

# Determination of braking distance and driver behaviour based on braking trials



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# Outline

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- Introduction and background
- Measurement programme
- Results from braking trials
- Effects from parameters not included in programme
- New recommended braking distances

# Braking distance

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One of the most important road design parameters

Braking distance - the most important factors:

- speed
- coefficient of friction between tyres and roadway
- driver's braking behaviour/technique
- vehicle's braking system and condition
- tyre condition
- road's vertical grade

# Present method in Danish Road Standards and Guidelines

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$$L_{brake} = \frac{V^2}{2 \cdot g \cdot (\mu_{brake} + s) \cdot 3.6^2}$$

$L_{brake}$  = braking distance

$V$  = speed (km/h)

$g$  = acceleration due to gravity (9.81 m/s<sup>2</sup>)

$\mu_{brake}$  = coefficient of friction

$s$  = roadway grade

Speed (km/h)	$\mu_{brake}$	$L_{brake}$
80	0.34	74 m
110	0.30	159 m
130	0.28	237 m

# Programme

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Study initiated by the Danish Road Directorate

Main purpose:

- to study the braking behaviour among non professional drivers
- to study braking distances at different physical conditions (speed, vehicle, road surface)
- to study relation between braking distance and friction

# Parametres in programme

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Parameter	Levels	
speed	3	80, 110 and 130 km/h
friction	3	road sections with friction in range 0.4-0.8
road surface	2	wet and dry road surface
vehicle	2	small + medium sized passenger car
tyre type	1	ordinary summer tyres

# Measurement programme

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2 professional test drivers on each test track  
- all combinations (vehicle/speed/road surface)

A total of 72 braking trials

16 non professional test drivers (spread on 3 test tracks)  
- almost all combinations (vehicle/speed/road surface)

A total of 115 braking trials

In addition: 30 comfort braking manoeuvres

# Non professional test drivers

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Sex	Age			Total
	25-39	40-59	60->	
Female	4	1		5
Male	6	3	2	11
Total	10	4	2	16



# Test cars

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Make: Opel Vectra  
Model: 1.8 Comfort  
Year: 2004  
Weight: 1275 kg



Make: Fiat Grande Punto  
Model: 1.4 Dynamic  
Year: 2006  
Weight: 1060 kg

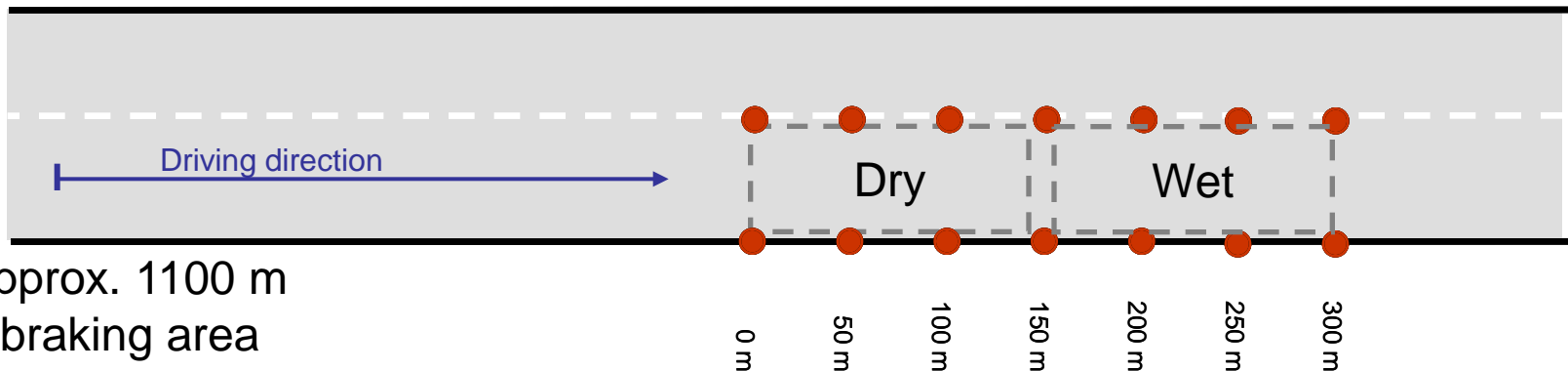
# Measurement equipment

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# Tests tracks - Friction values

Test track		Friction	
		Dry-section	Wet-section
1	Existing free-way	0.49	0.49
2	New free-way	0.52	0.64
3	Air field	0.75	0.74



Start approx. 1100 m  
before braking area

# Wet road surface



Approx. 1.0 – 1.2 mm water layer

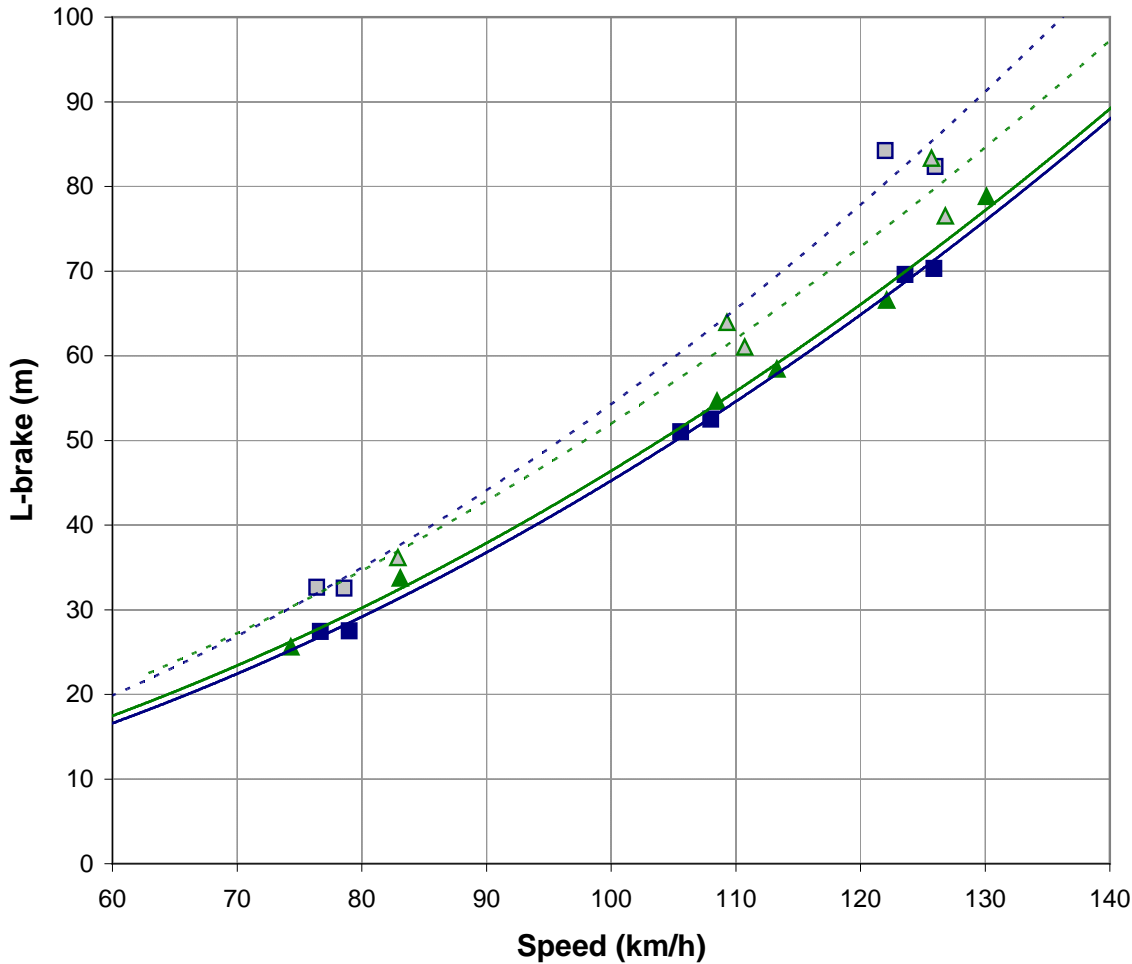






# Results – professional test drivers

Test track 1

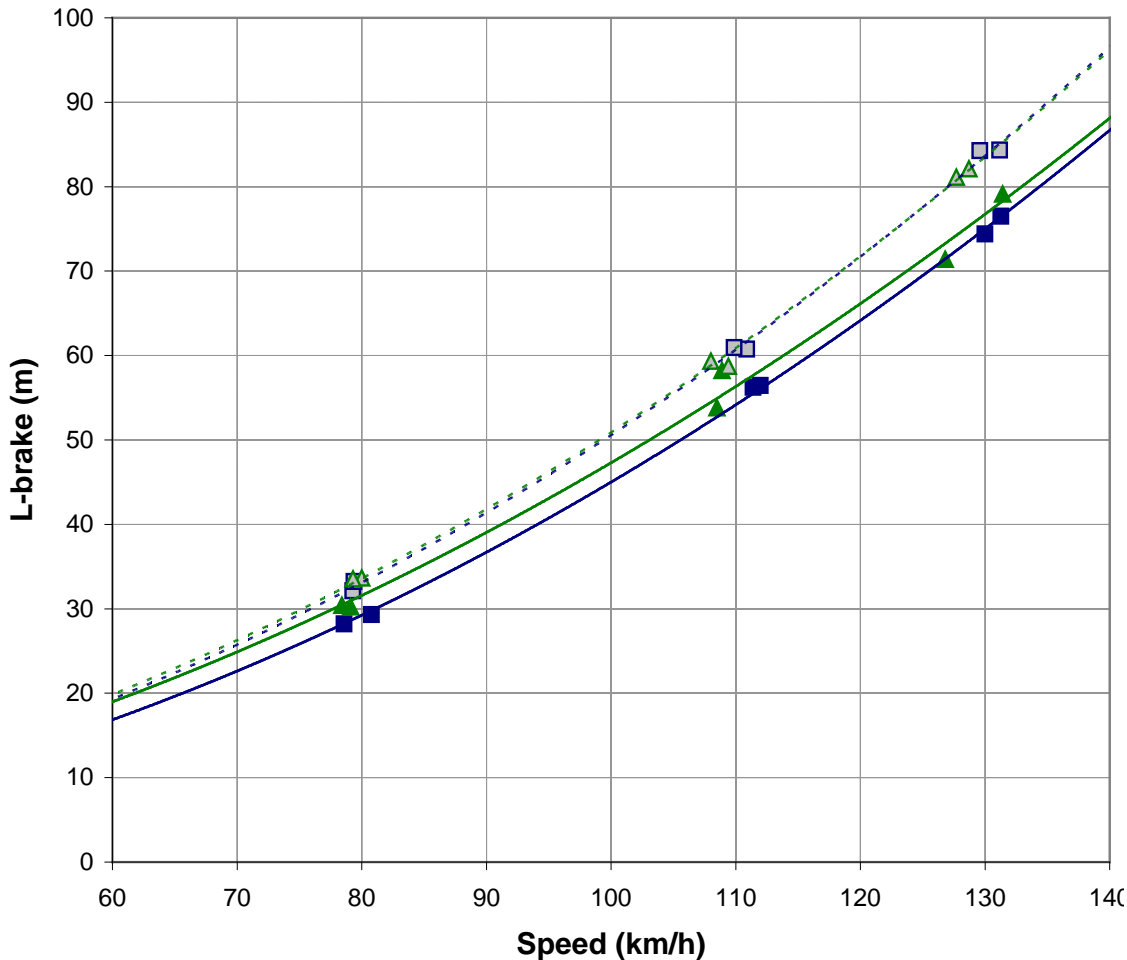


- Car1 - dry road ———
- Car1 - wet road - - - -
- ▲ Car2 - dry road ———
- △ Car2 - wet road - - - -



# Results – professional test drivers

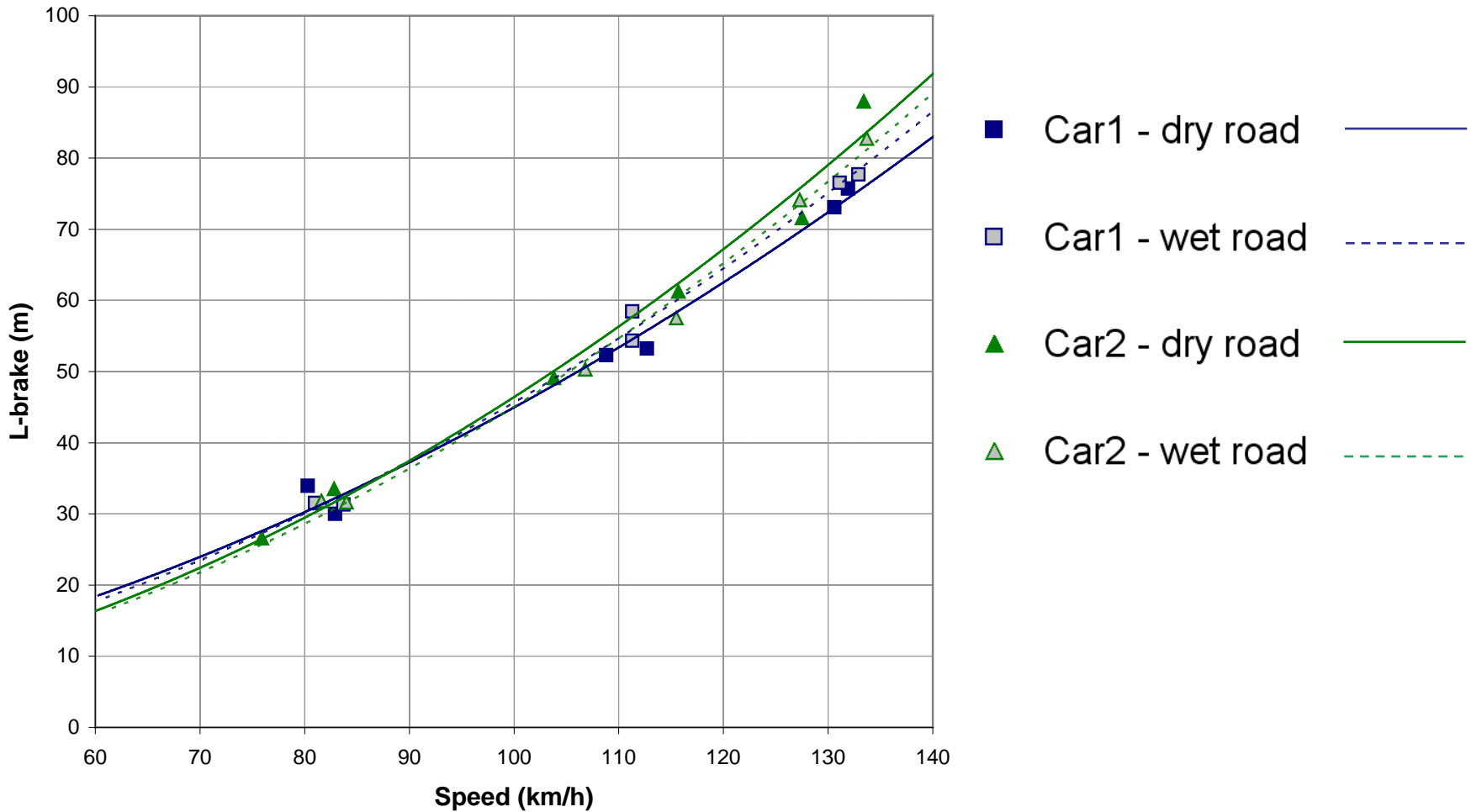
Test track 2



- Car1 - dry road ———
- Car1 - wet road - - - -
- ▲ Car2 - dry road ———
- △ Car2 - wet road - - - -

# Results – professional test drivers

Test track 3



# Deceleration values

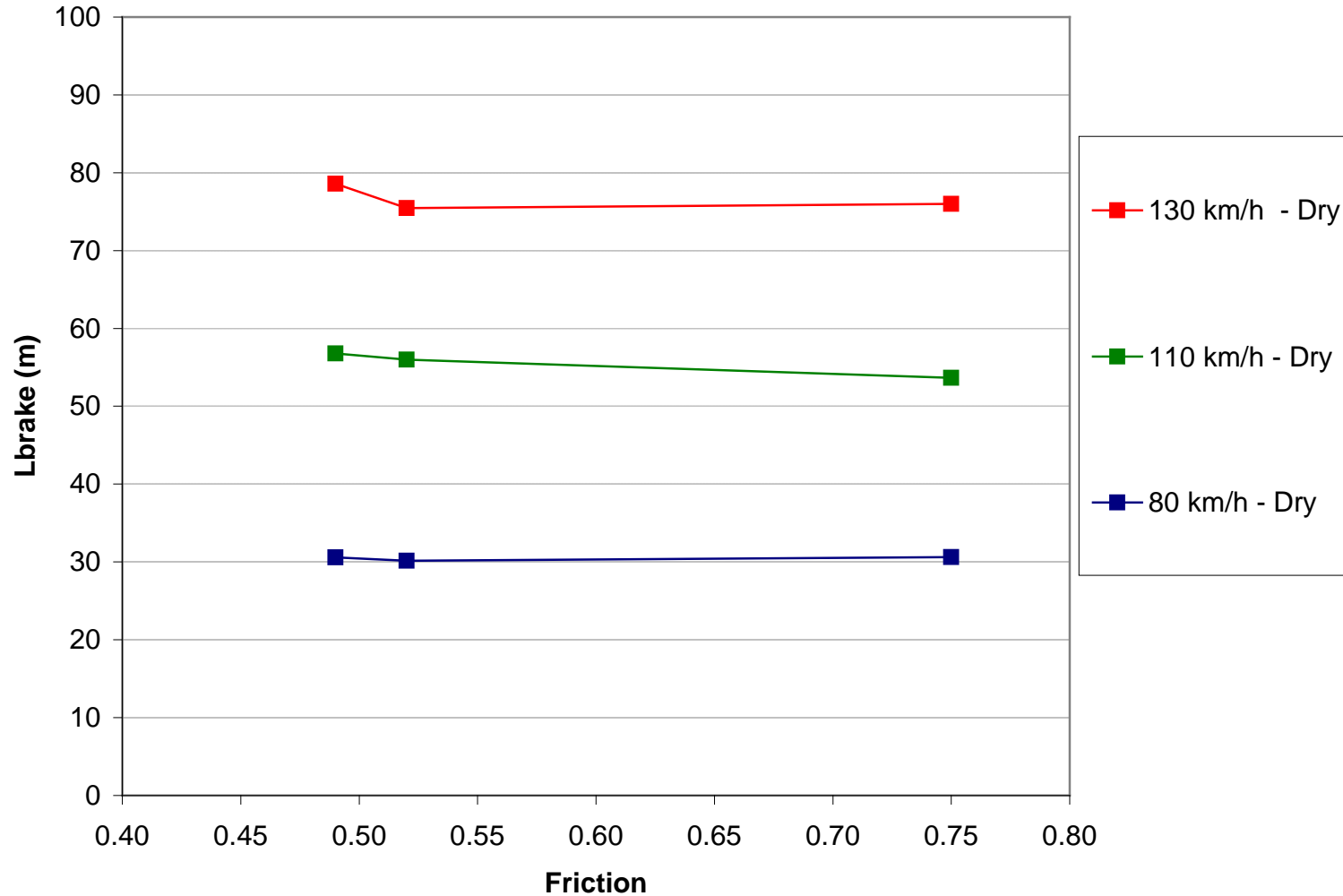
	Dec <sub>brake</sub> (m/s <sup>2</sup> )	Dec <sub>brake</sub> (m/s <sup>2</sup> ) in speed interval			
		120-100 km/h	100-70 km/h	70-50 km/h	50-30 km/h
Dry	8.4	8.6	9.1	9.2	9.5
Wet	7.8	8.1	8.3	8.4	8.8

Dec<sub>brake</sub> (m/s<sup>2</sup>) in speed interval 70-50 km/h

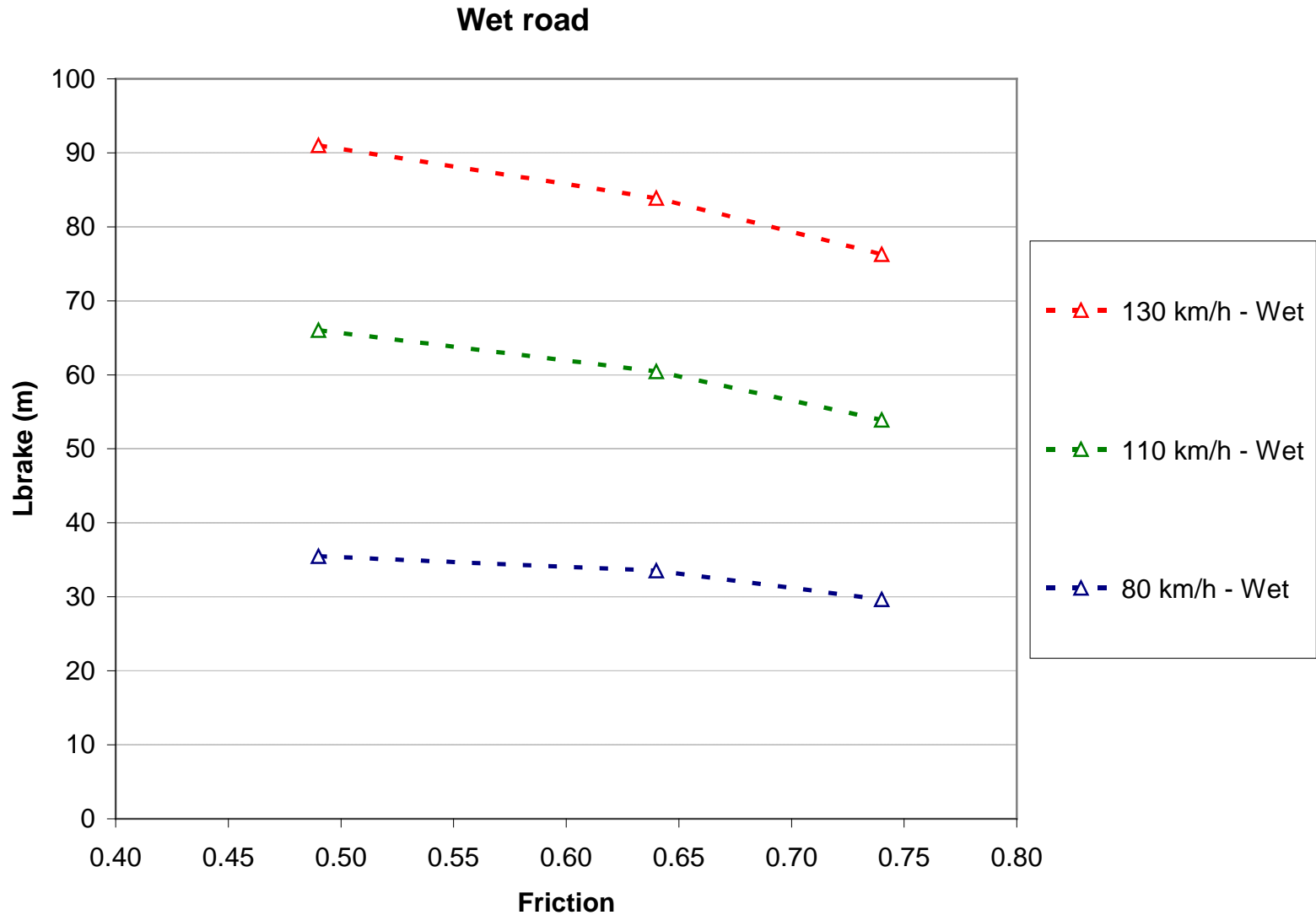
	Initial speed		
	80 km/h	110 km/h	130 km/h
Dry	9.1	9.2	9.4
Wet	8.1	8.6	8.5

# Braking distance and friction

Dry road



# Braking distance and friction



# Relation between deceleration, friction and initial speed (only wet road)

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$$Dec_{brake} = a \cdot \sqrt{\mu_{fric}} + b \cdot V_0$$

where:

$Dec_{brake}$  is the average deceleration for the entire braking run (m/s<sup>2</sup>)

$\mu_{fric}$  is the recorded friction on the test track

$V_0$  is the initial speed before braking (m/s)

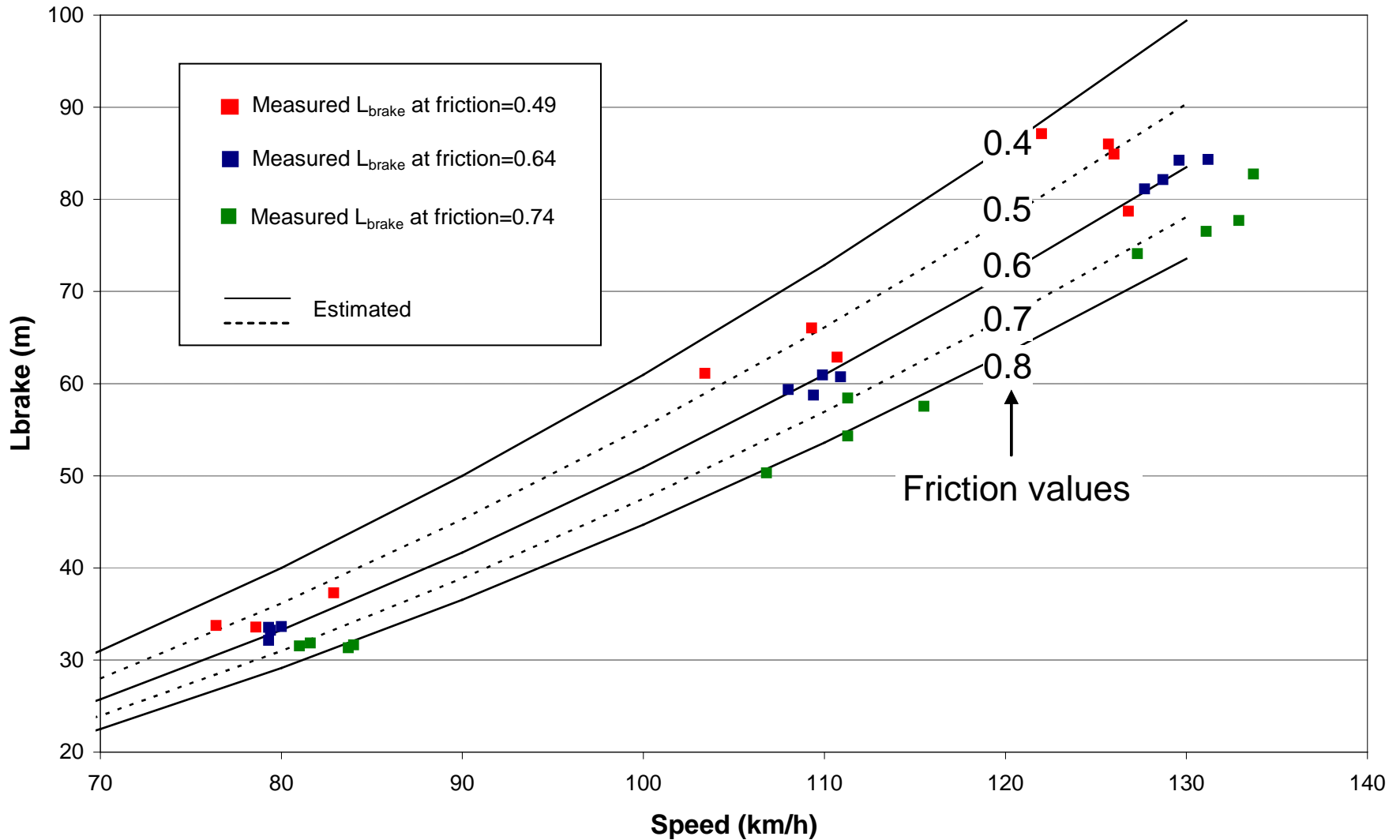
For the recorded deceleration values on wet road (33 observations), the following results were obtained:

$$Dec_{brake} = 8.79 \cdot \sqrt{\mu_{fric}} + 0.028 \cdot V_0 \quad R^2 = 0.97$$

## Estimated $L_{brake}$

$$L_{brake} = \frac{V_0^2}{2 \cdot Dec_{brake}} = \frac{V_0^2}{2 \cdot (8.79 \cdot \sqrt{\mu_{fric}} + 0.028 \cdot V_0)}$$

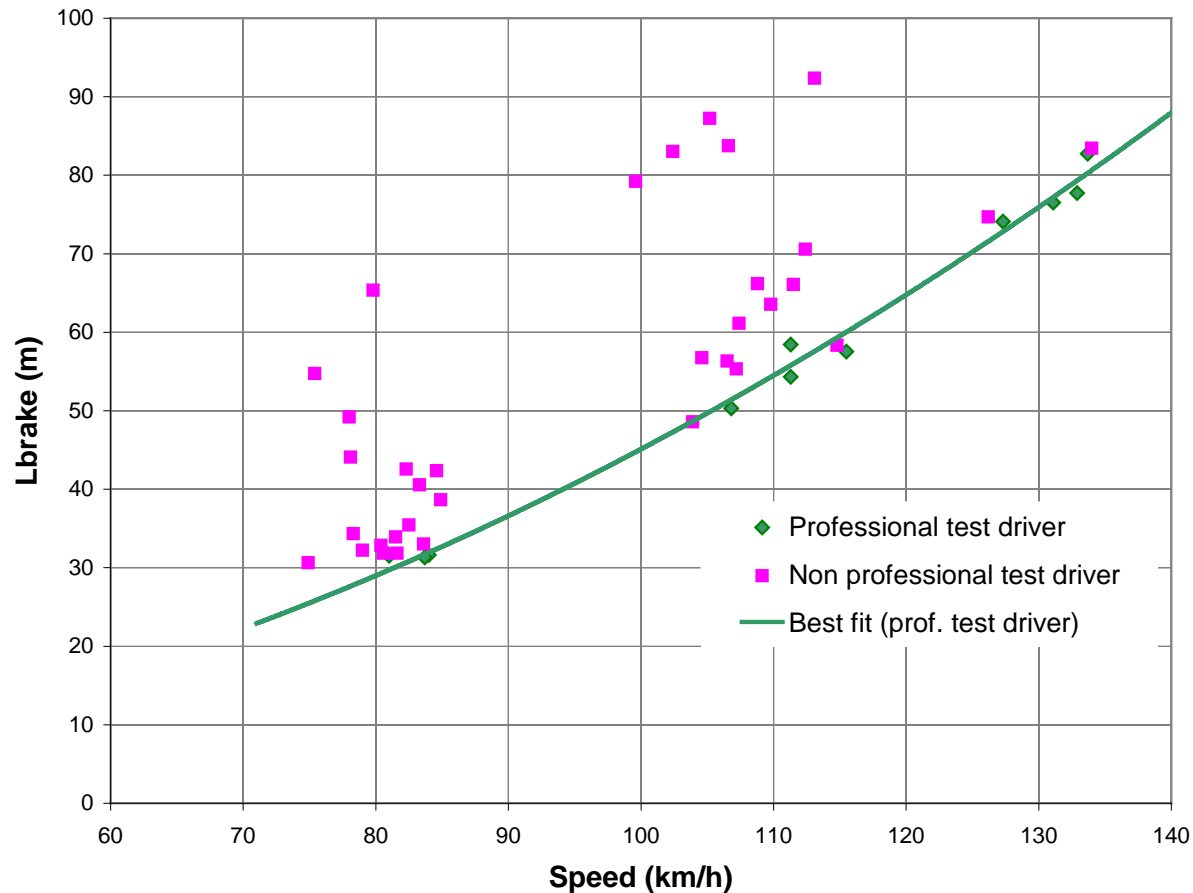
## Estimated and measured braking distance ( $L_{brake}$ ) on wet road at different friction values (0.4 - 0.8)





# Non-professional test driver

Example:  
Braking distance for prof. and non prof. test drivers  
(car1+car2, only wet, test track 3)



## Non-professional test driver – result cont.

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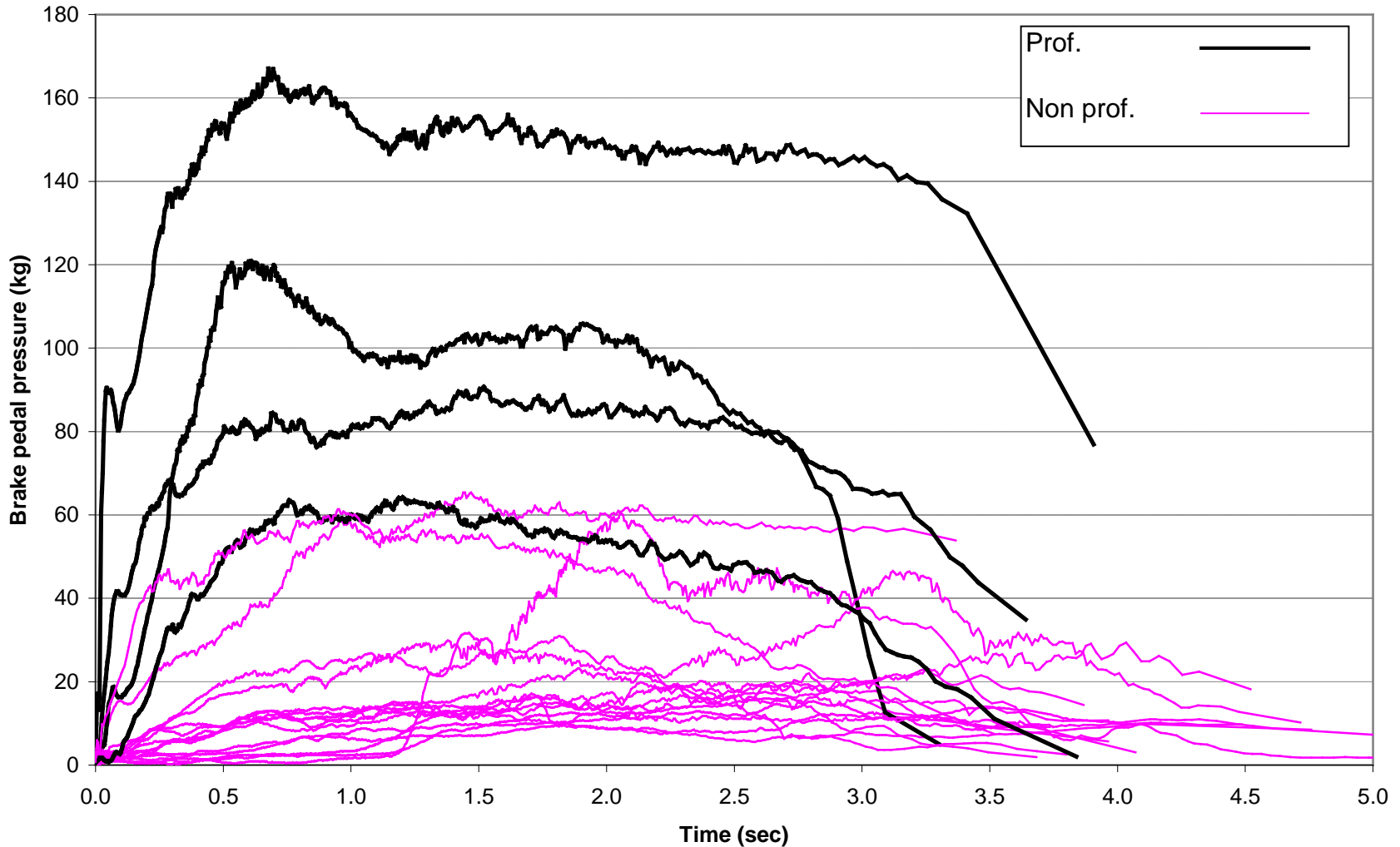
- learning effect - better braking after 5-6 trials
- male test drivers have shorter  $L_{\text{brake}}$  compared to female
- age group 50-70 years have the longest  $L_{\text{brake}}$
- high speed combined with wet road conditions
  - > cautious braking behaviour
- in general - little difference between car 1 and car 2
- comfortable braking – deceleration  $\approx 3.2 \text{ m/s}^2$

# Brake pedal pressure

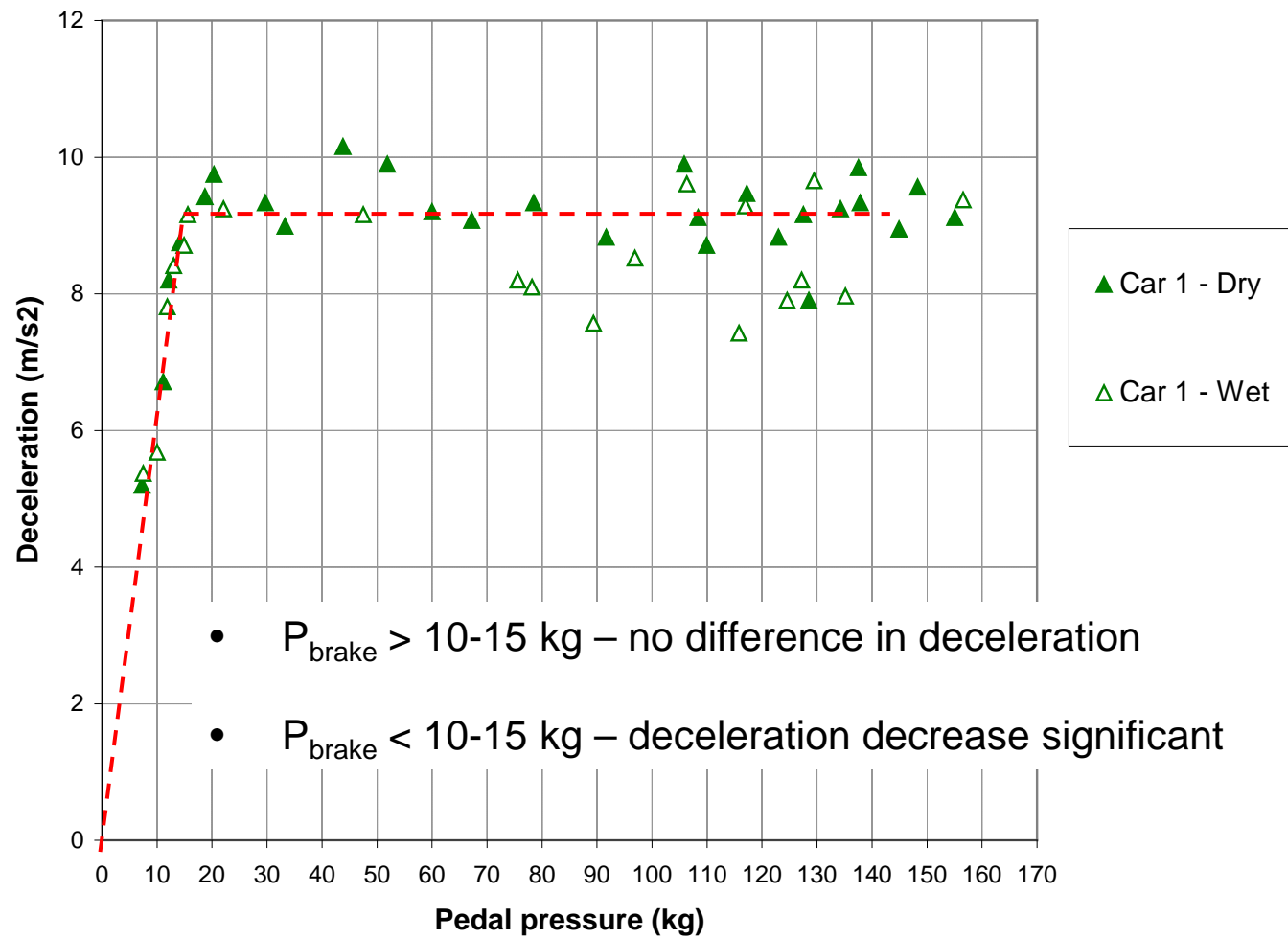
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Test driver	$P_{\text{brake}}$	Time $P_{\text{brake}} > 10 \text{ kg}$
Non professional	35 kg	0.83 sec
Professional	74 kg	0.05 sec

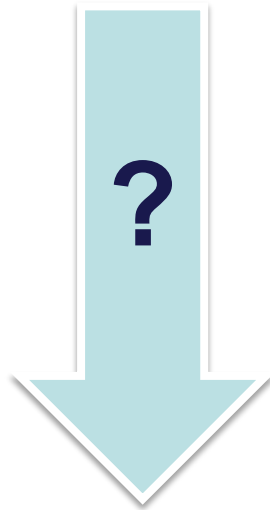
# Example: Brake pedal pressure during braking (110 km/h. wet. test track 3)



**Example:**  
**Brake pedal pressure and deceleration values 100-70 km/h**  
**(only car 1, prof. and non prof., all test tracks)**



**Results from measurement programme**



**Recommended braking distance**

# Effect from parameters not included in the measurement programme

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- based on a literature review
- only wet road

Parameter	Effect in relation to:	[min/max]
Make of tyre	Average tyre	-10% - +10%
Winter tyre	Summer tyre	+5% - +35%
Tread depth 1.6 mm	8 mm	+0% - +50%
Make of car	Average car	-10% - +10%
Loaded	Non-loaded	-10% - +15%

**Vehicle with poor braking capability have 30-60% longer braking distance compared to test cars used in program**

# New recommended braking distance

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The braking distance should reflect:

- worst-case-scenario road conditions (wet road, friction = 0.4) Estimated – based on prof. test drivers
- vehicle with poor braking capabilities (little tread depth, winter tyres, loaded. ... ) Vehicle increment: +45%
- braking behaviour among the worst performing drivers Behavioural increment: +30%



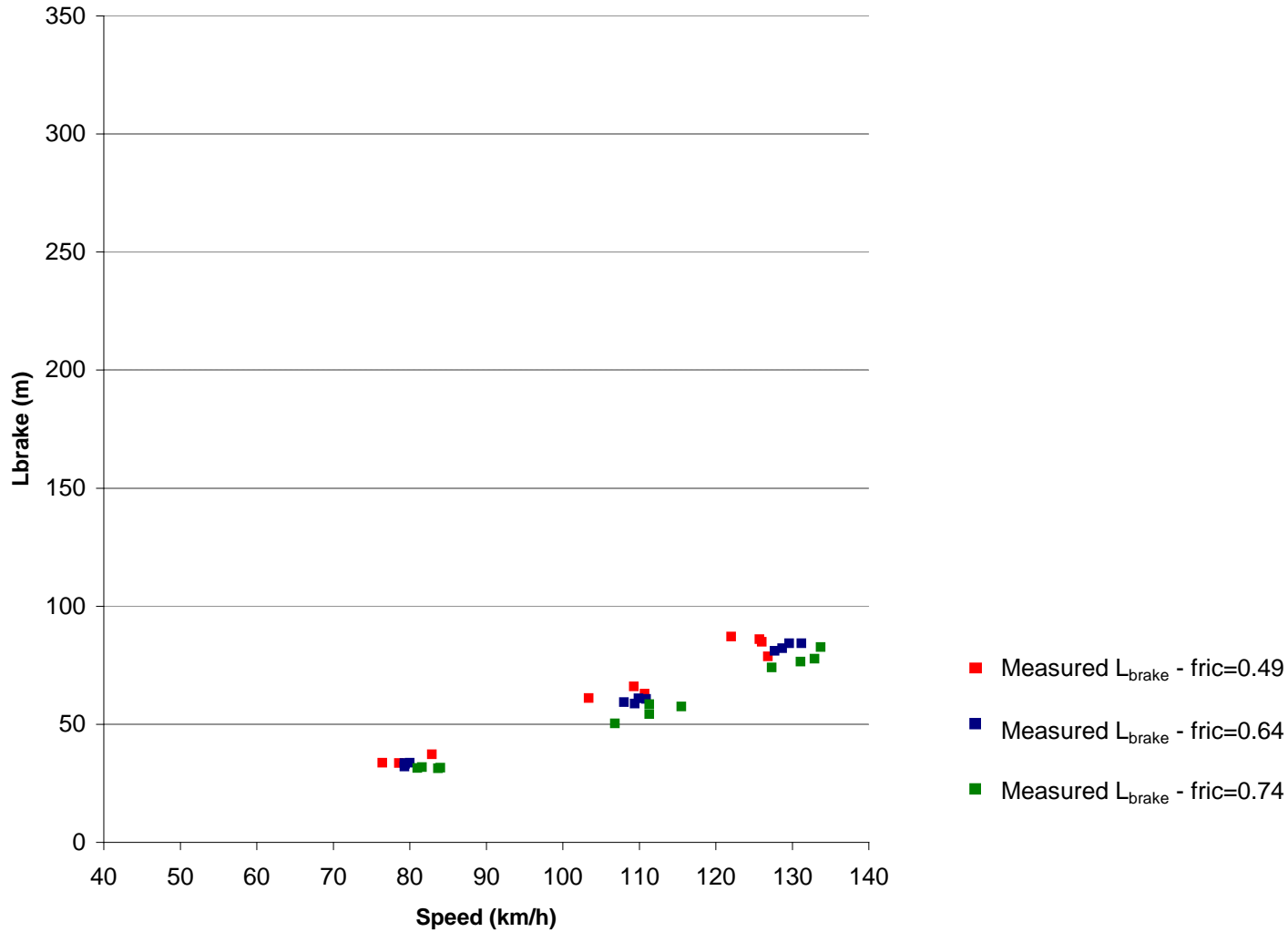
# New recommended braking distances

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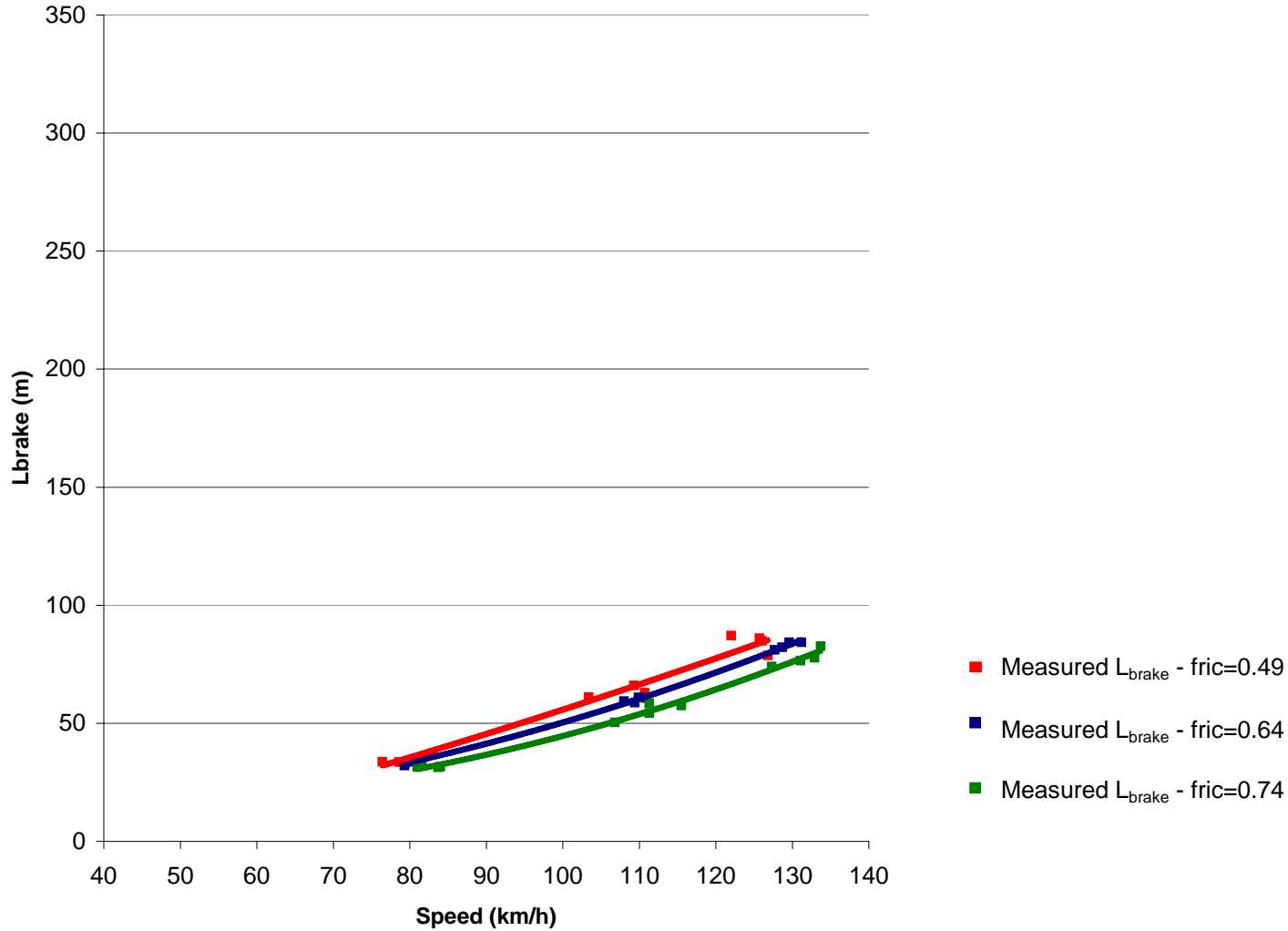
	80 km/h	110 km/h	130 km/h
$L_{\text{brake}}$ – professional in test car	40 m	73 m	99 m
Behavioural increment: (+30%)	12 m	22 m	30 m
Vehicle increment: (+45%)	18 m	33 m	45 m
<b>Recommended <math>L_{\text{brake}}</math></b>	<b>70 m</b>	<b>128 m</b>	<b>174 m</b>

**$L_{\text{brake}}$  - > Decc. ~ 3.7 m/s<sup>2</sup>**

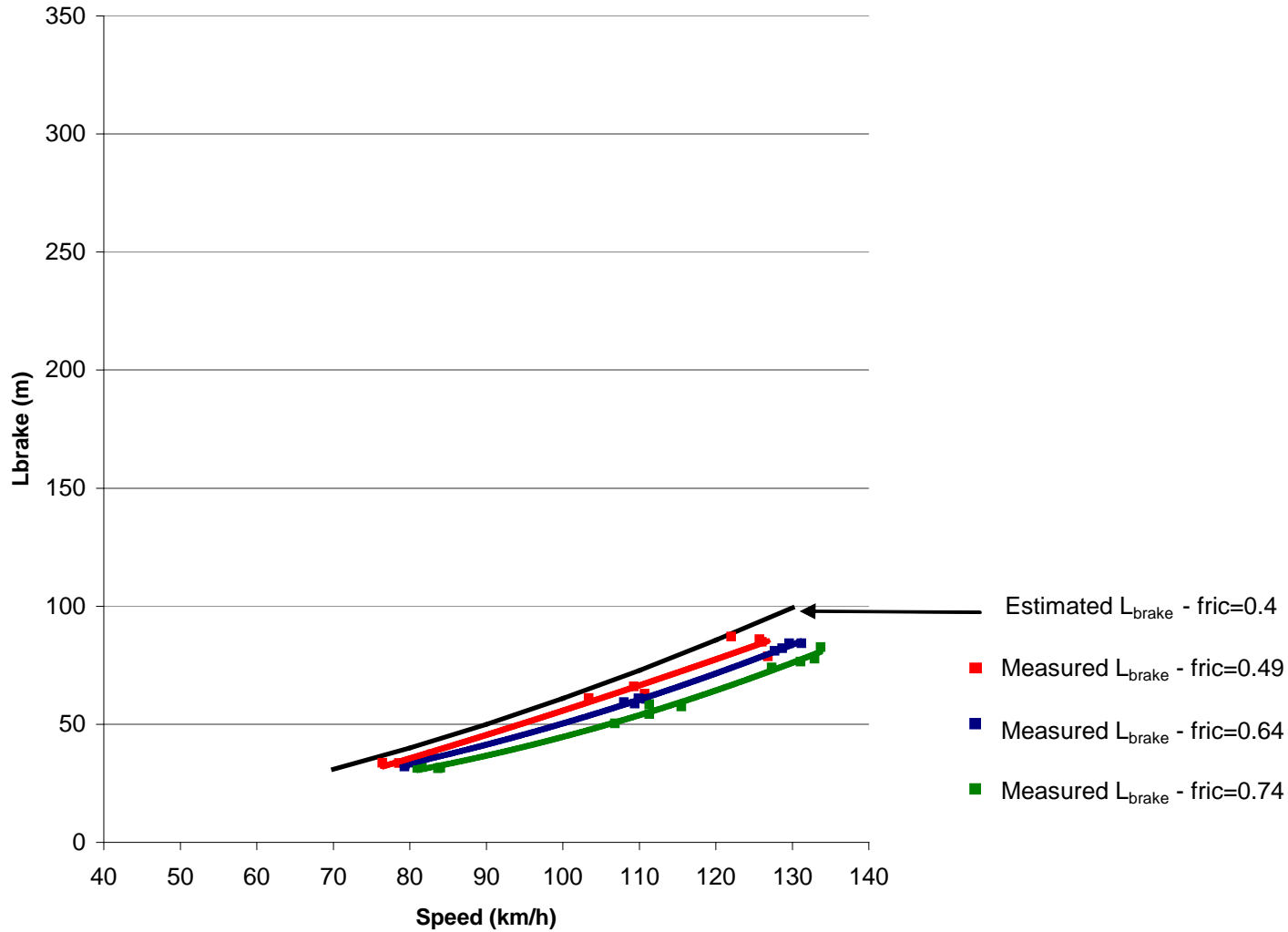
**Braking distance for respectively:  
Measured in programme, Danish Guidelines, Green Book and new recommended values**



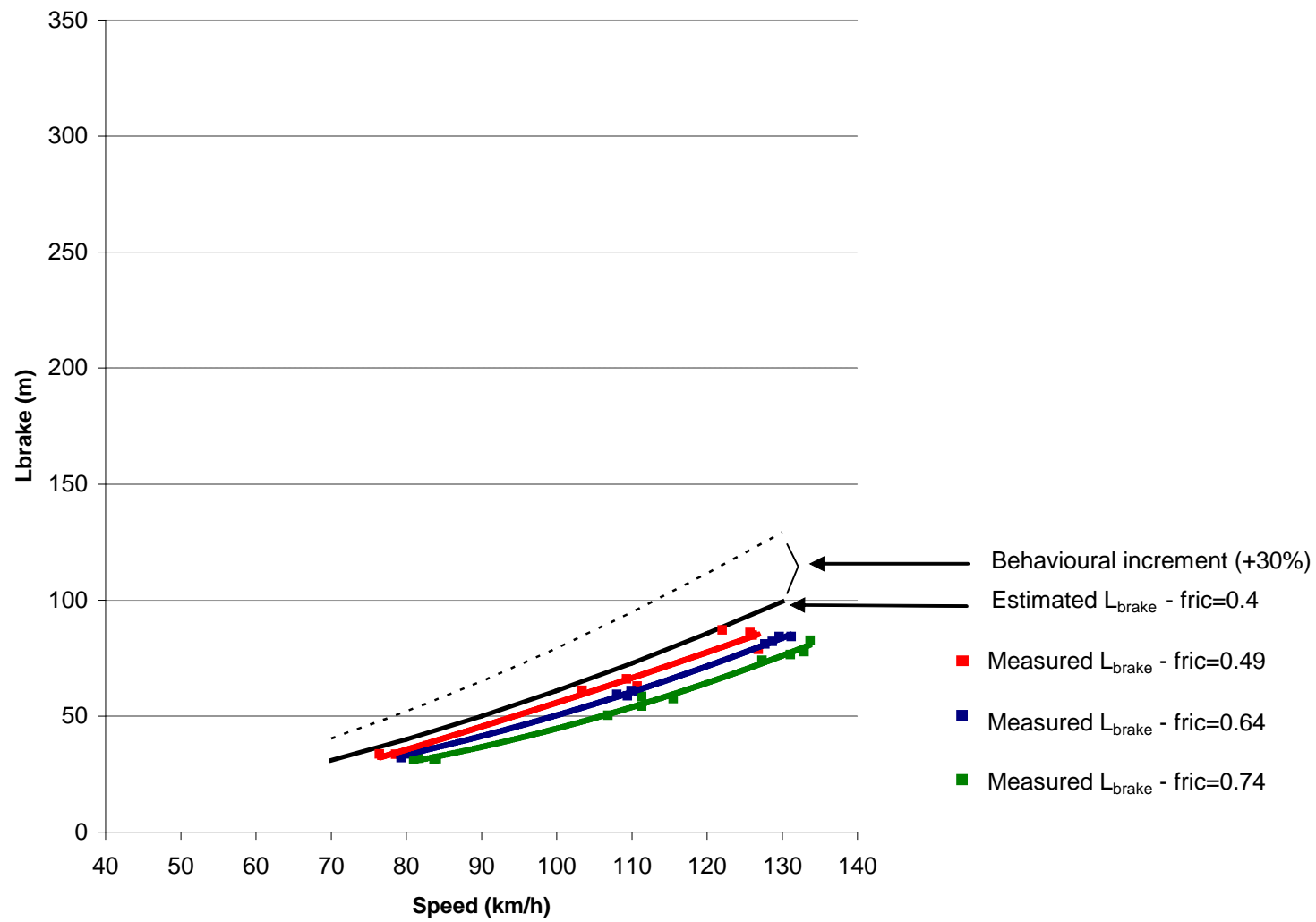
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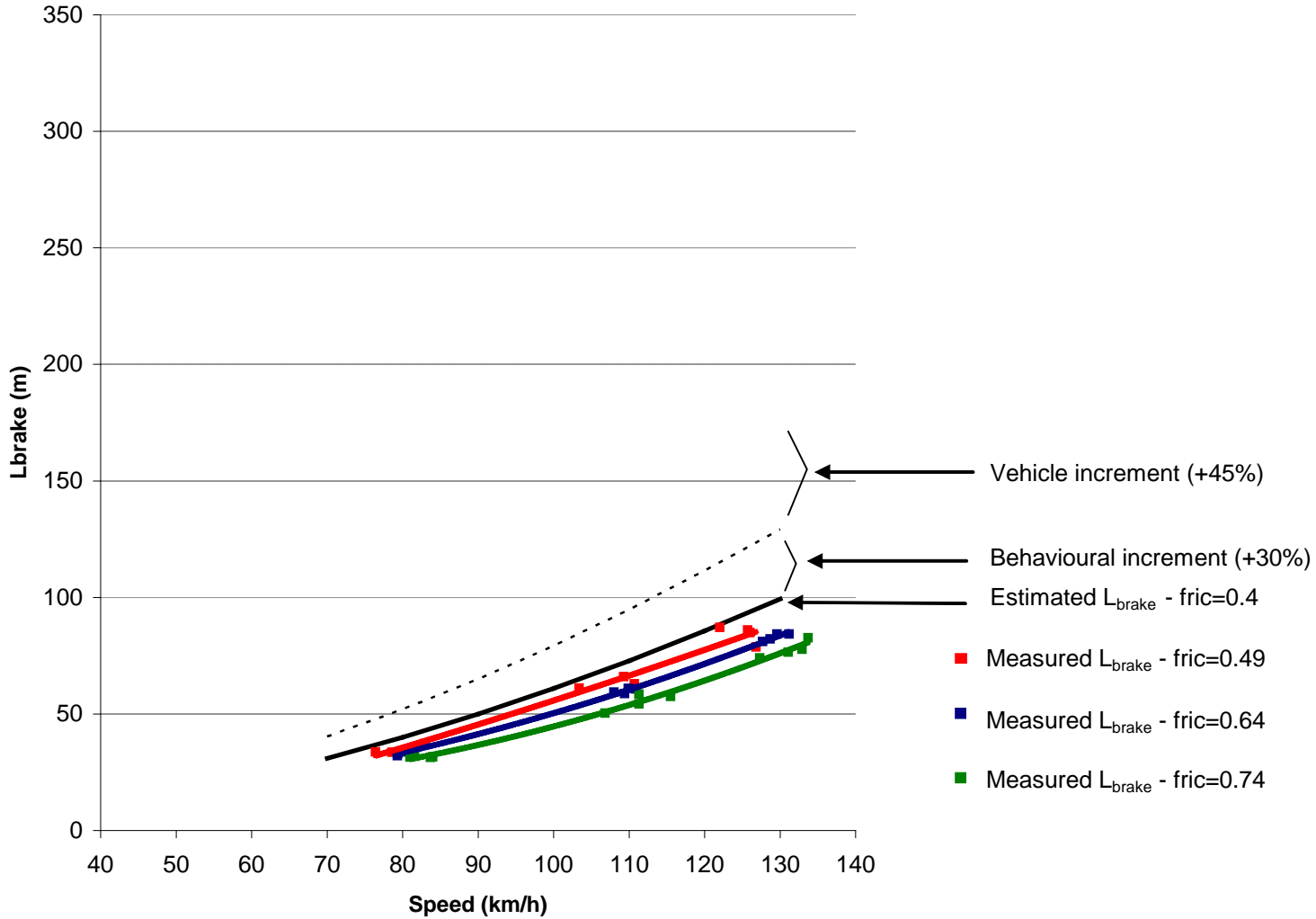
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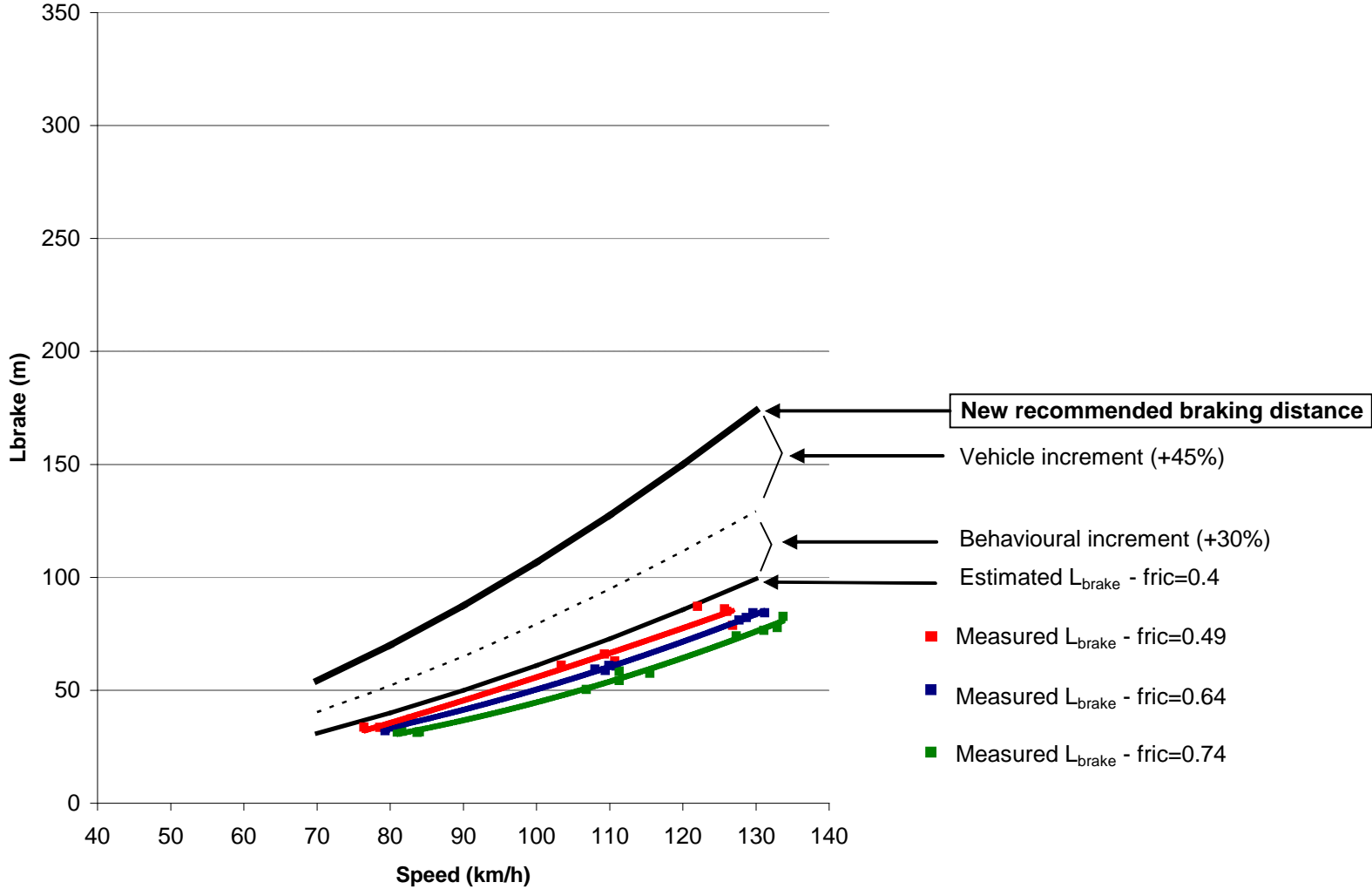
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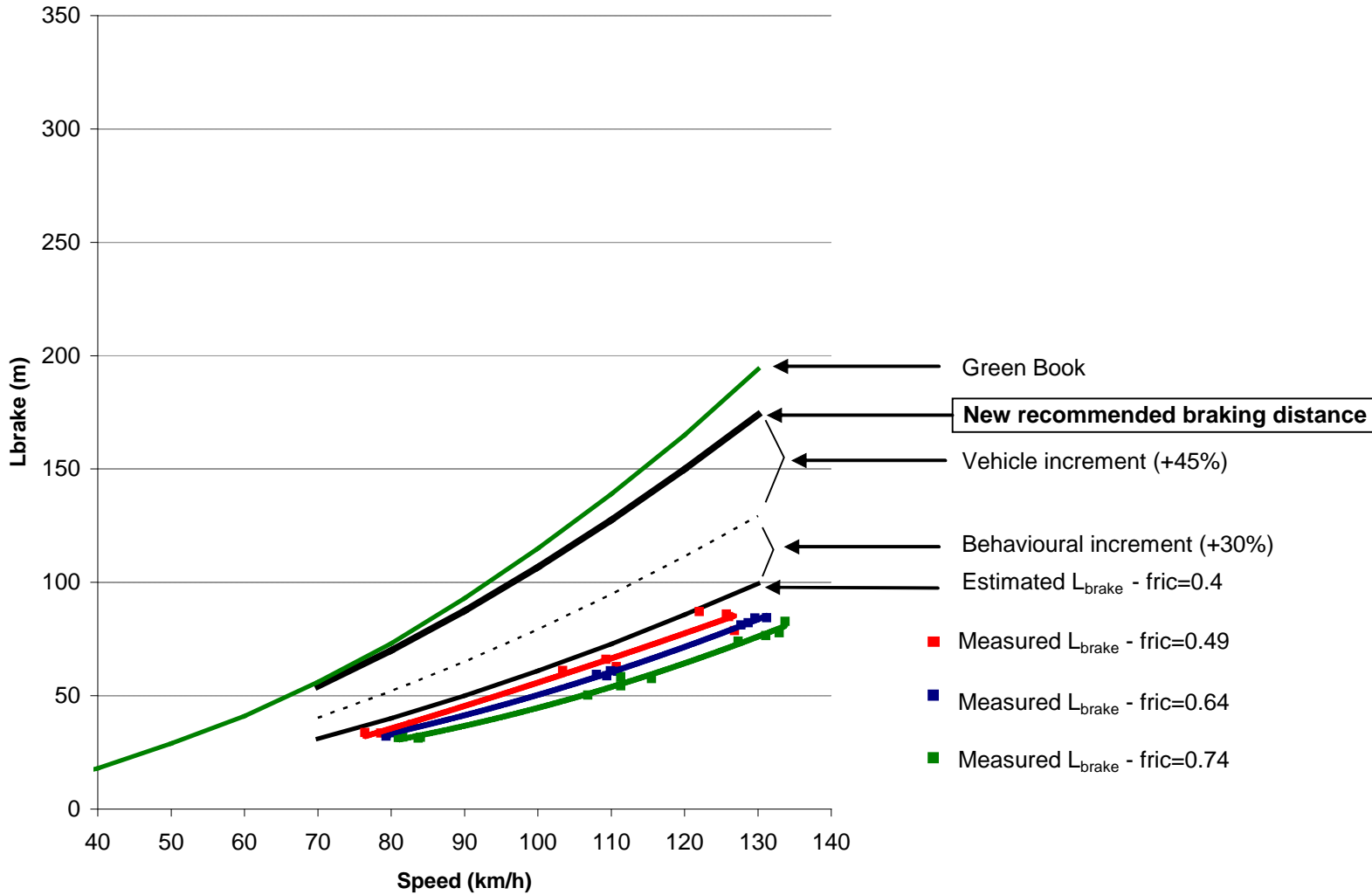
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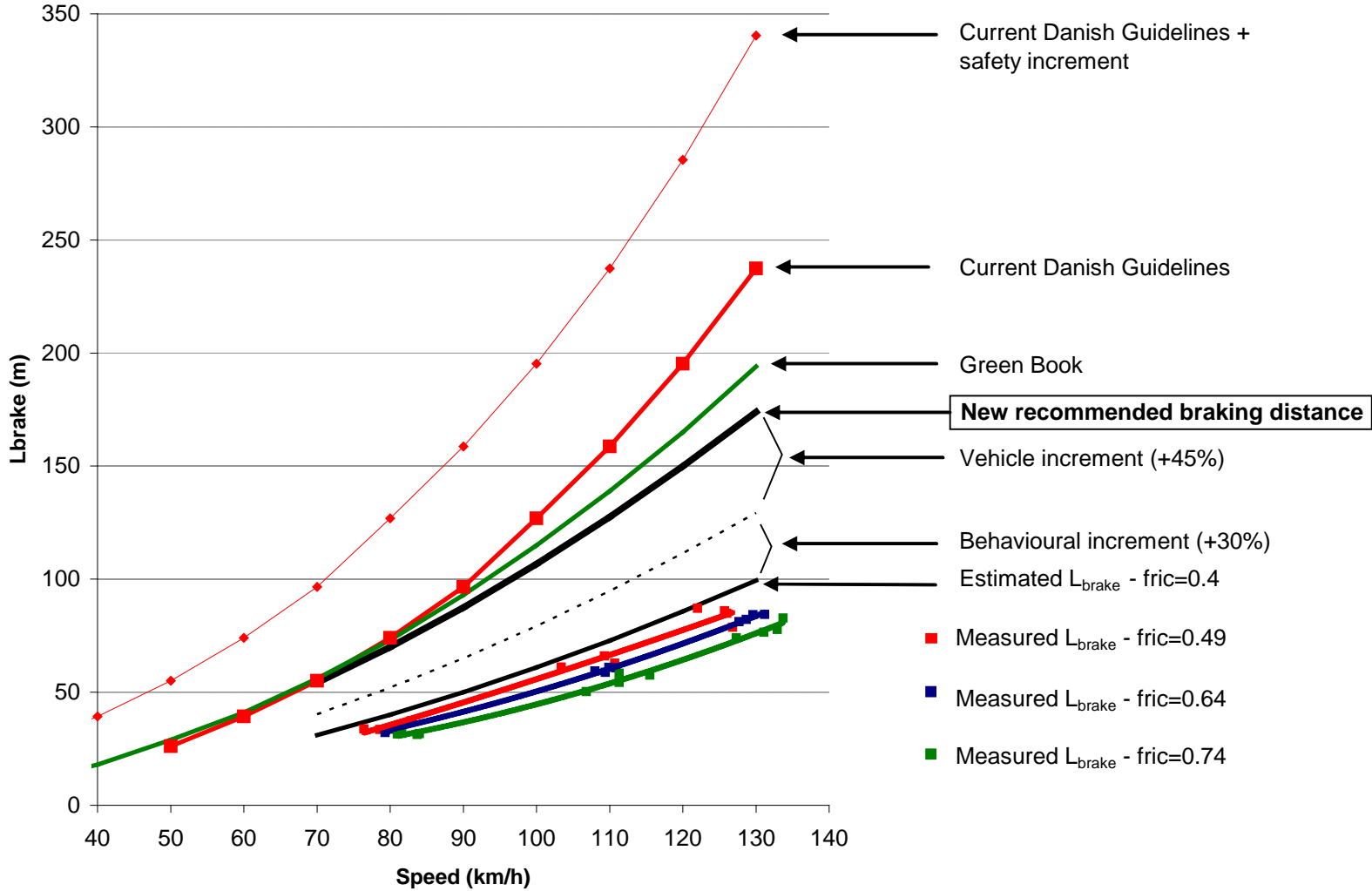


**Braking distance for respectively:  
Measured in programme, Danish Guidelines, Green Book and new recommended values**





**Braking distance for respectively:  
Measured in programme, Danish Guidelines, Green Book and new recommended values**



## Braking distance - international values

