Effect of Tinted Windshields and Vehicle Headlighting on Night Visibility

EFFECT of TINTED WINDSHIELDS on NIGHTTIME-VISIBILITY DISTANCES

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IN the past several years there have been developments in the glazing of motor vehicles that may affect the visibility distances of roadway obstacles. These developments have been made primarily to provide a glass which is effective in reducing radiant-heat transmission into a vehicle. Chemical compositions, usually utilizing iron, are employed so the glass will absorb a large quantity of infra-red radiation. The changes made to reduce the heat transmission of the glass also reduce the transmission of light in the visible region if the glass is to be at all effective, since most of the heat of the sun is radiated in the visible spectrum. In general, the absorption of infra-red radiation causes the transmittance for safety windshields to be reduced from values in the order of $87\frac{1}{2}$ to $89\frac{1}{2}$ percent for standard safety plate to values in the order of 71 to 73 percent for heat-absorbing and tinted safety plate when using a tungsten filament light source at a color temperature of 2,848 K.

In addition to increasing the heat absorption of the glass itself, other changes have been made in the plastic sheets used to laminate the safety glass. Tinted colors are used in order to increase the comfort of daytime driving. Some of the tinted plastic laminations have a uniform density while others have a graduated density with greatly reduced transmission in a narrow band at the top serving to reduce sky glare.

State officials faced with the problem of approval of safety glass have had to appraise the effect of various glazing materials on the safe operation of motor vehicles. The usual basis for such appraisal is tests made in accordance with American Standards Association specifications (1). The tests normally made on the glazing materials cover the physical factors of strength, stability, quality, and light transmittance. The tinted and heat-absorbing glass produced by the principal manufacturers and now on the market have been found to conform to the ASA Safety Code.

The subject in question is the effect on visibility distances of safety glass having a light transmittance that has been purposely reduced to approximately the ASA minimum of 70 percent. Is the present minimum an adequate requirement, or is it so low as to increase the hazards of night driving when windshields barely meeting the specification are used in place of presently available safety glass having greater light transmission properties?

OBJECT OF INVESTIGATION

It has been the object of this investigation to attempt to establish actual driver test conditions which would indicate whether or not any differencesin nighttime visibility distances result from a change in the color and visible-light transmittance of the windshield.

Since the number of variables in any test of visibility distances is large and since the extent of this test program was necessarily limited, it was felt that the most significant type of test would be one in which drivers were performing under actual roadway conditions with as many of the roadway conditions controlled as possible. This method of attack was selected in lieu of a laboratory test procedure in order to obtain a more readily acceptable evaluation of the effect of tinted windshield glass on visibility distances. Tests were not made against opposing headlamps since data of this type were concurrently being obtained by the Automobile Manufacturers Association (2).

EXPERIMENTAL PROCEDURE

Visibility distances were measured by a recorder mounted inside the vehicle. A drum driven by the speedometer cable through a gear reduction box of approximately 600 to 1 transported paper past a marking pen. The pen produced a continuous line on the unrolling paper strip. When a control button was pressed, the pen moved laterally producing an offset line until the button was released.

The observer-driver momentarily pressed the hand-held button when the roadway object was first seen and then again at the time the object was passed. The distance between the lateral marks on the paper could later be measured with a calibrated scale to obtain the visibility distance for each observation. The gear reduction was such that 1 in. on the paper equalled a distance of 250 ft. traveled by the vehicle. Readings could easily be made to the nearest 5 ft.

The vehicle used for the tests was the technical research unit of the California Highway Patrol, which had a two-piece, curved windshield. The left half of the windshield mounting was modified so the clear glass and the green-tinted glass could easily be interchanged. The tinted glass used in the tests was E-Z-Eye Hi-Test LOF Safety Plate having a visibile light transmittance of 71 percent, measured perpendicular to the surface. An upper 4-in. shaded section gradually increased in density toward the top. Observations were made only through the lower part of the glass having uniform transmittance.

The clear glass employed as a standard was Hi-Test LOF Safety Plate having transmittance of 89 percent. The light transmittance for the particular samples used in the test was measured using a color corrected photocell and a light source at a color temperature of 2,900 K. The values for the tinted and clear glass slanted at 45 deg., as in the vehicle, were found to be 69 and 86 percent respectively. Under these conditions the transmittance of the tinted glass was 20 percent less than that of the clear glass.

The site for the tests was a 2-mi. stretch on the newly completed San Lorenzo to San Leandro section of the East Shore Freeway near Oakland, California. This four-lane, divided highway was paved with longitudinally broomed concrete and had not been opened to traffic. The highway was unlighted and there was no light from opposing headlamps to interfere with vision. All of the test section except a portion at one end was located in an unpopulated area. At a few points luminaires from distant streets came into the field of view causing some disturbance in seeing about three of the objects.

Sixteen objects were used for most of the runs. The first tests were made with objects of different sizes and shapes, and the last ones with all objects the same. No attempt was made to place the objects in exactly the same location for each observer. The car was driven at a speed of 50 mph. with the headlamps on low beam and with the adjustable dash lamps at maximum brightness.

At the beginning of the study, in each of the first three series, all of the observations with one type of glass were run before the windshield was changed. During the last four tests the glass was changed every six runs to reduce possible effects of a gradual change in ambient lighting, driver fatigue, and other conditions with the passage of time.

Two of the observers wore vision-correcting glasses, and one had normal vision without glasses. The observations were made without the driver knowing what the numerical results of his observations were. The observers knew they were being tested, were concentrating on the seeing tasks, and had a knowledge of how the results were to be used. The observations are, however, considered to be unbiased by such knowledge. The long-visibility distances obtained on low beam will not normally apply under average driving conditions where the driver is less alert. The relative distances between tinted glass and clear glass should be reasonably the same.

EXPERIMENTAL RESULTS

The results obtained during the complete series of tests are contained in Tables 1 to 8. The number of runs, the arithmetic mean, and the standard deviation of the observations are given for each object viewed through the clear and the green-tinted windshields.

The difference between the averages is given both in feet and as a percentage of the average for the clear glass. Underlined values indicate the green-glass readings were greater than the clear-glass readings.

The difference divided by its standard deviation (D/σ_d) furnishes an indication of the probability of a significant difference between the two types of glass. Assumptions that there is an actual difference would be correct 84.2 percent of the time for a value of $D/\sigma_d = 1$; 97.7 percent for a value of 2; and 99.9 percent for a value of 3.

The probable error of the difference by standard statistical definition is 0.675 times the standard deviation of the difference expressed as a percentage of the clear glass average. This means that there is a

50-50 chance that the average difference of all possible readings for the same object under the particular conditions existing at the time of the test will fall within the average difference of the observed readings plus or minus the probable error.

The equations used for the standard deviation of the means were

$$\sigma_{\bar{X}} = \frac{\sigma_s}{\sqrt{N-1}} \quad \text{for 30 or more readings,}$$

$$\sigma_{\bar{X}} = \frac{\sigma_s}{\sqrt{N-2}} \quad \text{for 11 to 29 readings, and}$$

$$\sigma_{\bar{X}} = \frac{\sigma_s}{\sqrt{N-3}} \quad \text{for 5 to 10 readings,}$$

The computed standard deviations of the differences are not too reliable, in most cases, due to the small number of observations.

TABLE 1

OBSERVER: W. M. Heath
DATE: 6 December 1951 Half Moon

Object		Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
1.	Westbound	8	304	28	7	287	29	17	19	5.6	±4.2
2.	Westbound	9	305	11	6	290	15	15	10	4.9	±2.2
3.	Westbound	9	305	11	6	283	23	22	14	7.2	±3.1
4.	Westbound	9	578	43	5	511	43	67	35	11.6	±4.1
5.	Eastbound	9	534	74	9	474	40	60	34	11.2	±4.4
6.	Eastbound	9	540	24	8	505	21	35	13	6.5	±1.7
7.	Eastbound	8	440	17	10	409	35	31	15	7.1	±2.4
8.	Eastbound	6	265	26	10	282	20	<u>17</u>	17	<u>6.4</u>	±4.3

Underlined values indicate green average is greater than clear average.

Runs 1 - 12 inclusive - green glass
Runs 13 - 22 inclusive - clear glass

Objects: (first dimension is vertical)
1. Dark-green board (2½ ft. by 1 ft.)
2. Weathered planks in inverted V (3 ft. by 3 in.)
3. Weathered plank (3 ft. by 1 ft.)
4. Light pine box (3 ft. by 1 ft.)
5. Aluminum bucket (8 in. by 8 in.)
6. Light pine box (1 ft. by 3 ft.)
7. Olive-drab box (2½ ft. by 1½ ft.)
8. Dark-green board (1 ft. by 2½ ft.)

TABLE 2

OBSERVER: D. M. Finch
DATE: 20 December 1951 No Moon

Object	Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
Westbound										
1.	11	255	24	9	201	34	54	16	21.2	±4.3
2.	11	386	44	9	325	22	61	18	15.7	±3.1
3.	11	381	24	10	337	37	44	16	11.5	±2.8
4.	11	313	19	9	263	11	50	8	15.8	±1.7
5.	11	344	25	10	328	32	16	18	4.5	±3.5
6.	11	217	37	10	201	18	16	14	7.5	±4.4
7.	11	403	20	10	362	31	41	14	10.1	±2.3
8.	11	447	38	10	400	25	47	16	10.6	±2.4
Eastbound										
9.	11	393	24	8	339	22	54	13	13.7	±2.2
10.	11	316	18	10	251	20	65	10	20.4	±2.1
11.	11	296	22	10	243	20	53	11	18.0	±2.5
12.	11	345	20	9	291	22	54	11	15.7	±2.3
13.	11	310	22	10	264	28	46	13	14.8	±2.8
14.	11	323	28	9	252	23	71	14	21.8	±2.8
15.	11	265	13	10	208	19	57	9	21.4	±2.2
16.	11	389	21	9	349	22	40	12	10.3	±2.0

Runs 1 - 12 inclusive - green glass
Runs 12 - 23 inclusive - clear glass

Objects on drainage curb
Vehicle in right lane

Objects: (first dimension is vertical)
1. Dark-green board (20 in. by 16 in.)
2. Galvanized panel (16 in. by 20 in.)
3. Red, white, and black sign (1 ft. by 1½ ft.)
4. Weathered planks in inverted V (3 ft. by 3 in.)
5. Aluminum bucket (8 in. by 8 in.)
6. Dark-green board (1 ft. by 2½ ft.)
7. Olive-drab box (3 ft. by 1½ ft.)
8. Light pine box (2½ ft. by 1 ft.)
9. Stake on shoulder (3 ft. by 2 in.)
10. Weathered plank (3 ft. by 1 ft.)
11. Weathered planks in inverted V (3 ft. by 3 in.)
12. White sign (1 ft. by 1½ ft.)
13. Light colored rock (approx. 8 in. dia.)
14. Dirt pile (1½ ft. by 3 ft.)
15. Green tool box (15 in. by 8 in.)
16. Aluminum painted drain grate

Table 3 shows the results of tests made using green-tinted glasses. The observer in the series of tests here reported normally wears vision-correcting glasses, and on this particular date he was wearing a green-tinted pair. This fact went unnoticed at the time both by the observer and the passenger, so the results were not prejudiced by such knowledge.

TABLE 3

OBSERVER: B. Andrews (green-tinted glasses)
DATE: 3 January 1952 Quarter Moon during last part of test

Object	Direction	Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
1.	Westbound	19	228	29	19	239	43	11	13	4.8	±3.8
2.	Westbound	20	393	44	18	414	35	21	14	5.3	±2.4
3.	Westbound	19	229	24	20	229	31	0	9	0	±2.8
4.	Westbound	20	318	39	19	343	53	25	16	7.8	±3.4
5.	Westbound	20	344	24	19	351	29	7	9	2.0	±1.8
6.	Westbound	19	412	46	20	430	44	18	15	4.4	±2.4
7.	Westbound	20	445	36	20	482	40	37	13	8.3	±1.9
8.	Westbound	20	206	27	20	221	20	15	8	7.3	±2.6
9.	Eastbound	20	402	19	20	405	39	3	10	0.7	±1.7
10.	Eastbound	19	373	36	20	388	34	15	12	4.0	±2.2
11.	Eastbound	20	313	21	20	326	34	13	9	4.1	±2.0
12.	Eastbound	20	394	38	20	409	54	15	16	3.8	±2.7
13.	Eastbound	19	400	50	19	442	48	42	17	10.5	±2.8
14.	Eastbound	20	287	23	19	291	23	4	8	1.4	±1.8
15.	Eastbound	20	396	40	20	429	73	33	20	8.3	±3.4

Underlined values indicate green average greater than clear average.

Objects on drainage curb
Vehicle in right lane

Runs 1 - 20 inclusive - clear glass
Runs 21 - 40 inclusive - green glass

Objects: (first dimension is vertical)
1. Dark-green board (2½ ft. by 1 ft.)
2. Galvanized metal panel (16 in. by 20 in.)
3. Weathered plywood (6 in. by 24 in.)
4. Weathered plank (3 ft. by 1 ft.)
5. Aluminum pan (1 ft. by 2 ft.)
6. Brown composition sheathing (3 ft. by 5 ft.)
7. Light pine box (3 ft. by 1 ft.)
8. Dark green board (1 ft. by 2½ ft.)
9. Olive-drab box (3 ft. by 1½ ft.)
10. Red, white, and black sign (16 in. by 20 in.)
11. Weathered planks in inverted V (3 ft. by 3 in.)
12. Light wood frame (18 in. by 24 in.)
13. Galvanized metal panel (20 in. by 16 in.)
14. Green toolbox (8 in. by 16 in.)
15. Light wood frame (18 in. by 24 in.)

It was felt the results in Table 3 may also have been influenced by light from the moon which rose during the last half of the runs, especially since all of the clear runs were made first, followed by all of the green runs. In order to determine if there was an increase in visibility distance with learning or with an increasing amount of light, the curves in Figures 1 and 2 were plotted showing the visibility distance versus the order of the runs. The objects selected were the two having the least and the most difference between the green and clear averages in each direction of travel.

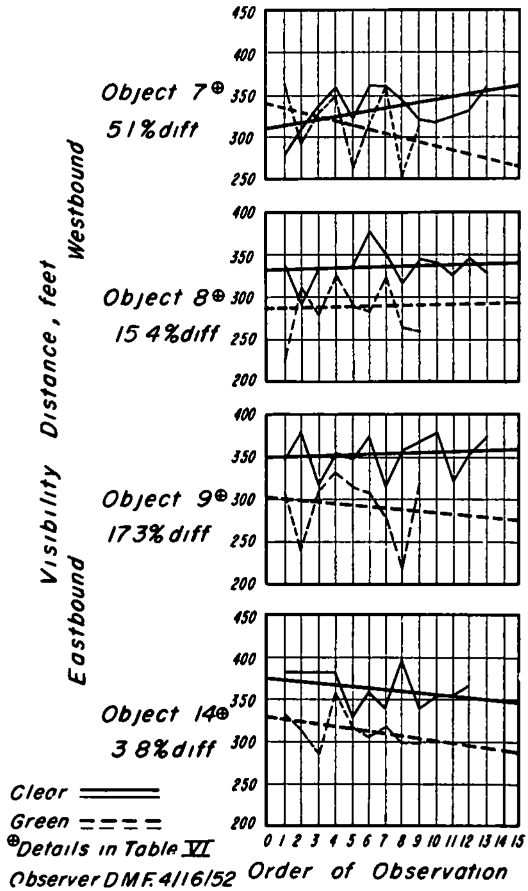

Figure 1. Nighttime-Visibility Distances.

A trend line drawn through the points would indicate changes in seeing distance with the passage of time. Straight-line trends were computed using the method of least squares and employing a moving average of three readings to smooth out the extreme values. For purposes of comparison, Figure 1 is shown with data from Table 6 for a night in which there was no moon and during which the glass was changed every six runs. It can be seen that the trend lines are substantially different for each of the objects shown.

An examination of Figure 2 in which the green-glass values were greater than the clear-glass values shows no trend which was consistent for all the objects selected. There is no general increase in seeing distance with the passage of time as would be the case if the slightly increased illumination due to the moon, or if the driver's learning were to primarily account for the seeing distance being greater with the green windshield than with the clear when tinted glasses were being worn. However, the green readings for the west-bound objects show an upward trend, whereas the reverse is true for the east-bound objects. In the west-bound runs the moon was slightly to the left and behind the observer, and for the east-bound runs it was slightly to the right and ahead of the observer, although at no time was it within the normal field of view while making the runs.

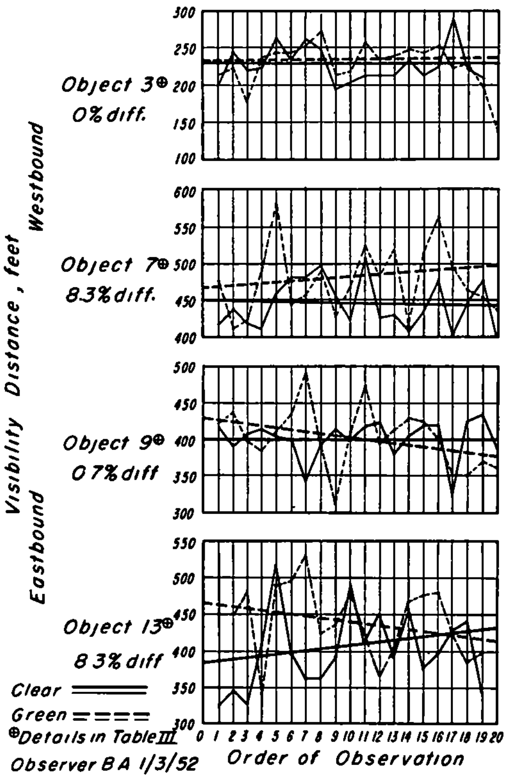

Figure 2. Nighttime-Visibility Distance.

Although all objects were the same for the data shown in Tables 4 to 7, there are considerable differences in the visibility distances of the 16 objects for each observer. A major part of the differences can be traced to the slightly uneven profile of the highway. The pavement was not a perfect plane in a longitudinal direction but had a shallow wave appearance in the daytime. The various objects were therefore lighted by different parts of the headlamp beam, depending upon the locations of the vehicle and object.

An experimental error was introduced into the results by the reaction of the driver when pressing the control button as he was passing the object. The difference between the longest and the shortest recorded distance measured between each pair of objects varied from approximately 20 to 50 ft. Although much of the error may cancel out, it would be well in any future tests to make each run from a fixed starting point. The exact location of each object could thus be fixed on the recording tape.

TABLE 4

OBSERVER: B. Andrews
DATE: 5 February 1952 No Moon

Object		Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
1.	Westbound	6	251	-	3	240	-	11	-	4.3	± -
2.		6	243	-	4	216	-	27	-	11.1	± -
3.		6	287	33	5	243	26	44	27	15.3	±6.3
4.		6	321	-	4	280	-	41	-	12.8	± -
5.		6	309	33	6	271	7	38	19	12.3	±4.2
6.		6	277	14	6	259	16	18	12	6.5	±3.0
7.		4	316	-	6	284	-	32	-	10.1	± -
8.		5	270	23	6	283	41	13	29	4.8	±7.2
9.	Eastbound	6	281	38	7	289	28	8	26	2.8	±6.3
10.		6	240	19	7	245	43	5	24	2.1	±6.8
11.		6	333	35	7	317	35	16	28	4.8	±5.7
12.		5	270	-	2	223	-	47	-	17.5	± -
13.		6	337	70	6	290	24	47	43	13.9	±8.6
14.		6	320	29	7	271	29	49	22	19.6	±4.7
15.		6	290	25	7	247	32	43	22	14.8	±5.1
16.		6	278	38	5	259	21	19	26	4.1	±6.7

Underlined values indicate green average greater than clear average.

Runs 1 - 3, and 11 - 13 inclusive - green glass
Runs 4 - 9 inclusive - clear glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards

Tests cut short because of ground fog forming in patches on last run.

The final series of tests given in Table 8 were made to eliminate some of the variables present in previous tests. Each run was started from a fixed point as suggested above, the speed of the vehicle was reduced from 50 mph. to 40 mph., and the objects used were covered with gray cardboard having a reflectance of 26 percent. The effect of better control of test conditions and an increased number of runs is revealed by the substantial reduction in the variation of percentage differences obtained for identical objects.

TABLE 5

OBSERVER: B. Andrews
DATE: 3 April 1952 Quarter Moon

	Object	Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
Westbound	1.	18	299	36	18	295	23	3	11	1.1	±2.4
Westbound	2.	18	298	36	18	286	38	12	13	4.0	±3.0
Westbound	3.	17	325	32	18	319	34	6	12	1.7	±2.5
Westbound	4.	18	331	33	18	316	23	15	10	4.4	±2.1
Westbound	5.	18	376	23	18	362	44	15	13	3.9	±2.3
Westbound	6.	18	358	27	18	353	28	6	10	1.6	±1.8
Westbound	7.	18	338	24	18	338	37	0	11	0.1	±2.2
Westbound	8.	17	312	40	18	309	72	2	21	0.7	±4.5
Eastbound	9.	17	384	38	17	365	26	19	12	4.8	±2.1
Eastbound	10.	18	354	36	17	339	23	15	11	4.3	±2.0
Eastbound	11.	18	375	46	18	380	44	5	16	1.3	±2.8
Eastbound	12.	18	338	39	16	341	31	3	13	0.9	±2.5
Eastbound	13.	18	417	58	18	371	35	46	17	11.0	±2.8
Eastbound	14.	18	365	43	18	329	29	36	13	9.9	±2.4
Eastbound	15.	17	385	39	18	357	50	28	16	7.3	±2.8
Eastbound	16.	17	343	39	17	317	45	26	16	7.6	±3.1

Underlined values indicate green average is greater than clear average.

Runs 1 - 3, 10 - 15, 22 - 27, 34 - 36 inclusive - green glass
Runs 4 - 9, 16 - 21, 28 - 33, inclusive - clear glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards.

TABLE 6

OBSERVER: D. M. Finch
DATE: 16 April 1952 No Moon

Object	Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
Westbound										
1.	12	328	17	9	296	21	32	10	9.9	±2.0
2.	13	317	29	9	295	39	22	18	7.0	±3.9
3.	12	337	17	9	301	19	36	9	10.8	±1.9
4.	12	335	19	9	297	23	38	11	11.5	±2.2
5.	12	326	32	9	303	17	23	12	7.0	±2.5
6.	12	347	32	9	312	24	35	14	10.0	±2.7
7.	12	331	27	9	314	39	17	18	5.1	±3.7
8.	13	336	18	9	284	32	52	14	15.4	±2.9
Eastbound										
9.	13	354	22	9	293	38	61	17	17.3	±3.3
10.	13	356	29	9	319	14	37	11	10.4	±2.1
11.	13	323	20	9	302	25	21	12	6.4	±2.4
12.	13	346	24	9	298	22	48	11	13.9	±2.2
13.	11	403	33	9	353	19	50	13	12.3	±2.2
14.	11	329	22	9	317	20	12	11	3.8	±2.2
15.	12	338	21	9	288	14	50	9	14.7	±1.7
16.	11	343	28	9	284	27	59	14	17.1	±2.8

Runs 1 - 3, 10 - 15 inclusive - green glass
Runs 4 - 9, 16 - 22 inclusive - clear glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards

TABLE 7

OBSERVER: W. M. Heath
DATE: 1 May 1952 Clear Sky, Quarter Moon

Object	Nc	$\bar{X}_c$	σ_c	Ng	$\bar{X}_g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
Westbound										
1.	6	409	22	7	387	26	22	18	5.4	±3.0
2.	6	408	38	7	393	29	15	26	3.7	±4.3
3.	6	420	56	7	385	37	34	37	8.2	±5.9
4.	6	432	25	7	443	43	10	26	2.4	±4.1
5.	6	431	21	7	425	42	6	23	1.3	±3.6
6.	6	419	32	7	413	30	6	24	1.3	±3.8
7.	6	417	11	7	396	26	21	14	5.1	±2.3
8.	6	418	22	7	418	37	0	22	0.1	±3.6
Eastbound										
9.	10	564	55	11	526	44	38	25	6.7	±3.0
10.	10	407	30	11	392	34	15	16	3.7	±2.7
11.	10	474	48	11	457	52	17	25	3.6	±3.6
12.	10	405	30	11	396	33	9	16	2.1	±2.6
13.	10	556	61	11	512	58	44	30	7.9	±3.7
14.	10	442	20	11	421	44	21	17	4.7	±2.5
15.	10	448	28	11	414	35	24	16	5.4	±2.4
16.	10	441	46	11	412	29	29	20	6.6	±3.0

Underlined values indicate green average greater than clear average.

Runs 1 - 3, 10 - 15 inclusive - clear glass
Runs 4 - 9, 16 - 22 inclusive - green glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards

TABLE 8

OBSERVER: W. M. Heath
DATE: 24 October 1952

Object	Direction	Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
1.	Northbound	28	415	34	27	396	42	19	11	4.6	±1.8
2.	Northbound	27	413	35	27	401	46	12	12	2.9	±1.9
3.	Northbound	27	409	40	28	395	82	14	10	3.5	±1.5
4.	Northbound	24	414	52	28	385	61	29	17	7.0	±2.7
5.	Northbound	24	419	44	28	410	58	9	15	2.1	±2.4
6.	Southbound	28	395	62	30	375	32	20	14	5.1	±2.4
7.	Southbound	28	417	21	31	391	38	26	7	6.3	±1.2
8.	Southbound	26	428	37	30	403	33	25	10	5.9	±1.5
9.	Southbound	25	443	46	31	418	38	25	12	5.7	±1.8
10.	Southbound	25	480	45	31	448	49	32	13	6.6	±1.8

Runs 1-10, 21-30, 41-50, and 61-64 inclusive -- clear glass
Runs 11-20, 31-40, and 51-60 inclusive -- green glass

Objects located to right of vehicle

Objects: 8 in. by 12 in. gray cardboard having 26 percent reflectance.

DISCUSSION

The tests were undertaken after a preliminary study made by us in 1951 showed a need for more extensive data (3). The previous experiments consisted of two runs each by five observers and employed three objects. The data gave changes in seeing distance of from + 6 percent to -71 percent, depending on the object and the observer. The results were not considered conclusive, due to the wide variations in readings and the small number of runs.

The present study did not include runs against opposing headlamps as such tests using heat absorbing glass were being made in Florida by the Automobile Manufacturer's Association (2). Results of the Florida study show values for one of the objects comparable to those we obtained. Table 9 gives data from the AMA report on the last object approximately 1,700 ft. past the meeting point.

The values of the probable error of the difference were computed by us. The last object was picked as a comparison since conditions of no glare similar to the tests reported herein prevailed. The 16-in.-square objects used in the Florida tests had a reflectance of 7.5 percent and thus were considerably darker than the unfinished boards used in our tests which had a reflectance of approximately 36 percent.

TABLE 9

VISIBILITY DISTANCE DATA FROM AMA REPORT*

Observer	N_c	$\overline{X}_c$	σ_c	N_{ha}	X_{ha}	σ_{ha}	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.	ft.	%	%
Devine	30	250	28	30	235	33	15	8	6.0	±2.2
Boylan	30	310	34	32	280	33	30	9	9.7	±1.9
Besch	30	288	33	30	270	30	18	8	6.3	±1.9
Wagar	31	283	45	30	266	34	17	10	6.0	±2.5

*Subscript c refers to clear glass; subscript ha to heat-absorbing. For explanation of other symbols see legend.

The results in the present study show great variations in the effect of tinted glass on visibility distances as compared to clear glass. The greater part of the data obtained showed considerable reduction in visibility where the green glass was used, although there are several instances where the tinted glass gave higher readings than the clear glass. It does not appear feasible to assign an over-all percentage value to represent the difference between the two types of glass.

When the original tests were made, it was thought at first that the differences in percentage reductions were due to the size, color, and contrast of the different objects. The later tests, however, show the same extreme variations in percentage differences for a given observer, even though all objects used were practically identical. A study of the data fails to show a consistent relationship between percentage difference and any of the other recorded variables to account for the variations.

The use of tinted windshields appears to cause a reduction in visibility distances in night driving. Though the percentage difference between the types of glass appears small in some instances, the measured difference in seeing distance should not be lost sight of. Distances of from 10 to 70 ft. might easily mean the difference between striking an object and avoiding it.

It is recommended that the 70-percent-minimum luminous transmittance requirement for windshields in the American Standard Safety Code Z26.1-1950 be reconsidered in view of the present data.

The tests reported upon above were made under the best of roadway conditions and further tests are believed necessary to indicate the effect of tinted glass under adverse weather conditions. Effort should be made in future tests to rigidly control all known variables in the hope that reproducible results may be obtained on identical objects viewed by the same observer.

LEGEND

X = visibility distance in feet
N = number of observations
$\bar{X}$ = arithmetic mean of observations, $\frac{\Sigma X}{N}$, in feet
σ = standard deviation of observations, in feet

$$= \sqrt{\frac{\Sigma (X-\bar{X})^2}{N}}$$

D = difference between arithmetic means of clear glass and tinted glass visibility distances, in feet. Data are underlined where tinted glass values were greater than clear glass values.

σ_d = standard deviation of the differences between clear glass and tinted glass visibility distances.

$$= \sqrt{(\sigma_{\bar{X}_c})^2 + (\sigma_{\bar{X}_g})^2}$$

subscript c = values for clear glass
subscript g = values for green-tinted glass
subscript ha = values for heat-absorbing glass

Percent Difference $= \frac{D}{Xc} \times 100$

Percent Probable Error $= 0.675 \frac{d}{Xc} \times 100$

REFERENCES

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3. Roper, Val J., Nighttime Seeing Through Heat-Absorbing Glass Windshields, 1952.