EVALUATION OF RUMBLE STRIPS

by

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Virginia Highway & Transportation Research Council
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SUMMARY

Rumble strips have been used for a number of years at locations where a physical stimulus was needed to alert a motorist to some hazard. However, little study has been done to determine the optimum spacings for the strips. Through testing existing Virginia rumble strip installations and various spacings at a test location, a basis was established for the spacings. The study revealed the following:

(1) A spacing of 2'(0.61 m) or less created a large amount of wheel hop and/or did not allow the tires to descend between the rumble strips, both of which are undesirable.

(2) A 10' (3.05 m) was found to be the best for a stopping situation such as at an intersection.

(3) A 5' (1.52 m) spacing was best for use on the shoulders of roadways.

(4) Strips should be no higher or lower than 1/2" (12.7 mm).

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INTRODUCTION

Rumble strips have been used for a number of years to provide a physical stimulus to drivers so as to alert them to immediate and possibly unseen hazards where a visual stimulus would not be sufficient. Presently in Virginia there are a few sites where rumble strips are located before dangerous intersections, however no set pattern is being used for the spacing of these strips. In considering a spacing for a particular intersection, various speeds may have to be taken into account along with the road geometry.

A second use for rumble strips has been as warning devices on the shoulders of high speed roadways such as freeways and interstate highways. This use is being tested in at least two states. In California they are being tested on the shoulders of freeways to determine their effect in alerting a fatigued, or possibly sleeping, driver that his vehicle has left the roadway. There a spacing of 5' (1.5 m) has been considered the best for this application.(1) In Virginia, rumble strips have been cut into the shoulder of the road on I-64 across Afton Mountain and are being evaluated for their effectiveness in warning a driver who has left the roadway because of not being able to see the edge line due to fog or other adverse weather conditions.

Among other applications, strips have been used on sections of roadways preceding road construction operations. In England, strips in place of speed bumps have been used in one particular case to limit the speed of vehicles in residential areas.(2)

PURPOSE

The purpose of this study was to determine optimum spacings relative to speed for rumble strips installed as (1) warning and speed reduction devices before intersections and other applicable locations, and (2) warning devices on the shoulders of interstate and other high speed highways. The optimum spacings were determined by measurements of car and rear axle vibrations and the noise level within the vehicle. Heights of 1/2" (12.7 mm) and 3/8" (9.525 mm) were evaluated, but the time available for the study did not allow the evaluation of various strip widths.

Several characteristics of rumble strips that could affect the optimum spacings could not be covered in the scope of this project. All of these involve the test vehicle used in taking the vibration and noise measurements. To begin with, a variety of vehicles would travel over rumble strips installed on a highway, whereas this study considered only full-size automobiles. Relevant vehicle factors other than size include the following: size of wheelbase, vehicle weight, type of suspension, condition of shocks, size of tires, and balance of tires. A project to evaluate the effects of all these factors would be of considerable size; however, the results of the present project will provide a basis for further work and through visual observation of various vehicles in actual traffic situations with rumble strips these factors could be evaluated.

EQUIPMENT

The first task in the study was to determine a method for evaluating the rumble strips. Two possible means were available. The first was to outfit an automobile with two semiportable sound meters, with one being connected through an integrator to an accelerometer attached to the floorpan to measure the velocity of the floorpan due to vibrations. The second was to utilize the road roughness car, a 1970 Plymouth Fury I, which has been instrumented by the Virginia Highway and Transportation Research Council to measure variations in the distance between the rear axle and the passenger compartment due to road irregularities, (3) and to use a hand-held sound meter to determine the sound level within the automobile

The latter method was chosen because of its availability and its ease of operation. Also it was felt that knowing the reaction of the rear axle to the rumble strips would be of importance. Finally that data from the road roughness car could be read in the field while the data from the first method would have to be analyzed from a magnetic tape.

The road roughness equipment measures the vertical movement between the passenger compartment and the rear axle of the automobile induced by pavement roughness. A braided cable connects the differential in the drive train with a roller switch, which in turn is secured to the passenger compartment. The switch is connected to an electrical counter that records variations from 1/8" (3.175 mm) to a maximum of 1 1/2" (38.1 mm) in increments of 1/8" (3.175 mm). With this equipment, the reaction of the rear axle to various spacings of rumble strips can be determined. Figures 1 and 2 show the equipment in the car.

The sound level meter used is a small, hand-held unit with a range from 30 dB to 140 dB (see Figure 3). It was set to measure the sound range which most closely corresponds to human hearing. (4)

Figure 1. Recording device for roughness equipment located on seat of road roughness car.

Figure 2. Roughness indicator located on dash of road roughness car.

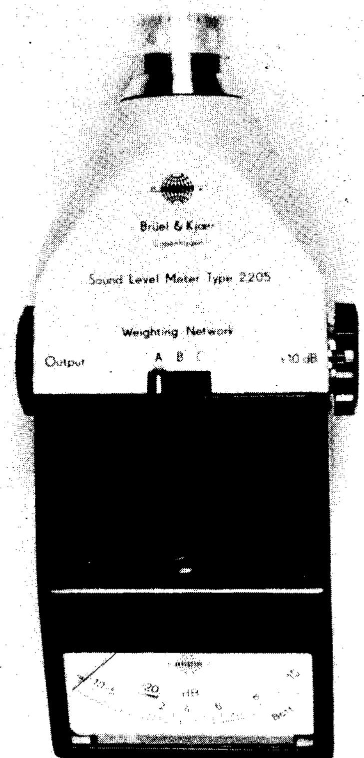


Figure 3. Sound level meter.

EXISTING RUMBLE STRIP SITES

The next aspect of the study was to visit the present sites of rumble strips in Virginia and to use these sites to develop a testing procedure. These sites provided a variety of spacings from 10' (3.05 m) to a few inches (millimetres). In addition, the sites provided both strips cut into the pavement and those built up on the pavement. In descriptions of the sites, those with the longest spacings are considered first. Table 1 gives locations and descriptions of the sites tested.

Table 1. Existing Rumble Strips.

SITE NUMBER	LOCATION	DESCRIPTION OF STRIPS
1	Rt. 28 approaching Rt. 17, Fauquier County	Total length 130' (39.6 m), separation 10' (3.05 m), width 2' (0.61 m), built-up 1/4" (6.35 mm)
2	Shoulder I-64, Afton Augusta County	Total length 426' (130 m), separation 2.75' (0.838 m), width 7" (0.13 m), and cut 1/4" (6.35 mm)
3	Rt. 606 approaching Rt. 1, Spotsylvania County	Total length 60' (18.3 m), separation 1.5' (0.46 m), width 7" (0.18 m), built-up 1/8 - 1/4" (3.175 - 6.35 mm)
4	Rt. 29 approaching Rapidan River Bridge, Greene County	Total length 32' (9.75 m), 2 sections, separation 1.5' (0.46 m), width 6" (0.15 m), cut
5	Rt. 28 approaching Rt. 7 in Loudoun County	Total length 50' (15.2 m), 4 sections, separation 1' (0.31 m), width 6" (0.15 m), build-up 7" (25.4 mm)
6	Rt. 207 approaching Rt. 1, Caroline County	Total length 15' (4.57 m), 5 sections, separation 0.75' (0.23 m), width 2" (51 mm), cut 1/4" (6.35 mm)
7	Interstate gore areas	Total length varies, separation 4" (102 mm), width 3" (70 mm), built-up 1 - 1.5" (25.4 - 38.1 mm)

The first site is located on Route 28 in Fauquier County north of the intersection with Route 17. Its total length is 130' (39.6 m), with a 10' (3.05 m) separation between the strips. This 10' (3.05 m) separation is the same length as the average wheel base of the standard size American car. The site has build-up strips 1/4" (6.350 mm) high and 2' (0.61 m) wide. At this location the noise level and vibration increased as speed increased, thereby providing an increase in physical stimulus as the speed increased. Figures 4 and 5 show two views of this site.

The second site is on the shoulder of I-64 across Afton Mountain in Augusta County. It is located on the eastbound side between the exit ramp and the entrance ramp for Route 250. The purpose of this site is to evaluate rumble strips for their effectiveness in warning a driver who has left the roadway due to fog. The strips are cut into the pavement with a separation of 2.75' (0.838 m), a width of 7" (0.18 m), and a depth varying around 1/4" (6.34 mm). This site produced the most vibration at a speed of 30 mph (13 m/s), indicating a resonance at this speed which is an undesirable effect. Figures 6 and 7 provide two views of the site. There is another location on the exit ramp from the Afton overlook with a wider spacing, however, the strips there could not be evaluated due to the roadway's configuration making it unsafe to perform tests.

Figure 4. Rumble strips on Route 28 before the intersection of Route 17.

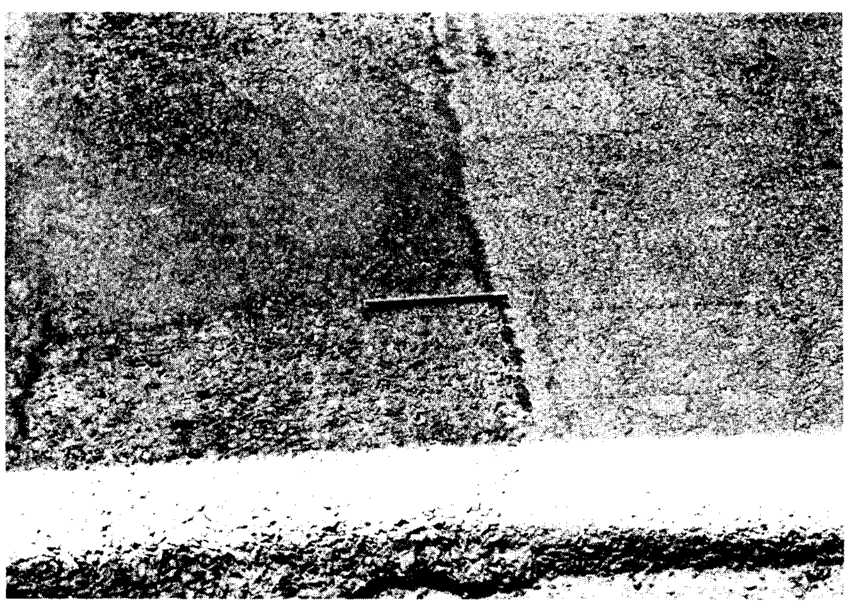


Figure 5. Close view of rumble strip on Route 28.

Figure 6. I-64, Afton Mountain.

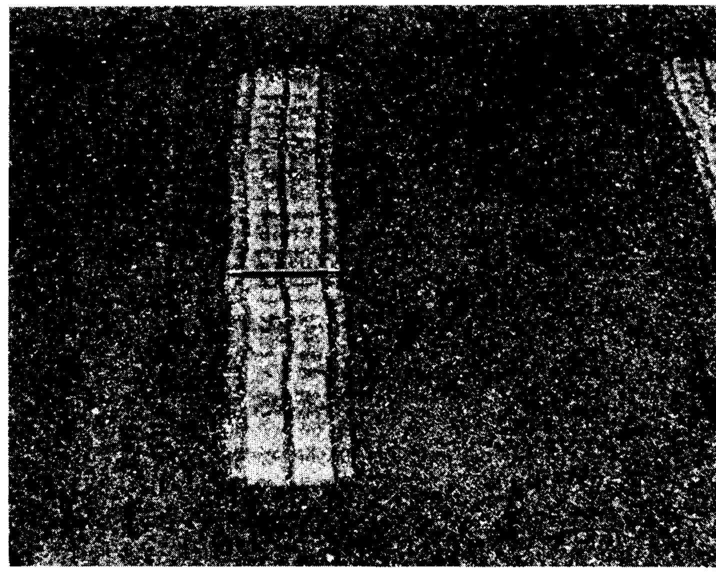


Figure 7. Close-up of Figure 6.

The third site (Figures 8 and 9) is located on Route 606 as it approaches Route 1 from the east in Spotsylvania County. There are two sections, each with a total length of 60' (18.3 m). The strips have a separation of 1.5' (0.46 m) and are built-up 1/8 to 1/4" (3.175 - 6.35 mm) with a 7" (0.18 m) width. It is believed that the spacing at this site is too close, since low speeds caused an increase in the vibration and relative noise level.

The fourth site is located on Route 29 on the approach to the Rapidan River Bridge from the south in Greene County. There are two 32' (9.75 m) sections. Each strip was formed by cutting four 3/4" (19.05 mm) grooves in the pavement 3/8" (9.525 mm) apart to give a total strip width of 6" (0.15 m). These strips proved to be rather ineffective due to the narrow width of the grooves which did not allow the tires to descend into the groove. Figures 10 and 11 show the traffic lane which is quite worn. Figures 12 and 13 show the passing lane.

Figure 8. Rumble strips located on Route 606 before the intersection of Route 1.

Figure 9. Close view of the rumble strips on Route 606.

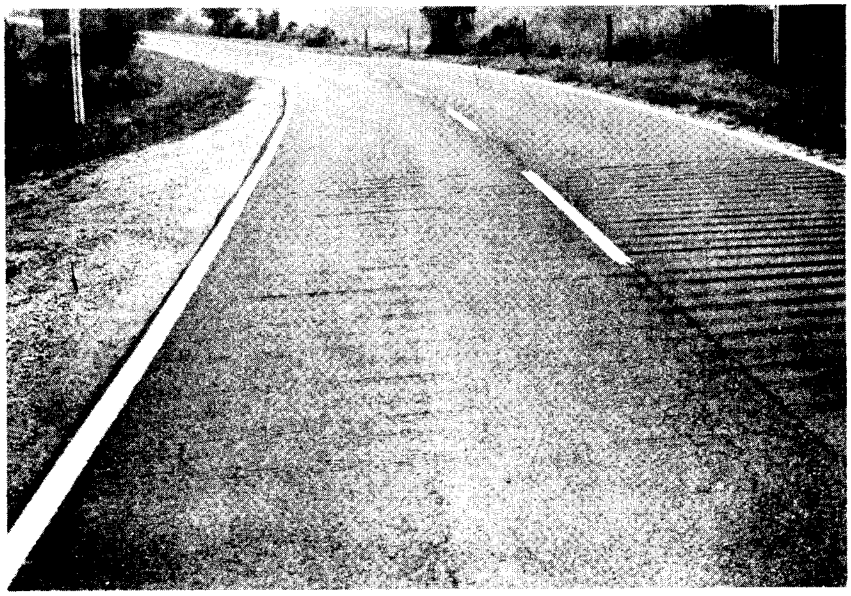


Figure 10. Rumble strips cut into Route 29 before Rapidan River. View is opposing traffic direction (traffic lane).

Figure 11. Close view of rumble strips cut into traffic lane on Route 29.

Figure 12. Rumble strips cut into passing lane of Route 29 before Rapidan River. View is opposing traffic direction.

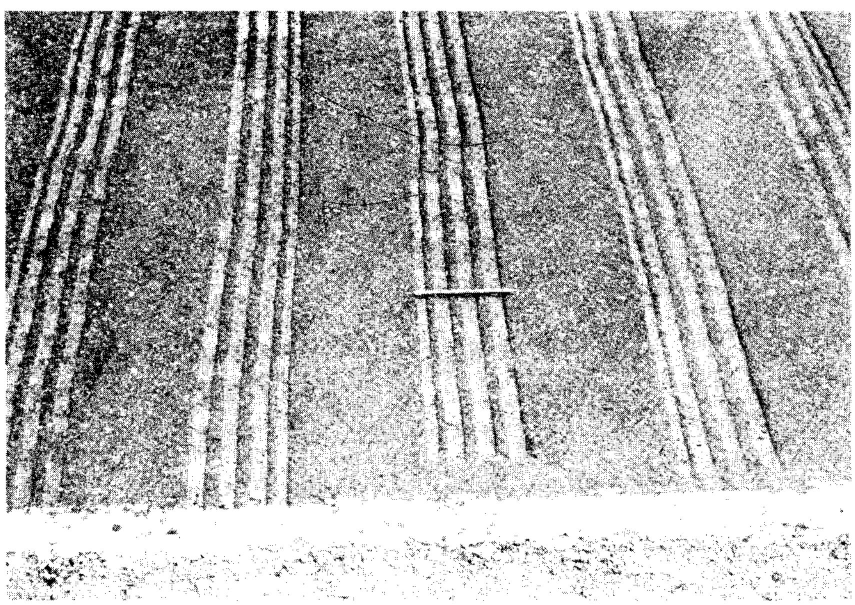


Figure 13. Close view of rumble strips cut into passing lane of Route 29.

Site number 5 is located on Route 28 approaching Route 7 from the south in Loudoun County. It has four sections, each with a length of 50' (15.2 m). The built-up strips are 1" (25.4 mm) high, 6" (0.15 m) wide, and 1' (0.31 m) apart. This configuration causes the noise and vibration to increase as the speed is reduced, which, as was the case with the strips at site three, defeats the purpose of the strips. Figures 14 and 15 show this location.

The sixth site is on Route 207 east of the intersection with Route 1 in Caroline County. It has 5 sections each with a total length of 15' (4.57 m). Quarter-inch (6.35 mm) grooves are cut an average of 2" (51 mm) in width and with a separation of 9" (0.23 m) (Figure 16). These strips provided very little vibration due to the narrow width of the grooves for the same reason as stated with regard to Site 4.

The final site is in general the gore areas found on the first constructed interstate highways in the state. These strips are built-up with a height between 1 to 1.5" (25.4 - 38.1 mm), a width of 3" (76 mm), and a separation of 4" (102 mm). Figures 17 and 18 show views of the gore area.

The testing at all of these sites involved operating the car at various speeds up to the safest possible limit. The roughness readings were taken separately from the sound readings and in some cases the sound tests involved using a different automobile.

Table A-1 of the Appendix shows the data from these tests.

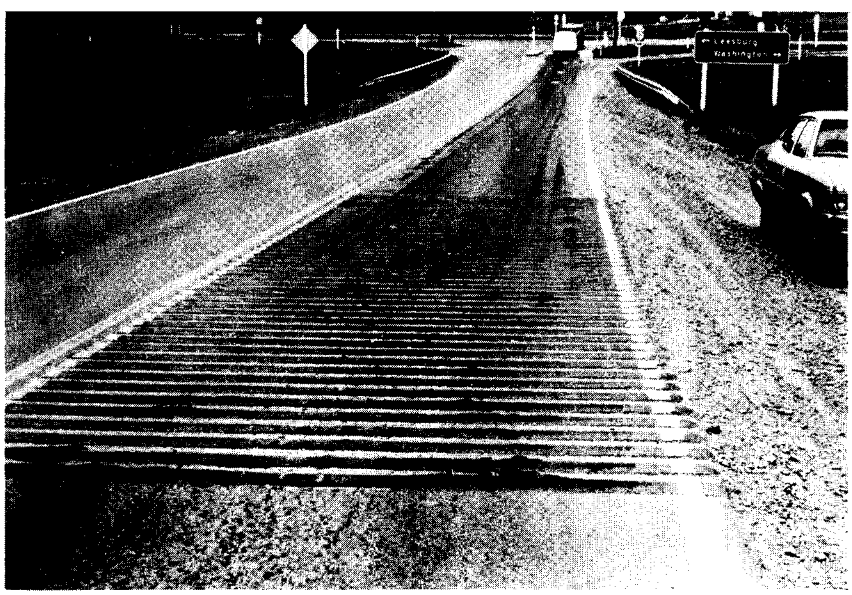


Figure 14. Rumble strips on Route 28 before the intersection of Route 7.

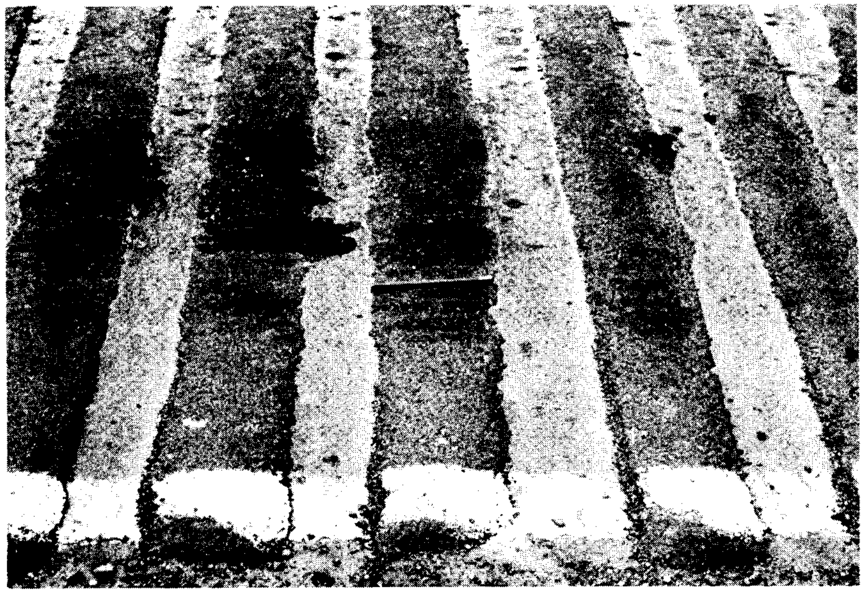


Figure 15. Close view of the rumble strips on Route 28 before Route 7.

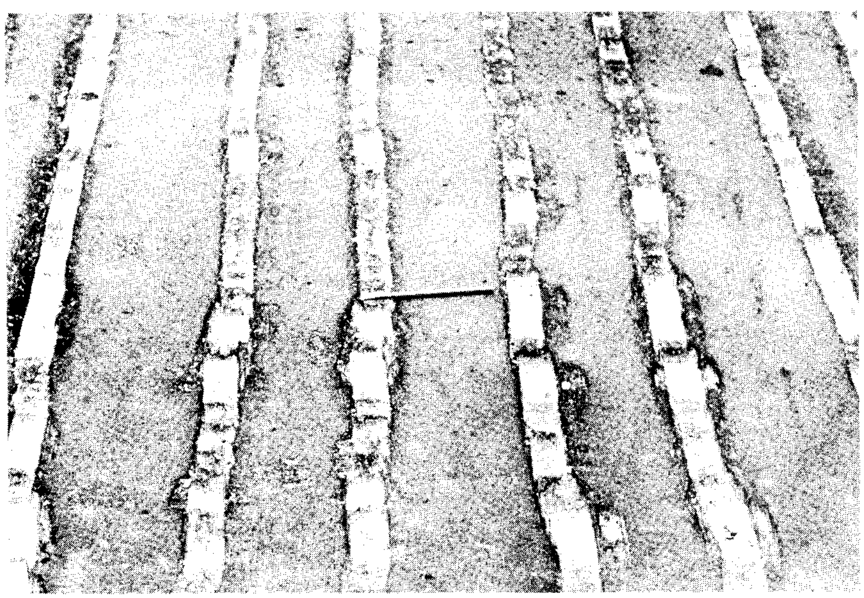


Figure 16. Close view of the rumble strips cut into Route 207 before the intersection of Route 1.

Figure 17. Rumble strips on interstate gore area.

Figure 18. Close view of the rumble strips on gore **area**.

824

TESTING VARIOUS SPACINGS

The final aspect of the study was to find a location to test a variety of spacings. An unopened rest area on I-64 between Gum Springs and Charlottesville proved to be an ideal location. Because of the rest area configuration, tests up to 70 mph (31 m/s) were possible. Four-inch (102 mm) wide plywood boards were used to make the rumble strips, whose height varied from 1/4 to 1/2" (6.35 - 12.7 mm). The strips were secured to the pavement with roofing nails and the spacings evaluated were as follows: 15' (4.57 m), 10.5' (3.20 m), 10' (3.05 m), 7.5' (2.24 m), 5' (1.52 m), 3.75' (1.14 m), 3.25' (0.991 m), 2.5' (0.762 m), 2' (0.610 m), and 1.25' (0.381 m).

The testing involved setting out the strips at a particular spacing and then operating the car with the roughness equipment attached. The roughness tests involved three passes at each speed of 70, 60, 50, 40, 30, and 20 mph (31, 27, 22, 18, and 13 m/s) and any additional passes needed to check any unusual results. The sound tests were then conducted with the roughness equipment disconnected, and involved two passes at each of the aforementioned speeds, with additional runs being made if the readings varied more than .5 dBA. The sound meter was operated with the car's windows closed and the air conditioner and fan on the lowest setting. Figures 19 - 21 are views of the car in operation at 70 mph (31 m/s) and a view of the rumble strips (Figure 21). The data for these tests are located in Tables A-2, A-3, and A-4 in the Appendix.

Figure 19. Road roughness car being used for testing at 70 mph (31 m/s).

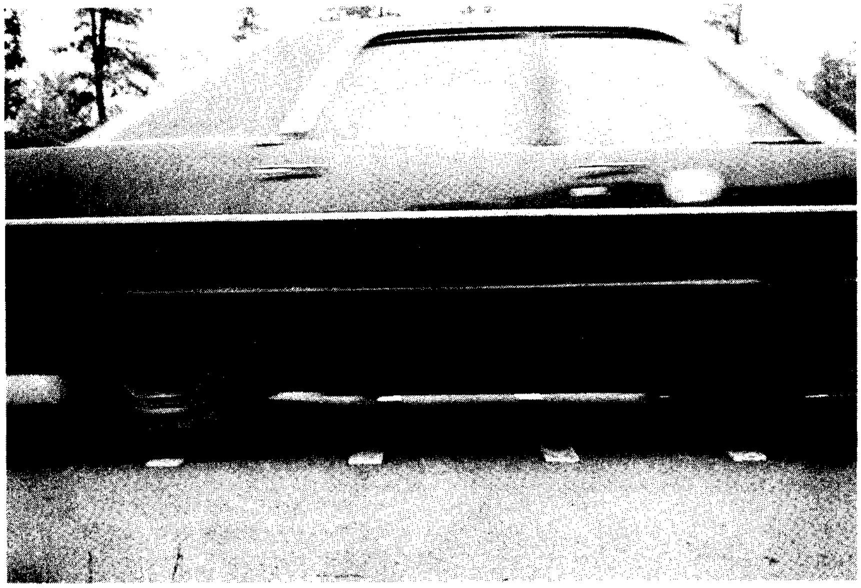


Figure 20. Second view of 70 mph (31 m/s) test.

Figure 21. View of the plywood strips used for the rumble strips.

8..6

RESULTS AND RECOMMENDATIONS

From the initial site evaluations, it became obvious that closely spaced strips, spacings of 2' (0.61 m) and less, caused an increase in noise level and vibration as the vehicle speed was decreased. This phenomenon was also observed in a study on rumble strips done by the Michigan Department of Highways(5) and is attributed to the fact that as the speed increases the tires do not descend between the individual strips but skim over the top. At one particular location (the approach of Route 28 to Route 7 in Loudoun County) where strips had a spacing of 12" (0.31 m), motorists were observed to speed up when going over the strips or to drive around the strips by going onto the shoulder or into the lane of oncoming traffic. It has been theorized by the Michigan Department of Highways that rough mats (or strips) "antagonize the drivers to such an extent that they relieve their frustrations by increasing the speed of their vehicles."(5)

The location in Virginia that seemed to be the most effective was at the approach of Route 28 to Route 17 in Fauquier County. At this site the spacing was 10' (3.05 m), the average wheelbase of an automobile, and the noise and vibration decreased as speed decreased. Strips cut into the pavement seemed to be as effective as built-up strips, as long as the strips are wide enough to allow the tire to descend into the cut.

From the results of the testing of the plywood strips, it appears that a few spacings can be eliminated completely. One is the 15' (4.57 m) spacing, the reason being that this spacing does not produce enough noise and vibration to warrant its use. In addition, as soon as the strips have been worn to around 3/8" (9.525 mm) in height the readings are reduced considerably. It is felt that spacings of 2' (0.61 m) and less should not be used because noise and vibration decrease with increased speed and at high speeds the tires tend to skim over the tops of strips and therefore lose road contact.

There doesn't seem to be a definite correlation between the road roughness readings and the sound level readings. This can be explained somewhat through a description of one of the tests. With the 1/2" (12.7 mm) strips spaced at 3.75' (1.14 m) and being tested at 30 mph (13 m/s), the roughness equipment showed readings up to 3/4" (19.05 mm). However, there was only a small amount of vibration in the car and the sound meter readings were the same as at the 5' (1.52 m) spacing. Pictures were being taken at this time, and it was observed that the rear suspension and axle were vibrating a good deal more than usual. The automobile, including the front suspension, was not vibrating. During some tests the car would vibrate with the rear suspension and during others the front suspension would vibrate.

Following are three hypothetical situations that illustrate various rumble strip spacings. The first is a situation involving a gradual reduction of speed such as before a toll booth or a road construction site on a high speed roadway. Figures 22, 23, and 24 illustrate this. First it was assumed that deceleration would be the result of engine braking only, which corresponds to a deceleration rate of 3 ft/sec.^{2} (0.91 m/sec.^{2}). Using equation (1) this gives a stopping distance for 70 mph (31 m/s) of about 817 feet (249 m).

$$SD = \frac{V^2}{2A} \qquad (1)$$

where

SD = Stopping Distance
A = Acceleration
V = Speed

It was decided that the rumble strips would be spaced so as to create a constant road roughness as the vehicle slowed down. With the deceleration rate stated above, the distances required to slow from 70 mph (31 m/s) to 60 mph (27 m/s), then 60 mph (27 m/s) to 50 mph (22 m/s), etc., were determined using equation (1). These are plotted in Figure 22.

A spacing sequence was determined to give as much a constant road roughness as possible. In addition 1/2" (12.7 mm) high strips were decided upon due to the large traffic volume that would cause a large amount of wear of the strips. It is felt that no height greater than 1/2" (12.7 mm) should ever be used since they cause a large amount of wheel hop. As can be seen from the graph, a spacing of 10' (3.05 m) was used from 70 mph — 40 mph (31 — 18 m/s); then from 40 mph — 30 mph (18 — 13 m/s) a spacing of 7.5' (2.29 m), a spacing of 3.25' (0.991 m) from 30 mph — 20 mph (13 — 9 m/s), and finally 2.5' (0.762 m) from 20 mph — 10 mph (9 — 4.5 m/s). Figures 23 and 24 show the road roughness and the sound level, which are both fairly constant.

The second hypothetical situation considered involves a T-intersection with the minor approach having a speed limit of 55 mph (24.5 m/s). From the minor approach it is impossible to see the intersection when the initial reaction must be taken for braking. The safe stopping sight distance (SSSD) for a speed of 55 mph (24.5 m/s) would be about 420 feet (128 m). This would be assuming a reaction time for braking of 2.5 seconds and a skid number (SN) for the road surface of 45. This calculation was made with equation (2), which was taken from Traffic Engineering by Matson, Smith, and Hurd. [6]

$$SSSD = 1.47 \cdot P \cdot V + \frac{V^2}{30 \cdot f} \qquad \text{------------------}(2)$$

where P = Reaction Time
V = Speed
f = Coefficient of Friction $= \frac{SN}{100}$

To include a safety margin, 600 feet (183 m) was chosen as the distance from the intersection where the first reaction must take place. Again, as in the first situation, the speeds and distances were plotted (Figure 25) and spacings decided upon. The first 202 feet (61.6 m) would be the reaction time of 2.5 seconds. At the beginning of this zone a 50' (15.2 m) section of 10' (3.05 m) rumble strips would be placed to provide a physical stimulus. These strips could be carried the whole length of the reaction zone if necessary. Again a constant road roughness was desired and the only differences in this situation and the previous one are the 3/8" (9.525 mm) strips for the 3.25' (0.991 m) spacing and the elimination of the 2.5' (0.762 m) spacings. Figures 26 and 27 show the noise level and road roughness the spacings create. Figures 28 and 29 are included to show the values for maximum road roughness and sound levels for the corresponding spacings at each particular speed.

The final situation considered is the placement of rumble strips on the shoulders of freeways and interstate roads. This situation would involve a number of speeds and the spacing would have to be wide enough so as not to create a large amount of wheel hop and loss of vehicle control. And yet the spacing must create enough noise and vibration to alert the motorist who has left the roadway.

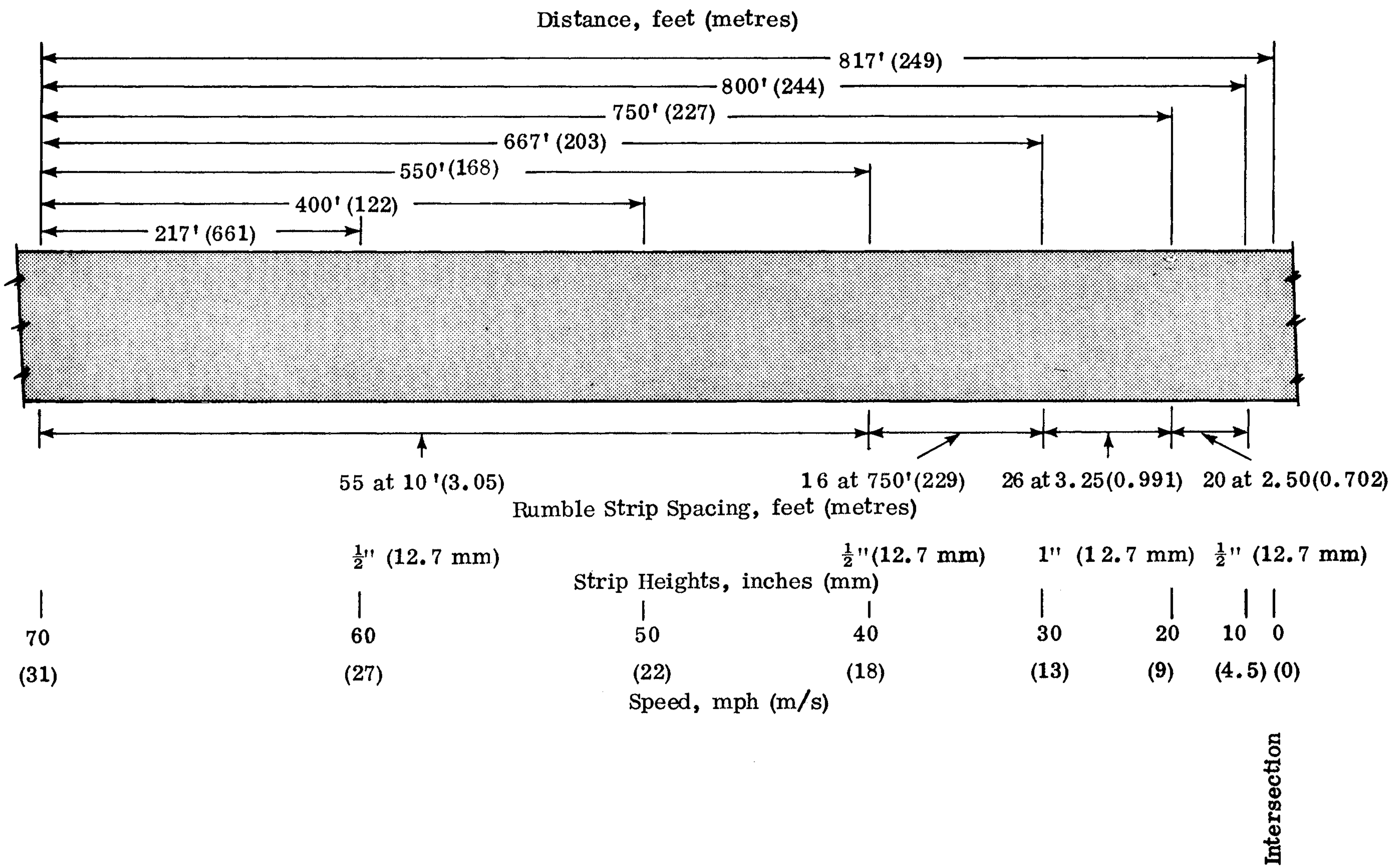
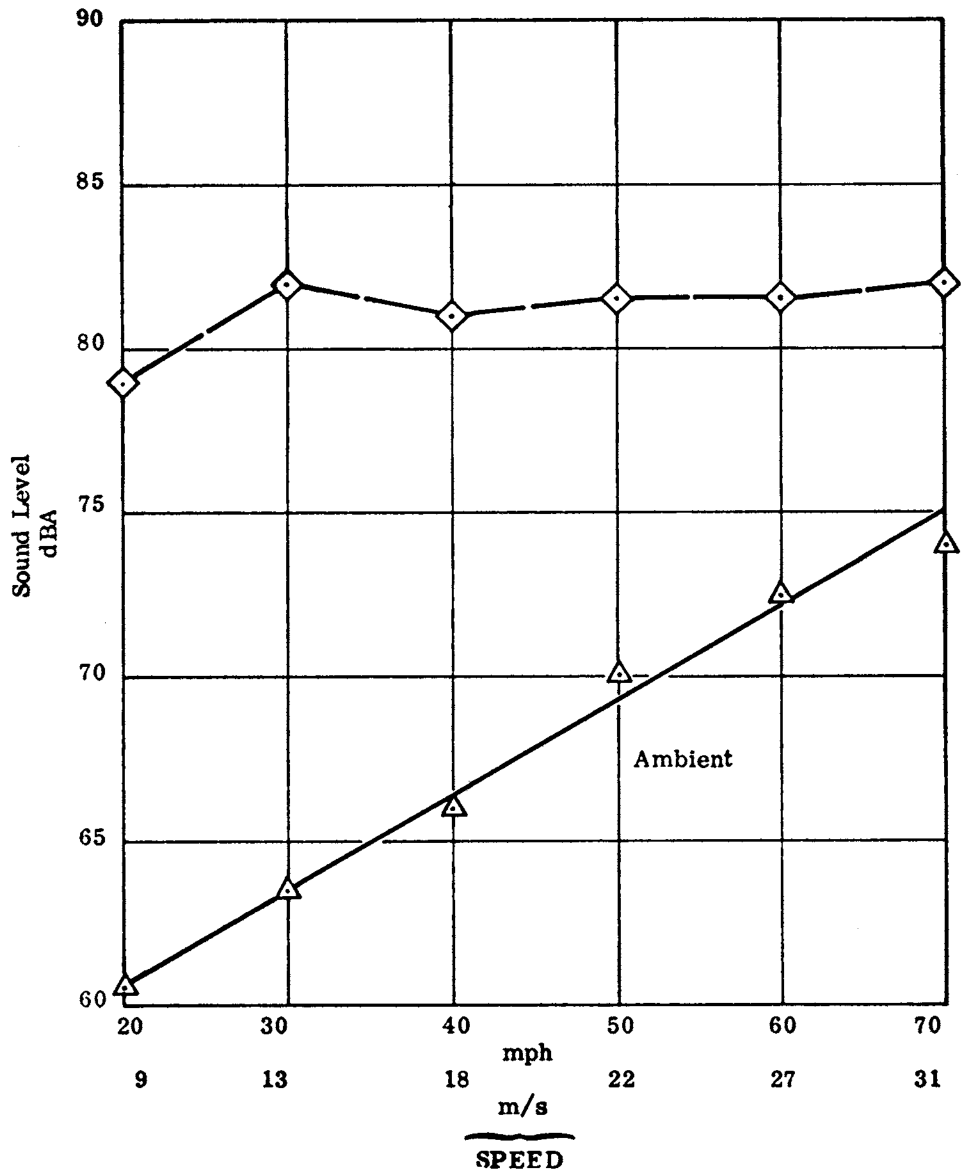


Figure 22. Rumble strip spacings for a stopping situation in the high speed highway example.



STRIP HEIGHT	20 mph	30 mph	40 mph	50 mph	60 mph	70 mph
½"	2.50	3.25	7.50	10.0	10.0	10.0
	Feet					
12.7 mm	0.762	0.991	2.29	3.05	3.05	3.05
	Metres					

SPACINGS

Figure 23. Sound levels resulting from the rumble strip spacings for the high speed highway example.

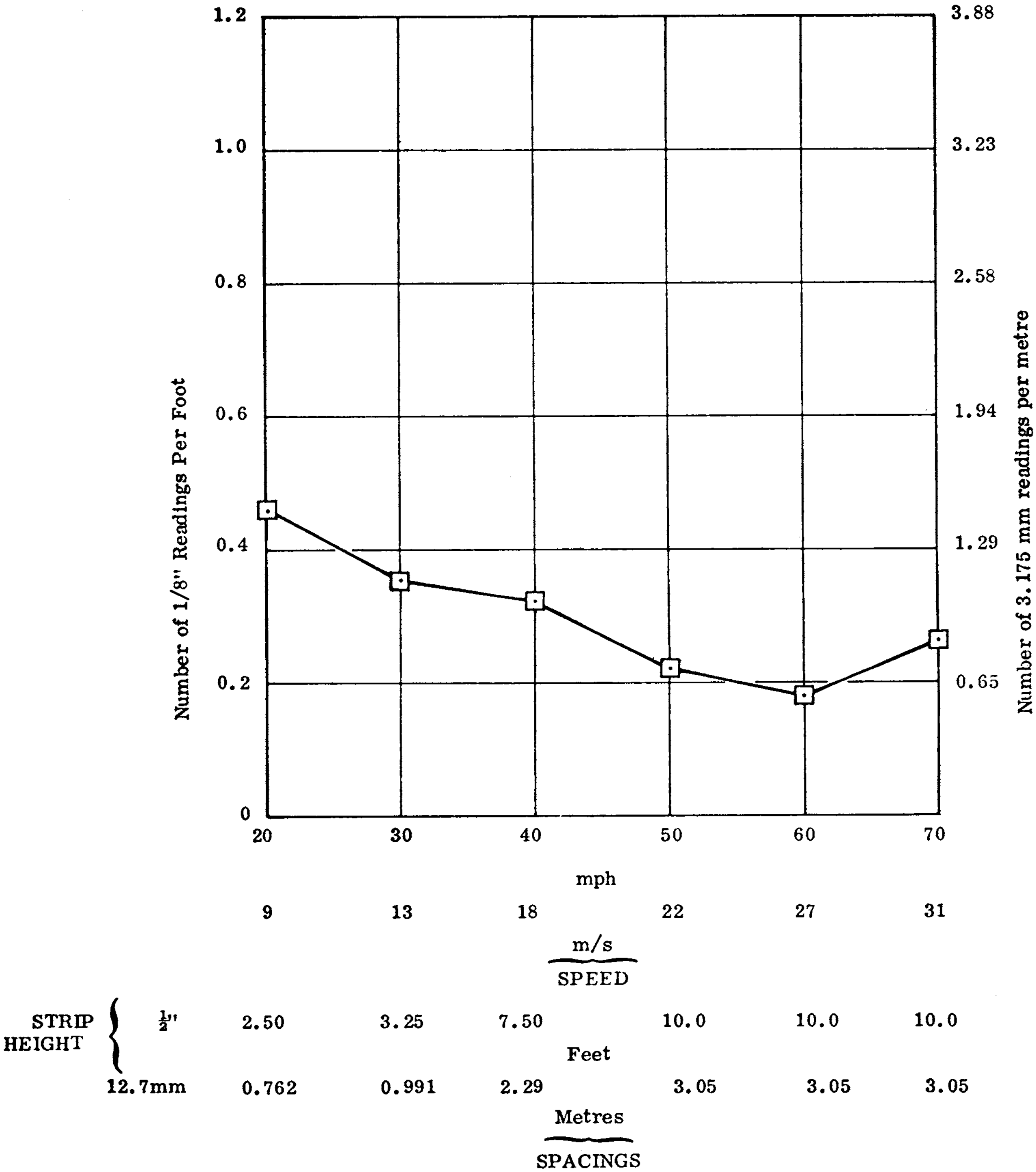


Figure 24. Roughness readings resulting from the rumble strip spacings for the high speed highway example.

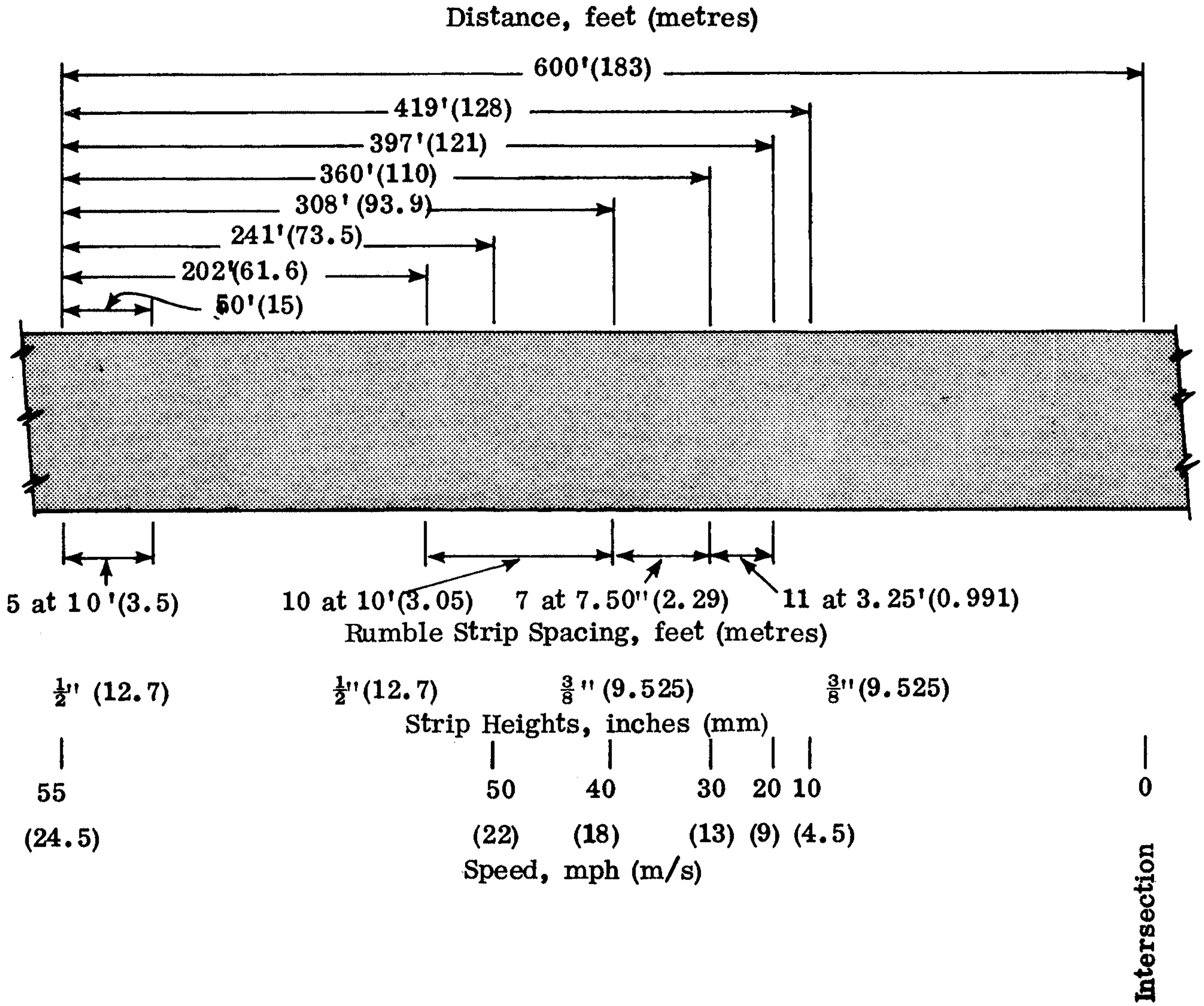


Figure 25. Rumble strip spacings for a stopping situation in the intersection example.

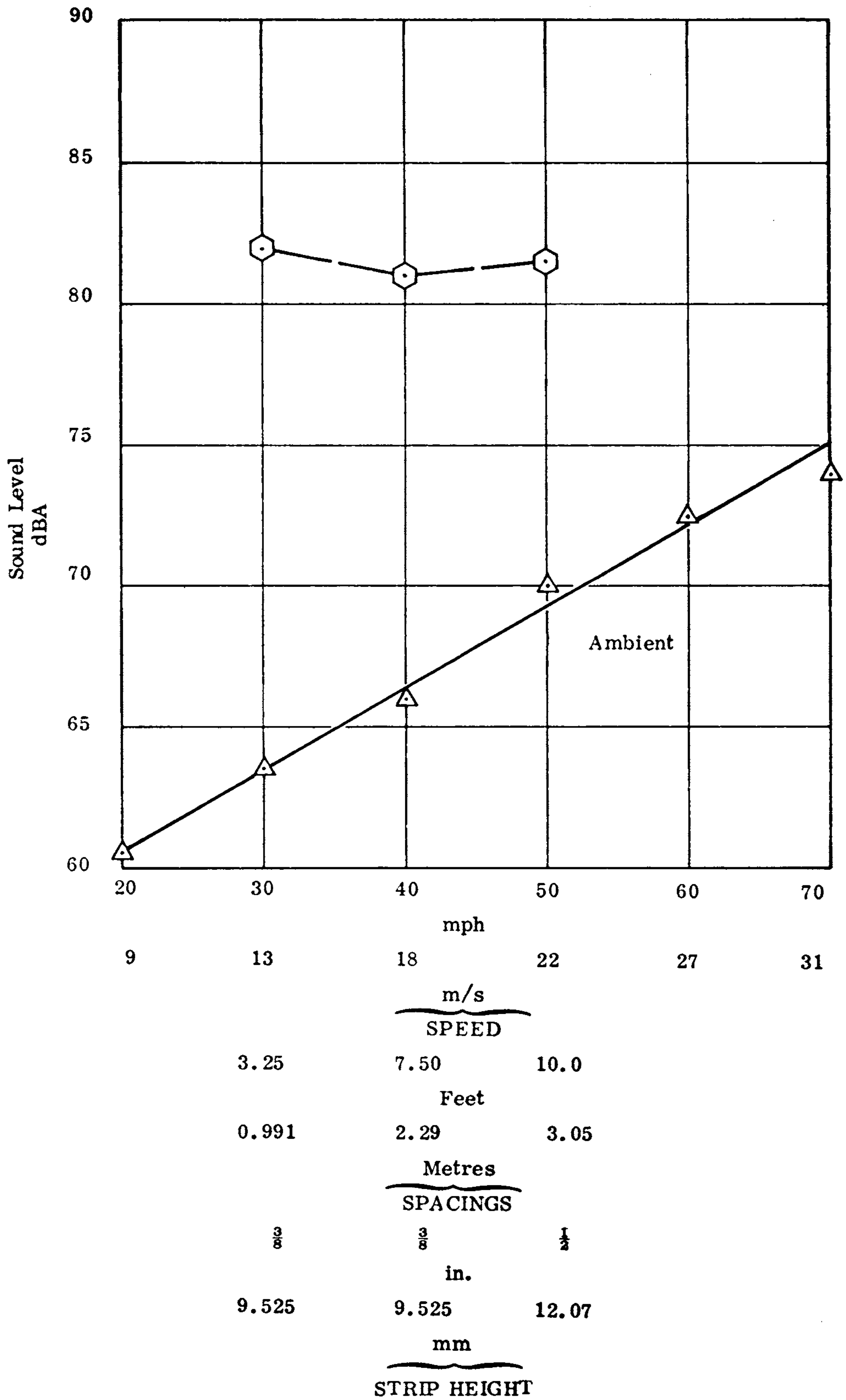


Figure 26. Sound levels resulting from the rumble strip spacings for the intersection example.

833

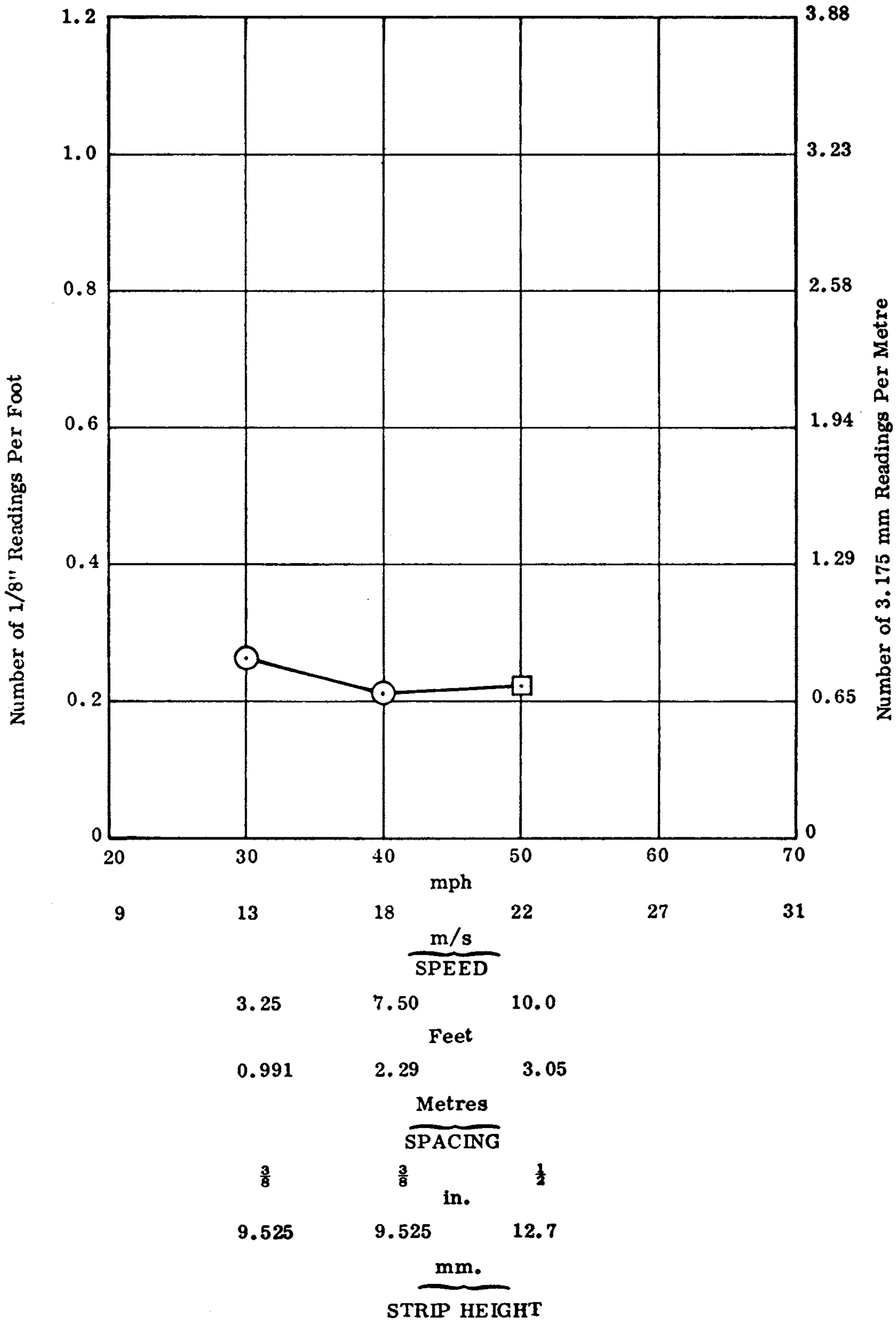
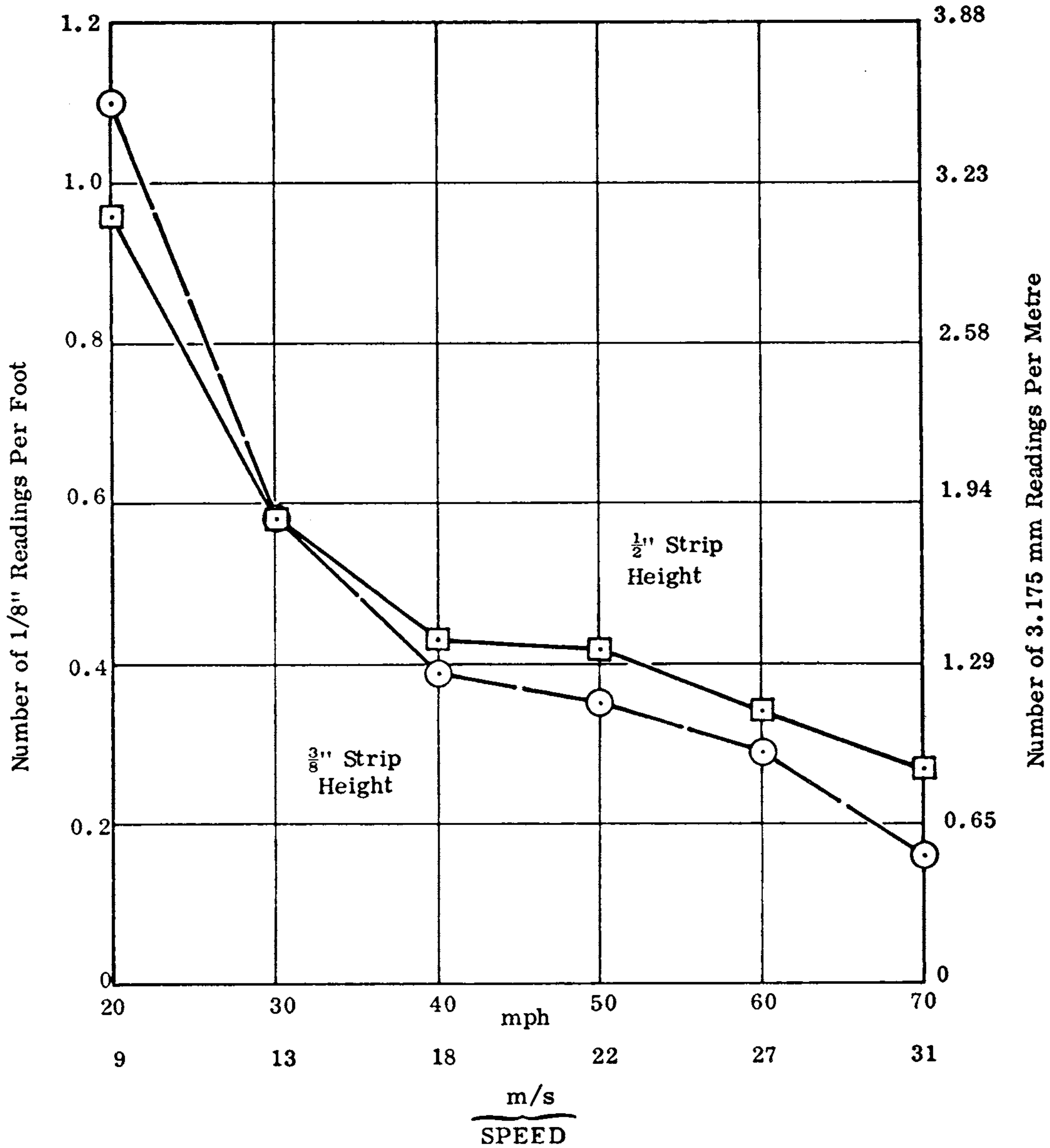


Figure 27. Roughness readings resulting from the rumble strip spacings for the intersection example.



STRIP HEIGHT	½"	1.27	7.50	3.25	2.00	7.50	1.25	Feet
	12.7 mm	0.381	2.29	0.991	0.61	2.29	0.381	Metres
STRIP HEIGHT	⅜"	2.00	3.75	5.00	5.00	7.50	7.50 & 1.25	Feet
	9.525 mm	0.61	1.14	1.52	1.52	2.29	2.29 & 0.381	Metres

SPACINGS

Figure 28. Spacings for maximum roughness at indicated speeds and strip heights.

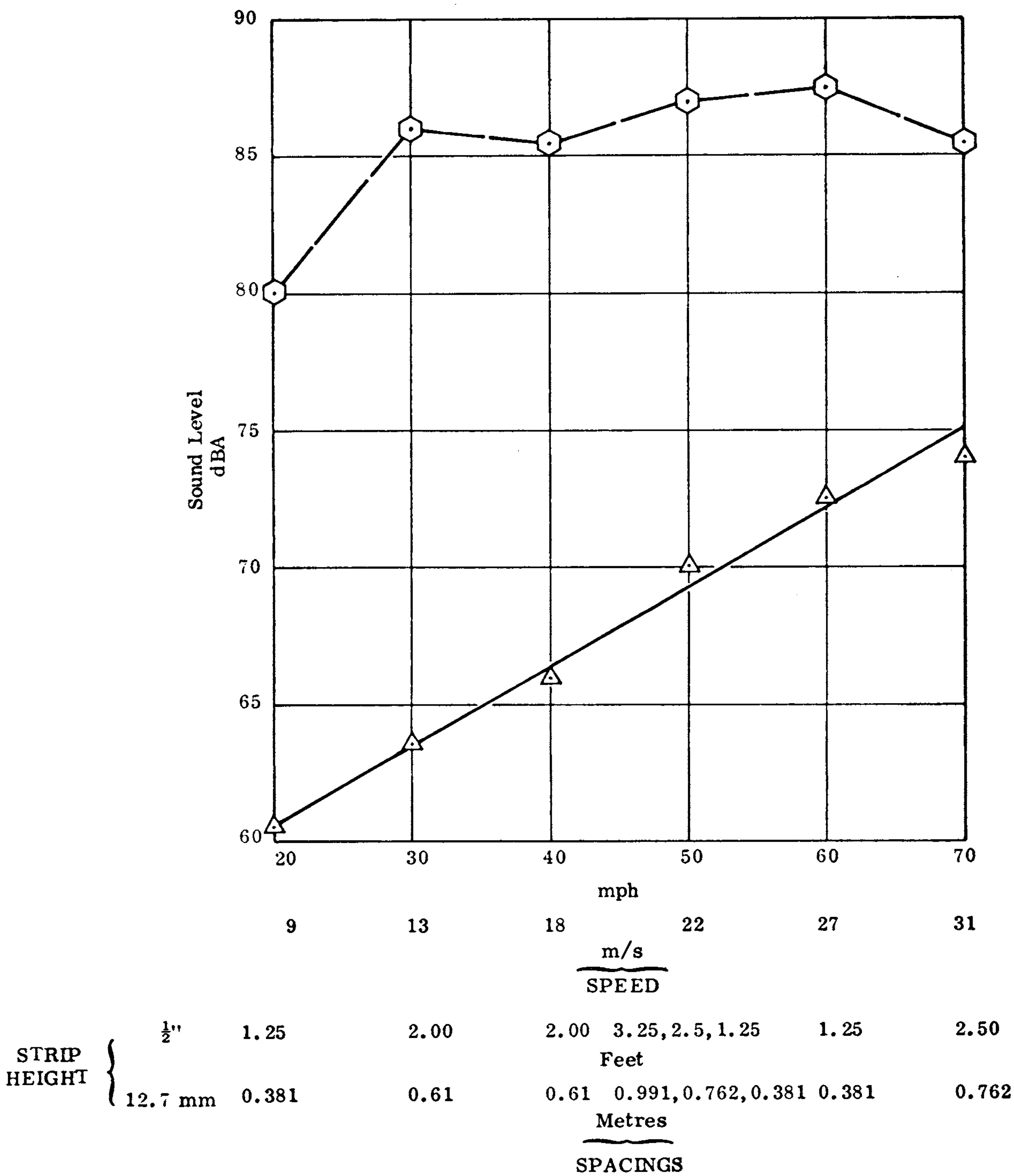


Figure 29. Spacings for maximum sound levels at indicated speeds and half-inch strip height.

8.6

The spacing that seems best fitted for these criteria is 5' (1.5 m). This distance is wide enough not to create wheel hop or loss of vehicle control, and it causes vibration and noise at the speeds that would be encountered in a real situation. In addition, this is the spacing that the California Division of Highways has decided upon for such situations.[1]

SUMMARY AND CONCLUSIONS

This project has provided a basis from which to work in using rumble strips as warning devices. The main difficulty in the project was the number of variables encountered in deciding the rumble strip spacings. In addition, the ambient noise level and vibration are dependent upon these variables. This makes it difficult to decide upon a specific spacing since it is the increased noise and vibration over ambient levels that the decision is based on. However, four definite conclusions can be drawn from the testing of the present sites and the experimental tests.

(1) A spacing of 2' (0.61 m) or less created a large amount of wheel hop and/or did not allow the tires to descend between the rumble strips, which created a situation in which the noise level and vibrations, ambient conditions, increased as speed decreased.

(2) A 10' (3.05 m) spacing, such as at the site in Fauquier County, was found to be the best single spacing (where the spacing is not varied) for a stopping situation, such as at an intersection.

(3) A 5' (1.5 m) spacing seemed to be the best suited for use on the shoulders of roadways.

(4) Strips should not be of a height or depth greater than 1/2" (12.7 mm).

ACKNOWLEDGEMENTS

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820

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APPENDIX

TABLE A-1

DATA FROM VIRGINIA SITES

SITE	70 MPH			60 MPH			50 MPH			40 MPH			30 MPH			20 MPH		
	dBA	1/8*	1/4**	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4
(Feet) (Metre)																		
#1 10' (3.05)											.23	.13		.39	.17		.40	.17
CONTROL											.10	.03		.12	.02		.08	.00
#2 2.75' (0.838)	85.5	.05	.03	84	.08	.03	81	.08	.02	77.5	.09	.02	73.5	.35	.10	71.5	.77	.25
CONTROL	76	.04	.01	72.5	.04	.01	69	.06	.00	67.5	.05	.01	63	.04	.00	63.5	.05	.00
#3 1.5' (0.46)										83.5	.12	.03	74	.20	.02	78.5	.26	.00
CONTROL										66	.05	.00	63	.07	.00	62.5	.00	.00
#4 1.5' (0.46)								.26	.23		.30	.10		.41	.03		.33	
CONTROL								.03	.01		.03	.00		.05	.00		.04	
#5 1' (0.31)				82			83			79.5			86.5			76		
CONTROL				73			71			70.5			68			63.5		
#6 .75' (0.23)				76			73.5			72	.13	.01	73.5	.34	.00	76	.49	.00
CONTROL				73			69.5			68	.06	.01	63.5	.07	.00	62.5	.04	.00
#7 .33' (0.101)	86			82			82.5			83.5			78.5					
CONTROL	76.5			73.5			71.5			70			68					

* # of 1/8" readings per foot (for 3.175 mm per metre divide data by .31)

** # of 1/4" readings per foot (for 6.35 mm per metre divide data by .31)

8-4

APPENDIX cont.

TABLE A-2

DATA FROM TEST SITE WITH ¼" HEIGHT AND 4" WIDTH

	70 MPH			60 MPH			50 MPH			40 MPH			30 MPH			20 MPH		
	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4
CONTROL	78	.01	.00	72	.02	.00	70.5	.02	.00	66	.03	.00	63.5	.04	.00	61	.00	.00
(Feet) (Metre) 15' (4.57)		.12	.01	76.5	.18	.00	77	.12	.00	73.5	.17	.01	71.5	.23	.01	67.5	.28	.03
10.5' (3.20)																		
10' (3.05)	79	.07	.00	77.5	.11	.00	77.5	.12	.00	76	.24	.00	72.5	.22	.00	68	.40	.01
7.5' (2.29)	80	.11	.02	79	.18	.08	79.5	.15	.00	76.5	.14	.00	74.5	.46	.03	70	.55	.13
5' (1.52)	80.5	.08	.00	79.5	.07	.00	79	.22	.00	78	.33	.15	76	.27	.00	70.5	.83	.17
3.75' (1.14)	82	.09	.00	81	.10	.00	82	.10	.01	79.5	.15	.00	77	.46	.23	74	.54	.02
3.25' (0.991)																		
2.5' (0.762)	82	.05	.00	82.5	.11	.00	83.5	.07	.00	80	.10	.00	79	.27		75	.60	.35
2' (0.610)																		
1.25' (0.381)																		

APPENDIX cont.

TABLE A-3

DATA FROM TEST SITE WITH 3/8" HEIGHT AND 4" WIDTH

	70 MPH			60 MPH			50 MPH			40 MPH			30 MPH			20 MPH		
	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4
CONTROL	74	.01	.00	72	.02	.00	70.5	.02	.00	66	.03	.00	63.5	.04	.00	61	.00	.00
(Feet) (Metre) 15' (4.57)	80	.09	.00	79.5	.19	.02	79	.20	.00	77	.22	.00	73.5	.23	.02	68	.39	.07
10.5' (3.20)	80.5	.18	.01	80	.15	.00	81	.20	.00	78	.32	.05	75.5	.46	.04	71.5	.67	.11
10' (3.05)	81.5	.14	.06	80	.20	.00	80	.18	.00	77	.36	.09	74	.32	.01	68	.69	.17
7.5' (2.29)	81	.16	.00	80.5	.29	.09	79.5	.29	.03	79.5	.21	.01	76	.50	.08	71	.52	.06
5' (1.52)	82	.12	.00	82	.17	.00	83.5	.35	.00	80.5	.39	.14	76	.42	.06	73.5	.78	.22
3.75' (1.14)	82.5	.09	.00	83	.14	.00	82.5	.16	.00	81.5	.29	.00	78.5	.58	.24	73.5	.64	.10
3.25' (0.991)	82.5	.12	.06	84.5	.09	.00	86	.15	.00	83	.26	.00	81	.26	.26	74.5	.88	.42
2.5' (0.762)	83.5	.10	.00	84.5	.09	.00	85.5	.07	.00	84	.05	.00	80	.37		76	.51	.39
2' (0.610)	83.5	.13	.00	85.5	.26	.00	85	.24	.00	84.5	.14	.03	85	.47	.03	76	1.10	.69
1.25' (0.381)	83	.16	.07	86.5	.20	.04	85	.30	.04	82	.29	.13	81.5	.50	.10	78.5	.59	.04

APPENDIX cont.

TABLE A-4

DATA FROM TEST SITE WITH 1/2" HEIGHT AND 4" WIDTH

	70 MPH			60 MPH			50 MPH			40 MPH			30 MPH			20 MPH		
	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4	dBA	1/8	1/4
CONTROL	74	.01	.00	72	.02	.00	70.5	.02	.00	66	.03	.00	63.5	.04	.00	61	.00	.00
(Feet) (Metre) 15' (4.57)	83	.18	.04	81.5	.29	.06	81	.29	.02	78.5	.25	.09	75	.30	.14	70	.48	.20
10.5' (3.20)																		
10' (3.05)	82.5	.26	.12	83	.18	.03	83	.22	.02	79	.40	.15	78	.48	.11	72.5	.61	.25
7.5' (2.29)	83.5	.23	.11	83.5	.34	.11	83.5	.37	.08	82.5	.32	.06	79	.58	.24	74.5	.64	.28
5' (1.52)	85	.12	.01	84	.21	.00	85.5	.34	.05	83	.22	.16	81	.56	.22	77	.65	.37
3.75' (1.14)	85.5	.12	.01	86.5	.13	.00	86.5	.23	.01	85	.36	.09	81	.20	.22	76.5	.91	.37
3.25' (0.991)	85.5	.15	.01	86.5	.15	.00	87.5	.16	.00	85	.43	.05	83.5	.35	.48	78.5	.73	.60
2.5' (0.762)	86.5	.20	.01	87.5	.28	.00	88	.24	.01	86.5	.30	.00	84.5	.46	.02	80	.46	.21
2' (0.610)	86	.26	.05	88	.31	.01	87.5	.42	.02	86.5	.12	.00	87.5	.34	.04	81.5	.95	.11
1.25' (0.381)	84.5	.27	.20	88.5	.28	.14	89	.26	.11	83.5	.34	.12	84	.46	.08	82	.96	.44