NBSIR 78-1467

Influence of Some Wetting Parameters on Bicycle Braking Performance

Leonard Mordfin

Institute for Materials Research
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Final Report

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INFLUENCE OF SOME WETTING PARAMETERS ON BICYCLE BRAKING PERFORMANCE

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ABSTRACT

One approach toward evaluating the braking capability of a bicycle in wet weather involves riding tests in which the stopping distance of the bicycle with wet brakes is measured from a preselected initial speed. The results of some domestic and foreign riding tests of this kind are reviewed. It is found that the amount of water available at the brake surfaces, above some small minimum, is not significant. There are some sparse data that suggest that the manner of wetting (e.g., hose, trough or rain) may affect the test results but this evidence is questionable due to the uncharacterized influences of other test parameters. Recommendations for additional tests are given.

This report is an addendum to NBSIR 78-1416.

Key Words: Bicycles; braking, bicycle; braking, wet; consumer product safety; measurements, bicycle braking; riding tests; safety, bicycle; standards, bicycle safety; test methods, bicycle; wet braking.

1. INTRODUCTION

The U.S. Consumer Product Safety Commission (CPSC) and the International Organization for Standardization (ISO) are interested in methods for evaluating the braking performances of bicycles in wet weather. The approach which is presently under consideration involves riding tests, under simulated wet-weather conditions, in which the bicycle is braked to a halt from a preselected speed and the measured stopping distance is used as the indicator of braking performance. Some aspects of this approach were examined in NBSIR 78-1416 [1][1] with regard to their relevance to a possible standard test method for wet-braking performance.

One of the findings of the earlier report was that the braking performance of a caliper-braked bicycle depends quite heavily on whether the braking surfaces are wet or dry, but that the specific means by which the surfaces are wetted is immaterial. Neither the film thickness of the water (exceeding some relatively small minimum) nor its manner of application was found to exert a significant influence on stopping distance. This finding -- which has obvious implications on the amount of detail needed to properly specify a standard test method -- was deduced from theoretical considerations and from the results of various laboratory tests.

In this report the results of several series of actual riding tests under wet conditions are reviewed in order to test the validity of the

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[1]Numerals in brackets denote the similarly numbered references listed in Section 5 of this report.

earlier finding. As such, this report may properly be considered an addendum to NBSIR 78-1416. The reader is advised to consult that report for much of the detail that has been omitted here in the interest of brevity.

This report was prepared for the NBS Office of Consumer Product Safety at the request of CPSC.

2. HOSE-WETTING AND RAINY-WEATHER TESTS

One of the experimental methods which has been used for intentional wetting of bicycle brakes employs small-diameter plastic tubing to direct a flow of water to the brake pads and the wheel rims. The water supply is carried onboard the bicycle and four tubes emit a flow of 4 ml/s (0.14 fl oz/s)[2] to each of the four caliper brake pads for a period of time sufficient to ensure complete wetting prior to braking.

A series of tests was performed by bicycle manufacturers, under ISO auspices, to examine the effect of the interval (expressed in distance traveled) between the cessation of flow and the initiation of braking [2-8]. The intervals examined were 0, 5, 15, and 30 m (0, 16, 49 and 98 ft). In addition, comparison tests were performed (1) with dry brakes, (2) with water flow allowed to continue throughout the braking process, and (3) in actual rainy weather without added water. Each bicycle was braked from an initial speed of 16 km/h (10 mph) and, except as noted hereafter, the total mass of each bicycle, its rider, onboard equipment and ballast was 90 kg (198 lb). The test results, in terms of measured stopping distances, are given in Table 1 where each result is the average of five test runs. Although all of the seven bicycles listed were different from each other, and were each tested by a different organization, they were all fitted with nominally identical wheels having chrome-plated-steel rims and nominally identical brakes.

The results show that the stopping distances under wet conditions are considerably greater than they are under dry conditions, which is not surprising. Of greater interest, at this point, is the fact that the interval between water cutoff and brake initiation did not exhibit any consistent, significant effect on stopping distance. This tends to support the thesis that the amount of water at the brake surfaces is not an important parameter.

The test results in Table 1 which were obtained in actual rain are somewhat more difficult to interpret. While the stopping distances in rain were not consistently greater or smaller than the stopping distances with simulated wetting, the differences between the two are sufficiently great, in some cases, to justify further examination.

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[2]About 1 cup per minute.

Table 2 lists the stopping distances in rain as a function of the severity of the rainfall, as described by the investigators, and presents the ratios of the rainy-weather stopping distances to the dry-weather stopping distances. It may be seen that there is no correlation between rainfall severity and the stopping-distance ratio. This supports the contention that the amount of water at the brake surfaces is not relevant. How, then, can the inconsistent differences in observed braking performance between rainy weather and simulated wet-weather conditions be explained?

To answer this question it must be recognized that the simulated wet-weather tests and the dry tests were performed in dry weather and were all carried out, by each testing organization, at one time (i.e., in a single day or, perhaps, in two successive days). In order to conduct the rainy-weather tests, on the other hand, it was necessary to wait for the appropriate weather conditions to prevail. This may have entailed delays of several weeks and, in some cases, months [2,6]. It is not unreasonable, therefore, to surmise that the two sets of tests involved different rider reaction times -- and perhaps even different riders -- as well as different pavement conditions, wind speeds, ambient temperatures, etc., all of which influence stopping distances [1,9]. In short, it is not inconsistent to conclude that the differences in the stopping distances between the rainy-weather and the simulated wet-weather conditions may not, in fact, reflect effects of the different means of wetting.

An additional set of tests conducted by one of the testing organizations is of particular interest [7]. The brakes on Bike No. 206 were hose-wetted as in the previous tests and a braking test run was performed with zero interval between the cessation of flow and the initiation of braking. Then, nineteen additional braking test runs were carried out at 40-s intervals with no further wetting. The stopping distances were measured for all twenty runs and then the entire series was repeated. Table 3 shows, in abbreviated form, the manner in which the stopping distances varied as the number of test runs increased. The data show that more than five braking test runs had to be performed before any sensible braking recovery was observed, and that full recovery of dry braking performance was not obtained even after twenty runs. This is consistent with the results of laboratory tests cited previously [1], and supports the thesis that very little water need actually be present at the brake surfaces in order to destroy dry braking capability.

3. TROUGH-WETTING TESTS

An effective method of intentionally wetting the brake surfaces, which is simpler than the hose method, involves riding the bicycle through a water trough before it is accelerated to the desired test speed and then braked. The depth of water in the trough is sufficient to cover the wheel rims. This wetting method was used in order to investigate the effects of relatively long intervals (i.e., 50 and 100 m (164 and 328 ft)) between wetting and braking [10-13].

The test results are summarized in Table 4, where each stopping-distance entry represents the average of five test runs, except the 50-m data for Bike No. 212, which represents the average of three test runs. These results extend those given in Table 1 and show, once more, that the interval between wetting and braking does not appear to exert any consistent, significant influence on braking performance.

Unfortunately, no tests were conducted to specifically compare braking performances with hose wetting and with trough wetting. It appears from information available [5,11] that Bike No. 204 (Table 1) and Bike No. 212A (Table 4) were probably identical, at least nominally, and if this is indeed the case, then the data suggest that stopping distances were substantially shorter in the tough-wetting tests -- in which the intervals between wetting and braking were relatively longer -- than stopping distances in the hose-wetting tests. However, these two sets of tests were conducted more than seven months apart and, as mentioned earlier, differences in rider reaction times and environmental factors tend to render the validity of such comparisons questionable.

In an earlier report [1] it was pointed out that it is quite difficult to assess the systematic errors involved in stopping-distance tests because of the absence of test data by different laboratories on the same bicycle. To this shortcoming might be added the need implied by the above discussion, i.e., a need for systematic tests by a single laboratory on a single bicycle at widely disparate times.

4. CONCLUDING REMARKS

The results of several series of riding tests, which were conducted in order to investigate the wet-braking performances of caliper-braked bicycles, were reviewed. It was found that:

1. Distance intervals up to at least 100 m (328 ft), between the wetting and the actuation of bicycle brakes, exert no consistent, significant influence on stopping distance.
2. The severity of a rainfall exerts no consistent, significant effect on stopping distance provided that the duration of the rainfall and the distance traveled have been sufficient to wet the wheel rims.
3. Once caliper brakes become wet, dry braking performance is not recovered even after a substantial number of braking sequences.
4. There is some evidence which suggests that the manner in which the brakes are wetted may influence braking performance. However, the paucity of this evidence renders it inconclusive.

In short, there is no rational basis at this time to refute the contention that the wet-braking performance of a bicycle is independent of the means by which the brakes are wetted or the amount of water used (beyond some very small minimum).

In order to properly characterize the uncertainties involved in riding tests to measure wet-braking performance, it is recommended that nominally identical tests be performed by different laboratories on the same bicycles, and by individual laboratories at different times.

5. REFERENCES

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[2] Proprietary data.

[3] Anon, Braking Tests Dry, and Braking Tests Wet (Wasserzufuhr 4 ml/s), Weinmann, Feb. 7, 1977.

[4] Edinger, K., private communication.

[5] Proprietary data.

[6] Proprietary data.

[7] Okajima, R., Braking Test, Mar. 4, 1977.

[8] Proprietary data.

[9] Mordfin, L., The CPSC Road Test of Bicycle Braking Performance -- Kinetic and Error Analyses, NBSIR 75-786 (Oct. 1975).

[10] Proprietary data.

[11] Proprietary data.

[12] Proprietary data.

[13] Cooper, T. Z., Wet Brake Test Report, CPSC ref. 540644, Nov. 4, 1977.

Table 1. Delayed Braking Following Hose Wetting[a]

Bike No.[c]	Average stopping distance							
		Wet						
		Water cutoff distance before braking, m[b]						
	Dry	None[d]	0	5	15	30	Rain	Ref.
	m (ft)	m (ft)	m (ft)	m (ft)	m (ft)	m (ft)	m (ft)	
201	2.39 (7.84)	12.1 (39.7)	- -	12.9 (42.3)	10.8 (35.4)	11.9 (39.0)	8.4 (28.)	2
202	2.53 (8.30)	11.41 (37.43)	12.55 (41.18)	12.13 (39.80)	12.58 (41.27)	12.30 (40.35)	- -	3
203	2.67 (8.76)	- -	10.97 (35.99)	10.75 (35.27)	9.75 (31.99)	10.5 (34.4)	12.25 (40.19)	4
204	2.39 (7.84)	12.98 (42.59)	12.76 (41.86)	13.37 (43.86)	12.51 (41.04)	12.23 (40.12)	8.43 (27.7)	5
205[e]	1.8 (5.9)	- -	- -	11.9 (39.0)	12.5 (41.0)	12.5 (41.0)	10.5 (34.4)	6
206	1.88 (6.17)	12.93 (42.42)	13.42 (44.03)	13.91 (45.64)	13.74 (45.08)	13.34 (43.77)	12.21 (40.06)	7
207[f]	2.2 (7.2)	13.7 (44.9)	13.7 (44.9)	13.5 (44.3)	13.5 (44.3)	12.8 (42.0)	13.5 (44.3)	8
Avg.	2.27 (7.45)	12.62 (41.40)	12.68 (41.60)	12.64 (41.47)	12.20 (40.03)	12.22 (40.09)	11.38 (37.34)	

(a) The special conditions under which these tests were run are described in Section 2.

(b) Refers to distance the bicycle was allowed to travel between water cutoff and initial application of brakes.

(c) Numbers assigned by author.

(d) Water flow allowed to continue throughout braking process.

(e) Tested with total mass of 101.2 kg (223.1 lb).

(f) Tested with total mass of 93.0 kg (205.0 lb).

Table 2. Rainy Weather Tests

Bike No.[a]	Rainfall	Avg. stopping distance m	(ft)	No. of runs	Ratio, rain/dry[b]
201	very lt shower	8.4	(28)	4	3.5
203	not specified	12.25	(40.19)	5	4.5
204	heavy rain	8.80	(28.9)	1	3.7
	medium rain	8.86	(29.1)	3	3.7
	medium lt rain	8.52	(28.0)	1	3.6
	light rain	8.37	(27.5)	1	3.5
	drizzle	8.63	(28.3)	1	3.6
	light drizzle	7.91	(26.0)	2	3.3
	very lt drizzle	8.07	(26.5)	1	3.4
205	2.75 in in 48 h (avg. 1.46 mm/h)	10.5	(34.4)	5	5.7
206	heavy rain	12.21	(40.06)	5	6.5
207	0.88 mm/h	13.5	(44.3)	5	6.1

(a) See Table 1.
(b) Ratio of stopping distance in rain to stopping distance under dry conditions.

Table 3. Braking Recovery Tests [7]

Run No.	Average stopping distance	
	m	(ft)
1	13.30	(43.64)
5	13.14	(43.11)
10	10.24	(33.60)
15	5.60	(18.37)
20	4.29	(14.07)

Table 4. Delayed Braking Following Trough Wetting[a]

Bike No.[d]	Initial speed	Payload[e]	Average stopping distance[b]			Ref.
				Wet		
				Trough-to-test distance, m[c]		
			Dry	50	100	
	km/h (mph)	kg (lb)	m (ft)	m (ft)	m (ft)	
208	16 (10)	84.4 (186)	2.2 (7.1)	21.3 (69.9)	20.9 (68.7)	10
209	16 (10)	74.4 (164)	2.2 (7.2)	21.5 (70.4)	22.8 (74.7)	10
210	16 (10)	71.2 (157)	2.0 (6.6)	15.1 (49.7)	14.8 (48.7)	10
211	16 (10)	89.4 (197)	2.3 (7.5)	24.5 (80.5)	24.4 (80.1)	10
212A	16 (10)	77.9 (172)	-	7.43 (24.4)	8.62 (28.3)	11
212B	16 (10)	77.9 (172)	-	5.91 (19.4)	3.45 (11.3)	11
212C	16 (10)	77.9 (172)	-	7.77 (25.5)	9.00 (29.5)	12
212D	16 (10)	77.9 (172)	-	10.03 (32.9)	9.64 (31.6)	12
212E	16 (10)	77.9 (172)	-	7.11 (23.3)	6.45 (21.2)	12
212F	16 (10)	77.9 (172)	-	4.23 (13.9)	6.01 (19.7)	12
213A	24 (15)	83.4 (184)	2.1 (6.8)	22.6 (74.1)	25.0 (82.0)	13
213B	24 (15)	83.4 (184)	2.9 (9.4)	17.1 (56.1)	14.5 (47.5)	13
214A	24 (15)	83.4 (184)	3.2 (10.6)	31.5 (103.2)	35.7 (117.2)	13
214B	24 (15)	83.4 (184)	2.8 (9.3)	15.4 (50.4)	15.1 (49.6)	13

- continued

Table 4. Continued

(a) The special conditions under which these tests were run are described in Section 3.

(b) The stopping distances listed for Bikes 213 and 214 were corrected for payloads exceeding 70 kg (154 lb) at the rate of 0.3 m/4.5 kg (1 ft/10 lb).

(c) Distance between exit from trough and initiation of braking.

(d) Numbers assigned by author. Postscript letters designate different brake pads on the same bicycle.

(e) Values listed for payload represent rider mass for Bikes 208 thru 211, and rider plus onboard instrumentation mass for Bikes 212 thru 214.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

One approach toward evaluating the braking capability of a bicycle in wet weather involves riding tests in which the stopping distance of the bicycle with wet brakes is measured from a preselected initial speed. The results of some domestic and foreign riding tests of this kind are reviewed. It is found that the amount of water available at the brake surfaces, above some small minimum, is not significant. There are some sparse data that suggest that the manner of wetting (e.g., hose, trough or rain) may affect the test results but this evidence is questionable due to the uncharacterized influences of other test parameters. Recommendations for additional tests are given.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Bicycles; braking, bicycle; braking, wet; consumer product safety; measurements, bicycle braking; riding tests; safety, bicycle; standards, bicycle safety; test methods, bicycle; wet braking.

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