ABS PERFORMANCE ON GRAVEL ROADS

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ABSTRACT

Anti-lock brake systems (ABS) have become common on most passenger cars and light trucks in North America yet ABS braking performance can vary widely between vehicle makes and on different road surfaces.

The present ABS designs restrict wheel lockup which may be inefficient for gravel and snow covered roads where locked wheels can produce much higher deceleration rates. Based on the growing number of public complaints of poor braking on gravel roads, tests were conducted to determine the performance variation between vehicles with different ABS controllers and between the same vehicle with and without its ABS activated. Significant deceleration differences were noted.

INTRODUCTION

The approximate equal kilometers of paved to unpaved roads in the western USA and Canada suggests that ABS design must include road surface type detection and 'best method' braking algorithms for different surfaces.

This paper presents test data on six ABS equipped vehicles and one non ABS equipped vehicle while braking on gravel roads with the ABS activated and deactivated. ABS tests were also run on dry pavement for each vehicle to establish a base line deceleration value.

TEST CONDITIONS AND PROCEDURES

Test Road Surfaces

A well traveled, bituminous asphalt surfaced road was chosen for the base line brake tests. The road had a -1.5% to -1.8% grade in the test direction and was in good repair. An adjacent, recently graded, loose gravel road was chosen for the comparison brake tests. It also had a grade of -1.5% to -1.8% in the test direction. Samples were taken of the gravel surface for sieve analysis. The analysis was conducted by the Geotechnical and Materials Branch of the BC Ministry of Transportation and Highways according to ASTM C136, C117. The grain size distribution chart is shown in Appendix A. The weather was dry, calm, 15° C with partial cloud cover.

Test Vehicles

The seven vehicles tested were:
- 1993 GMC Suburban 4x2, automatic, RWD
- 1995 GMC Suburban 4x4, automatic, tested in 2WD
- 1994 GMC Yukon 4x4, automatic, tested in 2WD
- 1994 Ford F150 XL 4x4, standard, tested in 2WD
- 1993 Ford Explorer 4x4, automatic, tested in 2WD
- 1996 Chevrolet Cavalier, automatic, FWD
- 1991 Ford Crown Victoria (not ABS equipped), automatic, RWD

All vehicles were inspected before testing and were in good mechanical repair. Further vehicle and tire information is contained in Appendix B, Tables 1 and 2.

Instrumentation

G-Analyst - This commercially available tri-axial accelerometer was used in each vehicle to record deceleration values. The data was captured at a sample rate of 10 Hz and then downloaded to a computer for graphing. The resolution, measured in units of gravity (g), is ±0.01 g. The accelerometer was placed at floor level close to the vehicle's centre of gravity and pitch and roll settings were set to zero g/g to obtained unaltered values.

Vericom VC2000PC - This is also a commercially available accelerometer which measures in one plane, samples at 100 Hz and has a resolution is ±0.001 g. It has a pre-set factory calibration for vehicle pitch. It was used in conjunction with the g-analyst to capture ABS modulations near 10 Hz which may not be captured by the G-analyst.

Kustom Falcon Radar - This hand held unit's calibration was checked before testing and was operated by trained police officers to determine the test vehicle speed at braking. The unit has a resolution of ±1 km/h.

Bumper Gun - A brake light activated bumper gun was used to mark the point of first brake application. The distance from the shot mark to the stopped vehicle provided the total stopping distance.

Test Procedures

Each test vehicle was inspected, documented and

weighed. The instrumentation was installed and calibrated as per the manufacturer's instructions. The Vericom was set to 'auto start' which begins recording once a 0.2 g threshold is exceeded.

Three test conditions of high effort brake application, in straight line braking from 50 km/h, were run for each vehicle: 1) on dry pavement; 2) on gravel with ABS activated and 3) on gravel with ABS deactivated. A minimum of three tests were run under each condition, more if there was a discrepancy greater than 10% between the measured values. A driver and observer of approximately equal weight were onboard for every test. G-analyst and Vericom data were down-loaded and radar speed and total stopping distance recorded. Several brake tests were run at higher speeds to observe vehicle rotation on the gravel surface.

TEST RESULTS

Bumper Gun

Appendix C, Table 3, contains the tabular results derived from the bumper gun measurements. Averages of the speed and stopping distance of at least three runs were taken for each test condition. Test runs at higher speeds to observe directional control were not included in the averages. The deceleration value, a, was calculated from equation (1.):

$$a = S^2/(254 \times d) \qquad (1.)$$

where: a is deceleration in g
S is speed in km/h
d is stopping distance in meters

The slope influence (-1.5% to -1.8%) was corrected to a level surface by adding 0.02 g to each test result.

A moderate to significant improvement in braking without ABS was observed. Percent differences between ABS on and off on the gravel surface ranged from 10% for the Ford F150 (rear wheel only ABS) to 38% for the Chevrolet Cavalier (all wheel ABS). The second largest difference (33%) was for the 1993 GMC Suburban.

In no test did the ABS provide equal or higher deceleration values. In no test was there appreciable vehicle rotation with the ABS deactivated, even at speeds up to 77 km/h.

G-analyst and Vericom

Table 4 in Appendix C summarizes the averaged values from the G-analyst and Vericom accelerometers for each test surface condition. The first and last 0.5 second of each braking event were ignored in calculating the G-analyst average. This gives an average maximum deceleration by eliminating the initial ramp-up and final ramp-down values. The G-analyst values were also corrected for road gradient. The Vericom's internal software provided an average deceleration for each test run. These were then averaged for each of the three test conditions.

Variation between the G-analyst and Vericom data sets is small, typically less than 5% for the gravel test values.

A percent difference in braking deceleration was also calculated for the gravel surface condition with the ABS on and off. As with the bumper gun results, decelerations improved in each case with the ABS deactivated.

Appendix D contains G-analyst plots of braking on the gravel surface with and without ABS for test vehicles 1 to 6. In each case, the plots clearly show a significant difference in braking between the ABS on and off. Test vehicle 4 shows the least difference possibly because only the rear wheels are ABS controlled. A higher speed of 66 km/h was also included to show that speed has little influence on the braking values. Test vehicle 7 was not included because it was not ABS equipped.

CONCLUSIONS

Comparative brake testing of specific vehicles on a gravel surface shows significant performance differences with ABS on and off. Averaged G-analyst deceleration values with ABS deactivated range between 0.59 and 0.66 g while values with ABS activated range from 0.37 to 0.52 g. This translates into increased stopping distances for one test vehicle of up to 60%. The highest value with ABS activated, 0.52 g, was from test vehicle 4 which had rear wheel only ABS.

The ABS control logic of the test vehicles does not utilize the potential maximum deceleration rate which locked wheels may achieve on gravel. It should be noted that no appreciable vehicle rotation occurred with the ABS deactivated even at speeds up to 77 km/h.

Further refinement in ABS should consider a 'best method' braking approach which could include wheel lock up on some surfaces.

The measured performance of these vehicles is not necessarily indicative of ABS performance of other vehicle models under similar test conditions and caution should be used in extrapolating these results. Further testing is required to determine different vehicles' ABS performance characteristics.

ACKNOWLEDGMENTS

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APPENDIX A

SIEVE ANALYSIS OF THE GRAVEL TEST ROAD SURFACE

GEOTECHNICAL AND MATERIALS ENGINEERING
MINISTRY OF TRANSPORTATION AND HIGHWAYS
PROVINCE OF BRITISH COLUMBIA

SOILS AND AGGREGATE LABORATORY
THOMPSON - OKANAGAN REGION

SIEVE ANALYSIS SUMMARY REPORT - ASTM C136, C117

GRAN_SVE.XLW Rev. 6/18/94

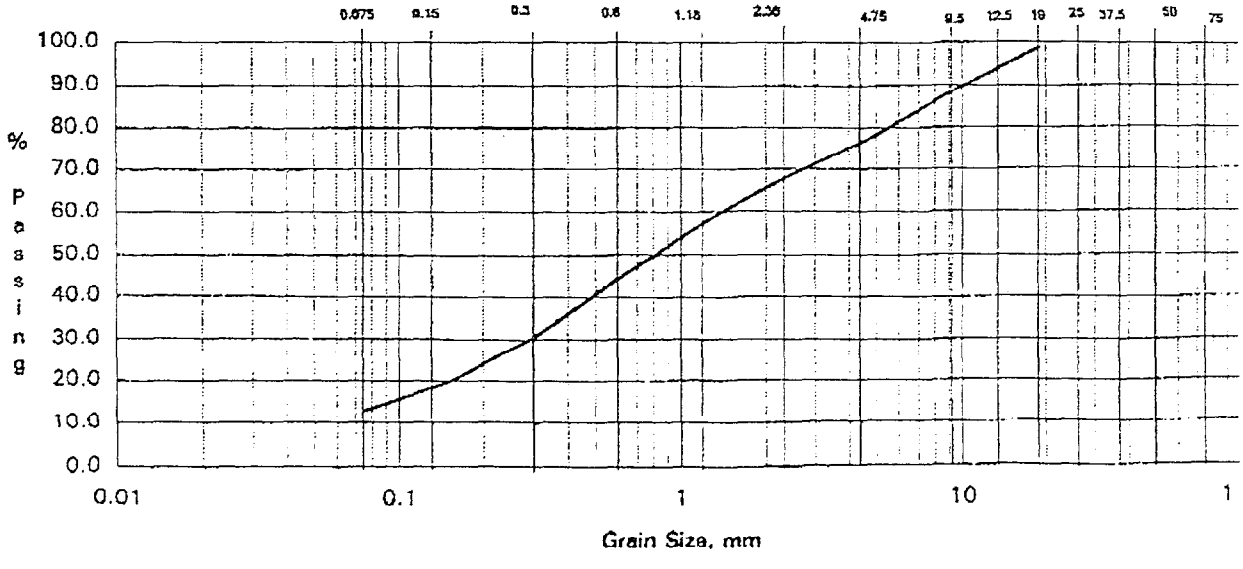
Project:	TAC.STUDY	Sample No.:	N/A	Bag No.:	PAIL
Project No.:	241-05930-3000	TP / TH #:	GRAB	Depth:	SURFACE
Material:	Pit Run	Date Rec'd:	OCT31/97	Date Tested:	NOV3/97
Sample Source:	ROAD BASE	Tested By:	H.L.		
Client:	TRANSPORT CANADA	Sampled By:	M.Macnabb	Lab. No.:	610-1

Sieve Fraction Size, mm	Cumulative % Passing		MOTH Specifications
75			
50			
37.5			
25			
19	98.8		
16			
13.2			
12.5			
9.5	88.9		
6.3			
4.75	77.4		
2.36	68.1		
1.18	57.2		
0.6	44.2		
0.3	30.3		
0.15	19.7		
0.075	13.0		

Test Mass	8101.1 gm		
Deg		SE	
Fracture		PI %	
% Gravel	22.6	Cc	1.3
% Sand	64.5	Cu	29.8
% Fines	13.0	USCS	SM1

Comments:
HARD & ANGULAR ROCK
SILTY SAND WITH GRAVEL

Grain Size Distribution Chart



APPENDIX B - TEST VEHICLE INFORMATION

Table 1.
Vehicle Information

Test Vehicle	Year	Make / Model	ABS Make/ Model	mileage (km)	weight (kg)
1	1993	GMC Suburban	KH* EBC 4	118,834	2,850
2	1995	GMC Suburban	KH EBC 310	8,267	2,875
3	1994	GMC Yukon	KH EBC 4	83,692	2,675
4	1994	Ford F150 XL	RABS II	43,384	2,650
5	1993	Ford Explorer	Teves Mark IV	65,809	2,200
6	1996	Chevrolet Cavalier	Delco VI	17,332	1,600
7	1991	Ford Crown Victoria	N/A	138,956	2,150

* Kelsey-Hayes Company

Table 2.
Tire Information

Test Vehicle	Tire Make	Size	Depth (mm)	Pressure (kPa)
1	Michelin LTX	245/75R16	4	220
2	Firestone Steeltex A/T	245/75R16	12	220
3	Firestone Steeltex A/T	245/75R16	6	220
4	Goodyear Wrangler RT/S	265/75R15	7	220
5	Michelin LTX	235/75R15	8	220
6	BF Goodrich Touring T/A	195/65R15	7	220
7	Bridgestone WT11	225/70R15	4	220

APPENDIX C - TEST RESULTS

Table 3.
Bumper Gun Results

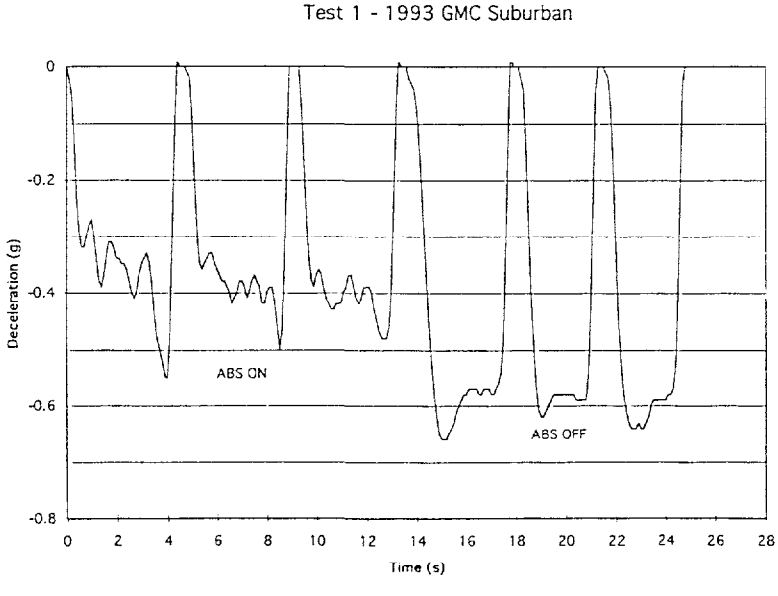
Test Vehicle	ABS	Surface Condition	Average Speed (km/h)	Average Stop Distance (m)	Raw Accel. (g)	Slope Adjust Accel. (g)	% Diff 1-(On/Off)
1	ON	Pavement	49.3	13.45	0.71	0.73	
	ON	Gravel	49.0	26.22	0.36	0.38	
	OFF	Gravel	50.7	18.32	0.55	0.57	33.3
2	ON	Pavement	48.8	15.80	0.59	0.61	
	ON	Gravel	49.0	21.90	0.43	0.45	
	OFF	Gravel	48.0	17.04	0.53	0.55	18.2
3	ON	Pavement	49.5	16.61	0.58	0.60	
	ON	Gravel	49.7	25.35	0.38	0.40	
	OFF	Gravel	49.7	18.78	0.52	0.54	25.9
4	ON	Pavement	49.7	13.76	0.71	0.73	
	ON	Gravel	49.7	19.28	0.50	0.52	
	OFF	Gravel	48.3	16.32	0.56	0.58	10.3
5	ON	Pavement	50.8	15.35	0.66	0.68	
	ON	Gravel	49.3	20.68	0.46	0.48	
	OFF	Gravel	47.0	15.28	0.56	0.58	17.2
6	ON	Pavement	53.0	12.72	0.87	0.89	
	ON	Gravel	50.3	25.02	0.40	0.42	
	OFF	Gravel	52.0	16.15	0.66	0.68	38.2
7	OFF	Pavement	57.5	16.25	0.80	0.82	
	OFF	Gravel	54.0	18.73	0.61	0.63	n/a

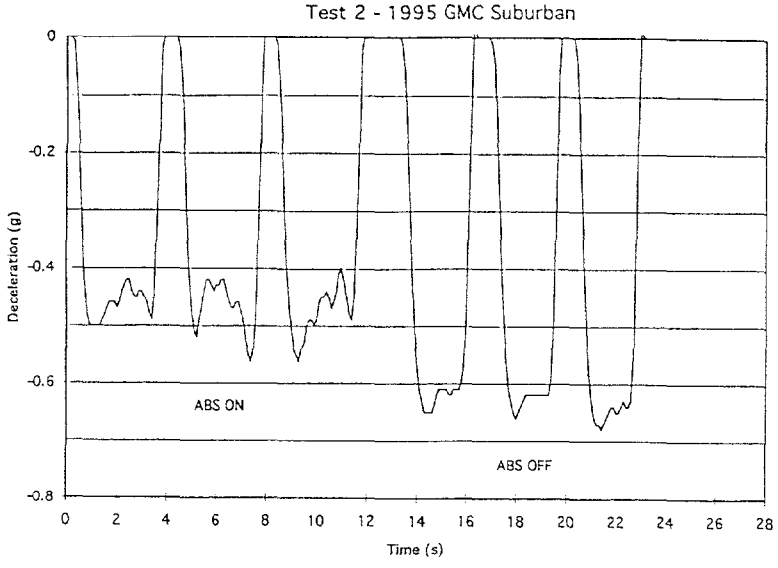
Table 4.
G-analyst and Vericom Results

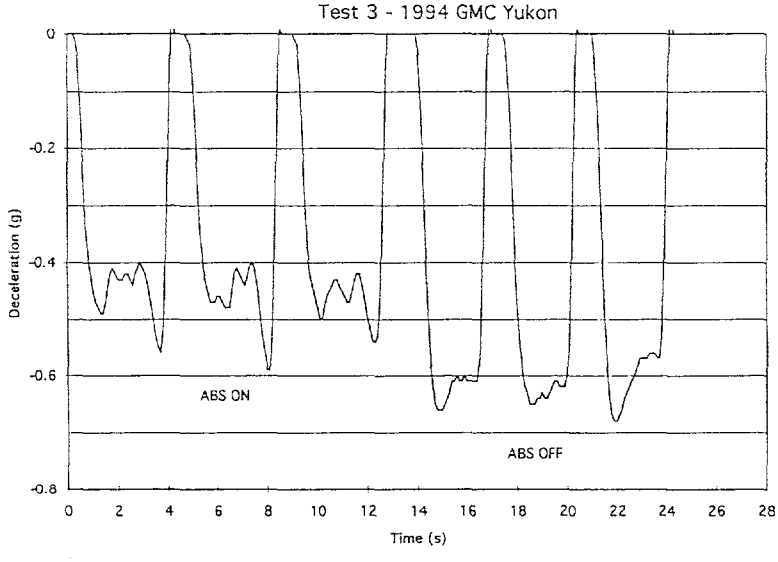
Test Vehicle	ABS	Surface Condition	G-analyst average (g)	% Diff 1- (On/Off)	Vericom average (g)	% Diff 1- (On/Off)
1	ON	Pavement	0.85		0.78	
	ON	Gravel	0.37		0.38	
	OFF	Gravel	0.59	37.3	0.56	32.1
2	ON	Pavement	0.76		0.71	
	ON	Gravel	0.47		0.46	
	OFF	Gravel	0.62	24.2	0.59	22.0
3	ON	Pavement	0.75		0.71	
	ON	Gravel	0.45		0.45	
	OFF	Gravel	0.61	26.2	0.58	22.4
4	ON	Pavement	0.83		0.76	
	ON	Gravel	0.52		0.48	
	OFF	Gravel	0.63	17.5	0.58	17.2
5	ON	Pavement	0.79		0.74	
	ON	Gravel	0.50		0.47	
	OFF	Gravel	0.66	24.2	0.62	24.2
6	ON	Pavement	0.89		0.93	
	ON	Gravel	0.42		0.40	
	OFF	Gravel	0.66	36.4	0.65	38.5
7	OFF	Pavement	0.88		0.83	
	OFF	Gravel	0.63	n/a	0.61	n/a

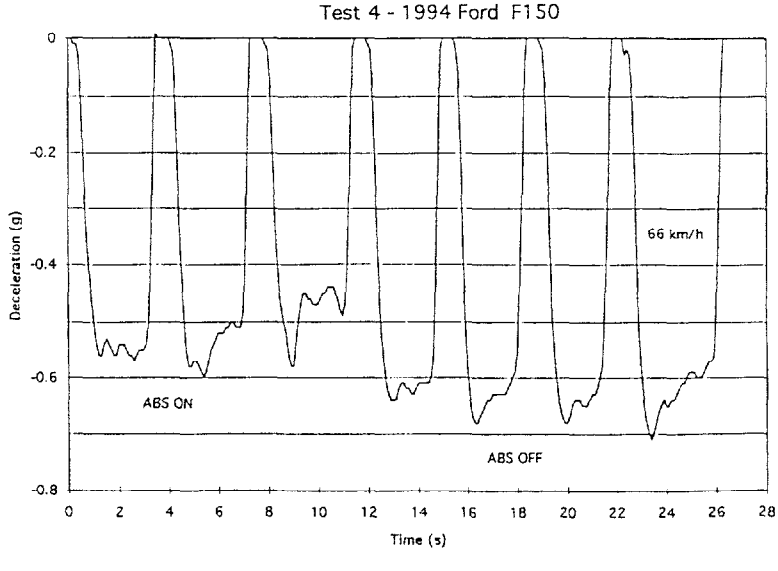
APPENDIX D

G-ANALYST PLOTS OF BRAKING ON GRAVEL SURFACE WITH ABS ON AND ABS OFF

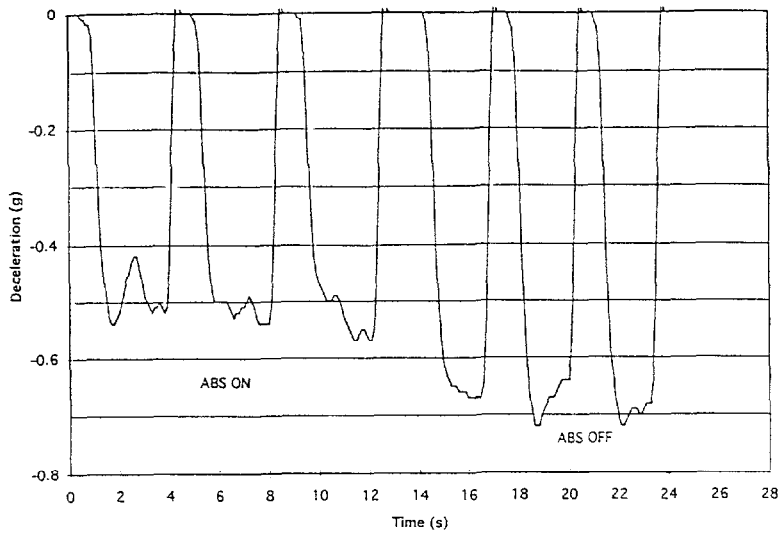



Test 2 - 1995 GMC Suburban
Deceleration (g)
0
-0.2
-0.4
-0.6
-0.8
ABS ON
ABS OFF
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
Time (s)


Test 3 - 1994 GMC Yukon
Deceleration (g)
0
-0.2
-0.4
-0.6
-0.8
ABS ON
ABS OFF
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
Time (s)


Test 4 - 1994 Ford F150
Deceleration (g)
0
-0.2
-0.4
-0.6
-0.8
66 km/h
ABS ON
ABS OFF
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
Time (s)

Test 5 - 1993 Ford Explorer



Test 6 - 1996 Chevrolet Cavalier