



Pages 162-178

ROADTRAIN SWAY STABILISATION

J.Sandell, D.Roach, S.McFarlane

ABSTRACT

This paper describes the performance of a sway stabilisation device, which has been shown to reduce undesirable lateral dynamics in multi-articulated road vehicles. The stabilisation device called Sway Stay senses the onset of oscillation in the angle between the dolly and the hauling unit and applies a retarding torque at the automatic coupler, which reduces yaw oscillation between the coupled units. The stabilisation device and its principle of operation are described. The results from tests on a road train fitted with Sway Stay and the results from computer simulation of the lateral dynamics of a road train are presented. The data show Sway Stay reduces rearward amplification and improves tracking in road trains.

INTRODUCTION

A road train comprises a prime mover with two or more trailers, each being supported by an A-type converter dolly, which is pulled by the unit in front of it. During operation the rear of the vehicle exhibits lateral motion. This may be from driver input to the steering wheel, which will tend to amplify through the combination, or due to differences in road profile. To rectify this oscillation a driver will sometimes accelerate, to pull the trailer into line. The use of speed limiters has reduced the effectiveness of the acceleration option and therefore driving skills are paramount. To reduce the possibility of oscillation a yaw motion braking system, called Sway Stay, has been developed and is being tested to measure its effectiveness. Sway Stay has been tested on a range of vehicles. Initially tests were conducted to determine the effectiveness of Sway Stay in reducing undesirable lateral dynamics that result from a standard lane change manoeuvre. Sway Stay has also been tested over extended periods on road trains during normal operation in Western Queensland and the Northern Territory.

PRINCIPLE OF OPERATION

Sway Stay mounts centrally under the automatic pin-coupling unit at the rear of a trailer as shown in [Figure 1](#). Attached to the dolly drawbar is a pedestal and tongue, the tongue having free forward/reverse movement in the brake drum. This tongue forces the brake drum to rotate in-line with the dolly drawbar about the automatic pin-coupling axis. Under normal operating conditions the dolly has free yaw motion. However, there is a restriction on the vertical rotation in that there is a $\pm 15^\circ$ movement in the brake body with respect to the trailer chassis and also $\pm 15^\circ$ movement between the dolly drawbar and the tongue. Roll is not impeded, although roll coupling could be introduced.

Shown in **Figure 2** is a diagram of Sway Stay, the figure shows that Sway Stay consists of a circular brake drum free to rotate about the automatic pin-coupling axis. This brake drum fits into the brake frame which is attached, via a swivel frame, to the trailer chassis. Clutch plates and wear plates are mounted between the brake drum and the brake frame. When the brake is activated, pneumatic pistons in the lower section of the brake frame compress the clutches preventing rotation of the brake drum. Thus restricting the yaw movement of the dolly drawbar.

Sway Stay senses the yaw angle between the dolly drawbar and the hauling unit using two magnetic sensors. *Sway is said to have occurred if an oscillation of $\pm 0.5^\circ$ is detected within a period of 5 seconds.* This represents a movement of $\pm 125\text{mm}$ at the end of a 12m trailer. Timing starting from the first detection of a yaw angle greater than 0.5° . If the yaw angle exceeds 3° then there is considered to be a major change in direction and the brake is not allowed to operate. As soon as sway is detected then the brake will be activated during the next 5 seconds *provided* that the steering wheel is within $\pm 10^\circ$ of the straight ahead position, ie the driver intends to drive in a straight line. Various operating conditions are indicated in **Figure 3**. It is of note that the three braking waveforms can be mirrored about the 0° axis.

Air for the pneumatic system is supplied from the truck braking system feeding into a reservoir only when the braking system exceeds a predetermined level. Safety valves are included so that if the Sway Stay system has a break in its air lines then this does not affect the braking system of the truck. Within the driver's cabin there is a sensor detecting the angle of the steering wheel, this data is transmitted to the control unit adjacent to the Sway Stay and is used to determine if the driver intention is to go straight. There is also a visual indicator for the driver advising when the device is energised and when the brake is activated. In the event that the Sway Stay does not operate correctly an audio and visual indication is sent to the driver so that he/she can take extra precautions. So as to assist the driver when reversing it is possible to manually lock Sway Stay from within the cabin, this action effectively eliminates the articulation between the dolly and the towing trailer.

Once Sway Stay is switched on, operation is automatic and does not require driver intervention.

INITIAL TESTING

Initial testing of the Sway Stay is described in detail in a research report compiled by Central Queensland University [1]. These tests took place on 5 to 7 May 1994.

The testing program was designed to record data for calculation of the rearward amplification and the offset tracking of a three-trailer roadtrain with Sway Stay fitted between each pair of trailers.

The test vehicle was a 1988 Mack Superliner prime mover with three trailers, the first a 7.24 tonne tare Fruehauf cattle crate with a 3.6 t Fruehauf dolly followed by two 9.4 t Byrne cattle crates and a 2.78 t dolly.

The data acquisition system comprised two National Instruments LabPC+ cards storing data on a 80486 laptop computer through 8 differential channels at 250 samples per second.

The test involved a single lane change manoeuvre at 80 kilometres per hour which required the driver to follow a path that had been painted onto the road. The path moved laterally to the right a distance of 1.463 metres over a distance of 57.91 metres along the course. The test course was similar to the course described in SAE J2179 [2]. The test site was a closed section of the old Bruce Highway at Yaamba which is approximately 30 kilometres North of Rockhampton in Central Queensland.

Both empty and loaded road trains were tested both load cases were tested with and without Sway Stay operational. Two hundred and sixty three drums each filled with two hundred litres of water were used to simulate a full load for the road train bringing the loaded gross mass to 110 tonnes. The axle loading for the empty roadtrain are shown in Table 1 and the location of the water drums in the loaded road train is given in Table 2.

Table 1 Tare Mass Test Vehicle

Axle Number	Number of Tyres	Unladen Mass (t)
1	2	5.77
2	4	5.50
3	4	5.49
4	4	4.93
5	4	3.64
6	4	3.79
7	4	3.48
8	4	3.01
9	4	3.20
10	4	3.16
11	4	3.67
12	4	3.15
13	4	2.53
14	4	2.55
15	4	3.40
Total Mass		57.72

Table 2 Load Distribution

Location	Number of drums	Location	Number of Drums
Trailer Number 1		Trailer Number 1	
Top Front Section	36	Top Rear section	16
Bottom Front Section	27	Bottom Rear Section	19
Trailer Number 2		Trailer Number 2	
Top Front Section	24	Top Rear section	16
Bottom Front Section	30	Bottom Rear Section	36
Trailer Number 3		Trailer Number 3	
Top Front Section	0	Top Rear section	0
Bottom Front Section	36	Bottom Rear Section	24

The path of the prime mover and the path of the rear trailer were marked on the road by two water sprays directed vertically downwards onto the road. The sprays were connected to the front axle of the prime mover and to the rear axle of the rear trailer. The path of each spray was recorded after each test run by measuring the offset of the mark made by each spray from the standard track, which had been painted, on the road. The offset of each spray was measured at twenty-two locations along the course. The path of the prime mover and rear trailer was reconstructed from these measurements.

Four video cameras were used to record various aspects of the testing. Camera 1 was a hand held camera used to record the hand movements of the driver. Camera 2 was placed on top of the first trailer facing back to show the relative movement of the following trailers. Visual indicators were attached at the ends of each trailer to emphasise lateral trailer yaw. Camera 3

recorded the operation of the second Sway Stay. Camera 4 was used in a chase helicopter or car to record the road train behaviour.

There were only six test runs completed at eighty kilometres per hour on Day 1. The water spray tracks showed that the driver had difficulty following the lane change manoeuvre on the first day of testing. A sight was mounted on the front of the prime mover to assist the driver in aligning the prime mover with the lane-change path that he was attempting to follow.

The Sway Stay was not operational on any of the tests for the first day of testing. No comparable data was obtained due to the wide variation in the paths followed by the prime mover.

On the second and third days the driver had developed a technique of “feeling the way” through the lane-change manoeuvre.

Two special tests were performed. One special test had the Sway Stay locked permanently on to determine the behaviour resulting from a malfunction in the electronic control circuit. Another special test run was completed with the interconnecting tongues of the Sway Stay devices removed to record the response without any restraining torque from the Sway Stay.

Rearward Amplification

Rearward amplification is defined as the ratio of the amplitude of the accelerometer records taken at a point vertically below the centre of gravity of the rear trailer to the amplitude of the accelerometer records taken from a similar point on the prime mover.

In the following table Rearward Amplification, RA, has been calculated from the peak to peak values of the accelerometer records. This technique is not the approach specified in the draft standard, which uses a root mean square value of accelerometer records after application of data smoothing to the records.

Table 3 Rearward Amplification Empty Road Train

Run Number	Entry Speed (km/h)	Sway Stay	RA
2/1	81	on	1.4
2/4	82	on	1.4
2/7	77	off	1.5
2/9	79	off	1.6

Table 4 Rearward Amplification Loaded Road Train

Run Number	Entry Speed (km/h)	Sway Stay	RA
3/2	76	off	1.8
3/4	78	off	1.8
3/5	-	off	2.0
3/3	78	on	1.6
3/6	79	on	1.6
3/7	79	locked on	1.8
3/8	79	no tongues	2.2

High Speed Dynamic Offtracking

Figure 4 shows a typical roadtrain response to the lane change manoeuvre with and without Sway Stay. The case of a loaded vehicle shows the undesirable tracking characteristics that were typical of those tests when Sway Stay was turned off. Without Sway Stay the prime mover would overshoot the exit from the test section. The rear trailer without Sway Stay would develop hunting and the trailer followed a tighter curve than the hauling vehicle. With Sway Stay engaged the driver was able to follow the test path more accurately and the rear trailer followed the same profile as the hauling vehicle without hunting.

EXTENDED TRIAL OF SWAY STAY

To assess Sway Stay under operational conditions McIver Corporation operated a cattle road train, with either two or three trailers, for ten months between Western Queensland and the Northern Territory. The Sway Stay was placed between the lead trailer and the second trailer. During the first part of the test the vehicle logged 40,859 km with a total number of operations of Sway Stay being 13,373. It is of note that the number of operations ranged from 0.55 km/operation with a loaded vehicle on an unmade road to 23 km/operation with no load on a good bitumen surface. This test also brought out a number of operational problems, which have been rectified [3], eg replacement of the air valve to prevent dust ingress.

COMPUTER SIMULATION

Using the University of Michigan Transportation Research Institute (UMTRI) AUTOSIM™ software, Yaw/Roll simulation models were developed for the following vehicle configurations:

- General freight double-bottom road train
- General freight triple-bottom road train
- rigid-plus-two tipper
- rigid-plus-three tipper
- SR-double (Sway Control and Roll Coupling)
- General Freight B-doubles

All combinations were simulated with vehicle designs typical and with conventional mechanical suspension throughout.

For the SR-double, **Fig 5**, the Sway Stay is an integral part of the vehicle combination and provides both sway control and roll coupling.

The vehicles were evaluated for the following key performance attributes, which are influenced by the presence of Sway Stay:

- Rearward Amplification
- Load Transfer Ratio
- High-Speed Dynamic Offtracking

These performance attributes are defined below.

Rearward Amplification

Rearward amplification is defined as the ratio of the lateral acceleration at COG of the rearmost unit to that at the hauling unit in a dynamic manoeuvre of a particular frequency ([Fig 6](#)). Rearward amplification expresses the tendency of the vehicle combination to develop higher lateral accelerations in the rear unit when undergoing avoidance manoeuvres; it is therefore an important consideration, additional to roll stability of the rear unit, in evaluating total dynamic stability; it also expresses the amount of additional road space used by the vehicle combination in an avoidance manoeuvre. Rearward amplification was computed for all vehicle configurations, using developed AUTOSIM™ models. Rearward amplification was determined for a speed of 90 km/h and for a steering frequency of 2.5 rad/s. The manoeuvre used to compute rearward amplification is shown in [Fig 7](#).

Load Transfer Ratio

Load transfer ratio is defined as the proportion of load on one side of a vehicle unit transferred to the other side of the vehicle in a transient manoeuvre. Where vehicle units are roll-coupled - as in the SR-double - the load transfer ratio is computed for all axles on the vehicle. When the load transfer ratio reaches a value of 1, rollover is about to occur.

The load transfer ratio was computed for the steering axle required to follow a specified path in a lane-change manoeuvre with a frequency of 2.5 rad/s. The standard manoeuvre used is shown in Figure 7, evaluated at a speed of 90 km/h. In each case, the vehicle was made to follow a path so that the lateral displacement of all vehicle's steering axle path remained constant. In some cases, for road trains not fitted with Sway Stay, the lateral deviation was reduced below 1.8m in order to avoid rollover of the rear trailer.

High-Speed Dynamic Offtracking

High-speed dynamic offtracking is a measure of the lateral excursion of the rear of the vehicle with reference to the path taken by the front of the vehicle during a dynamic manoeuvre. This expresses the amount of additional road space used by the vehicle combination in an avoidance manoeuvre.

High speed dynamic offtracking was computed for the lane-change manoeuvre as shown in Fig 7, at a speed of 90 km/h. In each case, the vehicle was made to follow a path so that the lateral displacement of all vehicle's path remained constant.

Results of Computer Simulation

Table 4 shows the simulation results for all vehicle combinations with and without Sway Stay. As mentioned above, the lateral displacement of the transient manoeuvre was varied as required in order to prevent rollover of the less stable combinations.

Table 4. Dynamic Performance of Vehicle Configurations With and Without Sway-Stay

VEHICLE CONFIG'N	SWAY STAY FITTED	ROLL-COUPLED	LATERAL DISP' OF LANE CHANGE (m)	RA	LTR	HSDOT (mm)
Double-bottom roadtrain	no	no	1.8	2.36	0.90	750
	yes	no	1.8	2.18	0.78	600
Triple-bottom roadtrain	no	no	1.1	3.30	0.90	700
	yes	no	1.1	3.00	0.59	550
Rigid-plus-two	no	no	1.1	1.97	0.76	540
	yes	no	1.1	1.76	0.66	472
Rigid-plus-three	no	no	0.9	2.58	0.99	640
	yes	no	0.9	2.11	0.68	527
SR-double	no	no	1.8	2.10	0.85	630
	yes	yes	1.8	1.65	0.55	450
Range of Current comparable B-doubles	no	yes	1.8	1.55 - 1.75	0.55 - 0.65	330 - 500

The results from the simulation show that Sway Stay can improve the dynamic performance of double roadtrains by between 8 and 20% in the key dynamic performance aspects investigated. The result is even more significant for the triple roadtrain which can have key dynamic performance aspects improved by between 10 and 50%.

The results also show that the SR-Double could be a good alternative to the B-double with performance aspects similar to the current range of B-doubles.

CONCLUSIONS

The experimental results clearly show that for the loaded vehicles Sway Stay improved the lateral dynamics, in terms of better tracking and lower rearward amplification, for the roadtrain

The uniquely controlled selective operation of the Sway Stay is shown to improve the lateral dynamics when compared to permanently locked Sway Stay.

Examination of the Sway Stay components after testing indicated that the device as manufactured has sufficient strength to perform satisfactorily and to give trouble free operation for the stringent requirements of the testing program.

Although the extended test highlighted a number of operational problems solutions to these have been found.

Video recording within the driver's cab during testing and subsequent interviews indicates that drivers are satisfied with the reduction in sway.

Computer simulation modelling of the Sway Stay on a range of vehicles has shown that it can improve the dynamic performance in the key aspects of rearward amplification, load transfer ratio and high-speed dynamic offtracking.

The computer simulation modelling also showed that the SR-Double could be a good alternative to the B-double with similar dynamic performance characteristics to current B-doubles.





REFERENCES

- [1] Sandell J, Roach D, Thomas R, Gorman M, “Testing of Sway Stay”, Central Queensland University Research Report, 1994.
- [2] S.A.E. “J2179 Draft - A Test for Evaluating the Rearward Amplification of Multi-Articulated Vehicles”, Society for Automotive Engineers, 1992.
- [3] Sandell J, Gorman M, Morrison S, Prestidge L, “Test Report on the Extended Trial of Sway Stay”, Central Queensland University Research Report No. 96 05 001, 1996.
- [4] McFarlane S, Sweatman P, “Optimisation of Sway Stay”, Roaduser Research Report 95-173, 1995.
- [5] Sweatman P, McFarlane S, “Potential Alternative to B-double”, Roaduser Report 95-177 1995.
- [6] Sweatman P, Dovile P, “Specification for SR-double”, Roaduser Report 95-196, 1995.
- [7] Sweatman P, Dovile P, “Revised Options for SR-double”, Roaduser Report 95-214, 1995
- [8] Sweatman P, McFarlane S, Dovile P, “Performance Evaluation of 25m SR-double: an Alternative to B-doubles”, Roaduser Report 95-214-2, 1995.





AUTHOR BIOGRAPHIES

Jack Sandell FIEE is a senior lecturer in the Electrical Engineering Department at Central Queensland University. His research interests are in the industrial application of Field Programmable Gate Arrays and data communications.

Dudley Roach is a senior lecturer in the Department of Mechanical Engineering at Central Queensland University and Director of Train Dynamics Projects in the Centre for Railway Engineering at CQU. He has nearly thirty years experience in engineering education at university and is a member of the National Committee on Bulk Materials Handling of the Institution of Engineers Australia. His research interests are in vehicle dynamics and bulk materials handling.

Scott McFarlane

Mr Scott McFarlane plays a leading role in advancing Roaduser's worldclass developments in computer simulation of heavy road vehicle systems. His accomplishments include computer simulation, assessment and evaluation of the dynamic performance of heavy vehicle configurations, investigations into stability, braking, safety, design and road effects of heavy vehicle configurations, accident analysis, reconstruction and investigation.

His ability to develop complex, cost-effective models of heavy vehicles has significantly contributed to Roaduser's understanding of how vehicle size and weight interact with the transportation infrastructure. Mr McFarlane is recognised as a world leader in the use of the powerful AUTOSIM™ simulation tool for creating dynamic simulation models and advanced modelling and animation of heavy road vehicle dynamics. He recently completed the MADYMO training course at TNO in The Netherlands and has begun to develop models of complex road vehicle systems with this versatile simulation tool.

A regular attendee at international conferences concerned with the investigation of heavy road and rail vehicle dynamic systems, he is also a member of the International Society of Automotive Engineers (SAE).

A graduate of Royal Melbourne Institute of Technology, Mr McFarlane earned a Bachelor's degree of Engineering (Aerospace) with Honours.



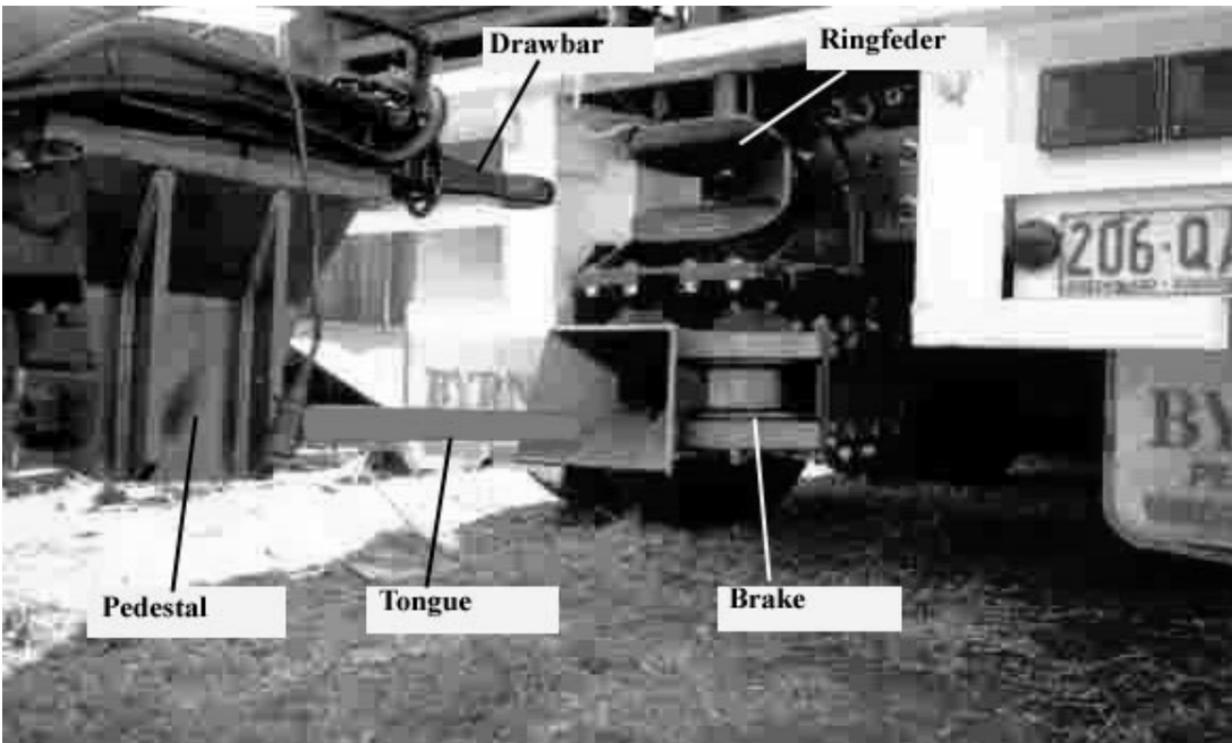


Figure 1 Positioning of Sway Stay

[Return
to paper](#)

[Content](#)

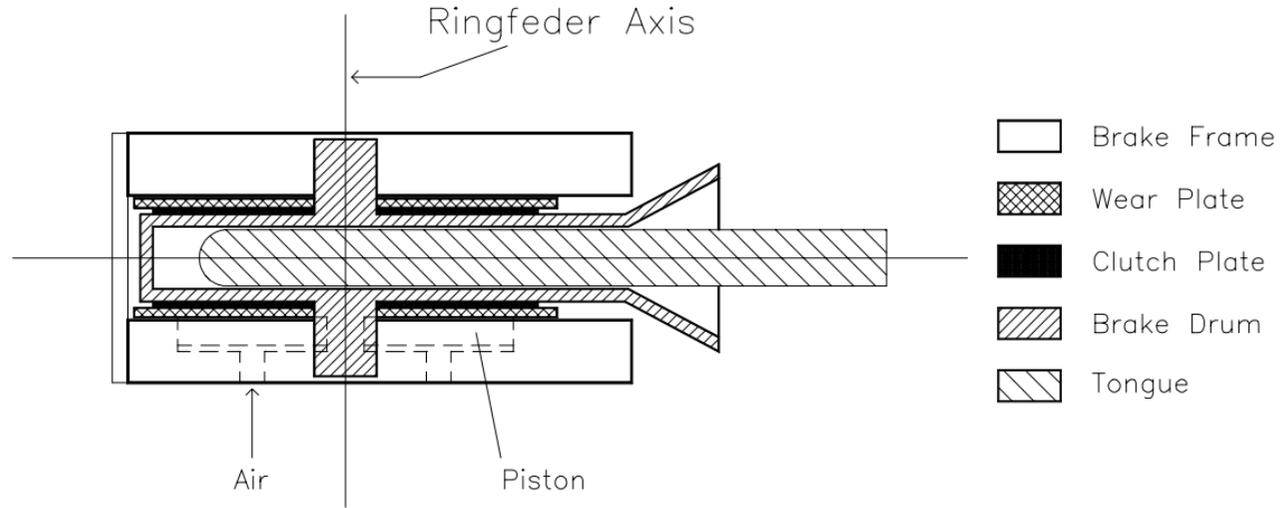


Figure 2 Section through Sway Stay



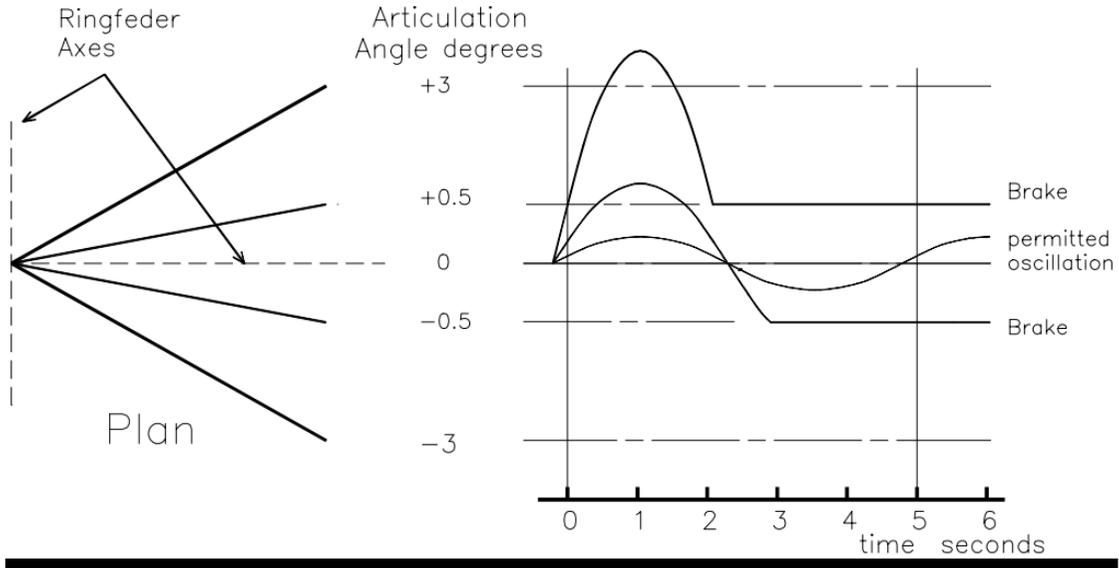


Figure 3 Conditions for the application of Sway Stay brake



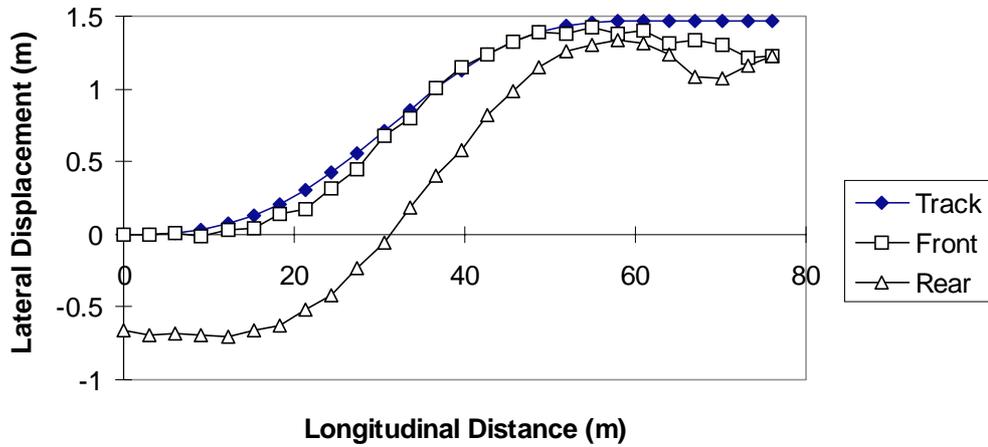


Figure 4a Dynamic Offset Tracking Characteristics Loaded Vehicle With Sway Stay Inactive

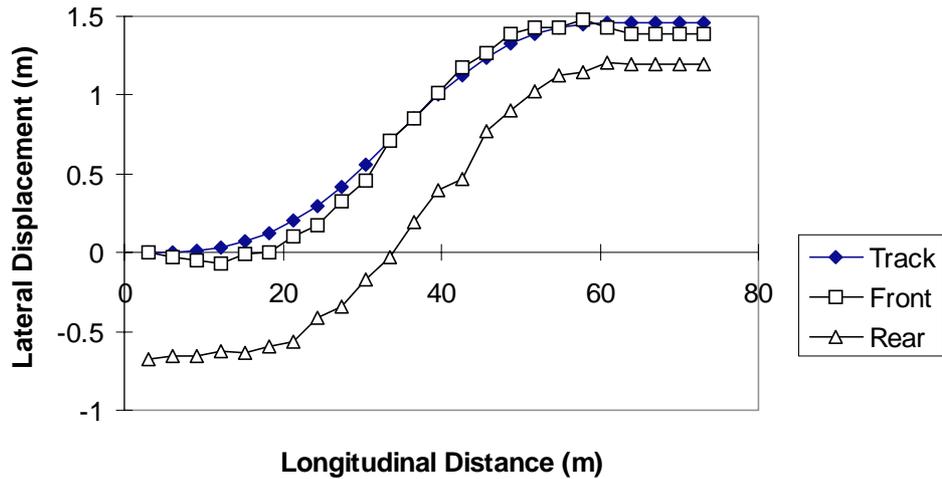


Figure 4b Dynamic Offset Tracking Characteristics Loaded Vehicle With Sway Stay Active

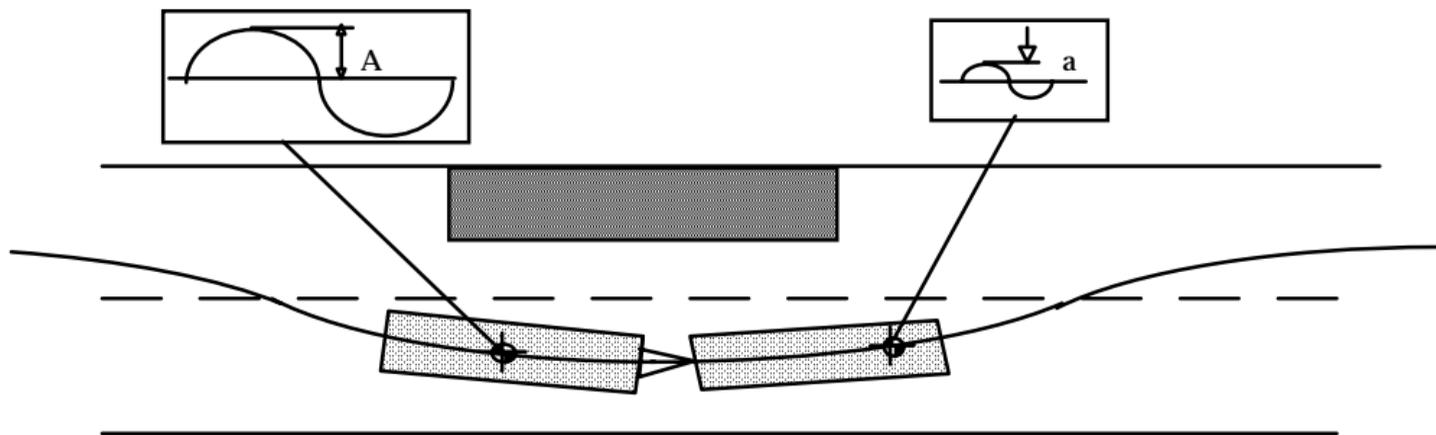




GCM 62.5t

Figure 5 SR-Double





$$RA = A/a$$

Figure 6 Rearward amplification of lateral acceleration



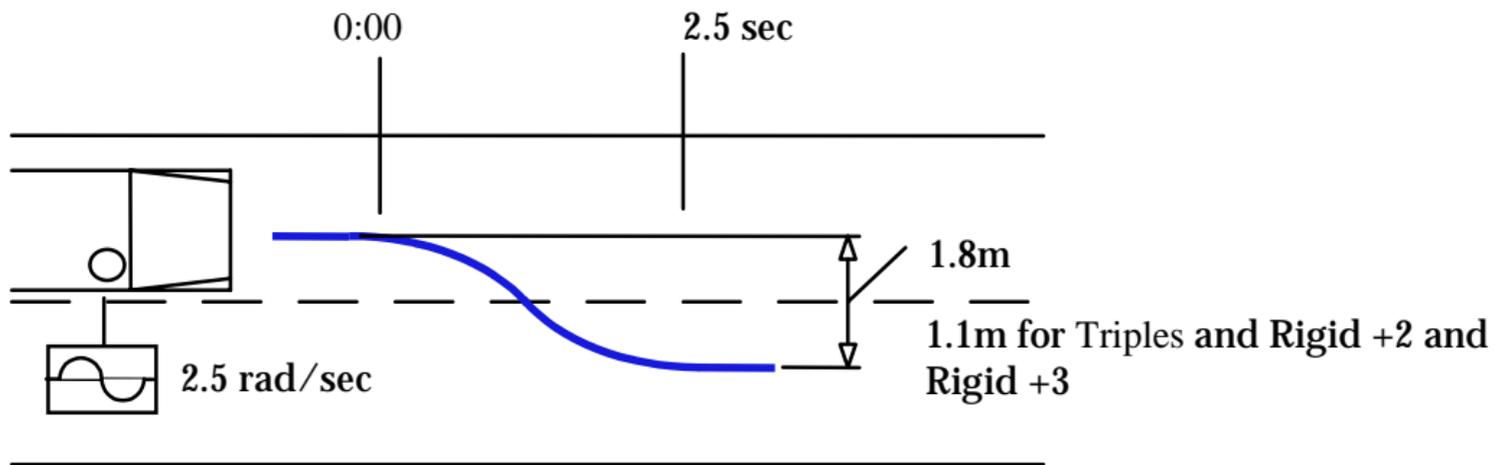


Figure 7 Standard transient manoeuvre

