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ARTICULATED VEHICLE ROLL STABILITY: METHODS OF ASSESSMENT AND EFFECTS OF VEHICLE CHARACTERISTICS

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ABSTRACT

Nine high laden articulated vehicle combinations from 32 tonnes (Mg) to 45 tonnes (Mg) gross train weight were driven into a roll over condition on different manoeuvres to assess their stability in roll and the effect of different vehicle characteristics. The vehicles were also tilted sideways on a platform to the point of balance. Roll over occurred at lateral accelerations from about 0.2g. Trailer roll was the governing factor in the overturning of the combinations tested. Increased spring stiffness, spring base width and coupling stiffness increased the trailer roll resistance. Measurements demonstrated that the tilt method gave a good indication of roll stability. Calculated results from a computer program of lateral acceleration required for roll over differed from the dynamic results by 10 to 40 per cent. Roll over occurs in 3–4 per cent of heavy goods vehicle injury accidents. A higher percentage of articulated vehicles roll over than rigid vehicles. Reasons for this are considered to be geometric layout, lack of driver awareness of the total roll of an articulated combination and a tendency for a rigid vehicle to become self stabilising due to loss of drive in roll. Multiple turn manoeuvres did not increase the risk of roll over. A roll over warning device could be useful.

1. INTRODUCTION

Roll over occurred in 3–4 per cent of heavy goods vehicle injury accidents with articulated vehicles twice as likely to roll over as rigid vehicles. Heavy goods vehicle roll over accident rates are discussed. In some earlier work[1], the Laboratory developed a method of test in which large commercial vehicles could be driven through different manoeuvres to the point at which they would normally roll over. This test has now been used to determine the limits of lateral acceleration for roll over of several high laden articulated vehicles and the effect of some different vehicle characteristics on these limits. This report describes the tests made and the results obtained. A comparison is made of the results from these dynamic tests with those from static tilt tests and a computer program developed from a theoretical appraisal by the Motor Industry Research Association[2].

2. ROLL OVER ACCIDENTS TO ARTICULATED AND RIGID VEHICLES

Data concerning fatal and injury accidents occurring in the UK are recorded by the Police and processed by computer at the Laboratory (see Stats 19). Data have been tabulated for the years 1971, 1972 and 1973 which indicate the number of articulated and rigid vehicles that rolled over at roundabouts, at other junctions and at non-junctions. The numbers are also given as a percentage of total accidents in each category (Table 1).

Overturning occurred in 3 per cent to 4 per cent of injury accidents involving heavy goods vehicles and as Table 9 shows the majority (about 60 per cent) involved only single vehicles, indicating that vehicle stability and roll over were the cause rather than the result of the accident. An earlier survey of commercial vehicle accidents[2] has shown little difference in the accident rates of rigid goods vehicles and articulated goods vehicles. The figures in Table 1 therefore indicate that articulated vehicles had twice the proportion of roll overs as rigid vehicles in their accidents and overturning of the former is particularly likely at roundabouts. For these vehicles roll over occurred in 30 per cent of all accidents on roundabouts and in over 90 per cent of these cases no other vehicles were involved.

In accidents occurring in Hampshire from 1965 to 1968 overturning accidents accounted for 20 per cent of all injuries to medium and heavy commercial vehicle occupants[3]. Frequently however, roll over accidents do not involve injury and are therefore not reported in national accident statistics (Stats 19). At one roundabout on the A33 Hampshire County Council reported that 10 roll over accidents occurred to heavy goods vehicles in a 2 year period, but none involved injury and were not therefore reported as accidents. This type of accident can still be very costly since load damage alone may amount to thousands of pounds per incident. In 1973 one overturning accident on the M5 resulted in both carriageways being closed for more than 12 hours resulting in severe traffic congestion and delays to users of this and other roads in the area.

3. TESTS MADE

Static tilt and dynamic roll tests were made to assess the following vehicle combinations. Details of the vehicles used in these tests are given in Tables 2 to 4.

3.1 Roll stability of High Laden Vehicles of different gross weight

The first series of tests was made with four articulated tractor and skeletal semi-trailer combinations carrying either two 6m containers or one 12m container ballasted to give a gross train weight to the manufacturers' recommendation ranging from 32 tonne to 45 tonne. The containers were packed with small, aggregate-filled boxes, uniformly distributed and firmly anchored in position. Thus the centre of gravity of the load lay at the centre of the containers, about 2.5m above ground when in position on the trailer.

All the combinations were instrumented as shown in paragraph 3.2.3.

3.2 Effect of trailer spring base

Fully instrumented tests were made with a three axle tractor coupled to a semi-trailer with a normal spring base, and then with one having the spring mountings set 115mm further apart. Both semi-trailers were otherwise to the same specification, made by the same manufacturer, and were new. Two 6m containers loaded as previously were used to give a gross vehicle weight of 32 tonnes with each semi-trailer. Results from these tests were used for comparison with the computer program.

3.3 Effect of liquid load

Tests on which only the lateral acceleration and speed were measured were carried out on a 3 axle tractor and a semi-trailer tank carrying liquid nitrogen to indicate the effect of movement of a liquid load on the lateral stability of a vehicle. The combination was tested at 32 tonnes gross train weight when the volume of the tank semi-trailer was only 75 per cent full. Some additional tests were later made with a 27,400 litre petrol tanker, details of which are given in paragraph 5.5, Table 10.

3.4 Effect of 2 or 3 axle tractor

Some firms had indicated a driver preference for 3 axle tractors on the grounds of increased stability. Tests were made with the liquid nitrogen trailer in combination with a 2 axle and with a 3 axle tractor of the same make. Both combinations were tested at 32 tonnes train weight, more nitrogen being carried with the 2 axle tractor. There were other differences between combinations, perhaps the most important being the positioning of the fifth wheel coupling relative to the tractor rear axle. This was further to the rear on the 3 axle tractor than was the case with the 2 axle tractor. The load centre of gravity with the 2 axle tractor was about 2.5m above ground level with the 3 axle tractor and reduced load it was 2.1m.

3.5 Effect of steering torque and rates

It has been suggested that combinations having tractors fitted with power steering are more likely to suffer roll over accidents, as the drivers can manoeuvre them faster. Some measurements of steering torque and rates of turn were therefore made.

4. DESCRIPTION OF TESTS

4.1 Static tilt tests

Vehicle combinations were first tilted laterally (Plate 1). The combinations in test condition except for the skid were driven onto a tilt platform and loosely chained to the platform. The wheels on the lower side were chocked to prevent sideways sliding. The platform was then tilted hydraulically at different increments from level to the point of balance, the increments becoming smaller as the latter was approached. This was determined as the point at which the complete outfit could be readily rocked by one hand from the rear uppermost trailer platform corner, or to where the angle of the vehicle tended to increase without additional tilting. At this point the upper trailer rear wheels were well off the platform, and in most cases the upper tractor rear wheels were also clear. Theoretical work in Germany[4] showed that when this occurred a combination could be considered to be in a roll over condition. All vehicle combinations were tilted in the straight ahead position. One or two tests were made with the trailer parallel to the platform and the tractor at an articulated angle of about 35° to determine any differences due to articulation.

4.1.1 Measurements made At each increment of tilt, measurements were taken of platform angle, tractor angle, and trailer angle using a clinometer. Measurements were also made of axle centre heights from both the ground and the load platform of the trailer. Fifth wheel separation at the upper outer edge was also noted. Platform and trailer angles were noted at each end and the average of each used in the results. (The measurements are shown in Figure 1.)

4.2 Dynamic tests

The main object of these tests was to obtain the roll characteristics of high laden vehicles. These were obtained to compare with suggestions of a theory[5] that coincidence of steering rate and roll frequency in multiple manoeuvres such as S bends and roundabouts would amplify the roll angle and increase the risk of roll over. It was decided to carry out one or two tests on these manoeuvres as well as those on a single radius curve.

4.2.1 Outrigger To enable a point of instability to be reached without permitting the vehicle to roll right over an outrigger was fitted to the trailer to arrest the roll when a shoe on the end of the outrigger came into contact with the ground. The height of the shoe from the ground was adjusted to allow an angle of roll slightly greater than that achieved on the tilt platform. This device proved adequate in stopping roll and no damage was caused either to a vehicle or to the surface in these tests. In demonstrating that the trailer governed the degree of roll, the tilt tests indicated that outriggers were not required on the tractor. Plate 2 shows the outrigger fitted and in roll contact with the ground.

4.2.2 Test procedure Complete circles of 20m, 30m and 40m radius were used for the steady state tests. The S bend consisted of 30m radius curves and the roundabout island was of 20m radius (Figure 2).

On the curve and 'S' bend manoeuvres, the test procedure consisted of driving the vehicle at a steady speed anti-clockwise around the desired path for one complete lap, keeping the rear nearside trailer wheels as close as possible to the nominated curve for the whole of the run. At the end of each run the vehicle was driven on a curve in the opposite direction to that taken on the test, to remove any "set" which might have been put in the springs. The 'straight ahead' direction through the roundabout was chosen, as this gave the most rapid steering reversals. The choice of line taken was left to the driver to be the one most likely taken on the road, assuming a clear run through. In all cases this resulted in the driver entering the roundabout with his offside wheels close to the entrance lane centre line, then keeping his trailer wheels as close as possible to the roundabout inner radius before leaving this tangentially to bring the tractor off-side wheels close to the centre line of the exit lane. Subsequent runs of any type were made with the speed being increased each time until the vehicle rolled over onto the skid. As soon as this happened, the driver straightened the vehicle to bring the trailer back up again. Radio contact was kept with the driver through-out the run to give him the precise moment at which the skid touched the ground, as it was felt undesirable to prolong this. The driver could otherwise tell when the skid was on the ground only by observing it in his mirror.

4.2.3 Measurements made The following data was recorded for each run on a galvanometer recorder carried in the cab of the vehicle.

(1) Roll Angle of tractor and semi-trailer using gyroscopes coupled to potentiometers. The outputs from the gyroscope proved somewhat unreliable, and spring deflection and axle lift were used to obtain roll angles in some instances.

(2) Spring Deflection of the tractor and semi-trailer axles by potentiometers at each end of the axles, linked between the axle and chassis so as to measure the relative movement between them.

(3) Angles of the rear tractor and semi-trailer axles relative to the ground. Measured by potentiometers linked between the axle outer ends and arms of a trailing castor (Plate 2).

(4) Steering Wheel Angle from a friction driven potentiometer.

(5) Lateral Acceleration. A potentiometric accelerometer mounted midway along the trailer just below platform level. The measurements obtained were corrected for semi-trailer roll as indicated by (1).

(6) Articulation Angle of tractor and semi-trailer by a potentiometer linked between the two.

(7) Speed. By a fifth wheel mounted near the longitudinal centre line of the tractor. A direct reading indicator head graduated in ½ mile/hr was placed in the cab in a position where it was visible to the driver at all times.

A record showing these traces as a vehicle went on to the outrigger shoe is shown in Plate 3.

4.2.4 Trailer suspension natural frequency A potentiometric accelerometer was mounted vertically on the side of the trailer. Six-inch ramps with a vertical drop at one end were positioned under the semi-trailer wheels on one side only and the trailer then driven very slowly over them, allowing the wheels to drop simultaneously. The accelerometer output recorded on the film against a time base gave the natural frequency and decay rate.

4.2.5 Steering torque On some of the combinations a strain gauged steering wheel (clamped to the standard one) was used to measure the maximum torque required to steer them on a 180^{o} turn round a 20m inside radius. The turn was approached and left at a tangent. A constant speed of 16 km/h was maintained during the test, except where combinations with power steering systems were tested in the power failed mode. In these tests the combination approached the turn at 16 km/h, the engine was turned off before the curve was entered and the vehicle coasted round.

4.3 Computer assessment

The MIRA computer program[6] uses data from tilt tests to calculate roll stiffnesses which are then used in a set of equations and solved by computer.

However, in order to get the roll stiffnesses required, it is necessary to obtain measurements at intervals as the tilt platform angle is reduced as well as when it is increased. This is to determine the hysteresis in the system. It is also necessary to tilt the trailer (loaded) without the tractor to obtain the roll stiffnesses and hysteresis of the trailer alone. This gives a measure of the stiffness contributed by the tractor through the fifth wheel coupling.

The latter test was done on the last vehicle only (the trailer with a wide spring base), and was carried out at MVEE Chobham using a rig comprised of a framework with a fifth wheel plate mounted on it, to support the trailer at the king pin. This was placed in position (using the landing legs as interim support for the trailer) and subsequently turned through 90^{o} to give support only in the vertical and fore-aft directions. The trailer was free to pivot laterally at this point. The trailer was then loosely chained and tilted until the rear nearside bogie wheels were well clear of the platform. At this point, the trailer was being restrained by the chains, and the point of balance had been passed. The platform angle was then reduced and further readings taken. An attempt was made to obtain information from manufacturers and to estimate the required data for three of the other vehicle combinations to obtain further comparisons.

5. RESULTS

5.1 Dynamic tests

The track area used for the dynamic tests has a constant slope of 1 in 50 and roll on to the skid occurred at the point of maximum slope. Corrected values of roll angle relative to a level surface are given in the tables and are the values used for the figures.

5.1.1 Constant radius turns The results of the dynamic tests on the circles are given in Table 5. Curves of lateral acceleration of tractor and trailer plotted against the roll angle (of the body relative to the track) achieved on the 30m radius curve are given in Figures 3–11, together with those for the equivalent lateral acceleration obtained on the static tilt tests. There was little difference in the shape of the curves or the values on either the 20m, 30m, or 40m curves used in the tests. The results obtained on the 30m curves are given in Figures 3–11 only because they are the middle of the range results.

Table 5 shows that the lateral accelerations at roll over ranged from 0.2g to over 0.3g. It can be seen that the greatest difference was between combinations of vehicles rather than radius of turn. The similarity in the results on the different radii indicates that the articulation angle between tractor and trailer within the 10 degrees to 12 degrees achieved had no significant effect on the roll stability of these vehicles.

From both the curves of roll angle against lateral acceleration given in Figures 3–11 and from visual observation on the curves it was obvious that the degree of roll of the trailer was the governing factor. The body roll of the tractor with the vehicles tested was about half that of the trailer at roll over point (Figures 3–11). This was also confirmed by results obtained when the trailer from the 38 tonnes combination was used with the tractor from the 45 tonnes combination. Peak lateral accelerations at a roll over of about 0.27g were obtained as for the original 38 tonnes combination. These compared with 0.20g for the 45 tonne combination.

Observations during these tests also substantiated the theoretical work done in Germany[4] which indicated that both inner trailer wheels could lift clear of the ground, but the vehicle would still be in a stable condition. However, if the tractor drive axle lifted as well the vehicle would roll over.

5.1.2 Other manoeuvres Earlier unpublished work by the Laboratory has shown that there is no practical difference in the speeds at which vehicles of this type can negotiate a multiple bend manoeuvre compared with a single radius turn. The reasons for this are discussed in an article published in the Commercial Motor[5]. Runs were made with the fully instrumented 45 tonne combination on the S bend manoeuvre and with 4 combinations on the roundabout manoeuvre to check that roll overs are not the result of steering and suspension frequencies coinciding to cause even greater degrees of roll. Records of steering wheel movement in both S bend and roundabout manoeuvres showed a smooth sinusoidal movement from one side to the other.

5.1.2.1 S-bend manoeuvre Table 6 shows the time between the maximum roll points corresponds to a frequency completely out of phase with the natural frequency of the trailer suspension as predicted in Reference 5. It is not surprising therefore, that the results obtained on the 'S' bend and the plain circle of equivalent radius are very similar.

5.1.2.2 Roundabout manoeuvre The roll over speed on the roundabout manoeuvre was greater than that on the equivalent constant circle test (Table 7) not less as might have been expected with an adverse roll momentum effect. It was observed however, that the driver took the straightest line possible in this manoeuvre. The rate of steering movement necessary for this manoeuvre and the roll frequency of the trailer were completely out of phase.

5.1.3 Speed at roll over Table 5 shows that the speed at roll over point varied from about 23 km/h to about 30 km/h on the 20m circle, from about 28 km/h to 35 km/h on the 30m circle and from 32 km/h to 40 km/h approximately on the 40m circle for the different vehicle combinations tested. On a smaller radius turn or with a higher load centre of gravity, a given vehicle would roll over at even lower speeds. The difference in speed from all wheels being in ground contact to the speed at roll over could be less than 2 km/h on a 20m radius curve. It did not exceed 4 km/h on the 40m radius curve.

The actual time for roll over to occur was not measured. In the 'S' bend manoeuvre however, the distance travelled at constant speed from the change of direction point when the trailer wheels were last observed in ground contact to their position on the curve when the skid touched down indicated that this was no more than 2 secs even in the slowest case.

5.2 Tilt tests

Curves of roll angle of the tractor and trailer against equivalent lateral acceleration (actually the gravitational component acting parallel to the tilt platform) are shown in Figures 3–11. The points show some deviation from a smooth curve but this can be attributed to friction in the vertical suspension which gave rise to sudden lurches at different angles during testing. Binding of suspension springs against hanger brackets was frequently observed. The readings of trailer angle differed by about 2^{o} between front and rear at the roll over point. The average of the two readings is used in the graphs. The results obtained with an articulation angle of about 35^{o} were similar except that the roll over point was reached at a slightly lower tilt angle (about 3^{o} less) in all cases. This endorses the results of the dynamic tests on curves of different radii (5.1.1), which indicated that articulation had little effect.

Table 8 shows the lateral acceleration for roll over deduced from the tilt tests for the different combinations tested to be from 0.21g to 0.33g and to be the same or not more than 0.02g higher than those obtained in the dynamic tests.

5.3 Comparison of a computer assessment with the results of tilt and dynamic tests

Where complete tilt programmes of the vehicle combination and the trailer alone were carried out to provide basic data, the computed limiting lateral acceleration was the same as that obtained from the dynamic tests, (Table 7 ERF/TASKER wide spring base). With the other combinations shown in Table 8 data obtained from a tilt test of the complete combination only supplemented by data obtained from manufacturers or, where this was not available, estimated, gave good agreement in two cases. With the other two combinations the results showed differences of more than 40 per cent.

As a small exercise, it was decided that for the three vehicles where good agreement was obtained, to put in values for the fifth wheel coupling stiffness (KIF) of zero and a figure approaching infinity. This has the effect of simulating an outfit where the trailer is free to roll about the fifth wheel and one where it is held perfectly rigid in the roll sense. This should show how the fifth wheel coupling is performing in practice, and the results are shown in Table 8. In all cases where the computed figures are considered, an improvement in stability could be made by making the fifth wheel coupling less compliant. The figures computed for the normal fifth wheel stiffness for the ERF/Tasker combination, suggest that there is no advantage in having a wide spring base on the trailer, but the dynamic results show a small advantage.

5.4 Effects of vehicle characteristics

The height of the centre of gravity of the vehicle and its load are of primary importance in the roll behaviour of a vehicle[6]. In a fully laden vehicle in which the load forms the greater part of the mass this will depend to a large extent on the nature of the load and the height of the load platform. Tyre loadings and vehicle size regulations tend to dictate the platform height in present day vehicles. Results of tests to determine the influence of other design factors were as follows.

5.4.1 Suspension stiffness The effect of trailer suspension stiffness is shown in Figure 12. The trailer used in the 45 tonnes combination rolled much more relative to the rear axle for a given lateral acceleration than the other comparable vehicles reducing the roll over speed on a 30m radius curve to 0.21g the lowest value recorded in these tests. The total stiffness of trailer suspension was 3.6 MN/m compared with 4.9 MN/m for the 38 tonnes combination which achieved 0.27g. The delay in the rise of the roll angle for the 38 tonnes Guy/Crane Fruehauf is thought to be due to friction in the suspension system due to a spring leaf binding on a spring hanger in this particular test.

5.4.2 Spring base width Both the dynamic and tilt tests showed that with two trailers identical except for the trailer spring base increased from 965mm to 1080mm the speed at which instability occurred rose by 2 km/h (0.02g) on a 30 metre radius, an increase of about 7 per cent. Figure 13 shows the reduction in trailer body roll relative to the rear axle, due to the wider spring base.

5.4.3 Fifth wheel couplings All the vehicle combinations tested were fitted with fifth wheel type couplings. Measurement of the gap between the trailer plate and the edge of the fifth wheel during tilt tests indicated little roll stiffness at the king pin until a considerable roll angle had developed on the trailer (Figure 14) in some cases. Table 8 shows the calculated effect of fifth wheel stiffness on some of the combinations using the MIRA computer program. This can be as high as 0.07g.

5.4.4 Two and three axle tractor In these tests the rear-most axle of the three axle tractor lifted off the ground before the trailer wheels, due possibly to the coupling position being different in relation to the rear wheels from what it was with the two axle tractor.

Inspection of the curves of lateral acceleration and body roll obtained from the results (Figures 10 and 11) indicates that roll over would have occurred at a lateral acceleration of about 0.32g for the three axle tractor combination, compared with about 0.31g for the two axle tractor combination. The figures obtained on the tilt test (0.33g and 0.31g respectively) are consistent with these.

From these tests it would appear that the combination with the three axle tractor was marginally the more stable, but weight regulations necessitated reducing the payload, hence lowering the centre of gravity, in order to compensate for the extra weight of the heavier tractor and this provided the additional stability.

However, whereas with the 2 axle tractor combination the tractor rolled to an angle of 4^{o} at a lateral acceleration of 0.25g (Figure 11), with the 3 axle tractor combination, the lateral acceleration for the same degree of tractor roll was over 0.3g (Figure 11). It could therefore be expected that drivers of 3 axle tractors would feel more confident despite very little difference in roll over stability of the combinations. This suggests that the 2 axle combination may be the safer.

5.4.5 Steering torque Only one of the combinations tested had manual steering, the 32 tonnes Guy/Boden combination. Table 9 shows that the torque required at the steering wheel rim was 65 Nm compared with 50 Nm of the heaviest of the powered steering systems. The rate of application of the steering was governed in all the tests by the manoeuvre and radius of turn rather than the effort required from the driver. When the three power steering systems were cut off, the steering torques required were in excess of 176 Nm and the driver was beginning to experience difficulty with all three vehicles in getting the lock on quickly enough to retain the desired path. With the engine off, speeds fell to about 3 km/h at completion of the turn.

5.5 Effect of liquid load

In the tests with the low temperature bulk liquid tanker with about 75 per cent of the tank volume occupied by the liquid, there was no practical difference in the lateral acceleration achieved on the S bend manoeuvre than that achieved on a steady radius turn, the lateral accelerations corresponding to the point of instability being 0.31g and 0.32g respectively. This indicates that liquid movement due to changes in lateral acceleration was having little effect on vehicle roll.

Movement of a liquid inside a tanker trailer is commonly considered to contribute to roll over. Some additional tests have therefore been made with a petrol tank trailer partially filled with water. (The liquid nitrogen tanker used in the main tests had a limited liquid capacity.) Table 10 gives details of the vehicle and Figure 2 the tests made. The results (Table 11) confirm the earlier tests made with tanker vehicles and show no practical difference in the degree of roll from the various tests at nominally similar conditions. In view of the light construction of the tank, it was considered inadvisable to permit the skid to actually make ground contact and tests were not taken to the point of actual roll as the difference in the dynamic test results and those of the tilt tests indicate. The roll stability of the tanker trailer in these tests was as good as the best of the container vehicles.

A pendulum freely suspended in the front tank compartment and cine film taken of the water movement relative to the tank and pendulum (Plate 4) clearly showed that the water surface always remained normal to the pendulum with no apparent lag or out of phase movement. There was no evidence of liquid resonance. In tests in Sweden with a rigid tanker carrying a liquid load, the frequencies of a double lane change manoeuvre were also too low to cause liquid resonance[7]. In roll, movement of the tank is transmitted to the fluid only by friction between the two and in this case appeared negligible. In braking or acceleration the tank structure acts directly on the fluid causing flow and turbulence which rocks the trailer in a longitudinal direction and can be felt in the cab of the vehicle. This would seem to indicate that longitudinal baffles might have little practical effect on roll stability. It was thought that braking with the vehicle approaching the limit of lateral acceleration might cause added roll due to the forward surge of the load and the vehicle articulation angle. A test was therefore carried out in which the brakes were applied quickly and reasonably hard when the vehicle was in a turn at an estimated articulation angle of 10^{o} and the inner wheels of axles 3 and 4 lifting clear of the ground. The trailer immediately returned on to all wheels with no increase in roll angle. The evasive tests (Figure 2) made with this vehicle showed that it was possible to carry out a manoeuvre that would result in roll over on a straight road at speeds as low as 40 km/h. It is possible that with liquid loads having a relatively high viscosity out of phase movement could occur and adversely affect handling and stability. No work has been carried out on this.

6. DISCUSSION OF RESULTS

Tilt tests are already required in the United Kingdom as an indication of P.S.V. stability. Good agreement of the results obtained in the dynamic tests with those deduced from tilt tests indicate that a tilt test is a reliable indication of the limiting lateral acceleration of a laden commercial vehicle due to roll. It should of course be remembered that roll over will occur only where the friction characteristics of tyre and road surface exceed the lateral roll over acceleration of the vehicle. If lateral acceleration exceeds the friction available, trailer swing and/or jack-knifing will result.

There are a number of tilt platforms in the UK used for tilt testing public service vehicles but only two, those at the Ministry of Defence, Military Vehicle Experimental Establishments of Chobham and Christchurch are capable of tilting vehicles over 8 metres long or 16 tonnes gross weight. Since publication of earlier results by the Laboratory, some operators are known to be using this method to compare the roll characteristics of vehicles in their fleet.

The computer program prepared by MIRA[2] uses data obtained from tilt tests, which themselves give good correlation with the dynamic tests. However, the real advantage of the program is that having established its validity for an existing vehicle, any one of several parameters can be varied theoretically to see what effect this might have on stability. This facility should be very useful to the vehicle manufacturers. However, using spring rates quoted by the vehicle manufacturers, the combination which had the softest trailer springing (Guy/Scammell) gave the highest forecast of roll over g (0.32g) whereas the figure obtained in the dynamic tests (0.21g) was the lowest of the combinations tested. It is possible that this is one area in the computer program which could usefully be improved.

In the tests reported in this note, there was no indication that vehicle roll for a given radius of turn and speed built up to a greater degree in 'S' bend and roundabout manoeuvres than on a single bend. As the rate of steering required in even the tightest of these manoeuvres was governed by the manoeuvre and not driver effort power steering is unlikely to be a significant contributory cause in roll over accidents. The much larger percentage of articulated vehicles than rigid vehicles rolling over particularly on roundabouts, requires some explanation however. Consideration of the results indicate that the reasons may be:

1. The difference in geometric layout between articulated and rigid vehicles. The effective track width is 2a rather than $2a_1$ (see Figure 15) in the critical parameter for roll (ie the ratio of centre of gravity height to track). The further forward the load centre of gravity on a semi-trailer, the greater the reduction below 2a. It is probable that the roll in the cab of an articulated combination is less than that in the cab of an equivalent rigid vehicle.

2. The rigid vehicle is inherently more stable than an articulated vehicle combination, because apart from its geometric layout, there is a loss of drive when the rear wheels on one side lift.

3. There is only a small increase in speed or reduction in radius of turn from an all wheels in ground contact situation to one of actual roll over. With modern long articulated vehicles and elongated roundabouts, it is possible that drivers can accelerate while still in the roundabout, the 2 km/h or so necessary to cause overturning when leaving the roundabout before the trailer straightens up. Alternatively, a driver may have to change his course abruptly through a roundabout, either because of misreading the correct path or because of interference from other traffic. As Table 5 shows, a vehicle with a high load travelling at 30 km/h on a 30m radius with all wheels in ground contact, may roll over if the radius of turn is reduced to 20m (representing about a quarter of a turn of the steering wheel) if speed is not also reduced.

As the results show, some improvement in roll stability can be obtained by increasing the roll stiffness of the trailer. Spring bases and overall width and track should be as wide as vehicle width regulations permit. The trailers carrying comparable loads on stiff suspensions achieved higher lateral accelerations to roll over than one with a soft suspension. Soft suspensions, however, cause less wear and tear on the road surfaces[8] and may be required for load protection. Dual mode suspensions, relatively soft in the bump condition but stiffening considerably at high levels of roll, may be feasible (ie analogous to anti-roll bars for cars).

Ensuring maximum stiffness at the coupling will assist by providing greater utilization of the side stabilising influence of the tractor and also, by making the degree of roll of tractor and trailer more nearly equal, increase the driver's awareness of the situation of the combination as a whole. A different form of coupling to give the semi-trailer a wider front linkage than that achieved with a fifth wheel coupling would further improve trailer roll resistance.

Road layouts in which the severity of the bend or layout of the junction is not readily visible and cannot be appreciated by a driver should be avoided. This would reduce the probability of a driver having to tighten up on a turn in a manoeuvre. Excessive adverse camber should of course also be avoided on bends and roundabouts. At one site in London where the Laboratory investigated a number of roll over incidents, excessive negative camber on the exit of a 90 degree turn was considered to be the main cause of the incidents.

Roll over at even lower lateral accelerations (and hence speed) than reported here, may well be experienced in actual use. It has already been shown[1] in earlier work by the laboratory that at smaller radius of turns where the articulation angle approaches 90^{o}, the component of trailer roll resistance provided by the tractor approaches zero. Forward acceleration of the tractor at these large articulated angles results in a proportional lateral acceleration force on the trailer. Loads with high centres of gravity such as those suspended from van roofs or with centres of gravity further forward than the trailer centre whether due to loading or movement when braking, are other examples where lower roll over speeds may be expected.

Perhaps the greatest reduction in roll over accidents can be achieved by greater driver awareness that roll over is caused by too high a speed and too sharp a turn and that, depending on the tightness of the turn, the critical speed can be very low. In some earlier tests onset of roll over at 22 km/h on a 20m radius was recorded with one vehicle. Some Swedish work has shown that drivers tend to overestimate the cornering capacity of their vehicles at low speeds[7].

If a vehicle does begin to roll, an increase in the radius of turn (running out) or reducing speed by braking has been shown to return the vehicle to normal, providing the actual roll over point has not been reached.

7. CONCLUSIONS

The work described in this report demonstrates that:

(1) Articulated vehicles carrying loads with a centre of gravity about 2.5 metres above the ground can roll over at lateral accelerations of about 0.2g. This represents a speed of about 24 km/h on a 20 metre radius curve. Lateral accelerations sufficient to result in roll over can be generated in evasive and similar manoeuvres within a 6.5m carriageway.

(2) Roll over stability of both rigid and articulated vehicles can be effectively determined from lateral tilt tests. Results deduced from tilt tests agreed very well with those obtained in dynamic roll over tests.

(3) A computer program gave a good prediction of roll over where a separate tilt test of the trailer was carried out to provide basic data.

(4) With the vehicle and load configurations used in these tests, the trailer rolled to a greater extent than the tractor and eventually pulled the latter over. Stiffening the trailer suspension, reducing play by redesign of the fifth wheel coupling and widening the spring base increases the resistance to roll. Optimisation of the fifth wheel and suspension characteristics of existing designs would improve roll stability. Future design work should aim to reduce the centre of gravity of the loaded trailer as much as possible. The use of low profile tyres should be considered.

(5) There was no indication that multi-directional turn manoeuvres increased the amount of roll compared with that for a single uni-directional turn at the same speed and radius. Tests indicated that this held true for liquid loads of low viscosity (water) as well as fixed loads.

(6) Roll over occurred in 3 per cent to 4 per cent of reported heavy goods vehicle injury accidents and over 60 per cent of these were single vehicle accidents. Articulated vehicles are twice as likely to roll over as rigid vehicles in all manoeuvres leading to injury accidents. On roundabouts they are four times as likely to roll over. Reasons for this are probably:–

(i) The difference in geometric layout of articulated and rigid vehicles.. With lateral freedom in the coupling, the trailer, which governs the roll behaviour of an articulated combination is supported on a triangular base of its wheels and coupling point, but the rigid vehicle has a rectangular base of front and rear wheels. This has two effects. The trailer has more roll and so more easily overturns while the tractor portion has less roll and the driver in the cab may not be fully aware of the situation. The driven wheels are also the rearmost on a rigid vehicle and are likely to lift first, causing the vehicle to slow down and so reduce the roll before the point of instability is reached.

(ii) An abrupt change of course because of traffic conditions or misreading the correct path is more likely on a roundabout and can reduce the radius of turn sufficiently to cause the vehicle to roll over if speed is maintained.

(7) The greatest reduction in roll over accidents might be achieved by driver acceptance that roll over is caused (other than in a collision) by too high a speed and too tight a turn. Suggestions of a slow roll phenomenon based on increasing roll momentum with multiple left/right or right/left bends have not been substantiated.

(8) Design improvements which lower the centre of gravity will improve roll performance. Increased coupling stiffness, use of a roll warning device or roll sensitive driver seat suspension could be used to increase driver awareness of approaching roll over.

8. ACKNOWLEDGEMENTS

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The work described in this report was carried out in the Vehicle Safety Division of the Safety Department of TRRL, though the Accident Investigation Division retrieved the accident data.

9. REFERENCES

1. HOLMES, K E. Articulated Vehicle Roll: effect of inverting the coupling. *Department of the Environment, TRRL Report* LR464, Crowthorne 1972. (Transport and Road Research Laboratory).

2. FARR, B N and I D NEILSON. A survey into the accident rates of articulated and rigid commercial vehicles. *Ministry of Transport RRL Report* LR197, Crowthorne 1968 (Road Research Laboratory).

3. JONES, I S. Accidents involving injury to occupants of Commercial Vehicles. 14th International Automobile Technical Congress of FISITA. London, 25–30 June 1972. Paper 3/9.

4. ISERMAN, H. Overturning Limits of Articulated Vehicles with Solid and Liquid Loads. (Die Kippgrenze von Sattelkraftfahrzeugen mit fester und flüssiger Ladung) Dt Kraftforsch und Strass-Verk Tech. No 200. Germany 1970.

5. RILEY, B S. Does Roll Frequency affect Commercial Vehicle Roll-Over? *Comm. M.* 1972 *135* (3458) 42-43.

6. MILLER, D W G and N F BARTER. Roll over of articulated vehicles. Proceedings of a Conference on Vehicle Safety Legislation – Its Engineering and Social Implications held at Cranfield Institute of Technology, 10–11 July 1973. (The Institution of Mechanical Engineers).

7. STRANDBERG, L, O NORDSTROM and S NORDMARK. Safety Problems in Commercial Vehicle Handling. Proceedings of a Symposium on Commercial Vehicle Braking and Handling, held at Ann Arbor Michigan USA, May 1975, Report No 82A (National Swedish Road and Traffic Institute, Linkoping 1975).

8. LEONARD, D R, J W GRAINGER and R EYRE. Loads and vibrations caused by eight commercial vehicles with gross weights exceeding 32 tons (32.5 Mg). *Department of the Environment, TRRL Report* LR582, Crowthorne 1974. (Transport and Road Research Laboratory).

TABLE 1

Injury accidents involving overturning of a heavy goods vehicle

	ARTICULATED VEHICLES								
	1971			1972			1973		
	Total No of Accidents	OVERTURNING All	OVERTURNING Single Vehicle Accidents	Total No of Accidents	OVERTURNING All	OVERTURNING Single Vehicle Accidents	Total No of Accidents	OVERTURNING All	OVERTURNING Single Vehicle Accidents
ROUNDABOUT	188	58 (31)	55 (29)	161	46 (28)	44 (27)	190	52 (27)	50 (26)
OTHER JUNCTION	1682	54 (3)	31 (2)	1637	50 (3)	34 (2)	1495	57 (4)	40 (3)
NON JUNCTION	2333	138 (6)	100 (4)	2311	132 (6)	88 (4)	2344	143 (6)	118 (5)
TOTAL	4203	250 (6)	186 (4.5)	4109	228 (6)	116 (4)	4029	252 (6)	208 (5)
	OTHER HEAVY GOODS VEHICLES								
ROUNDABOUT	309	17 (5.5)	16 (5)	288	17 (6)	13 (4.5)	326	24 (7)	20 (6)
OTHER JUNCTION	6289	94 (1.5)	49 (1)	5969	96 (1.5)	41 (0.5)	5954	184 (3)	50 (1)
NON JUNCTION	7700	290 (4)	187 (2.5)	7235	286 (4)	195 (2.5)	7636	276 (3.5)	185 (2.5)
TOTAL	14298	407 (3)	252 (2)	13492	405 (3)	249 (2)	13916	484 (3)	255 (2)

Figures in brackets give the percentage of the individual total

TABLE 2

Vehicle details

TRACTOR	GUY 32 TONNE	GUY 45 TONNE	ATKINSON 32 TONNE	ATKINSON 38 TONNE	ERF 32 TONNE (BOTH OUTFITS)	AEC MANDATOR	AEC MAMMOTH MAJOR
Model	Big J.4.T.4x2	Big J.6.T.6x4	TRS 3266 x B6x4	TRS 3868 LxB6x2	64 CU 220	2TG 4 R	TG6 RT 6x4
Steering	Manual	Power assisted	Power assisted	Power assisted To 1st and 2nd Axles	Power assisted	Power assisted	Power assisted
Power Unit	Rolls Royce 220 bhp	Cummins V8 252 bhp Turbo charged	Cummins 220 bhp	Gardner 240 bhp	Cummins 220 bhp	AEC AV 760 205 bhp	AEC AV 760 205 bhp
Tyres Front Rear	Michelin X	Michelin X	Michelin X	Michelin X	Michelin X	Michelin X Dunlop SP 111	Dunlop SP 111 Michelin X

TRAILER	BODEN	SCAMMELL	CRANE FRUEHAUF	CRANE FRUEHAUF	TASKERS*	AIR PRODUCTS OWN MANUFACTURE
Model	Sk.F2F.7 Skeletal	HVFN 492 P 100x20 Platform	SK32F 2EWH8 Skeletal	SK32F 2EWH8 Skeletal	Skeletal	7000 gallon capacity Liquid Nitrogen tank
Tyres	Dunlop Highway	Michelin X	Firestone-Transport	Firestone-Transport	Good Year Hi-Miler	Firestone Duplex super Singles
Suspension	Compensating Multi-Leaf Semi-Elliptical Springs				Compensating Single-Leaf Semi-Elliptical Springs	Air Suspension with central torque reaction bar

* Both standard and wide spring base trailers

TABLE 3

Vehicle weights

VEHICLE AND MAXIMUM GROSS TRAIN WEIGHT	AXLE	UNLADEN WEIGHT TONNES (Mg)	LADEN WEIGHT TONNES (Mg)
BODEN TRAILER + 32 TONNE GUY	1	4.57	5.75
	2	4.31	10.91
	3 + 4	5.49	15.92
	TOTAL	14.37	32.58
SCAMMELL TRAILER + 45 TONNE GUY	1	} 12.68	6.86
	2		9.40
	3		8.70
	4 + 5	6.66	19.71
	TOTAL	19.34	44.67
CRANE FRUEHAUF TRAILER + 32 TONNE ATKINSON	1	} 10.76	5.45
	2		1.10
	3		10.10
	4 + 5	5.74	16.56
	TOTAL	16.50	33.21
CRANE FRUEHAUF TRAILER + 38 TONNE ATKINSON	1 2 3	} 10.91	19.64
	4 + 5	5.91	18.85
	TOTAL	16.82	38.49
GUY + CRANE FRUEHAUF TRAILER COMBINATION 38 TONNE	1 2 3	} 12.12	20.83
	4 + 5	5.91	18.88
	TOTAL	18.03	39.71
TASKER TRAILER + 32 TONNE ERF (NORMAL SPRING BASE)	1		5.89
	2		9.40
	3 + 4		18.24
	TOTAL		33.53
TASKER TRAILER + 32 TONNE (WIDE SPRING BASE)	1		6.13
	2		9.31
	3 + 4		18.39
	TOTAL		33.83
AEC MANDATOR (2 axle tractor) + AP TANK TRAILER	TOTAL		33.12
AEC MAMMOTH MAJOR (3 axle tractor) + AP TANK TRAILER	TOTAL		32.78

Vehicle dimensions

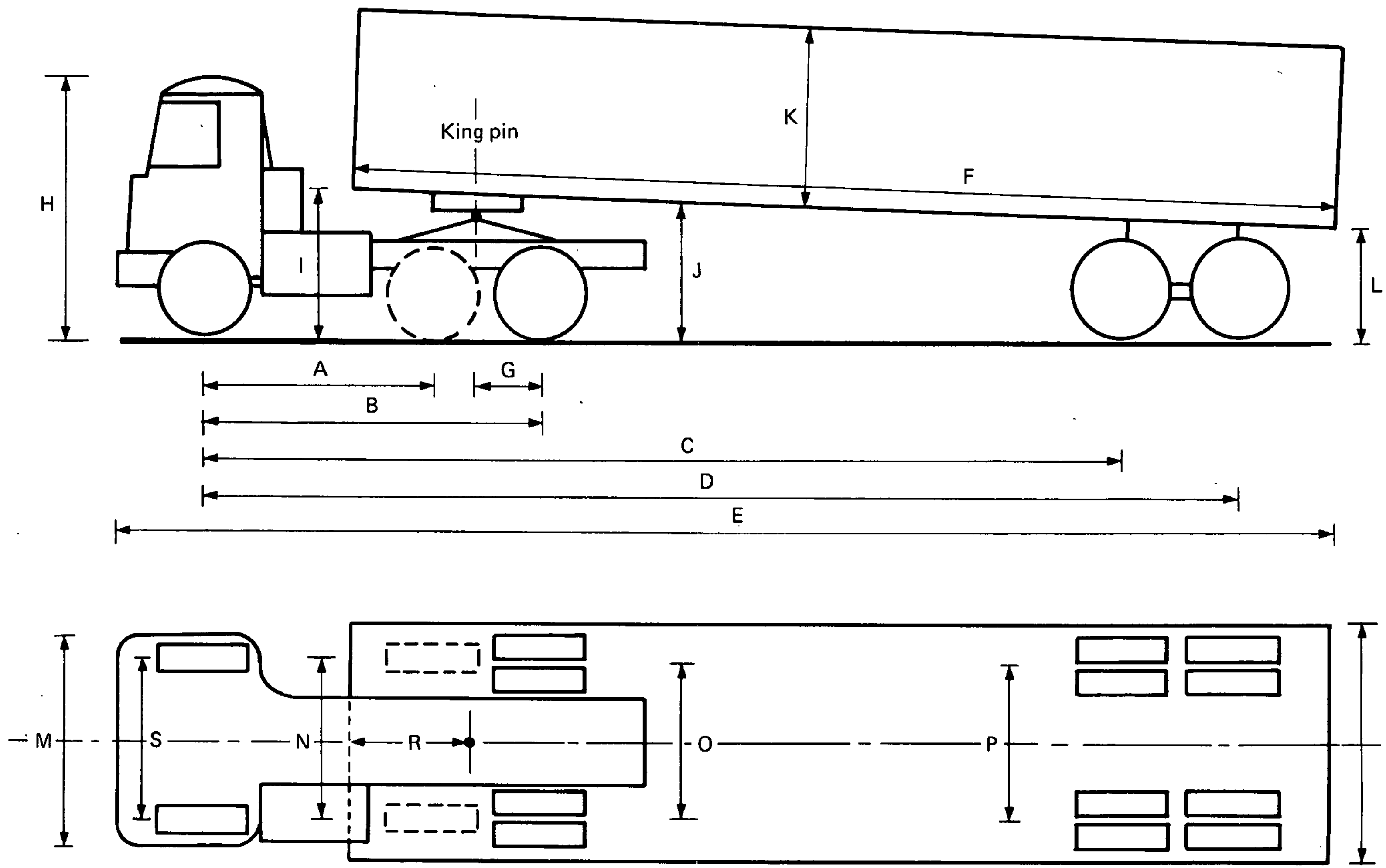


TABLE 4
Vehicle dimensions

DIMENSIONS (m) \ VEHICLE	GUY/ BODEN 32 Tonne	GUY/ SCAMMELL 45 Tonne	ATKINSON/ CRANE FRUEHAUF 32 Tonne	ATKINSON/ CRANE FRUEHAUF 38 Tonne	GUY/ CRANE FRUEHAUF 38 Tonne	ERF/ TASKER 32 Tonne	AEC 2 axle/ AP Tank 32 Tonne	AEC 3 axle/ AP Tank 32 Tonne
A	–	2.68	2.06	2.77			–	2.84
B	2.9	4.03	3.19	3.93		2.88	2.92	4.25
C	9.63	10.32	10.47	10.8	10.77	9.42	8.6	9.4
D	11.96	12.38	12.6	12.93	12.89	11.49	9.85	10.65
E	15.00	15.00	15.27	15.4	15.91	15.00	13.04	13.84
F	12.2	12.22	12.43	12.36		12.20	10.32	10.32
G	0.46	0.48	0.52	0.83		0.58	0.5	1.03
H	2.93	2.68	2.67	2.68			2.67	2.67
I	1.46	1.56	1.6	1.59	1.6	1.55	1.25	1.25
J	1.11	1.23	1.25	1.21		1.18	1.13	1.13
K	2.44	2.44	2.44	2.44			2.75	2.75
L	1.33	1.47	1.31	1.3	1.28	1.38		
M	2.37	2.49	2.41	2.46			2.4	2.4
N	–	1.83	2.06	2.06				1.81
O	1.82	1.83	1.84	1.88			1.81	1.81
P	1.82	1.82	1.83	1.87		1.96	1.88	1.88
Q	2.44	2.49	2.49	2.43		2.45	2.5	2.5
R	1.09	1.59	0.7	0.7			1.17	1.17
S	1.99	1.97	2.06	2.07			2.04	1.91
Height of C of G of load above ground at trailer centre (estimated)	2.3	2.5	2.5	2.4	2.5	2.5	2.3	2.1

TABLE 5

Results obtained on dynamic tests of roll stability of different articulated vehicle combinations in constant radius turns

VEHICLE	CIRCLE RADIUS m	ARTICULATION ANGLE DEGREE°	APPROX. TURN ON THE STEERING WHEEL REVS	SPEED AT POINT OF MAX. ROLL ON TRACK km/h	SPEED CORRECTED FOR LEVEL GROUND km/h	MAX. SPEED FOR ALL WHEELS TO BE JUST IN CONTACT WITH LEVEL GROUND	LATERAL ACCELERATION AT POINT OF MAX ROLL (LEVEL GROUND)
GUY/BODEN 32 TONNE	20	10	0.7	26.2	27.3	25	0.26
	30	5	0.3	30.2	31.5	30	0.24
	40	3	0.2	36.0	36.0	34	0.24
GUY/SCAMMELL 45 TONNE	20		0.9	22.7	23.9	21	0.20
	30		0.6	28.0	29.5	26	0.21
	40		0.4	32.0	33.7	29	0.21
ATKINSON/CRANE FRUEHAUF 32 TONNE	20	12	0.6	28.3	29.3	26	0.30
	30	7	0.4	34.3	35.2	31	0.30
	40	5	0.3	38.9	40.4	35	0.30
ATKINSON/CRANE FRUEHAUF 38 TONNE	20		0.7	27.3	28.3	25	0.28
	30		0.5	32.8	34.0	30	0.28
	40		0.4	36.8	38.2	34	0.27
GUY/CRANE FRUEHAUF 38 TONNE	20			27.3	28.3	25	0.28
	30			32.1	33.4	30	0.27
	40			36.8	38.2	35	0.27
ERF/TASKER NORMAL SPRING BASE 32 TONNE	20			26.7	27.8	25	0.27
	30			32.8	34.0	30	0.28
ERF/TASKER WIDE SPRING BASE 32 TONNE	20			27.8	28.8	26	0.29
	30			34.0	35.2	32	0.30
	40			39.6	40.1	36	0.31
AEC 2 axle/AP TANK 32 TONNE	20			28.8	29.8	27	0.31
	30			34.6	35.8	33	0.31
	40			39.6	40.1	38	0.31
AEC 3 axle/AP TANK 32 TONNE	20			29.3	30.3	27	0.32
	30			35.2	36.4	32	0.32
	40			40.3	41.6	37	0.32

TABLE 6

Characteristics of trailer suspension and the steering rate in an 'S' bend manoeuvre of an articulated vehicle combination

VEHICLE	ROLL DATA FOR S BEND				ROLL DATA FOR 30m CIRCLE		TIME BETWEEN MAX. ROLL POINTS ON S BEND SECS	NATURAL FREQUENCY TIME (SEC) FOR ONE CYCLE
	1st BEND		2nd BEND					
	SPEED km/h	MAX ROLL° ANGLE	SPEED km/h	MAX ROLL° ANGLE	SPEED km/h	MAX ROLL ANGLE°		
GUY/SCAMMELL 45t	27	12	27	12	28	12	8.5	0.5

TABLE 7

Natural frequency of trailer suspension and steering rate of some articulated vehicle combinations in a roundabout manoeuvre

VEHICLE	ROLL DATA FOR ROUNDABOUT				ROLL DATA FOR 20m CIRCLE		TIME BETWEEN MAX. ROLL POINTS ON ROUNDABOUT		NATURAL FREQUENCY TIME (SECS) FOR 1 CYCLE
	ENTRANCE SPEED km/h	ENTRANCE ROLL ANGLE	CENTRE ROLL ANGLE	EXIT ROLL ANGLE	SPEED km/h	MAX. ROLL ANGLE	ENTRANCE TO CENTRE SECS	CENTRE TO EXIT SECS	
GUY/SCAMMELL 45t	27.4	6	12	7.5	21.8	12	5.3	4.1	0.5
GUY/BODEN 32t	28.2	5	12	6.5	25.0	12	4.81	4.4	0.45
ATKINSON/CRANE FRUEHAUF 38t	29.0	5.5	12.5	6.0	25.8	11	4.7	3.9	0.42
ATKINSON/CRANE FRUEHAUF 32t	30.6	3	7	3.5	26.6	7	4.6	3.3	0.38
GUY/CRANE FRUEHAUF 38t	30.6	3.5	12.5	4.5	25.8	12	4.7	3.5	0.42

TABLE 8

Comparison of lateral acceleration at roll over obtained from tilt and dynamic tests and by computer calculation for some different articulated vehicle combinations

TEST METHOD \ VEHICLE	GUY/ SCAMMELL 45 Tonne	ATKINSON/ CRANE FRUEHAUF 32 Tonne	ATKINSON/ CRANE FRUEHAUF 38 Tonne	ERF/ TASKER (NORMAL) SPRING BASE) 32 Tonne	ERF (WIDE SPRING BASE) 32 Tonne	GUY/ BODEN 32 Tonne	GUY/ CRANE/ FRUEHAUF 38 Tonne	AEC 2-AXLE TRACTOR+ TANKER 32 Tonne	AEC 3-AXLE TRACTOR+ TANKER 32 Tonne
DYNAMIC TRACK TEST (AVERAGE)*	0.21g	0.30g	0.28g	0.28g	0.30g	0.25g	0.27g	0.31g	0.32g
MIRA PROGRAMME NORMAL FIFTH WHEEL STIFFNESS	0.32g	0.29g	0.20g	0.30g	0.30g				
MIRA PROGRAMME HIGH FIFTH WHEEL STIFFNESS		0.30g		0.32g	0.32g				
MIRA PROGRAMME ZERO FIFTH WHEEL STIFFNESS		0.25g		0.25g	0.27g				
TILT TEST	0.21g	0.32g	0.30g	0.29g	0.30g	0.27g		0.31g	0.33g

* Average value for the 20, 30, 40m radius circles

TABLE 9

MEASUREMENTS OF STEERING TORQUE

Maximum torque required to enter and maintain a 20m radius curve at 16 km/h

VEHICLE	TYPE OF STEERING	STEERING TORQUE Nm	STEERING TORQUE Nm WITH ENGINE OFF
45 TONNE GUY/SCAMMELL	POWER ASSISTED	30	176*
32 TONNE GUY/BODEN	MANUAL	65	65
38 TONNE ATKINSON/ CRANE FRUEHAUF	POWER ASSISTED	50	176*
32 TONNE ATKINSON/ CRANE FRUEHAUF	POWER ASSISTED	34	176*

* This was the maximum figure that could be recorded with the equipment used. The true figure would be somewhat higher than this

TABLE 10

Details of tanker combination used in additional tests
with liquid load and of tests made

TRACTOR:– GUY BIG J4T 4X2 WITH CUMMINS NH 220 ENGINE

TRAILER:– 7 COMPARTMENT 27,500 litre YEWCO TANK ON CRANE FRUEHAUF 2-axle RUNNING GEAR

DIMENSIONS	B	C	D	E	G	K	L	J	N	M	S	Tank Centre to ground
(see Table 3) m	2.84	8.82	10.17	12.50	0.36	1.50	1.06	1.20	1.80	2.50	1.95	2.14

Vertical Axis of Tank = 1.5m, horizontal axis 2.4m

CAPACITY

	NOMINAL (litres)	FULL LOAD (Max permitted axle weight) (litres) (using water)	NORMAL LOAD (As used by Texaco Ltd) (litres)
Tank No			
1 (Front)	4600	2400	2800
2	4600	4400	2000
3	2200	Sealed	Sealed
4	2200	1200	850
5	4600	4300	3200
6	4600	4900	3200
7 (Rear)	4600	1000	3200
Total:	27400	18200	15250

WEIGHT (kg)

	Plated	Full Load	Normal Load	Empty
Total	33786	31250*	27580	11370
Axle No 1 (Front)	5335	5370	5150	4340
2	10161	10100	8060	3200
3	9145	6600	6250	1900
4 (Rear)	9145	9180	8120	1930

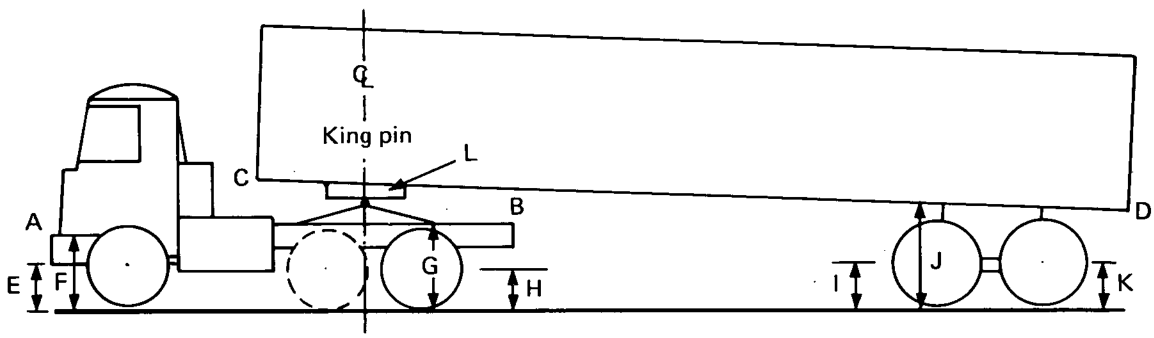
* Additional load increased weight on axle 4 beyond plated weight

TABLE 11

Results of additional tests on a tanker combination with a liquid load

TESTS	Load Condition	Articulation Angle degrees	Angle of Tilt platform at balance degrees	Max. test speed km/h	Equivalent lateral acceleration g	Maximum Trailer Roll Angle Degrees	REMARKS
DYNAMIC:–							
30m radius circle	FULL		–	35	.3	7.4	
(Vehicle mean R = 32.25m)	NORMAL		–	35	.3	7.1	
30m radius S bend	FULL		–	35	.3	7.1	
(R = 32.25m)	NORMAL		–	34	.28	7.9	Trailer beginning to run wide.
	EMPTY		–	43	.45	2.4	
Evasive Manoeuvre							Lateral acceleration measured on tractor.
x = 30m				45	.38	6.1	
x = 25m				40	.31	6.6	
TILT:–	FULL	0°	21	38	.36	7	Speed and acceleration calculated from angle of tilt of platform.
		45°	21	38	.36	7.5	
	NORMAL	0°	20.5	38	.35	5.6	
	EMPTY	0°	33.5	47	.55	2.5	

NOTE:– Results corrected to level ground condition where applicable



ANGULAR MEASUREMENTS

A = Lateral angle Tractor chassis front
B = Lateral angle Tractor chassis rear
C = Lateral angle Trailer platform front
D = Lateral angle Trailer platform rear

LINEAR MEASUREMENTS
(Taken both sides)

F = Chassis height above tilt platform at Tractor front axle
G = Chassis height above tilt platform at Tractor rear axle
J = Platform height above tilt platform at Trailer rear axle
E = Axle height above tilt platform at Tractor front
H = Axle height above tilt platform at Tractor rear
I = Axle height above tilt platform at Trailer axle 1
K = Axle height above tilt platform at Trailer axle 2
L = Fifth wheel plate edge separation

Fig. 1 DETAILS OF MEASUREMENTS TAKEN DURING TILT TESTING

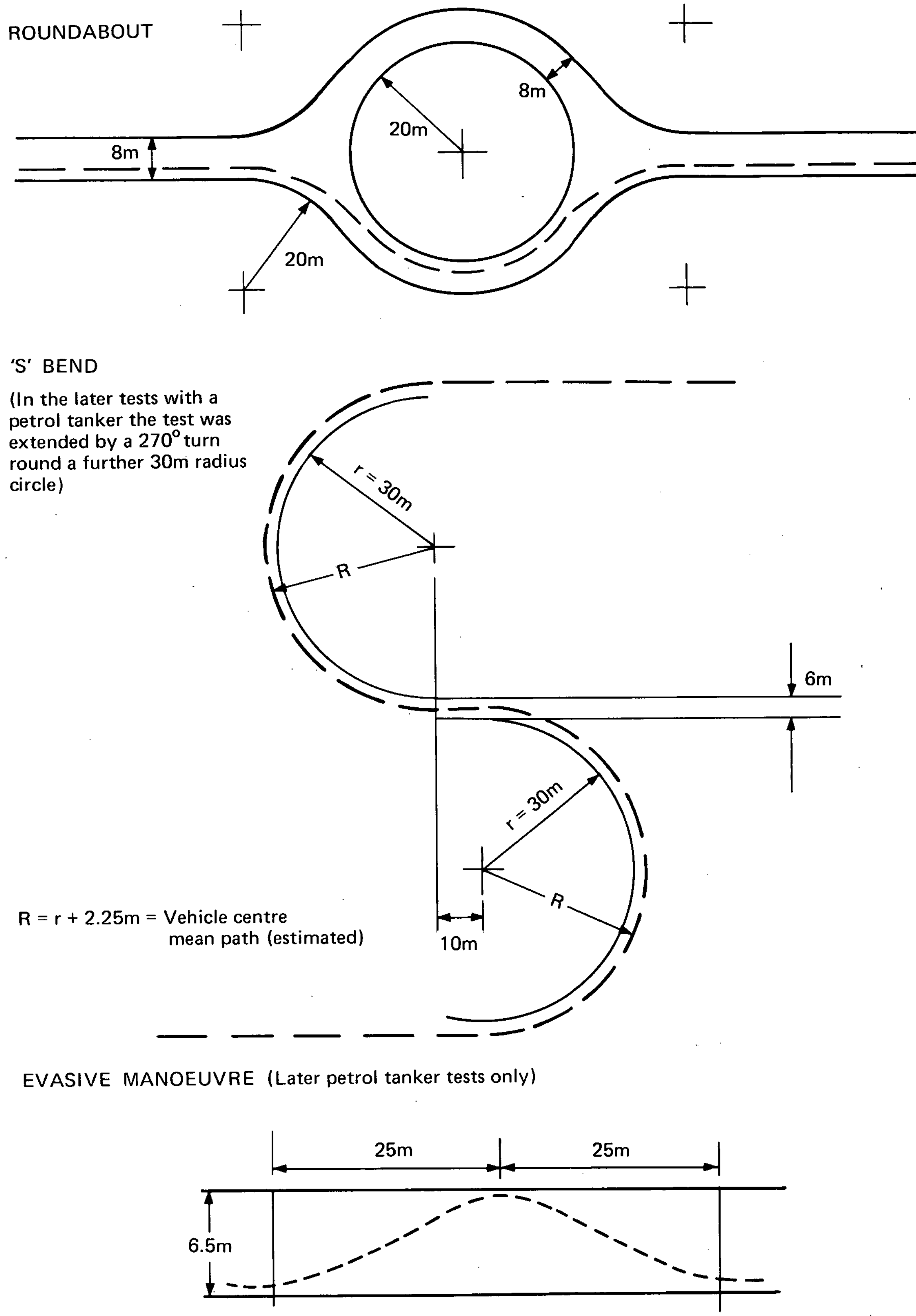


Fig. 2 DIAGRAM OF ROUNDABOUT, 'S' BEND AND EVASIVE MANOEUVRES USED IN DYNAMIC TESTS

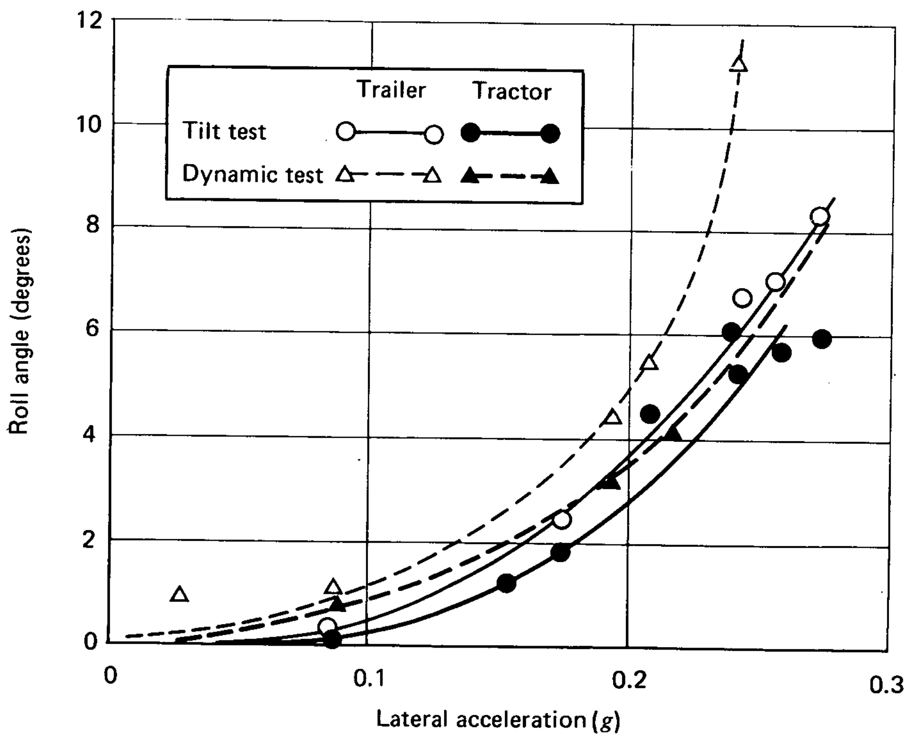


Fig. 3 LATERAL ACCELERATION AND ROLL ANGLE OF 32 TONNE GUY/BODEN COMBINATION

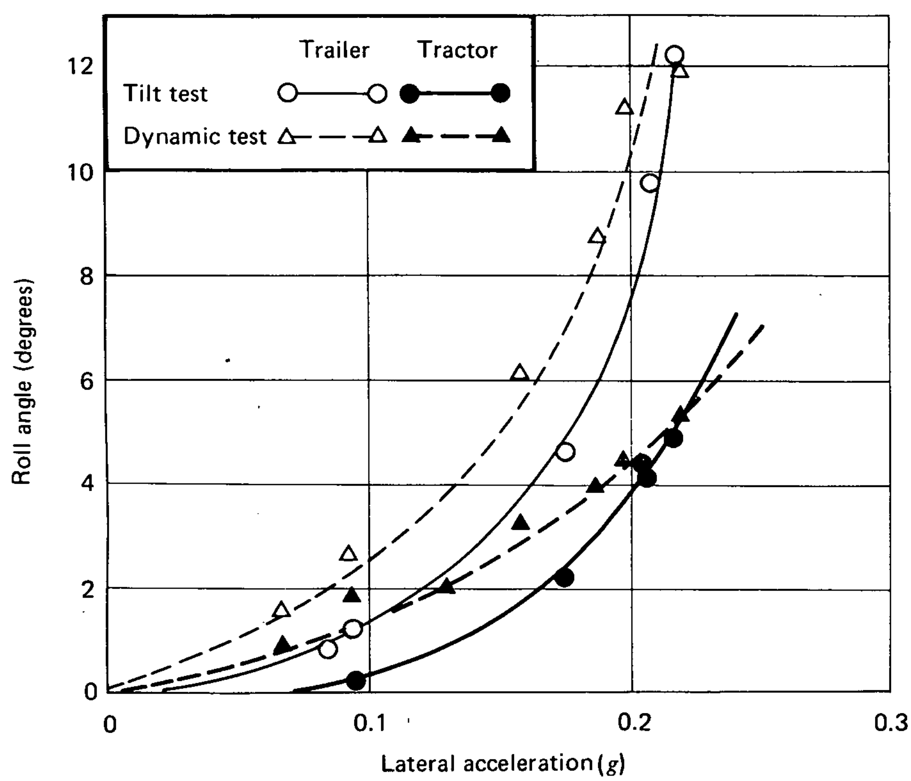


Fig.4 LATERAL ACCELERATION AND ROLL ANGLE OF 45 TONNE GUY/SCAMMELL COMBINATION

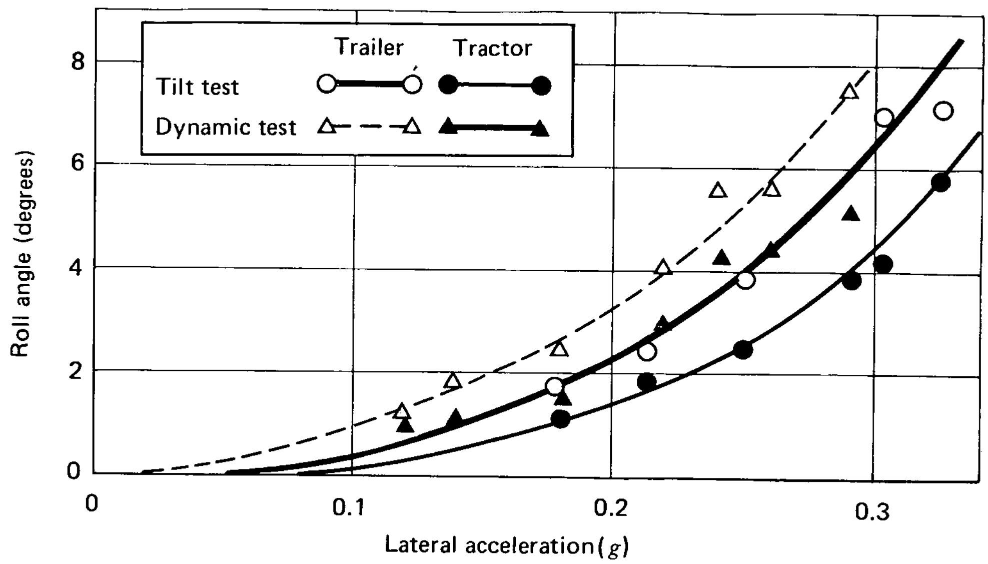


Fig.5 LATERAL ACCELERATION AND ROLL ANGLE OF 32 TONNE ATKINSON/CRANE FRUEHAUF COMBINATION

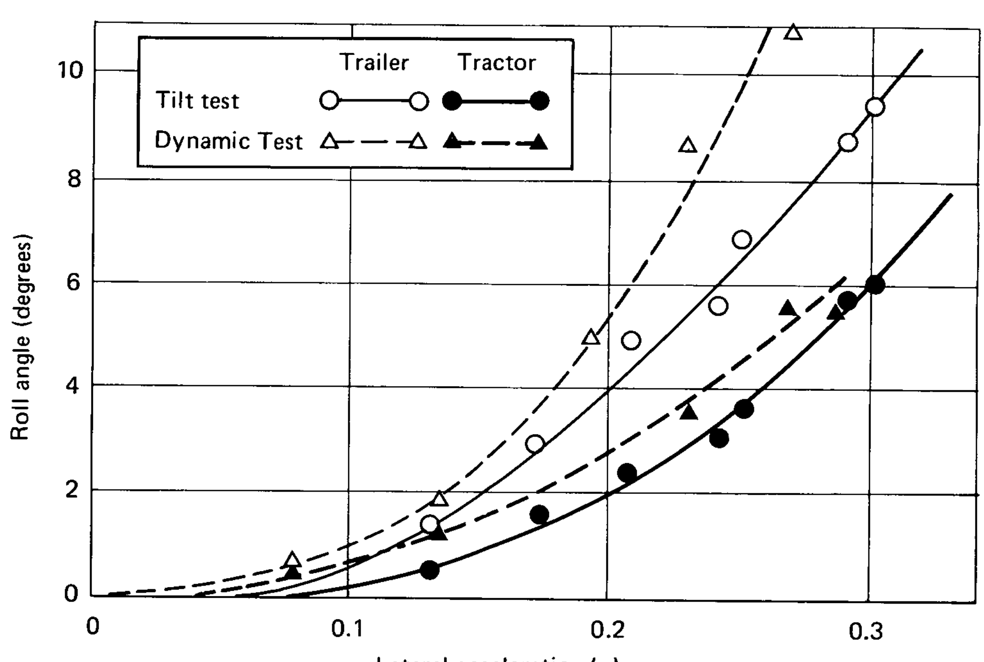


Fig.6 LATERAL ACCELERATION AND ROLL ANGLE OF 38 TONNE ATKINSON/CRANE FRUEHAUF COMBINATION

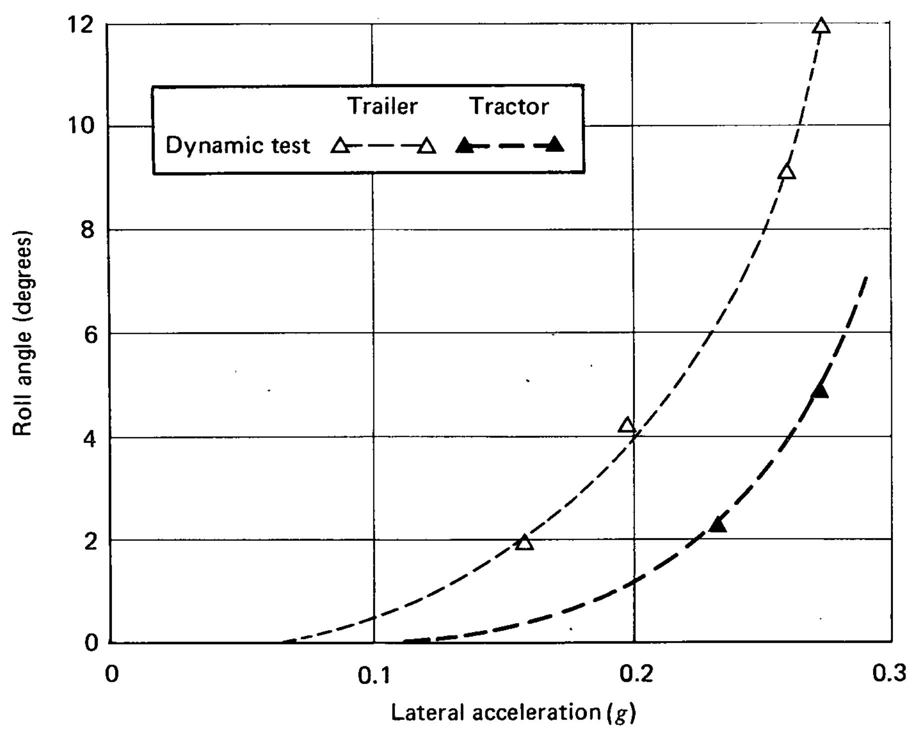


Fig.7 LATERAL ACCELERATION AND ROLL ANGLE OF 38 TONNE GUY/CRANE FRUEHAUF COMBINATION

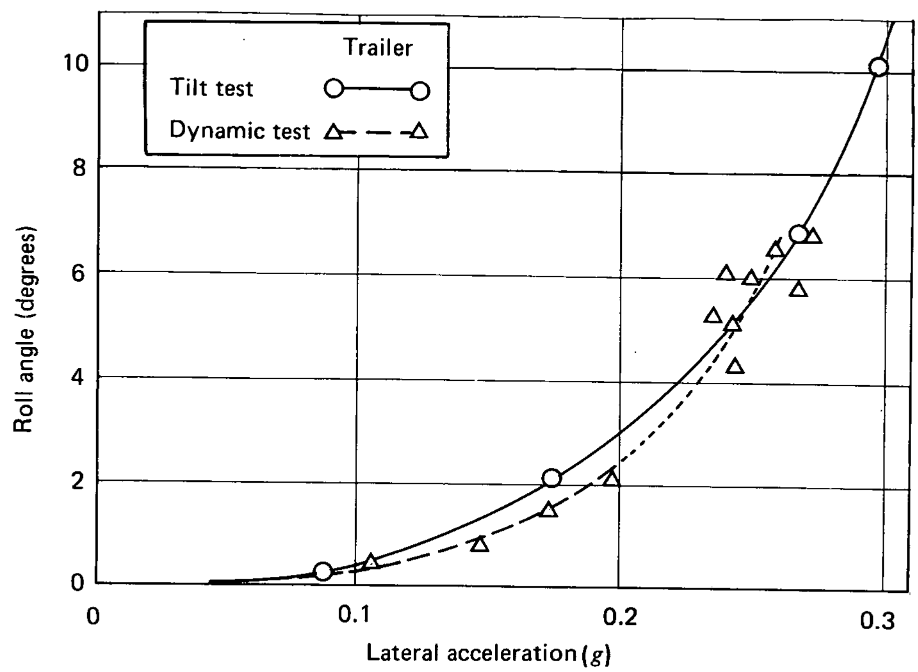


Fig.8 LATERAL ACCELERATION AND ROLL ANGLE OF TASKER STANDARD SPRING BASE TRAILER AT 32 TONNES

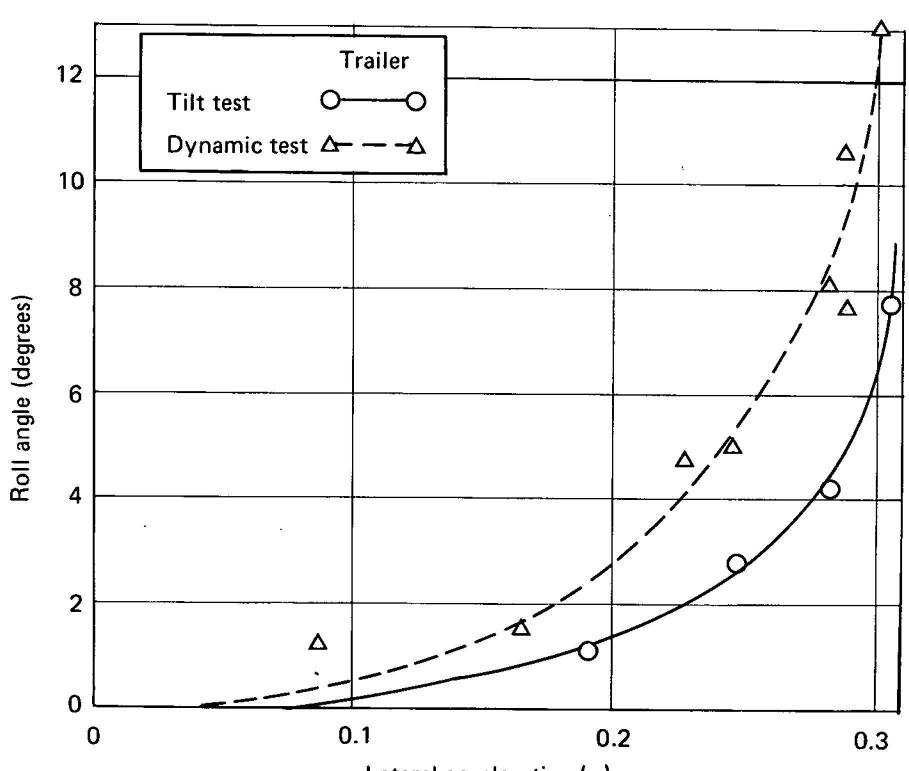


Fig.9 LATERAL ACCELERATION AND ROLL OF TASKER WIDE SPRING BASE TRAILER AT 32 TONNES

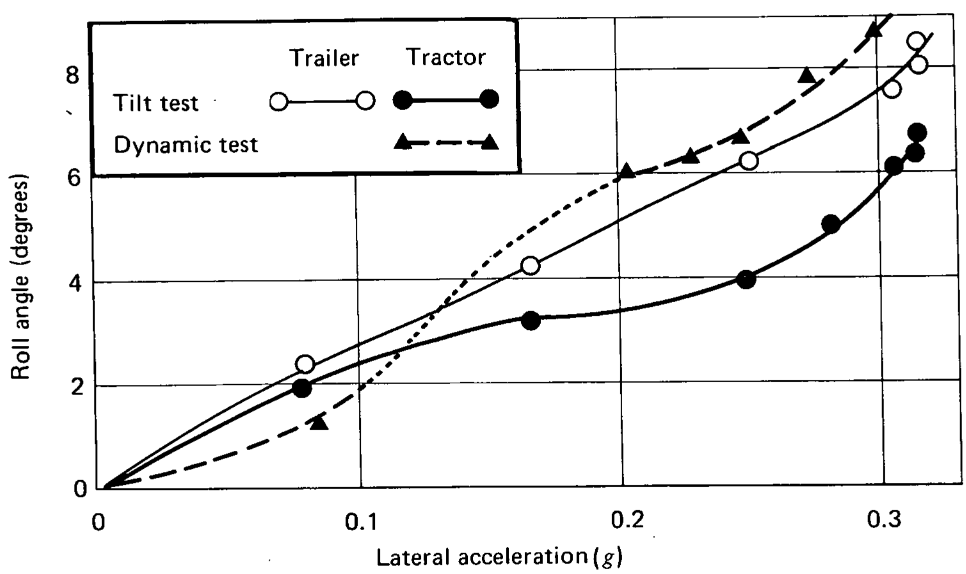


Fig. 10 LATERAL ACCELERATION AND ROLL ANGLE OF TANK TRAILER AND 2 AXLE TRACTOR AT 32 TONNES GROSS WEIGHT

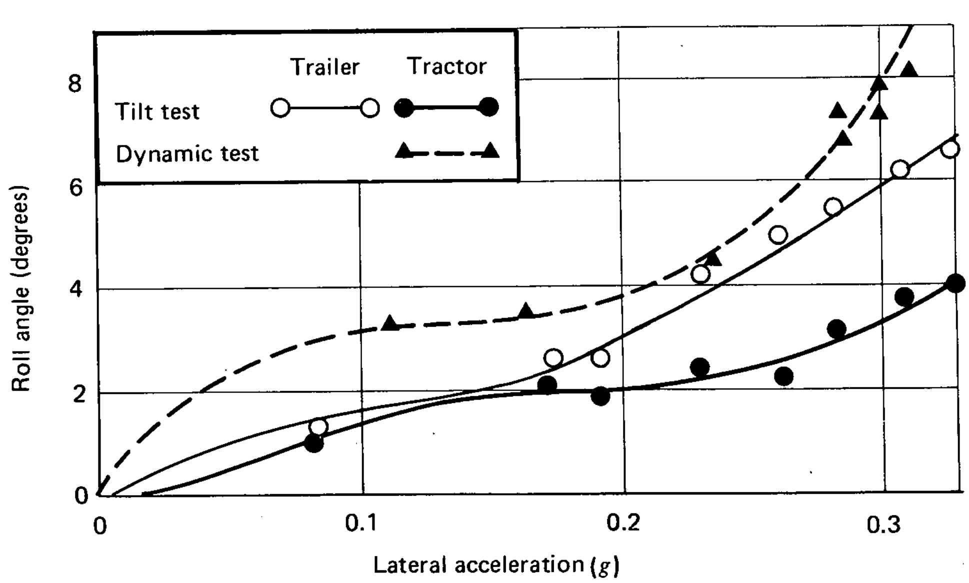


Fig. 11 LATERAL ACCELERATION AND ROLL ANGLE OF TANK TRAILER WITH 3 AXLE TRACTOR AT 32 TONNES GROSS WEIGHT

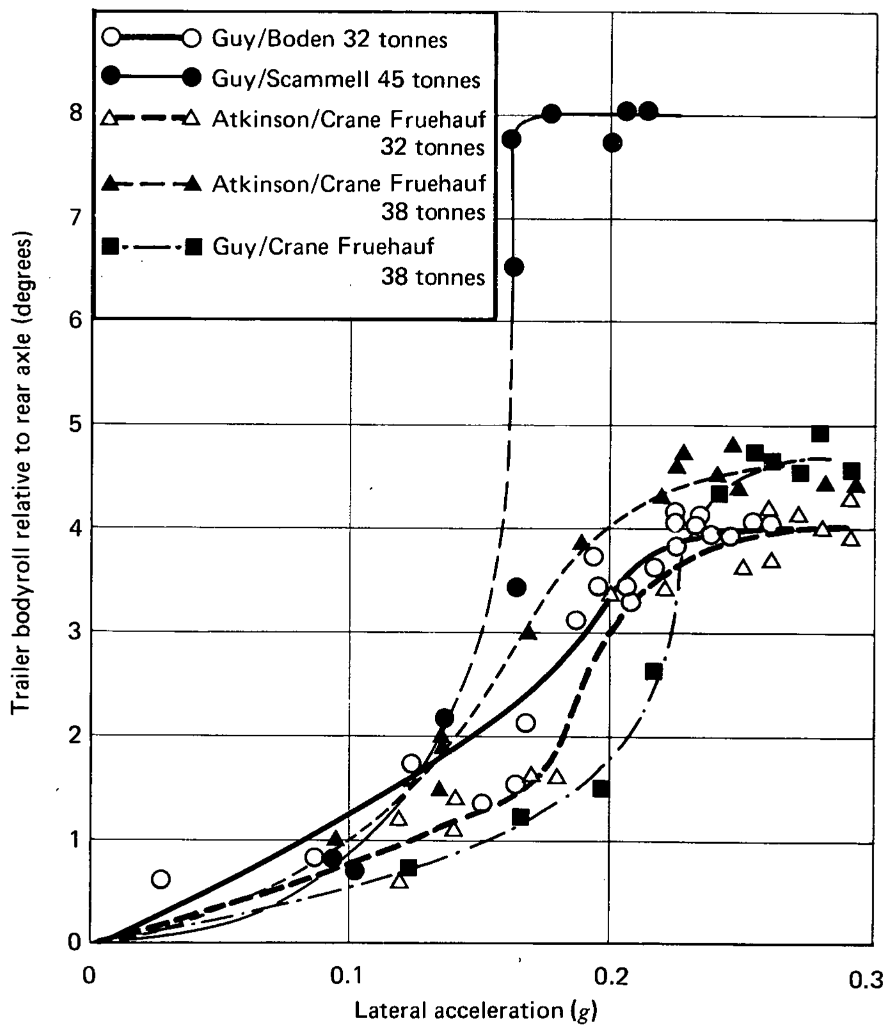


Fig.12 TRAILER BODY ROLL AT DIFFERENT LATERAL ACCELERATIONS IN DYNAMIC TESTS WITH DIFFERENT VEHICLE COMBINATIONS

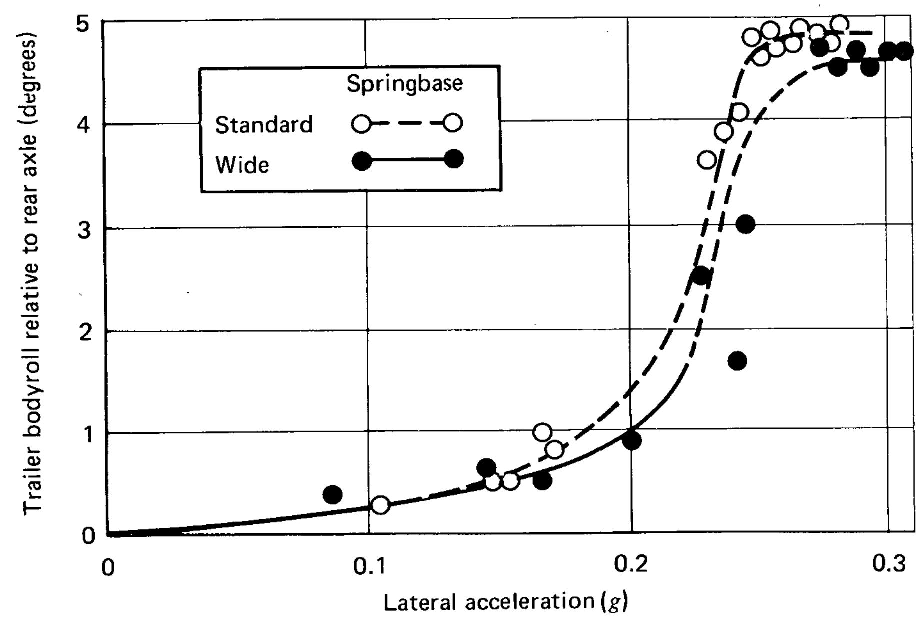


Fig.13 TRAILER BODY ROLLER DIFFERENT LATERAL ACCELERATIONS IN DYNAMIC TESTS ON A30 IN CURVE WITH ERF/TASKER COMBINATION AND WIDE TRAILER SPRING BASE

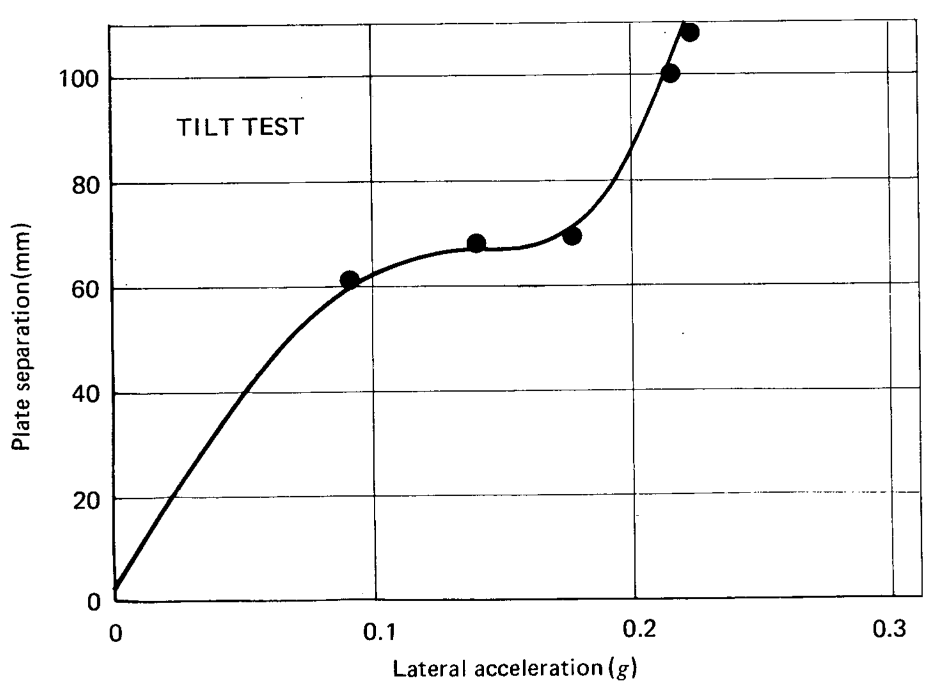


Fig.14 LATERAL ACCELERATION AND FIFTH WHEEL PLATE SEPARATION FOR THE 45 TONNE COMBINATION

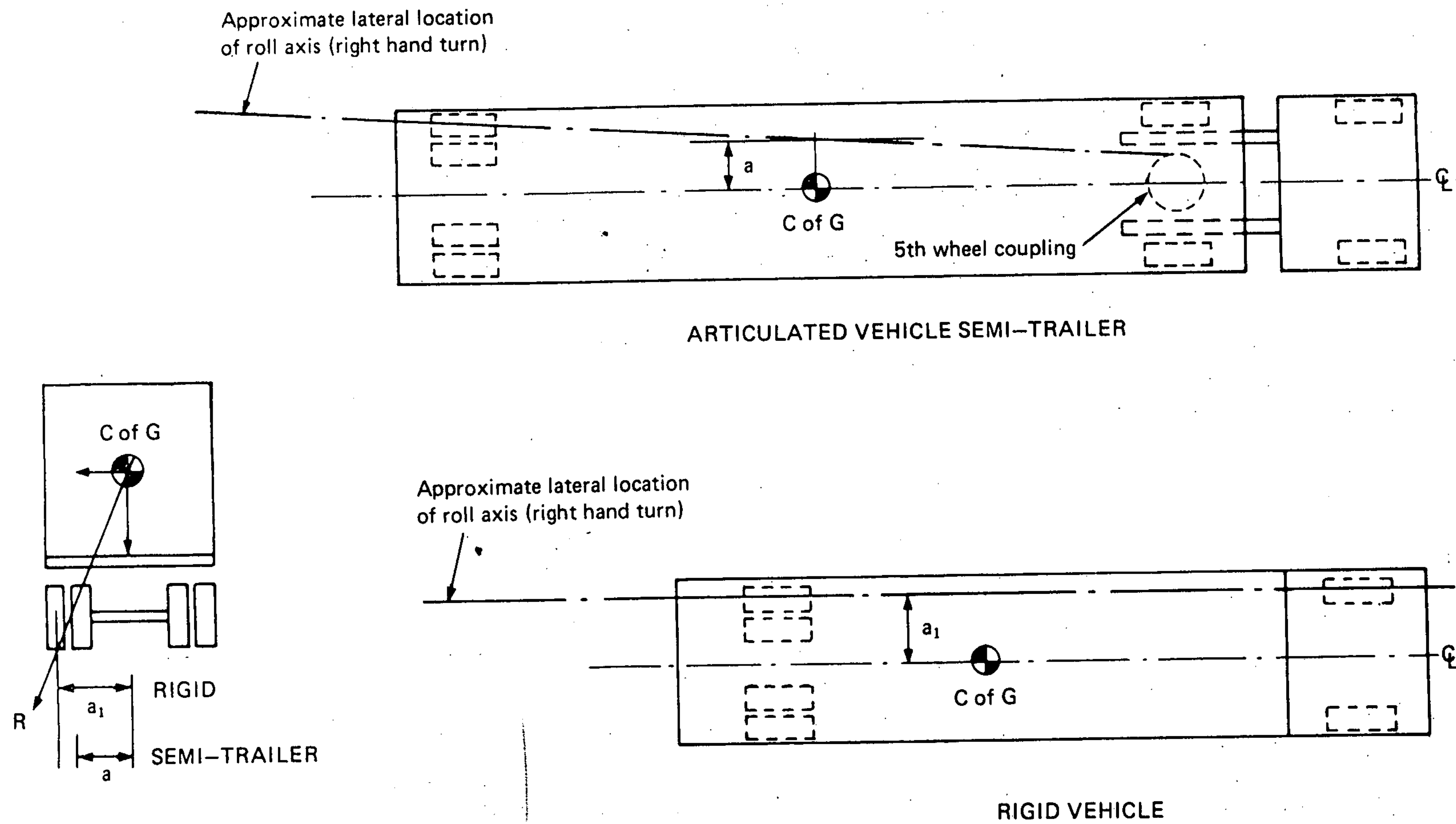
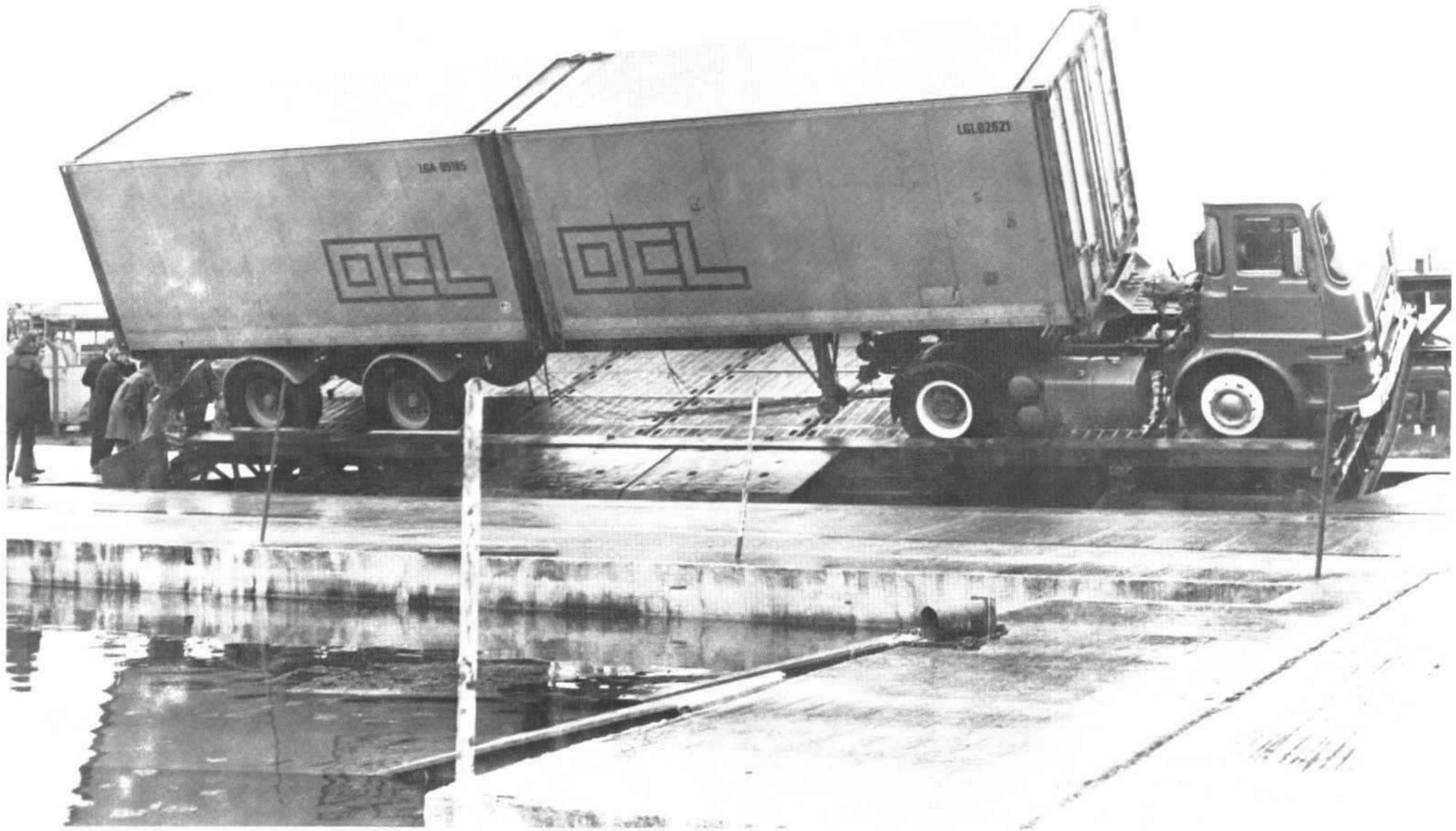


Fig. 15 APPROXIMATE LATERAL LOCATION OF THE ROLL AXIS OF A RIGID VEHICLE AND OF AN ARTICULATED VEHICLE SEMI–TRAILER



Neg. M V E E Christchurch

Plate 1 32 TONNE E R F ON THE TILT PLATFORM AT M V E E CHRISTCHURCH

Neg. no. R1143/71/7

Plate 2 38 TONNE ATKINSON LEANING ON THE OUTRIGGER DURING DYNAMIC TESTING AT T R R L

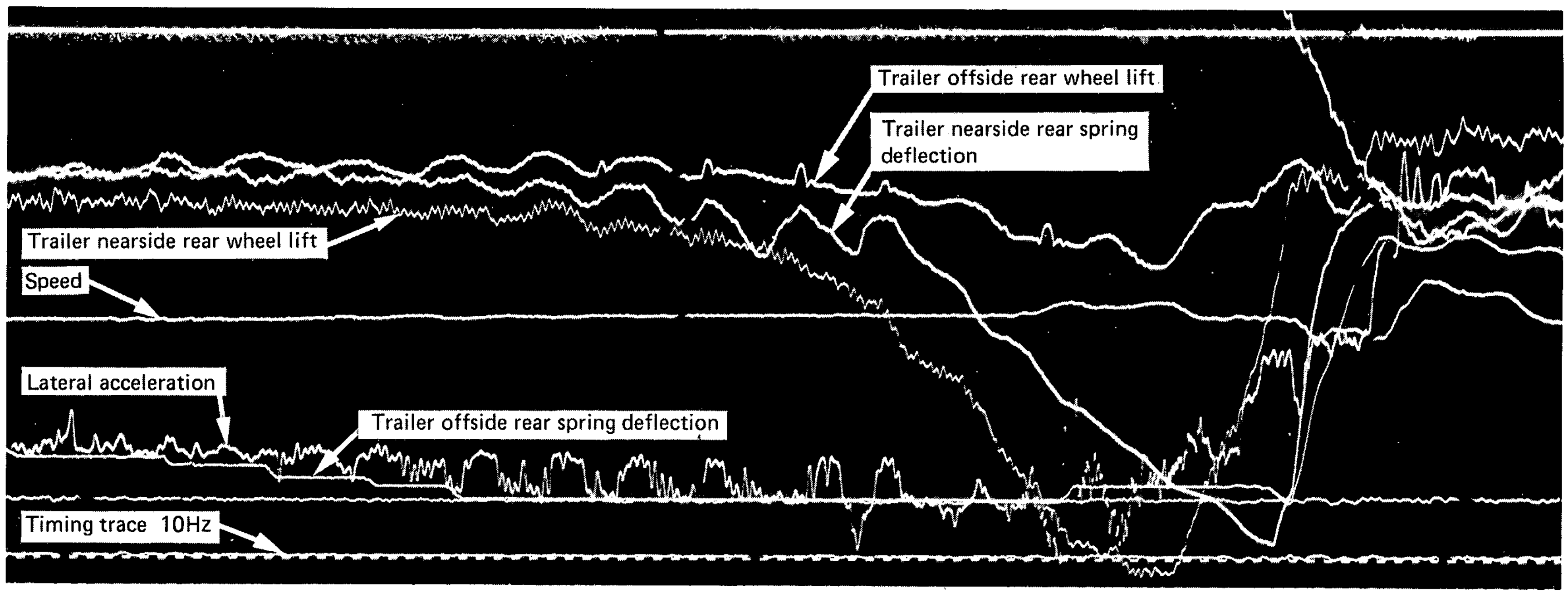


Plate 3 EXAMPLE OF THE DYNAMIC RECORDS

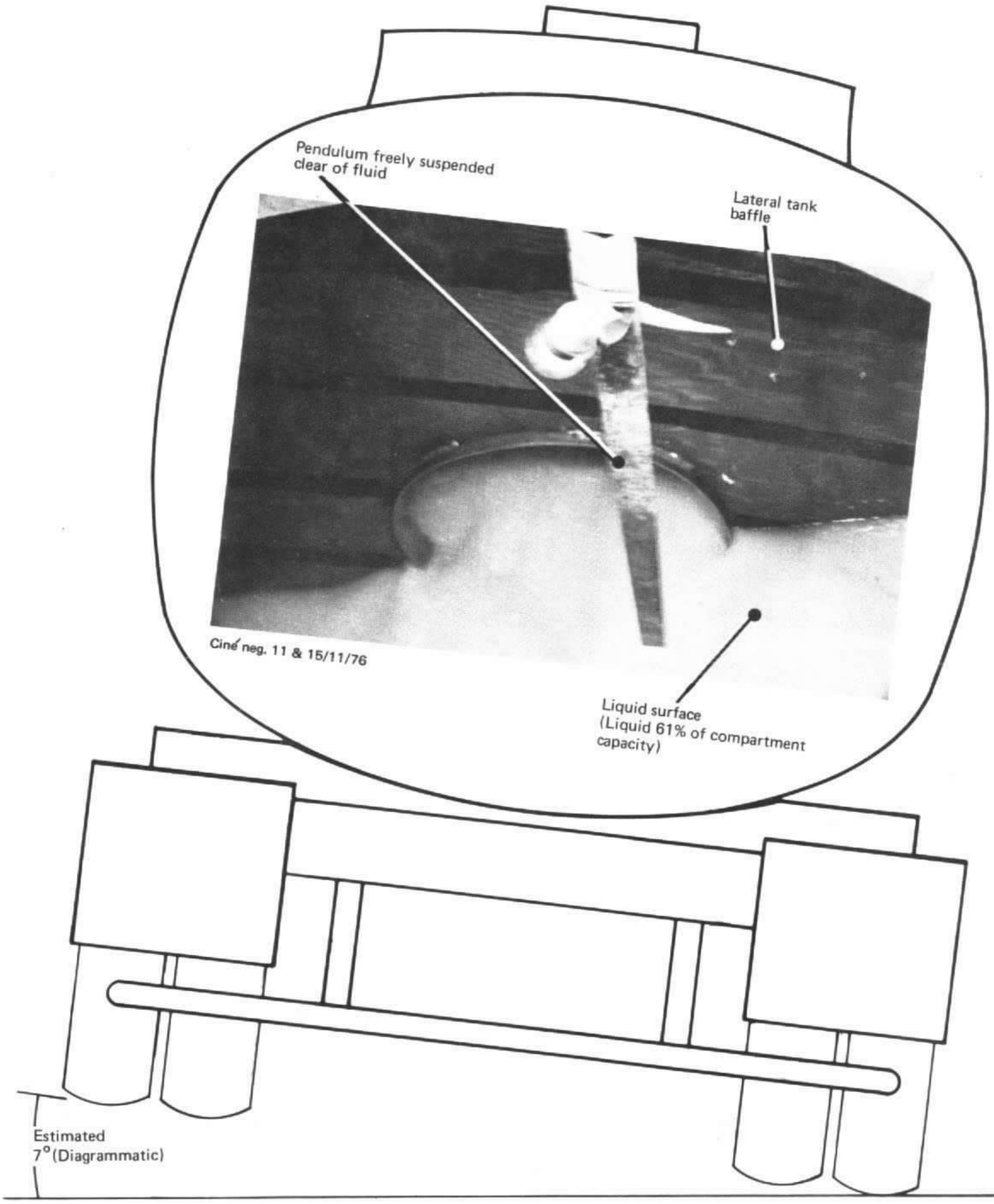


Plate 4 RELATIVE MOVEMENT OF TANK AND FLUID AFTER THIRD DIRECTION CHANGE ON 30m 'S' BEND MANOEUVRE. SPEED 34km/h

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ABSTRACT

Articulated vehicle roll stability: methods of assessment and effects of vehicle characteristics: R N KEMP, C Eng MRAeS B P CHINN and G BROCK: Department of the Environment Department of Transport, TRRL Laboratory Report 788: Crowthorne, 1978 (Transport and Road Research Laboratory). Nine high laden articulated vehicle combinations from 32 tonnes (Mg) to 45 tonnes (Mg) gross train weight were driven into a roll over condition on different manoeuvres to assess their stability in roll and the effect of different vehicle characteristics. The vehicles were also tilted sideways on a platform to the point of balance. Roll over occurred at lateral accelerations from about 0.2g. Trailer roll was the governing factor in the overturning of the combinations tested. Increased spring stiffness, spring base width and coupling stiffness increased the trailer roll resistance. Measurements demonstrated that the tilt method gave a good indication of roll stability. Calculated results from a computer program of lateral acceleration required for roll over differed from the dynamic results by 10 to 40 per cent. Roll over occurs in 3–4 per cent of heavy goods vehicle injury accidents. A higher percentage of articulated vehicles roll over than rigid vehicles. Reasons for this are considered to be geometric layout, lack of driver awareness of the total roll of an articulated combination and a tendency for a rigid vehicle to become self stabilising due to loss of drive in roll. Multiple turn manoeuvres did not increase the risk of roll over. A roll over warning device could be useful.

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