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Comparative Analysis of Motorcycle Braking Performance in Emergency Situation

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Abstract – *This study was conducted to assess motorcycle braking performance in simulated emergency situation. Braking distances and G-force values (peak) during the braking test of 6 distinct underbone motorcycles of 100-150cc were measured and compared based on different test conditions namely type of brake system (disc and drum), method of braking operation (front and rear brakes) and test load (rider only and rider with pillion). The results indicate that type of braking system and method of braking operation significantly influenced braking distance and G-force value. However, test load was found insignificant. The shortest braking distance and highest deceleration rate were 12.48 meters and 8.52 m/s2, respectively. The lowest G-force value (peak) was recorded 0.39 throughout the test. It is to be noted that this study is unique on its own due to certain limitations although some of the methods were adopted from the established international braking test standards. Even though this study is considered fundamental, the findings could provide vital information on the braking performance of underbone motorcycles especially to the motorcycle manufacturers and OEMs, as well as to the relevant authorities (driving institutes and Road Transport Department).*

Keywords: Braking performance, braking distance, underbone motorcycles, low engine capacity motorcycles

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1.0 INTRODUCTION

1.1 Road Fatalities Involving Motorcycle

Motorcyclists are often subjected to a higher risk of road accidents as compared to occupants of passenger cars due to their exposed body regions and little protection offered by motorcycle safety devices during a collision (NHTSA, 2007; DfT, 2010). In term of road accident statistics, motorcycle crashes and casualties have long been a serious concern in Malaysia with the motorcyclists contributed more than half of the total road fatalities each year with an average of 2% increment for the last ten years (Roslan et al., 2011; Muhammad Marizwan & Várhelyi, 2012). From the figures, 'out of control' was revealed to be the second largest group of motorcycle fatalities by type of collision after 'angular or side', which accounted for 21.4% of the total motorcycle fatalities (Muhammad Marizwan & Várhelyi, 2012). The 'out of control' group is described by the Royal Malaysia Police (RMP) as 'single vehicle accident' because motorcycles are often found lying off-road and by themselves (RMP, 2009).

A review of Fatality Analysis Reporting System (FARS) data showed that single vehicle crashes account for about 45% of all motorcycle fatalities in the United States (Shankar, 2001; IIHS, n.d.). Furthermore, the study found that braking and steering maneuvers possibly contribute for almost 25% of the fatalities. Other established studies carried out overseas also supported improper braking as one of the major factors leading to road crashes involving motorcyclists (Hurt et al., 1981; Kasantikul, 2002; ACEM, 2004).

1.2 Motorcycle's Braking Performance and Operation

Braking performance of motor vehicles is undoubtedly one of the most important characteristics that affect vehicle safety. When the brake is applied to stop the vehicle, the vehicle will decrease in its speed to a certain deceleration rate. The deceleration rate generally influenced by the vehicle's braking performance and driver's foot action against brake pedal which is individually unique (John El & Antoine, 2007).

Brake operation on most motorcycles is much more complex than of passenger cars (Teoh, 2009). Most motorcycles have independent controls for the front and rear brake systems, which are typically manually operated as opposed to single control of passenger cars. To synchronise both systems to provide optimum braking performance is thus far very challenging and require skills and experiences.

1.3 Motorcycle Registration

The trend for motorcycle registration in Malaysia is increasing from time to time. By registration, cumulative motorcycle numbers had reached approximately 11.5 million as at September 2014 which represented about half of the country's 24.8 million total registered vehicles (RTD, n.d.). Correspondingly, with respect to classification, engine capacity of less than 150cc dominated, with a percentage exceeding 99% (Hussain et al., 2005; RTD, 2009). This type of motorcycles with low engine capacity are widely used in Malaysia (as well as in other Southeast Asia countries) and commonly known as "underbone motorcycle" (Figure 1).

Figure 1: Example of typical underbone motorcycle (image by the authors)

An underbone motorcycle uses structural tube framing with an overlay of plastic or non-structural body panels and contrasts with monocoque or unibody designs where pressed steel serves both as the vehicle's structure and bodywork. Underbone may also refer to a class of lightweight motorcycles that use the construction type, known colloquially as step-throughs, mopeds or scooters.

1.4 Objective of the Study

At present, to the best knowledge of the author, limited research has been conducted on the braking performance of low engine capacity (underbone) motorcycles. Hence, a need exists to foster a great understanding of the braking performance of underbone motorcycles since proper braking is one of the important manoeuvres for crash avoidance and this type of motorcycles comprises majority of the nation's motorcycle population. This study was conducted with the objective of assessing and comparing braking performance of low engine motorcycles in an emergency situation based on different type of motorcycle brake system, method of braking operation, and test load.

2.0 METHODOLOGY

Braking performance is determined by the shortness of the distance in which a vehicle can stop and maintain its stability at the time of braking. Currently, there are two established brake test standards for motorcycle, which are Federal Motor Vehicle Safety Standard, FMVSS 122 (United States) and United Nations Regulation No. 78 (UN R78). Due to equipment and facility limitations, certain parameters will be adopted from the standards and modified to suit the outdoor test method for this study.

2.1 Motorcycle Description

The motorcycles were selected to represent a cross-section of motorcycle types commonly used in Malaysia. Table 1 shows the make and model of motorcycles that were used in the tests.

Table 1: Test motorcycles

No.	Motorcycle	Engine capacity (cc)	Brakes	
			Front	Rear
1.	2014 Modenas CT100	100	Drum	Drum
2.	2014 Honda EX-5	100	Drum	Drum
3.	2011 Yamaha Ego S	110	Disc	Drum
4.	2005 Yamaha Lagenda	115	Disc	Drum
5.	2014 Honda Future	125	Disc	Drum
6.	2012 Yamaha LC	135	Disc	Disc

2.2 Test Conditions and Procedure

Testing was performed with six underbone motorcycles (100 – 150cc). The motorcycles were accelerated up to 50 km/h (≈48 km/h or 30 mph in UN R78) and maintained until braking was initiated. A successful braking manoeuvre is defined by the rider's capability to stay in their lane (direction) and maintain steering control during the braking manoeuvre. The maximum stopping distance (from start of brake to full stop) and G-force value experienced during each run were measured and recorded.

The test site was a straight, flat and level road (dry surface asphalt) with adequate width and secured traffic cones for safety purpose. Different type of brake system combinations were considered for the test which are: disc + disc, disc + drum, and drum + drum. As for method of braking operation, only rear brake (foot pedal activation), and both front and rear brakes (hand lever and foot pedal activations) operations were used. Activation of front brake only was not considered due to the potential risk to both occupant and motorcycle.

Prior to the actual braking test, several training sessions and runs of pilot test were carried out to familiarise the test rider with the testing procedure to achieve consistent, tolerable results and to assess feasibility, time, cost and adverse events for study design improvement. One test is defined as a test with a configuration of one brake operation, one test load and one type of brake system. For instance, test number 1 required both brake operation (front and rear) at 50 km/h test speed with disc-disc brake system.

Each test was undertaken twice (2 runs) to obtain the average result which totalled up to 48 runs for the braking test. Normal video and high speed cameras (at min. of 1,000 frames per second, fps) were used to document the test event for post analysis. Figure 2 illustrates the setup for the braking test.

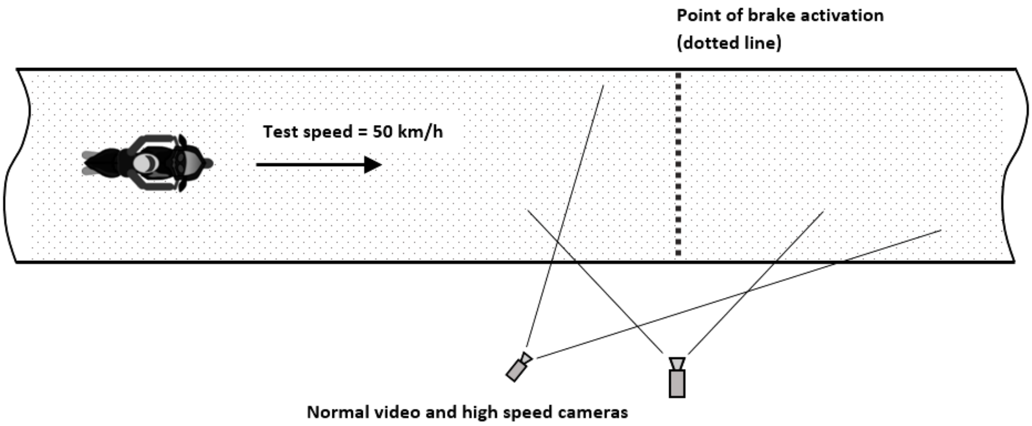

Figure 2: Motorcycle Braking Test Setup

A Racelogic Performance Box (also known as VBox) was used as a data acquisition system (DAS) to measure the speed and peak G-force value experienced during braking. The capabilities of the DAS allow it to measure velocity at an accuracy of 0.1 km/h with an update rate, resolution and latency of 10 Hz, 0.01 km/h and <160 ms, respectively. It also has a brake test resolution and accuracy of 0.01 second.

2.3 Data Analysis

Measured test results data (braking distance and G-force value experienced during braking with respect to predetermined dependent variables) and other test information for each test run were entered and evaluated for analysis by using Statistical Package for Social Science (SPSS) software version 17.0.0. Nonparametric Tests were carried out to determine the normal distribution of the measured braking distances. One-way ANOVA was then conducted to compare means of the measured data with the type of brake system, method of braking operation and test load. Independent T-Test analyses were also done to evaluate the significant differences in means of braking distances and recorded G-values for each test run.

3.0 RESULTS AND DISCUSSION

The tests (48 runs in total) were conducted according to the predetermined test conditions to obtain the desired results (Table 2). From the overall braking tests, shortest braking distance and highest deceleration rate were measured and recorded for test number 13 with 12.48 meters and 8.52 m/s^2, respectively. The values were recorded for test condition with both method of braking operation (front and rear brakes) on a motorcycle equipped with disc and drum for front and rear, respectively. On the other hand, longest braking distance of 30.60 meters and lowest deceleration rate of 3.55 m/s^2 were recorded for test number 19 of test condition with single brake operation on rear drum brake. Both tests (number 13 and 19) were performed with the single rider without pillion configuration.

The G-force values recorded by the DAS during braking were peak values. The value is termed as proper acceleration experienced by an object (in this case, the motorcycle with rider/pillion) that is due to the vector sum of non-gravitational forces acting on the object’s freedom to move. The results show that the lowest (good) and the highest (not good) G-force values recorded were 0.39 and 0.86, respectively.

Preliminary analysis of the data for the type of brake system revealed that the total mean braking distance and G-force values equal to 22.31 meters and 0.56, correspondingly. Nevertheless, the mean distances and G-force values were different for each of the five types of brake system configuration (Table 3). Thus, there are significant differences in the recorded values of braking distances and G-force values from a different type of brake system configuration. The lowest means distances and G-force values equal to 15.04 meters and 0.41, were recorded for disc and drum (front and rear brakes) and disc only (rear brake) brake system configurations, respectively The One-way ANOVA (analysis of variance) analyses yielded significant results with F-ratios of 22.51 and 30.55 which were significant at the 0.05 level (p = 0.00) which implies that type of brake system configuration as defined in this study influenced the braking distance and the G-force value.

Means analyses performed for a method of braking operation showed average braking distance of 22.31 meters and G-force value of 0.56 (Table 3). The lowest means were 16.84 meters (SD: 3.56) (both – front and rear) for braking distance and 0.42 (SD: 0.02) (rear only) for G-force value. Independent T-Tests results shown in Table 4 reveal that there are significant differences between the mean of both braking operation (front and rear brakes) and the mean of single rear brake operation. The resulting level of significances is 0.00 for both variables. Thus, there are significant differences between the means of the two methods of braking operation – front and rear, and rear only. Findings from this study show that front and rear method of braking operation provided shorter braking distance than rear only method. However, on the contrary, the G-force value recorded was lower for a rear only method of braking operation as compared to both front and rear.

Further analysis was done for test load. Independent T-Tests results show that the mean of both braking operation (front and rear brakes) and the mean of single rear brake operation are not significantly different (Table 5). This finding suggested that the test load as defined in this study did not influence both the braking distance and the G-force value.

Table 2: Test results

Test no.	Motorcycle	Engine capacity (cc)	Method of braking operation	Type of brake system	Test load	Brake distance (m)*	Deceleration rate (m/s^2)*	Recorded G-force (peak)*
1	Modenas CT100	100	Both (Fr + Rr)	Drum + Drum	Rider only	20.25	-5.70	0.54
2					Rider + Pillion	24.43	-4.66	0.50
3			Rear only	Drum	Rider only	26.10	-4.44	0.40
4					Rider + Pillion	26.00	-4.25	0.41
5	Honda EX-5	100	Both (Fr + Rr)	Drum + Drum	Rider only	14.31	-7.07	0.63
6					Rider + Pillion	16.00	-7.06	0.62
7			Rear only	Drum	Rider only	25.10	-3.95	0.41
8					Rider + Pillion	26.90	-3.95	0.44
9	Yamaha Ego S	110	Both (Fr + Rr)	Disc + Drum	Rider only	14.13	-8.47	**0.86**
10					Rider + Pillion	18.55	-6.11	0.67
11			Rear only	Drum	Rider only	29.30	-3.80	0.40
12					Rider + Pillion	28.82	-4.05	0.43
13	Yamaha Lagenda	115	Both (Fr + Rr)	Disc + Drum	Rider only	**12.48**	**-8.52**	0.81
14					Rider + Pillion	14.63	-7.58	0.74
15			Rear only	Drum	Rider only	28.69	-3.81	0.41
16					Rider + Pillion	26.45	-3.91	0.45
17	Honda Future	125	Both (Fr + Rr)	Disc + Drum	Rider only	16.49	-6.70	0.84
18					Rider + Pillion	16.54	-6.55	0.83
19			Rear only	Drum	Rider only	**30.60**	**-3.55**	0.44
20					Rider + Pillion	30.24	-3.85	0.41
21	Yamaha LC	135	Both (Fr + Rr)	Disc + Disc	Rider only	13.36	-8.36	0.78
22					Rider + Pillion	20.89	-5.59	0.71
23			Rear only	Disc	Rider only	28.86	-4.13	**0.39**
24					Rider + Pillion	26.29	-4.22	0.42

Note: **Average values of two runs for each test; Fr = Front braking via hand lever application; Rr = Rear braking via foot pedal activation*

Table 3: Braking distance and G-force by type of brake system and method of braking operation (Means analysis)

	Braking distance			G-force value		
	Mean	**N (test)**	**Std. deviation**	**Mean**	**N (test)**	**Std. deviation**
Type of brake system						
Disc	27.5750	2	1.81726	0.4050	2	0.02121
Drum	27.8200	10	1.94149	0.4200	10	0.01826
Disc + Disc	17.1250	2	5.32451	0.7450	2	0.04950
Disc + Drum	15.0350	4	1.92129	0.8050	4	0.04509
Drum + Drum	17.9450	6	3.98208	0.6367	6	0.12596
Total	22.3087	24	6.23722	0.5642	24	0.17179
Method of braking operation						
Both (front + rear)	16.8383	12	3.55771	0.7108	12	0.12011
Rear only	27.7792	12	1.84211	0.4175	12	0.01865
Total	22.3087	24	6.23722	0.5642	24	0.17179

Table 4: Characteristics between both (front and rear) and rear only method of braking operation

Variables	**Method of braking operation**		**Mean diff. (95% CI)**	**t-statistic (df)**	***P* value**
	Both (Front + Rear) (N = 12) Mean (SD)	**Rear only (N = 12) Mean (SD)**			
Braking distance	16.84 (3.56)	27.78 (1.84)	-10.94 (-13.34, -8.54)	-9.46 (22)	0.00
G-force value	0.71 (0.12)	0.42 (0.02)	0.29 (0.22, 0.37)	8.36 (22)	0.00

Table 5: Characteristics between lightly loaded (rider only) and loaded (rider with pillion) test

Variables	**Test load**		**Mean diff. (95% CI)**	**t-statistic (df)**	***P* value**
	Lightly loaded (Rider only) (N = 12) Mean (SD)	**Loaded (rider and pillion) (N = 12) Mean (SD)**			
Braking distance	21.64 (7.16)	22.98 (5.40)	-1.34 (-6.71, 4.03)	-0.52 (22)	0.61
G-force value	0.58 (0.20)	0.55 (0.15)	0.02 (-0.13, 0.17)	0.33 (22)	0.75

4.0 CONCLUSION

The study was conducted to compare braking performance of widely used low capacity engine (underbone) motorcycles in Malaysia with the normal braking system in a simulated emergency situation. The results show that type of braking system configuration and method of braking operation significantly influenced braking distance and G-value. However, test load showed insignificant results. Also, the results show that method of braking operation for both front and rear provided better brake performance, i.e. shortest braking distance. The study design allowed for differences in motorcycle engine capacity as well as tyre dimension. It is to be noted that the study is fundamental that it did not consider tyre thread pattern and compound. Furthermore, it did not consider the location of data acquisition placement at the centre of gravity which might affect the resulted G-value.

It is suggested for similar study to be done to evaluate the effect of advanced braking systems such as Antilock Braking System (ABS) and Automated Emergency Braking (AEB) on the braking performance of the motorcycles. Such technologies have proven effective in improving the braking performance and safety of passenger cars and large engine capacity motorcycles. Hence their effectiveness on low engine capacity motorcycles are still uncertain. This fundamental study could provide vital information on motorcycle braking performance to the relevant authorities and motorcycle manufacturers for the improvement of driving education curriculum and motorcycle safety feature, respectively.

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