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ROAD HUMPS FOR THE CONTROL OF VEHICLE SPEEDS

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ABSTRACT

The suitability and effectiveness of humps for alerting drivers and controlling vehicle speeds have been investigated. Seven vehicles including private cars, goods vehicles, a moped and a bus were used in the tests and six subjects made estimates of the noticeability and discomfort of the different humps at various crossing speeds.

Two main classes of hump have been studied, short humps which could be straddled by the wheels of most vehicles and long humps which could be straddled only by some large vehicles. The humps ranged from 2 in to 12 ft (0.05m to 3.66m) in length and from 0.5 in to 6 in (13mm to 152mm) in height.

A hump 6 in (152mm) long with a height between 0.75 and 1.5 in (19 and 38mm) was capable of alerting drivers by producing a noticeable vibration. Increasing the height of short humps introduced safety problems such as the risk of loss of control or of vehicle damage by grounding and increased the severity of impact on the tyres and vehicle suspension.

Increasing the length of a hump tended to reduce the hazard and a hump 12 ft (3.66m) long and 4 in (0.10m) high showed promise for controlling vehicle speeds. Nevertheless the use of humps especially at sites where vehicle approach speeds are high should be undertaken with caution.

1. INTRODUCTION

The need often arises to discourage motorists from travelling fast along certain roads or using routes which are not suitable for through traffic as short cuts. Of the various ways of achieving this, one possibility is the construction of humps or undulations across the road. Although humps have been widely used in many countries and some have been installed on private roads in Britain(1) no study of effectiveness of various designs appears to have been made. It is of course well known that some humps can cause discomfort to the driver and some may cause damage to the vehicle or its load.

There are two basic classes of humps, those which are short enough to be straddled by the wheels of all normal vehicles and longer humps which cannot be straddled except by a minority of (large) vehicles. Short humps administer a sharp jolt to the vehicle suspension except at very low speeds when the crossing time is long enough for the vehicle body to be deflected upwards as each axle passes over the hump. The response of individual vehicles is a function of their suspension characteristics and laden state with the extremes represented by a laden passenger car and an unladen goods vehicle. The latter is effectively very stiff compared to the car and will suffer a severe jolt compared to the car at low crossing speeds. At higher crossing speeds the vehicles' tyres and suspension tend to deflect more and there is less deflection of the body. Nevertheless, the tyres and suspension may be subjected to considerable impact loads by short humps and the maximum useable height of them is in any case limited by the ground clearance of low slung vehicles. It is known that short humps may be crossed at high speeds without undue discomfort to the vehicle occupants whereas at lower speeds the ride may be very unpleasant; the driver is, however, sometimes deterred from doing so by fear of damage to his vehicle or of losing control of it.

Long humps by their nature provide a less severe ramp effect and a longer crossing time; a greater height may be used without fear of grounding low-slung vehicles. The main effect of long humps is to cause a vehicle body deflection rather than a rapid deflection of tyres and suspension.

This report describes research into the design of humps which will be effective in reducing the crossing speeds of most vehicles to a low level of about 15 mile/h (25 km/h) or less whilst minimising danger and retaining ride comfort at low speeds. A limited amount of research has been carried out previously on alerting drivers to hazards by means of small ramps or ridges and that study is complementary to this information. The study includes investigation of the optimum spacing of humps as well as the design of the individual hump.

2. EXPERIMENTAL METHOD

2.1 Procedure for testing humps

Fifteen humps were tested and for each vehicle subjects were asked to select a hump at random and cross it at various speeds. The vehicle speeds were chosen, for the majority of the tests again in any random order, from the following list of speeds:

5, 10, 15, 20, 25, 30, 40, 50, 60 and 70 mile/h
(8, 16, 24, 32, 40, 48, 64, 81, 97 and 113 km/h)

This procedure was followed until all humps had been crossed at all the given speeds up to the maximum speed consistent with safety. With the higher humps, where there was a risk of damaging the vehicle especially at relatively high speeds, subjects were told to start at the lowest crossing speed and then systematically increase speed in subsequent tests. Subjects recorded how uncomfortable the ride over the hump was after crossing at one of the given speeds. The following rating scale was used:—

0	1	2	3	4	5	6
Comfortable		Slightly uncomfortable		Uncomfortable		Very uncomfortable

Subjects were asked to use 1, 3 and 5 as well as 0, 2, 4 and 6, as required.

In a similar way subjects also reported how noticeable the hump was, taking into account any noise or vibration that was experienced.

The scale used was:—

0	1	2	3	4	5	6
Not noticeable		Just noticeable		noticeable		very noticeable

The subject who was the passenger would record his scores first and then ask for the scores of the driver. Subjects were asked not to discuss their scores.

After covering the range of speeds that was thought to be safe and not excessively uncomfortable over a particular hump, subjects were asked to record the speed, or range of speeds, they would prefer if they were to cross it on the public highway.

2.2 Humps

The 15 humps were constructed from wood to cover a range of lengths and heights, their dimensions are given in Fig.1. The length and height of a hump are defined in Fig.1, and throughout the report these dimensions are given by quoting the length first followed by height. All the humps had a cross-section which was a segment of a circle (see Fig.1 and Plates 1 and 2). The length ranged between 2 in and 12 ft (0.05m and 3.66m) and the height between 0.5in and 6 in (13mm and 152mm). They were secured to the bituminous surface with steel bands and nails where necessary.

2.3 Subjects

During some pilot tests it was found that subjects who were passengers and then became drivers did not change their assessments if tests were repeated.

Six subjects were asked to make assessments of the ride over the humps. Two of the subjects were laboratory drivers, aged 47 and 49, who drove all vehicles in the tests because of the range of vehicles involved. Two other subjects, aged 19 and 25, sat in the front passenger seats of the vehicles and recorded their own assessments and those of the drivers. The remaining two subjects aged 31 and 34, were concerned only with testing a moped over the humps. Except for the moped pillion rider all subjects were male.

2.4 Vehicles

The vehicles used in the tests were: 1967 Raleigh moped, 1971 Mini Clubman estate, 1967 Hillman Minx estate, 1970 Ford Transit minibus, Bedford tipper lorry of unladen mass 4 ton (4 Mg), double decker bus and an unladen Ford articulated lorry of mass 6 ton (6 Mg). The two subjects who were passengers in the tests recorded their assessments at the front and rear of the bus.

2.5 Recording of vertical acceleration

It was expected that the vertical acceleration experienced by subjects would be related to the subjective impression of discomfort and it was decided to measure this component of acceleration in the Mini Clubman and unladen Bedford tipper lorry whilst they crossed most of the humps. An accelerometer was attached to a light box and held securely across the subject's lap. A spirit level was attached to the top of the box so that the accelerometer could be positioned to measure acceleration within a few degrees of the vertical. The recorder was placed on a seat and a continuous trace of the vertical component of acceleration against time was recorded on photographic film as the vehicle crossed each of the humps at various speeds.

2.6 Recording vehicle behaviour

High speed cine film at 150 frames per second was taken of the Mini Clubman as it crossed various humps. The maximum displacement of the centre of the wheel and tyre tread was noted as was the maximum angular and vertical displacement of the car body. The wheels of the car left the ground over some of the humps and the time for which contact was lost was measured for both front and rear wheels.

2.7 Measurement of vehicle speeds on and near humps

In order to keep vehicle speeds consistently low along a length of road several humps will normally be needed to prevent any appreciable build up of speed between them.

In order to estimate the average speed of vehicles along a road when a succession of similar humps are employed the effect of a single isolated hump on vehicle speeds along a road was investigated at a private site. The hump had a profile similar to the ones tested at the Laboratory, its length was 12 ft (3.7m) and its height was estimated to be in the range 4–5 in (100–125mm). It had been constructed on a 24 ft (7m) wide straight level section of road. Speed measurements were taken of vehicles crossing the hump and vehicles approaching and receding from it at distances of 82.5, 165 and 330 ft (25, 50 and 100m) from the installation. A radar speed meter was used to measure speeds and the antenna was mounted on the side of an unmarked car parked on the pavement where it would cause minimum interference to passing vehicles.

To test further what order of speeds are possible between humps at various spacings given different hump crossing speeds, three cones were deployed at 90 ft (27m) intervals along a straight level section of road. A driver was asked to drive the Hillman Minx estate car (automatic transmission) past each cone at 5 mile/h (8 km/h) to simulate crossing humps at this speed. At first the driver was asked to accelerate and brake between the cones at a moderate rate and then at a severe rate. The maximum speeds achieved, as indicated on the speedometer, were recorded by an observer seated behind the driver. For each test two readings were taken and averaged. The driver was then asked to follow the same procedure but to pass the cones at speeds of 10, 15 and 20 mile/h (16, 24 and 32 km/h). Maximum speeds were again recorded. Finally, the tests were repeated with cone separations of 150, 300 and 600 ft (46, 91 and 183m).

3. RESULTS

3.1 Assessment of noticeability

Subjects scores are recorded in Table 1. Each block of 4 digits refers to the ratings made by each of four subjects. Scores for subject A are to the left and scores for subject D are to the right. Subject A was 19 years old, subject B was a laboratory driver aged 47, subject C was aged 25 and subject D was a laboratory driver aged 49. In the case of assessments made by subjects riding the moped, only two digits appear. The first refers to the rider aged 31 and the second to his passenger aged 34.

Scores for humps of greater size than 6 x 3 in (152 x 76mm) virtually all fell within the range noticeable to very noticeable and therefore do not appear in the Table.

The main findings are as follows:–

2 x 0.5 in and 4 x 0.5 in (51 x 13mm and 102 x 13mm) humps

Except for the unladen tipper lorry and articulated lorry, scores recorded in all the vehicles were generally in the range not noticeable to just noticeable. In the articulated lorry at the two lowest speeds the recorded scores were in the range noticeable to very noticeable. Scores for the unladen tipper lorry crossing the 4 x 0.5 in (102 x 13mm) hump ranged from just noticeable to very noticeable at the lowest speed. At the highest speeds scores were generally very low in the heavy vehicles. Subjects on the moped thought that the humps were not noticeable at any of the crossing speeds.

6 x 0.75 in (152 x 19mm) hump

Scores tended to be in the range not noticeable to noticeable in all vehicles except the articulated lorry. At most speeds the hump was not noticeable on the moped. Scores tended to remain constant with increasing speed in the cars, minibus, and double-decker bus whilst in the lorries there was a decrease with increasing speed. All subjects agreed that the hump was very noticeable in the articulated lorry at low speeds.

6 x 1.5 in (152 x 38mm) hump

In the small vehicles and double-decker bus subjects' scores varied by a large amount for a given ride but the mean of scores indicated that the hump was noticeable at all speeds. The humps were thought to produce a very noticeable vibration in the lorries.

6 x 3 in (152 x 76mm) hump

Subjects recorded a score of very noticeable in all the vehicles at every crossing speed.

3.2 Assessment of discomfort

Table 2 lists the discomfort scores of the subjects* in the same order as for the noticeability scores

2 x 0.5 in and 4 x 0.5 in (51 x 13mm and 102 x 13mm) humps

All subjects agreed that at all speeds in all the vehicles except the articulated lorry there was no discomfort. In this lorry at 5 and 10 mile/h (8 and 16 km/h) some subjects thought it was slightly uncomfortable. From the preferred crossing speed data for all vehicles it appears that these humps would have little effect on vehicle speeds.

6 x 0.75 in (152 x 19mm) hump

* To test how reproducible assessments were subject C drove the Hillman estate over nine of the largest humps one week later and made assessments at all the possible speeds. There were 43 assessments in all and these were compared with previous assessments. In 16 cases identical assessments were made, in 17 cases the scores were more, and in 10 cases they were less. Using the Wilcoxon matched-pairs signed-ranks test it was shown that there was insufficient evidence for saying the scores differed significantly. However, the repeated tests did show that scores for similar test runs could differ by as much as 3 points on the discomfort scale.

This hump produced a slightly uncomfortable ride in most vehicles at low speed but at the higher speeds there was a tendency for subjects to score the ride as comfortable. Discomfort scores recorded in the articulated lorry were again the highest recorded in any vehicle the ride being generally judged as uncomfortable at low speeds. All subjects agreed that the ride in the Hillman estate at all speeds was comfortable. Again this hump would have little effect in determining a driver's choice of speed.

6 x 1.5 in (152 x 38mm) hump

Generally subjects judged the ride in the unladen Bedford tipper as uncomfortable at very low speeds although the ride became progressively more comfortable with increasing speed. The ride in the laden tipper was more comfortable at all speeds. The ride in the articulated lorry was judged to be at least uncomfortable at all speeds. At all speeds in the other vehicles subjects tended to judge the ride as slightly uncomfortable. There was however, a tendency for ride comfort to improve with increasing speed in the Hillman estate and minibus. Subject D generally scored higher than other subjects. From the preferred crossing speed data it would seem that this hump could cause the driver of the articulated lorry to reduce speed.

6 x 3 in (152 x 76mm) hump

Subjects agreed that the ride in all vehicles except the double-decker bus was uncomfortable to very uncomfortable. Tyre deflection was excessive on the moped and the wheel rim grounded at 5 mile/h (8 km/h) and tests were not continued above this speed. The ride at 10 mile/h (16 km/h) was extremely uncomfortable in the lorries. Hydraulic fluid was spilt from the lifting gear in the unladen tipper lorry and dust was flung into the air in the driver's cab. The minibus jumped out of gear at 30 mile/h (48 km/h) and a lead became detached from a sparking plug in the Hillman estate. At the end of a preliminary test with a loaded articulated lorry it was found that ropes securing the load had broken and the load had moved to the rear of the vehicle. Subjects said they would only cross this hump if it was absolutely necessary and then only at a very low speed.

2 ft x 3 in (610 x 76mm) hump

There was agreement that at all speeds in all vehicles except the moped the ride was very uncomfortable. In the lorries subjects bounced in their seats and dust was again flung into the air. When preliminary tests were carried out with a Bedford pantechnicon the tail gate flew open repeatedly. The moped rider again grounded the wheel rim at the lowest speed. Subjects agreed that they would only cross this ramp if it was really necessary and then only at a very low speed.

4 ft x 2 in (1.22 x 0.05m) hump

Scores for a given ride varied a great deal. At most speeds except the lowest, scores recorded in the smaller vehicles tended to fall within the range slightly uncomfortable to uncomfortable. There was a tendency for discomfort scores to decrease in the Mini Clubman and Minibus at the higher speeds. The ride at 5 mile/h (8 km/h) in the heavy vehicles tended to be slightly uncomfortable although subjects A and D recorded high scores in the tipper and articulated lorry. From the preferred crossing speed data it is apparent that the heavier vehicles were the most affected, drivers preferred to cross at about 5 mile/h (8 km/h) whilst car drivers would choose to cross at speeds up to 30 mile/h (48 km/h).

4 ft x 3 in (1.22 x 0.08m) hump

Scores for a given ride varied considerably especially at the lowest speed. However, it appears that at 5 mile/h (8 km/h) the ride was generally judged to be slightly uncomfortable in the smallest vehicle whilst uncomfortable in the larger vehicles. Above this speed the ride tended to be in the range uncomfortable to very uncomfortable in all vehicles at all speeds. In the small vehicles subjects generally preferred not to cross at more than 10 mile/h (16 km/h). In the larger vehicles they would choose to cross at about 5 mile/h (8 km/h).

4 ft x 4 in (1.22 x 0.10m) hump

Subjects disliked crossing this hump in any of the vehicles. Scores tended to be high at all speeds in all the vehicles. Preferred crossing speed was 5 mile/h (8 km/h) or less except for the Hillman estate.

8 ft x 2 in (2.44 x 0.05m) hump

Generally subjects agreed that the ride was comfortable in most of the vehicles at 5 mile/h (8 km/h). There was a progressive increase of discomfort with speed although in the small vehicles the ride tended only to be slightly uncomfortable at the highest speed. In the minibus there are indications that the ride became more comfortable at 50 mile/h (81 km/h). Subjects on the moped reported that the ride was virtually comfortable at all speeds. The ride became uncomfortable in the heavier vehicles at about 15 mile/h (24 km/h). Preferred crossing speeds were as high as 40 mile/h (64 km/h) in the small vehicles and within the range 5–20 mile/h (8–32 km/h) in the heavy vehicles.

8 ft x 3 in (2.44 x 0.08m) hump

Subjects tended to score the ride in the small vehicles as comfortable at 5 mile/h (8 km/h). Above this speed discomfort progressively increased in the cars. Above 30 mile/h (48 km/h) there is an indication that the ride becomes more comfortable in the Mini Clubman with further increases in speed. At the highest speed in the cars scores ranged from slightly uncomfortable to very uncomfortable. The ride on the moped was judged to be slightly uncomfortable at the highest speed. At 5 mile/h (8 km/h) in the large vehicles scores ranged from comfortable to very uncomfortable but at 15 mile/h (24 km/h) all subjects agreed that the ride was very uncomfortable. Subjects on the moped preferred to cross at almost the top speed whilst subjects in the cars preferred to cross at speeds up to 20 mile/h (32 km/h). Subjects' choice of crossing speeds in the heavy vehicles tended to be 5 mile/h (8 km/h).

8 ft x 4 in (2.44 x 0.10m) hump

A large range of scores were recorded at 5 and 10 mile/h (8 and 16 km/h) in the small vehicles. Subjects A and D tended to score higher and at 5 mile/h (8 km/h) in the minibus these subjects judged the ride to be very uncomfortable whilst other subjects thought the ride was comfortable. In the small vehicles at 20 mile/h (32 km/h) and above, scores were generally in the range uncomfortable to very uncomfortable. Assessments made at low speeds in the heavy vehicles also showed large variations but subjects were virtually all agreed that the ride at 10 mile/h (16 km/h) or more was at least uncomfortable. Preferred crossing speeds were generally low, not exceeding 10 mile/h (16 km/h) for cars and minibus and not exceeding 5 mile/h (8 km/h) for the heavy vehicles. Preferred crossing speed on the moped was again relatively high being in the range 10–15 mile/h (16–24 km/h).

12 ft x 4 in (3.66 x 0.10m) hump

Generally subjects scored the ride as comfortable in all the vehicles at 5 mile/h (8 km/h). There was a steady increase of discomfort with speed in the small vehicles and most subjects assessed the ride at 25 mile/h (40 km/h) or above as uncomfortable. In the large vehicles all subjects said that the ride was at least uncomfortable at 15 mile/h (24 km/h). Preferred crossing speeds for the light vehicles were in the range 5–20 mile/h (8–32 km/h). Preferred crossing speeds in the heavy vehicles were about 5 mile/h (8 km/h).

12 ft x 5 in (3.66 x 0.13m) hump

Subjects said that the ride was comfortable at 5 mile/h (8 km/h) in the small vehicles although they tended to score the ride slightly uncomfortable in the large vehicles. Again there was a progressive increase in discomfort with speed in the small vehicles and except for subjects on the moped the assessments were all in the range uncomfortable to very uncomfortable at 20 mile/h (32 km/h) and above. Subjects thought the ride at 10 mile/h (16 km/h) in the large vehicles was at least uncomfortable. Preferred crossing speeds were very similar to the 12 ft x 4 in (3.66 x 0.10m) hump.

12 ft x 6 in (3.66 x 0.15m) hump

Generally this hump produced scores in the range comfortable to slightly uncomfortable in the small vehicles at 5 mile/h (8 km/h). Except for the moped the ride in these vehicles was very uncomfortable at 20 mile/h (32 km/h). Scores at 5 mile/h (8 km/h) in the heavy vehicles ranged from comfortable to very uncomfortable. At 10 mile/h (16 km/h) in these vehicles most subjects said the ride was very uncomfortable. Preferred crossing speeds tended to be a little lower than corresponding speeds for the 12 ft x 4 in (3.66 x 0.10m) hump.

The main findings may be summarised as follows:–

(1) Vehicles can be grouped according to the discomfort scores recorded in them. Generally the lowest average scores for a given hump and crossing speed were recorded on the moped and the highest were recorded in the heavy vehicles (lorries and double-decker bus). The cars and minibus formed a middle group and average scores tended to be similar in these vehicles (see Fig.2).

(2) The three smallest humps 2 x 0.5 in (51 x 13mm), 4 x 0.5 in (102 x 13mm) and 6 x 0.75 in (152 x 19mm) caused little discomfort in any of the vehicles except the articulated lorry and from the preferred crossing speed data it would seem that these humps would have little influence on a driver's choice of speed.

(3) There are indications that ride discomfort in some of the small vehicles over humps up to 3 in (0.08m) high and up to 8 ft (2.44m) long reached a maximum level as crossing speed was increased and at higher speeds became slightly less; the effect was most marked over humps 2 in (51mm) high (see Fig.3) but can also be seen in the data for 3 in (76mm) high humps (see Fig.4).

(4) In general the longest humps produced the most comfortable ride at the lowest speeds whilst short high humps tended to be uncomfortable at most speeds. Fig.4 shows average scores for the cars and minibus plotted for humps 3 in (76mm) high. (See also Fig.2).

(5) Several of the humps tested were unacceptable on safety grounds.

3.3 Correlation of acceleration and discomfort data

Measurements of the peak value of positive vertical acceleration were taken from the traces of acceleration against time recorded on photographic film using a Benson Lehner analyser (see Table 3). These values were then plotted against the corresponding average discomfort scores and are shown for the Mini Clubman estate and Bedford lorry in Figs. 5 and 6. The correlation coefficients of 0.83 and 0.84 are significant at the 0.1 percent level. The slopes of the two graphs are very similar and it can be seen that average scores are approximately proportional to the peak readings.

Other vibrations are present in vehicles apart from those in the vertical direction(2) and over some humps these vibrations may have made a significant contribution to the discomfort of the ride. For example some of the extreme points on the graphs refer to readings recorded over the short high humps when low readings were obtained from the accelerometer but all the discomfort scores were high. In this case significant horizontal vibrations may have been present or the subjects may have been worried by knowing of the jolt taken by the suspension.

Thus although peak acceleration is a factor influencing ride comfort there are other factors which may be important such as the rate of change of acceleration, horizontal vibrations and cognitive stimuli. By considering the variation of peak vertical acceleration with speed and hump dimensions it is possible to gain some understanding of subjects' scores.

3.4 Variation of peak acceleration with speed and hump dimensions

Fig. 7 shows how the peak acceleration experienced in the Bedford tipper lorry falls with increasing speed over humps 6 in (152mm) long. This is also true of subjects' scores as has been pointed out.

Figs. 8 and 9 demonstrate how peak acceleration recorded in the Mini Clubman estate varies with crossing speed and hump length for humps 2 in and 3 in (51 and 76mm) in height. The trend is for the maximum readings to occur at higher speeds as length of hump increases. At low speeds, 5–25 mile/h (8–40 km/h), the shorter humps produced the highest readings whilst the long humps produced the smallest. The converse is true at higher speeds. There is an indication from subjects' scores that the ride over the 4 ft x 2 in (1.22 x 0.05m) hump improves at the higher speeds and this is reflected in Fig. 8. 3 in (0.08m) high humps 2 ft and 4 ft (0.61 and 1.22m) long produced values of peak acceleration greater than 0.9 g (corresponding to an uncomfortable score on the subjective scale) for almost the whole range of speeds covered whereas the longest hump produced values lower than 0.6 g in the range 5–25 mile/h (8–40 km/h). Subject scores are in general agreement showing that humps 2 ft x 3 in (0.61 x 0.08m) and 4 ft x 3 in (1.22 x 0.08m) generally produced an uncomfortable ride throughout the speed range whilst the 8 ft x 3 in (2.44 x 0.08m) hump was reasonably comfortable at 5 and 10 mile/h (8 and 16 km/h).

Fig.10 shows how peak readings vary with speed and hump length for 4 in (102mm) high humps. The trend is for vertical acceleration to increase with increasing speed, however, the rate of this increase at 5 mile/h (8 km/h) decreases with increasing length. The peak reading at 5 mile/h (8 km/h) also falls with increasing length. Subjects' scores support these trends.

From the correlation graph in Fig.5 it appears that the highest scores on the discomfort scale are generally recorded by subjects when peak values of acceleration reach approximately 1 g. Any further large increase in peak acceleration could not, therefore, be indicated by an increase in score and it is for this reason that the variation in peak readings at high levels of vertical acceleration are not reflected in subjects' scores.

3.5 Vehicle behaviour

The cine film records of the Mini Clubman being driven over humps of height 3 in and 4 in (76 and 102mm) and of various lengths were examined on a Vanguard Motion Analyser and Table 4 lists some of the effects that were measured. At 20 mile/h (32 km/h) the wheels lost contact with the ground in all cases except over the 12 ft (3.66m) long hump. The 4 ft x 4 in (1.22 x 0.10m) hump caused the rear wheels of the car to lift clear of the ground for 0.15s, the longest period recorded in these tests.

The displacement of the tyre tread relative to the centre of the wheel was greatest for the 6 x 3 in (152 x 76mm) hump where a displacement of approximately 2 in (51mm) occurred, about 40 percent of the total depth of the visible tyre. However, the displacement of the car body was very little, the greatest angular displacement to the horizontal being 1^{o} and the largest vertical displacement of the car's centre of gravity was less than 0.5 in (13mm). The maximum angular and vertical displacements of the car body were 6^{o} and 3.5 in (89mm) respectively and occurred when the car crossed the 12 ft x 4 in (3.66 x 0.10m) hump. These corresponded to the smallest wheel displacement and tyre deflection.

3.6 Vehicle speeds on and near humps

A histogram in Fig.11 shows the speed distribution of 133 cars and vans over the 12 ft (3.7m) long hump of height 4–5 in (0.10–0.13m) installed on a private road. The average crossing speed was 11.5 mile/h (18.5 km/h) and the average approach speed 330 ft (100m) from the hump was 28.3 mile/h (45.6 km/h). The average speed of cars and vans approaching and receding from the hump at distances of 82.5, 165 and 330 ft (25, 50 and 100m) are given in Table 5. Table 6 lists the maximum speeds attainable under moderate and severe acceleration in the Hillman Minx estate car for given crossing speeds and separations between humps.

4. DISCUSSION OF RESULTS

4.1 Peak vertical acceleration and subjects' assessments

The average scores on the noticeability scale at various crossing speeds can be related to the discomfort scores. Comparing Tables 1 and 2 it can be seen that the noticeability scores are usually higher than the corresponding discomfort scores. The vibration produced by these small humps were generally not severe and so were given low scores on the discomfort scale. However, because these humps were often heard and felt they were given relatively high scores on the noticeability scale.

It has been shown that the average of discomfort scores recorded in the cars and minibus at low crossing speeds falls as hump length is increased and that there was a tendency for scores to decrease slightly at high speeds over the shorter humps. The peak acceleration data as well as correlating with these scores also demonstrates these effects and lends support to the method of using the averages of subjects' scores as an indicator of discomfort.

To understand the variation in the peak acceleration and therefore go some way in explaining subjects' scores in the smaller vehicles it is helpful to consider Figs. 8 and 9. The trend is for the maximum peak acceleration to occur at higher speeds as the length of the hump is increased. At these critical speeds the time for a wheel to cross the hump was 150 ms in 4 out of the 6 cases and it is likely that the response of the car body is greatest because the crossing time coincides with some function of the body bounce periodic time. Increasing this crossing time for a given hump by crossing more slowly or decreasing the time by crossing at a higher speed will produce less response in the sprung mass and recorded peak acceleration values will tend to be smaller. Also maximum response will occur at low speeds over short humps whereas over long humps it will occur at a relatively high speed.

In Fig.10 peak readings are plotted against speed for humps of height 4 in (102mm). As would be expected peak readings are generally larger over these higher humps and again it is evident that the shortest humps produced the highest readings at low speeds. Nothing can be said about the speeds at which the maximum response occurs since tests were not carried out at the higher speeds for fear of damaging the vehicles.

It has been shown that average scores are similar for the Bedford lorry, double-decker bus and articulated lorry and so again it is possible to investigate the variation in peak acceleration in the Bedford lorry and relate findings to the other vehicles. Because of its harsh suspension the range of speeds covered by the tipper lorry over humps longer than 6 in (152mm) was small and so only a few readings were taken. However, it is clear that at these low speeds the longer the hump of given height the smaller is the recorded peak acceleration as was shown for the smaller vehicles.

4.2 Vehicle behaviour

From Table 4 the 6 in (152mm) long hump caused the greatest displacement of the tyre tread (2 in (51mm)) and such an installation may present a hazard at higher speeds since tyre deflection is likely to be even more severe. The smallest wheel displacement and tyre deflection was recorded when the car crossed the longest hump and it was also established that the vehicle's wheels never left the ground in this case. It would appear, therefore, that this hump is less likely to damage the vehicle and cause loss of control at this speed and perhaps higher speeds than shorter humps of similar height.

The angular and vertical displacements were greatest over the longest hump because the suspension was held in a compressed state for the longest period of time producing the greatest impulse on the car body.

4.3 Effects of several humps on vehicle speeds

Since it is known from Table 5 how a single hump of length 12 ft (3.7m) and height 4–5 in (0.10–0.13m) installed on a straight level section of road influences speed within 330 ft (100m) it is possible to estimate the average speed along the road if the humps are set at 330 ft (100m) apart or less (see appendix). The calculations indicate that if the hump crossing speed is 11.5 mile/h (19 km/h) and the spacing 250–330 ft (75–100m) then the average speed of cars and vans will be 15–20 mile/h (24–32 km/h).

Table 6 shows how the maximum inter-hump speeds at moderate and severe rates of acceleration vary with spacing. As would be expected the maximum inter-hump speeds increased as separation was increased. The difference between the maximum speed achieved for a separation of 90 ft (27m) and that for a separation of 600 ft (183m) was 11–16 mile/h (18–26 km/h) for moderate acceleration and 21–24 mile/h (34–39 km/h) for severe acceleration depending on hump crossing speed. Hump crossing speed had a relatively small effect on the maximum speed attained if the crossing speed was 15 mile/h (24 km/h) or less. Thus the difference between the maximum speed achieved for a hump crossing speed of 5 mile/h (8 km/h) and that for 15 mile/h (24 km/h) was 1–5 mile/h (2–8 km/h) for moderate acceleration and 0–3 mile/h (0–5 km/h) for severe acceleration depending on separation.

5. APPLICATION TO DESIGN OF SPEED CONTROL HUMPS

The ideal speed control hump should probably exhibit the following characteristics:–

(i) At and below the design speed all drivers should be able to cross the hump without damage to load or vehicle, or loss of control and they should suffer no discomfort.

(ii) Above the design speed the driver should suffer a degree of discomfort depending on the amount by which he violates the design speed but there should still be no damage to load or vehicle or risk of loss of control.

Fig.12 shows ideal characteristics of a hump whose design speed is 12 mile/h (19 km/h). The ride is uncomfortable at 5 mile/h (8 km/h) above the design speed and very uncomfortable at 8 mile/h (13 km/h) above the design speed. Humps of height 3 in (76mm) or more tend to be at least slightly uncomfortable at 5 mile/h (8 km/h) in most of the vehicles tested, and some drivers may easily learn that the ride over humps of height 3 in (76mm) or less becomes more comfortable as speed is increased. To deter a motorist from deliberately driving at high speed over a series of humps, the height of each would probably have to be at least 4 in (100mm) with consequent risk of vehicle damage. In this case the body of the car will probably rise very little but the wheels will be deflected by a large amount, causing the suspension to hit the bump stops and producing a jolt. In practice the height of humps smaller in length than the wheelbase of an average car (approximately 8 ft (2.5m)) needs to be restricted to about 3 in (76mm) to avoid grounding low slung vehicles.

Humps 12 ft (3.66m) in length can have greater height since both sets of wheels of a car, for example, are raised when the centre of the vehicle is near that of the hump. In this position the underside of the vehicle is elevated allowing greater height before grounding occurs than is possible with shorter humps. Calculations indicate that the driver of a car with a wheel base of 8 ft (2.5m) and a minimum ground clearance at the centre of the vehicle of only 3 in (76mm) will just be able to cross a 12 ft x 6 in (3.66 x 0.15m) hump at low speed without grounding.

It appears that of those studied, humps 12 ft (3.66m) long and of height 4–5 in (0.10–0.13m), most nearly satisfy the specified conditions. The ride over these was generally comfortable at 5 mile/h (8 km/h) in all vehicles, see Fig.4.

The longer humps may also reduce the stresses imposed on the vehicles. Thus from Table 4 it appears that the 12ft x 4 in (3.66 x 0.10m) hump subjected the Mini Clubman suspension to less stress at 20 mile/h (32 km/h) than did the shorter ones listed, of similar height or less.

From the maximum preferred crossing speed data recorded by each subject it appeared that subjects are prepared to suffer up to 1.7 points of discomfort on the subjective scale on average when crossing a hump. If this is representative of the general public it would appear, for example, that the 12 ft x 4 in (3.66 x 0.10m) hump would be effective in reducing the speed of cars and vans to below 15 mile/h (24 km/h), two wheeled vehicles to about 22 mile/h (35 km/h) and lorries and buses to below 10 mile/h (16 km/h). Tests have shown that the average crossing speed of cars and vans over a hump 12 ft (3.7m) long and height 4–5 in (0.10–0.13m) was in fact 11.5 mile/h (18.5 km/h). Humps of this length but of greater height will tend to reduce speeds still further.

A motorist deliberately driving at high speed over a long hump would probably be able to retain control but normally humps should not be located in any area where a vehicle can enter at high speed, unless there is adequate warning. It may be possible to alert a driver entering a low speed area at speed by grading the severity of a series of humps. Signs should be used to alert drivers to the need to reduce speed and to warn of the humps ahead. In the low speed area it will generally be necessary to have a series of humps, and calculations indicate that if the crossing speed is 12 mile/h (19 km/h) and the spacing 250–330 ft (75–100m) then the average speed of cars and vans will be 15–20 mile/h (24–32 km/h). Increasing the spacing of the humps will probably increase the average speed and the maximum inter-hump speeds may then be high, e.g. in the Hillman estate car a speed of 49 mile/h (79 km/h) was possible with a hump spacing of 600 ft (183m).

6. CONCLUSIONS

6.1 Noticeability of humps

The smallest humps 2 x 0.5 in (51 x 13mm) and 4 x 0.5 in (102 x 13mm) were not effective for alerting the drivers of all vehicles. Humps of 6 x 0.75 in (152 x 19mm) and 6 x 1.5 in (152 x 38mm) were noticeable in most vehicles over the speed range, the greater height producing a more severe effect. Short humps of greater height were judged to be unacceptable on safety grounds.

6.2 Control of vehicle speeds

(1) Short humps produced widely differing results between the vehicles tested. Because of this the possibility of using small humps for controlling vehicle speeds without creating an unacceptable safety problem is

remote. The main difficulty, however, lies in the fact that short humps tend to have characteristics which are the converse of those desired, i.e. their effects tend to become less prominent at the higher approach speeds.

(2) Increasing the length of a hump tended to reduce the hazard and a hump 12 ft (3.66m) long and 4 in (0.10m) high produced an uncomfortable ride in most of the vehicles tested at speeds in excess of 20 mile/h (32 km/h). At the low speed of 5 mile/h (8 km/h) drivers of all vehicles could cross the hump with reasonable comfort.

(3) The tests indicated that humps should not be located in any area where a vehicle can enter at high speed unless adequate prior warning is given.

(4) In order to keep vehicle speeds consistently low along a stretch of road it will normally be necessary to have a series of humps. If the hump crossing speed is 12 mile/h (19 km/h) and the spacing 250–330 ft (75–100m) then it is estimated that the average speed of cars and vans will be 15–20 mile/h (24–32 km/h).

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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9. APPENDIX

Estimate of average speed where humps are installed

Consider humps set 330 ft (100m) apart and consider the speed of a vehicle travelling from one to another. From Table 5 the average speed of vehicles crossing the humps is 11.5 mile/h (18.5 km/h) and the average speed of vehicles receding from the hump at 165 ft (50m) is 20.4 mile/h (32.8 km/h). Assume that the vehicle accelerates at a constant rate from 11.5 mile/h (18.5 km/h) at the hump to 20.4 mile/h (32.8 km/h) at 165 ft (50m) then its speed at 82.5 ft (25m) will be 16.5 mile/h (26.6 km/h) which is in reasonable accord with Table 5, the average speed being 16.9 mile/h (27.2 km/h). For simplicity assume it travels at 20.4 mile/h (32.8 km/h) until it reaches the 245 ft (75m) mark and then decelerates at a constant rate to 11.5 mile/h (18.5 km/h) at the next hump at the 330 ft (100m) mark. For cars and vans approaching a hump the average speed 80 ft (25m) away is 19.8 mile/h (31.9 km/h) which is close to the assumed speed of 20.4 mile/h (32.8 km/h).

We can now calculate the average speed of the vehicle by considering the total time taken to travel between humps. For constant acceleration along a straight line we have:

$V^2 = v^2 + 2as$, where 'V' is the final speed (ft/s) 'v' is the initial speed (ft/s) and 'a' is the acceleration (ft/s^2).

Using this equation we can calculate 'a'

$$\text{acceleration rate from 0–165 ft} = \frac{(29.85)^2 - (16.84)^2}{2 \times 165} = 1.85 \text{ ft/s}^2$$

$$\text{deceleration rate from 245–330 ft} = \frac{(29.85)^2 - (16.84)^2}{2 \times 82.5} = 3.71 \text{ ft/s}^2$$

Also we have V = v + at and knowing V, v and a we can calculate time taken.

Time taken from 0–165 ft (t_1) $= \frac{29.85 - 16.84}{1.85} = 7.04$ s

Time taken from 165–245 ft (t_2) $= \frac{82.5}{29.85} = 2.75$ s

Time taken from 245–330 ft (t_3) $= \frac{29.85 - 16.84}{3.71} = 3.51$ s

Total time taken from 0–330 ft $= t_1 + t_2 + t_3 = 13.30$ s

Hence average speed between humps $= \frac{330}{13.30} = 24.8$ ft/s

or 17 mile/h (27 km/h)

If the spacing was 245 ft (75m) we could assume that the constant speed phase of the journey would disappear so:–

total time $= t_1 + t_3 = 10.55$ s

and average speed $= \frac{245}{10.55} = 23.3$ ft/s

or 16 mile/h (26 km/h)

TABLE 1

Scores on noticeability scale

Hump Dimensions 2 x 0.5 in (51 x 13mm)

Crossing Speed mile/h km/h / Vehicle Type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113
Raleigh Moped	00	10	01	00	00	00	00	–	–	–
Mini Clubman Estate	1110	1122	1221	1221	1232	1122	1223	1122	1223	1224
Hillman Minx Estate	2222	2232	3232	2232	2232	2222	2222	2122	2222	2221
Ford Minibus	1012	2112	1122	1122	1022	1010	1000	1020	2120	–
Unladen Bedford Tipper Lorry	2232	2022	2002	0002	0000	0000	0000	0000	0000	–
Laden Beford Tipper Lorry	1211	1210	1200	0201	0200	0200	0200	–	–	–
Double Decker Bus (Front)	0100	0100	0000	0000	0000	0000	–	–	–	–
Ford Articulated Lorry	5446	5446	4234	4214	2202	0000	0000	–	–	–

Hump Dimensions 4 x 0.5 in (102 x 13mm)

Vehicle Type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113
Raleigh Moped	00	00	00	00	00	00	00	–	–	–
Mini Clubman Estate	4220	4232	3232	3232	3221	3234	3234	3021	3223	3213
Hillman Minx Estate	2220	2222	2232	2241	2231	2240	2042	2240	1240	1230
Ford Minibus	1010	2012	1122	1122	1020	1010	1000	1000	1000	–
Unladen Bedford Tipper Lorry	4246	4234	2212	0002	0010	0000	0010	0010	0010	–
Laden Bedford Tipper Lorry	2210	2210	1210	1210	1000	0000	0000	–	–	–
Double Decker Bus (Front)	1200	1000	0200	0000	0000	0000	–	–	–	–
Ford Articulated Lorry	5455	5445	3444	2224	2002	2002	2014	–	–	–

Hump Dimensions 6 x 0.75 in (152 x 19mm)

Vehicle Type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113
Raleigh Moped	12	02	00	00	00	00	00	–	–	–
Mini Clubman Estate	1142	2244	2142	2242	2144	2244	2142	2144	2144	2222
Hillman Minx Estate	1242	1242	1240	0240	0240	0240	0230	0220	0220	0220
Ford Minibus	2042	2142	1042	2242	1032	1032	1022	1012	1212	–
Unladen Bedford Tipper Lorry	4444	4246	3246	1244	2224	2214	1214	0010	0200	–
Laden Bedford Tipper Lorry	3266	3266	3246	3244	2234	2222	12--	–	–	–
Double Decker Bus (Front)	1210	1220	1210	1200	0200	0200	–	–	–	–
Ford Articulated Lorry	6666	6666	6666	6456	6456	2446	2444	–	–	–

Scale: 0 = Not Noticeable, 2 = Just Noticeable, 4 = Noticeable, 6 = Very Noticeable

TABLE 1 Contd.

Scores on Noticeability Scale

Hump Dimensions 6 x 1.5 in (152 x 38mm)

Crossing Speed mile/h km/h / Vehicle Type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113
Raleigh Moped	33	33	44	44	44	45	55	–	–	–
Mini Clubman Estate	2264	3264	3166	2166	2266	3266	2266	3166	3266	3466
Hillman Minx Estate	5664	5666	4666	4666	4466	4466	4266	4266	4264	4264
Ford Minibus	4264	4265	5266	4266	4266	3266	3164	3266	3266	–
Unladen Bedford Tipper Lorry	6666	6666	- 66-	- 66 -	- 66-	- 66-	- 66-	- 45-	- 44-	–
Laden Beford Tipper Lorry	6466	6666	66--	66--	66--	66--	66--	–	–	–
Double Decker Bus (Front)	2440	3441	3441	3641	4240	4240	–	–	–	–
Ford Articulated Lorry	6666	6666	6666	- 66-	- 66-	- 66-	–	–	–	–

Hump Dimensions 6 x 3 in (152 x 76mm)

Vehicle Type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113
Raleigh Moped	65	–	–	–	–	–	–	–	–	–
Mini Clubman Estate	6666	6666	6666	6666	6666	6666	6666	–	–	–
Hillman Minx Estate	6666	6666	6666	6666	–	–	–	–	–	–
Ford Minibus	6666	6666	6666	6666	6666	–	–	–	–	–
Unladen Beford Tipper Lorry	6666	6666	–	–	–	–	–	–	–	–
Laden Bedford Tipper Lorry	6666	6666	–	–	–	–	–	–	–	–
Double Decker Bus (Front)	6666	6666	6666	6666	6666	6666	6666	–	–	–
Ford Articulated Lorry	6666	6666	–	–	–	–	–	–	–	–

Scale: 0 = Not Noticeable, 2 = Just Noticeable, 4 = Noticeable, 6 = Very Noticeable

TABLE 2

Scores on Discomfort scale

Hump Dimensions 2 x 0.5 in (51 x 13mm)

Vehicle type \ Crossing speed mile/h km/h	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	00	00	00	00	00	00	00	–	–	–	40 (64)
Mini Clubman Estate	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	30–70 (48–113)
Hillman Minx Estate	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	30–70 (48–113)
Ford Minibus	0000	0000	0000	1000	1000	0000	0000	0000	0000	–	25–60 (40–97)
Unladen Bedford Tipper Lorry	0001	0000	0001	0000	0000	0000	0000	0000	0000	–	30–60 (48–97)
Laden Bedford Tipper Lorry	0000	0000	0000	0000	0000	0000	0000	–	–	–	30–40 (48–64)
Double Decker Bus (Front)	0000	0000	0000	0000	0000	0000	–	–	–	–	20–30 (32–48)
Ford Articulated Lorry	2002	2002	2002	1002	0000	0000	0000	–	–	–	25–40 (40–64)

Hump Dimensions 4 x 0.5 in (102 x 13mm)

Raleigh Moped	00	00	00	00	00	00	00	–	–	–	40 (64)
Mini Clubman Estate	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	25–70 (40–113)
Hillman Minx Estate	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	30–70 (48–113)
Ford Minibus	0000	0000	2200	0000	1100	0000	0000	1000	0000	–	15–60 (24–97)
Unladen Beford Tipper Lorry	1001	1001	0001	0000	0000	0000	0000	0000	0000	–	40–60 (64–97)
Laden Bedford Tipper Lorry	0000	0000	0000	0000	0000	0000	0000	–	–	–	30–40 (48–64)
Double Decker Bus (Front)	0000	0000	0000	0000	0000	0000	–	–	–	–	15–30 (24–48)
Ford Articulated Lorry	2112	2112	1001	1001	1000	1000	1001	–	–	–	25–40 (40–64)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable, 4 = Uncomfortable, 6 = Very uncomfortable

TABLE 2 Contd.

Scores on discomfort scale

Hump Dimensions 6 x 0.75 in (152 x 19mm)

Crossing speed mile/h km/h / Vehicle type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h km/h
Raleigh Moped	00	00	00	00	00	00	00	–	–	–	40 (64)
Mini Clubman Estate	1100	1100	0000	0100	1000	1100	1000	1100	0000	0000	25–70 (40–113)
Hillman Minx Estate	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	30–70 (48–113)
Ford Minibus	2200	1000	1100	1100	1100	0100	1100	1100	2100	–	15–60 (24–97)
Unladen Bedford Tipper Lorry	2132	2124	1112	1112	1102	0101	0001	0000	0000	–	40–60 (64–97)
Laden Bedford Tipper Lorry	1022	1022	1011	0010	0001	0000	0000	–	–	–	30–40 (48–64)
Double Decker Bus (Front)	0000	0000	0000	0000	0000	0000	–	–	–	–	15–30 (24–48)
Ford Articulated Lorry	4432	4434	4424	2022	3123	1122	1122	–	–	–	25–40 (40–64)

Hump Dimensions 6 x 1.5 in (152 x 38mm)

Raleigh Moped	01	11	21	21	21	12	12	–	–	–	25–30 (40–48)
Mini Clubman Estate	1020	2121	2122	2122	2134	2135	2225	1125	2224	2212	25–50 (40–81)
Hillman Minx Estate	2222	2213	2214	2114	2214	2214	1004	1102	0003	0002	30–70 (48–113)
Ford Minibus	1222	2224	2232	2222	1025	1025	2000	2111	2000	–	15–60 (24–97)
Unladen Bedford Tipper Lorry	5646	6646	- 64-	- 43-	- 44-	- 44-	- 22-	- 22-	- 11-	–	5–60 (8–97)
Laden Bedford Tipper Lorry	1146	3246	32--	22--	22--	22--	12--	–	–	–	25–40 (40–64)
Double Decker Bus (Front)	1112	1112	1223	1133	1122	2112	–	–	–	–	15–30 (24–48)
Ford Articulated Lorry	6546	6646	6656	- 65-	- 64-	- 64-	–	–	–	–	5–10 (8–16)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable, 4 = Uncomfortable, 6 = Very uncomfortable

TABLE 2 Contd.

Scores on discomfort scale

Hump Dimensions 6 x 3 in (152 x 76mm)

Vehicle type \ Crossing speed mile/h km/h	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	53	–	–	–	–	–	–	–	–	–	Not at all vehicle grounded
Mini Clubman Estate	6656	6656	6656	6646	6646	- -46	- -46	–	–	–	<5–10 (<8–16)
Hillman Minx Estate	6656	6656	6656	6646	–	–	–	–	–	–	<5–10 (<8–16)
Ford Minibus	6656	6646	6646	6646	6646	66- -	66- -	–	–	–	<5–10 (<8–16)
Unladen Bedford Tipper Lorry	6666	6666	–	–	–	–	–	–	–	–	<5 (<8)
Laden Bedford Tipper Lorry	6666	6666	–	–	–	–	–	–	–	–	<5 (<8)
Double Decker Bus (Front)	4326	5246	4146	4226	4216	4226	–	–	–	–	<5–30 (<8–48)
Ford Articulated Lorry	6666	6666	–	–	–	–	–	–	–	–	<5 (<8)

Hump Dimensions 2 ft x 3 in (610 x 76mm)

Raleigh Moped	51	–	–	–	–	–	–	–	–	–	Not at all vehicle grounded
Mini Clubman Estate	6666	6566	6666	6666	6666	- - 56	–	–	–	–	<5–10 (<8–16)
Hillman Minx Estate	6346	6656	6656	6646	–	–	–	–	–	–	<5–10 (<8–16)
Ford Minibus	6656	6656	6656	6656	6656	–	–	–	–	–	<5–10 (<8–16)
Unladen Bedford Tipper Lorry	6666	6666	–	–	–	–	–	–	–	–	<5 (<8)
Laden Bedford Tipper Lorry	6666	6666	–	–	–	–	–	–	–	–	<5 (<8)
Double Decker Bus (Front)	6646	6646	6656	–	–	–	–	–	–	–	<5 (<8)
Ford Articulated Lorry	5666	6666	–	–	–	–	–	–	–	–	<5 (<8)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable 4 = Uncomfortable 6 = Very uncomfortable

TABLE 2 Contd.

Scores on discomfort scale

Hump Dimensions 4 ft x 2 in (1.22 x 0.05m)

Crossing speed mile/h km/h / Vehicle type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	10	22	32	42	42	–	–	–	–	–	10–15 (16–24)
Mini Clubman Estate	2002	3014	4225	6226	6226	6226	5225	4225	4 - -5	–	5–30 (8–48)
Hillman Minx Estate	0000	1023	3013	3114	4445	4645	5646	5646	–	–	20–30 (32–48)
Ford Minibus	4000	4022	4243	4152	5254	5253	4252	4252	–	–	5–10 (8–16)
Unladen Bedford Tipper Lorry	4014	6666	–	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	1010	6666	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	2122	4124	6124	3135	- 13-	- 14-	–	–	–	–	5–20 (8–32)
Double Decker Bus (Rear)	0- 1-	3- 4-	4- 4-	5- 4-	5- 5-	6- 4-	–	–	–	–	5 (8)
Ford Articulated Lorry	4015	6236	6666	–	–	–	–	–	–	–	5 (8)

Hump Dimensions 4 ft x 3 in (1.22 x 0.08m)

Raleigh Moped	20	31	53	54	64	–	–	–	–	–	10 (16)
Mini Clubman Estate	2331	5444	6345	6656	6656	6646	–	–	–	–	5–15 (8–24)
Hillman Minx Estate	2012	4235	6245	5656	6666	6666	–	–	–	–	5–10 (8–16)
Ford Minibus	4224	5326	5426	6466	6566	–	–	–	–	–	5–10 (8–16)
Unladen Bedford Tipper Lorry	6146	6666	–	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	6646	6666	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	6046	6246	6266	6666	–	–	–	–	–	–	5–10 (8–16)
Double Decker Bus (Rear)	3 -3 -	6- 5-	6- 6-	–	–	–	–	–	–	–	5 (8)
Ford Articulated Lorry	5235	6666	–	–	–	–	–	–	–	–	5 (8)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable, 4 = Uncomfortable, 6 = Very uncomfortable

TABLE 2 Contd.

Scores on discomfort scale

Hump Dimensions 4 ft x 4 in (1.22 x 0.10m)

Vehicle type \ Crossing speed mile/h km/h	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	44	65	–	–	–	–	–	–	–	–	5 (8)
Mini Clubman Estate	5224	6656	6666	- 6-6	–	–	–	–	–	–	5 (8)
Hillman Minx Estate	3115	6666	6666	–	–	–	–	–	–	–	5–10 (8–16)
Ford Minibus	6426	6666	6666	–	–	–	–	–	–	–	5 (8)
Unladen Bedford Tipper Lorry	6646	–	–	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	6646	–	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	6656	6666	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Rear)	6- 6-	6- 6-	–	–	–	–	–	–	–	–	5 (8)
Ford Articulated Lorry	6646	6666	–	–	–	–	–	–	–	–	5 (8)

Hump Dimensions 8 ft x 2 in (2.44 x 0.05m)

Raleigh Moped	00	00	00	00	11	11	11	–	–	–	40 (64)
Mini Clubman Estate	0000	0000	1011	2011	3012	3013	4014	4014	–	–	5–40 (8–64)
Hillman Minx Estate	1000	1000	1000	2112	3123	3223	2222	3222	–	–	20–30 (32–48)
Ford Minibus	0000	1102	2202	3223	2223	4224	3123	0221	–	–	10–40 (16–64)
Unladen Bedford Tipper Lorry	3002	6116	6236	6466	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	0000	1012	6622	6666	–	–	–	–	–	–	5–10 (8–16)
Double Decker Bus (Front)	1010	2222	4142	4235	5225	6226	–	–	–	–	10–20 (16–32)
Double Decker Bus (Rear)	0- 0-	2- 3-	3- 4-	4- 4-	4- 4-	5- 4-	–	–	–	–	5–10 (8–16)
Ford Articulated Lorry	4112	5114	5245	6646	6656	–	–	–	–	–	5–10 (8–16)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable, 4 = Uncomfortable, 6 = Very uncomfortable

TABLE 2 Contd.

Scores on discomfort scale

Hump Dimensions 8 ft x 3 in (2.44 x 0.08m)

Vehicle type \ Crossing speed mile/h km/h	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	00	01	11	22	32	22	33	–	–	–	30 (48)
Mini Clubman Estate	0000	1221	3222	4234	5645	6546	6336	6336	–	–	5–20 (8–32)
Hillman Minx Estate	2001	2102	3213	5244	5645	5646	6636	6636	–	–	5–20 (8–32)
Ford Minibus	0010	5015	6246	6446	6656	6656	–	–	–	–	5–10 (8–16)
Unladen Bedford Tipper Lorry	3003	4116	6666	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	1022	6246	6666	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	2010	3220	6666	6666	–	–	–	–	–	–	5–10 (8–16)
Double Decker Bus (Rear)	1- 2-	6- 5-	6- 6-	6-6-	–	–	–	–	–	–	5 (8)
Ford Articulated Lorry	4124	6646	6666	–	–	–	–	–	–	–	5 (8)

Hump Dimensions 8 ft x 4 in (2.44 x 0.10m)

Vehicle type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	00	00	10	42	54	–	–	–	–	–	10–15 (16–24)
Mini Clubman Estate	3012	6026	6646	6656	6666	6666	–	–	–	–	5–10 (8–16)
Hillman Minx Estate	1011	2022	2643	6666	6666	–	–	–	–	–	5–10 (8–16)
Ford Minibus	5005	5035	6646	6656	6656	6666	–	–	–	–	5–10 (8–16)
Unladen Bedford Tipper Lorry	6026	6246	6666	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	5122	6666	6666	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	2212	6646	6666	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Rear)	1- 4-	6- 6-	–	–	–	–	–	–	–	–	5 (8)
Ford Articulated Lorry	2622	6666	–	–	–	–	–	–	–	–	5 (8)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable, 4 = Uncomfortable, 6 = Very uncomfortable

TABLE 2 Contd.

Scores on discomfort scale

Hump Dimensions 12 ft x 4 in (3.66 x 0.10m)

Crossing speed mile/h km/h / Vehicle type	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	00	00	10	20	32	42	44	–	–	–	20 (32)
Mini Clubman Estate	1000	1011	4025	6046	6236	6656	–	–	–	–	5–15 (8–24)
Hillman Minx Estate	0000	2001	2022	1244	5645	6666	- 6-6	–	–	–	5–15 (8–24)
Ford Minibus	0000	2021	4234	4445	5645	6646	6 --6	–	–	–	5–10 (8–16)
Unladen Bedford Tipper Lorry	3002	6246	6656	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	0022	5244	6656	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	0010	-12 -	6646	6646	–	–	–	–	–	–	5–10 (8–16)
Double Decker Bus (Rear)	2-2-	6- 4-	6- 4-	–	–	–	–	–	–	–	5 (8)
Ford Articulated Lorry	0010	6136	6656	–	–	–	–	–	–	–	5 (8)

Hump Dimensions 12 ft x 5 in (3.66 x 0.13m)

Raleigh Moped	01	11	21	22	33	54	–	–	–	–	15 (24)
Mini Clubman Estate	0010	2012	4235	6446	6666	6666	–	–	–	–	5–15 (8–24)
Hillman Minx Estate	0000	0001	2111	4644	6656	6666	–	–	–	–	5–15 (8–24)
Ford Minibus	1000	2222	5645	6666	–	–	–	–	–	–	5–10 (8–16)
Unladen Bedford Tipper Lorry	2003	5666	–	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	3024	6666	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	0121	6646	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Rear)	3- 1-	6- 6-	–	–	–	–	–	–	–	–	5 (8)
Ford Articulated Lorry	1120	6646	6666	–	–	–	–	–	–	–	5 (8)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable, 4 = Uncomfortable, 6 = Very uncomfortable

TABLE 2 Contd.

Scores on discomfort scale

Hump Dimensions 12 ft x 6 in (3.66 x 0.15m)

Vehicle type \ Crossing speed mile/h km/h	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97	70 113	Preferred Crossing Speed mile/h (km/h)
Raleigh Moped	10	10	21	31	44	–	–	–	–	–	10–15 (16–24)
Mini Clubman Estate	3113	4224	5655	6666	–	–	–	–	–	–	5–10 (8–16)
Hillman Minx Estate	0000	2102	1221	6666	–	–	–	–	–	–	5–15 (8–24)
Ford Minibus	2101	5214	5665	6666	–	–	–	–	–	–	5–10 (8–16)
Unladen Bedford Tipper Lorry	4015	6666	–	–	–	–	–	–	–	–	5 (8)
Laden Bedford Tipper Lorry	4145	6666	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Front)	2122	6646	–	–	–	–	–	–	–	–	5 (8)
Double Decker Bus (Rear)	4- 2-	6- 6-	–	–	–	–	–	–	–	–	5 (8)
Ford Articulated Lorry	0020	6646	–	–	–	–	–	–	–	–	5 (8)

Scale: 0 = Comfortable, 2 = Slightly uncomfortable, 4 = Uncomfortable, 6 = Very uncomfortable

TABLE 3

Peak Vertical Acceleration readings for Mini Clubman Estate car and Bedford Tipper Lorry (unladen) in units of g

Hump size	Crossing Speed mile/h km/h / Vehicle	5 8	10 16	15 24	20 32	25 40	30 48	40 64	50 81	60 97
2 x 0.5 in	Car	0.06	0.05	0.07	0.04	0.03	0.03	0.11	0.20	0.10
(51 x 13mm)	Lorry	–	–	–	–	–	–	–	–	–
4 x 0.5 in	Car	0.05	0.04	0.05	0.08	0.04	0.05	0.05	0.14	0.18
(102 x 13mm)	Lorry	–	–	–	–	–	–	–	–	–
6 x 0.75 in	Car	0.08	0.05	0.13	0.06	0.11	0.08	0.10	0.21	0.23
(152 x 19mm)	Lorry	0.39	0.28	0.37	0.44	0.41	0.18	0.18	–	–
6 x 1.5 in	Car	0.23	0.28	0.27	0.17	0.23	0.21	0.24	0.28	0.23
(152 x 38mm)	Lorry	1.03	0.91	0.93	0.97	0.67	0.62	–	–	–
6 x 3 in	Car	0.79	0.77	0.53	0.56	0.53	0.34	–	–	–
(152 x 76mm)	Lorry	>1.50+	–	–	–	–	–	–	–	–
2 ft x 3 in	Car	1.65*	1.39	1.29	1.26	1.57	1.03	–	–	–
(610 x 76mm)	Lorry	>1.50+	–	–	–	–	–	–	–	–
4 ft x 2 in	Car	0.43	0.57	0.69	0.74	0.85	0.57	0.53	–	–
(1.22 x 0.05m)	Lorry	0.38	>1.50+	–	–	–	–	–	–	–
4 ft x 3 in	Car	0.79	1.39	1.47	1.80*	1.21	1.20	0.99	–	–
(1.22 x 0.08m)	Lorry	1.03	>1.50+	–	–	–	–	–	–	–
4 ft x 4 in	Car	0.72	1.80*	>1.50+	>1.50+	–	–	–	–	–
(1.22 x 0.10m)	Lorry	1.13	–	–	–	–	–	–	–	–
8 ft x 2 in	Car	0.27	0.37	0.28	0.30	0.44	0.82	0.97	0.93	–
(2.44 x 0.05m)	Lorry	0.30	0.53	1.65*	>1.50+	–	–	–	–	–
8 ft x 3 in	Car	0.18	0.50	0.43	0.43	0.57	1.03	1.08	0.97	–
(2.44 x 0.08m)	Lorry	0.32	0.56	>1.50+	–	–	–	–	–	–
8 ft x 4 in	Car	0.22	0.70	0.73	0.99	1.05	1.17	–	–	–
(2.44 x 0.10m)	Lorry	0.77	1.70*	>1.50+	–	–	–	–	–	–
12 ft x 4 in	Car	0.18	0.40	0.58	0.93	1.39	1.75*	–	–	–
(3.66 x 0.10m)	Lorry	0.38	1.50	1.36	–	–	–	–	–	–
12 ft x 5 in	Car	0.44	0.53	0.68	1.24	1.75*	1.80*	–	–	–
(3.66 x 0.13m)	Lorry	0.72	–	–	–	–	–	–	–	–
12 ft x 6 in	Car	0.56	0.60	1.25	>1.50+	–	–	–	–	–
(3.66 x 0.15m)	Lorry	0.69	1.85*	–	–	–	–	–	–	–

* Peak value estimated-trace off film at maximum values.

\+ Peak value impossible to estimate – trace too far off film at maximum values.

TABLE 4

Effect of humps on Mini Clubman travelling at 20 mile/h (32 km/h)

Hump Dimensions	Maximum Displacement of Front Wheel in (mm)	Maximum Displacement of Tyre Tread in (mm)	Max. Vertical Displacement of Centre of Car in (mm)	Max. Angular Displacement of Car Body (degrees)	Time for which Front Wheel lost Contact with Ground (s)	Time for which Back Wheel lost Contact with Ground (s)
6 x 3 in (152 x 76mm)	2 (51)	2 (51)	<0.5 (13)	1	0.02	0.02
4 ft x 4 in (1.22 x 0.10m)	3 (76)	1 (25)	2.5 (64)	3	0.09	0.15
8 ft x 4 in (2.44 x 0.10m)	2.5 (64)	0.5 (13)	3 (76)	5	0.07	0.00
12 ft x 4 in (3.66 x 0.10m)	2 (51)	0.5 (13)	3.5 (89)	6	0.00	0.00

TABLE 5

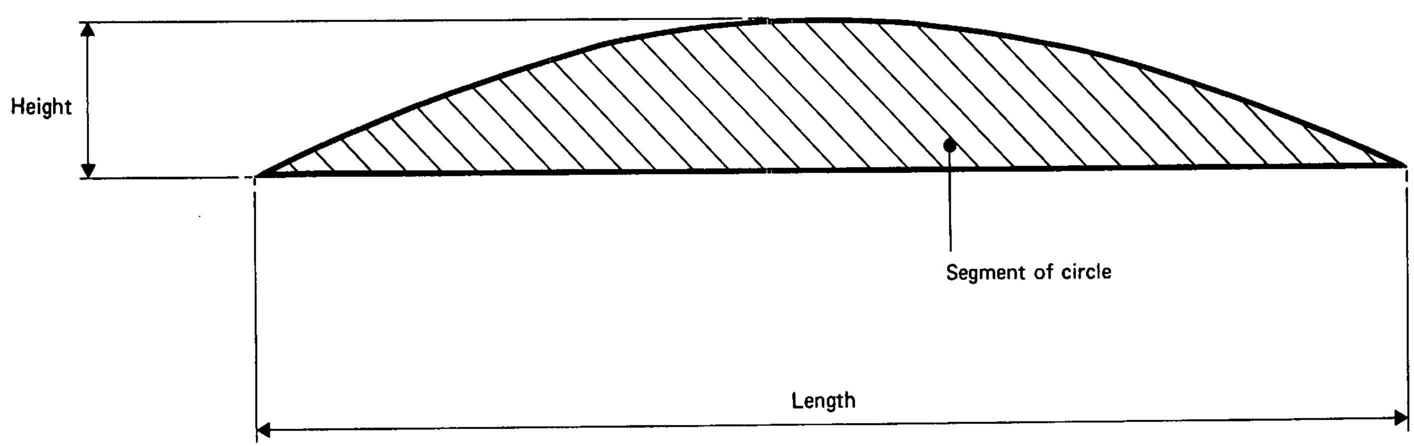
Average speed of cars and vans on and near a 12 ft (3.7m) long hump

Distance from Hump ft (m)	330 (100)		165 (50)		82.5 (25)		0
A = Approaching R = Receding	A	R	A	R	A	R	
Average Speed mile/h km/h	28.3 45.6	25.2 40.6	23.2 37.4	20.4 32.8	19.8 31.9	16.9 27.2	11.5 18.5
Number of Readings	47	60	153	110	109	103	133
Standard deviation of mean mile/h km/h	0.61 0.98	0.45 0.73	0.27 0.43	0.30 0.49	0.30 0.48	0.27 0.44	0.23 0.37

TABLE 6

Maximum inter-hump speeds for Hillman Minx Estate car

Hump Separation ft (m)	Rate of acceleration and braking \ Hump Crossing Speed mile/h km/h	5 8	10 16	15 24	20 32
90 (27)	Moderate mile/h km/h	12 19	13 21	17 27	21 34
	Severe	18 29	20 32	21 34	25 40
150 (46)	Moderate	16 26	18 29	20 32	26 42
	Severe	26 42	26 42	27 44	31 50
300 (91)	Moderate	21 34	24 39	25 40	29 47
	Severe	32 52	32 52	32 52	38 61
600 (183)	Moderate	28 45	28 45	29 47	32 52
	Severe	40 64	41 66	42 68	49 79



Length	2in (51mm)	4in (102mm)	6in (152mm)	6in (152mm)	6in (152mm)	2ft (610mm)	4ft (1·22m)	4ft (1·22m)	4ft (1·22m)	8ft (2·44m)	8ft (2·44m)	8ft (2·44m)	12ft (3·66m)	12ft (3·66m)	12ft (3·66m)
Height	0·5 in (13mm)	0·5 in (13mm)	0·75in (19mm)	1·5in (38mm)	3in (76mm)	3in (76mm)	2in (0·05m)	3in (0·08m)	4in (0·10m)	2in (0·05m)	3in (0·08m)	4in (0·10m)	4in (0·10m)	5in (0·13m)	6in (0·15m)

Fig.1 TYPICAL CROSS SECTION AND DIMENSIONS OF HUMPS

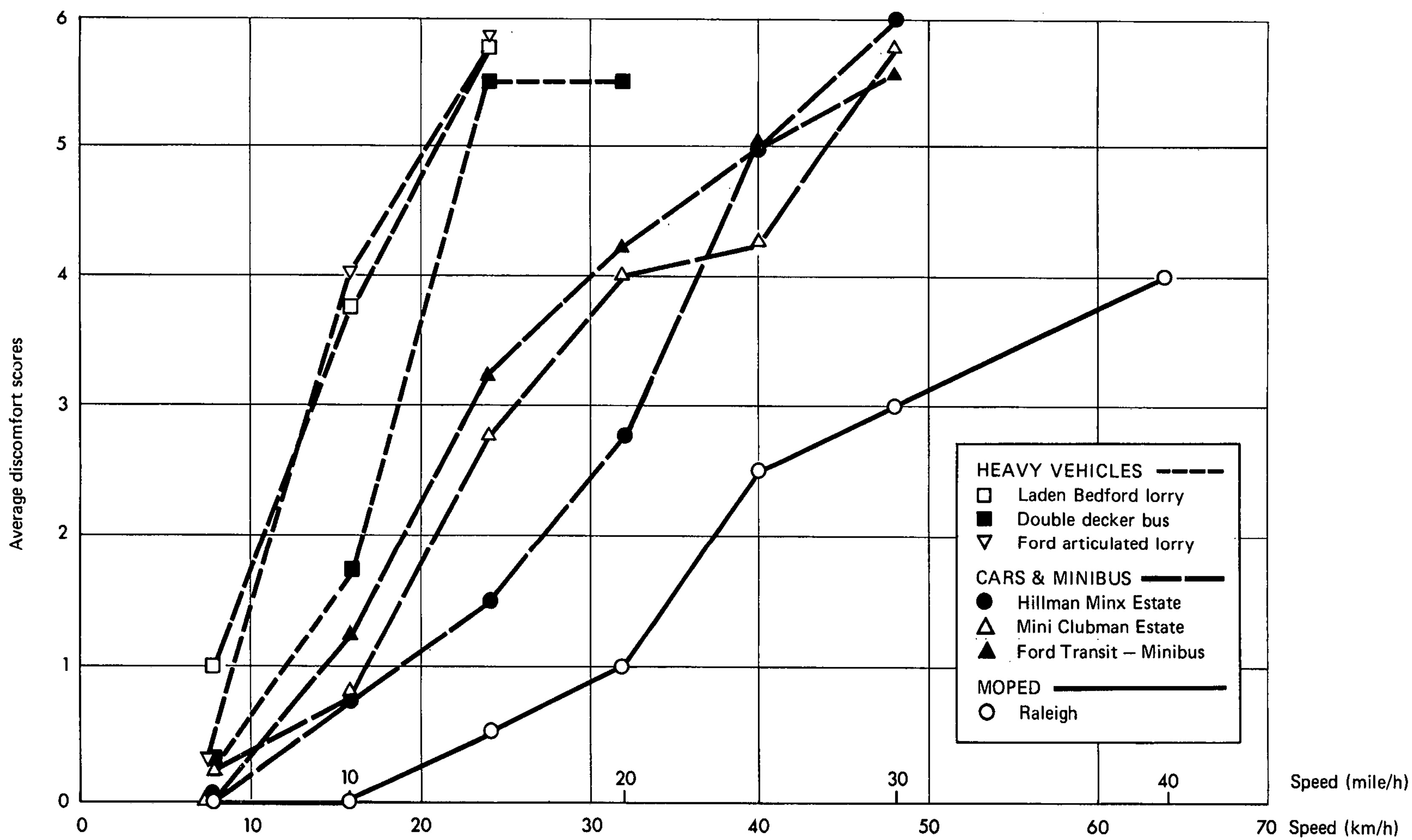


Fig. 2 VARIATION OF DISCOMFORT WITH SPEED FOR VEHICLES TRAVERSING A 12ft x 4in (3·66m x 0·10m) HUMP

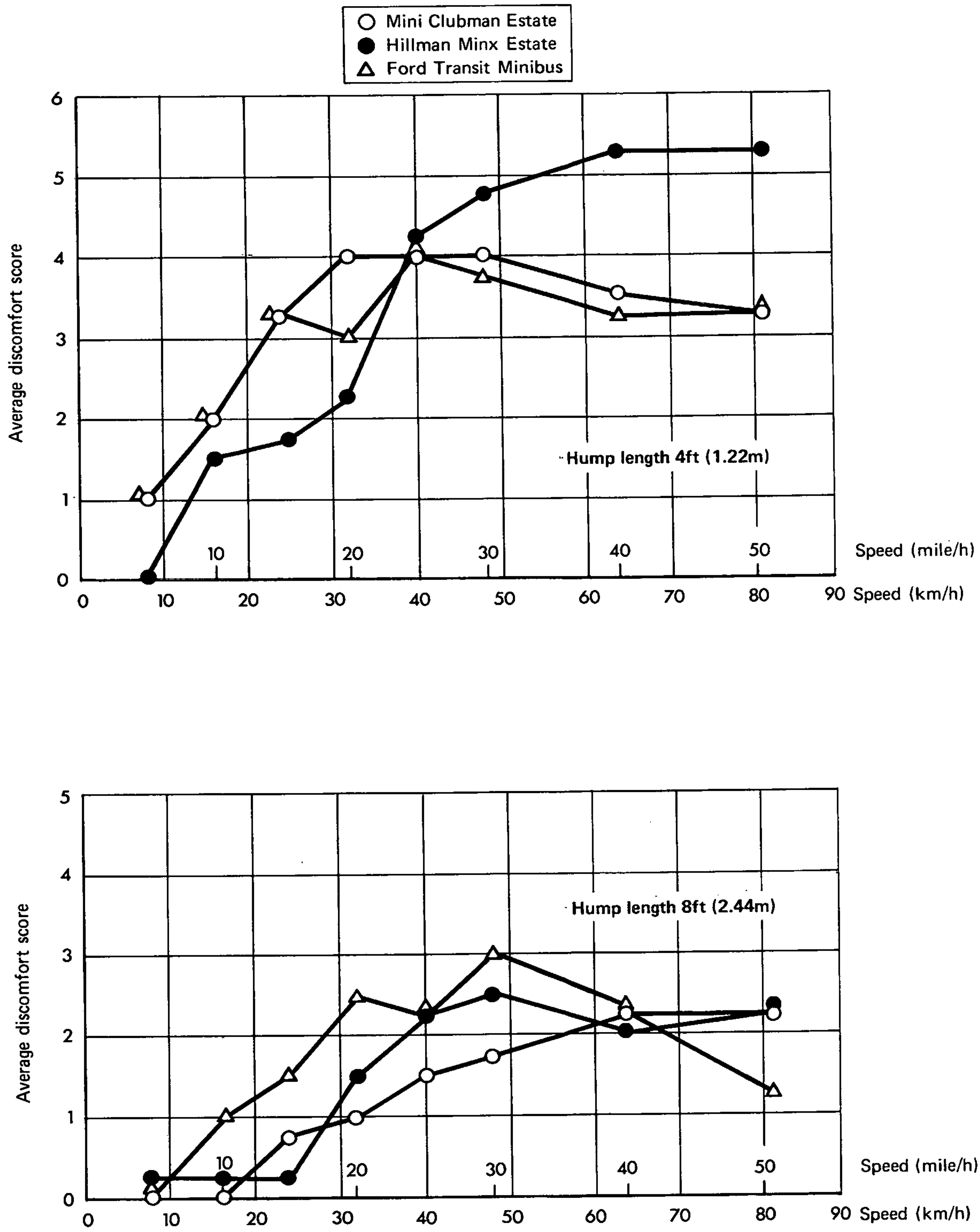


Fig. 3 AVERAGE DISCOMFORT SCORES IN CARS AND MINIBUS TRAVERSING 2in (51mm) HIGH HUMPS OF DIFFERENT LENGTHS AT VARIOUS SPEEDS

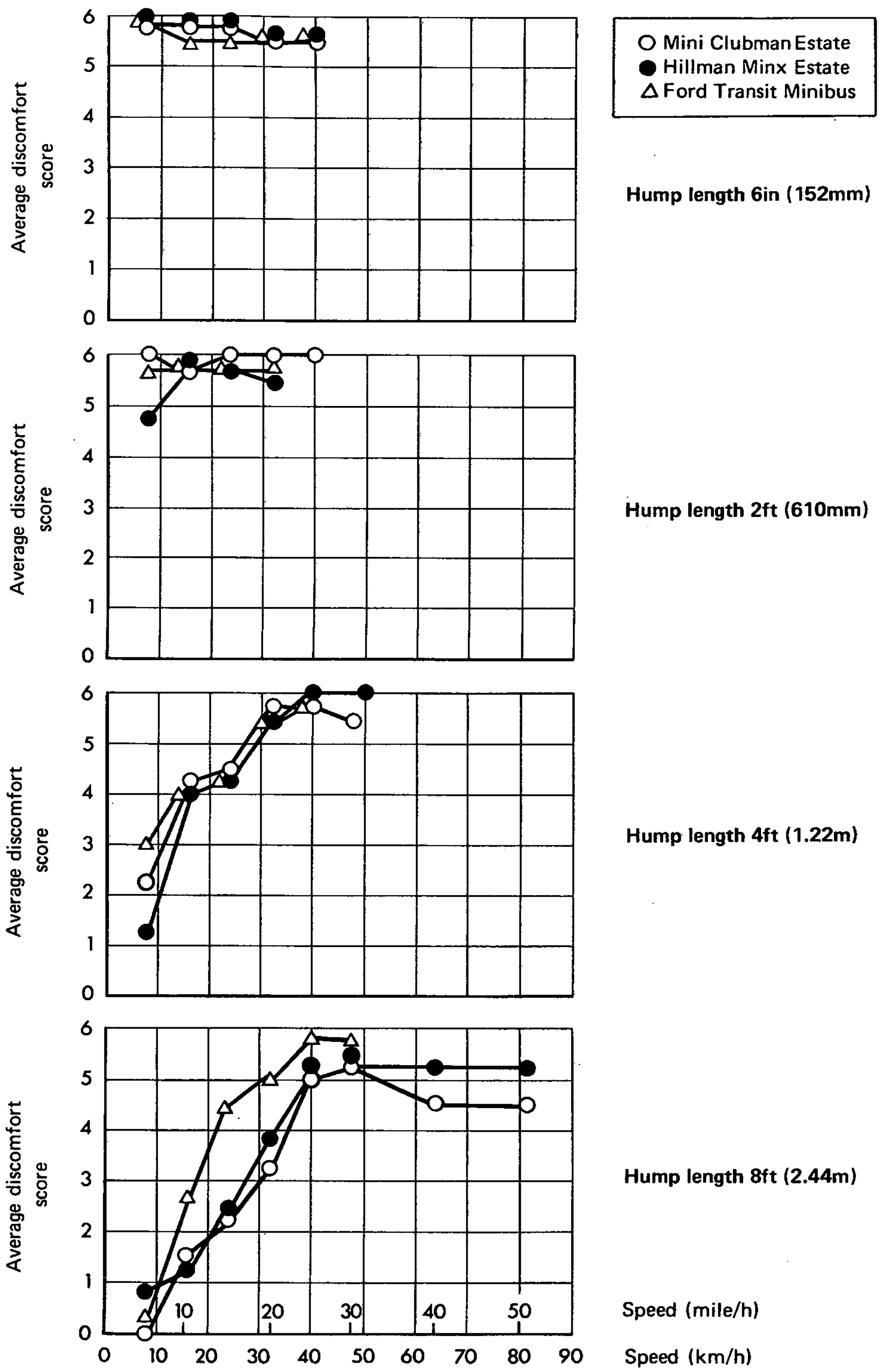


Fig.4 AVERAGE DISCOMFORT SCORES IN CARS AND MINIBUS TRAVERSING 3in (76mm) HIGH HUMPS OF DIFFERENT LENGTHS AT VARIOUS SPEEDS

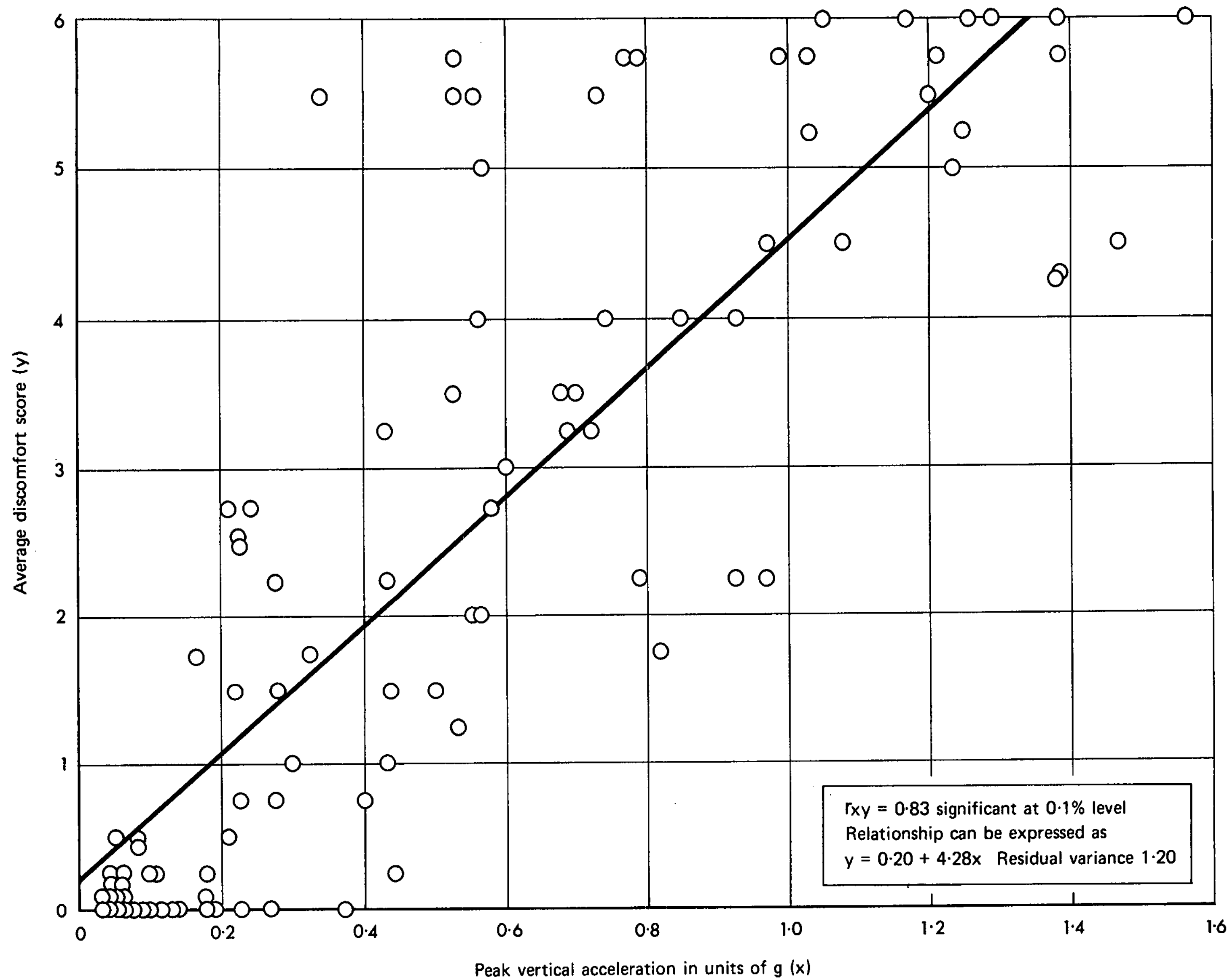


Fig.5 RELATION BETWEEN PEAK ACCELERATION VALUES AND AVERAGE DISCOMFORT SCORES FOR MINI CLUBMAN ESTATE

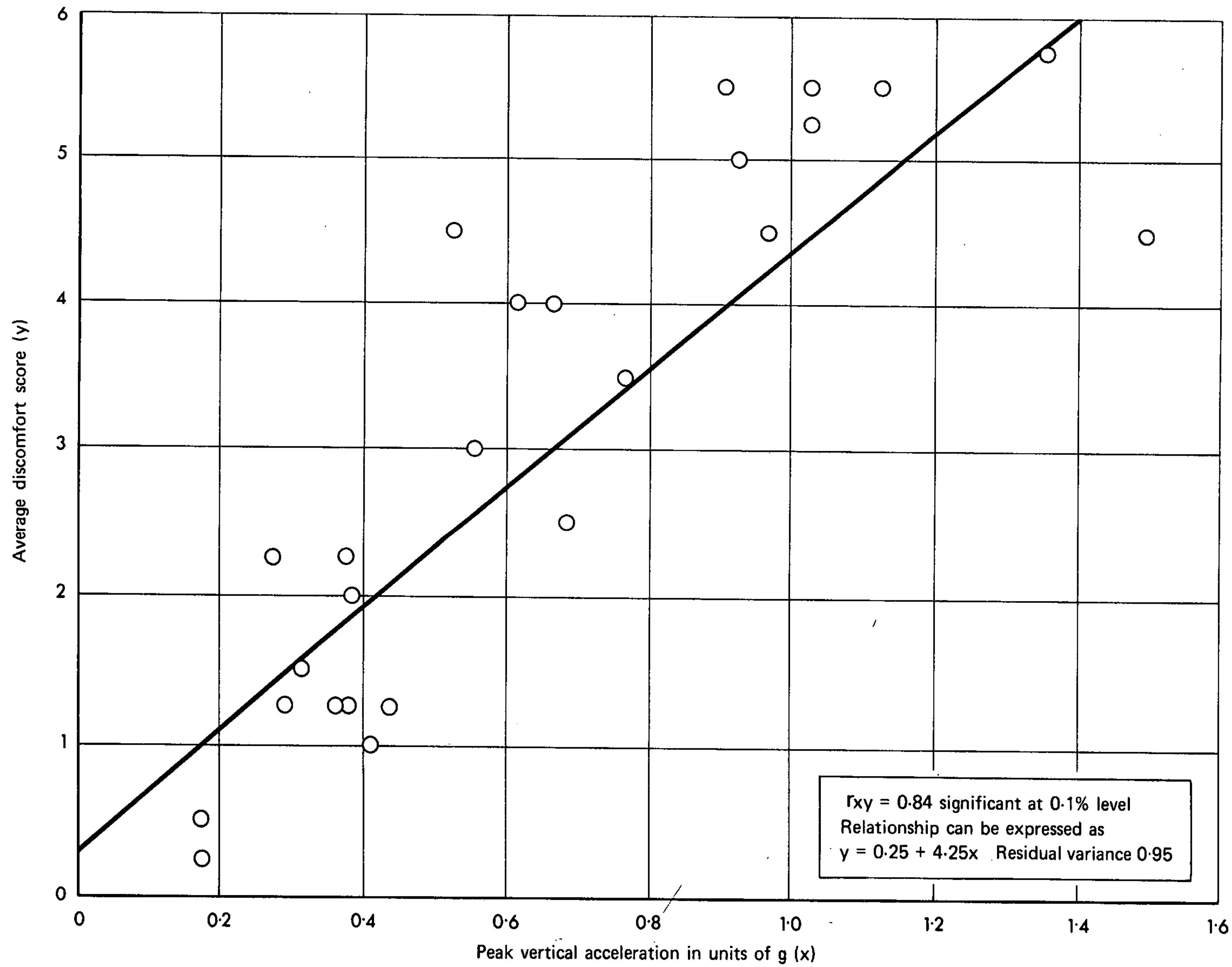


Fig.6 RELATIONSHIP BETWEEN PEAK ACCELERATION VALUES AND AVERAGE DISCOMFORT SCORES FOR BEDFORD TIPPER LORRY

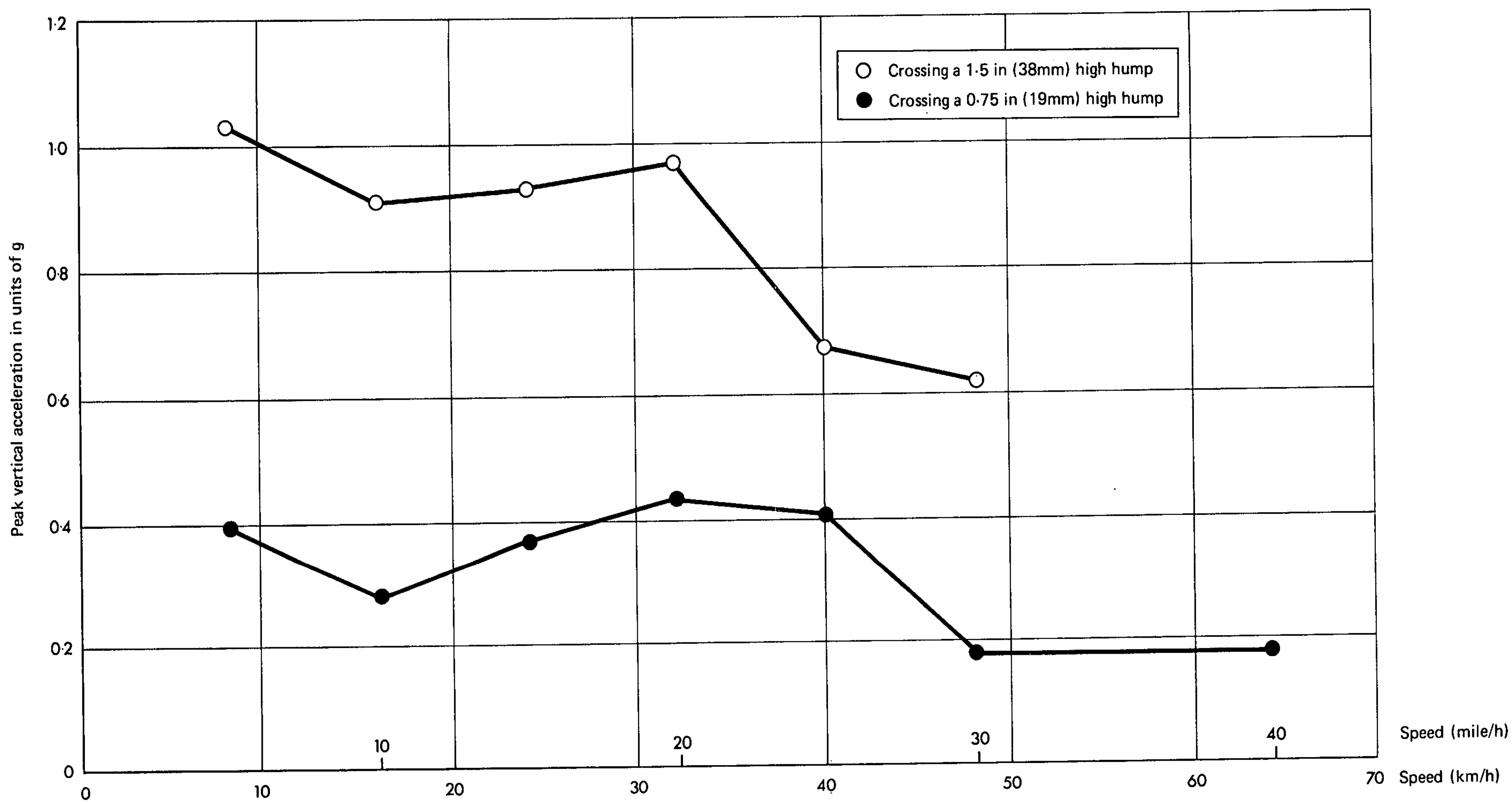
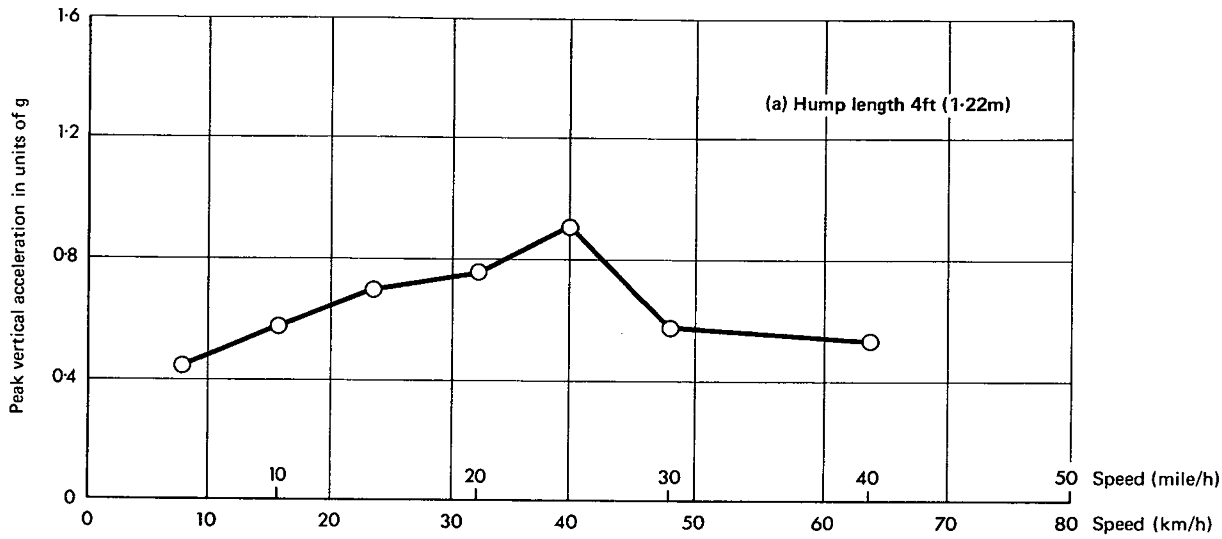


Fig.7 VERTICAL ACCELERATION (DISCOMFORT) OF A PASSENGER IN A BEDFORD TIPPER LORRY TRAVERSING 6in(152mm) WIDE HUMPS AT VARIOUS SPEEDS



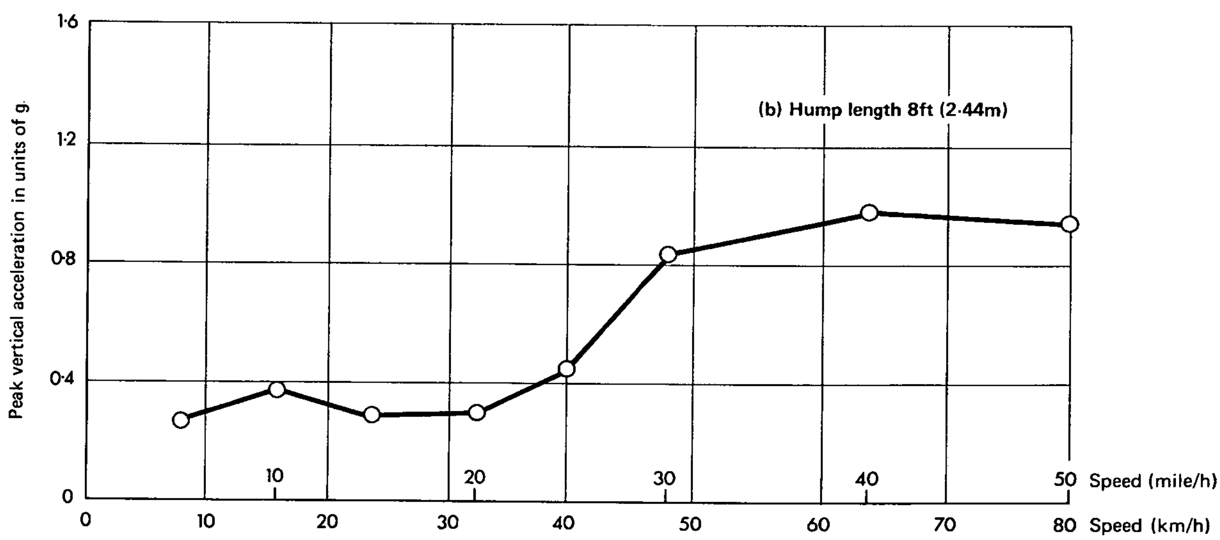


Fig.8 VERTICAL ACCELERATION (DISCOMFORT) OF A PASSENGER IN A MINI CLUBMAN ESTATE TRAVERSING 2in(51mm) HIGH HUMPS OF DIFFERENT LENGTHS AT VARIOUS SPEEDS

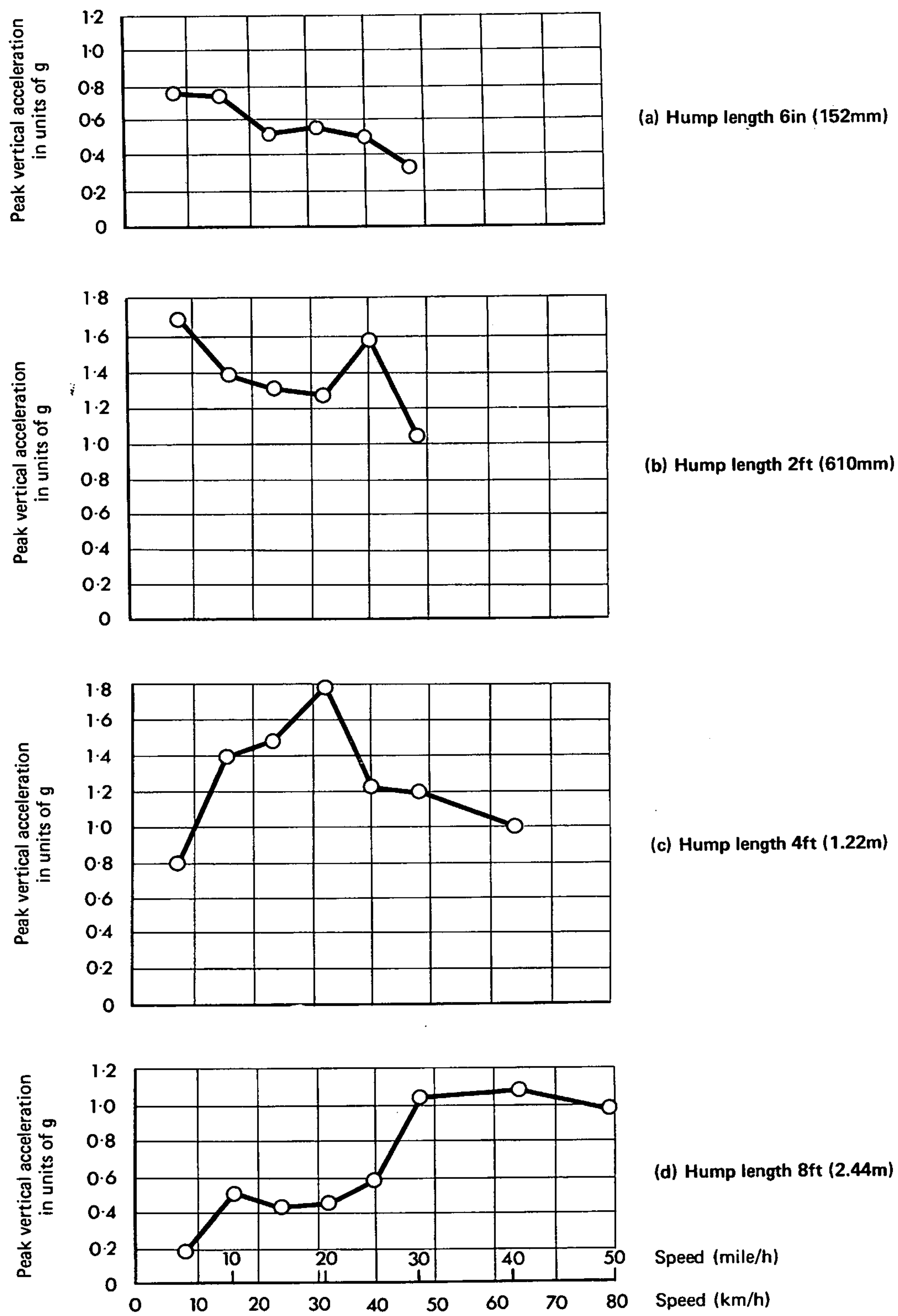


Fig. 9. VERTICAL ACCELERATION (DISCOMFORT) OF A PASSENGER IN A MINI CLUBMAN ESTATE TRAVERSING 3in (76mm) HIGH HUMPS OF DIFFERENT LENGTHS AT VARIOUS SPEEDS

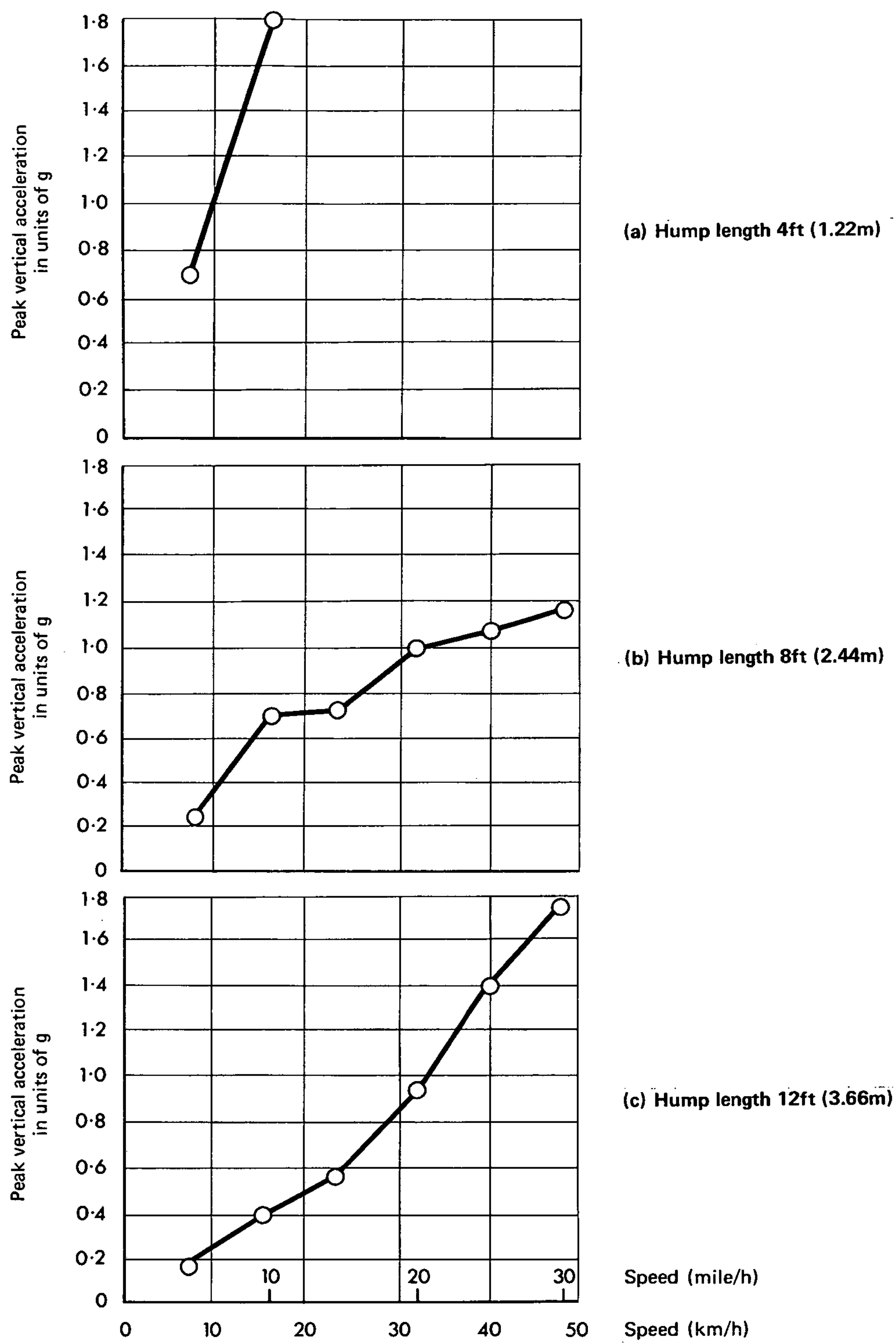


Fig.10 VERTICAL ACCELERATION (DISCOMFORT) OF A PASSENGER IN A MINI CLUBMAN ESTATE TRAVERSING 4in(102mm) HIGH HUMPS OF DIFFERENT LENGTHS AT VARIOUS SPEEDS

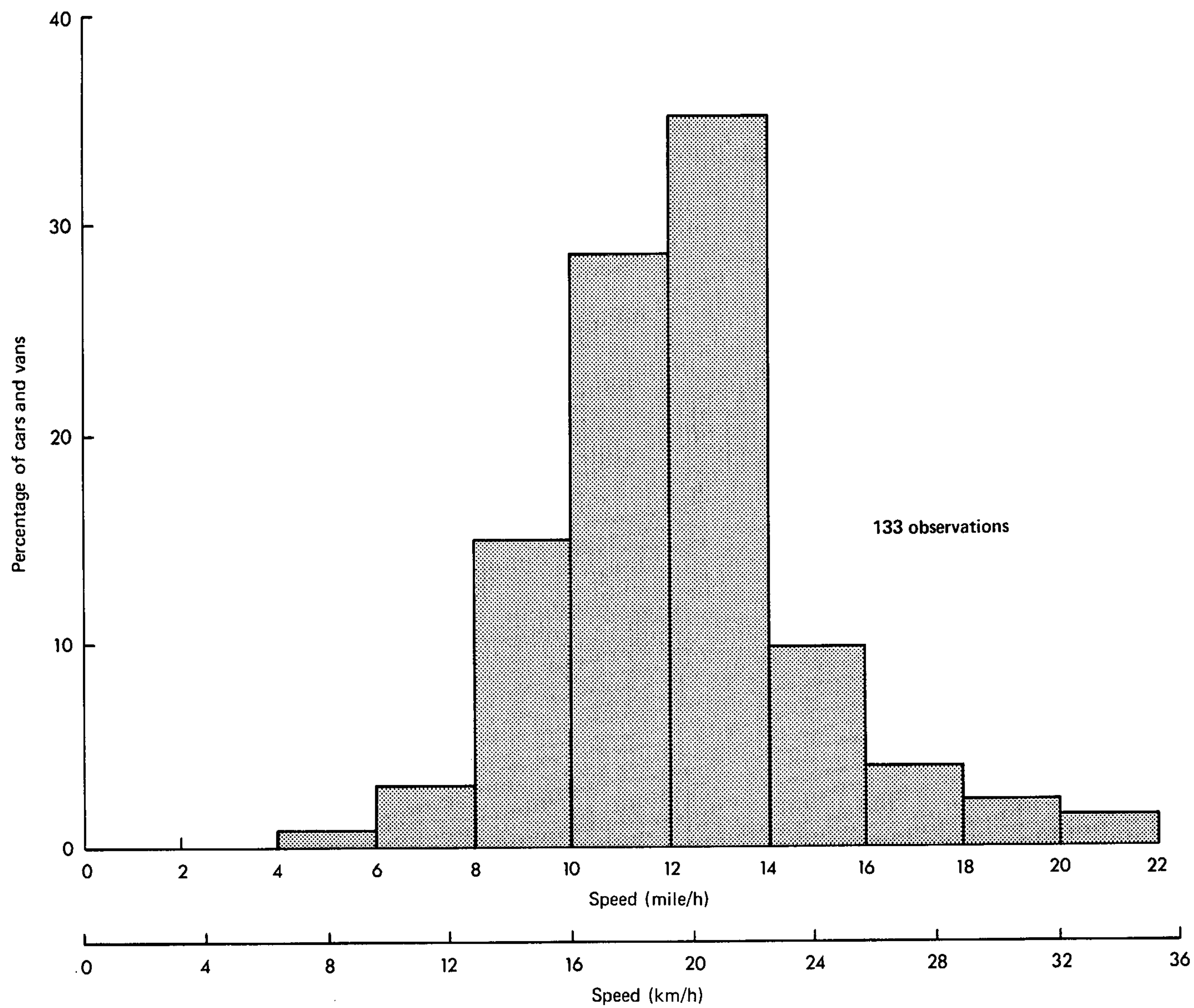


Fig.11 HISTOGRAM OF CAR AND VAN SPEEDS OVER A 12ft (3·7m) LONG HUMP OF HEIGHT 4–5in (100–125mm)

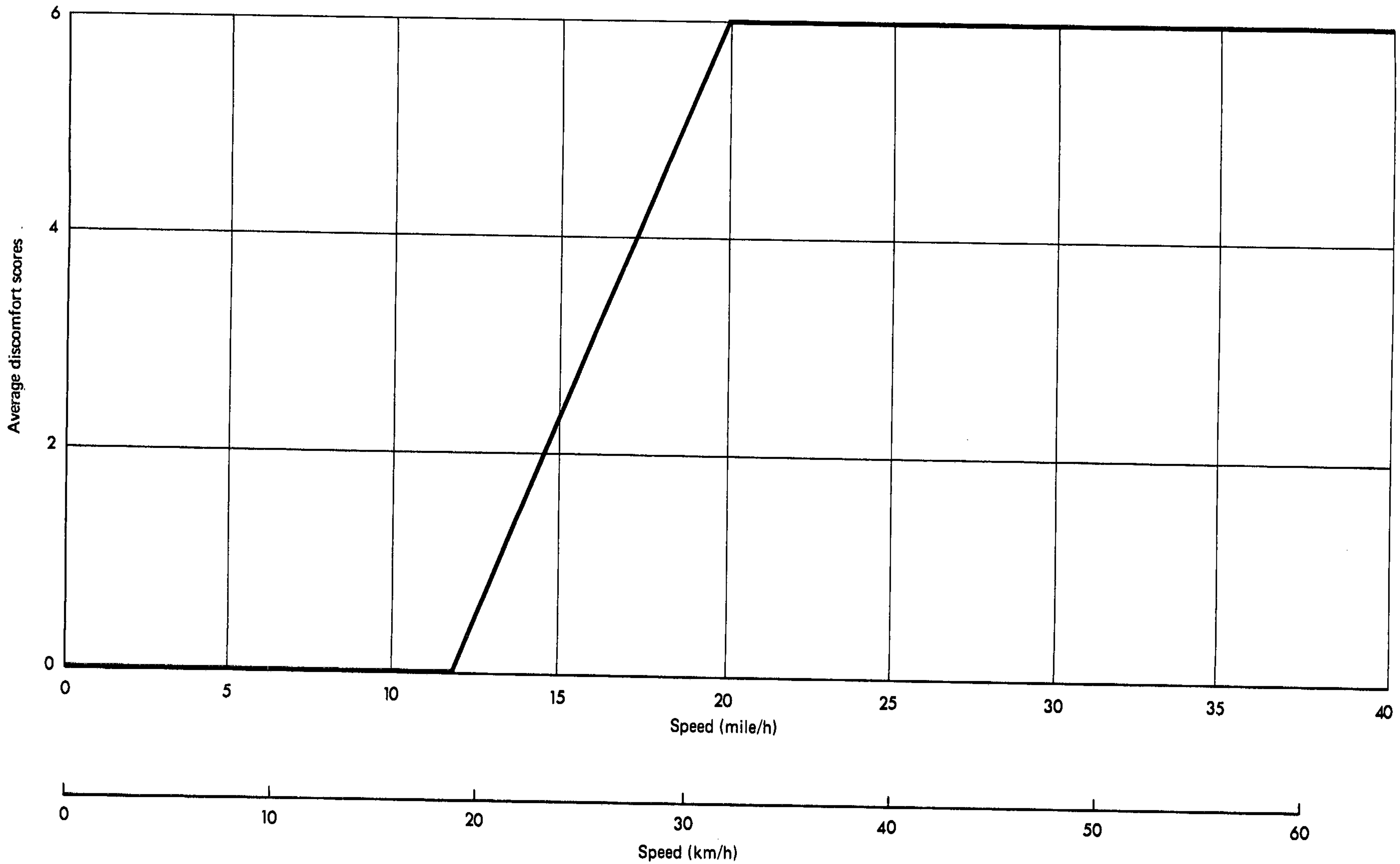


Fig. 12 IDEAL CHARACTERISTICS OF A RAMP DESIGNED FOR 12 mile/h (19km/h)

Neg No R 1519/72/7

PLATE 1

Bedford tipper lorry crossing a 6 in x 3 in (152 x 76 mm)
hump at 20 mile/h (32 km/hour)

Neg No R 1255/72/2

PLATE 2

Mini clubman estate car crossing a 12 ft x 4 in (3.66 x 0.10 m) hump at 20 mile/h (32 km/hour)

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ABSTRACT

Road humps for the control of vehicle speeds: G R Watts: Department of the Environment, TRRL Report LR 597: Crowthorne 1973 (Transport and Road Research Laboratory). The suitability and effectiveness of humps for alerting drivers and controlling vehicle speeds have been investigated. Seven vehicles including private cars, goods vehicles, a moped and a bus were used in the tests and six subjects made estimates of the noticeability and discomfort of the different humps at various crossing speeds.

Two main classes of hump have been studied, short humps which could be straddled by the wheels of most vehicles and long humps which could be straddled only by some large vehicles. The humps ranged from 2 in to 12 ft (0.05m to 3.66m) in length and from 0.5 in to 6 in (13mm to 152mm) in height.

A hump 6 in (152mm) long with a height between 0.75 and 1.5 in (19 and 38mm) was capable of alerting drivers by producing a noticeable vibration. Increasing the height of short humps introduced safety problems such as the risk of loss of control or of vehicle damage by grounding and increased the severity of impact on the tyres and vehicle suspension.

Increasing the length of a hump tended to reduce the hazard and a hump 12 ft (3.66m) long and 4 in (0.10m) high showed promise for controlling vehicle speeds. Nevertheless, the use of humps especially at sites where vehicle approach speeds are high should be undertaken with caution.

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