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ASPECTS OF ROAD LAYOUT THAT AFFECT DRIVERS' PERCEPTION AND RISK TAKING

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ABSTRACT

Various road locations were investigated by requiring 60 volunteer drivers to make assessments of risk on a 16 mile route. The route covered a wide range of road types and hazards, eg rural dual carriageways, narrow sub-urban roads, sharp hill crests, level crossing. The locations were ordered on these subjective evaluations and compared with the ranking on objective risk which was obtained from accident and traffic flow data. At some locations wide discrepancies were found between the subjective and objective risk levels. Possible reasons for these differences are discussed.

Drivers' speeds were also recorded on the 16 mile route and at those locations where drivers were generally able to set their own speed, the forward visibility distances were measured. This allowed the calculation of a measure of safety margin. It was found that at one left-hand bend almost all drivers tested adopted a negative safety margin. Recommendation for improving this and similar sites are made.

1. INTRODUCTION

The on-the-spot road accident investigation of over 2000 road accidents reported by Sabey and Staughton[1] allowed an assessment of the possible importance of environmental factors in accident causation. Through inspections of road environments and in-depth interviews with drivers and passengers shortly after the events, they concluded that road environmental factors were judged to be contributory in 28 per cent of these accidents. Important factors identified included: misleading visual information provided by poor road design, insufficient and ambiguous signing, obstructions in the carriageway and slippery road surfaces.

Singleton[2] notes that the human operator is able to trade off his error rate against speed of operation, attention and effort. Where the perceived risk is less than the actual risk, in situations where errors may lead to accidents, he may select a non-optimum trade-off. This may unnecessarily increase the probability of accidents. A study which illustrates this notion was carried out by Dunn[3] who asked chain saw operators to rank, on a scale of risk, the parts of the body which were likely to be injured. The objective risk was obtained from an analysis of 250 accidents reported to the Forestry Commission. It was established that although operators were consistent in their rankings, there was no significant correlation between the subjective and objective rankings. It was concluded that one strategy of accident prevention is to try to ensure that an operator's subjective risk model corresponds closely to reality.

The possible presence of misleading situations on a 16 mile test route was examined using subjective assessments of risk made by 60 drivers. Using accident and traffic flow data it was possible to estimate the objective risk and allow the identification of situations which were often incorrectly perceived. It was considered that the results should indicate problem locations for drivers in general, since a reasonably representative cross-section of drivers was used for assessing risk levels.

A number of countermeasures are suggested which are aimed at reducing the accident risk at these locations. Attention is also given to the safety margins adopted at bends and hill crests on the test route. The calculation of the safety margins was based on the measurement of sight-line distances and estimates of stopping distance. It was therefore possible to isolate high risk locations on the basis of whether or not a large proportion of drivers tested set very small or negative safety margins.

2. METHOD

2.1 Subjects

The drivers used for the tests were recruited from the general motoring public. The names and addresses were obtained from the electoral roll of towns within 20 miles of the laboratory, ie Reading, Maidenhead, Slough, Farnborough and Aldershot, and house calls were made by experienced interviewers. Sampling was carried out so that the age profile and the proportion of female drivers corresponded with national exposure data[4]. All subjects recruited held full driving licences and were required to bring a car since a road test would be involved.

The subjects carried out a number of additional tests reported elsewhere[5].

2.2 Subjective risk

A 16 mile route was selected which contained a wide range of road types (eg suburban and rural single and dual carriageway sections) and hazards (eg sharp bends, brows, junctions with poor visibility, a hump back bridge). Forty-five locations on this route were selected, including a variety of hazards and some relatively safe sections of road.

A description of the locations is given in Table 1 and a map of the test route is given in Figure 1. At these points subjects were cued to give a verbal rating of risk on an 11 point scale. The zero end of the scale represented 'no chance of a near miss' and the high end represented a 'good chance of a near miss'. A near miss was defined as a situation involving severe braking or swerving on the part of the driver, or on the part of another driver attempting to avoid the subject's car. This definition is adapted from the conflict research[6] conducted at TRRL. A near miss would be equivalent to a type 3 conflict. The subject gave the rating while driving and his assessment was recorded on one track of a stereo tape recorder controlled by the experimenter who sat on the rear seat. The experimenter noted the road location on the other track of the tape and also recorded the speed as indicated by the speedometer. The minimum value was taken for bends and hill crests where speed changes were relatively rapid. Subjects were instructed to drive around the test route twice. On the first occasion the rating task was practised and only the results from the second trial were used in the analysis.

In the analysis of the results these ratings were used to provide a ranking of the locations in terms of subjective risk.

2.3 Objective risk

Reported injury accidents occurring in daylight hours during the period 1973 to 1976 inclusive were used to calculate the measure of objective risk. Official accident records (Stats 19) record a six figure grid reference to aid location. Accidents which occurred at junctions were easy to locate but in the case of accidents occurring between junctions it was impossible to determine the precise location. For this reason

TABLE 1

Description of measurement points on 16 mile test route

Location number	Description of location	Speed limit (mph)	Road class	Manoeuvres required of subjects to follow route
1	Rural, Traffic lights	50	Unclassified	Right turn onto another road
2	Rural, Straight	50	Unclassified	Continue on major road
3	Rural, Junction on left	50	Unclassified	Continue on major road
4	Rural, Brow	50	Unclassified	Continue on major road
5	Rural, Right bend Junction on left	50	Unclassified	Steer right
6	Rural, Left bend	50	Unclassified	Steer left
7	Rural, Junction on left	50	Unclassified	Turn left off the major road
8	Rural, Level crossing	50	Unclassified	Slow
9	Rural, Right bend	50	Unclassified	Steer right
10	Rural, T-junction Restricted visibility	50	Unclassified	Give way and turn right onto major road
11	Suburban, Junction on left	40	'A'	Continue on major road
12	Suburban, Staggered junction	40	'A'	Continue on major road
13	Suburban, Junction on left	40	'A'	Continue on major road
14	Suburban, Roundabout	40	'A'	Give way and continue on major road
15	Suburban, Dual carriageway	60	'A'	Continue on major road
16	Suburban, Dual carriageway	40	'A'	Continue on major road
17	Suburban, Roundabout	40	'A'	Give way and continue on major road
18	Rural, Junction on left	50	'A'	Continue on major road
19	Rural, Crossroads	50	'A'	Turn right off major road
20	Rural, Brow	50	'B'	Continue on major road
21	Rural, Hump-back bridge	50	'B'	Continue on major road
22	Rural, Straight	50	'B'	Continue on major road
23	Rural, T-junction Restricted visibility	50	'B'	Give way and turn right onto major road
24	Rural, Straight	50	'A'	Continue on major road
25	Rural, Brow	50	'A'	Continue on major road
26	Rural, Straight	50	'A'	Continue on major road
27	Rural, Roundabout	50	'A'	Continue; have right of way into roundabout
28	Rural, Roundabout	50	'A'	Give way and turn right onto dual carriageway
29	Rural, Straight Dual Carriageway	60	'A'	Continue on major road
30	Rural, Straight Dual Carriageway	60	'A'	Continue on major road
31	Rural, Straight Dual Carriageway	60	'A'	Continue on major road
32	Rural, Junction on left Dual Carriageway	60	'A'	Continue on major road
33	Rural, Right bend	50	'A'	Steer right
34	Suburban, Staggered junction	30	'A'	Continue on major road
35	Suburban, Garage on left	30	'A'	Continue on major road
36	Suburban, Junction on left	30	'A'	Turn left off major road
37	Suburban, Left bend	30	Unclassified	Continue on major road
38	Suburban, Shopping centre	30	Unclassified	Continue on major road
39	Suburban, Straight	30	Unclassified	Continue on major road
40	Suburban, Straight	30	Unclassified	Continue on major road
41	Suburban, Straight	30	Unclassified	Continue on major road
42	Suburban, Straight Dual Carriageway	60	'A'	Continue on major road
43	Suburban, Pedestrian crossing	50	'A'	Continue on major road
44	Suburban, Pelican crossing	50	'A'	Continue on major road
45	Rural, Staggered junction	50	'A'	Turn right off major road

only accidents occurring within ± 100m of the measurement points were used for comparative purposes.

However, Bull and Roberts[7] and Hobbs et al[8] have shown that not all injury accidents are reported to the police and that serious under-reporting occurs for single vehicle accidents[7]. For this reason it is possible that the accident data for the rural bends and brows may be incomplete since these are the locations where it would be expected that this type of accident occurs. The reported accident descriptions were also incomplete since the directions of travel of the vehicles involved in the incidents are not recorded. A further problem was the alteration of parts of the test route during the period of testing the subjects (approximately 6 months). For example resurfacing occurred on the A3095 and a pelican crossing was installed at location 44 (see Figure 1). In addition 'economy' speed limits of less than 70 mph were in force on the rural sections of road.

Thus only a crude measure of objective risk could be obtained at the locations where subjective evaluations were made. The objective risk was based on the number of daylight accidents per 10^8 vehicles using the site, since a high accident frequency does not necessarily reflect a high risk if the vehicle flow rate is also high. Flow counts were taken between 9.30 am and 4.00 pm during September 1975.

2.4 Definition and calculation of safety margin

At 16 locations on the test route, drivers were generally able to set their own speed since traffic flow levels were low and there were no traffic controls such as traffic lights or give-way signs. Because driving was essentially self-paced at these locations it was possible to define the risk levels or safety margins that drivers were adopting. The definition of safety margin chosen was the difference between the distance ahead (measured along the road) that was visible and the overall stopping distance. If the stopping distance exceeds the visibility distance the driver is at risk since he will not be able to stop before an obstruction that may suddenly become visible on the road such as a pedestrian, a parked car or a tree branch. He can of course swerve across the road but this is a hazardous manoeuvre since oncoming vehicles may be present.

The overall stopping distance will depend on the driver's speed, deceleration rate, and the time it takes for the driver to perceive the hazard and commence corrective action. For the construction of roads in rural areas[9] the total reaction time is taken to be 2s and the deceleration rate 0.33g. The figure of 2s is in reasonable accord with the result of 1.85s obtained by the authors[5] for the reaction time to simulated hazardous traffic incidents when allowance is made for movement time from accelerator to brake. Emergency braking on straight, dry and level roads is assumed to be 0.67g in the Highway Code. However, levels of braking would probably need to be lower on sharp bends and hill crests in order to reduce the chances of loss of control.

It was assumed in calculating the safety margin at bends and hill crests that the minimum speed at a bend or hill crest site occurs at the point of minimum sight-line distance. In fact a small pilot study[5] showed that the median difference between the minimum speed observed and the speed at the point of minimum sight-line distance was just over 2 mph and so the assumption was substantially correct.

2.5 Measurement of sight-line distance

The forward visibility or sight-line distance was measured according to the instructions given in the advisory manual[9]. This requires that sight-line distances be measured between points 1.05m above the centre of the lane on the inside of the bend. The sight-line distance was measured by closing the section of road to be studied by restricting traffic to single file past the site by means of appropriate signs and traffic controls. An observer, standing in the middle of the lane, and viewing at a height of 1.05m, sighted a mark on a target rod at a similar height. The target rod was held by an assistant who also stood in the middle of the lane for which measurements were being taken. The assistant, who was in radio contact with the observer, receded until the observer could no longer see the mark on the target rod. The shortest distance between observer and target holder, measured along the lane was recorded as the sight-line distance at that point. At seven locations, at hill crests and bends, the sight-line distance changed rapidly along the section of road and so visibility measurements were made at several points on the approach and through the actual hazard in order that the minimum sight-line distance could be obtained.

3. ANALYSIS

3.1 Comparison between objective and subjective risk

For each driver, the locations were given ranks based on the assessments of risk made during the road test. For each of the 45 locations the sum of the ranks over the 60 drivers was calculated and these totals were used to derive the final ranking. These are shown in Table 2. Kendall[10] suggested that the best estimate of the 'true' ranking is provided (if agreement between judges is significant) by the order of these sums of ranks. Agreement between drivers was found to be significant at the 0.1 per cent level; the Kendall coefficient of concordance was 0.34 when corrected for ties. Using the Friedman two-way analysis of variance[11] it was shown that the locations differed significantly, in terms of subjective risk levels; $\chi_r^2 = 542$ being significant at the 0.1 per cent level.

The ranking of locations on objective risk was based on the accidents per 10^8 vehicles using the site. The rankings are given in Table 2 with details of accident totals, flow and accident rate.

The Spearman rank correlation coefficient (Spearman's rho) was used to determine the degree of agreement between subjective and objective risk. The coefficient was found to be 0.37 which was significant at the 1 per cent level. Since agreement was not perfect, differences were found in the rankings and these are also listed in Table 2. Locations which have a negative difference indicate sites which are under-rated, the relative perceived risks being less than the relative objective risks. Positive differences indicate locations which are over-rated. Table 3 lists the five most under- and over-rated locations. It is interesting to note that eleven injury accidents were reported in four years at the under-rated locations while no accidents were reported at sites which were over-rated.

3.2 Safety margins adopted

The mean safety margins adopted at the 16 sites where vehicles were generally freely moving are listed in Table 4. As expected the margins were found to be smallest at vertical and horizontal curves and these are the sites where remedial measures may be necessary.

In Figures 2 to 8 showing the variations of sight-line distances through the sites, the stopping distances are drawn for the average speeds and also for one standard deviation above and below these averages. In this way it is easy to obtain an indication of site safety by noting the proportion of drivers who have positive safety margins. For each site three values of safety margin were calculated [d(mean), d(low) and d(high)]based on the three stopping distances. These are listed on each figure. Figure 2 shows how these margins are defined.

TABLE 2

Objective and subjective levels of risk

Location reference number	Brief description	Total accidents in daylight during 1973–76 inclusive	Average hourly flow	Accidents per 10^8 vehicles	Ranking based on objective risk	Ranking based on subjective risk	Difference in rank
1		5	229	128	44	23	–21
2	Rural	0	214	0	8	1	–7
3	Unclassified	1	214	27	31	24	–7
4	50 limit	1	103	57	39	13.5	–25.5
5		3	103	170	45	38	–7
6		1	159	37	34	35	+1
7		2	159	74	42	17	–25
8		0	150	0	8	40	+32
9		1	150	39	36	41	+5
10		3	150	117	43	45	+2
11	Suburban	1	1221	5	16	19	+3
12	'A' Road	2	1221	10	26	25	–1
13	40 limit	0	1221	0	8	15	+7
14		2	1221	10	26	28	+2
15	Suburban 'A' Road dual carriageway 60 limit	1	774	8	22	10	–12
16	Suburban 'A' Road	1	911	6	17.5	11	–6.5
17	dual carriageway 40 limit	1	911	6	17.5	16	–1.5
18	Rural 'A' Road	0	911	0	8	20	+12
19	50 limit	8	911	51	37	42	+5
20	Rural 'B' Road	0	97	0	8	4.5	–3.5
21	50 limit	0	97	0	8	43	+35
22		0	97	0	8	7	–1
23		1	97	60	41	34	–7
24	Rural 'A' Road	0	825	0	8	8	0
25	50 limit	1	825	7	20	18	–2
26		1	825	7	20	12	–8
27		1	825	7	20	37	+17
28		0	N/A	0	8	32.5	+24.5
29	Rural 'A' Road	2	749	16	29	4.5	–24.5
30	dual carriageway	0	749	0	8	3	–5
31	60 limit	0	749	0	8	9	+1
32		1	749	8	23.5	32.5	+9
33	Rural 'A' Road 50 limit	0	749	0	8	36	+28
34	Suburban	7	749	55	38	44	+6
35	'A' Road	3	749	23	30	22	–8
36	30 limit	1	749	8	23.5	31	+7.5
37	Suburban	1	101	58	40	29	–11
38	Unclassified	0	101	0	8	39	+31
39		0	118	0	8	26	+18
40	30 limit	1	205	29	32	13.5	–18.5
41		0	205	0	8	6	–2
42	Suburban 'A' Road dual carriageway 60 limit	1	436	13	28	2	–26
43	Suburban 'A' Road	1	611	10	26	21	–5
44	50 limit	3	611	29	33	30	–3
45	Rural 'A' Road 50 limit	4	611	38	35	27	–8

TABLE 3

Under- and over-rated hazards

Location	Description	Difference in rank
	UNDER-RATED HAZARDS	(Eleven accidents in total)
42	Suburban dual carriageway near a pedestrian bridge	–26.0
4	A rural brow on a single carriage-way road	–25.5
7	A left turn off a rural road	–25.0
29	A derestricted rural dual carriageway site near a picnic area	–24.5
1	Rural X-roads controlled by traffic lights	–21.0
	OVER-RATED HAZARDS	(Zero accidents in total)
21	Hump bridge on a rural road	+35.0
8	Level crossing on a rural road	+32.0
38	A suburban shopping centre in a 30 mph limit	+31.0
33	Right bend at the end of a rural dual carriageway	+28.0
28	Right turn onto a rural dual carriageway	+24.5

TABLE 4

Data and derived indices for locations where vehicles are often freely moving

Location	Description of location	Lane width (m)	Minimum sight-line distance (m)	Average speed (mph)	Stopping distance (m)	Safety margin (m)	Rank of safety margin	Rank of subjective risk
2	Straight	3.25	551.6	42.0	92.1	+459.5	14	16
3	Straight	3.30	100.1	31.0	57.5	+ 42.6	7	6
4	Brow	2.80	125.4	40.5	86.9	+ 38.5	6	7
5	Right bend	2.78	47.4	22.7	36.3	+ 11.1	5	3
6	Left bend	2.80	24.2	26.4	45.2	– 21.0	1	4
9	Right bend	2.72	30.3	18.7	27.5	+ 2.8	3	2
15	Straight (dual-carriage)	6.70	339.0	38.5	80.3	+258.7	12	8
20	Brow	2.75	243.2	39.8	84.6	+158.6	8	12.5
21	Brow	2.50	51.5	28.0	49.3	+ 2.2	2	1
22	Straight	2.70	301.3	39.0	81.9	+219.4	11	10
29	Straight (dual-carriage)	7.30	1203	49.7	120.8	+1082.2	16	12.5
30	Straight (dual-carriage)	7.30	574.3	53.0	134.2	+440.1	13	14
31	Straight (dual-carriage)	7.20	789.0	51.5	128.0	+661.0	15	9
37	Left bend	2.80	56.3	26.9	46.5	+ 9.8	4	5
41	Straight	3.40	237.7	34.4	67.4	+170.3	9	11
42	Straight	8.30	287.3	43.8	98.5	+188.8	10	15

The safety margins adopted at the shallow vertical curves (locations 4 and 20) shown in Figures 2 and 6, even at speeds of one standard deviation above the mean, are positive by a large amount, ie +21.8 and +141.4m. At the hump bridge (Figure 7) at location 21 however, nearly 50 per cent of drivers adopt a negative safety margin. In fact the fastest 16 per cent of drivers have a safety margin of approximately −13.0m or less.

Considering horizontal curves it can be seen from Figure 4 that the left bend at location 6 creates a situation where nearly all drivers were found to have a negative safety margin, the average safety margin being −21.0m. At the left bend in the suburban area (location 37) the safety margin was positive for approximately 85 per cent of drivers as can be seen from Figure 8. Figures 3 and 5 show the situation at the two right bends (locations 5 and 9). At location 5, over 85 per cent of drivers adopted a positive safety margin and over 50 per cent of drivers had a positive margin at location 9.

It was expected that drivers would be aware of the risk resulting from restrictions in forward visibility and their own speeds. The 16 locations were therefore ranked on size of safety margin and on subjective risk levels (Table 4). Agreement was remarkably good, ie the Spearman rank correlation coefficient (r_s) was found to be 0.80. Controlling for road width, by selecting only the 11 single carriageway sites, the value of r_s increased to 0.88.

3.3 Factors affecting speeds on bends

Consideration was given to likely factors that could exert an influence on average vehicle speeds at bends and therefore the safety margins that are adopted. Such factors as visibility, road width, camber, surface and radius may be important. Perhaps the most studied characteristic is the radius of the curve; see for example Taragin[12], Department of the Environment[9] and Emmerson[13]. Emmerson, for example, empirically derived the formula

$$V = 74\,[1 - \exp(-0.017r)], \quad r \text{ in metres and } V \text{ in km/h.}$$

The Department of the Environment gives the average speed on a bend in imperial units as

$$V = 2\sqrt{r} \quad \text{for speeds up to 35 mile/h (56 km/h), r in feet and V in mile/h.}$$

To determine whether the observed speeds in the present study could be predicted simply from the bend radius, actual and predicted values were compared. To enable the predicted values to be calculated the bend radii at the four bend sites were determined by measuring the arc lengths between tangent points of the approach roads to the curves, and determining the angular deflections of the roads from large scale (2½ inch to the mile) Ordnance Survey maps. The radius of a curve was then given by arc length ÷ angle in radians. The expected average speeds, derived from the two formulae, and the observed speeds are listed in Table 5.

In three cases out of four the formula $V = 2\sqrt{r}$ gave the best prediction. Using this formula the agreement was remarkably good at the rural bends, the largest difference being only 1.5 mile/h (2.4 km/h). At the suburban site, the presence of a 30 mile/h (48 km/h) speed limit and school entrance near the apex may have resulted in the observed speed being less than that predicted. This is plausible since the expected figure is actually in excess of the speed limit. From the limited data available, it would appear that bend radius is an important factor in determining speed at the rural sites.

TABLE 5

Predicted and actual speed on bends

Location	Radius of bend (m)	Observed speed mph (km/h)	Predicted speed (DOE formula)	Difference	Predicted speed (Emmerson formula)	Difference
RURAL BENDS						
Location 5 (Right bend)	34.2	22.7 (36.5)	21.2 (34.1)	+1.5 (2.4)	20.3 (32.7)	+2.4 (3.9)
Location 9 (Right bend)	25.6	18.7 (30.1)	18.3 (29.5)	+0.4 (0.6)	16.2 (26.1)	+2.5 (4.0)
Location 6 (Left bend)	48.3	26.4 (42.5)	25.2 (40.6)	+1.2 (1.9)	25.8 (41.5)	+0.6 (1.0)
SUBURBAN BEND						
Location 37 (Left bend)	74.9	26.9 (43.3)	31.4 (50.5)	–4.5 (–7.2)	33.1 (53.3)	–6.2 (–10.0)

Another factor of importance could be the road width. Farouki and Nixon[14] developed an empirical equation using data obtained from freely moving vehicle speeds on suburban roads of various widths. The best fit to the data was found to be $V = 30.0 + 2.80w$, where w is road width in metres and V is in km/h. On the single carriageway roads in this study, road width varied between 5.4 and 6.8m which could result in an expected speed difference of approximately 2 mile/h (3.2 km/h). Adverse cambers and poor surface conditions[15] would also be expected to reduce speeds. Where sight-line distances are severely restricted, for example at location 6, some further reduction of speed would also be thought likely.

4. DISCUSSION

4.1 Variation in perceived risk

The significant agreement between drivers' rankings of the locations suggests that different drivers are applying essentially the same criteria in estimating risk levels. The strong association between rankings on perceived risk and those based on the measure of safety margin ($r_s = 0.88$) indicates that drivers were aware of the differences between forward visibility distances and their stopping distances and were able to represent the risk reasonably accurately using the rating technique. This is some support for the validity of the risk rating method of obtaining levels of perceived risk. Applying the Friedman two-way analysis of variance test to the sums of ranks, there was shown to be a significant difference, at the 0.1 per cent level, between locations.

Taylor[16], on the basis of skin conductance measurements taken on the road, proposed that driving was a self-paced task governed by the level of emotional tension or subjective risk that the driver was prepared to tolerate. In this model speed is adjusted so that the risk level experienced remains constant. This model would not be expected to apply where the behaviour of other road users contributes substantially to the level of risk experienced, and the driver cannot easily reduce the level of risk by his own actions, eg driving in central London or on a busy motorway. However, it may be thought to be applicable where drivers are freely able to set their own speeds, although the results from the present study do not fully support this notion.

4.2 Misperception of hazards

In contrast to the findings of Dunn[3] the results of the present study showed significant association between rankings of the locations on subjective and objective risk levels. However the association was weak ($r_s = 0.37$) and the possibility therefore exists that the hazards, at some locations at least, may have been incorrectly assessed by many of the drivers. Only a tentative analysis of the differences is possible because of the inherent unreliability of the accident data. For this reason, only sites where gross differences occurred were examined. The method would be more appropriate for examining misperceptions at high accident risk locations (it should be noted that the highest accident rate on this route was only 8 accidents in 4 years). With large numbers of accidents greater precision in estimating the 'true' average objective risk could be achieved. Table 3 lists the five most over- and under-rated locations.

Location 42 on a suburban dual carriageway had the largest difference in rankings. A single-vehicle accident had occurred in the area of the measurement point but its precise location cannot be determined since it did not occur at or near a road junction. The sight-line distance of 290m is adequate at this location and this probably contributed to the relatively low risk ratings. Little could be learned from accident details so it is difficult to suggest causes.

The rural brow at location 4 was the scene of one single-vehicle accident in the four year period. The average safety margin was 39m on the 1.05 criterion, but using a 0.15m target height (as used in the United States) it was found the average dropped to –14.0m. This could have been a contributory factor in the accident that had occurred if it involved an object that would not have been visible with the lower target height, such as a tree branch or a large pot-hole.

The third most under-rated site was at location 7, a rural T-junction, where drivers were required to turn left off the major road. Three accidents had occurred in daytime during the four year period. The rural nature of the junction and the low traffic flow levels probably contributed to the relatively low rating. Some drivers who are required to give way may not expect vehicles to appear on the major road and consequently may emerge dangerously. The role of expectancy is likely to be of importance at this and other misperceived locations.

Location 29, a straight stretch of rural dual carriageway where the sight-line distance is 1200m was also under-rated. The excellent visibility and wide segregated carriageways would have led to the relatively low risk ratings. However there is a gap in the median strip at this point which allows vehicles access to a picnic area. Although this is signed it is not obvious from the road layout, and should a vehicle emerge dangerously, drivers on the main road may be ill-prepared to take avoiding action because of the low expectancy of this happening.

One of the most important sites from a safety point of view is at the rural crossroads controlled by traffic lights (location 1). This was the second most dangerous site; a total of five injury accidents having been recorded. It is unusual to control minor road rural junctions with traffic lights. High speeds on the straight approach roads and the uninterrupted tree lines may produce a 'perceptual trap' (see Plate 1). The presence of the other road is not very obvious. Particularly at risk, of course, are drivers unfamiliar with the particular stretch of road who may not perceive the presence of the traffic lights until it is too late, and cross the junction against the lights. Drivers in the present experiment would not be expected to behave in this way since they were directed to turn right at the traffic lights. Another possibility is that because of low traffic volumes, drivers perhaps occasionally take risks and cross the junction against the lights. The relatively low risk ratings given by drivers in the experiment suggest that they may not have considered the possibilities of these events occurring on the other approaches where drivers face similar problems. Certainly none of the recorded hazard comments indicated that drivers were aware of these particular risks.

Perhaps it is because the hazards are not readily perceived at these sites that drivers are not set to respond to emergency situations that may arise. One strategy of accident prevention suggested by this evidence is to make hazards more visible so that drivers may more readily perceive the risks. On some roads in Finland there are dangerous drops at the road shoulders which are often hidden from view by long grass. The hazard can be made easily more perceptible by grass cutting as suggested by Naatanen and Summala[17]. Crossroads, where the major road is not easily discernible, can be emphasised by placing the give-way sign on a traffic island in the mouth of the minor road, or by painting the kerbs with white paint. Rockwell et al[18] showed that emphasising a horizontal curve by wide edge markings had a beneficial effect.

The five most over-rated locations are also listed in Table 3. One of the reasons why no accidents had occurred at these locations may be because drivers tend to over-rate the hazard and overcompensate by driving carefully.

The high rating given for the level crossing (location 8) may result from the fact that when automatic barriers were first introduced, a number of dramatic accidents produced much publicity and it may still be the case that drivers in general consider them to be dangerous locations. The hump bridge (location 21) may appear dangerous because of the severely restricted forward visibility and the risk that a large vehicle may be met head-on. At the exit to the roundabout on the dual carriageway (location 28), drivers are required to give way and then cross a stretch of dual carriageway. The high speed of traffic on the dual carriageway would be expected to encourage a high degree of caution particularly since drivers are required to cross effectively two lanes when making the manoeuvre. At location 38, a shopping centre with a small car park adjacent to the road is sited on a hill brow. When approaching this site cars are frequently seen reversing into the road and pedestrians are often crossing. Thus it is not surprising that this site is highly rated. Location 33 is a right bend at the end of a derestricted dual carriageway section and has now been removed as the dual carriageway has been extended. The general road side clutter, due to roadworks and poor road surface, may have contributed to the high ratings. Single-vehicle accidents would be expected because of high approach speeds. It is possible that the low objective risk resulted from the under-reporting of single-vehicle accidents.

4.3 Adopted safety margins

The average bend speed is $2\sqrt{r}$ mile/h (in imperial units) where r is in feet. For speed in feet per second the expression is $2.93\sqrt{r}$. Now lateral acceleration (in g) is $V^2/32r$ and so the approximate average lateral acceleration experienced is $(2.93)^2/32$ or 0.27g. This level of acceleration may reflect a driver's consideration of safety but it lies well within the cornering capabilities of modern vehicles under dry conditions. Other important factors limiting speed might be comfort[19] and wear and tear of the vehicle. Also, where forward visibility is very restricted, reductions greater than those predicted by the speed-radius relationship would be expected. However at a left bend (location 6) where the smallest recorded sight-line distance was measured, the bend radius was relatively large and this in fact resulted in a high average speed, as predicted by the equation.

The reason for the restricted visibility at this site is a 1.5m high hedge at the kerbside (see Plate 2). It would seem that under conditions of reduced visibility drivers are prepared to accept short term increases in risk levels rather than reduce speeds to more appropriate levels. This conclusion is supported by measurements of speed at urban sites. Bennett[20] suggests that the effects of reduced visibility on speeds at bends are likely to be marginal. The average safety margin adopted (–21.0m) would seem dangerously small and remedial measures are clearly needed. The safety margins adopted at the hump bridge are also dangerously low. Last minute braking is inevitable if a wide vehicle approaches at speed from the opposite direction since the road width is narrow, as can be seen in Plate 3.

It is interesting to note that some traffic engineers have recommended the reduction of sight-line distances on housing estate roads in order to reduce vehicle speeds and bring about increases in pedestrian safety[21]. In the light of the results of this study, caution should be exercised in adopting such measures since the accident risk could be increased rather than decreased. An alternative form of speed control for residential areas is the use of speed control humps[22]. For example, a one year installation in a housing estate in Oxford has resulted in a considerable decrease in average speed (27 mile/h to 15 mile/h) and also apparently in a benefit in road safety.

If, as results suggest, drivers' speeds on bends are insensitive to forward visibility it should be possible to enlarge the safety margin by increasing sight-line distances. Simple measures for increasing the safety margin at vertical curves by increasing sight-line distance are not possible since the only obvious solution is levelling. Partial levelling, which increases forward visibility by a relatively small amount, may exacerbate the problem if the average speed rises drastically. A cheap, but less effective solution, is the use of double white lines on the approaches to the hill crest. This discourages overtaking and parking along the section where visibility is reduced.

5. CONCLUSIONS

1. There was found to be significant agreement between drivers in ranking the subjective risks of a wide range of road locations.

2. When these locations were ranked on the basis of relative subjective and objective risk levels, a small but significant association was found. There was some evidence that the hazards at certain locations were misjudged and a number of countermeasures are suggested. However the uncertainty of the accident data at individual sites must be borne in mind when drawing conclusions.

3. A measure of safety margin, appropriate for locations where drivers are free to set their own speeds, correlated well with risk ratings. It was shown that the average safety margin adopted on one horizontal curve was negative.

6. ACKNOWLEDGEMENTS

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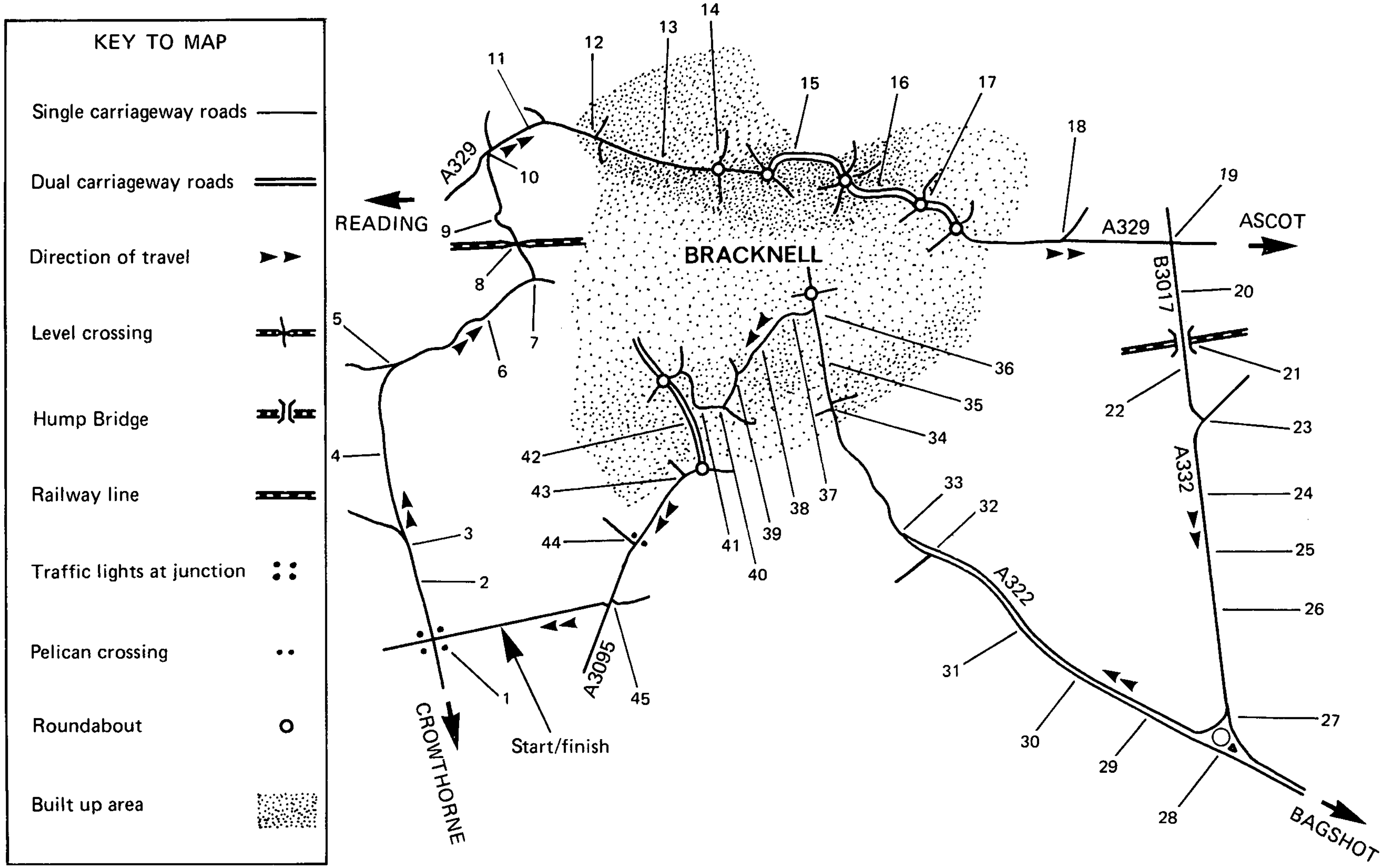

Fig.1 TEST ROUTE SHOWING MEASUREMENT POINTS

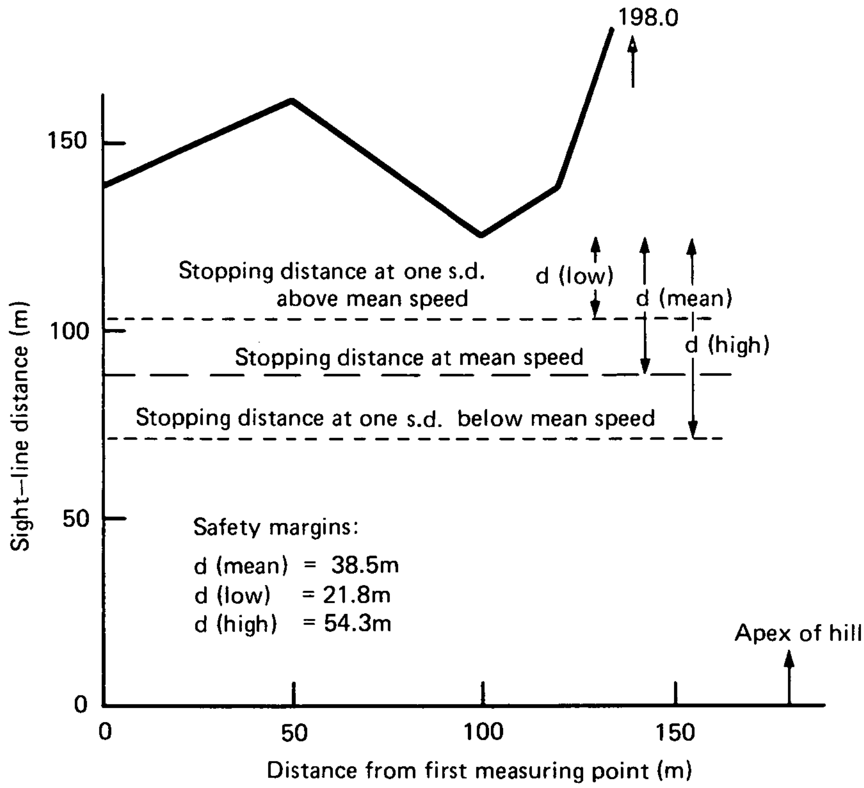

Fig.2 VARIATION OF SIGHT–LINE DISTANCE AT A RURAL BROW (LOCATION 4)

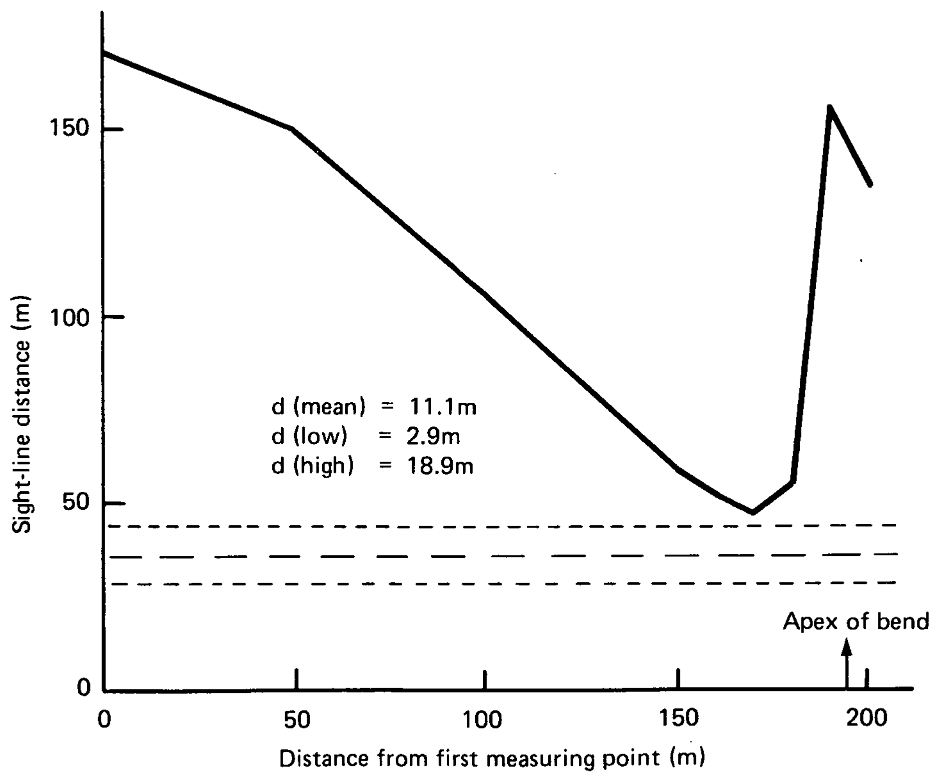

Fig.3 VARIATION OF SIGHT–LINE DISTANCE AT A RURAL RIGHT BEND (LOCATION 5)

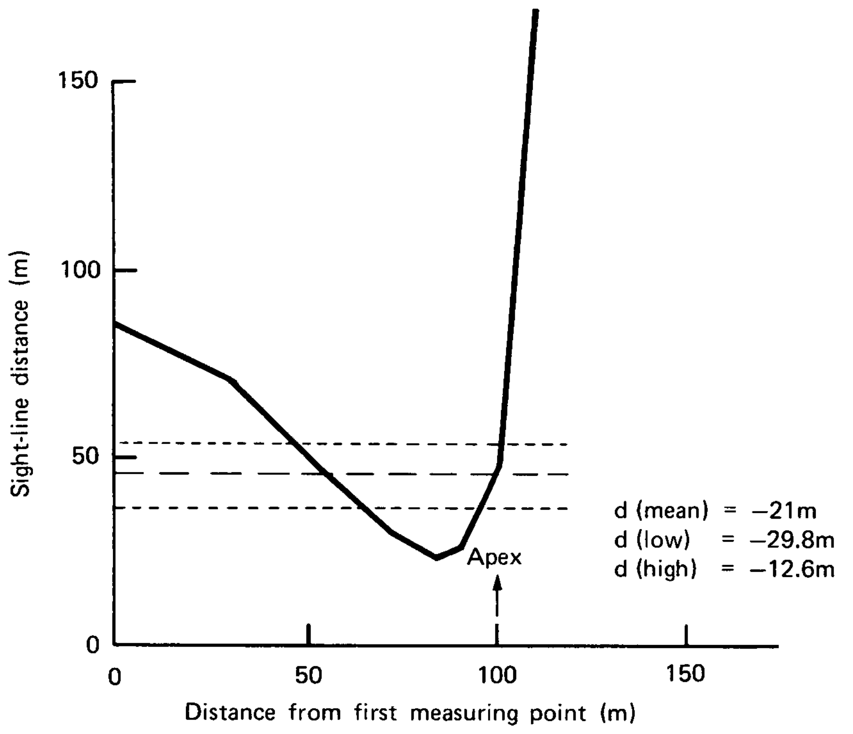

Fig.4 VARIATION OF SIGHT–LINE DISTANCE AT A RURAL LEFT BEND (LOCATION 6)

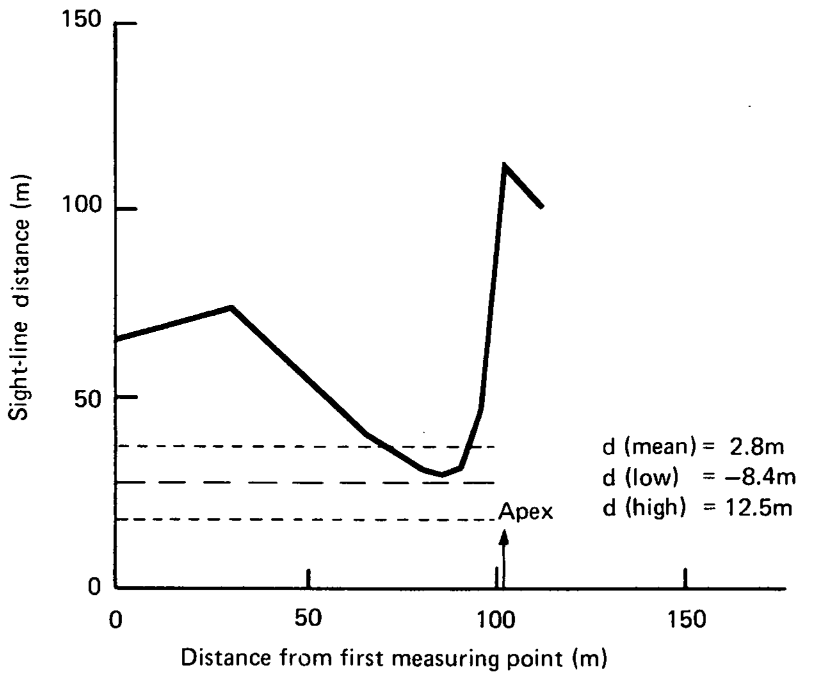

Fig.5 VARIATION OF SIGHT–LINE DISTANCE AT A RURAL RIGHT BEND (LOCATION 9)

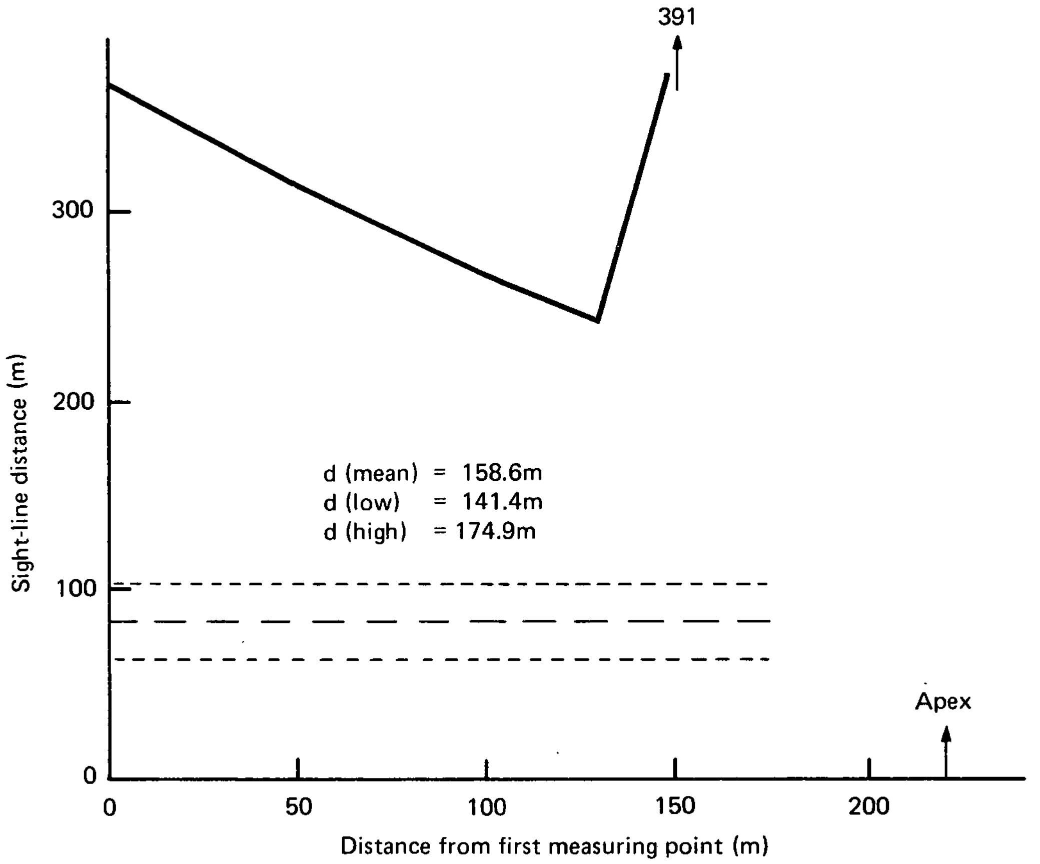

Fig.6 VARIATION OF SIGHT–LINE DISTANCE AT RURAL BROW (LOCATION 20)

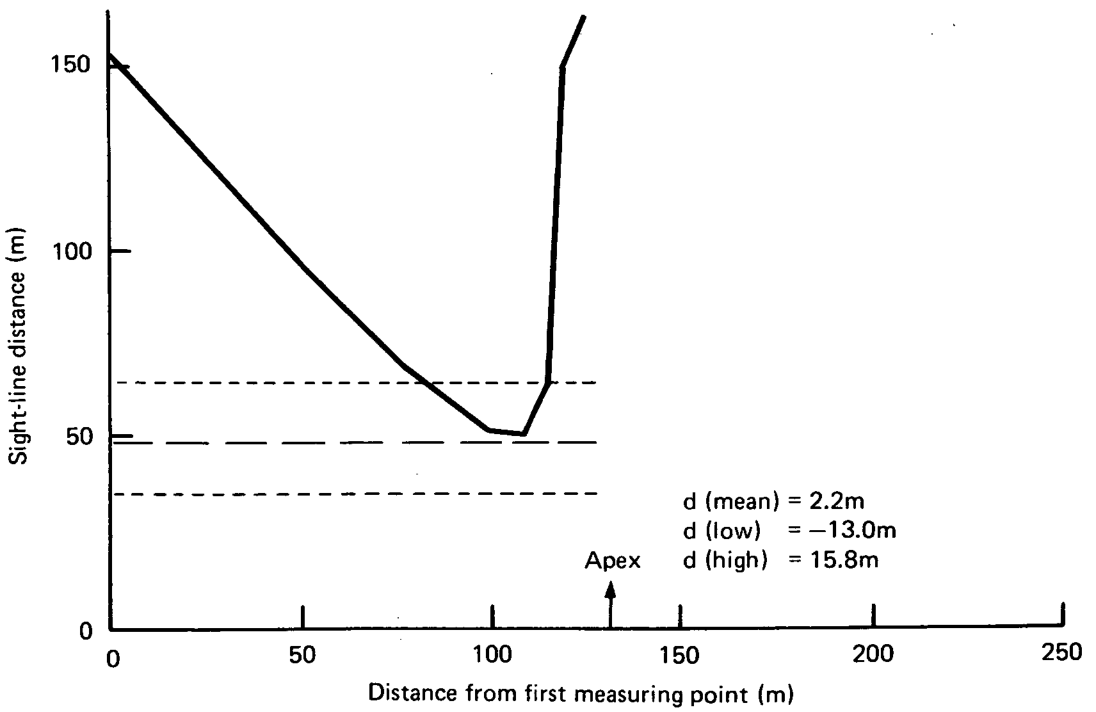

Fig.7 VARIATION OF SIGHT–LINE DISTANCE AT A RURAL HUMP BRIDGE (LOCATION 21)

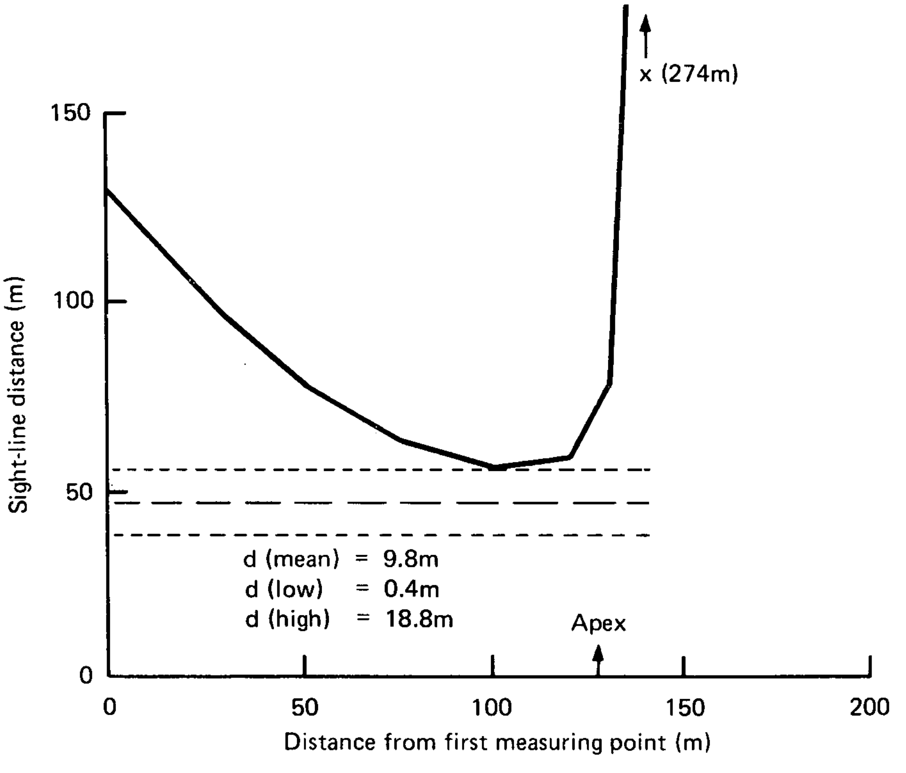

Fig.8 VARIATION OF SIGHT–LINE DISTANCE AT A SUBURBAN LEFT BEND (LOCATION 37)

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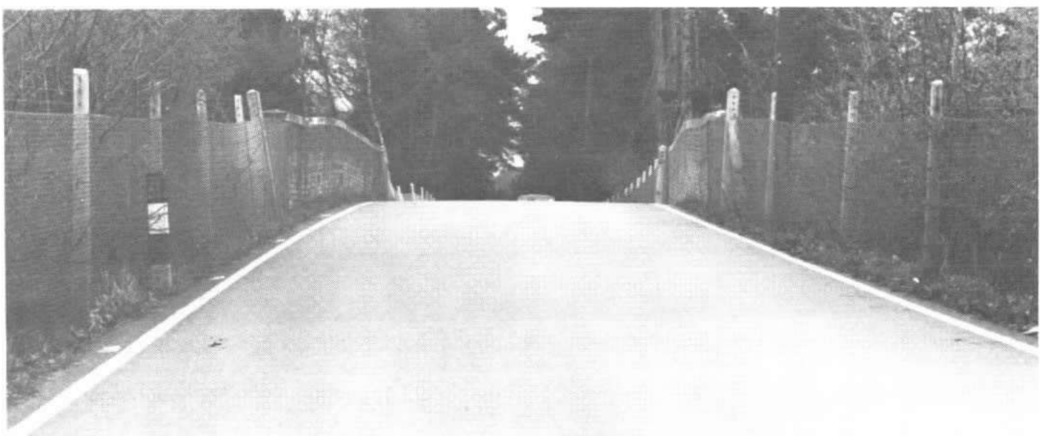
Plate 1 CROSSROADS (LOCATION 1)

Neg. no. R822/77/4

Plate 2 LEFT BEND (LOCATION 6)



Neg. no. R835/77/36

Plate 3 HUMP BRIDGE (LOCATION 21)

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ABSTRACT

Aspects of road layout that affect drivers' perception and risk taking: G R WATTS AND A R QUIMBY: Department of the Environment Department of Transport, TRRL Laboratory Report 920: Crowthorne, 1980 (Transport and Road Research Laboratory). Various road locations were investigated by requiring 60 volunteer drivers to make assessments of risk on a 16 mile route. The route covered a wide range of road types and hazards, eg rural dual carriageways, narrow suburban roads, sharp hill crests, level crossing. The locations were ordered on these subjective evaluations and compared with the ranking on objective risk which was obtained from accident and traffic flow data. At some locations wide discrepancies were found between the subjective and objective risk levels. Possible reasons for these differences are discussed.

Drivers' speeds were also recorded on the 16 mile route and at those locations where drivers were generally able to set their own speed, the forward visibility distances were measured. This allowed the calculation of a measure of safety margin. It was found that at one left-hand bend almost all drivers tested adopted a negative safety margin. Recommendation for improving this and similar sites are made.

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