

Frictional Characteristics of Roadside Grass Types

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ABSTRACT

The level of friction provided by a grass verge is important in situations where a vehicle is involved in a multiple surface skid, involving the roadway and the grass verge. Ideally, in such situations the difference in friction between the two surfaces should be kept to a minimum to avoid the likelihood of the vehicle yawing in the event of one or two wheels skidding on the grass verge. Differential friction can either exacerbate the effects of an emergency manoeuvre (e.g. a locked-wheel skid for example) or precipitate an emergency during an otherwise normal manoeuvre (e.g. unexpected locking of a wheel).

Given the lack of knowledge regarding dry and wet friction levels of grass types found on New Zealand roadside verges, a limited study involving both tyre dragging tests and locked-wheel braking tests was undertaken to:

- (1) identify if there is a significant difference in the level of dry and wet friction provided by white clover compared to other common grasses; and
- (2) establish if a potential safety issue could arise from differences in friction level between the grass verge and the roadway.

The principal findings were as follows:

- A limited comparison of friction values obtained by the tyre dragging test and the locked-wheel braking test identified that the tyre dragging test, which utilises a lightly loaded part tyre, produces much higher values and is more sensitive to wetness. Therefore more comprehensive comparative testing is required to establish whether or not it is appropriate to use the tyre dragging test to rank different grass surfaces and other soft surfaces in terms of friction wherever locked-wheel braking tests can't be safely performed.
- The locked-wheel braking tests showed that, in dry conditions, a white clover surface provides braking friction that is about 60% that of rye-grass. For a braking initiation speed of 40 km/h, this equates to a difference in stopping distance of around 13 m. Under wet conditions, the difference in braking friction is not as pronounced but still gives a significant stopping distance difference of about 9 m. On the basis of this result, the use of white clover on verges is not recommended.

Key Words: crash reconstruction, grass surfaces, locked-wheel braking tests.

1. INTRODUCTION

Representative coefficient of friction values for car tyres on various surfaces can be readily found in reference texts associated with vehicle handling dynamics and accident reconstruction. Table 1, sourced from Noon (1994) is an example of what is typically available.

Table 1: Coefficients of Friction of Various Roadway Surfaces (Noon, 1994)

Surface Type	Coefficient of Friction (μ)
Gravel and dirt road	0.35
Wet, grassy field	0.20
Dry asphaltic concrete	0.65
Wet asphaltic concrete	0.50
Dry concrete	0.75
Wet concrete	0.60
Snow	0.20-0.25
Ice	0.10-0.15
Loose moist dirt that allows tyre to sink about 5 cm	0.60-0.65

The coefficients tabulated in Table 1 are average values over a slide to stop i.e. locked-wheel braking manoeuvre. Although these coefficients were derived for American roadways, they appear to be suitable for local conditions as values given for gravel and asphaltic concrete are in agreement with locked-wheel braking tests performed in New Zealand by Opus Central Laboratories and reported respectively in Cenek et al (1999) and Cenek et al (2000). However, the applicability of the coefficient of friction for wet grassy fields to different grass types found on road verges has been questioned by Transit New Zealand, New Zealand's national road agency.

The level of friction provided by a grass verge is important in situations where a vehicle is involved in a multiple surface skid, involving the roadway and the grass verge. Ideally, in such situations the difference in friction between the two surfaces should be kept to a minimum to avoid the likelihood of the vehicle yawing in the event of one or two wheels skidding on the grass verge. Differential friction can either exacerbate the effects of an emergency manoeuvre (e.g. a locked-wheel skid for example) or precipitate an emergency during an otherwise normal manoeuvre (e.g. unexpected locking of a wheel).

Given the lack of knowledge regarding dry and wet friction levels of grass types found on New Zealand roadside verges, a limited study involving both tyre dragging tests and locked-wheel braking tests was undertaken to:

- (1) identify if there is a significant difference in the level of dry and wet friction provided by white clover compared to other common grasses; and
- (2) establish if a potential safety issue could arise from differences in friction level between the grass verge and the roadway.

This paper summarises the numerical and physical investigations that were performed along with the principal findings.

2. MEASUREMENT PROGRAMME

2.1 SELECTION OF TEST SITES

Two, approximately 80m long, adjacent strips of medium length white clover and rye-grass were located at AgResearch's Aorangi Farm near Palmerston North. Another strip of mown rye-grass was also located nearby. These strips had sufficient length and were smooth and flat enough to enable locked-wheel braking tests to be safely performed on them.

Small areas of Browntop and Agridark, suitable only for tyre dragging tests were located at AgResearch's nearby Grasslands complex.

The sites are summarised in Table 1 along with the type of test utilised to obtain coefficient of friction values.

Table 2: Test Site Details

Site No	Location	Surface Type	Test Type	
			Tyre Dragging	Locked-wheel Braking
1	Aorangi Farm	Clover	Yes	Yes
2	Aorangi Farm	Rye-grass (long)	Yes	Yes
3	Aorangi Farm	Rye-grass (short)	No	Yes
4	Grasslands	Browntop	Yes	No
5	Grasslands	Agridark	Yes	No

Photographs of sites 1 to 4 are provided in the appendix. No photographs of site 5 are available because of a camera malfunction.

2.2 EQUIPMENT

2.2.1 Tyre Drag Sled

A New Zealand manufactured tyre with a tread depth of about 1.5 to 2mm was cut and filled with concrete and lead weights, then fitted with towing eyes to enable it to be dragged with a calibrated spring balance attached. The total weight of the filled part-tyre was 15.05 kg. Figure 1 shows a photo of the tyre drag sled being used to obtain friction coefficient measurements.



Figure 1: Tyre dragging test in progress

2.2.2 Instrumented Test Vehicle

A non-ABS (Antilock-Braking-System) late model Hyundai Sonata, shown in Figure 2, was used to perform test skids. It was instrumented with a calibrated Vericom™ VC2000 supplied by the New Zealand Police. This single accelerometer based device, shown in Figure 3, continuously records the deceleration time history during braking, which can be downloaded to a computer for viewing. It is mounted on the test vehicle's windscreen and can be activated externally from the brake lights or internally by the braking force of the test vehicle.



Figure 2: Vehicle used for test skids

The Vericom™ VC2000 automatically processes the deceleration time history to provide the following user selectable outputs:

- Vehicle speed when braking is initiated
- Time taken from when braking is initiated to when the vehicle comes to a stop
- Distance travelled during the braking manoeuvre
- Average and peak coefficient of friction during the braking manoeuvre



Figure 3: Vericom™ VC2000 unit mounted in test vehicle

2.3 DETERMINATION OF COEFFICIENT OF FRICTION

2.3.1 Tyre Dragging Tests

The concrete filled part-tyre was dragged at a steady speed along the grass surface, and the average drag force reading from the spring balance was recorded. Care was taken to ensure that the angle of pull was parallel to the grass surface. The coefficient of friction was simply calculated by dividing the measured horizontal drag force by the weight of the part tyre (i.e. 15.05 kg)

The tyre dragging tests were carried out with the surface both dry and wet. Measurements were repeated a number of times at different locations on the same grass type to obtain a representative value of coefficient of friction. Four grass types were tested as listed in Table 2.

2.3.2 Locked-Wheel Braking Tests

Locked-wheel braking tests were conducted on three surfaces, these being white clover, and long and short rye-grass. For all the tests, braking was restricted to an initiation speed of between 35km/h and 45km/h for safety reasons. To assess the variability in the measured average and peak coefficient of friction values, the locked-wheel braking tests were repeated several times.

As the test sites each had very slight gradients, the braking tests were carried out in both upgrade and downgrade directions. The braking tests were first performed with the surfaces dry. Water was then applied from a water truck and the brake tests repeated on the wetted surface.

A member of the New Zealand Police Road Patrol Group, who had received special training and was experienced in conducting locked-wheel emergency braking tests, drove the test vehicle.

At the completion of each braking test the standard VC2000 outputs of (1) time to stop, (2) braking distance, (3) vehicle speed when braking initiated, (4) peak tyre-road friction value and (5) average tyre-road friction during the braking manoeuvre were displayed and manually recorded. The stored deceleration-time history was also downloaded for use in resolving any anomalies between repeated tests.

3. COEFFICIENT OF FRICTION FOR ROADSIDE GRASSES

3.1 TYRE DRAGGING TESTS

The site-averaged coefficient of friction values as determined by the tyre dragging tests are summarised in Table 3. These coefficient of friction values pertain to a steady-state condition of a very lightly loaded tyre slipping at a very slow speed (≤ 3 km/h) and so are expected to be higher than for a car sliding on a grass surface on a firm base. Therefore, the coefficient of friction values tabulated in Table 3 should only be used for ranking purposes.

With reference to Table 3, both clover and rye-grass show a significant reduction in the available friction when the grass becomes wet. By comparison, Browntop shows much less difference in friction between dry and wet conditions. Overall, the best

performing grass type was the Agridark, which gave marginally the highest value for both dry and wet conditions.

Table 3: Tyre Dragging Tests – Coefficients of Friction

Site No	Grass Surface	Coefficient of Friction	
		Dry	Wet
1	White Clover	0.68	0.59
2	Rye-grass (long)	0.77	0.59
4	Browntop	0.77	0.71
5	Agridark	0.80	0.74

3.2 LOCKED-WHEEL BRAKING TESTS

Coefficients of friction were determined from the Vericom™ VC2000 data for each upgrade and downgrade test run. These were combined to provide average values for the white clover and rye-grass test sites for dry and wet conditions. The resulting values are tabulated in Table 4 below.

Table 4: Locked-Wheel Braking Tests – Coefficients of Braking Friction

Site No	Grass Surface	Coefficient of Braking Friction		Stopping Distance (m) from 40 km/h	
		Dry	Wet	Dry	Wet
1	White Clover	0.21	0.17	30	37
2	Rye-grass (long)	0.36	0.21	17	30
4	Rye-grass (short)	0.38	0.24	17	26

These locked-wheel braking tests show that, in dry conditions, a white clover surface provides braking friction that is about 60% that of rye-grass. For a braking initiation speed of 40km/h, this equates to a difference in stopping distance of around 13 m. Under wet conditions the difference in braking friction is not as pronounced, but is still significant in terms of stopping distance, with the difference being about 9 m.

The length of the grass did appear to have some affect on wet braking performance, the stopping distance being 4 m less on the shorter length grass.

Further investigation into the relationship between grass length and dry and wet braking performance appears warranted on the basis of the rye-grass results, with differences of between 5% and 13% in coefficient of friction being observed. The investigation should consider whether this sensitivity to length applies to other grass types and if there is a critical length below which there is no improvement in the level of friction provided.

With reference to wet coefficient of braking friction values tabulated in Table 4, the range of 0.17 to 0.24 spans the value of 0.20 given in Table 1 for a wet, grassy field. This result gives a degree of confidence in the locked-wheel braking tests performed.

3.3 COMPARISON OF LOW SLIP SPEED COEFFICIENT OF FRICTION VALUES

As friction was continuously recorded during the locked-wheel braking tests, it was possible to compare the friction values when the vehicle was sliding at close to walking pace (1-3 km/h) with those obtained from the tyre dragging tests. Such a comparison permits the sensitivity of tyre friction on grass surfaces to load to be investigated. It also provides confidence that rankings of grass surfaces with respect to friction derived from the tyre dragging tests will equally apply to the situation of interest, which is a skidding car.

This comparison was able to be performed for two grass surfaces only: white clover and long length rye-grass. The associated results are tabulated in Table 5.

Table 5: Comparison of Low Slip Speed Coefficient of Friction

Site No	Grass Surface	Coefficient of Friction (Slow Slip Speed)			
		Dry		Wet	
		Tyre Dragging Test	Locked-Wheel Braking	Tyre Dragging Test	Locked-Wheel Braking
1	White Clover	0.68	0.36	0.59	0.33
2	Long Rye-grass	0.77	0.42	0.59	0.38

With reference to Table 5, coefficients of friction obtained for a sliding test tyre are much higher than for a car sliding on the grass when the sliding speeds are comparable. This finding has also been independently reported by Fricke (1990), though it cannot be easily explained. Fricke conjectures that there is some interaction of the tyre and grass at a light load that does not occur with typical wheel loads. It will also be noted that the tyre dragging test appears to be more sensitive to wetness, with differences between dry and wet coefficients of friction being almost 3 to 4 times greater.

Nevertheless, both test results are in agreement that long rye-grass provides improved friction characteristics over white clover for both dry and wet conditions.

3.4 UNDERLYING SOIL HARDNESS

No penetrometer tests were made to quantify the penetration resistance of the underlying soil. This possibly could be an issue for the locked-wheel braking tests because of the wheel loads carried, which are of the order of 400 kg for the test vehicle's front wheels and 200 kg for the rear wheels. However, as the three, locked-wheel braking, test sites were all in close proximity to each other and the ground was very hard due to a dry spell, it is unlikely that the coefficient of braking values tabulated in Table 4 will have been influenced by differing penetration resistance. Furthermore, because the ground was hard, these values are likely to be at the lower range of what can be expected as, with reference to Table 1, friction tends to increase on soft surfaces as a result of material build-up in front of the sliding tyres.

By analogy, it is expected that the tyre dragging test results are comparatively insensitive to soil penetration resistance because the sliding tyre has insufficient weight to cause such build-up.

4. EFFECT OF DIFFERENTIAL FRICTION

4.1 DESCRIPTION OF MODELLING APPROACH

A numerical six degree-of-freedom vehicle handling model of a typical passenger car has been developed by Opus Central Laboratories using Matlab (Simulink) software and incorporates a standard tyre model implementation of the Pacejka "magic tyre formula." The model has been found to be capable of realistic handling predictions for characteristic small roll, pitch and yaw angle changes in flat road cornering and braking manoeuvres. It was, therefore, used for evaluating differential skidding situations resulting from a vehicle traversing multiple surfaces

Simulation of the destabilising effect of skidding with left hand wheels on a grass shoulder and right hand wheels on sealed road was accomplished by adjusting the tyre-surface interface friction properties accordingly. The handling model then predicts the very high clockwise yaw rates that result when grip is re-established after brake release. This is the classic response following wheel lockup on surfaces that exhibit significant differences in wheel path friction (Hayhoe and Henry, 1981).

Two situations were investigated as follows:

1. left wheels on dry white clover ($\mu = 0.21$), right wheels on dry chipseal ($\mu = 0.70$).
2. left wheels on dry rye-grass ($\mu = 0.37$), right wheels on dry chipseal ($\mu = 0.70$).

Situation 1 represents the maximum differential friction condition likely to be encountered by a vehicle as, under wet conditions, the friction of a chipseal road surface reduces more than white clover so the differential is reduced (i.e. $\mu = 0.50$ (wet chipseal) cf $\mu = 0.17$ (wet white clover)). Situation 2 is representative of most common grasses and gravel.

For both situations the following emergency manoeuvre was simulated. A small front-wheel drive vehicle travels at 80 km/h with the left wheels on the grass shoulder and the right wheels on the chipseal surface when the brakes are fully applied for 0.5 s (resulting in wheel lock-up) and then released.

4.2 RESULTS

Figure 4 shows the numerically generated time histories of wheel lock-up, vehicle rotation, and vertical tyre forces for white clover (left hand-side plots) and rye-grass (right hand-side plots).

With reference to Figure 4, maximum clockwise yaw rates occur shortly after the wheels unlock. The values are 34 deg/s (at 1.28 s) on white clover and 22 deg/s (at 1.18 s) on rye-grass.

The coefficient of dry rye-grass is comparable to gravel. Therefore, although a yaw rate of 22 deg/s results in a potentially hazardous situation, it is no different to what motorists are normally exposed to when travelling on roads with shoulders that have not been sealed. However, adoption of white clover for roadside verges will make an already hazardous situation significantly more hazardous.

5. CONCLUSIONS AND RECOMMENDATIONS

Within the scope of the numerical and experimental study undertaken, the following conclusions and recommendations have been drawn.

1. Dry and wet friction of different roadside grasses determined by tyre dragging tests and locked-wheel braking tests identified that white clover was the worst performing species by a significant margin, particularly under dry conditions. Of the other grass species tested, rye-grass, Browntop, and Agridark, all appear to provide a similar level of friction to that of gravel in the dry and so are preferable to clover.
2. The grass length appears to have an effect on braking performance, the shorter the length the shorter the stopping distance. This effect is more pronounced for wet conditions. Therefore, it is recommended that a more detailed investigation should be performed to establish whether or not this sensitivity to length applies to grass types other than rye-grass and to determine if there is a critical length.

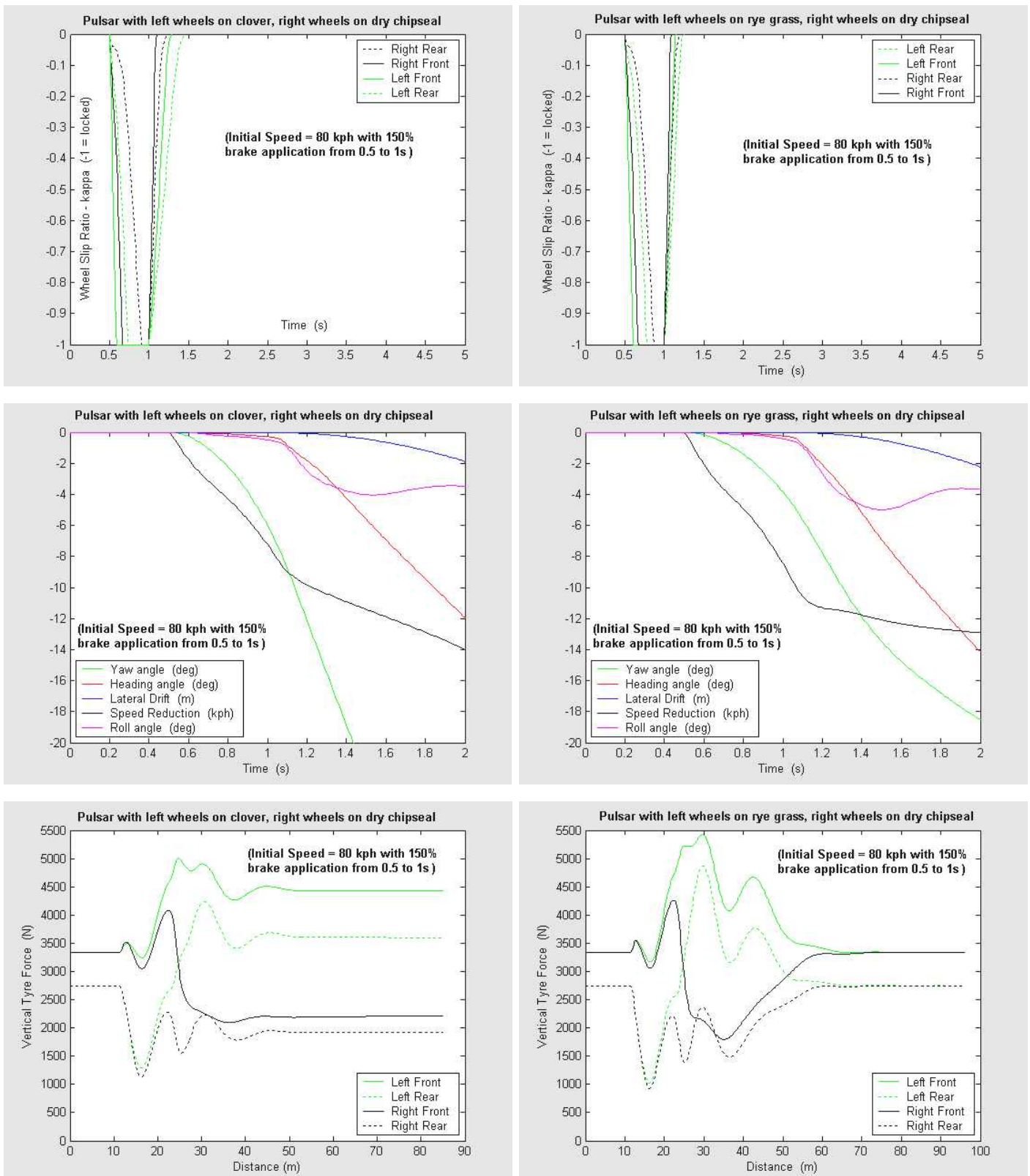


Figure 4: Comparative vehicle responses with left wheels on clover and rye-grass

3. A limited comparison of friction values obtained by the tyre dragging test and the locked-wheel braking test identified that the tyre dragging test produces much higher values and is more sensitive to wetness. Therefore more comprehensive comparative testing is required to establish whether or not it is appropriate to use the tyre dragging test to rank different grass surfaces and other soft surfaces in terms of friction because of the much lighter loading of the test tyre.
4. On the basis of tyre dragging tests, it appears that the friction provided by Browntop and Agridark grasses may be less sensitive to wetness than rye-grass. However, given concerns regarding the applicability of tyre dragging tests to grass surfaces, it appears worthwhile to conduct locked-wheel braking tests on Browntop and Agridark to quantify their dry and wet frictional characteristics under actual vehicle tyre loads and slip speeds. Benefits would be considerable if these grasses improved on the 40% difference between dry and wet coefficient of braking friction achieved with rye-grass.
5. The manoeuvre of brakes being applied from 80 km/h for 0.5 s and then released was chosen to assess the hazard associated with driving a car on a differential-frictioned surface that results from having two wheels on the verge and two wheels on the roadway. A simulation study established that a yaw rate of about 34 deg/s would occur if the verge comprises white clover. This yaw rate reduces by 35% to 22 deg/s if the verge is covered either with gravel or a common grass such as rye-grass. Therefore, the possible use of white clover for verge cover represents a significant worsening of an existing, accepted, hazard.

6. REFERENCES

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APPENDIX

	
Site 1: White Clover	
	
Site 2: Long Rye-Grass	
	
Site 3: Short Rye-Grass	



Site 4: Browntop