

SKID RESISTANCE OF ROADS CONTAMINATED WITH GRAVEL

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ABSTRACT

Skid resistance values found in older design manuals were typically based on studies where the worst case scenarios of bald tires, smooth pavement and wet conditions were used. The graphs depicting these values were first published in the AASHTO Policy for the Geometric Design of Rural Highways, 1954. In the AASHTO Policy for the Geometric Design of Highways and Streets, 2001, skid resistance ceased to define braking distance (the second component of Stopping Sight Distance) and a standard deceleration of 3.4 m/s^2 , based on comfort, became the design norm at all speeds.

These design values are of little use in the reconstruction of crashes. The skid resistance for specific scenarios must be determined. Values obtained from published sources can serve as guidance to orders of magnitude and as reference values. The stopping performance of modern cars under ideal conditions can be in the order of $8 \text{ to } 9 \text{ m/s}^2$. With GPS loggers and accelerometers now generally available, field tests can be done with similar vehicles under comparable conditions at a fraction of the cost of the formal testing equipment. The acceptance of these values has not been tested in court and the credibility of the results will have to be agreed by the experts acting for the Court or be tried by the court based on the facts presented.

Values for road surfaces contaminated by gravel (sand to stone chips) could not be found in literature. Tests, using a Race Technology DL1 data logger with accelerometer, were conducted on a good gravel road and on an abandoned section of sealed road with sand and crushed stone gravel on. All the tests were done in dry conditions. The gravel roads were included to establish a measure of comparison. The skid resistance of the gravel roads were found to be 0.53 to 0.63. The skid resistance of the sealed road with sand contamination were found to be between 0.36 and 0.44. The skid resistance of 13.2 mm and 6.7 mm stone used for seal resurfacing on the sealed road varied between 0.37 and 0.47.

The skid resistance of dry gravel roads and surface roads contaminated with sand and gravel are still greater than the comfort-based design value of 0.35. This does not imply that such areas are safe for all vehicles (motorcycle and bicycles being especially vulnerable). The skid resistances of surfaced contaminated roads do not meet the brake performance of 4.4 m/s^2 (skid resistance of 0.44) required in the National Road Traffic Act, Act 93 of 1996.

1 INTRODUCTION

Skid resistance values found in older design manuals were typically based on studies where the worst case scenario of bald tires, smooth pavement and wet conditions was used. The AASHTO Policy for the Geometric Design of Rural Highways, 1954, gives a good overview of the research on braking performance that formed the basis of modern highway design. See Figure 1. From 2001 onwards, the AASHTO Policy for the Geometric Design of Highways and Streets, 2001, ceased to use skid resistance to define braking distance (the second component of Stopping Sight Distance) and a standard deceleration of 3.4 m/s^2 , based on comfort, became the design norm at all speeds. This is also reflected in the local SANRAL Geometric Design Guidelines (CSIR, 2003).

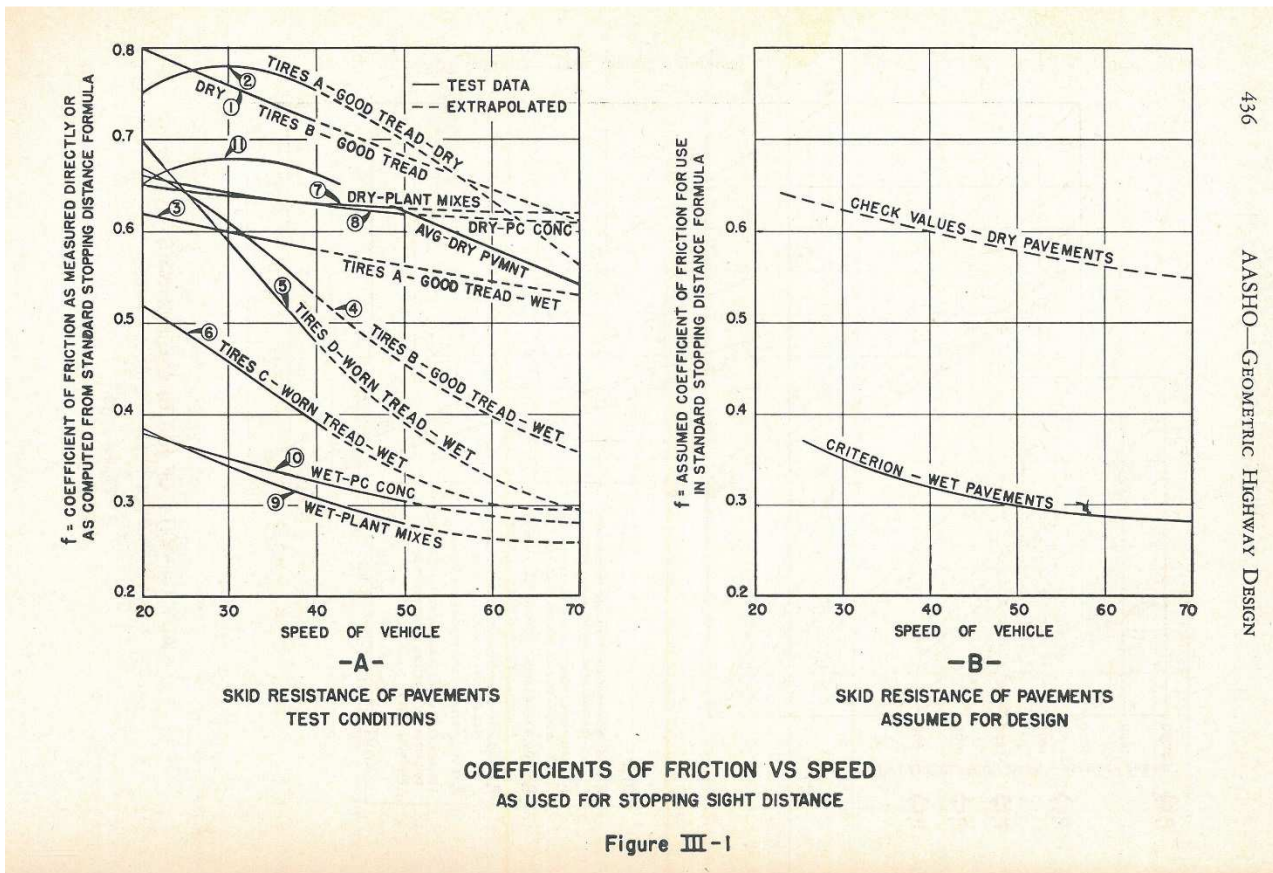


Figure 1: Coefficients of friction versus speed (AASHTO, 1954).

The term “skid resistance” refers to the frictional properties of the road surface. Skid Resistance will be used for consistency. Related concepts are coefficient of friction, brake force coefficient, drag factor and slip factor.

The stopping ability of modern cars under ideal conditions (flat surfaced road with good texture, new tires and ABS) is quite remarkable. Using a selection of vehicles from CAR magazine (CAR, March 2013; May 2012; May 2011) the values in Table 1 were calculated, assuming a constant skid resistance.

Table 1: Stopping performance of modern cars under ideal conditions.

Vehicle(s)	Stopping time 100 km/h – 0 Average of 10 stops [seconds]	Skid resistance generated
Audi A7 3,0 TDI BMW M3	2,7	1,050 *
VW Golf 7 1,4 TSI McLaren MP4 – 12 C	2,9	0,977
Ford Fiesta 1,0 VW GTI	3,0	0,944
Jeep Grand Cherokee 5,7 V8 Honda Civic 1,8	3,1	0,914
Toyota Avanza Hyundai Santa Fe	3,2	0,886
CWM C10	3,35	0,846

Source: CAR Magazine, various

* Note: the $f > 1$ results from aerodynamic effects and soft tires

2 PROBLEM STATEMENT AND REASON FOR INVESTIGATION

A number of crashes, in which expert witness reports were required, involved gravel roads and surfaced roads contaminated with gravel. A literature search found few references to skid resistance of gravel / unpaved roads. Paige-Green (1989) found skid resistance of 0.6 (deceleration 5.9 m/s^2) on dry roads for initial speed of 50 km/h. Lea and Jones (2007) conducted research in California, and found values ranging from 0.4 to 0.85 for speeds between 50 and 80 km/h. These values are indicative of the variability of the conditions. It was thus required to do some tests to determine some specific values that can be used in the local crash reconstructions.

For the most reliable reconstructions, values should be determined in the field using the Griptester, Scrim or similar calibrated equipment. These field tests are expensive and require long section of road to perform the test on, resulting in interference with traffic. With GPS loggers and accelerometers now generally available, field tests can be done with similar vehicles under comparable conditions at a fraction of the cost of the formal testing equipment. The acceptance of these values has not been tested in court and the credibility of the results will have to be agreed by the experts acting for the Court or be tried by the court based on the facts presented.

In this paper, the term "gravel" will be used to denote both a fine aggregate (sand) and coarse aggregate (stones). Gravel can also imply a mixture of fine and coarse aggregate, either of a continuous or gap grading. The Oxford Dictionary defines gravel as: " a mixture of small stones with coarse sand, used for paths and roads and as an aggregate. "

The investigations were limited to dry roads, as the crash reconstructions under consideration were all for dry conditions. The gravel roads of interest were all in reasonable state: sufficient wearing course material was in place and the extents of corrugations were limited. The effect of corrugations will be the subject of further research, as dynamic effects play come into play.

3 TEST EQUIPMENT AND METHODOLOGY

The skid resistance testing was done using two vehicles equipped with a Race Technology DL1 data logger. This data logger consists of a Global Positioning System

(GPS), with a 5 Hz (5 readings per second) recording rate which is used to determine speed and distance. It is equipped with a lateral and a longitudinal accelerometer, each able to measure $2g = 19.6 \text{ m/s}^2$. The sampling rate for the accelerometers is 100 Hz. The data was analysed in increments of 1/10 of a second.

The un-surfaced road tests were done on a road near Simonsvlei, Paarl district. The tests of contaminated surfaced road were done on a section of abandoned alignment of the old national road running parallel to the R101 between Klapmuts and Paarl. The contamination with sand occurred in a sag curve, due to sand transported by rain. The sand was spread in a uniform layer with brooms.

The tests on the 13.2 and 6.5 mm gravel were done on a crest curve, where the contractor for the re-sealing of R101 stockpiled the material for the chip and spray. At the time of the test, the work was completed and the contractor cleaned up the area using a loader. The effect of the loader bucket scraping along the surface resulted in two sections of uniform layers of 13.2 mm and 6.7 mm stone respectively.

4 SKID RESISTANCE ON GRAVEL ROADS

4.1 Values found in literature.

Lea and Jones (2007) studied the mechanisms of skid resistance of unpaved road and found:

"Unpaved roads have a dynamic surface, which can make it difficult to predict the skid resistance of a section for use in geometric design and gravel selection and to schedule maintenance. This investigation showed that there are three mechanisms for skidding on unpaved roads: intersurface friction, sliding on a thin layer of loose material, and ploughing through a thick layer of loose material. The main surface and material properties affecting skid resistance are the stoniness severity and extent, the severity and extent of raveling, and the amount of loose material in the 0.850-mm to 2.00-mm range on the surface. The range of coefficients of friction for unpaved roads is from 0.40 to 0.85, with the lower value being conservative."

The average skid resistance found by Lea and Jones (2007) on dry gravel road from 50 km/h was 0.67 and from 80 km/h 0.62 from samples sizes of 16 and 7 respectively.

Paige-Green (1989) produced values from a large sample. He found an average skid resistance value of 0.6 (deceleration 5.9 m/s^2) on dry roads for initial speed of 50 km/h.

4.2 Tests on local un-surfaced (gravel) road

The un-surfaced road used for the tests was re-gravelled in 2011 and in a reasonably good condition, with no rutting and little corrugations. The condition of the road is shown in Figure 2.



Figure 2: Gravel road surface.

A Chrysler Voyager with ABS was used and the initial speed was 80 km/h. The 80 km/h was higher than the values used by Lea and Jones (2007) and Paige-Green (1989), but was more in line with the speeds for which crash reconstructions had to be done.

A sample of 18 stops was recorded and the average skid resistance was 0.56 with a sample standard deviation of 0.03. The range of values was 0.53 to 0.63. The fairly uniform condition of the road limited the range when compared to the values found by Lea and Jones (2007). The average is close to that of Paige-Green (1989) which was 0.60.

4 SKID RESISTANCE ON SURFACED ROAD CONTAMINATED WITH SAND

The section on the skid resistance of sand contaminated roads is based on a final year project by Wahl (2012), and his contribution is acknowledged. Skid resistance was measured over a section of the surfaced test road described in Paragraph 3. The particle sizes of the sand varied from 5 mm and smaller. The tests were done with a Mazda Rustler light delivery van without ABS. Stops were done from 60 km/h and the front wheels locked.

The sand was spread in a 20 m wide area in the sag curve. Braking started approximately 5 m before the sand section. The deceleration measurements showed the start of the sand area. The tires showed severe aberrations after 10 stops. It was concluded that the so-called ball bearing effect of the coarser sand particles may not have occurred.

The results from 10 tests showed an average skid resistance of 0.39 with a range of 0.36 to 0.44 and standard deviation of 0.03.

5 SKID RESISTANCE ON SURFACE ROAD CONTAMINATED WITH COARSE GRAVEL (CHIPPING STONES)

The section of abandoned surfaced road described in Paragraph 3 was used as stockpiling area for the pre-coated chips used in the resealing of R 101. A sufficient length

of road was available to accelerate to 80 km/h. These tests were done with a Chrysler Voyager with ABS. The wheels did not lock and again the so called ball bearing effect was not observed.

The result of 10 stops on the 13.2 mm gravel was 0.39 with a standard deviation of 0.02 and a range of 0.37 to 0.41. The quantity of 13.2 mm gravel on the road surface was measured by isolating an area of known size and weighing the gravel. The spread rate was found to be 4.8 km/m². This is illustrated in Figure 3.

The result of 10 stops on the 6.7 mm gravel was 0.45 with a standard deviation of 0.014 and a range of 0.44 to 0.47. The spread rate of the 6.5 mm gravel was found to be 5.6 km/m² and this is illustrated in Figure 4.

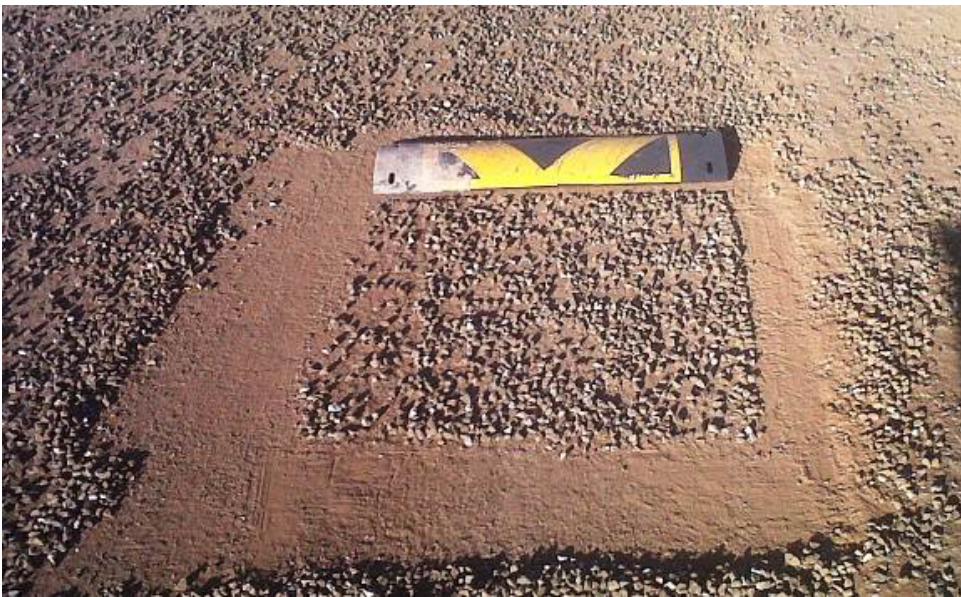


Figure 3: Aggregate spread 13.2 mm.



Figure 4: Aggregate spread 6.5 mm.

The narrow ranges are contributed to the uniform layers that were left after the chips were scraped off the road with the loader. The average skid resistances, with one standard deviation on either side, are shown in Figure 5.

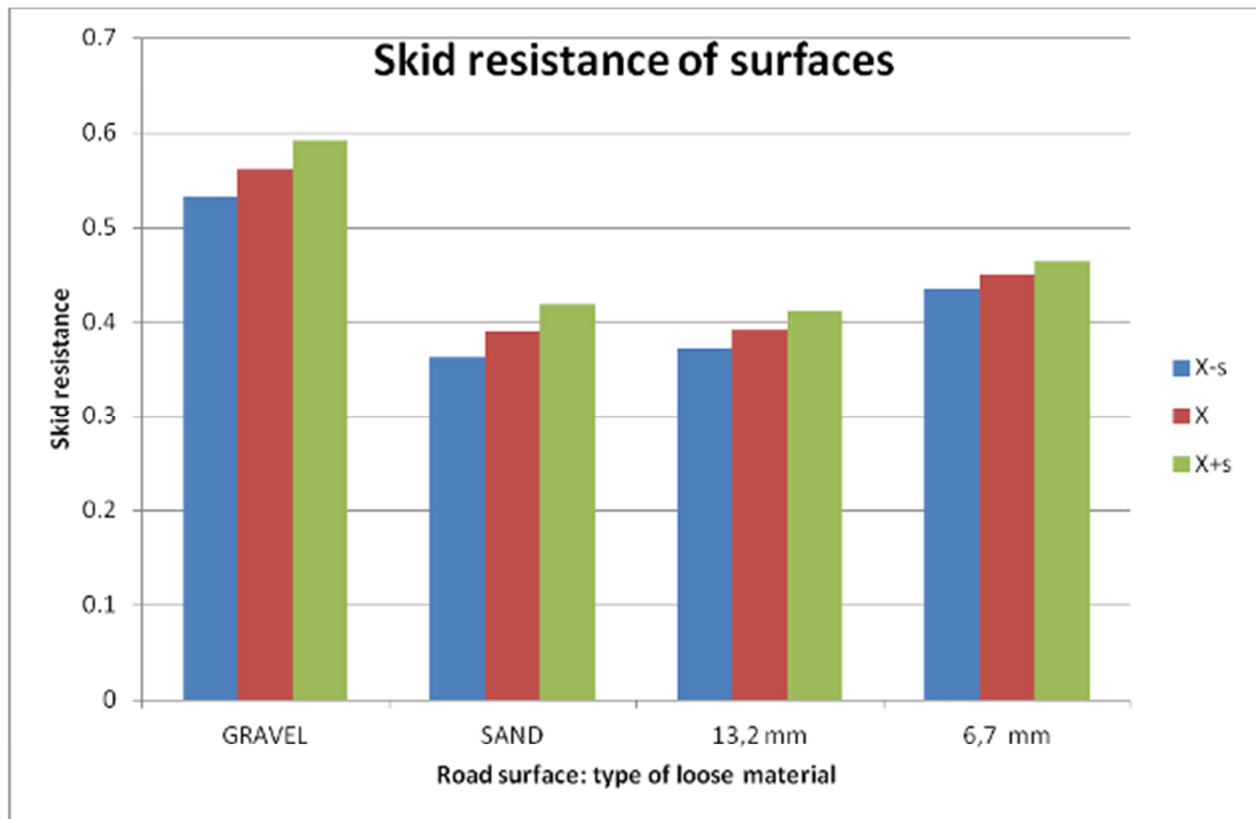


Figure 5: Skid resistance of surfaces tested.

6 DISCUSSIONS

The tests were done with cars. Cars have the advantage of four tires on the road, allowing some of the tires compensating for loss of friction of others, due to variability. This is not possible for two wheeled vehicles such as bicycles and motorcycles.

Un-surfaced gravel roads can be viewed as being in a constantly changing state of contamination with loose gravel. The average skid resistance of dry gravel roads in fair condition under braking with a normal sedan vehicle can be expected to be in excess of 0.55. This is also more than the 0.35 that is assumed for design of roads, based on comfort considerations.

Surfaced roads that are contaminated with fine or coarse gravel have average skid resistance in the order of 0.4. This is still in excess of the design value of 0.35, but is not legal. The braking performance of vehicles as required in the National Road Traffic Act, Act 93 of 1996, is 4.4 m/s^2 . Section 155: Braking performance of service, emergency and parking brakes, Table A, is shown in Figure 6.

REQUIREMENTS FOR BRAKING PERFORMANCE

Table A

Service brake of motor vehicle or combination of motor vehicles capable of exceeding speed of 40 km/h

[Table heading substituted by GNR.404 of 2007.]

	Initial speed in km/h	Maximum stopping distance in m	Minimum deceleration in m/s²	Minimum equivalent braking force in N/kg
Light motor vehicle.....	35	14	4,4	4,4
Heavy motor vehicle....	35	16	4,4	4,4

Figure 6: Requirements for braking performance.

7 CONCLUSIONS

Skid resistance of dry gravel roads and surface roads contaminated with sand and gravel are greater than the comfort-based design value of 0.35. This does not imply that such areas are safe for all vehicles (motorcycle and bicycles being especially vulnerable)

However, surfaced roads contaminated with gravel have a skid resistance in the order of 0.4, which is lower than the braking performance of vehicles of 0.44 required by the National Road Traffic Act, Act 93 of 1996.

The values obtained in the tests can be used as indicative of skid resistance for surfaced roads contaminated with coarse and fine gravel in the reconstruction of crashes.

8 REFERENCES

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