LATERAL AND LONGITUDONAL GRIP VARIATION

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ABSTRACT

Longitudinal measurement of wet skid resistance is used in many countries to manage the safety of its highway asset. The effect of aggregate type/size, asphalt type / age, degree of trafficking, climate, corners, braking etc. can all be seen in the measured data. However, longitudinal measurement does not show differences in grip across the lane being measured. This paper first considers typical longitudinal variation and then looks at the effect of lateral variation. Simple examples are given for each. The combination of longitudinal and lateral variation in then considered in the context of racing circuits. Three case studies explore how GPS based grip data can be plotted using GIS software. The case studies show how the vehicle/tyre interacts with the asphalt surface trying to seek equilibrium conditions.

1. INTRODUCTION

Skid resistance can be predicted either in the laboratory or measured directly on-site. Unless reported otherwise, all measurements are based on wet values. In dry conditions most aggregates and surfacing materials have similar high values of skid resistance. It is only when the aggregate or surface gets wet that major variation in skid resistance is possible.

Laboratory measurement typically assesses the 10mm aggregate size used in the manufacture of the surfacing material. This property is called polished stone value (PSV) and is considered one of the most important properties for surfacing material. A surfacing material made with low PSV aggregate is typically has low skid resistance whereas a surfacing material made with higher PSV aggregate is expected to have higher skid resistance. There are obvious limitations with this approach in situations where the surface is subjected to low levels of trafficking or very high levels of stressing. When the PSV test conditions are altered the resulting value adopted a different equilibrium value depending on the test alteration i.e. similar to what is found in-service. Laboratory prediction now favours assessment of the actual surfacing material using methods such as the German Wehner Schulze (Husckek, 2004; Woodbridge et al, 2006) or the Road Test Machine located at the University of Ulster. These subject the asphalt mix to simulated trafficking and offer better insight of in-service performance.

Many countries around the world still do not specify a level of skid resistance, either for the aggregate or for the trafficked road. The UK has been specifying skid resistance for its trunk road network since the 1970's (HD28 2004; HD36 2006). The specification has investigatory limits for testing at a range of sites ranging from straight line non-event locations to high risk sites such as approaches to road junctions and traffic lights. The investigatory limits are not a mandatory requirement but rather if routine testing falls below the quoted value further investigation of the site is required. Minimum values for aggregate PSV required for a given investigation level, traffic level and type of site are given. Traffic is based on the number of commercial vehicles per lane at design life. In-service measurement of skid resistance in the UK is assessed using SCRIM (BS 7941-1:2006) or GripTester (BS 7941-2:2000). The British Pendulum (BS 7976-2, 2002) is based on a swinging arm method were the retardation of a rubber pad on the bottom of the arm gives a measure of skid resistance. This is a time-consuming method and only gives a single point measurement. The SCRIM and GripTester methods use a smooth test wheel to record a continuous measurement of wet skid resistance. Both devices travel at 50km/h with a controlled amount of water applied to the surface immediately in front of the measuring wheel. The specification assumes that the road surface has reached equilibrium depending on trafficking and environmental conditions i.e. typically after a period of 1 to 2 years. In the UK there is no requirement for skid resistance during the pre-equilibrium stage i.e. the first 1 to 2 years of the surfacing life. This short review considers what is typically done. The remainder of this paper considers how this can be improved.

2. MEASUREMENT IN A LONGITUDINAL DIRECTION

There are over twenty devices used in Europe to measure skid resistance. Full details of each device can be found in Do and Roe (2008). Each method is controlled by a specific set of standard conditions chosen to reflect the practicalities of carrying out the test in relation to the complex reality of friction in the tyre/road interface. Although they all measure skid resistance the actual numbers recorded can differ widely for the same road surface. Most of these techniques have been simplified to measure the condition of the road surface. They measure in different ways the frictional force developed between a moving tyre or slider and the road surface. They typically wet the road surface and record a quotient of the measured force and applied vertical load i.e. a friction coefficient.

The range of devices can be sub-divided into three main groups (Do and Roe,2008) longitudinal friction, transverse friction or static/slow-moving techniques. Examples of devices are GripTester, SCRIM and British pendulum respectively. The longitudinal and transverse friction devices attempt to simulate the interaction of a braked tyre with the road surface in a longitudinal direction.

The GripTester is a three-wheel trailer that is typically towed behind a van. The device uses the longitudinal friction principle to measure skid resistance. It was originally developed to assess the skid resistance of oil platform heli-decks. It has subsequently become widely used around the world to measure the skid resistance of airport runways and highway surfaces. A constant film of water is sprayed in front of the smooth test tyre depending on test speed. A fixed gear and chain system constantly brakes the test tyre to give a fixed slip ratio of 15%. Continuous measurement of the slipping force and the vertical load allows calculation of a friction coefficient known as the GripNumber. Although it may be towed at speeds up to 130km/h the standard test speed is 50km/h with water applied to give a constant water film depth of 0.25mm under the test tyre.

Similar to the SCRIM, skid resistance is measured in the inside wheel-path of the inside lane. Example GripTester data measured every 1m is shown in Figure 1. This shows the variation in wet skid resistance for a section of road where high friction surfacing has been laid at three sets of traffic lights. The high friction surfacing plots as the three distinct areas of high GripNumber. Of interest in this example are the reduced levels of skid resistance approaching and immediately after the traffic lights relating to the vehicles braking and accelerating away from the lights respectively. Figure 2 shows data measured for a short section of low PSV limestone chip-seal between two sections of higher PSV greywacke chip seal. This example illustrates the importance of rock-type and wet skid resistance. The dry data shows that rock-type is typically not significant.

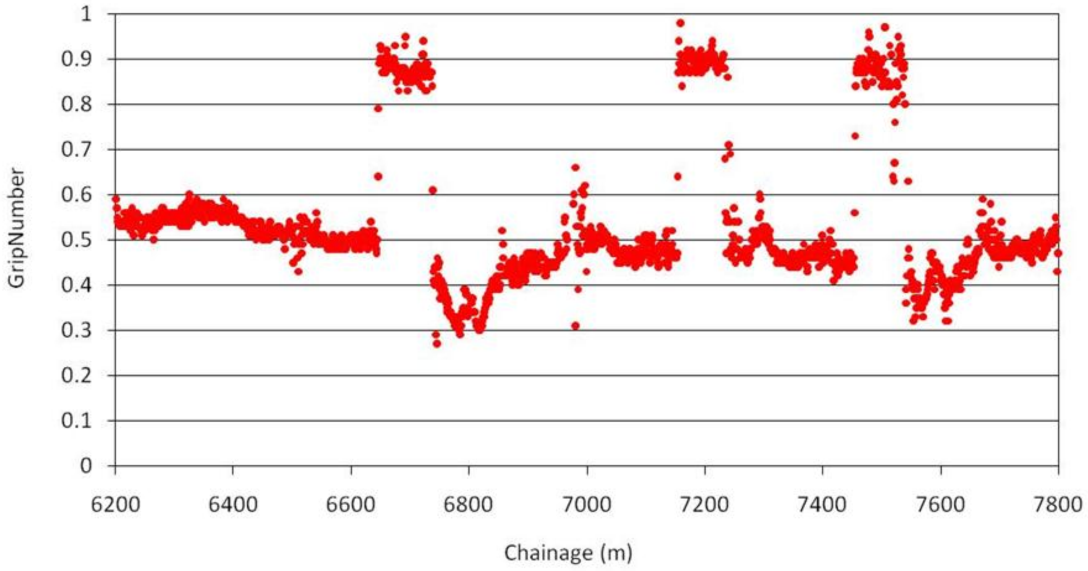

Figure 1 - Example GripTester data

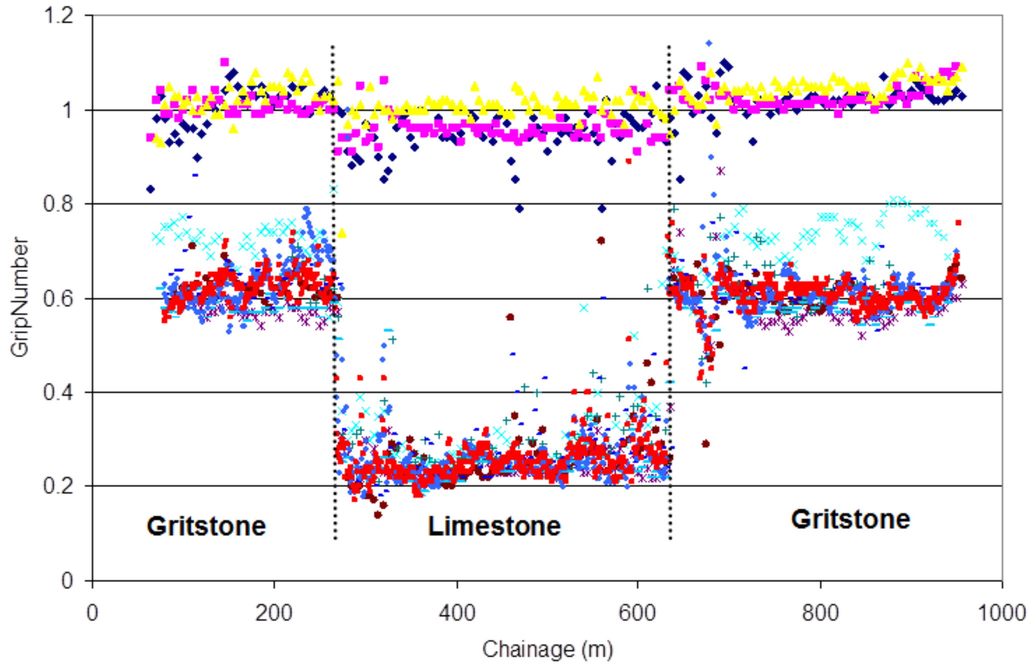

Figure 2 - Example GripTester data

3. MEASUREMENT IN A LATERAL DIRECTION

When roads are constructed, surface characteristics such as skid resistance, texture depth and noise are uniform laterally across the lane. However, some-time after it is opened to traffic, these characteristics start to change especially within the wheel paths due to higher concentration of trafficking. Gunay and Woodward (2007) investigated the lateral position of traffic. Figure 3 compares the frequency distribution of actual position with expected positions. The widths of these axles are the average values obtained from the data. The positions of these axles are exactly in the centre of the lane. The green and red colours in

Figure 4 refer to the left and right wheels of the inside lane vehicles (kerb side) respectively. The yellow and blue colours denote the left and right wheels of the outside lane vehicles, respectively. The distributions show considerable variation between the two lanes with the traffic positioned closer to the curb than would be expected. This simple example shows the difficulties of measuring a representative portion of the road with the actual trafficked line having 3 times as much traffic as the expected position only 40cm to the side.

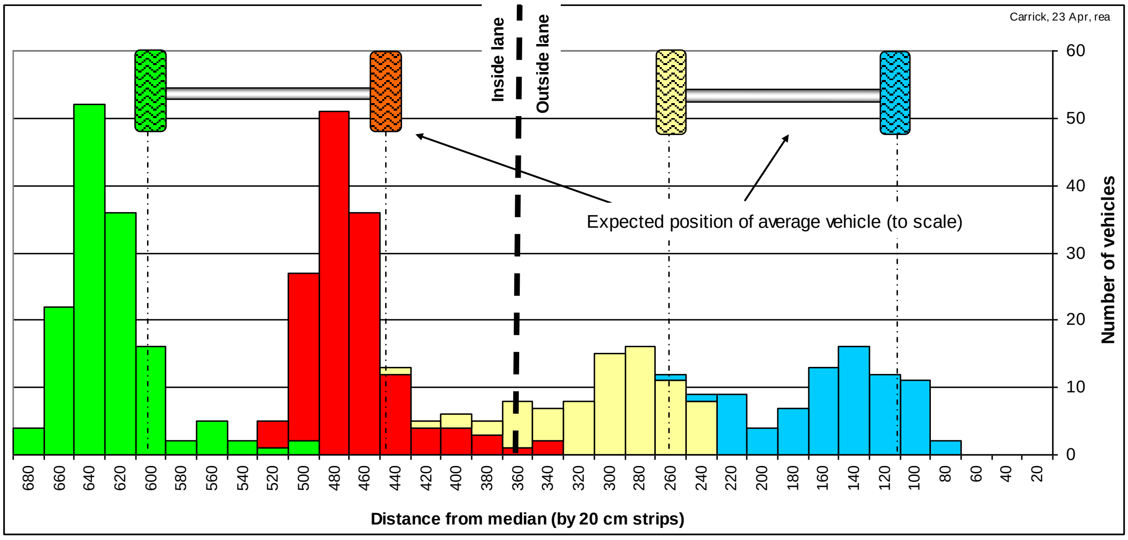

Figure 3 - Frequency distribution showing difference between expected and actual trafficking position

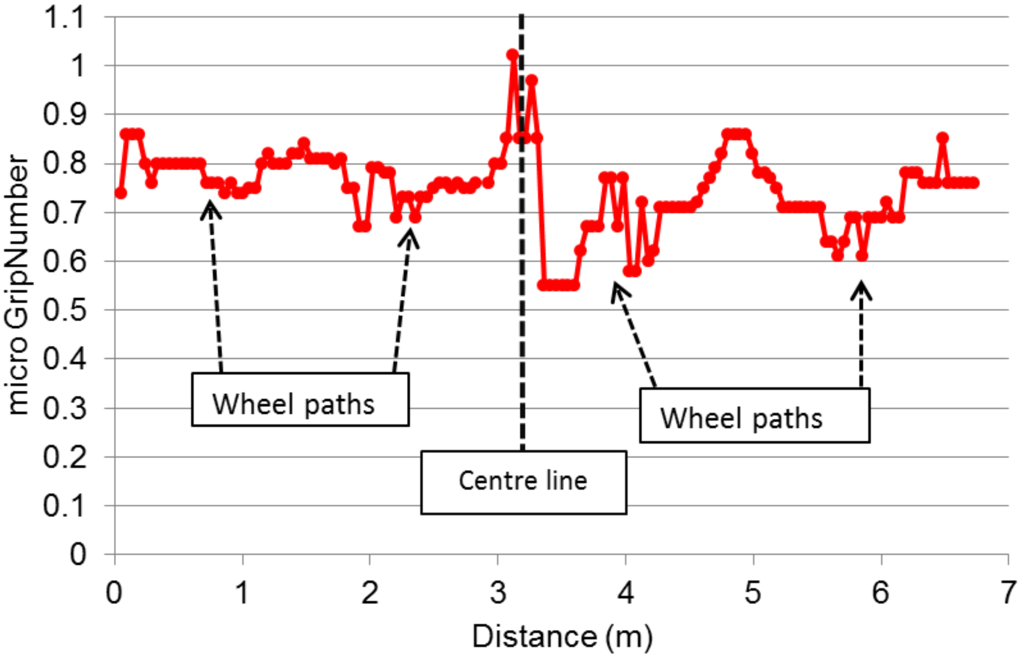

Figure 4 - Transverse variation in wet skid resistance across a rural road measured using micro-GripTester

Whilst it is possible to measure traffic position within the lane it is more difficult to measure the lateral variation in skid resistance. It would be possible using the GripTester in push-mode, but this is rarely done. It could also be done using devices such as the pendulum or Dynamic Friction Tester. However it would take a lane closure and a considerable period of time to do the individual measurements. In response to these practical problems, the micro-GripTester (µGT) was developed to measure either dry or wet skid resistance at a walking pace and to be used in applications such as pedestrian areas, road surfaces, paint markings, reinstatements, man holes and accident sites.

The device is a scaled down version of the GripTester and uses the same longitudinal friction principle. An on-board computer measures skid resistance every 48mm and records test data relating to GripNumber, chainage, speed, water application rate, latitude, longitude, altitude and temperature. An example of µGT data in Figure 4 shows the lateral variation in wet skid resistance across a rural road. Although the same type of asphalt was laid in both directions, the data shows variation between the inside and outside wheel-paths and between directions for this particular example. The few hundred individual measurements were recorded at walking pace and in this particular example, did not require any type of traffic management.

4. MEASUREMENT OF RACING CIRCUIT GRIP

Skid resistance is much talked about in motorsport. The term grip is preferred rather than skid resistance. However, in terms of actual measurement the reporting of a circuits grip level is not frequently used. The author first got interested in race track grip when asked to assess the effectiveness of a high pressure water-blasting system to remove tyre rubber deposits at an English racetrack. This equipment was being used to remove rubber deposits at the main UK airport runways caused by landing aircraft. GripTester data before and after treatment showed that high-pressure water blasting was able to remove the rubber deposits and improve wet grip. The measured data showed variation in longitudinal grip in areas that had not been treated. This variation appeared to coincide with racing line phenomena such as vehicle track position, location of braking and cornering.

Figure 5 shows an example of longitudinal track variation in grip for a section of circuit. This plots longitudinal grip at four positions (TP1 to 4) across the width of the track. TP1 was close to the inside white line, TP4 was close to the outside white line with TP2 and TP3 in between. The plotted data shows the change in grip in relation to a series of corners and the racing line. The somewhat confusing plot shows how longitudinal grip varies both along and across the width of the track. Figure 6 plots micro-GripTester data measured across the width of a karting circuit. The five runs shown relate to individual measurement runs approaching a corner, on the corner apex and exiting the corner. Again, a confusing plot showing variation in grip relating to track position and the karting line.

5. COMBINING LONGITUDINAL AND LATERAL MEASUREMENTS

Figures 6 and 7 illustrate that a better method is required to illustrate this longitudinal and lateral grip distribution. The result is known as GripMap - a system developed at the University of Ulster for mapping and displaying variation in lateral and longitudinal wet grip variation. The measured grip data is recorded along with GPS co-ordinates and used to produce a colour coded maps using GIS Software.

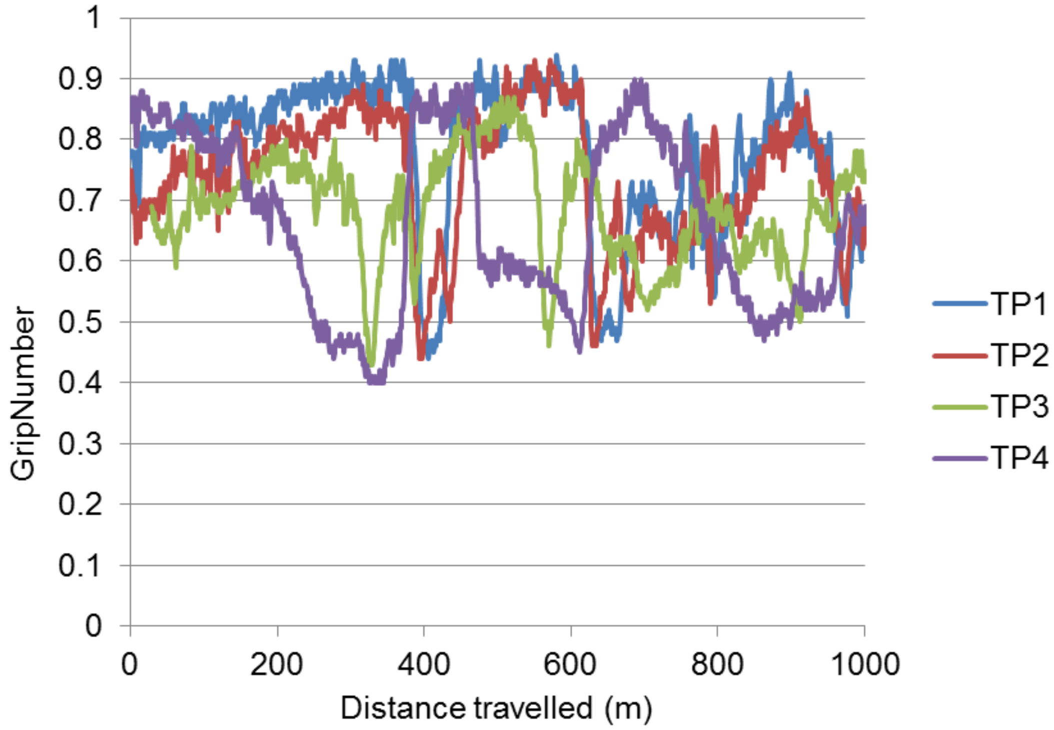

Figure 5 - Variation in longitudinal GripNumber at 4 equally distances across the width of a race circuit going around a series of corners

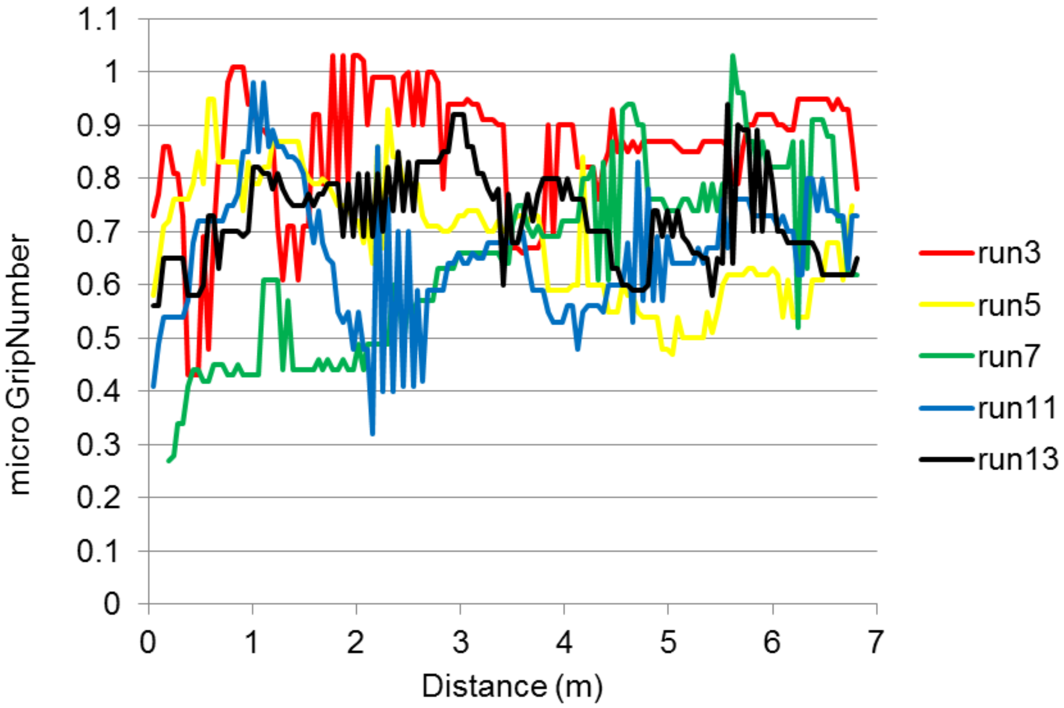

Figure 6 - Variation in lateral microGripNumber going around a corner

Like any type of grip measurement, a GripMap cannot relate directly to specific vehicle / tyre / surface interaction given the much higher speeds and the many different vehicle / tyre / driver / weather combinations during race conditions. It does however; offer a means of showing how grip varies with time, with circuit use or between different circuits and their surfacing materials. It shows the concentrated effect of vehicle and track surface interaction within the racing line, the effect of braking, cornering and in higher speed parts of the circuit the effects of down-force. Although the maps are based on wet grip variation they can also be used for dry conditions as they highlight the racing line and specific locations such as build-up of vehicle rubber and track rubber deposits. The GripMap for a specific circuit can be used as a basemap. Track position data recorded from vehicles using the track can be overlaid and details regarding grip extracted for evaluation purposes.

The standard test speed as recommended for both SCRIM and GripTester is a steady speed of 50+/-5km/h. It quickly became apparent that this test speed could not be maintained at all locations such chicanes and hair-pin bends. Being able to maintain a steady test speed and degree of wetness removes speed related issues. Any variation in grip can then be attributed to the surface. A constant speed of 30+/-3km/h was selected as the optimum test speed. The water application rate was reduced to give a water film thickness of 0.25mm under the test tyre. Using the automatic water system of the GripTester, much higher rates of water application can be applied to simulate flooded track conditions. Grip values are recorded every 1m distance travelled with circuit position recorded using GPS. Figure 7 shows GripTesting at the Yas Marina Circuit in Abu Dhabi.

Figure 7 – GripTesting at Yas Marina, Abu Dhabi

The methodology assesses the variation in grip for the entire circuit surface. This involves starting with the GripTester mounted to the left hand side of the tow vehicle and measuring the extreme outer edge of the track. The 30km/h test speed is constantly monitored using a SatNav with the GripTester software controlling the water application rate. After completion of the first lap the tow vehicle moves to the right by approximately 1m and a second measurement lap is started. Care must be taken not to cross over the previous test measurement. This is constantly checked by inspection the location of the water in the rear view mirrors. This element of the testing is the most difficult to maintain.
Modification of the system introduced a Racelogic VideoVBox to provide a record of track and GripTester position. The Racelogic Video VBox samples GPS location at 20 hertz and

overlays vehicle dynamics data on two video cameras. One camera faces forward whilst the second faces rear. Further improvement of track position has been made possible with a RaceLogic VBox 3i and DGPS giving 100hz position data at about 2cm accuracy.

The number of test measurement laps depends on the width of the circuit i.e. approximately every 1m. When it has been crossed to about 2 to 3m of the other edge, the testing is stopped and the GripTester moved to the right side of the tow vehicle. The last measurement run records the extreme inside edge of the track. This process builds up a data-set of wet grip variation based on an approximate 1m grid determined at constant test conditions. Depending on length and width a track takes between 30 minutes to 3 hours to test and could have a data-set of well-over 100,000 wet grip measurements.

The GripTester produces a CSV data file. This contains the basic data recorded during a test run i.e. chainage, GripNumber, load, speed, water flow, latitude, longitude, altitude and GPS time. Initial attempts to plot this data in the form of a map used Excel. This was later improved using ArcGIS software. The Findlay Irvine proprietary software program GT2SHP is used to convert the CSV file into a SHP file that can be imported into ArcGIS. Each test run can be imported as an individual layer or combined before conversion.

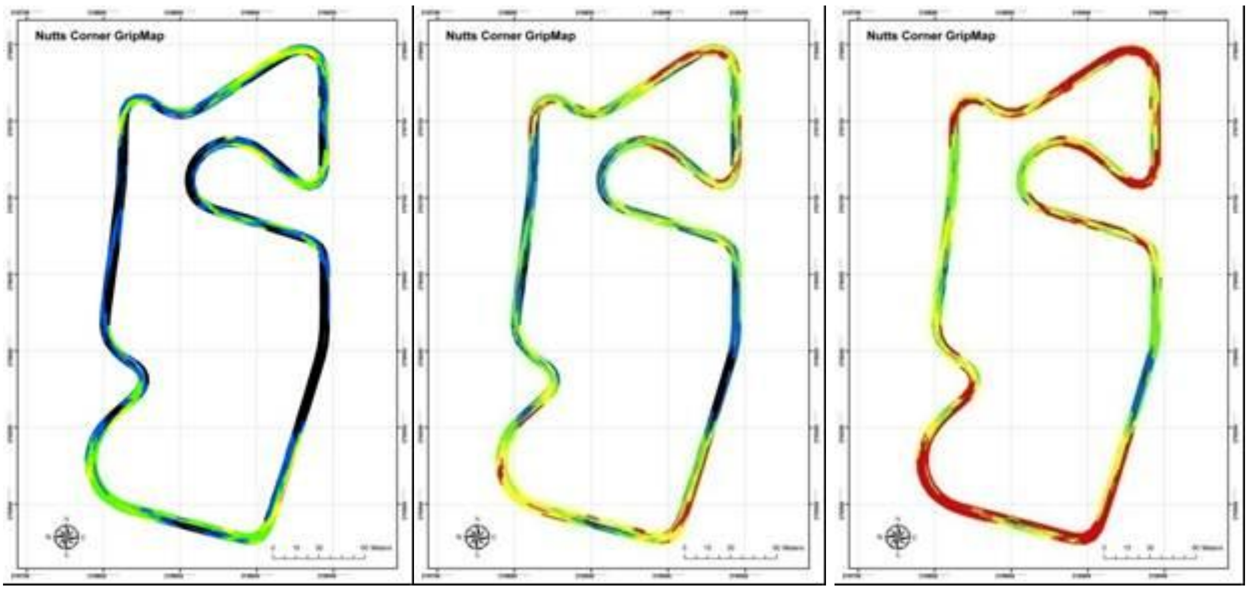

Figure 8 - Example GripMaps of a karting track using the same data-set and different threshold values

5.1. Karting example – Knutts Corner

Data measured at a karting track is shown in Figure 8 to illustrate the basic principles of the GripMap system. The data-set was used to prepare three simple GripMaps using ArcGIS. Threshold values have been used to colour code the resulting map into areas of lower and higher wet grip. In these 3 example plots, a 5 colour sequence is used to show variation in wet grip. The same colour sequence from lowest grip to highest grip has been used in all three maps i.e. lowest grip is red, with increasing wet grip shown as yellow, green, blue and black. Different threshold values have been used to plot the same data.

In the first map the colour red is used to show all parts of the track where the wet grip is less than 0.35. In the middle example the colour red is used to show all parts of the track were the wet grip is less than 0.45. In the third plot the colour red is used to show all parts of the track less than 0.55. The confusing example of lateral grip shown in Figure 6 was also measured at this track. The three plots show how easy it is to extract information from the same data-set using GIS. The number of threshold values can be changed to extract more or less detail from the map or simply to show areas of lowest or highest grip. These simple examples clearly show track phenomena such as the racing line, the start of braking coming into corners, higher stressing approaching and going around corners. These phenomena have been recorded at all of the circuits assessed to date.

5.2. Motorbike road racing example – North West 200

Ireland is one of a small number of countries were motor-bike road racing is carried out. This example is for a road circuit in Northern Ireland where speeds in excess of 200mph are achieved on 2 lane rural roads. A total of 29 different types of asphalt surface were recorded when this data-set was measured. The surface types were of different ages and included hot rolled asphalt, SMA, asphalt concrete, proprietary thin surfacing, high friction surfacing and chip-seal. Unlike typical highway testing were the measurements are recorded in the inside wheel-path, this testing was carried out late at night with the GripTester running approximately in the racing line.

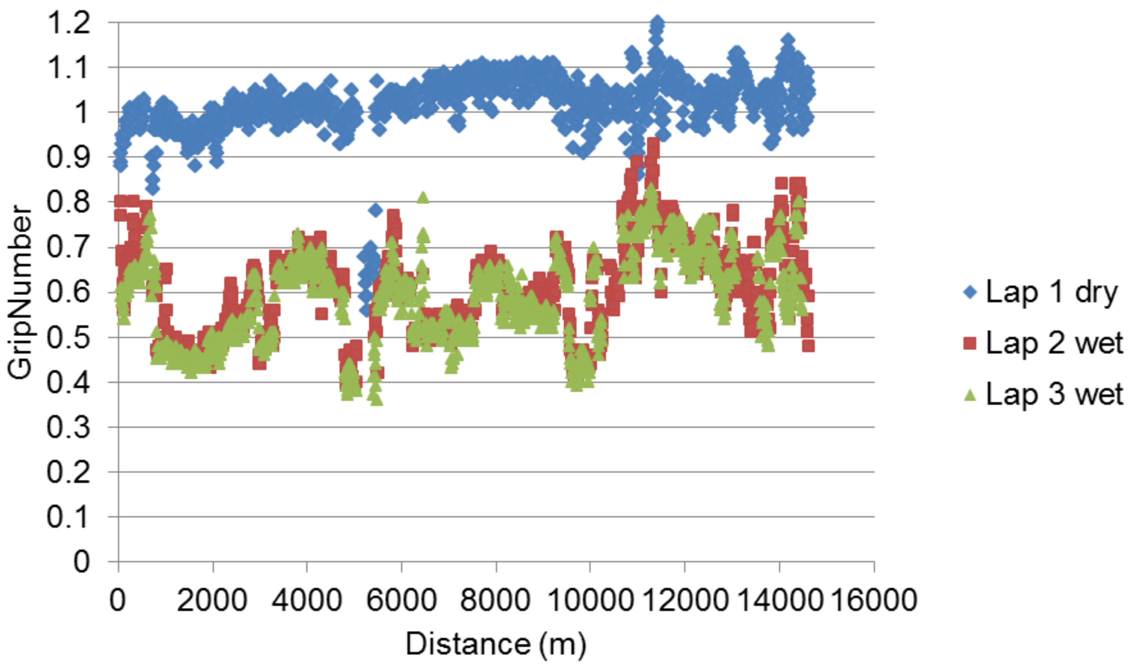

Figure 9 - Dry and wet GripTester data for a road circuit

Figure 9 illustrates the dry and wet data for the circuit. The missing section of data at 5500m relates to where the circuit goes around a roundabout in the wrong direction. This short section was not recorded. All of the 29 sections of asphalt had similar levels of measured dry grip. However, there was variation when wet grip was measured. The two sets of wet grip data for lap 2 and lap 3 show some variation between runs as the exact same part of the track was not recorded in both runs. However, there is general agreement between runs for the different asphalt sections.

Figure 10 shows the calculated percentage loss in dry grip due to the surface becoming wet i.e. after a shower of rain. When looking at this type of data it should be remembered that this relates to measurements taken under standardised conditions whereas during a race there are many other factors that influence tyre/ surface grip. The data plotted in Figures 9 and 10 are difficult to visualise. Figure 11 plots the wet data as a GripMap and in this example shows where the wet grip (measured at 50kmh) is less than a GripNumber of 0.4.

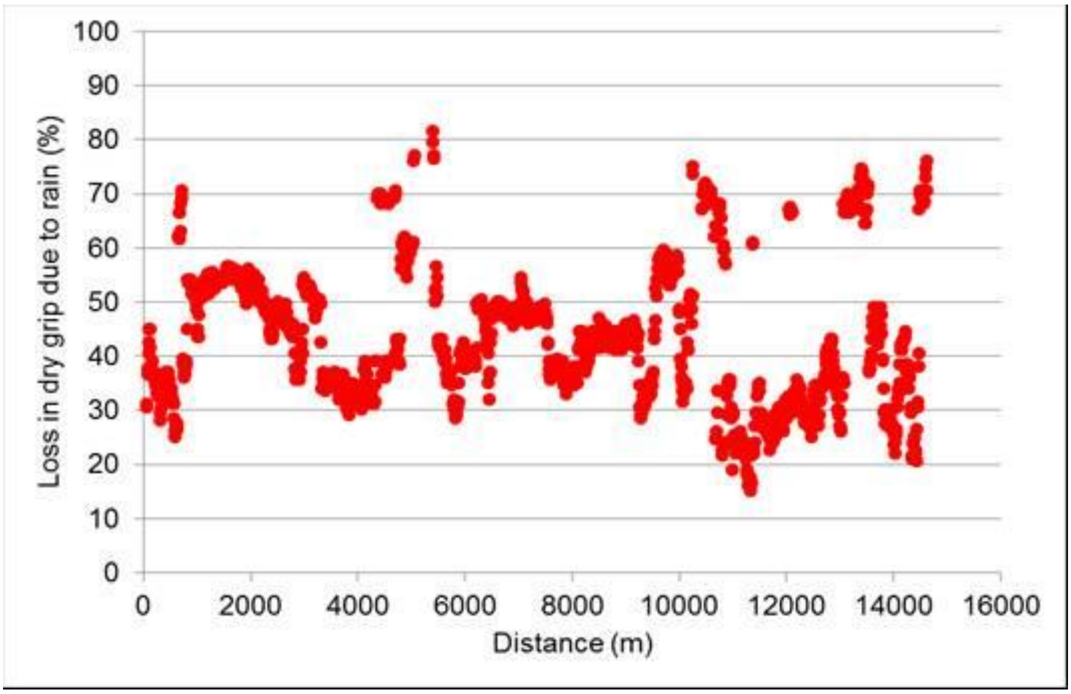

Figure 10 - Percentage loss in dry grip due to the surface becoming wet

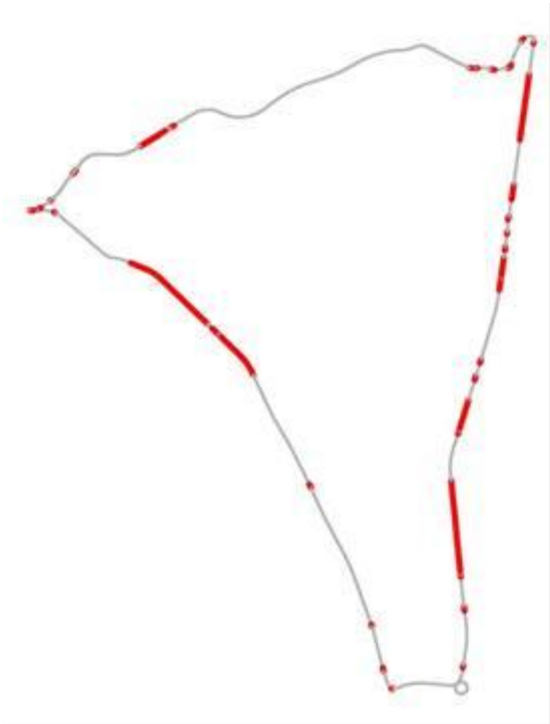

Figure 11 - Grip data plotted using GIS showing areas were wet grip is less than 0.4

5.3. Formula F1 example – Yas Marina Circuit

The FIA Formula One (F1) World Championship is the highest class of single seater car racing sanctioned by the Fédération Internationale de l'Automobile (FIA). The F1 season consists of 20 races held on purpose-built circuits and public roads around the world. F 1 cars are considered to be the fastest circuit-racing cars in the world. They race at speeds up to 220 mph, rely on aerodynamic down-force and have very high cornering speeds with lateral acceleration in excess of 5g.

The Yas Marina Circuit hosts the Abu Dhabi F1 Grand Prix. It was opened in 2009 and cost an estimated $1.3 billion. The circuit is 5.554m in length, has 21 corners and the second longest straight of the 20 F1 circuits. Figure 12 shows the circuit layout and detail of typical gear selection, speed (km/h and mph) and lateral g.

Figure 12 Yas Marina Circuit layout

In July 2011 a demonstration project was carried out at the invitation of Abu Dhabi Motorsport Management (ADMM) to assess the Yas Marina Circuit. This was done in collaboration with Findlay Irvine, the Scottish company who manufacture GripTester. This demonstration project highlighted the practical and logistical issues of doing this sort of work in an international context. Figure 7 shows the GripTester approaching the starting line of the circuit.

Figure 13 - Variation in longitudinal and lateral wet grip for corners 1,2 and 3

Wet grip data was collected and post-processed. Figure 13 shows an example of the longitudinal and lateral grip variation, measured at 30kmh, for corners 1, 2 and 3 superimposed on a Google Earth image. A five colour threshold has been used to plot the wet grip data. Red shows the lowest grip, with yellow, green, blue and black showing higher levels of wet grip.

Racing at this circuit is in a clock-wise direction. This example shows the relationship between track position and car/tyre/asphalt interaction equilibrium conditions. The racing line is seen to diagonally cross the straight approaching Corner 1. The onset and duration of braking is highlighted in red. The racing line quickly crosses to the apex of the corner and in this manner the effect on track surface grip is shown with subsequent corners and straights. The blue and black parts of the track with highest wet grip relate to those areas that are out-side of the racing line and rarely trafficked.

6. USING GRIPMAP DATA

Frequency distribution is a simple means of showing the measured data, the change in grip with time for a circuit, allow comparison between circuits or reflect changes ranging from a combination of seasonal environmental and / or track use to the effect of a single period of prolonged period of track activity such as a weekend event. Figure 14 plots the frequency distribution of 5 different tracks. This shows Tack E to have an almost identical distribution of grip to Track D. In contrast Track C has a much higher level of overall grip. Track A has lower grip with Track B having the lowest level of grip for the five sets of data shown. Figure 15 shows the change in grip frequency distribution before and after treatment to improve low grip values at corners around a circuit.

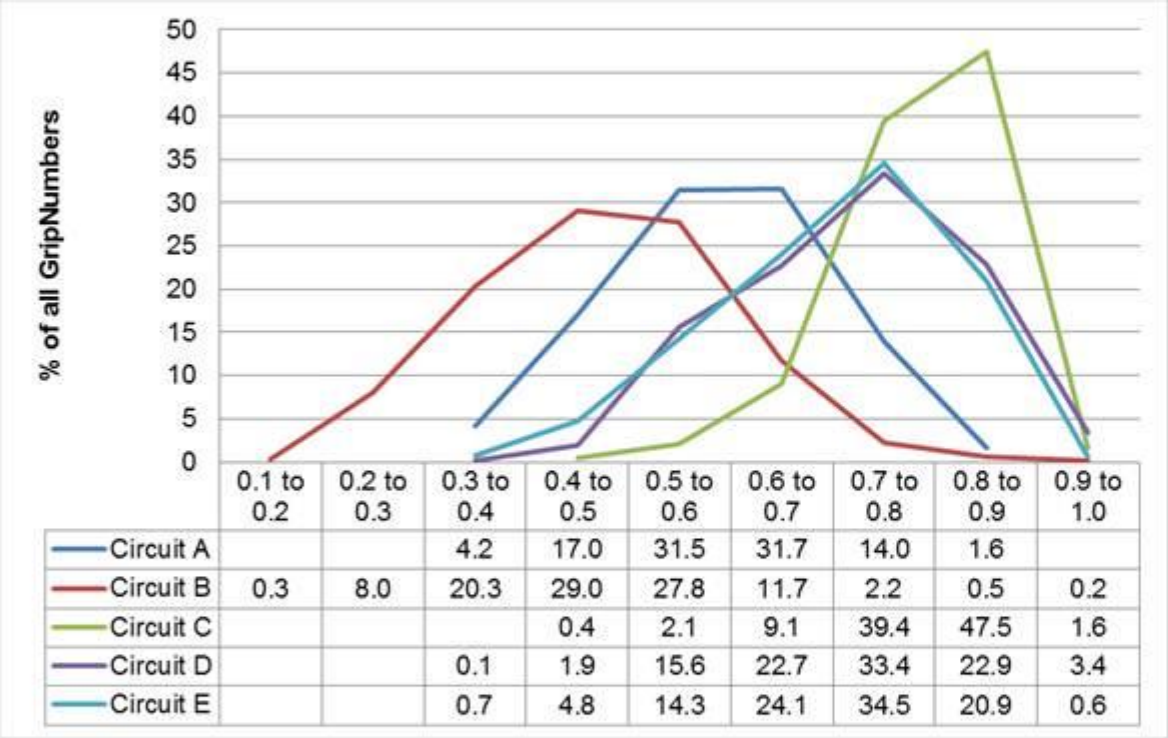

Figure 14 - Using frequency distribution to compare circuit grip levels

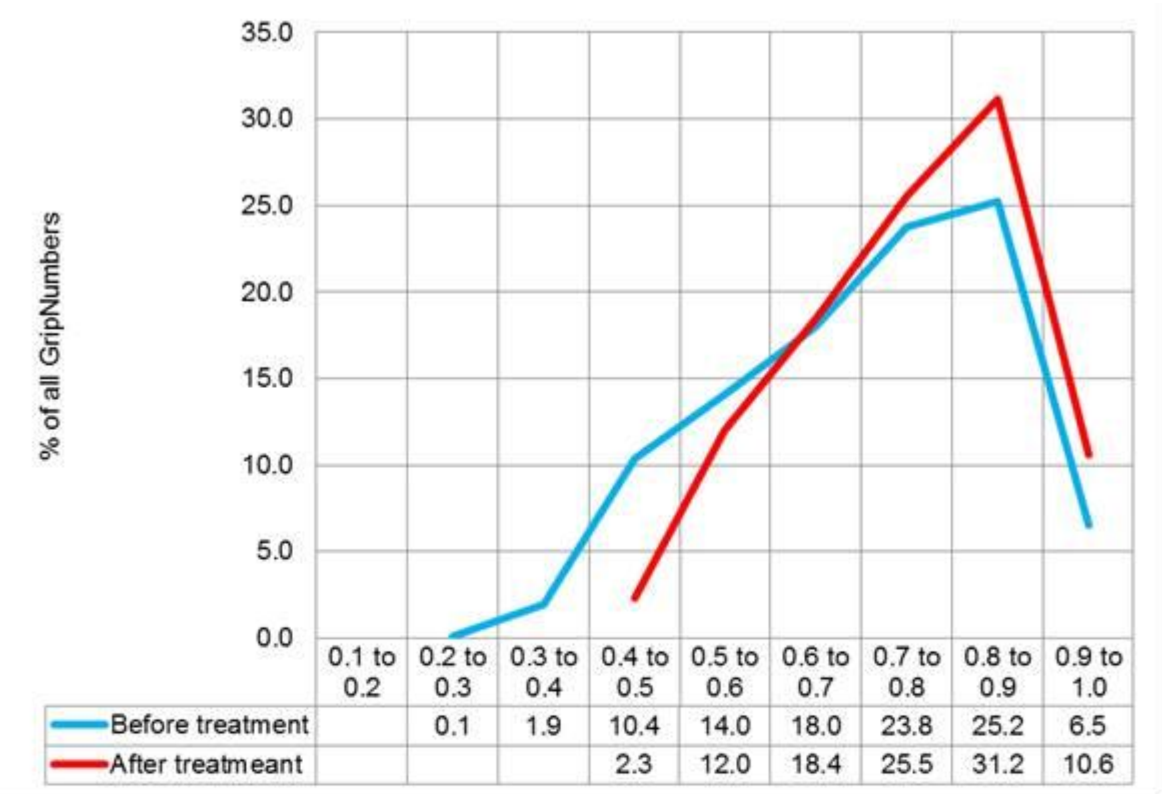

Figure 15 - Frequency distribution showing change in wet grip before and after treatment of corners

7. CONCLUSION

The ability to predict in the lab and to measure skid resistance – or grip – on-site has been around for quite a while. Longitudinal measurement in the wheel-paths of a highway is a simple way to measure and specify an important surfacing property. However, the lateral component of grip in the highway can significantly affect the measured value should the operator driving the tow vehicle or measuring vehicle not be sufficiently skilled to judge that the test wheel is exactly in the centre of the trafficked wheel-path. The implications to monitoring and maintaining a safe highway infrastructure are obvious.

Compared to the highway, a racing circuit probably has greater localised variation in grip levels. Combining longitudinal measurement of grip across the circuit in a lateral direction is a new way to help explain grip. The GripMap system was developed at circuits in the UK and Ireland. Within a few hours a data-set of 100,000+ individual measurements can be plotted using GIS to produce a base-map that offers considerable improvement into understanding longitudinal / transverse variation and vehicle / tyre / surface interaction.

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