EXPERIMENTAL SKID ANALYSIS OF A VEHICLE ON A GRAVEL ROAD

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ABSTRACT

Skid control on a typical dry rural sandy, gravel road had been investigated, to identify the skid and braking characteristics. Experimental analysis was performed on a vehicle travelling at three different speeds (80, 60 and 40 km/h) and for each speed three different levels of tyre wear condition (tyres with tread as new, approximately 38% and wholly illegal or below tread wear indicator level). The effect of severe tyre pressure difference on one side of the vehicle combined with the illegal tyres was also considered. Testing was undertaken with and without ABS braking. A drag factor (based on drag sled values obtained on the test section) of 0.52 was used as a theoretical value and basis of determining skid / stop distance.

The results of these tests are that

- The skid distances were observed to be similar to the theoretical skid distances (based on drag sled determined drag factors) when no ABS brakes were used.
- The general observation was that the skid distances on gravel increased, the smoother the tyres were.
- The observed differences between the different inflation levels of the tyres, showed a small difference.
- All runs where the RHS tyres were underinflated (1.1 bar or 50% inflation), presented with an obviously clearer, more defined ABS braking mark on the right side tyres, compared to the fully inflated tyres.
- There was generally a difference when the ABS brakes were activated, as the skid distance was more than the theoretical skid distance (based on drag sled determined drag factors).
- When the ABS brakes were deactivated, the vehicle skid out of control, yet when it was activated, the skid of the vehicle was in a straight line.
- Correction factors that could be used to calculate a more accurate skid distance on gravel roads using drag sled determined drag factors; when ABS brakes were used was found to be 1.165; and for illegal tyres 1.3.

1. INTRODUCTION

Of late and historically, there has been an inordinate number of rollover, loss of control and general crash cases considered on typical rural, sandy, gravel roads that needed careful consideration (Roodt, 2013; Bullas, 2004). The author from Accident Specialist have also investigated several such cases. Most of these were instigated by the short term insurance industry to determine liability in respect of some level of direct or contributory negligence.

A review of tyre and road experiments were performed to investigate these relationships (Sinnamon, 1974). The critical factor in these cases was the skid resistance or drag factor that played a role in loss of control.

In almost every case, some level of tyre condition, be this tread depth (the most common issue), improper tread wear, improper tyre pressures, mismatched tyre types and therefore tread patterns and even tyre size differences, needs to be considered (Bullas, 2004). Accident severity is often associated with vehicle speed (Rivers, 1997), and so it is with such road conditions, exasperated by tyre condition.

The literature review found very few research papers that specifically documented such sandy, gravel road testing, as most articles considered sealed roads (bitumen binders) and smooth tyres, worn or smooth road surfaces or wet surfaces (Roodt, 2013). The correlation of vehicle speeds on sealed road surface and brake stopping distance has been extensively researched before (Ibrahim and Abdullah, 2013). Characteristics on grass surfaces have also been identified in experimental research (Cenek et al., n.d.). Different techniques have been considered to identify the friction of the road surface for skid analysis (Wallman & Astrom, 2001). Although such sandy, gravel road testing and results are referenced in some papers (Ibrahim and Abdullah, 2013), none are specific. Tyre wear (Manas et al., 2009) and lifetime is dependent on the road surface (Lorne, 1970) and on the tyre inflation (Varghese, 2013), among other factors. The investigation of the coefficient of friction of gravel roads has been performed to some extent (Roodt, 2013).

According to Lyubenov and Kadikyanov (2014) the difference in the time that the vehicle stops due to whether it has anti blocking system (ABS) brakes or not, is negligible, and therefore don’t need to be taken into account for these calculations and tests. The drag co-efficient values could be any value between 0.4 and 0.8 for gravel roads (Harris, n.d).

The objectives of this investigation were:

1. To experimentally identify the skid distance of a vehicle on a sandy gravel road, travelling at speeds of 40 kph, 60 kph and 80 kph.
2. To experimentally identity the correlation between skid distance and the amount of tread on the tyres on a sandy gravel road.
3. To experimentally identify the correlation between skid distance and the inflation of the tyres on a sandy gravel road.
4. To validate the effect of ABS in its use on gravel road for new tyres fully inflated.
5. To validate the use of drag sled values as theoretical values on gravel roads.
6. To identify a formula that could be used to calculate a more accurate skid distance on gravel roads when ABS brakes were used.

2. VEHICLES SKID DISTANCE ON GRAVEL ROADS

According to Harris (n.d.), the speed of a vehicle can be determines by the distance of the skid mark, thus:

$$S = \sqrt{30xDxfxn} \quad (1)$$

Where S = speed in mph

D = distance in feet of skid marks (or measured stopping distance when no skid marks were present)

f = drag co-efficient value, which is a value less than 1

n = efficiency of the brakes, which is a value less than 1.

The efficiency of the brakes are considered as 1, as with these tests all four wheels of the brakes will be activated at the same time (Harris, n.d.).

The equivalent of formula (1) in SI units, is:

$$d = \frac{v^2}{254\, f\, n} \tag{2}$$

Where: d = braking distance in meters
v = vehicle speed in kph
f = drag co-efficient value, which is a value less than 1
n = efficiency of the brakes, which is a value less than 1.

Note that the constant 254 consists of conversion of km/h to m/s, the gravitational acceleration g = 9.8 m/s/s and the factor 2 that results from integrating speed to obtain displacement.

254 = 2 x 3.6 x 3.6 x 9.8 where 3.6 = 3600 seconds per hour / 1000 m per km.

The more general form of this formula as used in road engineering, with speed in m/s is:

$$d = \frac{v^2}{2g\,(f\, n \pm G)} \tag{2a}$$

Where all symbols are as previously defined and G = slope of the road.

The experimental results recorded in this paper have been compared with (2), to validate the accuracy of the theoretical values and determine correction factors.

3. EXPERIMENTAL SETUP

A VW Polo Vivo 2019 model, with 188 km on the odometer was used as it was a common class and has a similar drive layout of many of the vehicles involved in such incidents.

Considering the relationship of coefficient of friction and drag factors (George, 2005), the drag sled readings for the terrain-was investigated. Four different scales, of which each had three tests conducted, were performed. The average drag factor of the gravel road was 0.52.

The vehicle was fitted with various telemetry devices, particularly to measure the longitudinal deceleration force, duration thereof and further possible factors such as lateral or rotational forces. Different types of previously researched telemetry devices (Covaciu et al., 2014) were considered, which were available, however the VBox (Racelogic) was used, to allow for a greater precision in results. For the purpose of this paper, the VBox Lite recordings are discussed, due to the accuracy it had compared to the other devices that were used.

High definition video footage was obtained by placing a camera between the front seats of the vehicle, and another placed at the front left windscreen to observe the driver. The cameras were connected to the VBox Lite, which allowed for the video overlay with the vehicle speed indicator and a g-force indicator as seen in Figure 1. The location of the VBOX Lite equipment and the camera are shown in Figure 2. The observers also recorded video footage from the external side, and a few of the tests were also video recorded from above with a DJI Mavic drone. Video footage of some of the views of the experiments recorded, can be accessed at: https://www.youtube.com/watch?v=HKcjezFlRvI.

The vehicle was driven to the required speed, verified with a Global Positioning System (GPS) of the VBox Lite. Once the vehicle has reached the position where the test was to be performed, the driver would clutch in and apply brake completely and the vehicle brought to a complete stop. The area (and all testing results on the day) were surveyed with a Total Station instrument to provide precise layout of the area in respect of gradients, lengths, slopes, initial and final skid locations. The layout used for the tests conducted are shown in Figure 3, which shows the vehicle after a skid and stop in one of the tests. The dust cloud behind the vehicle is also seen in Figure 3.

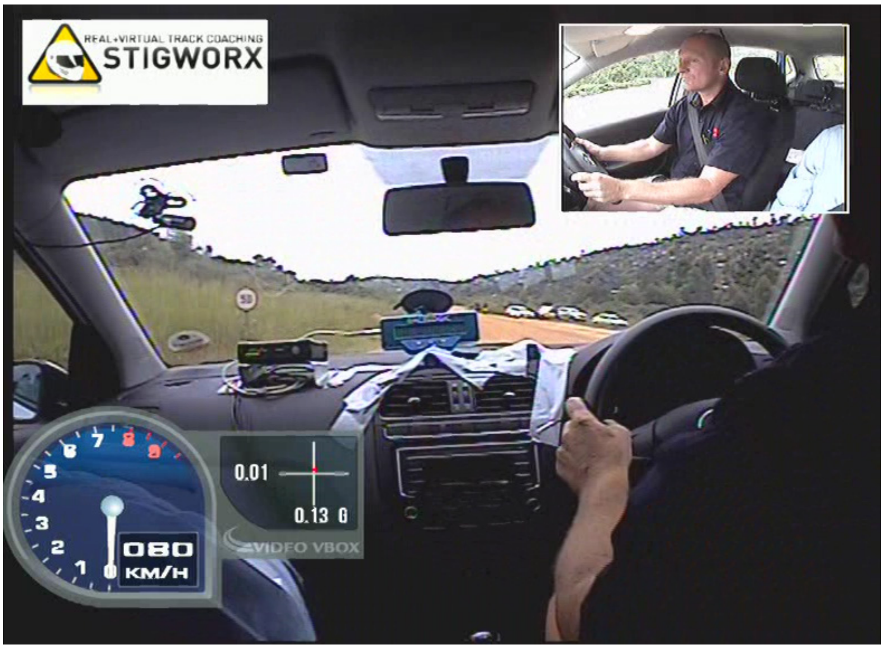

Figure 1: The overlaid camera view of the VBOX Lite

Figure 2: Position of the cameras and equipment

Figure 3: The layout of the tests conducted, when the vehicle stopped after a test

The surface itself is a moderately well used access road to an industrial and business area. The road surface is graded only when required and was graded a few weeks prior. The surface was dry and is well compacted, level, with a very slight convex crown. Some minor corrugations were evident at locations on the crest and left side for test direction of travel. Corrugations being small and sporadic are ignored in effect. The composition is a matrix of finer aggregate (sand), with some larger aggregate (stone), this is evident in Figure 4. Weather conditions were clear, dry, yet overcast. Figure 4 shows the gravel, where dimensions can be read.

Figure 4: The test road composition of finer aggregate (sand), with some larger aggregate (stone)

The tests were conducted at 80 kph, 60 kph and 40 kph for each set of tyres. The new tyres used were Continental Conti Premium Contact 175/70R14, with an average tread depth of 7.7 mm. The used tyres Goodyear Assurance 185/70R14, with an average tread depth of 2.9 mm (38%). The smooth tyres were a combination of Goodyear Assurance 185/70R14, Bridgestone BL250 185/70R14, Goodyear Duragrip 185/70R14 and Goodyear Assurance 185/70R14, with an average tread depth of 1.1 mm (14.1%), which is below the dread depth wear indicator of 1.6 mm as per the manufacturers' specifications. A common scenario of gravel road accidents in South Africa usually consist of vehicles with different types of tyres, and the reason why these were considered in this test. The smooth, 38% tread and the new tyres can be viewed in Figure 5. The new tyres were the new tyres that were on the vehicle.

Figure 5: The Smooth (left), 38% tread (middle) and new tyres used for the tests

For each set of tyre, the three different speeds were used for the tests, to be able to compare the skid differences. For each set of tyre, a test was conducted where all the tyres were fully inflated (2.2 bar); the two right hand sides tyres of the vehicle was 50% inflated (1.1 bar) while the left hand side tyres were fully inflated.

4. RESULTS

It was observed when the tests were conducted, that all runs where the RHS tyres were underinflated (1.1 bar or 50% inflation), presented with an obviously clearer, more defined ABS braking mark on the right-side tyres, compared to the fully inflated tyres.

It was also observed that the vehicle skid was out of control when the ABS brakes were deactivated, while the vehicle skid in a straight line when the ABS brakes were activated. The results obtained from the tests conducted are shown in Table 1. The theoretical (drag sled) value with the given drag factor of 0.52 for the specific speed, is indicated in Table 1, showing how the ABS brakes, ABS deactivated, and with the right-hand side (RHS) tyres deflated to 50% (1.1 bar) while the ABS brakes have been activated, for each set of tyres. Each test was conducted once.

The average drag factor that were calculated for all the test results were found to be 0.48, which is close to the drag sled measured 0.52, which correlates to the range indicated by Roodt (2013). The results shown in Table 1, have been graphically compiled, for the new tyres, 38% tread tyres and the smooth tyres, as shown in Figure 6, Figure 7 and Figure 8 respectively. The blue bar as the theoretical values for each speed if according to equation (2) and drag factor of 0.52.

In Figure 6, the new tyres comparison is shown. At 40 kph, the theoretical skid distance is equivalent to the ABS brakes values (including the RHS deflated to 50%), which is also observed in Figure 9. The theoretical skid distance is in range with all the tests conducted at 60 kph. At 80 kph, the theoretical skid distance is closer to the ABS tests conducted (as also seen in Figure 11), yet with the ABS brakes deactivated there is approximately 9 meters difference. In general, the theoretical skid distance is closer to the distance measured in the tests with the ABS activated.

Table 1: Braking distances [m] with different conditions and speeds

		40 kph		60 kph		80 kph	
		Theory Df = 0.52	Experimental	Theory Df = 0.52	Experimental	Theory Df = 0.52	Experimental
New Tyres	ABS		11,93		31,67		51,812
	No ABS		10,125		23,273		39,275
	ABS, RHS tyres deflated to 50%		11,7		31,375		53,236
38% Tread Tyres	ABS		14,77		31,857		55,8
	No ABS		11,833		25,667		45,8
	ABS, RHS tyres deflated to 50%	12,09	15,25	27,2	31,439	48,36	60,304
Smooth Tyres	ABS		16,667		35,143		58,445
	No ABS		11,867		25,533		44,909
	ABS, RHS tyres deflated to 50%		17,2		36,461		66,222

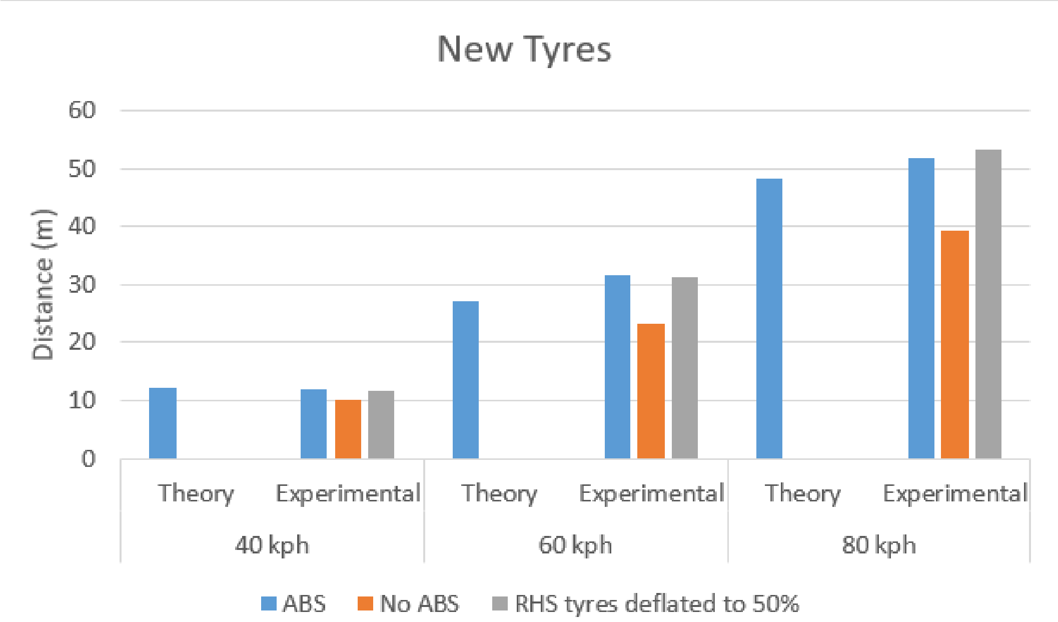

Figure 6: Theoretical comparison with ABS brakes, no ABS brakes and 50% pressure for 40 kph, 60 kph and 80 kph speeds with new tyres

In Figure 7, the 38% tread tyres comparison is shown. At 40 kph, the theoretical skid distance is equivalent to the distances measured for the tests when the ABS brakes were deactivated, yet the average distance difference with the tests when the ABS brakes are activated is in range (as seen in Figure 9). The average test values were similar to the theoretical skid value at 60 kph, as seen in Figure 10. At 80 kph, the theoretical skid distance is similar to the skid distances performed when the ABS brakes were deactivated (As seen in Figure 11), yet the times when the ABS brakes were activated, the test skid distances were at least 7.44 meters. In general, the theoretical skid distance is close to the skid distances recorded when the ABS brakes were deactivated.

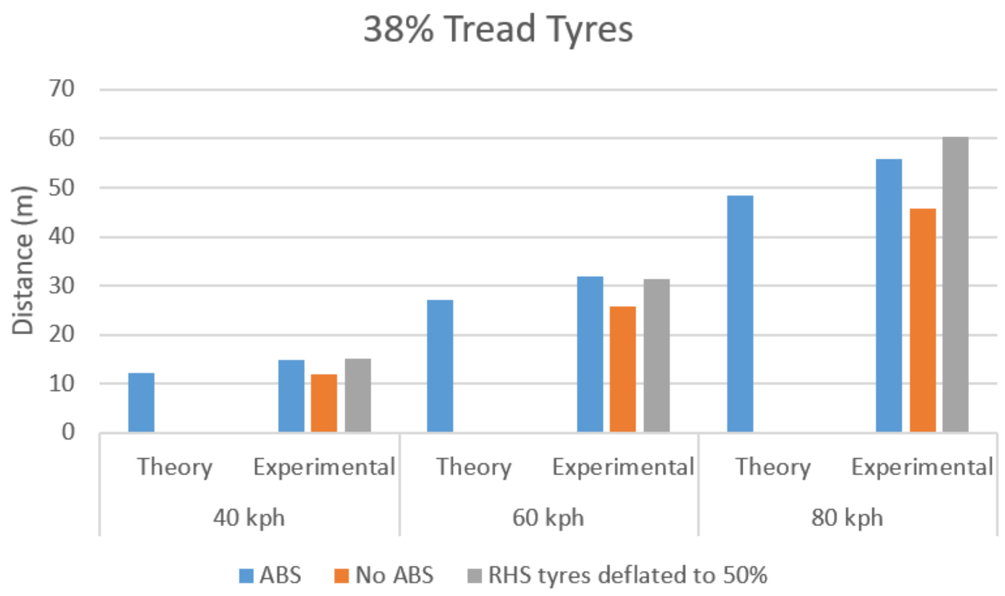

Figure 7: Theoretical comparison with ABS brakes, no ABS brakes and 50% pressure for 40 kph, 60 kph and 80 kph speeds with 38% tread tyres

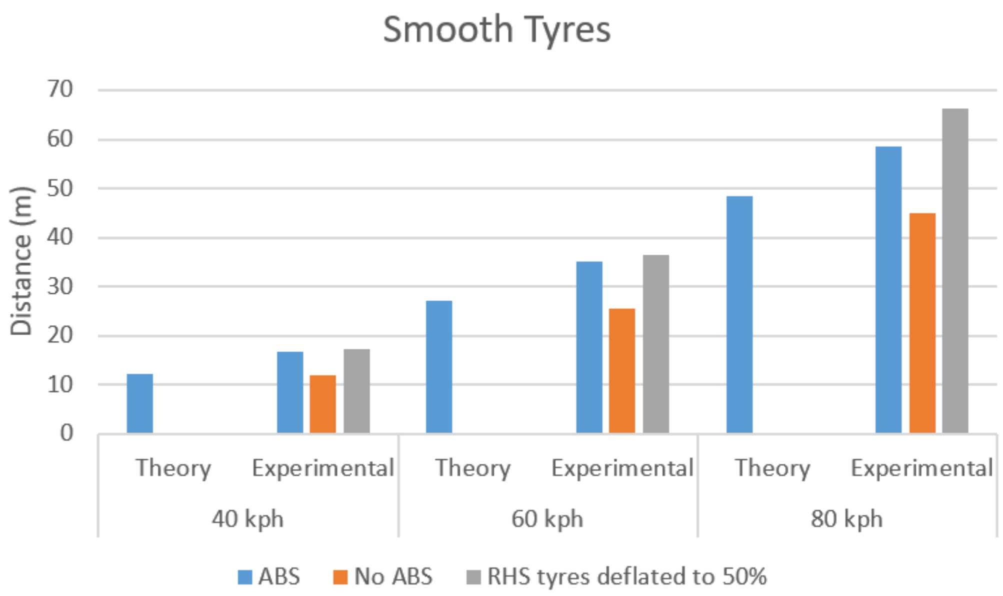

Figure 8: Theoretical comparison with ABS brakes, no ABS brakes and 50% pressure for 40 kph, 60 kph and 80 kph speeds with the smooth tyres

A comparison of the different tyres and test conditions for the same speeds (40 kph, 60 kph and 80 kph) are shown in Figure 9, Figure 10 and Figure 11 respectively. In Figure 8, the smooth tyres comparison is shown. At 40 kph, the theoretical skid distance is in range with the skid distance when the ABS brakes were deactivated. With the tests that the ABS brakes were activated, the skid distances were at least 4.6 meters more than the theoretical skid distances, as seen in Figure 9. The tests conducted at 60 kph with the ABS brakes deactivated, showed skid distances that were in range with the theoretical skid distances, yet the tests with the ABS brakes activated showed to be at least 7.9 meters more than the theoretical skid distances, as also observed in Figure 10. At 80 kph, the similar observation was observed as with the tests conducted at 60 kph, yet when the ABS brakes were used, the measured distances were at least 10 meters more than the theoretical distances (also seen in Figure 11). In general, the theoretical skid distances were close to the measured distances when the ABS brakes were deactivated.

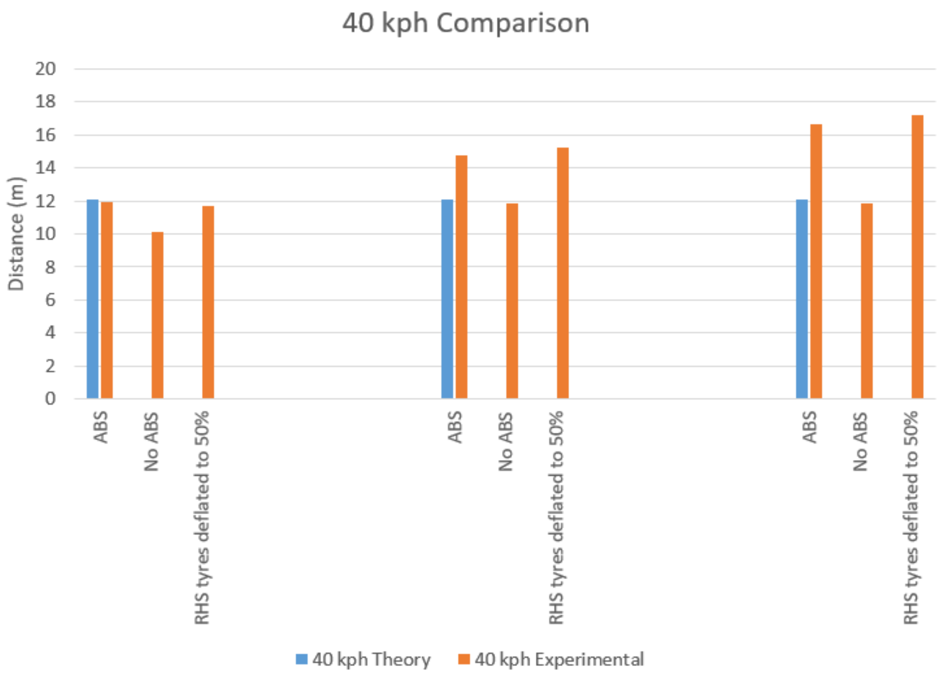

Figure 9: The new tyres (left), 38% tyres (centre), and smooth tyres (right) comparison for the 40 kph speed

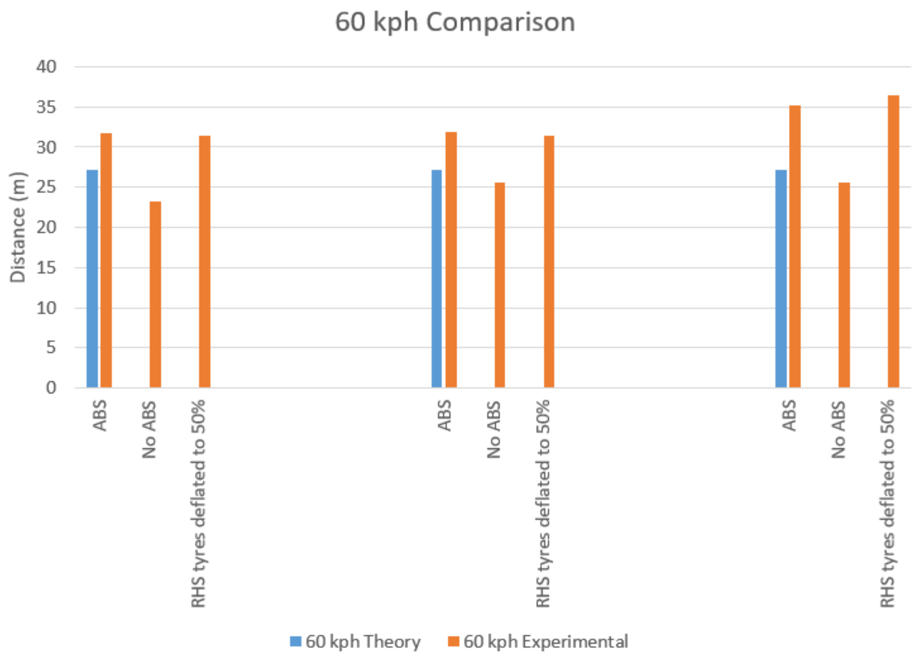

Figure 10: The new tyres (left), 38% tyres (centre), and smooth tyres (right) comparison for the 60 kph speed

The general observation from Figure 6 to Figure 11 were that the theoretical skid speeds are similar to the values when no ABS brakes were used. For speeds around 60 kph and below, the theoretical skid distances are similar to the different test results, irrespective whether the ABS brakes were activated or not, when the tyres are still legal. At 80 kph the measures skid distances of the tests conducted were in range with the theoretical skid distances, when the ABS is deactivated and the tyres are illegal and smooth. The 38% tread tyres at speeds of 80 kph when the ABS brakes are used, were also not in range with the theoretical skid distances. In general, the skid distances observed when the RHS tyres were deflated to 50% (1.1 bar), were slightly longer than when the tyres were all fully inflated, yet the difference was very small, enough to be ignored. Another general observation, which was expected, was that the smoother the tyres were, the longer the skid distance was observed for the specific speed, as seen in Figure 9, Figure 10 and Figure 11.

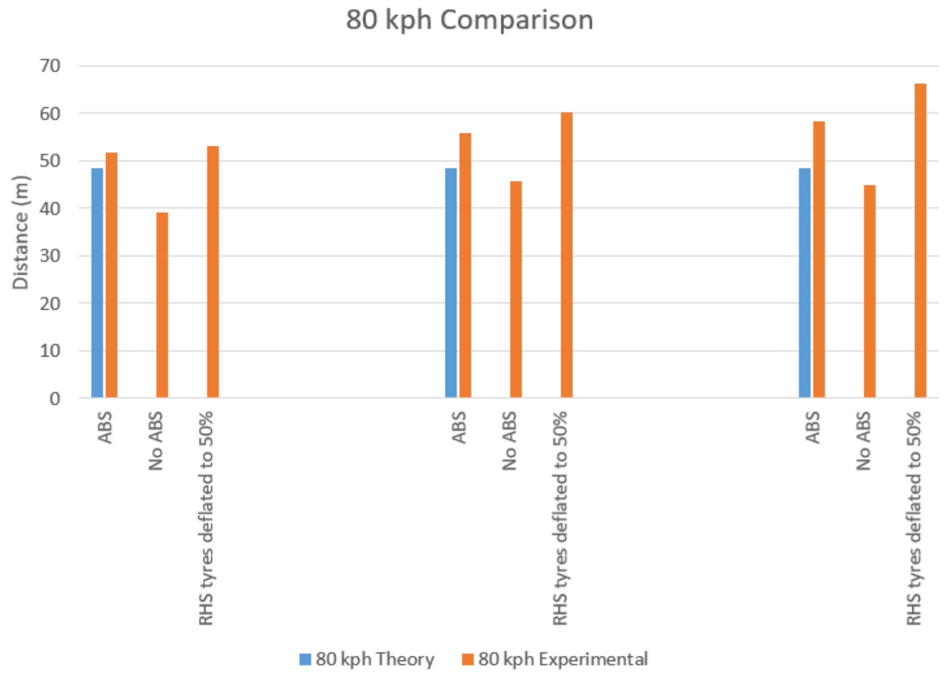

Figure 11: The new tyres (left), 38% tyres (centre), and smooth tyres (right) comparison for the 80 kph speed

These observations suggest that for high speeds and illegal tyres, a correction factor is needed to calculate theoretical skid distance. One could argue that the reason for the difference in reading with the smooth illegal tyres, is that the drag factor changes, which the authors are not disputing, yet when an investigation is conducted, a correction factor that can be used to predict a more exact skid distance and speed relationship, will be useful. Similarly, from (2) it is considered that the value of n = 1, as all tyres are braking and there is no loss in braking, which is not the case when ABS brakes are activated, due to the pulsating action of the brakes being gripped and let go. It is also realized that the theoretical value that was used in (2) were used in a time in history when there was no ABS brakes.

Therefore, keeping the drag factor constant as per the measured value with the drag sled scales, considering that n = 1, an average value was calculated from the different tests of similar speeds, to determine a correction factor to be used in formula (2), when the ABS brakes were activated. Using these conditions results (3).

$$d = 1.165 \frac{v^2}{254\, f\, n} \tag{3}$$

It must be noted that (3) can only be taken into account with vehicles that have legal tyres, and that have ABS brakes activated. In the event that smooth, illegal tyres were on the vehicle, (4) can be used to calculate the skid distances.

$$d = 1.3 \frac{v^2}{254\, f\, n} \tag{4}$$

With (3), it was found that for 60 kph the error was less than 1%. At 80 kph the error was below 8%. With (4), it was found that for 60 kph the error was less than 3%, while at 80 kph, the error was less than 7%.

5. CONCLUSION

A VW Polo Vivo 2019 vehicle was used to perform skid tests on a gravel road, to identify the characteristics at different speeds and different conditions of tyres. New tyres, 38% tread tyres and smooth illegal tyres were considered for skid distances measured on a gravel road.

The contributions and observations that were achieved in this paper are:

- To experimentally identify the skid distance of a vehicle on a gravel road, travelling at speeds of 40 kph, 60 kph and 80 kph. The skid distances were observed to be similar to the theoretical skid distances when no ABS brakes were used.
- To experimentally identity the correlation between skid distance on a gravel road and the amount of tread on the tyres. The general observation was that the skid distances on the gravel increased, the smoother the tyres were.
- To experimentally identify the correlation between the inflation of the tyres and the skid distance on a gravel road. The observed differences between the different inflation levels of the tyres, showed a small difference.
- To validate the effect of ABS in its use on gravel road for new tyres fully inflated. It was found that there was generally a difference when the ABS brakes were activated, as the skid distance was more than the theoretical skid distance. It was found that when the ABS brakes were deactivated, the vehicle skid out of control, yet when it was activated, the skid of the vehicle was in a straight line. It was observed when the tests were conducted, that all runs where the RHS tyres were underinflated (1.1 bar or 50% inflation), presented with an obviously clearer, more defined ABS braking mark on the right side tyres, compared to the fully inflated tyres.
- To identify a formula that could be used to calculate a more accurate skid distance on gravel roads when ABS brakes were used, for legal and illegal tyres, as seen in (1) and (2) respectively. Correction factors that could be used to calculate a more accurate skid distance on gravel roads using drag sled determined drag factors; when ABS brakes were used was found to be 1.165; and for illegal tyres 1.3.

Future work would be required to identify the accuracy of the suggested correction factors in (3) and (4), with speeds higher than 80 kph on gravel roads. Similarly, the accuracy of these suggested equations could be validated on other road surfaces with different drag factors. A comparison with experimental results on wet road surfaces would be valuable to investigate.

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