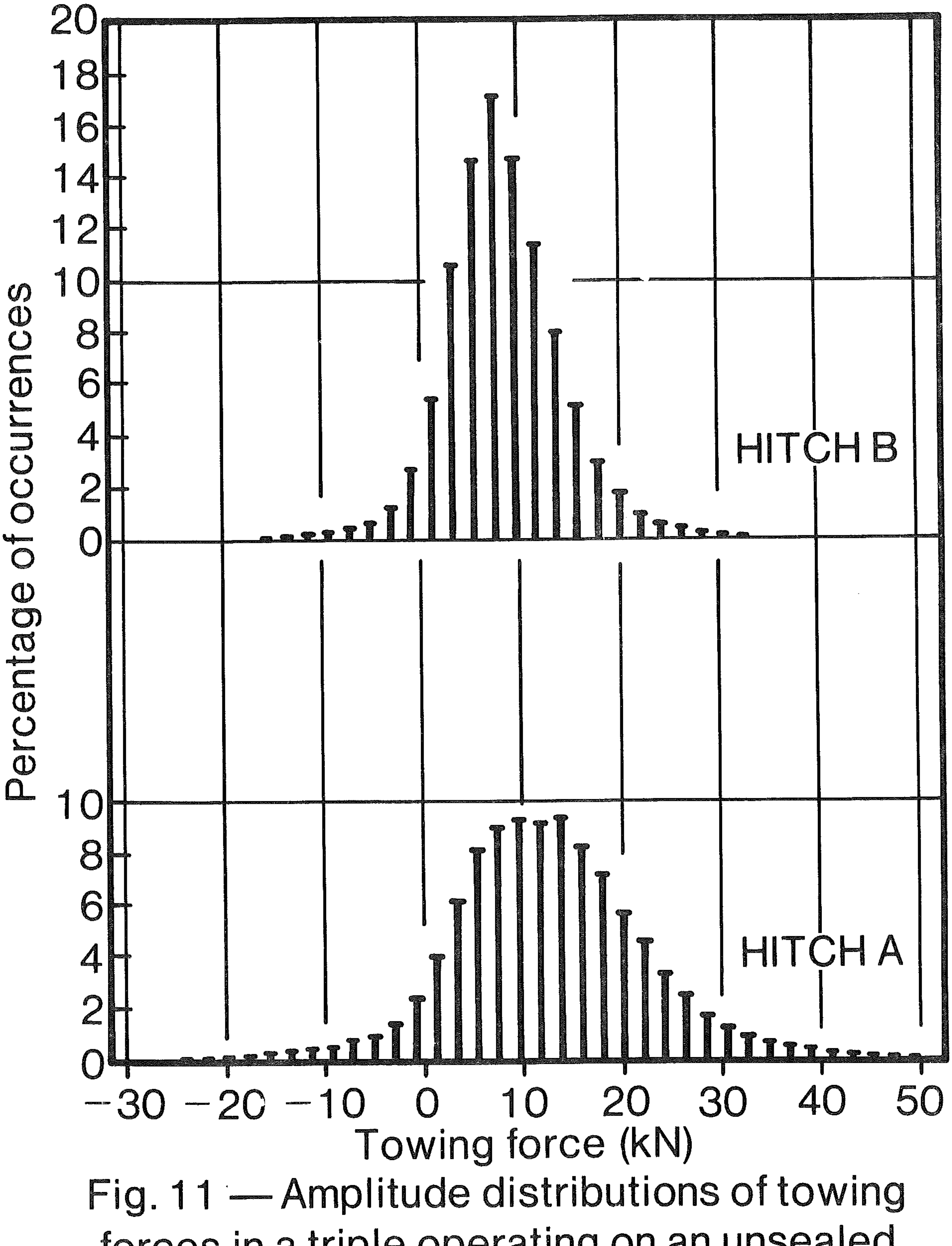


Fig. 11 — Amplitude distributions of towing forces in a triple operating on an unsealed road (log 13)

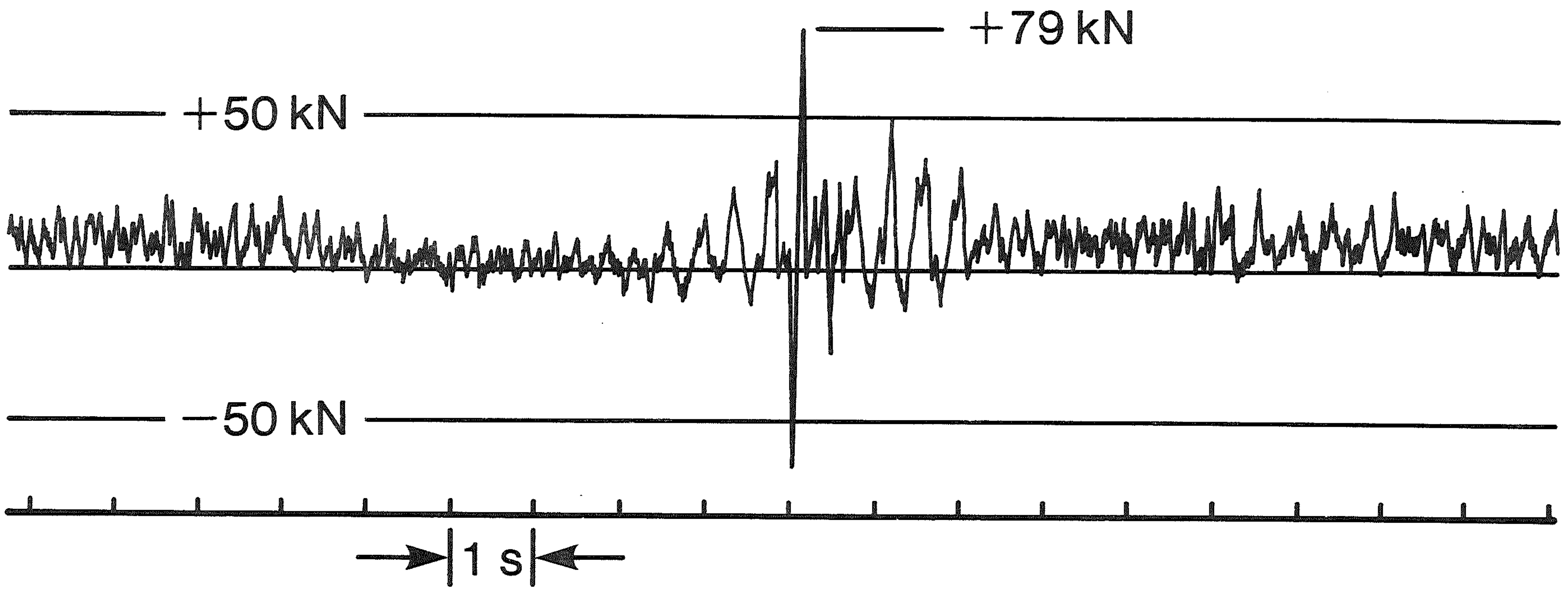


Fig 12 - Time history of hitch force in double travelling at low speed over rail crossing on unsealed road between Marla Bore S.A. and N.T. border. (log 18)

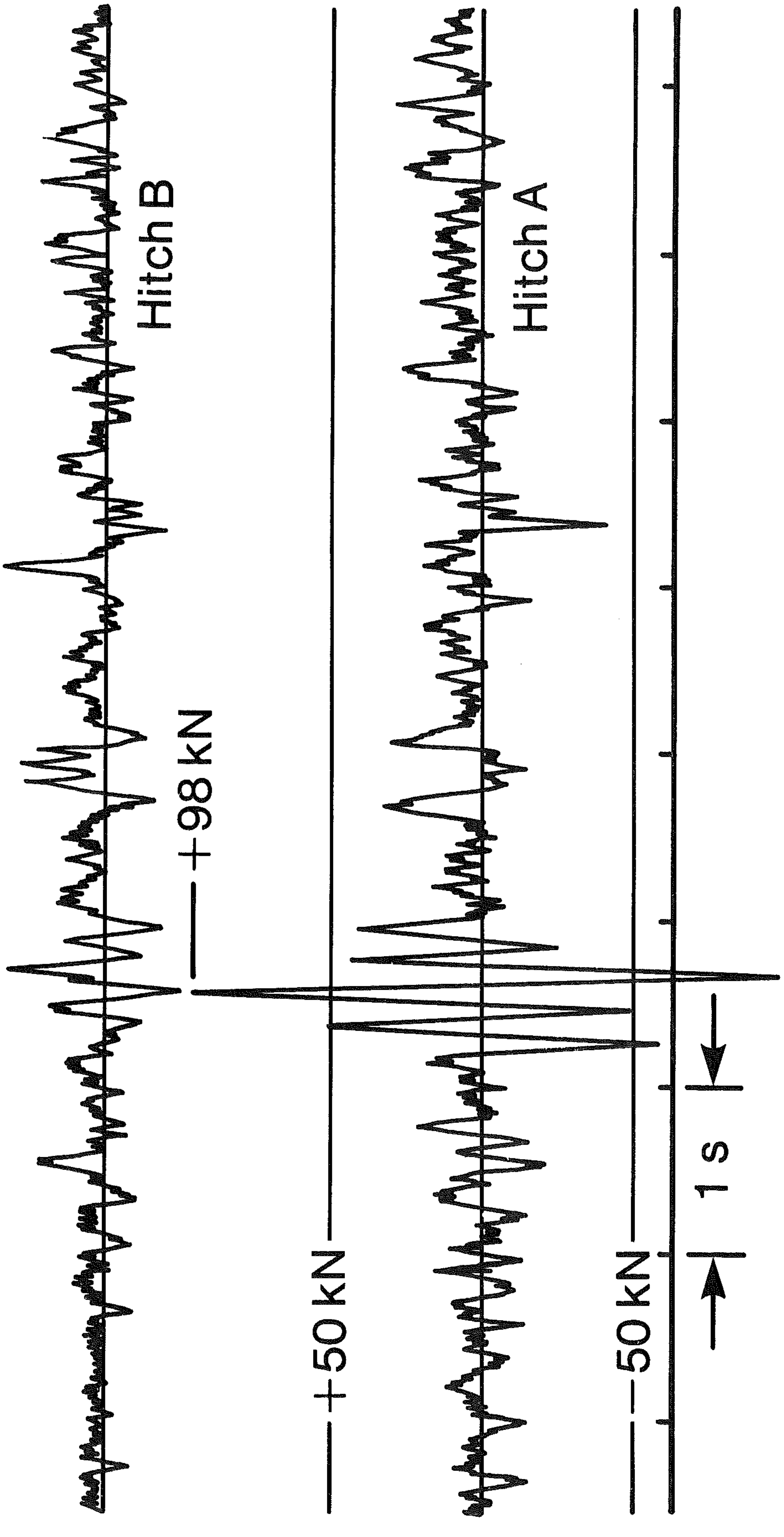
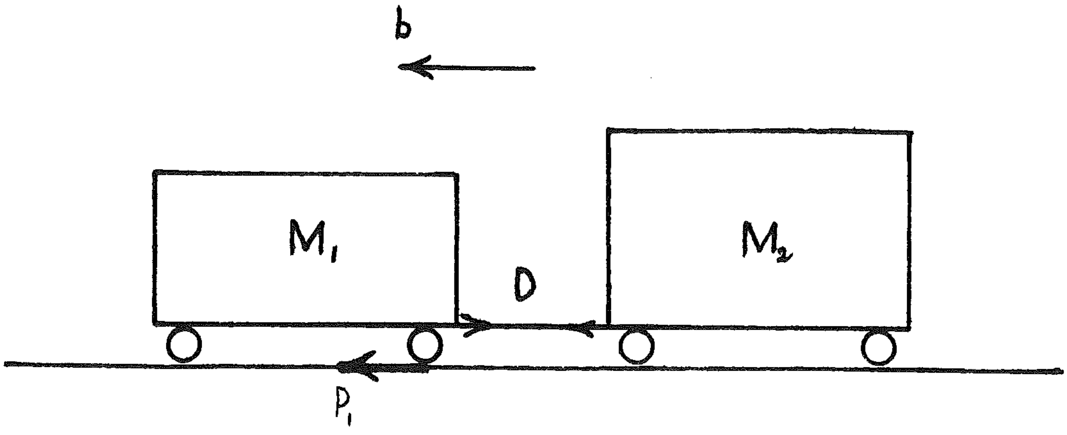
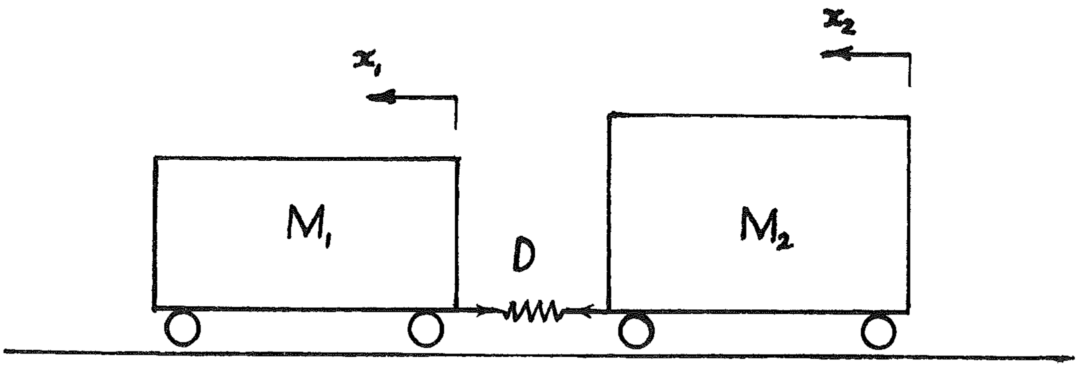


Fig 13 – Time histories of hitch forces in a triple travelling at low speed over rail crossing near Mt Willoughby S.A. (Log 14)



(a) Steady-state model used to derive D-rating.



(b) Dynamic model which can be related to D-rating.

Fig 14 - Steady-state and dynamic models of a double.

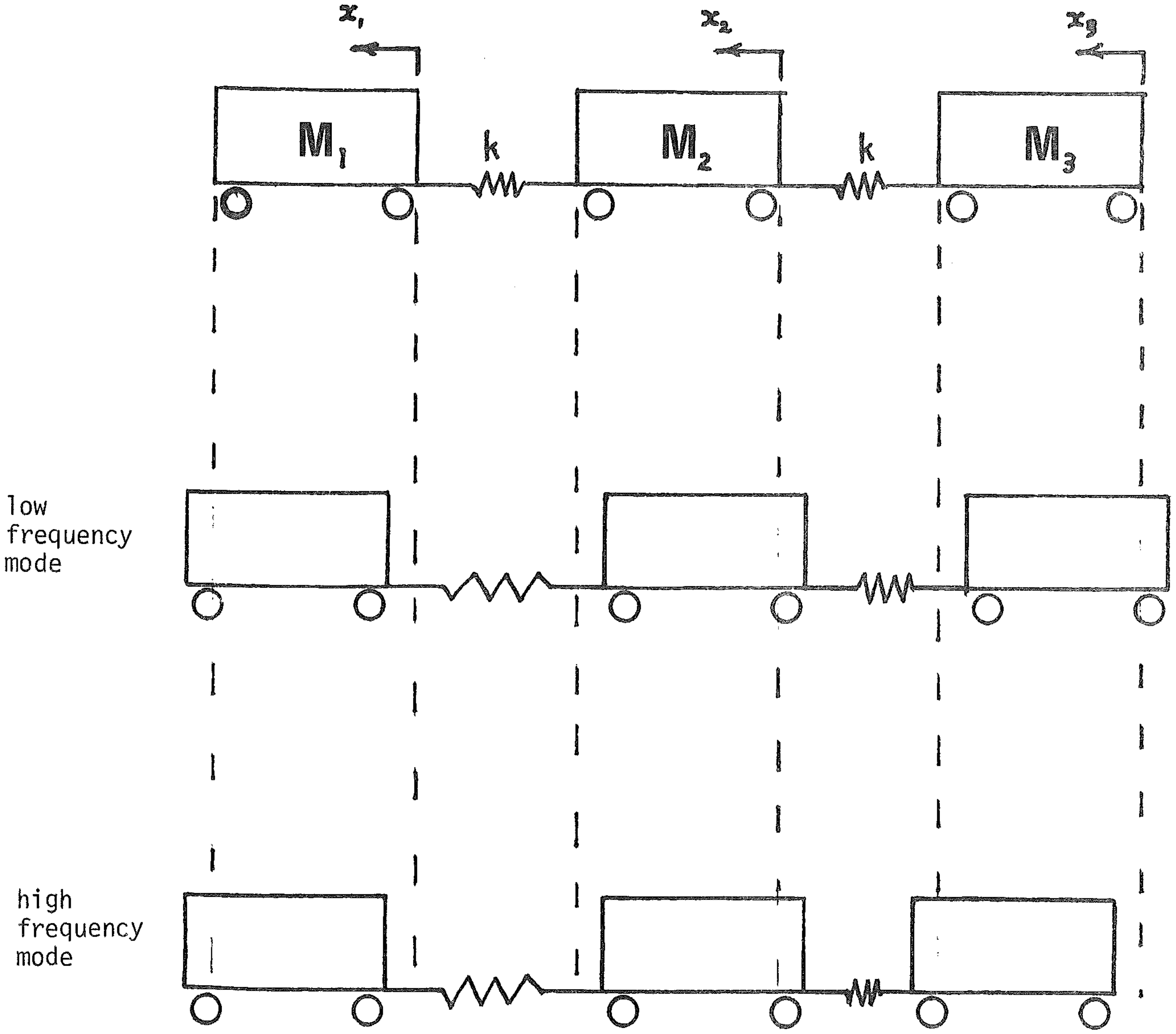
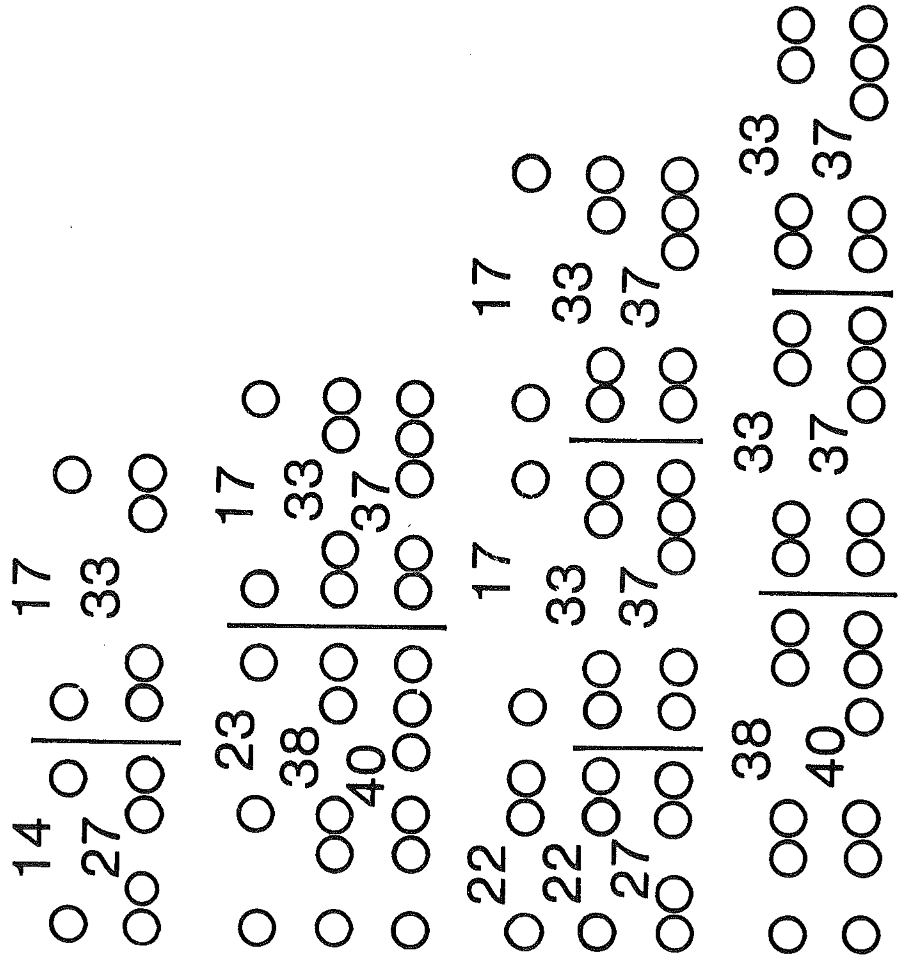


Fig 15 - Simple dynamic model of triple



D-Rating	Modified D-Rating	E-Rating
7.7	7.7	$\boxed{6.0}$
14.9	14.9	11.8
9.8	8.8	$\boxed{6.6}$
17.7	15.9	12.6
19.2	17.3	13.5
13.4	12.0	10.3
16.6	14.9	15.1
19.8	17.8	16.4
24.1	18.1	15.5
26.0	19.5	16.8

Fig 16 - Comparison of rating schemes

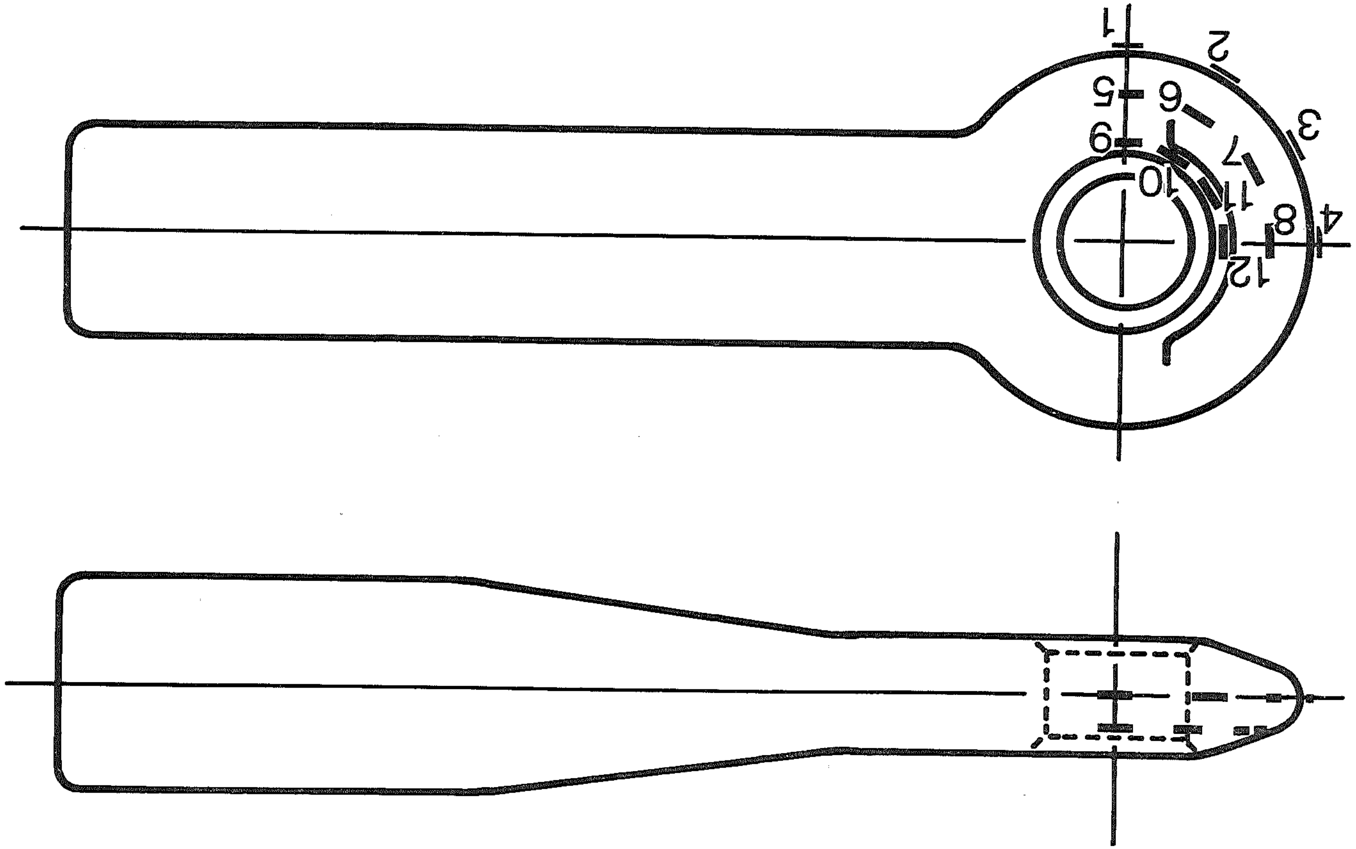


Fig 17 - Strain gauge layout used in laboratory testing of a 40 mm hitch eye.

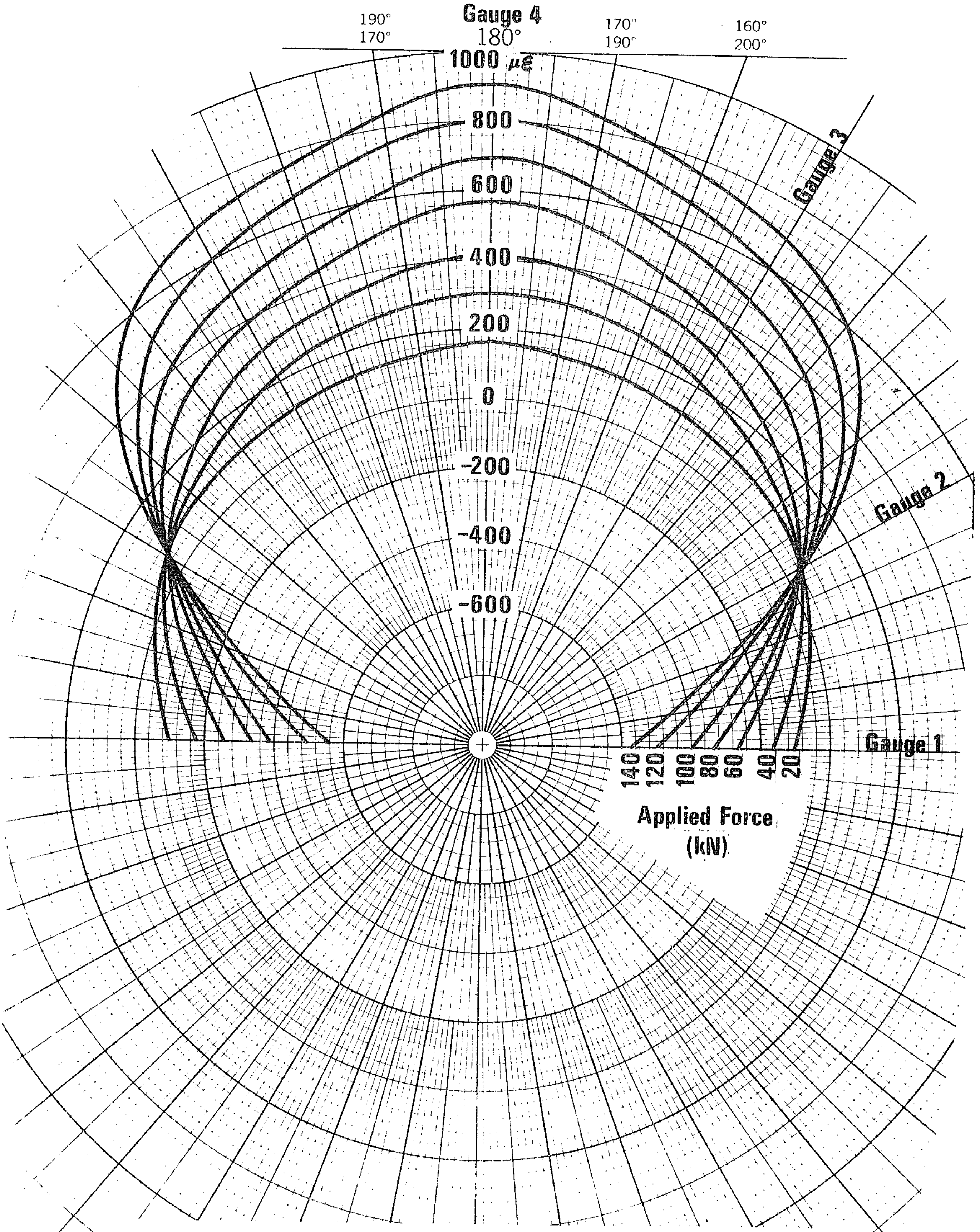


FIG. 18. Strain at selected locations on a 40 mm ISO drawbar eye as dependent on applied tensile force