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12-GTRBR-06

NMR's additional remarks

JC comments (brown) on 2006-03-13

IMMA comments in red. As the test plan will be circulated to all those participating in the test work, the comments are generalized and not necessarily specific to DRI.

Please circulate final test plan as soon as possible e.g. by 2006/03/10, to facilitate testing in Europe

NL (Stokreef) and UK (Thatcher) comments are in green.

DRI revisions to the test plan, and replies to IMMA and other comments, are in blue. Many of the latter replies are simply questions of clarification, answers to which may assist in refining or clarifying the revised test plan.

Revised 2006-03-07

Test Plan
Motorcycle ABS testing related to Draft GTR

The following items are an outline test plan for verifying the new ABS procedure for motorcycles, as discussed at 59/GRRF.

Objectives:

1. To confirm the feasibility and practicality of the proposed test methods in: § 4.9.3 (high μ), § 4.9.4 (low μ), and § 4.9.7 (Low-high transition)

2. To define any outstanding test parameters, e.g. maximum actuation force, μ-jump test low-high (time),

3. To check the performance requirements and any special test parameters for motorcycles with only one wheel controlled by ABS.

Test sequence:

1. Preliminary tests

2. Main tests:

Note: It is proposed that prior to the main tests with multiple riders and motorcycles, a preliminary test be undertaken with one engineering test rider and one example motorcycle. The purpose of this test series is to determine what aspects of the

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proposed GTR tests (4.9.3, 4.9.4, 4.9.7) and data reduction methods could benefit from being better defined or clarified prior to the main tests.

Test track:

DRI's test track in Shafter, California

1. High friction surface: dry asphalt

ASTM PFC	K factor (4 riders)		
	R1200GS	R1200GT	K1200LT
0.980 ± 0.034	0.695 ± 0.150	0.793 ± 0.172	0.608 ± 0.123

I am surprised that there is such a variation between the results – between ASTM and K and between the 3 motorcycles. The K value seems low, particularly the K1200LT. Why? Brake condition? Rider not braking with a control force near to lock up? Are both wheels near to lock point? Is the brake system (CBS?) without ABS functioning restricting brake pressure to 1 wheel? Hydraulic modification required?
(I would be interested to hear comments from Roland)

2. Low friction surface: wet, coal tar-sealed asphalt

ASTM PFC	K factor (4 riders)		
	R1200GS	R1200GT	K1200LT
0.500 ± 0.041	0.269 ± 0.142	0.331 ± 0.290	0.313 ± 0.072

Same comment as above. As stated elsewhere, probably partially due to lack of rider familiarity and no outriggers fitted.

Based on the requirements of the GTR, strictly speaking, this surface is unacceptable as it is higher than the 0.45 limit.

The worst case is the lowest friction surface, so IMMA recommends that the surface is as close to 0.3 as possible.

It would help to understand the basis for this statement. Is 0.3 a PBC value, and if so, using which measurement method and which test tyre?
0.3 is the PBC value and the GTR states that it may be measured "in accordance with the method specified in national legislation". which realistically means ASTM or K test. So, the test tyre would be either the standard tyre for ASTM, or the actual tyre fitted to the motorcycle for K test method.
With ABS systems, one type of "worst case" could be the "lowest friction," but another type of "worst case" would be a surface with the greatest difference between peak friction and sliding friction, for example. There could be several other "worst cases," as well.

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Agreed but at present we only specify the PBC in the GTR. I think it would be too complex if we were to specify such aspects as peak / slide friction ratios etc.

1. What examples of real road pavements exist that have a PBC of 0.30? This would be useful to know, for testing purposes. *At Lucas Girling, (and at MIRA) we used a basalt block surface- a pre cast stone like surface developed for test tracks from the material that is used to line the coal chutes of power stations. With polishing, the surface could be reduced to around 0.25. It was intended to simulate the slippery when wet cobbled streets found in old European towns.*
2. What is special about a PBC value of 0.3 (as opposed to 0.25 or 0.35 or 0.50)? *0.3 is considered to be the minimum friction value that a motorcycle could be ridden on.* Has a sensitivity analysis of this value been done?
3. The method with which a PBC of 0.3 has been measured is crucial. If this refers to an "ASTM PFC" value of 0.3 for example, this could correspond to some types of snow or ice surface. Is this really what is desired? *The 0.3 value was specified, based on K test experience (motorcycle + motorcycle tyre). K testing results in friction values of less than 0.2 for snow and 0.1 for ice. Car and motorcycle K test results are usually reasonably comparable on medium and low friction surfaces. It was hoped that the results of K and ASTM would also be reasonably similar such that either method could be used.*
4. With what tyre is a value of "0.3" measured, as the tyre will affect the PBC value?

Answered above.

To help with any questions arising from the analysis, please could the test teams state which method they used to measure the surface friction.

DRI fully supports this statement. It should be clarified which tyre is being used to measure "surface friction," and that the term "surface friction" in these sentences refers to "peak braking coefficient (PBC)," as that is what is used in the draft GTR.

Agreed but PBC could be obtained using the K test method.

Past experience has shown that the friction between the tyre and the surface may not remain stable, e.g. on epoxy paint surfaces, even if the surface is measured as being within the test parameters.

It would be very helpful to know what "stable" means, in this sentence? Does "stable" mean "constant" during the course of one stop? During one day? During several days? During one year? Over a specified number of subsequent runs in the same wheel track?" What is the basis for this statement? Is some test facility planning to use "epoxy?" "Epoxy paint" would seem to be an unrealistic coating for a road surface. Is IMMA saying that there should be limitations on the construction and materials used on the test track? If so, should this not be reflected in the draft GTR?

Good point. Stable was intended to apply to surfaces such as Epoxy which, as you say, is unrealistic and has a high mu/slip factor relationship. Also, surfaces which varied considerably during the period of testing (eg. due to the tyre polishing the surface) would also be judged as unsuitable. The reason for the comment was in order to try to use surfaces for these validation tests that would give consistent and repeatable results over the test programme whether carrying out ABS stops or measuring the surface using either ASTM or K methods.

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Those conducting tests are requested to check this point and measure the μ-slip curve of the surface i.e. how much μ varies with different degrees of tyre slip, and provide the data.

It should also be specified with what tyre and what method the μ-slip curve is to be measured. For the results to be comparable and to have any usefulness, the same measurement method and tyre should be used. What is IMMA's suggestion? Is IMMA suggesting that a different μ-slip curve should be measured for each motorcycle front and rear tyre to be tested on each test surfaces used? If so, then we should say this in the test plan.

Ideally, using the ASTM method of measurement, there should be mu slip results for the standard ASTM car tyre v a front and rear motorcycle "control" tyre.

For the F650 tyre we would recommend:

On-Off road use:
Front:
Dimension:100/90/19; Typ: Continental TKC 80,
Rear:
Dimension:130/80/17; Typ: Continental TKC 80,

Sports Tyre:
Front:
Dimension:100/90/19; Typ: Michelin Anakee,
Rear:
Dimension:130/80/17; Typ: Michelin Anakee,

This will allow the informal group to discuss the issue, should it be a problem.

Test riders:

4 experienced test riders, ~~(same riders as Phase I)~~

Test procedures:

1. Test 4.9.3 Stops on a high friction surface (App 1 hereto)
2. Test 4.9.4 Stops on a low friction surface: (App 2 hereto)
3. Test 4.9.7 Wheel lock check – low to high surface transition (App 3 hereto)
4. K measurement test – ECE R78 ABS Annex 4 Appendix (both brake systems only) Best performance stop with expert rider (App 4 hereto)
   - Wet Low Friction Surface
   - Dry High Friction Surface
   - Wet High Friction Surface
5. PBC "Chirp test" (ASTM E1337) – (App 5 hereto)
   - Wet Low Friction Surface
   - Dry High Friction Surface
   - Wet High Friction Surface
6. Test conditions (tests to be done according to the following conditions; see notes in App 1 and 3 hereto)

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Draft GTR clause	Condition or procedure
4.1.1.1	Test surface for dynamic brake tests (i.e., high friction surface); required PBC 0.9 nominal value is assumed to be measured with the K method.*or ASTM method* "High friction surface" low-high transition in 4.9.1.7 will be the "Wet high friction surface" defined in 4.9.1.7 with PBC of ≥0.8 (as measured with K method) *or ASTM method*
4.1.1.2	Low friction surface; required PBC value here is assumed to be as measured with the K method
4.1.1.4	Test lane width
4.1.2	Ambient temperature
4.1.3	Wind speed
4.1.4	Test speed tolerance
4.1.5	Automatic transmission (if any of the test motorcycles have it)
4.1.6	Vehicle [lane] position and wheel lock, except as allowed by 4.9.1
4.2.1	Engine idle speed
4.2.2	Tyre pressure
4.2.3	Control point application
4.2.4	Brake temperature measurement
4.2.5	Burnishing
4.9.2	Vehicle condition: lightly loaded, engine disconnected

In general, all the relevant test parameters/procedures which are given in the GTR, but not necessarily in the ABS section, should be used for the testing, e.g., loading conditions, temperature measurement, wheel lock observation, stability etc.

This is understood to mean the conditions applicable to, but not necessarily mentioned in the ABS section of the draft GTR. If so, then a table of the relevant cross-references has now been added to the test plan, above.
Correct but I have not checked in detail whether all relevant sections have been referred to.
The references to "stability" in the draft GTR should be further clarified, as currently it is not clear what is meant. Is this yaw, pitch or roll stability, or capsize stability, for example, or any or all of these? *May include all of these.* Is this to be objectively or subjectively measured? *Subjective* The following note in 4.9.1 is excessively vague and seems to allow, for example, the operator not to release the control, and to capsize, as long as he stays in the test lane:

"Wheel-lock shall be allowed provided that the stability of the vehicle is not affected to the extent that it *requires the operator to release the control* or that it causes a vehicle wheel to pass outside the applicable test lane."

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The following alternative wording is suggested to help clarify what is meant.

"Wheel-lock shall be allowed provided that the stability of the vehicle is not affected to the extent that it causes the vehicle to capsize or that it causes a vehicle wheel to pass outside the applicable test lane."

This extra wording may clarify things provided we have a definition of "capsize". Another way could be to state that "the outrigger must not contact the road surface". Note that the current text came from Transport Canada who thought that this was suitable wording for self certification.

Generally speaking, if a front wheel lock occurs on a motorcycle, especially on a low mu surface, it occurs much too quickly for a human "operator to release the control" (e.g., Zellner and White, "Advanced Motorcycle Braking," DOT-HS-9-02305, November 1981 and other references have quantified how quickly wheel can lock and have found that this is much quicker than human reaction times). To state that a wheel lock "*requires* the operator to release the control" is a mis-statement of what it is physically possible, in many or most cases of front wheel lock. Typically, if the front wheel locks, the motorcycle will capsize long before a human operator is physically able to sense the lockup, and to respond to it by releasing the control. The alternate wording is suggested as being clearer, being consistent with real vehicle dynamics and with real biomechanics, comprising a performance requirement, and as providing an objective rather than a subjective criterion.

Test motorcycles:

The number of test vehicles to be used in the NHTSA tests: 5 models supplied by IMMA, to be agreed, based on availability. Additional vehicles will be tested by the industry and other administrations. IMMA to investigate availability of motorcycles for other administrations.

Type of system	Large	Medium	Small
ABS + CBS			
ABS only, both wheels			
Single wheel ABS			

IMMA will provide a list of the contact names to go with the loan motorcycles. Any technical question related to the preparation of the motorcycle, e.g. the disconnection of the ABS system, should be addressed to them, to maximise the compatibility of results.

Test equipment

Motorcycle instrumentation

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Data acquisition:

SOMAT eDaq
  Sample rate: 100 Hz
  16 Bit system
  Portable
Digital / analog
Signal conditioning
Anti-alias filters

Sensors:

Front and rear wheel speed
Front and rear brake caliper pressure
Lever and pedal master cylinder pressure (or load cell) (It is important to ensure that the system volume is not increased by more than the amount induced by allowable pad wear)

Agreed, except this should say "by more than the amount induced by allowable pad wear." Brake pad wear, for example, increases brake system volume. Sensors which increase system volume are acceptable if the volume increases is smaller than that resulting from an allowable amount of brake pad wear. *Don't agree or I have misunderstood the comment. Pad wear takes place slowly and is compensated for automatically by the hydraulic actuation system.* ***Any*** *increase in system volume will be noted by the rider normally giving a poorer brake feel than standard.*

Overall speed (Vehicle-mounted radar)
Distance travelled
Longitudinal acceleration
Pitch rate and angle
Location of surface transition (low to high)
Embedded brake pad thermocouples

~~Other instruments~~

~~Hand held brake pyrometer; (The use of a "hand held brake pyrometer" is not clear to IMMA)~~
~~The temperature should be measured according to §4.2.4. For consistency in this set of tests, IMMA strongly recommends that the thermocouple should be embedded in the brake pad.~~

PBC (ASTM E1337) Equipment/Instrumentation

DRI Mobile Tire Tester (MTT)
Please could DRI provide details of this device for the Informal group's general information; and also in case other testers might find it useful.
(see Appendix 6 attached hereto which describes the MTT. Note DRI MTT can provide not only the numerical PBC, but also a graph of mu-slip ratio for the

range of free rolling to fully locked. This will help in the discussion about surface properties. It is planned to use the ASTM E1136 car-type tyre, however the MTT is compatible with motorcycle wheels and tyres as well. However, prior preparation would be needed if motorcycle tyres are to be tested.)

ASTM E1136 tire

Data reduction and analysis

Observed or Calculated from Measurements

Initial speed at brake application
Stopping distance
Stopping time
MFDD (Calculated in accordance with § 3.3.1)
Wheel slip ratio, front and rear
Brake application force (lever or pedal)
ABS fully cycling (yes or no)
Average force applied to the brake control over stopping interval
Response time ~~and distance travelled~~ for µ transition

IMMA understands that the issue being researched under this item is the time it takes for the system to respond after the change in the µ of the surface. (See also, IMMA expansion of this point in Appendix 3) Therefore, is it relevant to measure distance?
DRI agrees to remove "distance travelled."

K (ECE R78)
PBC (ASTM E1337)
Record any rider comments on stability in accordance with § 4.9.1, 5th sub-paragraph. This could be helpful in the analysis discussion, if there has been a problem.

As noted in the last blue paragraph under "Test Procedures," the description under 4.9.1 of "requiring the operator to release the brake" is felt to be overly vague, subjective and not physically possible because, if the front wheel locks on a low mu surface, the motorcycle will capsize long before it is possible for a human operator to sense, and to respond by "releasing" the control.

As an alternative, it is suggested to clarify the text to say:

"Wheel-lock shall be allowed provided that the stability of the vehicle is not affected to the extent that it causes the vehicle to capsize or that it causes a vehicle wheel to pass outside the applicable test lane."

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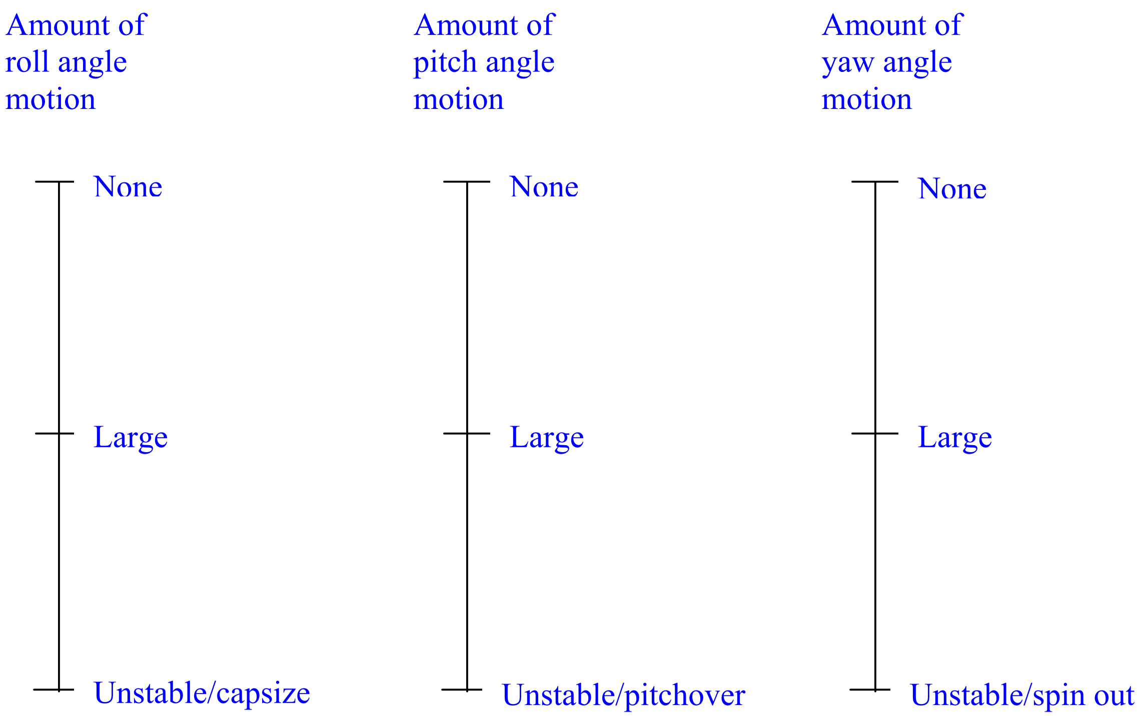
For purposes of the analysis and discussion, it is proposed to record rider rating using the following subjective rating scales:



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Example Test Matrix

Test	Surface	System	Rider			
			1	2	3	4
4.9.3 Stops on High μ	High μ	Both	X	X	X	X
4.9.4 Stops on Low μ	Low μ	Both	X	X	X	X
4.9.7 Wheel lock check, Low to High Transition	Low – High	Front	X	X	X	X
	Low – High	Rear	X	X	X	X
	Low - High	Both	X	X	X	X
PBC- K measurement (ECE R78)	High μ	Both	X	X	X	X
	Low μ	Both	X	X	X	X
PBC (ASTM E1337)	High μ	NA				
	Low μ	NA				
	Wet High μ	NA				

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Appendix 1 Instructions to tests riders for 4.9.3

Note: **Bold** text denotes clarifications made to the original text, for purposes of instructions to test riders

4.9.3. Stops on a high friction surface:

4.9.3.1. Test conditions and procedure

- Motorcycle in "lightly loaded" condition (2.11).

This should be further discussed as the nominal mass of the rider is 68 kg + 7 kg for luggage. 68 kg is less than a 50^{th} percentile male mass in Europe and North America, even if helmet, leathers, etc. is counted as part of the "luggage" weight. The instrumentation allowance of 15 kg, or 30 kg with outriggers is probably generous, however. Is required to ballast to achieve these weights exactly? *Yes*

- Initial brake temperature: $\geq$ 55 °C and $\leq$ 100 °C

- Test speed: 60 km/h or 0.9 Vmax, whichever is lower.

- Brake application:
  Simultaneous application of both service brake system controls, if so equipped**[,** or of the single service brake control in the case of a service brake system that operates on all wheels**]. Note: this phrase in brackets [ ] primarily applies to three-wheel motorcycles and does not apply to motorcycles having lever and pedal brake controls)**

- Brake actuation force **during the entire stop**:
  Hand control = 200 N ± 20 per cent
  Foot control = 350 N ± 20 per cent

These forces may be increased in order to ensure that the ABS is fully cycling during the stop**. "Fully cycling" means that the anti-lock system is repeatedly modulating the brake force to prevent the directly controlled wheels from locking. Brake applications where modulation <u>only occurs once during the stop</u> shall not be considered to meet this definition.**

NL (Stokreef): The intension of the tests mentioned in paragraph 4.9.1. is **<u>that the ABS is fully cycling</u>** during braking. Locking of wheels in that condition is not desirable. Moreover it is allowed to increase the actuation force <u>to be sure that the ABS is cycling</u>. Systems allowing locking of the wheels under these condition are very poor.

DRI agrees with this comment, and no change to the test plan is needed.

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For systems where the brake actuation force fluctuates due to ABS operation, the brake actuation force is the mean value applied for the duration of the stop **from the time when the brake actuation force enters the specified range until the vehicle speed is zero.**

- If one wheel is not equipped with ABS, the control for the service brake on that wheel shall be applied with a force that is lower than the force that will cause the wheel to lock.

- Number of stops: until the vehicle meets the performance requirements, with a maximum of 6 stops.

- For each stop, accelerate the vehicle to the test speed and then actuate the brake control under the conditions specified in this paragraph.

- **The vehicle shall be operated such that the vehicle does not capsize and the wheels stay within the test lane.**

~~4.9.3.2. Performance requirements~~

~~- When the brakes are tested in accordance with the test procedures referred to in paragraph 4.9.3.1.,~~

~~[(a) the stopping distance (S) shall be $\leq 0.0063V^2$ (where V is the specified test speed in km/h and S is the required stopping distance in meters) or the MFDD shall be 6.17 m/s^2,]~~

~~(b) there shall be no wheel lock, and the vehicle wheels shall stay within the test lane.~~

UK (Thatcher) Do we mean **No** wheel lock or should we say that the wheels can briefly lock providing stability is not affected and the vehicle wheels remain in the test lane.

With the addition of the bold blue text at the end of 4.9.3.1, this section 4.9.3.2 is no longer needed in the test rider instructions, as it is not an instruction to the test rider, but rather a list of "performance requirements" applicable to the test results. Note that there is currently a conflict between these performance requirements, and the text in 4.9.1 that *allows wheel lock*, so long as it does not result in loss of stability or the wheels not staying within the test lane.

OK, I think this is fine for the validation testing but afterwards, we shall have to carefully review/ discuss what goes into the GTR.

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Appendix 2 Instructions to test riders for 4.9.4

4.9.4. Stops on a low friction surface:

4.9.4.1. Test conditions and procedure:

As set out in paragraph 4.9.3.1. but using the low friction surface instead of the high friction one.

~~4.9.4.2. Performance requirements~~

~~When the brakes are tested in accordance with the test procedures set out in paragraph 4.9.4.1.,~~

~~[(a) the stopping distance (S) shall be $\leq 0.0188V^2$ (where V is the specified test speed in km/h and S is the required stopping distance in meters) or the MFDD shall be 2.05 m/s^2,]~~
~~(b) there shall be no wheel lock and the vehicle wheels shall stay within the test lane.~~

With the addition of the bold blue text at the end of 4.9.3.1, this section 4.9.4.2 is no longer needed in the test rider instructions, as it is not an instruction to the test rider, but rather a list of "performance requirements" applicable to the test results. Note that there is currently a conflict between these performance requirements, and the text in 4.9.1 that *allows wheel lock*, so long as it does not result in loss of stability or the wheels not staying within the test lane.

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Appendix 3 Instructions to tests riders for 4.9.7

Note: **Bold** text denotes clarifications made to the original text, for purposes of instructions to test riders

4.9.7. Wheel lock check - low to high friction surface transition

4.9.7.1. Test conditions and procedure

- Motorcycle in "lightly loaded" condition (2.11).

- Test surfaces:
  A wet low friction surface immediately followed by a wet high friction surface of > 0.8 PBC

- Initial brake temperature: ≥ 55 °C and ≤ 100 °C

- Test speed:
  The speed that will result in 50 km/h or 0.5 Vmax, whichever is the lower, at the point where the vehicle passes from the low friction to the high friction surface.

- Brake application:
  (a) Each service brake system control applied separately:
  (b) Where ABS is fitted to both brake systems, simultaneous application of both brake controls in addition to (a).

- Brake actuation force **during the entire stop**:
  Hand control = 200 N ± 20 per cent
  Foot control = 350 N ± 20 per cent

  These forces may be increased in order to ensure that the ABS is fully cycling during the stop.
  For systems where the brake actuation force fluctuates due to ABS operation, the brake actuation force is the mean value applied for the duration of the stop.

- Number of stops: until the vehicle meets the performance requirements, with a maximum of 3 stops

- For each stop, accelerate the vehicle to the test speed and then actuate the brake control before the vehicle reaches the transition from one friction surface to the other.

- **The vehicle shall be operated such that the vehicle does not capsize and the wheels stay within the test lane.**

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- Record the vehicle's continuous deceleration.

UK (Thatcher): Could 'continuous' be replaced with 'increase in'?

NL (Stokreef): It is difficult to determine the increase in deceleration without measuring the continuous deceleration.

DRI understands "Record the vehicle's continuous deceleration" to mean that the the deceleration tie history must be recorded. Performance indices and performance requirements based on this recorded time history are yet to be discussed by the Informal Working Group, as indicated in the IMMA comment below. *Correct.*

~~4.9.7.2. Performance requirements~~

~~- When the brakes are tested in accordance with the test procedures set out in paragraph 4.9.7.1., there shall be no wheel lock **except for [xxxxxx]** What does this addition mean? and the vehicle wheels shall stay within the test lane.~~

~~[After passing over the transition point between the low and high friction surfaces, the vehicle deceleration shall increase.] The Informal Group will conduct a validation test program to measure:~~

- ~~the time at which the brake system starts to respond to the change in surface friction~~
- ~~the time it takes to reach a new stabilised deceleration value after the change in surface friction~~

~~The Informal group will then discuss whether or not requirements for these parameters should be included in the GTR~~

With the addition of the bold blue text at the end of 4.9.7.1, this section 4.9.7.2 is no longer needed in the test rider instructions, as it is not an instruction to the test rider, but rather a list of "performance requirements" applicable to the test. Note that there is currently a conflict between these performance requirements and the text in 4.9.1 that *allows wheel lock*, so long as it does not result in loss of stability or the wheels not staying within the test lane.

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Appendix 4 Instructions for K test from R78 procedure

(Note: clarifications are indicated by **bold** font)

based on**:**

E/ECE/324 } Rev.1/Add.77/Amend.1
E/ECE/TRANS/505

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Annex 4

Appendix

1. DETERMINATION OF THE COEFFICIENT OF ADHESION (K) **FOR PURPOSES OF VERIFYING THE TEST SURFACES**

1.1. The coefficient of adhesion shall be determined from the maximum braking rate, without wheel lock, of the vehicle with the anti-lock device(s) disconnected and braking both wheels **or systems** simultaneously. [1]/1

1.2. Braking tests **shall** be carried out by applying the brakes at an initial speed of about 60 km/h (or, in the case of vehicles unable to attain 60 km/h, at a speed of about 0.9 Vmax) **to a stop** with the vehicle unladen (except for any necessary test instrumentation and/or safety equipment). **As** constant **a** force **as is practicable** must be used **on each brake control** throughout the tests.

1.3. A series of tests may be carried out up to the critical point reached **at incipient** wheel(s) lock by varying both the **hand** and the **foot** brake **control** forces, in order to determine the maximum braking rate of the vehicle. [2]2/

[1]/ Additional requirements may have to be established in the case of vehicles equipped with combined braking systems.

[2]/ As an initial step, to facilitate these preliminary tests, the maximum control force applied before the critical point may be obtained for each individual wheel **or system**.

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Appendix 5 ASTM E 1337 "Chirp test"

Designation: E 1337 -90 (Reapproved 2002)
Standard Test Method for
Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using a Standard Reference Test Tire[3]

This standard is issued under the fixed designation E 1337; the number immediately following the designation indicates the year or original adoption or, in the cue or revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (f) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of peak braking coefficient of paved surfaces using a standard reference test tire (SRTT) as described in Specification E 1136 that represents current technology passenger car radial tires. General test procedures and limitations are presented for determining peak braking coefficient independent of surface conditions. Actual surface test conditions are determined and controlled by the user at the time of test. Test and surface condition documentation procedures and details are specified. This measurement quantifies the peak braking coefficient at the time of test and does not necessarily represent a maximum or fixed value.

1.2 This test method utilizes a measurement representing the peak braking force on a braked test tire passing over a road surface. This test is conducted with a tire under a nominal vertical load at a constant speed while its major plane is parallel to its direction of motion and perpendicular to the pavement.

1.3 The measured peak braking coefficient obtained with the equipment and procedures stated herein may not necessarily agree or correlate directly with those obtained by other surface coefficient measuring methods.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

E 274 Test Method for Skid Resistance of Paved Surfaces Using A Full-Scale Tire[4]
E 556 Method of Calibrating a Wheel Force or Torque Transducer Using a Calibration Platform (User Level)[2]
E 867 Definitions of Terms Relating to Traveled Surface Characteristics[2]
E 1136 Specification for a Radial Standard Reference Tire[2]
F 377 Method for Calibration of Braking Force for Testing of Pneumatic Tires[5]

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[3] This test method is under the jurisdiction of ASTM Committee E-I7 on Pavement Management Technologies and is the direct responsibility of Subcommittee E17.21 on Field Methods for Measuring Tire Pavement Friction. Current edition approved Feb. 23, 1990. Published April 1990.
[4] *Annual Book of ASTM Standards,* Vol 04.03.
[5] *Annual Book of ASTM Standards,* Vol 09.02.

F 408 Method of Testing Tires for Wet Traction in Straight-Ahead Braking, Using a Towed Trailer[3]

F 457 Method for Speed and Distance Calibration of a Fifth Wheel Equipped with .Either Analog or Digital Instrumentation[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *chirp test*-the progressive application of brake torque required to produce the maximum value of longitudinal braking force that will occur prior to wheel lockup, with subsequent brake release to prevent any wheel lockup (tire slide).

3.1.2 For other definitions pertaining to this standard, see Definitions E 867 and Method F 408.

3.2 *Descriptions of Terms:*

3.2.1 *braking force coefficient: tire*-the ratio of braking force to vertical load.

3.2.2 *braking force coefficient, tire, peak*-the maximum value, as defined in 12.2, of tire braking force coefficient that occurs prior to wheel lockup as the braking torque is progressively increased.

3.2.3 *braking force coefficient, tire, slide*-the value of the braking force coefficient obtained on a locked wheel.

3.2.4 *braking force, tire-the* negative longitudinal force resulting from braking torque application.

3.2.5 *braking torque*-the negatively directed wheel torque.

3.2.6 *longitudinal force. tire (x)*-the component of a tire force vector in the *X'* direction.

3.2.7 *tire-axis system*-the origin of the tire-axis system is the center of the tire contact. The *X'* axis is the intersection of the wheel plane and the road plane with a positive direction forward. The Z' axis is perpendicular to the road plane with a positive direction downward. The Y' axis is in the road plane, its direction being chosen to make the axis system orthogonal and right-hand (see Fig. 1 in Method F 408).

3.2.8 *tire forces*-the external forces acting on the tire by the road.

3.2.9 *torque wheel (T)*-The external torque applied to a tire from a vehicle about the wheel spin axis. Driving torque is positive wheel torque; braking torque is negative wheel torque.

3.2.10 *Vertical loa*d *(Fz)*-the downward vertical component of force between the tire and the road.

4. Summary of Test Method

4.1 The measurements are conducted with a standard reference test tire (Specification E 1136) mounted on a test trailer towed by a vehicle. The trailer contains a transducer, instrumentation, and actuation controls for the braking of the test tire. See 6.6 for trailer instrumentation.

4.2 The test apparatus is normally brought to a test speed of 40 mph (64 km/h). The brake is progressively applied until sufficient braking torque results to produce the maximum braking force that will occur prior to wheel lockup. Longitudinal force, vertical load, and vehicle speed are recorded with the aid of suitable instrumentation and data acquisition equipment.

4.3 The peak braking coefficient of the road surface is determined from the ratio of the maximum value of braking force to the simultaneous vertical load occurring prior to wheel lockup as the braking torque is progressively increased.

5. Significance and Use

5.1 Pavement surfaces have different traction characteristics, depending on many factors. Surface texture, binder content, usage, environmental exposure, and surface conditions (that is, wet, dry) are some of the factors.

5.2 The measured values represent peak braking coefficients for tires of the general type in operation on passenger vehicles, obtained with a towed test trailer on a prescribed road surface, under user defined surface conditions. Such surface conditions may include the water depth used to wet the road surface and the type of water application method. Variations in these conditions may influence the test results.

6. Apparatus

6.1 The apparatus consists of a tow vehicle and test trailer. The vehicle and trailer must comply with all legal requirements applicable to state laws when operated on public roads.

6.2 *Tow Vehicle*-The vehicle shall have the capability of maintaining a test speed of 40 mph (64 km/h) within ±0.5 mph (±O.8 km/h) even at maximum level of application of braking forces.

6.3 *Test Trailer*-The test wheel shall be equipped with a sufficient braking torque to produce the maximum value of braking test wheel longitudinal force at the conditions specified.

6.3.1 Each of the trailer wheels shall have a suspension capable of holding toe and camber changes to within ±0.05 with maximum vertical suspension displacements under both static and dynamic conditions.

6.3.2 The rate of brake application shall be sufficient to control the time interval between initial brake application and peak longitudinal force to be between 0.3 and 0.5 s.

6.4 *Vertical Load*-The trailer shall be of such a design as to provide a static load of 1031 ± 15 Ibf (4S86 ± 67 N) to the test wheel and on detachable trailers a static down load of 100 to 200 Ibf (445 to 890 N) at the hitch point.

6.5 *Tire and Rim*-The test tire shall be the standard reference test tire (SRTT) for pavement tests, as specified in Specification E 1136, mounted on a suitable 14 by 6-in. rim.

6.5.1 When irregular wear or damage results from tests, or when wear or usage influences the test results, the use of the tire should be discontinued.

6.6 *Instrumentation*:

6.6.1 *General Requirements for Measuring System*-The instrumentation system shall conform to the following overall requirements at ambient temperatures between 40 and 100°F (4 and 38°C):

6.6.1.1 Overall system accuracy of ±1.5% of applied load from 200 Ibf (890 N) to full scale; for example, at 200 Ibf (890 N), Applied calibration force of the system output shall be determinable within ±3 lbf (±13 N).

6.6.1.2 The exposed portions of the system shall tolerate 100% relative humidity (rain or spray) and all other adverse conditions, such as dust, shock, and vibrations which may be encountered in highway operations.

6.6.1.3 B*raking Forces*-The braking force measuring transducer shall measure longitudinal reaction force within a range between 0 and 2000 Ibf (0 and 8.9 kN) generated at the tire-pavement interface as a result of brake application. The tire force-measuring transducer shall be of such design as to measure the tire-pavement interface force with minimum inertial effects. Transducers are recommended to provide an output directly proportional to force with hysteresis less than 1% of the applied load, nonlinearity less than 1% of the applied load up to the maximum expected loading, and sensitivity to any expected cross-axis loading or torque loading less than 1% of the applied load. The force transducer shall be mounted in such a manner as to experience less than 1% angular rotation with respect to its measuring plane at the maximum expected loading.

6.6.1.4 *Vertical Load*-The vertical load measuring transducer shall measure the vertical load at the test wheel during brake application. The transducer shall have the same specifications as those described in 6.6.1.3.

NOTE 1-Other transducer systems may be used to determine peak braking coefficients if they can be shown to correlate with the force-measuring transducer system with the same overall accuracy.

6.6.1.5 *Vehicle Speed-Measuring Transducers*-Transducers such as "fifth wheel" or a free-rolling wheel coupled tachometer shall provide speed resolution and accuracy of ±1.5% of the indicated speed or ±O.5 mph (±O.8 km/h), whichever is greater. Output shall be directly viewable by the driver and shall be simultaneously recorded. Fifth wheel systems shall conform to Method F 457.

6.6.1.6 *Signal Conditioning and Data Acquisition*-All signal conditioning and recording equipment shall provide linear output and shall allow data reading resolution to meet the requirements of 6.6.1.1.

6.6.1.7 All strain-gage transducers shall be equipped with resistance shunt calibration resistors or equivalent that can be connected before or after test sequences. The calibration signal shall be at least 50 % of the normal vertical load and shall be recorded.

6.6.1.8 A digital data acquisition system shall be employed to individually digitize the braking force, vertical load, and vehicle speed analog outputs. The braking force, vertical load, and test wheel speed input signals to be digitized shall be sampled (as close to simultaneous as possible to minimize phase shifting) at 100 samples per second for each channel from unfiltered analog signals. Vehicle speed can be analog filtered, if necessary, to remove noise since this is a steady-state signal.

NOTE 2-Experience indicates that data sampling at 100 samples per second of unfiltered analog skid trailer data will properly describe the significant frequencies. To prevent "aliasing, caution must be exercised in digitizing skid trailer data which contains any significant frequencies above 50Hz or other types of analog data.

7. Hazards

7.1 The test vehicle, as well as all attachments to it, shall comply with all applicable state and federal laws. AD necessary precautions shall be taken beyond those imposed by laws and regulations to ensure maximum safety of operating personnel and other traffic. No test shall be made when there is danger that dispersed water may freeze on the pavement.

8. Preparation of Apparatus

8.1 *Preparation of Test Tire:*

8.1.1 Trim the test tires to remove all protuberances in the tread area caused by mold air vents or flashes at mold junctions.

8.1.2 Test tires should be stored in such a location that they all have the same ambient temperature prior to testing and shield them from the sun to avoid excessive heating by solar radiation.

8.1.3 Mount the test tire on Tire and Rim Association (TRA) recommended rim[6] (6.5) by using conventional mounting methods. Caution: Assure proper bead seating by the use of a suitable lubricant. Excessive use of lubricant should be avoided to prevent slipping of the tire on the wheel rim.

8.1.4 Check the test tires for the specified inflation pressure at ambient temperature (cold), just prior to testing. The test tire inflation pressure shall be 35 +/- 0.5 psi. (241 ± 3 kPa).

9. Calibration

9.1 *Vehicle Speed*-Calibrate the test vehicle speed indicator at the test speed by determining the time for traversing at constant speed a reasonably level and straight, accurately measured pavement of a length appropriate for the method of timing. Load the test trailer to its specified operating weight for this calibration. Record speed variations during a traverse with the test system. Make a minimum of three runs at each test speed to complete the calibration. Other methods of equivalent accuracy may be used. Calibration of a fifth wheel shall be performed in accordance with Method F 4S7.

10. Conditioning

10.1 *Pretest Tire Conditioning:*

10.1.1 Test tire pretest conditioning shall be performed to precondition all tires prior to initial testing. Pretest conditioning is to be done only once per tire and prior to any actual test measurements. This process is recommended because the new tire burnish effect may have an influence on the peak braking coefficient obtained and to minimize test variability caused by transient, non-preconditioned, tire braking performance.

10.1.2 Pretest tire conditioning shall be conducted on a dry and level surface. Each tire shall be chirped ten times at 20 mph (32 km/h) under test load.

10.2 *General Test Conditions:*

10.2.1 The test surface shall be tree of loose material or foreign deposits.

10.2.2 Do not test when wind conditions interfere with wetted test repeatability. Test results may be influenced by wind speed, or direction, or both. The magnitude of this dependence is a function of the water depth, application procedures, and surface wind protection.

11. Procedure

11.1 Warm up electronic test equipment as required for stabilization.

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[6] Current recommendations available from the Tire and Rim Association. 3200 Market 51.. Akron. OH 44313.

11.2 Install an SRTT (Specification E 1136) in the test position of the test trailer. A tire with a similar loaded radius and high cornering properties should be used on the opposite side to level the axle and to minimize trailer yaw during brake torque applications.

11.3 Check and, if necessary, adjust the test trailer static weight on the test tire to the specified test load (see 6.4).

11.4 Check and adjust tire inflation pressure as required immediately before testing to specified value (see 8.1.4).

11.5 When testing on an externally wetted test surface, offset the trailer test wheel sufficiently to prevent "tracking" of the towing vehicle. Twelve to sixteen in. (305 to 406 mm) is suggested.

11.6 Record tire identification and other data, including date, time, ambient temperature, test surface temperature, tire durometer, test surface type, and water depth (if wetted surface is used). Measure the water depth with a variable height probe type device.

11.7 Record electrical calibration signals prior to and after testing each surface, or as needed to ensure valid data.

11.8 Perform pretest tire conditioning (10.1) if using a new tire.

11.9 Conduct test at the required test vehicle speed. It is recommended that peak braking coefficient measurement tests be conducted using the chirp test methodology to minimize tire damage due to tire sliding.

11.10 Make at 1east eight determinations of the peak braking coefficient evenly distributed over the test surface with the test system at the specified test speed.

11.11 *Lateral Positioning 01 Test Vehicle on Highway Surfaces*-Normally, testing shall be done in the center of either wheel track of a traffic lane on a highway. The specific details regarding lane and the wheel-path used should be provided when reporting the data.

11.12 Test Speeds-The standard test speed shall be 40 mph (64 km/h), and tests shall normally be conducted at that speed. Where the legal maximum speed is less than 40 mph, the tests may have to be conducted at a lower speed. Where the legal speed is considerably in excess of 40 mph (64 km/h), tests may be made at the prevailing traffic speed, but it is recommended that at the same locations, additional tests be made at 40 mph (64 km/h). Maintain test speeds within ±1 mph (1.5 km/h).

11.12.1 The test speed must be given when the peak braking coefficient is quoted. This may be done by adding the numerals of the actual test speed in miles per hour in parentheses to the coefficient, for example, 0.50(50) indicates the peak braking coefficient was obtained at a test speed of 50 mph (80 km/h).

12. Calculation

12.1 *Data Reduction:*

12.1.1 Digitally filter the digitized input analog signals of braking force, vertical load, and vehicle speed using a five point moving average technique.

12.1.2 *Digital Filtering Methodology*-Calculate an average value for the first five digital data points. Drop the first data point and add the sixth data point, calculate another five point average value. Repeat this procedure for all remaining data points. This sequence is done individually on all the above digitized input analog signals. The following example computations illustrate the method using one channel.

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$$(ptl + pt2 + pt3 + pt4 + pt5)/5 = PT1$$
$$(pt2 + pt3 + pt4 + pt5 + pt6)/5 = PT2$$
$$(pt3 + pt4 + pt5 + pt6 + pt7)/5 - PT3$$

A new set of data points (indicated by capital letters) arc then defined to represent the filtered data for each channel (that is, Avg ptx = PTy).

PTI, PT2, PT3, etc. - braking force
PT I, PT2, PT3, etc. - vertical force

12.2 Determining and Calculating Peak Braking Coefficient.

12.2.1 The peak braking coefficient shall be determined for each run (brake application).

12.2.2 Using the digitally filtered data (PT 1, PT2, PT3, etc.), scan the longitudinal channel and determine the highest absolute filtered value (PTy) prior to wheel lock up. Calculate an average peak braking force value using the highest filtered value (PTy) and one filtered point directly before (PTY_{-l}) and directly after it (PTY_{+l}) This three point average is the peak braking force value developed for this individual lock up.

12.2.3 Determine the vertical load value from its respective digitally filtered data that corresponds to the highest absolute value for braking force, from 12.2.2. Calculate an average vertical load value using this corresponding value and one point directly before and directly after it. This three point average is the vertical load value that corresponds to the average peak braking force for this individual lock up.

12.2.4 Calculate the peak braking coefficient by dividing the three point average peak braking force, determined from 12.2.2, by the three point average vertical load, as determined in 12.2.3. The peak braking coefficient should be reported to two (2) decimal places.

12.3 For each test (11.10) the mean and standard deviation for peak braking coefficient are calculated from the individual determinations.

13. Report

13.1 *Field Report*-The field report for each test section shall contain data on the following items:

13.1.1 Identify test procedure used,

13.1.2 Location and identification of test section, 13.1.3 Date and time of day,

13.1.4 Weather conditions,

13.1.5 Lane and wheel-path tested,

13.1.6 Speed of test vehicle (for each test), 13.1.7 Peak braking coefficient (for each test), 13.1.8 Water depth, if wetted surface is used, and 13.1.9 Ambient and surface temperature.

13.2 *Summary Report*-The summary report shall include, for each test section, data on the following items insofar as they arc pertinent to the variables or combinations of variables under investigation:

13.2.1 Location and identification of test section, 13.2.2 Number of lanes and presence of lane separators, 13.2.3 Grade and alignment,

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13.2.4 Pavement type, mix design of surface course, condition, and aggregate type (specific source, if available), 13.2.5 Age of pavement,

13.2.6 Average daily traffic,

13.2.7 Posted speed limit,

13.2.8 Date and time of day,

13.2.9 Weather conditions,

13.2.10 Lane and wheel-path tested,

13.2.11 Ambient and surface temperature, and

13.2.12 Average, high, and low peak braking coefficient for the test section and speed at which the tests were made. (If values are reported that were not used in computing the average, this fact should be reported.)

14. Precision and Bias

14.1 *Precision*-Data are not yet available for making a statement on the precision of this test method. When such data become available, a precision statement will be included in this test method.

14.2 *Bias*-There arc no standards or references with which the results of this test can be compared. The function of the test as indicated above is to be able to make comparisons among road surfaces tested with the same tire. It is believed that the results of the test method arc adequate for making such comparisons without an external reference for assessing accuracy. It must be noted that surface friction is affected by many variables such as environmental conditions, usage, age, surface contamination (externally applied water), etc., and measured values arc only valid until one of these conditions significantly changes.

15. Recommendations for Tire Use and Operational Requirements

15.1 When irregular wear or damage results from tests, or when wear or usage influences the test results, the use of the tire should be discontinued.

NOTE 3- Test results such as measured braking force may be influenced by tire groove depth or tread hardness, or both. The magnitude of this dependence is a function of the water depth, pavement characteristics, test speed, tire aging effects, and break-in (preconditioning).

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committee. which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards. 1916 Race St., Philadelphia, PA 19103.