Rumble devices for road traffic safety

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RUMBLE DEVICES FOR ROAD TRAFFIC SAFETY

SUMMARY

For the purpose of recommending ways in which rumble devices can be used to improve road traffic safety, a survey was made of present practice from enquiries to local engineers and from a study of available literature on the subject.

Rumble devices on roads are intended to alert the driver to the need for caution ahead and are used fairly widely in the U.S.A. The predominant types in use are the 90 metre long continuous rumble surface, and the intermittent rumble surfaces comprising approximately eleven sections of 7,6 metres each with the spacing between them varying from 30 m to 15 m. Surfacing materials are generally 13,2 mm 19,0 mm or 26,5 mm maximum sized crushed stone, or blast furnace slag. Rumble strips 203 mm wide and rumble bars 76 mm wide are used less often. Rumble installations have generally been found effective in reducing accidents at stop intersections by approximately 42% as a result of reduced speeds and improved stop observance.

A number of rumble installations have been constructed on rural roads in South Africa and although no local accident data are available the provincial roads engineers consider them of value in alerting drivers to the need for caution on the approaches to hazardous curves or intersections. City and town engineers had little to report on rumble installations but showed a keen interest in their potential usefulness.

Each type of rumble device has certain merits and these are discussed in the report. It is recommended that the intermittent

rumble/.....

rumble surfaces be used in rural areas and the continuous rumble surface in urban areas. The length of the installation should be related to the speed reduction desired. Guidelines to the layout and construction of rumble installations are given in the report.

It is concluded that rumble devices should be considered only as additional measures where existing warning signs and markings have proved to be ineffective on their own.

I N D E X

7. Local opinion/......

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FIGURES

ANNEXURE A

RUMBLE DEVICES FOR ROAD TRAFFIC SAFETY

1. INTRODUCTION

The National Road Safety Council of South Africa resolved to support in principle the use of rumble devices on tarred and on concrete roads where there is a high accident risk.

The National Institute for Road Research was requested to investigate the feasibility of drafting a specification for the construction of rumble installations, in consultation with the Provincial Roads Authorities.

As a first step in the investigation into the use of rumble devices to improve road traffic safety, a survey of present practice was carried out in two concurrent operations, namely by making local enquiries and by studying available literature on the subject.

1.1 Local Enquiries

Letters of enquiry were directed to engineers of the following South African authorities:

Department of Transport
Provincial Roads Departments
City and Town Councils
Divisional Councils

Information was requested concerning the location, layout, construction materials and costs, accident records and any local experience of the effectiveness of rumble strips installed on the approaches to hazardous locations such as isolated intersection stops, sharp bends, steep descents and unguarded railway level crossings.

1.2 Literature Survey

A survey of available literature on the use of rumble devices elsewhere in the world was undertaken to establish present practice and effectiveness.

1.3 Scope/.....

1.3 Scope of Report

In this report the information on rumble installations, gathered locally and from overseas literature, is summarised, presented and discussed. Warrants and guidelines are proposed for the use of rumble devices.

Guidelines for the layout and for the construction of typical rumble installations are included. Where necessary these could be modified to suit particular local conditions.

2. COMMUNICATION DEVICES

In order to appreciate the contribution to road traffic safety that the judicious installation of rumble devices can make, the ways in which information is conveyed to the driver should first be considered.

2.1 Danger Warning Signs

The South African Road Traffic Signs Manual makes provision for the erection of roadside signs such as the "crossroads", "T-junction", "traffic circle", "sharp curve", "unguarded level crossing", "steep descent" and "traffic signals ahead" signs. The function of these signs is to convey a warning message of danger ahead to the approaching driver.

2.2 Information Signs

Similarly the Manual provides for the erection of "Stop ahead" signs, "Chevron" boards and "Advisory speed information" plates to convey important roadside guidance to the driver.

2.3 Flashing signals

The Manual makes provision for flashing amber signals "to draw the attention of road users to the presence of particular hazards where more than ordinary caution is required ......"

2.4 Road /......

2.4 Road traffic markings

Roadway markings may be used where additional warning or information is required for a particular hazard, e.g. the word "STOP" with an arrow indicating a stop ahead may be painted on the roadway. Yellow bands, 610 mm wide, marked transversely at decreasing intervals on the approaches to road hazards encourage rapid deceleration by drivers (10), (16).

2.5 Rumble devices

The above methods of roadside communication with the driver all depend on visual contact. The tired and distracted driver may observe these roadside messages and yet fail to respond with the necessary action. In such cases the installation of rumble devices on the roadway is intended to alert the driver by producing a pronounced rumbling sound which he will hear within the vehicle, accompanied by a vibration which he will feel. The idea is that having been alerted by the rumble installation on the road, the driver will see the roadside messages and do the right thing.

2.6 Speed control humps

On private roads such as those found at schools, at holiday resorts, in nature reserves, and at camping sites, physical control of vehicle speed is sometimes exercised by means of so-called "speed humps" constructed across the roadway at strategic positions.

It is stressed that speed humps fall into a different category and should not be confused with rumble devices. Speed humps can only be negotiated in safety by the slow-moving driver who has already been alerted, instructed not to exceed the speed limit, and warned about the presence of the humps ahead. Speed humps fulfil an entirely different function and do not fall within the scope of this report.

3. DESCRIPTION OF RUMBLE DEVICES

Rumble devices on roads are intended to alert the driver to the need for caution ahead. They can be installed on the approaches to stop intersections and other hazardous locations such as sharp curves, traffic circles, steep descents and railway level crossings.

The rumble effect is generally created by adding a layer of coarser material to the existing road surface. Alternatively a rumble surface can be obtained by cutting transverse slots into the existing road surfacing. As the motor vehicle passes over the roughened surface a rumbling sound is set up by the tyres and heard clearly by the driver. This is accompanied by a vibration in the vehicle. The intensity of the rumble and vibration are dependent on the roughness of the rumble surface.

Although the general term "rumble strip" is widely used to denote this type of installation there are distinct differences in dimensions, materials, methods of construction and usage. For the sake of clarity various rumble devices are described.

3.1 Rumble surface

A rumble surface is a portion of bituminised or concrete road surface which has been so treated that it produces a rumbling sound when the tyres of a motor vehicle pass over it. The rumble effect is usually created by adding a 10 mm to 25 mm thick layer of coarser material to the existing road surface. Alternatively a rumble surface can be produced by cutting 3 to 13 mm deep slots into the existing road surfacing. Measured in the direction of travel individual rumble surfaces are generally each 5 to 10 metres long.

3.2 Rumble strip

Rumble strips are transverse strips of rumble surfacing varying from 150 mm to 2 metres wide measured in the direction of travel. Rumble strips are usually spaced at intervals equal to their width and extend across the full width of the approach lane(s) in advance of hazardous locations.

3.3 Rumble slot/...

3.3 Rumble slot

Rumble slots are transverse grooves cut into the existing road surface at intervals in order to create a rumble device. In width rumble slots vary from about 100 mm to 200 mm. Intensity of the rumble effect can be controlled by the depth of slot.

3.4 Rumble bar

Rumble bars are generally 50 to 100 mm wide transverse ridges projecting about 13 mm above the existing road surface. They are so spaced that in addition to a rumbling sound they also produce a vibration of jolting similar to that experienced on a corrugated road surface.

3.5 Rumble set

Rumble strips, rumble slots and rumble bars are generally constructed in sets (or groups) of about 15 to 20. Measured in the direction of travel the overall length of a rumble set varies from about 4 to 8 metres.

3.6 Rumble installation

Rumble surfaces or rumble sets can be installed in a pattern or a series at decreasing intervals to form a rumble installation. This is done to encourage greater reductions in vehicle speeds on the approaches to hazardous locations. Although rumble installations occupy overall distances ranging from about 90 metres at stop intersections up to 800 metres on high speed approaches, in general they take up a length of about 300 metres of approach roadway.

4. PRINCIPLES OF RUMBLE DEVICES

This section of the report deals with the psychological principles of how rumble devices work. It is based mainly on the information gathered from many sources as presented by Kermit and Hein (2,pp.478, 479).

4.1 Alerting/.......

4.1 An alerting device

Rumble devices alert the driver by producing a signal which he hears, feels and sees. A quick defensive reaction is produced. His full attention is directed to road conditions and to the appropriate road signs which tell the driver what hazard he is approaching and what action he will have to take.

To appreciate the need for a device to alert the motorist, it is necessary to consider some of the factors that contribute towards creating a hazardous situation for the unwary driver:

(i) Boredom, fatigue and drowsiness are experienced towards the end of a journey.

(ii) Sudden changes occur in driving conditions on approaching a built-up area.

(iii) Previous experience of warning signs may lead the driver to disregard them because he feels capable of judging the situation for himself.

(iv) Because of distractions the driver may see warning signs yet fail to react to their message.

(v) The driver may be unaware that his speed has not been reduced sufficiently for the changed conditions.

Rumble devices are particularly effective in alerting the approaching driver to an unexpected change in road conditions. As his vehicle passes over the installation of rumble surfaces alternating with the less noisy original road surface, he receives a strong warning stimulus which is audible, tactile and visual. His initial reaction is to slow down and exercise caution. Having been alerted he responds better to the message of the road signs which follow.

The reaction of the driver to the rumble signal is faster and more intense than his reaction to warnings that rely solely on sight. It has been found that brake reaction times for audible signals are shorter than for visual signals. The sudden contrast of the louder rumbling sound against the accustomed background noise level produces a rapid response from the driver in the form of positive action to prepare for the imminent change in road conditions.

4.2 A speed reduction device

In accomplishing the main function of alerting drivers to an impending change in road conditions, rumble devices also produce a reduction in approach speed.

The effectiveness of a transverse rumble installation in reducing speed is influenced by the spacing of the rumble devices within the installation.

The method generally adopted to effect reductions in approach speeds is to space the rumble devices at the beginning of the installation to suit the maximum speed limit of the approach road, and those at the end of the installation to suit the desired maximum approach speed ahead of the particular hazard.

A suitable spacing of the transverse rumble devices produces an intermittent rumble which has a steady reassuring rhythm if the rate of deceleration of the vehicle is satisfactory. If the driver is not slowing down quickly enough as he approaches the hazard, the "beat" of the rumble devices becomes faster and transmits a sense of alarm to him.

4.3 A roadway delineation device

Rumble strips and rumble bars when installed longitudinally can be used to delineate and define the edges of the roadway. They are more clearly visible than painted lines and retain effectiveness during wet weather and at night. Transverse rumble devices delineate a surfaced median (15,pp.132-134).

5. SURVEY OF RUMBLE INSTALLATIONS

5.1 History

The practice of using "audible pavements" to alert drivers approaching hazardous locations has been developing in the United States of America over the past twenty years.

As early in 1947 New Jersey experimented with "singing lanes" to warn drivers that they were encroaching on an adjacent lane (8, p.22). In 1952 Illinois experimented with 152 mm wide "vibrator units" of bituminous material 25 mm high with sides sloping at 30 degrees, to act as median delineators. Spaced transversely at 3,8 metre centres these provided "an adequate warning of encroachment without creating a real operational hazard". (1,p.111).

The idea of "rumbler" treatment of approaches to stop intersections was apparently introduced in 1954 by Cook County, Illinois (5,p.35). Since 1956 many "jiggle bars" have been installed on shoulders and medians throughout the state of Texas, and in Colorado "chatter bars" have been used on the approaches to major construction projects (4,p.86).

5.2 United States of America

The use of rumble devices to improve safety on roads is widespread in the United States. In Annexure A the names of States have been listed together with particulars of location, construction and effectiveness of installations.

Rumble installations in America have developed in four typical patterns as shown in figures 1 and 2. These have been named Type 1 to Type 4.

Type 1: Continuous rumble surface

A continuous rumble surface extending for a length of about 90 metres back from the stopline is used mainly at urban stop intersections. It has the added advantage of providing a non-skid braking area.

Materials/......

Materials used in the construction of continuous rumble surfaces are generally 13,2 mm 19,0 mm or 26,5 mm maximum sized crushed stone used as a surface treatment, or alternatively 26,5 mm maximum sized precoated blast furnace slag.

Type 2: Intermittent rumble surfaces

This typical installation of intermittent rumble surfaces occupies about 305 metres of approach lane length in advance of rural stop intersections. It comprises 11 rumble areas: 10 of which are each 7,6 metres long, installed at intervals of 30,5 and 15,2 metres clear spacing; and 1 rumble area 15,2 metres long at the stop position.

Materials used in the construction of intermittent rumble surfaces are generally 19,0 or 26,5 mm maximum sized crushed stone placed as an additional surface treatment on the existing road surfacing.

Type 3: Intermittent sets of rumble strips or rumble slots

This typical installation occupying 335 metres of approach lane length at rural stop intersections, comprises 6 sets of rumble strips or slots. Each set has 12 or 19 rumble strips (or slots) which are 203 mm wide and spaced 203 mm apart.

Rumble strips are generally constructed of 13,2 mm maximum sized stone on an epoxy resin tack coat. Rumble slots are cut 13 mm deep into the existing road surfacing.

Type 4: Intermittent rumble bars and sets of rumble bars

This is an installation used in New Jersey on the approach to an urban traffic circle (8). It comprises 10 rumble bars spaced at 3,175 metre centres, and one set of 19 rumble bars at 230 mm centres. A relatively short approach length of 36 metres is required to accommodate the installation.

The rumble bars have a bottom width of 76 mm, top width of 50 mm and project 13 mm above the surrounding road surface. They are formed of quartzite sand and epoxy resin and are let into or cast onto the existing road surfacing using an epoxy resin tack coat.

Summary/.......

Summary

The following summary gives an indication of the extent to which the various types of rumble devices have been installed in the United States of America as reflected by available literature and described in Annexure A:

1. Continuous rumble surfaces : 215 installations
2. Intermittent rumble surfaces : 252 installations
3. Intermittent sets of rumble strips : 52 installations
4. Intermittent rumble bars : 1 installation

5.3 Union of Soviet Socialist Republics

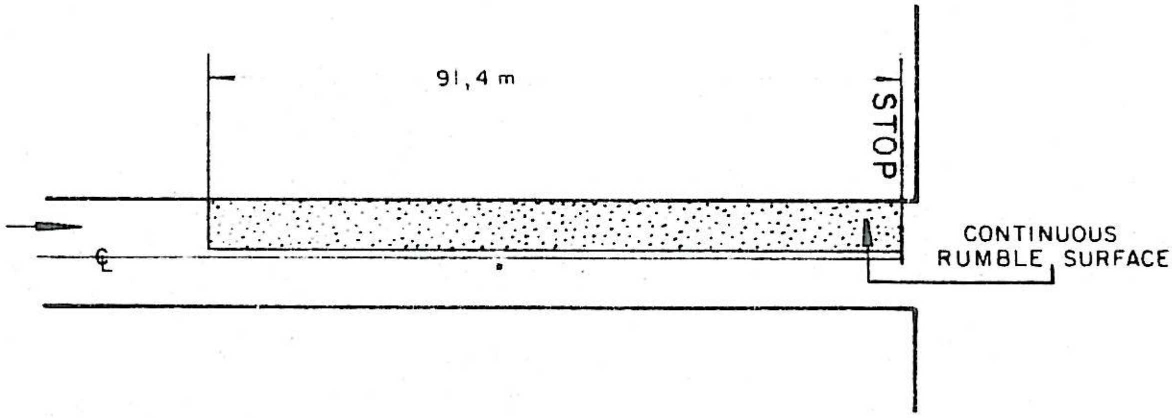
In the USSR transverse rumble strips were constructed on a two-lane road in the Uzbek SSR on the approach to a sharp curve of 100 m radius (12,p.2). These rumble strips were 1 metre wide. The distance between the strips varied from 20 metres at the beginning to 3 metres at the end of the installation. Aggregate sizes used were 5 to 15 mm.

From the results of studies Table 1 was compiled giving the number of rumble strips and spacing for a desired reduction in speed.

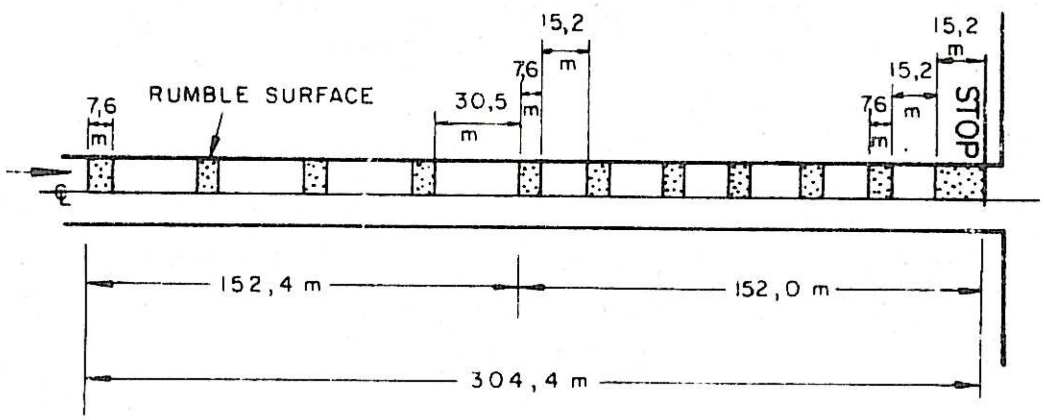
TABLE 1

RUMBLE STRIP LAYOUT USED IN USSR (12,p.4)

Required decrease in speed	No. of one metre wide rumble strips required	Clear distance in metres between rumble strips numbers							
		1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
10%	2	20m	-	-	-	-	-	-	-
20%	4	20	15	10	-	-	-	-	-
30%	6	20	15	10	6	6	-	-	-
40%	8	20	15	10	6	6	3	3	-
50%	9	20	15	10	6	6	3	3	3m



TYPE 1 Typical installation of continuous rumble surface at urban stop intersection
(Adapted for 'keep-left' rule of the road)

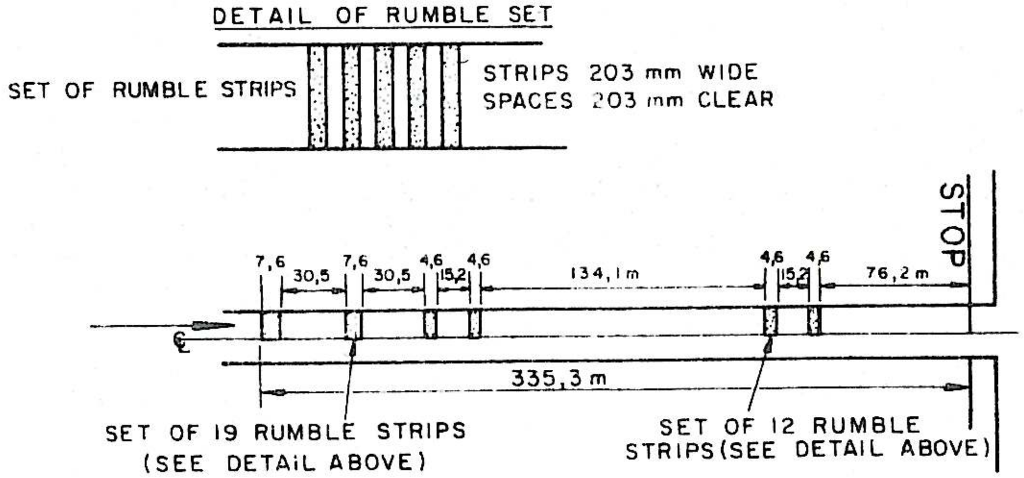


TYPE 2 Typical installation of intermittent rumble surface on approach lanes to rural stop intersection
(Adapted for 'keep-left' rule of the road)

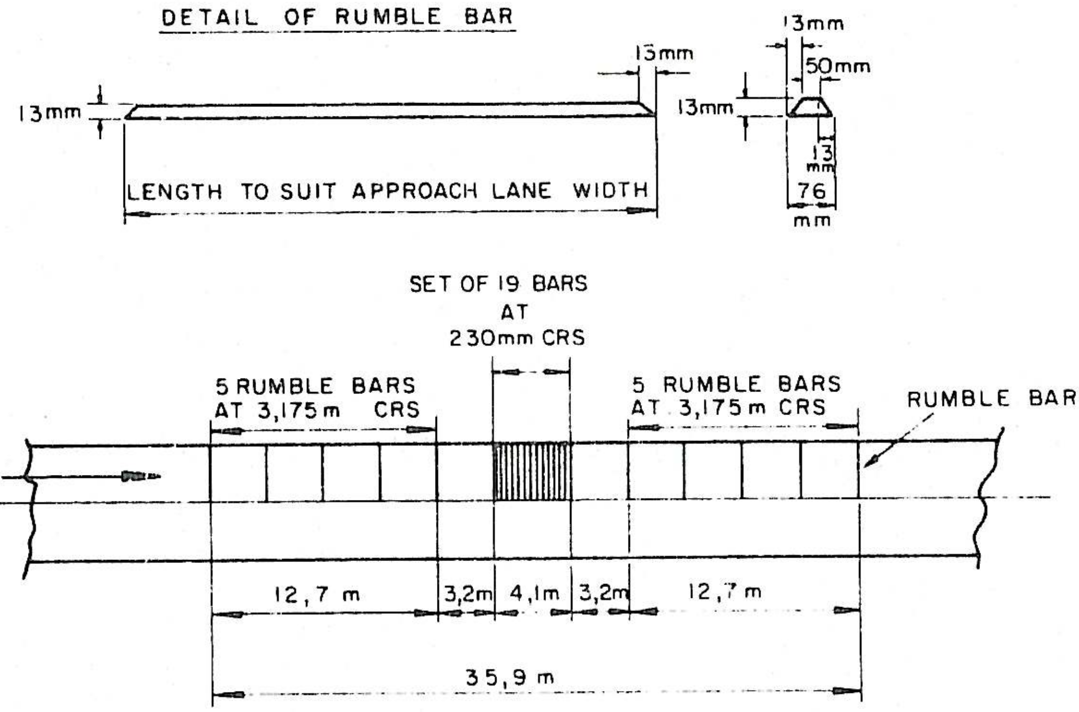
FIGURE 1

TYPICAL RUMBLE INSTALLATIONS IN THE UNITED STATES OF AMERICA

RG4-6397



TYPE 3 Typical installation of rumble strips (or rumble slots) on approach lanes to rural stop intersection
(Adapted for 'keep-left' rule of the road)



TYPE 4 Installation of rumble bars on approach lane to urban traffic circle
(Adapted for 'keep-left' rule of the road)

FIGURE 2

TYPICAL RUMBLE INSTALLATIONS IN THE UNITED STATES OF AMERICA

RG4 — 6398

5.4 United Kingdom

Regulation 26 of the Traffic Signs Regulations 1964 lays down that, apart from studs used to indicate parking bays or longitudinal lines, road markings shall not project above the surface of the carriageway in the immediate vicinity by more than 6,35 mm. It is not known whether this restriction has had any influence on the development of rumble devices in the United Kingdom.

Apart from a recent reference to surface irregularity as a means of reducing vehicle speed (14), there seems to be little available literature on the subject of rumble devices. Visitors to the U.K. are reported as having encountered isolated rumble installations. These may have been experimental rumble installations on two approaches to traffic circles near Salisbury and near Southampton in the south of England, where the Transport and Road Research Laboratory are reported to be testing rumble surfaces (11). According to this report "20 mm gritstone chippings" were spread on a "special thixotropic binder", and at each site seven sections of rumble material were laid, ranging in length from 13,4 m to 8,2 m separated by similar lengths of untreated road".

5.5 Republic of South Africa

A number of rumble installations have been constructed in South Africa. Some of these have been experimental. A few have been quite unsuccessful and have subsequently been removed. Most have proved satisfactory and have been retained. Physical properties of rumble installations at present used by the Transvaal, Cape and Natal Roads Department are shown in Table 2.

Transvaal

In the Transvaal rumble surfaces were installed towards the end of 1970 on the off-ramp leading from Ben Schoeman Highway to Eeufees Road, Pretoria. This installation comprised 6 rumble surfaces each 7,6 m long, plus 1 surface 15,2 m long at the stop line giving a total of 7 surfaces. The rumble surfaces commenced at a distance of 198 metres from the stopline and were installed with 3 clear spaces each 30,5 m long, followed by 3 clear spaces each 15,2 m long.

The surface was constructed of 19,0 mm precoated quartzite spread at the rate of 0,015 cubic metres per square metre. For precoating of the aggregate a mixture of tar prime and creosote was used at ambient temperature to promote adhesion. The surface material was laid on a tack coat of 150/200 penetration bitumen applied at the rate of 1,3 litres per square metre.

These rumble surfaces stood up well to traffic under severe braking conditions without appreciable loss of aggregate. They were covered over when the off-ramp was resurfaced in December, 1972.

Cape Province

The Department of Roads of the Cape of Good Hope has constructed a few rumble surface installations. A typical installation on the approach to an isolated rural stop intersection comprises 11 rumble surfaces each 7 metres long spaced at decreasing intervals. Starting at a distance of 262 metres from the stop line, the 11 surfaces are installed with 2 spaces of 30 metres, followed by 3 spaces of 15 metres, followed by 5 spaces of 7 metres, which leaves a clear distance of 45 metres at the stop.

A tack coat of anionic (60) bitumen emulsion is sprayed on the original road surface at a rate of 1,74 litres per square metre. On this 19 mm aggregate is spread relatively sparsely at 0,010 to 0,009 cubic metres per square metre to produce the rumble effect. The aggregate is rolled and then sprayed with a coat of anionic (60) bitumen emulsion at a rate of 1,74 litres per square metre. The emulsion is allowed to break, after which it is blinded with a thin layer of clear coarse sand which does not contain particles larger than 7 mm.

Natal/....

Natal

The Natal Roads Department has constructed rumble strip installations under contract at 20 locations scattered throughout the province. These occur on the approaches to isolated stop intersections and sub-standard horizontal curves.

The rumble strips used in Natal consist of 19,0 or 13,2 mm aggregate placed in 305 mm wide strips on the road surface. These strips are spaced at 3,175 m centres and are grouped in sets. Each set comprises 5 rumble strips and occupies an overall length of 13,0 metres. A typical installation consists of 6 sets of rumble strips at a clear spacing of 10,2 metres between sets. The rumble strip installation occupies an overall approach length of 129 metres which commences at a distance of 244 metres from the stopline and leaves a clear space of 115 metres between the last set of strips and the stopline.

On dual carriageways the rumble strips extend over the full width of the approach lanes. If the shoulder is surfaced then the strips are extended to include the shoulder.

Prior to commencing construction of a rumble strip installation the existing road surface is scrubbed with a non-ionic detergent and then washed down with water. A locally available epoxy tar material is mixed with a suitable graded silica aggregate and laid between 6,35 mm screed rails. Washed crushed stone is hand placed onto the wet mix and bedded down with the aid of a hand roller.

Where the existing approach surface is a premix, 13,2 mm cubical crushed stone is used. For other surfaces 19,0 mm size is specified. Where high approach speeds are encountered the first two sets of rumble strips are sometimes constructed of 13,2 mm crushed stone.

For approaches situated on curves a stone size of 13,2 mm is apparently considered preferable to 19,0 mm.

TABLE 2/.....

TABLE 2

TYPICAL RUMBLE INSTALLATIONS USED AT ISOLATED STOP INTERSECTIONS IN SOUTH AFRICA

Item	Description	Transvaal	Cape	Natal
1.	Approach distance from stopline to start of installation	198 m	262 m	244 m
2.	Overall approach length occupied by installation	198 m	217 m	129 m
3.	Clear space from end of installation to stopline at intersection	0	45 m	115 m
4.	Rumble elements comprising one installation:			
	(a) No. of rumble surfaces and length of each surface	6 No. 7,6 m 1 No.15,2 m	11 No. 7,0 m	
	(b) No. of rumble strip sets and length of each set			6 No.13,0 m
	(c) No. of rumble strips in one set and width of each strip			5 No. 0,305m
5.	Spacing of rumble elements within the installation:			
	(a) Clear spaces between rumble surfaces	3 No.30,5 m 3 No.15,2 m	2 No. 30 m 3 No. 15 m 5 No. 7 m	
	(b) Clear spaces between rumble strip sets			5 No. 10,2m
	(c) Clear spaces between individual rumble strips in set			4 No.2,870m
6.	Total area of rumble surfacing material required per installation for a 2 lane approach width of 7,4 metres	450 square metres	570 square metres	68 square metres
7.	Construction materials	19,0 mm precoated aggregate on penetration grade bitumen binder	19,0 mm aggregate on bitumen emulsion binder	13,2 mm or 19,0 mm aggregate on epoxy/tar binder

Johannesburg

Although strictly not in the same category as rumble devices, transverse "jiggle bars" have been installed on motorway shoulders in Johannesburg. Painted yellow and installed at an angle of about 60 degrees to the direction of travel, "jiggle bars" have also been used on carriageways where it has become necessary to channel two lanes of traffic into a single lane.

Precast corrugated concrete slabs and side kerbs have been in use for about 15 years to form traffic islands. The corrugations project 19 mm above the surrounding road surface and are spaced at 152 mm centres.

"Jiggle bars" 305 mm wide and projecting 25 mm above the surrounding road surface have been formed in bituminous premix material and spaced at 12,2m 6,1m and 3,0 metre centres on motorway shoulders.

On elevated motorways and motorway bridges transverse "jiggle slots" 13mm deep and 457mm wide have been formed at 6,1 metre centres in the concrete surfacing of the roadway shoulders.

Durban

Two rumble strip installations have been in use since October 1970 on the inbound terminal of the Western Freeway in Durban. Many drivers had failed to reduce speed before entering the city street system, in spite of warning signs informing them of the end of the freeway.

Each rumble installation occupies a total approach length of 158,5 metres and comprises 10 rumble strips each 300mm wide and extending from kerb to kerb. The first four strips over which the vehicle passes are at a constant distance apart. The spacing of the remaining six strips decreases towards the hazard. The centre to centre spacing of the rumble strips in the direction of travel is 19,5m 19,5m 19,5m 19,5m 18,9m 17,4m 16,0m 14,8m 13,4m.

Construction materials used were 19mm washed crushed stone hand placed on to a 6mm layer of suitably graded silica aggregate mixed with an epoxy/tar material, and compacted with a hand roller. The construction cost was R3,00 per linear metre.

Insufficient information is available as yet to assess the effect of these rumble installations on accident rates, but adverse driver reaction to the rumble and vibration has been reported.

6. EFFECTIVENESS OF RUMBLE INSTALLATIONS

Rumble installations have generally been found very effective in reducing accidents by reducing approach speeds at hazardous locations and by improving stop observance at junctions and intersections.

6.1 Approach speeds

The results of very thorough "before" and "after" field tests by Owens of 7 approaches to rural stop intersections in Minnesota showed that a 7% decrease in average approach speeds resulted from the installation of Type 2 rumble surfaces (5,p.47).

From radar speed studies Kermit and Hein found that after installation of Type 2 rumble surfaces on the approach to a rural stop intersection in California, "deceleration took place over a greater distance and was consequently much more gradual". A reduction of 22% was found in the average deceleration rate over the last 137 metres of the approach length (2,p.476).

Writing in 1968 on the rumble installations developed in Contra Costa County, California, Kermit says that "The distance between individual strips is variable and decreases as the driver approaches the problem location. If he heeds the message of the rumble strips, i.e. noise vibration of the vehicle, and slows down, the beat of the strips is constant. If he continues at his former speed, the beat of the strips becomes faster, thereby transmitting a sense of urgency. It is this particular arrangement that, in our opinion, has made our rumble strips so effective". (6,p.27).

Speed reductions of up to one-third have been reported for an installation of rumble strips on the approach to a sharp curve in the USSR (12,p.2).

A significant speed reduction of about 7% has been reported for two rumble installations on the approaches to traffic circles in the United Kingdom.(11).

6.2 Stop sign observance

Observations of more than 1000 vehicles at one intersection in Cook County (2,p.477) and seven intersections in Minnesota (5,p.50) showed an increase of 30% in the number of full stops made at urban intersections and an increase of 26% at rural intersections.

6.3 Centreline observance

The number of centreline violations was reduced by 11% in one case (2,p.477) while Owens concluded that there had been no appreciable change in centreline violations (5,p.51).

6.4 Accident Reductions

Very appreciable reductions have been recorded in the number of accidents after construction of rumble installations on the approaches to stop intersections and other hazardous locations. The available accident data has been summarised in Table 3 indicating an overall average reduction of 42%.

It is even more significant to note that the overrun type of accident caused by drivers approaching the hazard too fast and running off the road, has been almost eliminated in some cases where rumble installations have been constructed. Reductions have been recorded of 50% to 80% in overrun type of accident (7,p.39) (6, p.7).

Rear-end collisions caused by the car behind approaching too fast and failing to stop have been reduced by 42% (7,p.39).

As approach speeds are lower on rumble installations and deceleration is more gradual the results of accidents are generally less severe.

TABLE 3

ACCIDENT DATA BEFORE AND AFTER CONSTRUCTION OF RUMBLE INSTALLATIONS

Location	Rumble Installation type	No. of Sites	Average No. of Accidents per site per year		Accident Reduction
			Before	After	
California USA (2) (6)	2	4	3,5	0,9	-74%
Illinois USA (7)	3	9	6,0	4,1	-32%
Delaware USA (3)	2	3	(4)	(2)	-50%
New Jersey USA (8)	4	1	5,0	4,0	-20%
Uzbek USSR (10)	1 m strips	1	3,0	0	-100%
Overall totals (Approximately)		18	88	51	-42%

6.5 Cost and benefit

In 1962 Kermit and Hein estimated that the installation of rumble surfaces at 4 intersections had effected savings of 40 000 dollars per year on accident reductions. At that time the estimated construction cost of 2,40 dollars per square metre amounted to approximately 1000 dollars for a Type 2 typical installation on both sides of a four-way intersection (2, p.478).

Assuming a useful life of 5 years for the rumble surface the benefit/cost ratio would be 50.

6.6 Durability

Reports (7,8) indicate that with epoxy resin binders very little whip-off of the aggregate is experienced from rumble surfaces. They have been found maintenance-free and extremely serviceable. This was also the experience with the pre-coated stone of the rumble surfaces

on/....

on the Ben Schoeman ramp in Pretoria. Reports from Natal indicate that the stone adheres very well to epoxy/tar binders. In the Cape bitumen emulsion is used because it can be applied by ordinary handspray in remote areas where heating would be impracticable.

6.7 Noise levels

Noise inside the vehicle

Kermit and Hein reported that "both the frequency and intensity of the sound increased as speed increased" in a vehicle travelling over Type 2 intermittent rumble surfaces (2,p.472).

No information on inside noise levels appears in the available literature for vehicles travelling over rumble strips or rumble bars. Nor is there any indication of whether the rumble is effectively experienced inside heavy vehicles such as buses and trucks.

Noise outside the vehicle

In the available literature no specific information has been found on the outside noise generated by the tyres of vehicles travelling over rumble devices.

6.8 Layout pattern

Considerable research and experimental effort has been put into determining the required pattern and spacing of rumble devices for optimum effectiveness in reducing approach speeds.

Owens referred to excellent results of unpublished work done by Puy- Huarte at Ohio State University on the effect of transverse painted lines using a geometric or arithmetic progression to determine the spacing, and concluded that "these same patterns should be tried with rumble strips" (5,pp.36,39).

Bellis reported on a detailed investigation initiated by New Jersey to develop an effective rumble bar pattern (Type 4) by "controlled experimentation and field tests under actual traffic conditions" (8,p.22).

The spacing of rumble strips as reported by Babkov of the Moscow Automobile and Road Construction Institute (Table 1), was based on "electro-physiological" recordings and studies of "nervo-psychical tension"

set/......

set up in the driver by changing road conditions (12,p.2).

At the Transport and Road Research Laboratory, Crowthorne, a "Moving Road" simulator was used by Denton in studies of the influence of visual pattern on perceived speed. It was found that a pattern of transverse white lines painted at decreasing intervals on a road surface would have a considerable influence in increasing the driver's sense of apparent speed. The spacing used in these experiments was an "exponential decay function of distance along the line of travel" (10). This work was subsequently extended to field tests on installations at eight sites (16).

Three experiments with transverse pavement stripes and rumble bars have been conducted by the Michigan Department of State Highways. Tests were made on transverse plastic pavement stripes with gradually decreasing spacing: ABS plastic rumble bars in conjunction with yellow painted stripes; and polyvinyl chloride rumble bars. Both kinds of rumble bars resulted in larger speed reductions than the transverse stripes (13).

In the United Kingdom experiments on the use of surface irregularity as a means of reducing vehicle speed have been reported by Brown. The width and spaces between rumble strips (at half the wavelength) were designed to produce an uncomfortable vibration of 10 to 12 Hertz in vehicles exceeding the desired speed limit (14).

7. LOCAL OPINION

In response to the appeal by letter for information on rumble installations numerous prompt replies were received. The results of the local opinion survey are given briefly in Table 4. Unfortunately no recorded information was readily available on the occurrence of accidents, nor on other measures of the effectiveness of rumble installations in South Africa. Information on construction costs was not obtained.

7.1 City and Town Engineers

Only two effective rumble installations were reported in use by city and town engineers, but the consensus of opinion was that rumble devices would serve a useful purpose and could be very effective.

One reservation expressed about the use of rumble installations was the possible irritation to regular users of the particular road on which they have been installed, and annoyance to nearby residents as a result of the tyre noise produced. In one case concern was expressed at the possibility that having constructed a few rumble installations at hazardous intersections the local authority would find itself committed to providing them at all intersections. One opinion expressed was that rumble strips on curves might induce skidding in wet weather. Rumble bars were considered a possible danger to motorcycles and pedal cycles. An opinion received was that the construction of too many rumble installations would result in complacency on the part of the driving public. The importance of commencing the rumble installation well in advance of the hazard was stressed by a number of engineers.

7.2 Provincial Roads Engineers

In general the consensus of opinion of civil engineers controlling the planning, design, construction and maintenance of provincial roads in South Africa appears to be in favour of the use of rumble installations. The view has been expressed that this is an efficient method of alerting drivers so that they became aware of dangerous intersections or curves ahead. In some cases the installation of rumble devices might be considered essential. They are considered particularly useful in cases where a stop is required at the foot of a long decline, or where a pronounced reduction in speed is essential to negotiate a curve safely.

No reports were received of rumble installations on the approaches to unguarded railway level crossings.

TABLE 4/......

TABLE 4

RESULTS OF LOCAL OPINION SURVEY OF RUMBLE INSTALLATIONS

Particulars	City and Town Engineers	National, Provincial and Divisional Engineers	Totals
Letters of enquiry sent out by the Institute	45	7	52
Replies received	30	5	35
Effective installations reported	2	28	30
Unsatisfactory installations reported	2	2	4
Favourable opinion	11	4	15
Unfavourable comment	4	0	4
No comment	14	1	15
Requests to the Institute for further information	9	0	9

8. DISCUSSION

From the literature survey undertaken it is evident that the practice of constructing rumble devices on the roadway approaches to hazardous sites has gained increasing support during the past twenty years. Reliable evidence as to the effectiveness of rumble installations is limited mainly to detailed studies by only a few investigators. Kermit and Hein, Owens, and Bellis have been the major contributors.

8.1 An alerting device

Rumble installations are sometimes referred to as warning devices. This could be misleading. It would be more correct to say that rumble devices provide a signal to alert the driver. His attention is then directed to the warning itself, which is generally conveyed by a road sign. Rumble installations alone might well result in a driver stopping suddenly at the roadside to inspect his vehicle for some imagined defect. This action would probably create an additional road hazard. It follows therefore that rumble devices should not be used in isolation but should always be used in conjunction with the relevant warning information signs. Construction costs of rumble installations being at least 10 times

as much/.....

as much as erection costs of road signs, it also follows that warning devices such as road traffic signs and road traffic markings should first be installed. Overseas experience has shown that only in cases where these prove ineffective on their own, or in cases where there is a reasonable degree of certainty that they will prove to be insufficient, rumble devices should be installed. There is a danger that complacency or contempt may arise in the driving public should too many installations be encountered, or should rumble devices be installed at sites where their use is not warranted.

8.2 Choice of rumble type

As illustrated in Figures 1 and 2 there are basically 4 types of rumble installations in general use. The relative merits of each type are discussed briefly and conditions under which a particular installation might prove the most suitable are suggested.

Type 1: Continuous rumble surface

The relatively long (90 m) continuous rumble surface was specifically developed for installation at urban stop intersections in Cook County, Illinois (2,p.477). This type of installation appears to be particularly well suited to moderate speed traffic conditions in peri-urban areas where intersections are relatively far apart and controlled only by stop or yield signs and where there is often no streetlighting. Type 1 installations might well be used on the approaches to isolated pedestrian crossings. Unguarded railway level crossings might be made safer by the construction of rumble surfaces on the approaches to them. Where heavy braking is required at a stop intersection on a gradient, the continuous rumble surface would have a decided advantage.

Type 2: Intermittent rumble surfaces

Apart from minor variations in the dimensions and spacing of the 7 m long surfaces, the Type 2 rumble installations developed by Contra Costa County, California (2), have received wide acceptance. The rumble surface layouts used in the Cape Province and in the Transvaal are based on this type. The long approach lengths provide the driver with the opportunity of slowing down gradually and comfortably. Type 2 rumble surfaces are well suited for installation on the approaches from high speed roads to the following types of hazard:-

* An isolated rural stop intersection
* A T-junction at the end of a freeway off-ramp
* A hazardous sharp curve
* A deceleration lane preceding a sharp curve on a freeway off-ramp
* The end of a freeway on the approach to an undivided urban road with speed restriction
* A sudden steep descent following on gentle gradients
* An intersection where sight distance is poor
* An unguarded railway level crossing
* A hazard that follows after a long tangential approach
* A sharp dip or a narrow bridge at the foot of a decline.

Because of the wider tyres which are now being fitted to more and more passenger vehicles, the intensity of the rumbling sound produced by the tyres on Type 2 rumble surfaces is assured, even if the vibration is less noticeable in the larger, heavier and more comfortable vehicles. It is not known how the rumble effect produced by 19,0 mm or even 26,5 mm aggregate surfacing compares with the normal background noise level in large buses or heavy trucks, and to what extent the vibration is sensed by the drivers of heavy vehicles. There seems to be a need for further research in this direction.

Type 3: Rumble strips

The Type 3 pattern of closely spaced, relatively narrow (200 to 300 mm wide) rumble strips grouped in sets, was developed by the Illinois Division of Highways (3).

These rumble strips would tend to produce more vibration and less rumble than Type 2 rumble surfaces. In the smaller class of light cars or in passenger vehicles with inefficient shockabsorbers, it is thought that Type 3 rumble strips might create some roadholding problems on curves or in wet weather. On the other hand these rumble strips might well be more effective in the case of heavy transport

vehicles/.....

vehicles. Type 3 rumble strips has the obvious advantage of requiring a much smaller quantity of surfacing material than Type 2. This is probably offset by the higher hand labour costs involved in the construction method.

It is interesting to note that the surfacing materials and methods of construction of the 305 mm wide rumble strips used in Natal have been based on the Type 3 rumble strips, but that the layout pattern adopted in Natal has been based in a slightly modified form on the Type 4 rumble bars installation.

Suitable applications for Type 3 rumble strips would be on the approaches to urban hazards where the approach speeds are moderate and approach lengths are somewhat restricted. In such cases the number of sets of rumble strips in the installation would be reduced to suit the specific location.

The installation of rumble strips should prove particularly effective on the approaches to the following hazardous locations:-

*Isolated urban stop intersections or T-junctions.

*Urban intersections where visibility of one or more approaches is poor. This would include poor visibility of stop signs or traffic signals, or where the presence of a crossroad is easily overlooked.

*Urban traffic circles

*Isolated pedestrian crossings

*Unguarded railway level crossings in residential or industrial townships.

*Temporary construction barricades at deviations

Type 4: Rumble bars

The narrow (76 mm) Type 4 **rumble** bars developed by the New Jersey Department of Transportation are installed at 3,175 m centres to produce optimum "jolting" and at 230 mm centres to produce optimum "vibration rumble" (8,p.23).

In Texas/.....

In Texas rumble bars are used to delineate freeway medians and to discourage the practice of turning the paved shoulder into an additional traffic lane (4,p.86).

Rumble bars have been installed on an experimental basis in a few isolated instances in South Africa. Some of these experiments have resulted in numerous complaints from drivers who have objected to the discomfort of the jolting produced by rumble bars, and have expressed concern about the effects on nervous drivers, and about the wear and tear on vehicles and tyres. Concern has also been expressed about the possible danger of rumble bars to motorcycles and pedal cycles.

There would seem to be an application for the use of rumble bars as an emergency measure for alerting drivers who are approaching too close to the beginning of a median where a single carriageway becomes a divided carriageway. Another valuable application might be in cases where there is a reduction in the number of lanes forcing vehicles to travel in single file. It is clear that caution should be exercised in the choice of a site for the installation of rumble bars and that the bars could become a hazard in themselves if they projected too much above the surrounding road surface in the immediate vicinity of the bars.

8.3 Legal aspects

Concern has been expressed that on installing satisfactory rumble devices at certain hazardous stop intersections, the local roads authority might find itself committed to installing them at all intersections. It has been asked whether a road user involved in an accident at an intersection that has no rumble devices, would have any grounds for a claim of negligence against a local roads authority that had installed rumble devices at certain other intersections.

Negligence in this context could be defined as a lack of resonable care. The standard of reasonable care required of the local

roads/......

roads authority is determined impartially in relation to the safety of all road users. It is independent of the proficiency and experience of the individual driver. It is the responsibility of the local roads authority to ensure that the roads within its area of jurisdiction are "safe". It is also the responsibility of the road user to drive with skill and care. The driver is not absolved of this responsibility by the measures taken to assist him. Based on negligence he would not have any grounds for a claim against the local roads authority.

8.4 Noise annoyance

The effectiveness of rumble devices. is largely dependent on an increase in the noise level within the vehicle, and there is a related increase in noise outside the vehicle. Under certain circumstances this could give rise to complaints from occupants of buildings in the vicinity of the rumble installation. This could be countered by the choice of rumble installation type and the coarseness of surfacing materials to be used. In certain cases it might require an assessment of the priorities of road traffic safety versus acceptable noise climate.

9. WARRANTS AND GUIDELINES

Warrants

The installation of rumble devices on the roadway approaches to hazardous locations would be warranted under the following circumstances:-

(1) Where, after installation of the prescribed warning devices such as danger warning signs, information signs and road traffic markings, the accident rate for an existing hazardous location remains much higher than the average for similar locations elsewhere.

(2) Where, from experience of similar hazardous locations elsewhere, it can be accepted with a reasonable degree of certainty that a proposed road construction works with its prescribed warning sign(s) would still have a high accident risk factor.

Note: /......

Note: Any proposal to install rumble devices for the sake of road traffic safety should also take into consideration whether the outside noise generated by tyre rumble would be found disturbing by people who live and work in the vicinity of the rumble installation.

Guidelines

The following recommendations are provided as guidelines to the local roads engineer who has to plan a suitable rumble installation, and prepare working drawings and a specification for construction.

Step 1: Investigation

Study the available accident data for the hazardous location. Observe and record traffic flow, approach speeds, and traffic behaviour. Assess what factors are constributing to the predominant type of accident. Factors such as boredom, sudden changes in road conditions, disregard for signs, distraction or unawareness of speed, as described in Section 4.1 would indicate the use of rumble devices as a method of reducing the accident rate.

Establish whether existing information signs, warning signs and road markings are strategically placed, clearly visible and comply with the requirements of the South African Road Traffic Signs Manual. If there is room for improvement in the signing or marking then this should receive first attention. At this stage consideration could be given to the feasibility and cost of installing and maintaining flashing amber signals.

The general noise level of the neighbourhood during the day, at night and over weekends, should be taken into consideration in assessing whether the rumble of vehicle tyres would have an adverse effect on the environment in the vicinity of the proposed rumble installation. Every site would have to be assessed on its own particular merits and in relation to its own prevailing noise climate.

Decide whether under the prevailing conditions the particular location warrants the installation of rumble devices. It will be appreciated that the installation of rumble devices may not be necessarily always the most suitable method of improvement.

Step 2: Planning the layout

Select the rumble installation type that appears to be best suited to the particular location. Base your choice on the prevailing average approach speed, the speed reduction sought, and the length of roadway available.

The type of rumble installation recommended for urban, peri-urban and rural conditions is given in columns 4, 5, and 6 of Table 5.

Firstly, from column 3 determine the required length of the installation for the approach speed in column 1 and the reduced speed in column 2. (The lengths given in column 3 are based on the relationship between vehicle speed and stopping distance as given in Figure 3).

Secondly, from Figure 4 determine the layout details and dimensions of the specific rumble installation (or portion of it) selected for construction on the basis of the average approach speed and the reduced speed desired at the hazard.

Example on use of Table 5

The approach speed of vehicles is 112 kilometres per hour on a rural road. Warning signs erected to inform drivers that there is a sharp curve ahead have been disregarded. It is desired to alert drivers and assist them to reduce their speed to 70 km/h before reaching the curve.

From Table 5 (column 3) the installation length recommended is 163 metres for an approach speed of 112 km/h (column 1) to be reduced to a desired speed of 70 km/h (column 2) ahead of the hazard. An installation of intermittent rumble surfaces is recommended for rural highways (column 6).

From Figure 4 the recommended layout of intermittent rumble surfaces on a rural highway for a speed reduction from 112 to 70 km/h comprises 7 rumble surfaces each 7 m long. Measured from the beginning of the curve the driver will meet the first rumble surface at chainage 275 m (112 km/h), travel over 6 spaces measuring 24, 22, 20, 18, 16, 14 metres and leave the seventh rumble surface at chainage 112 m (70 km/h).

TABLE 5/.......

TABLE 5

GUIDELINES TO THE SELECTION OF RUMBLE INSTALLATIONS

1	2	3	4	5	6
Average approach speed km/h	Reduced speed desired km/h	Rumble installation length metres	Recommended type of rumble installation		
			Urban streets	Peri-urban roads	Rural highways
60	0	83	Continuous rumble surface		
80	60 50 40 0	57 79 96 140	Continuous rumble surface	Intermittent sets of rumble strips	
100	80 70 60 50 0	75 103 132 154 215		Intermittent sets of rumble strips	Intermittent rumble surfaces
112	80 70 60 50 0	135 163 192 214 275			Intermittent rumble surfaces
120	100 80 70 60 50 0	125 200 228 257 279 340			Intermittent rumble surfaces

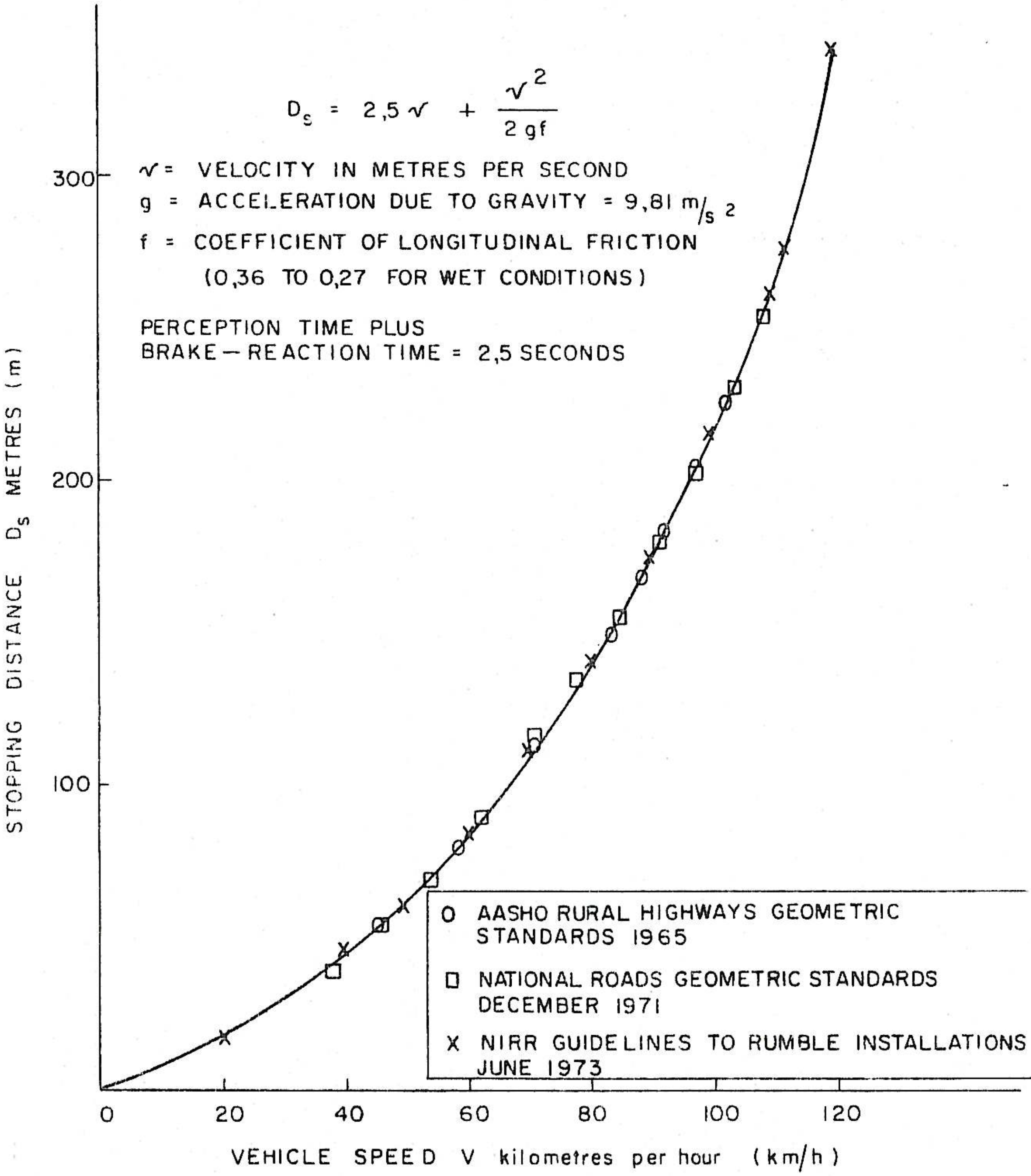


FIGURE 3

RELATIONSHIP BETWEEN VEHICLE SPEED AND STOPPING DISTANCE FOR LEVEL ROAD

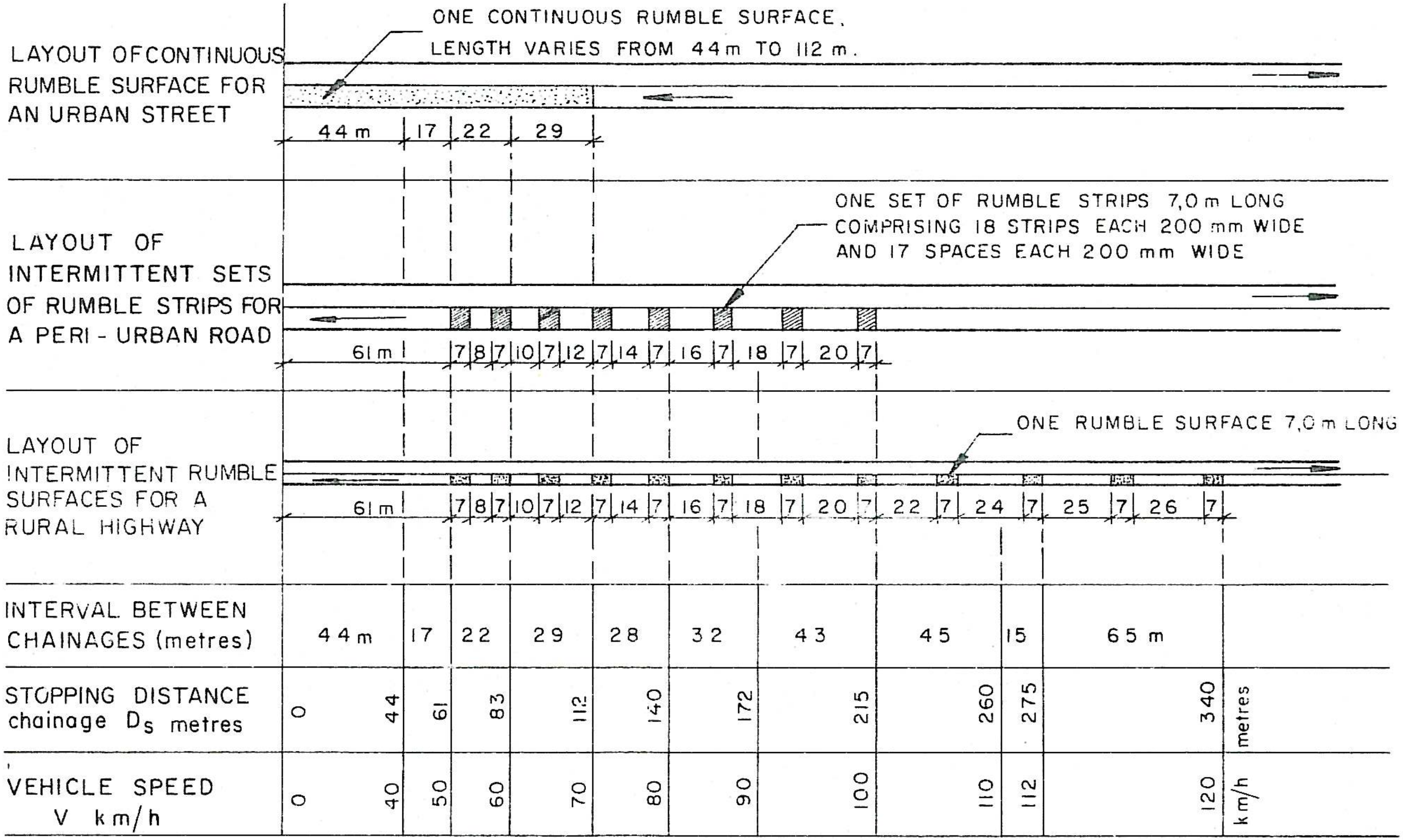


FIGURE 4

GUIDELINES TO LAYOUT OF RUMBLE INSTALLATIONS

Step 3: Construction

The following recommendations are provided as guidelines to the materials and construction aspects considered to be the best suited for each type of rumble installation, taking into account the particular road category and traffic conditions likely to be encountered.

Continuous rumble surfaces

Based on overseas experience the use of a hard, abrasion and polishing resistant aggregate embedded in a resin-based compound is preferred for urban conditions subject to heavy traffic. Suitable commercial preparations are available together with suppliers' recommendations for application. Alternatively, the guidelines for intermittent rumble surfaces could be applied to the construction of continuous rumble surfaces but using a 13,2 mm stone size.

Intermittent rumble surfaces

For construction of intermittent rumble surfaces on rural roads a 19,0 mm stone size is recommended. The stone should be hard, it should be cubical (low flakiness index) and it should have a good resistance to polishing (high polished-stone value). The stone should be spread by hand or by mechanical means at normal resealing coverage rates. Bitumen should be applied, preferably by means of a bitumen distributor, at a rate high enough to ensure adequate durability but not so high that a smooth texture would result, as it is important to produce an effective "rumble". The grade of bitumen and rate of application should conform with normal resealing practice.

Where it is intended to apply hot bitumen as a tack coat on the existing road surface, the stone should be precoated. (Precoating of stone is described in Technical Recommendations for Highways TRH3, published by the National Institute for Road Research, February 1971.)

Where it is intended to use a bitumen emulsion as a tack coat on the existing road surface, the stone should not be precoated. A fog spray of emulsion should be applied over the layer of stone to ensure adequate retention of the stone. After the fog spray of emulsion has broken, the surface should be blinded with a thin layer of clean coarse

sand/......

sand which should not contain particles larger than 7 mm.

The rates of application of the surfacing materials should be accurately controlled. Thorough rolling should be done, preferably using a pneumatic-tyred roller. Careful attention is required to the construction techniques.

Intermittent rumble strips

For the construction of intermittent rumble strips a 13,2 mm stone size is recommended. The stone should be hard, cubical in shape (low flakiness index) resistant to abrasion and polishing (high polished-stone value) and dust-free (washed). Suitable epoxy tar binders are available commercially and should be used in accordance with the supplier's instructions.

Prior to commencing construction of rumble strips the existing road surface should be thoroughly swept, scrubbed with non-ionic detergent and washed down well with water. A suitable graded silica aggregate mixed thoroughly with an epoxy tar binder should be applied by hand to the strips between 6 mm screed rails. The 13,2 mm stone should then be hand placed into the wet mix and rolled by hand roller.

Step 4: Evaluation

Observe and record traffic behaviour, approach speeds, stop observance, and accidents by number, type and severity. This should be recommenced a few months after construction to allow for a period of traffic adjustment, and should be continued for at least two years in order to compare the results with those of a two-year period before construction.

Finally, compare the results for the "after" period with a "before" period of the same length of time, and evaluate the success of the rumble installation in terms of accident reductions, speed reductions, improved stop observance and in terms of the cost of construction and maintenance.

10. CONCLUSIONS/......

10. CONCLUSIONS

10.1 Effectiveness of rumble devices

The use of rumble devices to improve road traffic safety has found wide acceptance, particularly in the United States of America. The construction of rumble installations can be recommended as an effective method of reducing accidents by alerting drivers to the need for caution ahead. Rumble installations should be considered as an additional alerting device only where the conventional warning signs and markings prove ineffective on their own.

10.2 Further investigations required

The following aspects of rumble devices need further investigation:

(i) Layout pattern

Different approaches have been used to determine the most effective layout pattern, and in particular to determine the optimum spacing of the individual rumble devices in a rumble installation. From the literature survey it is concluded that there is scope for increasing the effectiveness of rumble devices by improving the layout.

(ii) Rumble effects in different types of vehicle

The effectiveness of rumble installations should be investigated for heavy trucks and buses. This would entail the determination of the rumble effects (sound levels and vibration) in large commercial vehicles produced by various types of rumble devices.

(iii) Noise effects on surrounding development

On rural roads where buildings are generally situated well back from the road, the increased noise produced by tyre rumble is not likely to be disturbing. In urban areas the contribution of tyre rumble to the general noise climate should be investigated to determine whether the increased noise levels would be acceptable in the vicinity of residences, offices and institutions such as hospitals, schools, churches and homes for the aged.

10.3/......

10.3 Installation records

It is recommended that local roads authorities keep records of rumble installations, reflecting details of such aspects as location, date of construction, layout, construction methods and costs, before and after accident data and driver behaviour. The availability of such information would enable the National Institute for Road Research to study and evaluate the contribution made by rumble devices to road traffic safety in South Africa.

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ANNEXURE A

RUMBLE INSTALLATIONS IN THE UNITED STATES OF AMERICA

LOCATION AND TYPE	LAYOUT AND CONSTRUCTION (See Figures 1 and 2)	EFFECTIVENESS	
1. California, 1960 (2), (6) Contra Costa County 4 Type 2 rumble surface installations on approaches to rural stop intersections	7,6 m intermittent rumble surfaces spaced 30,5 m and 15,2 m apart 19 mm and 26,5 mm aggregates; seal coat asphalts and polyester resins	Accidents Approach speeds Centreline violations	- 74% - 13% - 11%
2. Illinois (2), (3), (7) Cook County, 1960 212 Type 1 rumble surface installations at urban stop intersections	91,4 continuous rumble surface. 26,5 mm pre-coated screened slag spread at 27 kg per square metre, 100-120 penetration petroleum asphalt binder	Stop sign observance Full stop Rolling stop	 + 30% - 26%
State Programme, 1962 30 Type 3 rumble strip installations on approaches to rural stop intersections	203 mm wide rumble strips in 7,6 m sets spaced 30,5 m apart and 4,6 m sets spaced 15,2 m apart; 13,2 mm aggregate, epoxy resin binder. Alternative: Cut 203 mm wide rumble slots 13mm deep in concrete roadway surface	Accidents: Total Overrun Rear end collisions Failed to yield and other Fatal Injury Property	 - 32% - 50% - 42% + 16% -100% - 51% - 8%
3. Virginia, 1960 (3) 2 Type 1 rumble surface installations at rural stop intersections	91,4 m continuous rumble surface	Inconclusive experience	

4. Delaware/.....

LOCATION AND TYPE	LAYOUT AND CONSTRUCTION	EFFECTIVENESS
4. Delaware, 1963 (3) 3 Type 2 rumble surface installations on approaches to isolated rural stop intersections	7,6 m intermittent rumble surfaces spaced 30,5 m and 15,2 m apart 26,5 aggregate on seal coat asphalt	Accidents - 50%
5. Kentucky (3) 1 Type 3 rumble strip installation on approach to temporary connector	9 sets of rumble strips beginning 762 m from hazard, each set comprised 12 strips 203 mm wide spaced 203 mm apart RC - 3 asphalt tack coat, 9.5 mm aggregate, PAC - 5 bitumen hot mix. Final layer thickness 6,4 mm	Speed reduction from 112 km/h to 72 km/h was required
6. Minnesota, 1962 - 1964 (5) 7 Type 2 rumble surface installations on approaches to rural stop intersections	7,6 m intermittent rumble surfaces spaced 30,5 m and 15,2 m apart 19, 0 mm aggregate, RS-3K cationic asphalt emulsion at 1,57 litres per square metre	Approach speed - 7% Stop sign observance: Full stop + 26% Rolling stop - 26% Centreline violations unchanged Accidents show decreasing trend
7. Texas, 1956 onwards (4) "Jiggle bars" on paved shoulders and medians throughout the state	Ceramic bars or strips on epoxy resin	
8. Maryland, 1966 (4) 238 Rumble surface installations on approaches to stop intersections	3 m rumble surfaces spaced 9 m apart, No. 3 clean slag or stone on bitumen	
9. Nebraska, 1964 - 1966 (4) 20 rumble strip installations on approaches to stop intersections	13,2 mm bonded aggregates, epoxy resins. 152 mm strips, spaced 305 mm apart, overall length of sets 18,3 m, sets spaced 22,9 m apart, installation starts 396 m from stopline	

LOCATION AND TYPE	LAYOUT AND CONSTRUCTION	EFFECTIVENESS
10. North Carolina, 1966 (4) 1 Continuous rumble surface 1 rumble strip installation on approach to stop intersection	213,4 m continuous rumble surface; coarse aggregate and sand tar 305 mm wide rumble strips spaced 305 mm apart over 152 to 182 m approach length; 26,5 mm thick sand asphalt	
11. Colorado, 1966 (4) "Chatter bars" on approaches to major construction works	19,0 mm high, hox mix asphalt. Bars in sets of 6 or 8 at 1,2 m spacing installation starts about 805 m from stopline	
12. New Jersey, 1965 (8) 1 Type 4 rumble bar installation on concrete roadway approach to urban traffic circle	rumble bars spaced at 3,175 m centres and at 230 mm centres, bars are botton width 76 mm, top width 50 mm, height 13 mm. Epoxy resin prime, rumble bars of quartzite sand and epoxy resin	Accidents - 20% Injuries - 40%
13. Wisconsin (9) 1 Experimental installation of rumble slots cut into existing road surface	3 sets of rumble slots, each set has 24 slots at 305 mm centres; slots are top width 100 mm, bottom width 90 mm, depth 3 to 10 mm	Improved surface water drainage and braking, no obstruction to tyres