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AUTOMOBILE STOPPING DISTANCES FOR JUDGING HEADLIGHT PERFORMANCE

BY W.F. CAMPBELL

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FIG. / DIAG. 1

Table 1

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AUTOMOBILE STOPPING DISTANCES FOR JUDGING HEADLIGHT PERFORMANCE

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AUTOMOBILE STOPPING DISTANCES FOR JUDGING HEADLIGHT PERFORMANCE

INTRODUCTION

One factor needed to measure the effectiveness of automobile headlights, now being investigated in an NRC/MOT programme, is the distance required by a driver to stop his vehicle once an obstacle has been observed in the road ahead. This distance is primarily a function of the speed at which the vehicle is moving at the time the braking commences, but there are many other variables involved as well, the condition of the road surface and of the vehicle brakes and tires, the weather, and the skill of the driver, for example. However, by splitting up the problem into four separate cases, namely driving at night <u>with</u> or <u>without</u> the opposing glare of a car approaching in the left lane, each combined with <u>wet</u> or <u>dry</u> pavement conditions, it is possible to make conservative estimates of stopping distance versus initial velocity for each of these cases. Thus it should be possible, given the headlight performance available in, for example, the car-meeting situation on a dry level road, to assign a maximum recommended speed suitable and safe for this particular case. The recommended maximum speed chosen should be such that most of the possible combinations of the other variables are covered, without being too restrictive in the majority of cases.

It is generally believed, and the figures of this report do nothing to dispell such a belief, that many vehicle operators "overdrive" their headlights. Judged by the results of previous work on headlights (for example Ref.1 & 9) there is certainly a need for improvement in automobile lighting systems.

GENERAL CONSIDERATIONS

Stopping distance is comprised of two quite separate components. First there is the distance the vehicle travels during the time that the driver decides that braking is necessary, plus the time he then takes to apply the brakes; the car is assumed to be travelling at the initial speed while this is happening. Then when the brakes are applied, the remaining distance covered is a function of the decelerating force generated at the tire-road contacting surfaces. Since the considerations involved in the calculation of stopping sight distances for highway design are similar to those for the case with no opposing glare, it is proposed to use the data in Ref. 2 for dry and for wet pavements. When opposing glare is present however, it is assumed that the driver will be much more alert with a consequent reduction in the perception plus brake reaction time. The deceleration stages will of course be the same as before for both the dry and the wet pavements respectively.

Attention has already been drawn to the fact that the presence of moisture on the roadway has an important bearing on the degree of deceleration available to a driver. Only so-called "wet" roads will be considered here, on the grounds that pavement surfaces covered with ice, or mud, or with an appreciable amount of free water sufficient to cause hydroplaning, are relatively rare nowadays, and when they do occur many drivers are aware of the large reduction in available friction and so drive at reduced speed.

Another factor that has not been taken into consideration explicitly, is whether or not the road is level in the direction of travel. A downslope can cause quite an appreciable increase in stopping distance. A simple formula for estimating this increase will be introduced later.

The minimum stopping distance in any particular combination of car and pavement is obtained by continuously and skilfully operating the brakes so that all four wheels are in the slip mode at the point where the coefficient of friction is at its maximum (typically at 15% to 20% slip). Unless the vehicle is equipped with an anti-lock device, it would take an expert driver to do this. The average driver will obtain shortest stopping distances if he uses maximum braking effort throughout the manoeuvre, operating in the skid mode (100% slip), at the risk of some spinning about the vehicle's vertical axis. Braking in the skid mode is assumed here.

FRICTION FACTOR.

Since the coefficient of friction between tire and road surface is not constant with velocity, it is convenient to use an averaged value, called the friction factor, f, defined as follows:

$$d = \frac{V^2}{30f}$$

where d = braking distance in feet

V = initial velocity in mph

and the numerical factor looks after the acceleration due to gravity and the mixed units.

Minimum braking distances, with corresponding values of f, for dry and wet level pavements, and for a series of initial velocities have been taken from Ref. 2 and tabulated in Table 1 of this report. These figures were chosen by the authors of Ref. 2 after a study of available experimental results, to be "nearly all inclusive, rather than average", covering "nearly all significant pavement surface types and the likely field conditions ... safe for worn tires as well as for new tires, and for nearly all types of treads and tire composition ... encompass(ing) the difference in vehicle and driver braking from different speeds ... (with) the values ... not ... so low as to be suitable for obsolescent or bleeding surfaces or for pavements under icy conditions".

This data has actually been taken with little change from an earlier edition of the same American Association of State

Highway Officials (AASHO) publication, dated 1954. "Geometric Design Standards for Canadian Roads and Streets" published by the Canadian Good Roads Association (now Roads and Transportation Association of Canada) in 1963, also uses the same original data for design stopping distances.

A search of some of the more recent literature on this subject has been made, but unfortunately the values of brake slip numbers, skid numbers and side force numbers (a "number" as used in this context is a friction coefficient multiplied by 100) which are widely quoted therein are not really comparable with the friction factor, since they are measured at specific velocities only. Suffice it to say that nothing that would indicate that the AASHO values chosen are out of date for their purpose was found. Of a more positive nature, the following items are reported.

Stopping tests from 30 mph using normal tires for comparison with studded tires, on dry and wet old concrete, and new and old bituminous surfaces (Ref. 3(a)) and dry Portland cement concrete (Ref. 3(b)) all gave somewhat shorter stopping distances than the AASHO values.

The authors of Ref. 4 say on p 36 "wet skid numbers of 100 have been measured by the author at 65 mph on a new slag surface placed on the Pennsylvania Turnpike. This illustrates that wet skid numbers in the 70's and 80's at speeds above 60 mph are technically obtainable without great effort. The drastic drop of the skid numbers to 77 on a two-month-old slag section, to 33 on a two-year-old, and to 26 on a four-year-old section placed by the same contractor and tested under the same conditions shows that the real problem is one of maintaining high friction levels over the years and with exposure to heavy traffic".

From Ref. 5 comes the quotation "The conclusion is drawn that the (friction factor information given in the) AASHO 'Policy'

(Ref. 2) is conservative at the low-speed end, for average pavements, but may be realistic for worn or low-quality surfaces and for worn tires. No change in the currently used values is warranted".

PERCEPTION PLUS BRAKE REACTION TIME, T

Both Ref. 2 and Ref. 6 contain useful discussions of the experimental results available, relevant to the choice of what value to choose for T, the perception plus brake reaction time. For design purposes the American Association of State Highway Officials assume a value of 2.5 seconds when calculating stopping sight distances on rural highways (Ref. 2) and since the situations are comparable, this value is chosen for the case of the driver that has no glare from an approaching car to contend with. For the glare case however it is assumed that the driver will be much more alert and his emergency reaction to seeing something on the road ahead is limited almost completely to braking. For this case a value of 1.0 second has been chosen. Supporting evidence for this choice follows.

Reference 6 states that either 0.75 or 1.0 second is generally used for T in the case of urban traffic. In an experiment carried out in Sweden (Ref. 7) using more than 300 alerted randomly chosen highway drivers in a comparable situation, the average value for T was 0.65 second and in less than 10% of the cases was T greater than 1.0 second. From the results of a car following study described in Ref. 8 values of T of 1.0 second or less for alert drivers would seem to be realistic.

In Table 1 total stopping distances have been calculated and tabulated for values of T = 1.0 second and 2.5 seconds. The former corresponds to what can be expected of a driver who is reasonably alert and ready to stop in an emergency - assumed to be the case when he is approaching another car coming in the opposite direction at night. The latter corresponds to the case of a driver cruising along a rural highway at night, two-lane or multi-lane, but who is not approaching another car with the attendant glare problem, and so is not particularly alert.

DISCUSSION

The figures in Table 1 are plotted as 4 separate curves in Fig. 1. To give some idea of what these curves mean for the purpose at hand, Ref. 1 gives the limit of visibility for standard SAE headlights as 200 ft. for the low beam versus low beam case and 460 ft. for the high beam without opposing glare case. From Fig. 1, the corresponding safe speeds to give these minimum stopping distances are 37.5 and 50 mph for wet pavement and 47.5 and 62 mph for dry pavement, respectively.

The effect of departure from the level may be accounted for as follows. For each percentage point of downward slope, 0.01 should be subtracted from the corresponding value of f (if the slope is upwards, it will be added). For example, for a 5% downward slope (a not uncommon value on a rural road) at 55 mph, f is effectively reduced from .30 to .25 on a wet road, adding a further 67 ft. ($336 \times \frac{30-25}{25}$) to the braking distance, giving

$S_{1.0}$ = 484 ft., increased from 417 ft. and

$S_{2.5}$ = 605 ft., increased from 538 ft.

CONCLUSION

As an aid to judging headlight performance, curves giving the minimum stopping distance versus initial speed to be expected of most cars and drivers in most driving situations are given, covering the four night driving cases:

(a) the alert driver meeting an on-coming car on a dry level road

(b) the same, on a wet level road

(c) the normal driver on a rural road with no oncoming traffic on a dry level road

(d) the same, on a wet level road.

REFERENCES

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2. American Association of State Highway Officials "A policy on geometric design of rural highways". 1965.

3. Highway Research Board Record No. 136, 1966.
   (a) p 24-30 "Studded tires - skid resistance and pavement damage" W.B. Burnett and E.J. Kearney.
   (b) p 42-58 "Some tests of studded tires in Illinois". John E. Burke and Lloyd J. McKenzie.

4. Highway Research Board National Cooperative Highway Research Program Report No. 37 "Tentative skid-resistance requirements for main rural highways" H.W. Kummer and W.E. Meyer, 1967.

5. Highway Research Board National Cooperative Highway Research Program Report No. 68 "Application of vehicle operating characteristics to geometric design and traffic conditions" Morton I. Weinberg and Kenneth J. Thorp, 1969.

6. Institute of Traffic Engineers "Traffic Engineering Handbook" 1965.

7. Human Factors, 1971, 13(1) p 23-27 "Drivers' brake reaction times" Gunnar Johansson and Kare Rumar.

8. Highway Research Board Report No. 336, 1970, p 1-20 "The effects of automotive rear-signal system characteristics on driving performance" R.R. Safford, T.H. Rockwell, and R.C. Banasik.

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Table 1

Pavement	V	f	d	$r_{1.0}$	$r_{2.5}$	$s_{1.0}$	$s_{2.5}$
Wet	28	0.36	73	41	103	114	176
	36	.33	131	53	132	184	263
	44	.31	208	65	161	273	369
	52	.30	300	76	191	376	491
	55	.30	336	81	202	417	538
	58	.29	387	85	213	472	600
	61	.28	443	90	224	533	667
	64	.27	506	94	235	600	741
Dry	30	0.62	48	44	110	92	158
	40	.60	89	59	147	148	236
	50	.58	144	73	183	217	327
	60	.56	214	88	220	302	434
	65	.56	251	95	238	346	489
	70	.55	297	103	257	400	554
	75	.54	347	110	275	457	622
	80	.53	403	117	293	520	696

where V= initial velocity, m.p.h.

f= friction factor

d= braking distance in feet, = $V^2/30f$

T= perception and brake reaction time, in seconds

r_T= VT

s_T= d+r_T

For glare case, driver is assumed to be alert, T= 1.0 sec., and for no glare case, T= 2.5 sec.

Source: Ref. 2.

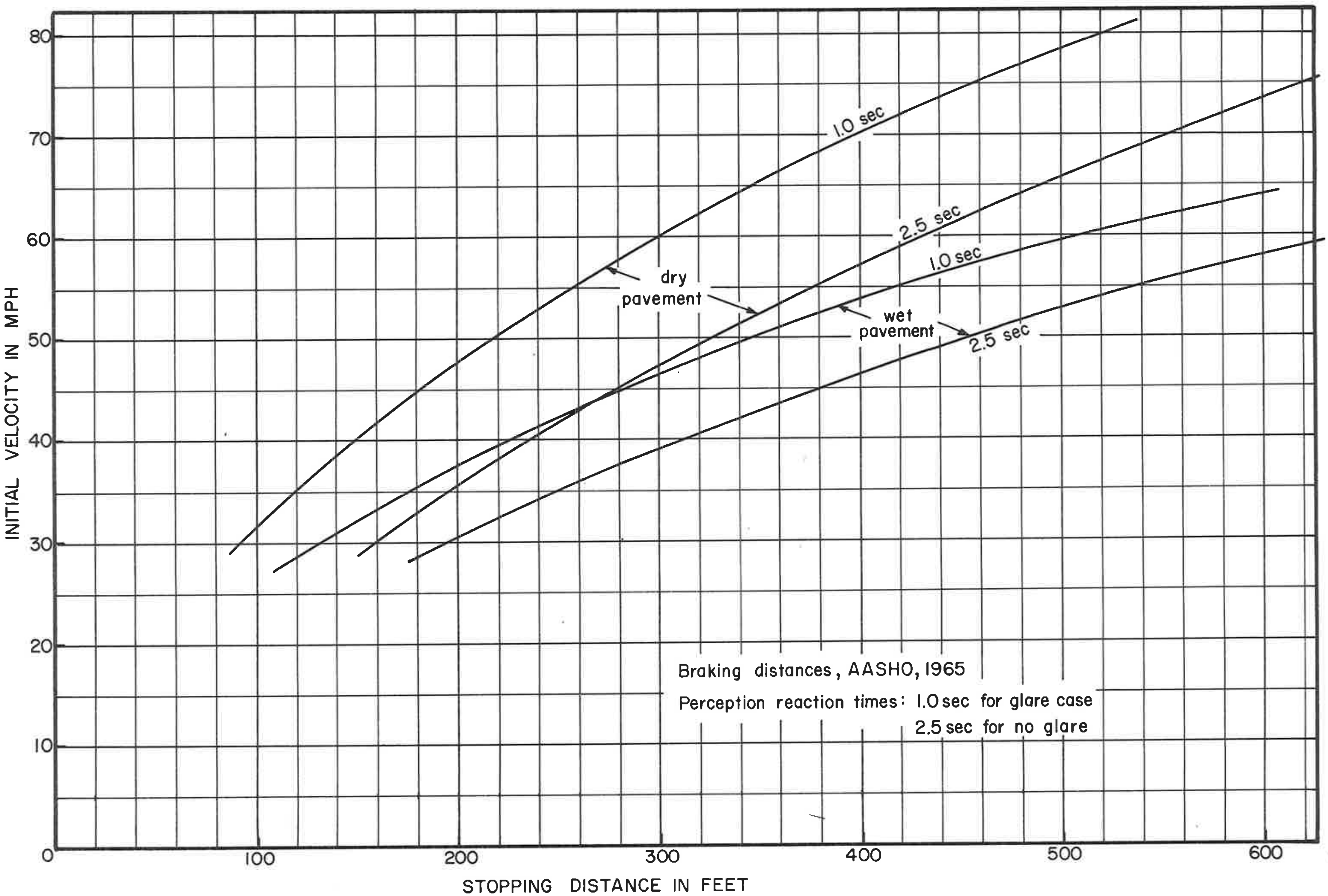
1.0 sec
2.5 sec
1.0 sec
2.5 sec
dry pavement
wet pavement
Braking distances, AASHO, 1965
Perception reaction times: 1.0 sec for glare case
2.5 sec for no glare
INITIAL VELOCITY IN MPH
STOPPING DISTANCE IN FEET
0
10
20
30
40
50
60
70
80
100
200
300
400
500
600

FIG. 1