USE OF RUMBLE STRIPS AS WARNING DEVICES ON NEW ZEALAND ROADS

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EXECUTIVE SUMMARY

Introduction
Driving is essentially a visual task where about 90% of the information for guidance of the vehicle is provided by visual means. Much of the information is processed within the mind at the pre-attentive level and then, if not used, discarded. To be noticed, road signage needs to intrude beyond the pre-attentive level, and to achieve this the signage must be conspicuous. A higher level of conspicuity is needed to gain attention (attention conspicuity) than is required if the object is being searched for (search conspicuity).

Rumble strips are modifications to the pavement surface that, when traversed, generate noise and vibration additional to that typically produced by the pavement. This additional noise and vibration alerts the driver to a hazard but can provide little information about the nature of the hazard. However, the additional stimuli claim the driver's attention so that a visual search for signage, delineation or other hazard commences.

The rumble strips appear to be particularly useful where the visual process is impeded, as in complex or cluttered backgrounds, or where the mind set of the driver has been dulled by uneventful driving such as on long straight sections of road where the hazard is not obvious. Rumble strips have additional value in gaining the driver's attention to a hazard at night time or in wet conditions where visibility is reduced.

An initial reading of the literature indicated that much of the evidence on the effectiveness of rumble strips was conflicting. A more detailed study of available international literature was therefore commissioned to assess the effectiveness of rumble strips, with particular reference to New Zealand road and driving conditions. This report describes the findings of that study carried out in 1994.

Design of Rumble Strips
The study found that rumble strips have been used since the 1950s in the United States (US), 1970s in the United Kingdom (UK), and in several other countries such as Australia.

Rumble strips comprise a series of grooves or raised portions, typically 10-20 mm deep or 10-20 mm high, on the pavement surface. The raised portions may be strips of coarse aggregate strongly adhered to the surface, thermoplastic strips or mounds, raised pavement markers, plastic strips, or an area of coarse aggregate overlay.

Rumble strips are used in two ways. When used on the carriageway, they are normally applied as an array of individual strips or studs laid out in a transverse group across the carriageway. These are repeated several times over, typically for 100-200 m preceding a hazard. Their purpose is as an enhancement to signage, to attract attention to the signage which warns of the nature of the hazard. To be effective, the signage must be visible as the rumble strips are crossed.

Rumble strips are also used longitudinally to provide lane delineation or to mark the edge of the roadway. Used in this way their function is to warn the driver that he/she is leaving the lane or straying from the roadway. In this mode no signage is needed as the driver notices that the vehicle is in the wrong position with respect to visually observed road/lane delineation. When used in this way, the rumble strips may be continuous or intermittent in the longitudinal direction.

Overseas, rumble areas consisting of transversely formed grooves, raised portions or coarse aggregate overlays are commonly used on the road shoulder.

Effectiveness of Rumble Strips as Warning Devices

The effectiveness of rumble strips has been assessed by accident reduction, speed reduction, and by change in driver behaviour measured by their compliance with traffic control signs.

The effectiveness of rumble strips in reducing accidents has been assessed in several investigations by before and after studies. However, while most quote a reduction in accidents (characteristically a 20% to 50% reduction), many of the studies reported in the literature, particularly studies of rumble strips on the carriageway, lack full statistical rigour. Nevertheless the studies do point to their effectiveness in encouraging driver compliance with traffic stop control signs, although their effectiveness as measured by speed reduction is minor. It appears from the literature that an important contributor to the effectiveness of rumble strips when used on the carriageway is the rarity with which they are encountered. When used to delineate a lane or mark the edge of the roadway, the frequency with which the rumble strips are used is less likely to detract from their effectiveness.

Adverse Effects of Rumble Strips

Rumble strips have been found to have adverse effects, the two main effects being on driver behaviour and nuisance noise. A number of drivers who regularly travel on a roadway with rumble strips on the carriageway derive no benefit from the warning they get from traversing the strip as they are well aware of the hazard. They see the strips as a nuisance value only, often avoiding the strip by driving into the opposing lane or onto the shoulder area. This reaction is best overcome by designing rumble strips which allow these drivers to adjust their path only slightly out of the normal wheeltracks in order to avoid the strips.

Rumble strips are deliberately designed to produce noise but this noise is a nuisance for adjacent residents. UK guidelines recommend that no rumble strip should be used on the road carriageway within 200-300 m of the nearest residence. When used to delineate a lane or mark the edge of a roadway, the noise nuisance is less of an issue as noise is generated only by those vehicles that have strayed from their path. Other adverse effects are that rumble strips cause instability for cyclists and motorcyclists, and that the strip can interfere with surface drainage.

Costs of Rumble Strips

Costs of rumble strips as reported in the literature vary widely. Indicative US costs (at 1993) for an installation on a carriageway ranged from about NZ$700 to NZ$5,000. The range in the UK for thermoplastic installations was similar but, for some sites with rumble areas on the carriageway, 1992 costs were about NZ$6,000 to NZ$26,000 per installation. An Australian cost (at 1992) was about NZ$1,200 per lane for a small group of strips.

Service Life of Rumble Strips

The service life for rumble strips on the carriageway was from 2 to 4 years for coarse aggregate strips. Overseas experience with ceramic markers was that most were lost within six months, and that grooved rumble strips lost their effectiveness within 4 to 6 years. Thermoplastic strips on the carriageway lasted about 4 years, but when used as road edge delineators they lasted considerably longer.

Applicability of Review Findings to New Zealand Roads

While all rumble strip types used in other countries could be used on asphaltic and friction course surfaces in New Zealand, only the raised type would be effective on chipseal roads. The most useful type for application in New Zealand are considered to be thermoplastic strips which are already being used on chipseals for road delineation. These strips offer the advantages of providing all three stimuli - visual, audible and tactile.

Ceramic or plastic raised pavement markers could also be used in a similar way. The New Zealand practice of using thermoplastic-bituminous adhesives should also provide a much improved retention rate as compared to an epoxy adhesive used overseas.

Coarse aggregate strips or rumble areas formed from a coarse aggregate overlay are less favoured as they lack visual conspicuity (e.g. they may be confused with normal pavement maintenance) and are unlikely to provide sufficient additional audible-tactile stimulus when used on coarse chipseal roads.

Future Research

The following studies are recommended for future research:

- Establish the rumble strip designs that provide the desired levels of increased noise, vibration and visual intrusion on the coarse chipseal surfaces used on New Zealand roads.
- Determine that the external noise levels will be within Transit New Zealand's guidelines on road noise.
- Determine the minimum distance for placing a rumble strip from the nearest residence.

- Monitor the extent that rumble strips can be applied without over-use, and to ensure that driver safety is not compromised.
- Evaluate the durability of high build thermoplastic strips (on chipseal roads in particular), the optimum thermoplastic formulation, the thickness to use, and their layout pattern.
- Establish that rumble strips do not cause loss of control for cyclists (and possibly motorcyclists) using the road.
- Instal trials at accident black spots on carriageways where treatments such as cleared lines of sight or additional signage have not been effective, to research their effectiveness, evidenced by changes in driver behaviour and accident reduction, based on statistically rigorous before and after studies.
- Undertake public education and/or appropriate signage to accompany any installations of rumble strips on the carriageway to minimise driver confusion.
- Determine usefulness of textured thermoplastic lines, discrete mounds of thermoplastic, or raised pavement markers as these are much less commonly used in New Zealand for lane delineation than overseas.
- Assess effectiveness of road edge delineation strips for providing guidance to motorists who stray off the edge of the road, at sites where run-off-the-road accidents have frequently occurred.
- Establish effectiveness of temporary rumble strips at road work sites.

ABSTRACT

A review of the international literature was undertaken in 1994 to identify the types of rumble strip available, situations where and how they are used, their effectiveness in reducing accidents and modifying driver behaviour, their adverse effects such as noise, and their expected service life. The available information was then interpreted to identify the suitability of rumble strips for New Zealand roads, the materials that might be employed and the cost of installation. As well issues which would need to be resolved by further research are recommended.

1. INTRODUCTION

1.1 Background

The nature of road surface texture and road roughness, and the pavement-tyre interaction means that there is always a substantial level of noise and a moderate level of tactile sensation when driving. Though guidance of the vehicle on the route ahead is regarded as essentially a visual task, with about 90% of the needed information received through the driver's vision, noise and vibration are further sensory inputs into the driving/guidance task. Manipulating noise and vibration levels to provide extra stimulus to the driver either to modify behaviour or to provide warning is an available control option. The additional stimulus is particularly appropriate in situations where the driver's vision is impaired by the weather conditions, such as driving rain or at night time, or to provide a warning in the event of driver tiredness. Devices known as rumble strips are low in profile and can be traversed safely at speed with strong, low amplitude vibration and a sharp increase in noise, thereby providing a warning to the driver to search for visual clues.

Speed humps differ from rumble strips in that they have a much higher profile. Vehicles traversing speed humps are badly shaken if the speed is excessive, which provides a strong incentive to reduce speed. Noise, if produced traversing the hump, is merely coincidental and is not intended to form part of the control measure.

1.2 Objectives of the Study

The objective of the study carried out in 1994 was to establish, by review of international literature:

- the types of rumble strip used;
- their effectiveness in providing warnings and how this benefit is assessed;
- the applicability of rumble strips to New Zealand roads;
- the installation costs of rumble strips; and
- associated disadvantages with their use.

1.3 Literature

The literature obtained was reasonably extensive and salient papers are given in the list of references.

Two of the references, the papers by Harwood (1993) and by Webster & Layfield (1993), stand out as being particularly relevant to this study.

1.4 Structure of Report

Sections 2 to 5 of this report are a review of the available literature on rumble strips, particularly with regard to the design, effectiveness, adverse effects and costs of strips used in other countries. Section 6 then considers this information with regard to the applicability to the New Zealand road situation, and the conclusions and recommendations are contained in Section 7.

2. USES OF RUMBLE STRIPS

Rumble strips have been used in the United States (US) since the 1950s, and in the United Kingdom (UK) since the 1970s. Reports on their limited use in Israel, South Africa, Australia, Sweden, Denmark, the Netherlands and France have also been published.

At the time of the literature review (1994), rumble strips were being used at numerous sites in the US and the UK to slow down or alert drivers to potential or actual hazards. As warning devices they are used to alert drivers about:

- a slow down or stop;
- changing lanes;
- changes in road alignment, e.g. approaching a tight curve;
- other potential hazards or unexpected situations such as work zones, pedestrian crossings, or recent changes in traffic control devices.
- running off the road or leaving the lane.

Rumble strip applications fall within two general categories and, although the basic element of the strip used may be similar in both categories, they have wide differences in use, function and acceptance.

The first category includes those that are laid transversely across the carriageway to warn drivers that they are approaching an intersection, built-up area, railway crossing, work zone or any other unexpected hazard. However, while the noise and vibration generated by crossing the strip indicates a hazard, the driver cannot generally discern the type of hazard. In such circumstances it is essential that signage is employed in conjunction with the rumble strip to identify the action that is required of the driver. This signage must be clearly visible as the rumble strip is traversed. Rumble strips used in this way, together with the signage they complement, are placed at discrete specific locations on the highway.

The second category includes rumble strips placed longitudinally along a highway and are intended to warn drivers they are either straying from the road or are leaving the lane. They are therefore placed between lanes, or on the road shoulder or other area outside the carriageway. Used in this way the rumble strip supplements the delineation, and may be placed for many kilometres continuously along the highway. The rumble strip may be formed totally or in part by the delineation, e.g. raised pavement markers or textured thermoplastics. Signage is not required for the longitudinal rumble strip to be effective as the visual supplement is provided by the delineation, whether formal or informal (hedges, etc.).

3. DESIGN OF RUMBLE STRIPS

3.1 Types

The common types of rumble strips (Figure 3.1(a)-(g)) include:

(a) raised bars;

(b) grooved bars;

(c) corrugated Portland cement concrete;

(d) concrete with widely spaced corrugations;

(e) overlays with exposed coarse aggregate;

(f) raised pavement markers; and

(g) continuous line of textured thermoplastic strip.

These are shown in Figure 3.1 ((a) to (e) are after Harwood 1993, of which (c) and (d) being applicable for concrete roads are seldom encountered in New Zealand). Rumble strips of types (a) through to (d) consist of a pattern or cluster of parallel bars or grooves spaced relatively closely to one another and oriented in a transverse direction across the carriageway or shoulder. Wide rumble "strips" consisting of an area of coarse aggregate overlay (i.e. type (e)) are commonly used in the UK, although this type is under further experimentation and trial in the US.

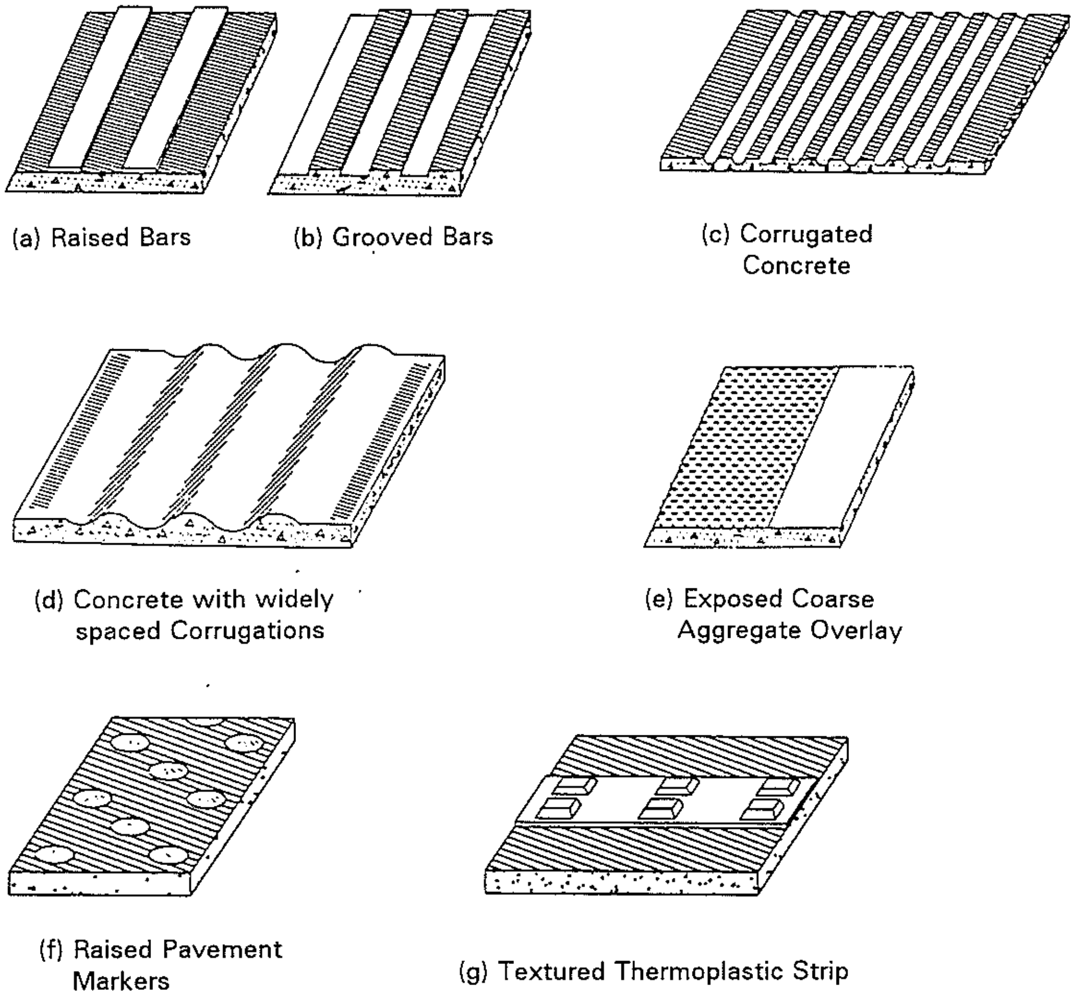
Rumble strips can also be formed by an array of raised pavement markers (or strips of polycarbonate), as shown in Figure 3.1(f). Textured thermoplastic strip used as rumble strips to delineate lanes or the edge of the road is shown in Figure 3.1(g). Raised pavement markers or discrete mounds of thermoplastic strip can also be used for lane or road edge delineation.

Most rumble strips installed on the carriageway consist of types (a), (b) and (e) shown in Figure 3.1. Most raised rumble strips in the US consist of asphalt bars placed on the surface of the carriageway using wooden forms to create the desired shape of the bar, while most grooved rumble strips consist of indentations formed in the pavement surface by grinding or sawing.

In the UK, most raised rumble strips are of the form shown in Figure 3.1(a), but with the raised bar consisting of thermoplastic material. Coarse aggregate overlay is also often used. Thermoplastic material is also used for rumble strips on the longitudinal shoulder of a roadway.

Many of the grooved/raised bar types used in the US are difficult to see while driving. However, Webster & Layfield (1993) note that part of the impact of rumble strips is visual and that rumble strips should be conspicuous so that, having identified something unusual on the road, surprise at subsequent noise and vibration will be minimised. Coarse texture aggregate overlays as rumble strips may not be very conspicuous against the road surface unless a contrasting coloured aggregate is used.

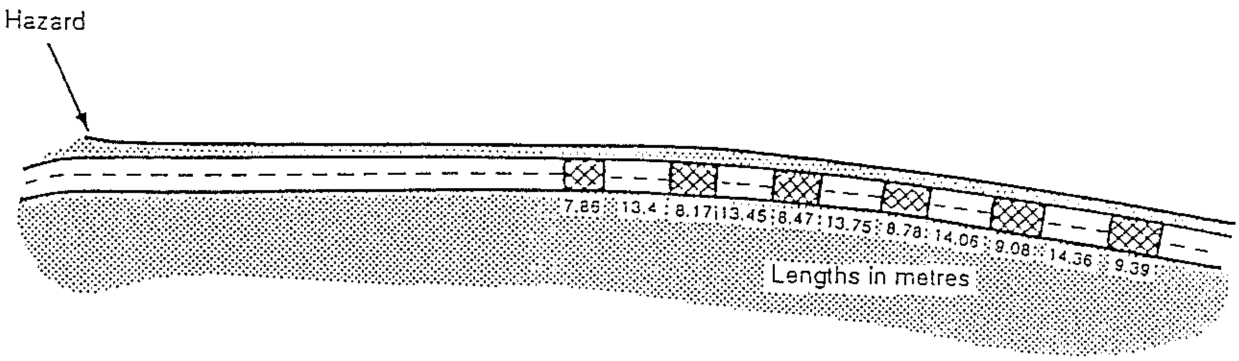
Figure 3.1 Types of rumble strips ((a) to (e) from Harwood 1993).



3.2 Layout and Dimensions

Rumble strip designs vary widely. Typically the strip will consist of blocks of raised or grooved bars distributed along the lane, interspersed with areas of untreated road. Figure 3.2 shows one such example. Variables include the length of each of the treated sections of road, the number of bars in each, and the spacings between each treated section; the width of individual bars; the centre of centre spacing between successive bars; the height of the raised bar (or depth of grooved bar); the cross-sectional shape of the bar (i.e. rectangular, tapered, vee-shaped or rounded) and the length of the bars, relative to the lane width.

Figure 3.2 Example of layout of rumble strip (Sumner & Shippey 1977).



3.3 US Design

In a comprehensive survey of US highway practice, Harwood (1993) reported that the number of bars per treated section of road ranged from 4 to 25, the depth of rumble strip grooves ranged from 3/16" to 1½" (5-38 mm), and the height of rumble strip bars from 3/16" to 1" (5-25 mm). Bar widths of raised bars were from 4" to 8" (100-200 mm). Harwood concludes that data are insufficient to enable an optimum design to be deduced.

US design practices for the number of rumble strip blocks used per installation and the spacing between each block on the approaches to "Stop" controlled intersections also vary widely. The number of rumble strip blocks was between 2 and 10, with the location of these blocks as close as 150 ft (45 m) to the intersection, and as far away as 2000 ft (600 m). Again, no data concerning the relative effectiveness of the different rumble strip designs are available (Harwood 1993). Often rumble strip spacings vary as a function of the approach speed, with some designs having decreasing spacing between successive blocks of rumble strips to give the impression of increasing speed for a vehicle travelling the installation at constant speed.

3.4 UK Design

The research available at the time of the literature review from the UK encompassed trial rumble strip installations with a considerable variety of layout and dimensions (Webster & Layfield 1993, Watts 1978). Although the spacing between successive blocks of rumble strips was generally related to the anticipated speed of the traffic and to specific site conditions, the actual layout of the installations at the 35 sites studied were very varied.

Rumble strip areas used 14 mm- or 19 mm-chip embedded in epoxy resin, with the number of treated sections ranging from 1 to 10, and the spacing between treated sections being uniform in some cases and increasingly reduced in others to give the impression of increasing speed, for a vehicle travelling at constant speed.

Where rumble strips were made from thermoplastic strips, the bars were from 6 mm to 20 mm in height, with the most common height being 10 mm. The width of the bars ranged from 60 mm to 100 mm, while the centre to centre spacing between bars generally fell into two categories: either 300-500 mm spacing or 2000-5000 mm spacing.

The number of rumble strip blocks used at each installation also varied considerably, from a single block up to 32 blocks. In some cases the spacing between blocks was constant, but in others an increasingly reduced spacing was used. One system based the spacing between successive blocks of rumble strips on the distance travelled in 1 second at the 85th percentile vehicle speed. This appears to have been partially successful, as two sites incorporating this design showed a 30% reduction in injury accidents (Webster & Layfield 1993).

3.5 Designs for Road Shoulder Rumble Strips

Rumble strips used on asphalt road shoulders in the US are almost always grooved rather than raised, with the grooves rolled into the asphalt during initial construction or re-surfacing. The most common US design is to place grooves at 8-9" (200-230 mm) centres, with groove depth ranging from ½" to 1" (13-25 mm).

Common practice in the UK is to incorporate a rumble strip as part of the road edge line delineation. The edge line commonly consists of a continuous thermoplastic strip with raised portions at about 250 mm spacings which generate noise and vibration when driven over. A similar technique is used in Australia where thermoplastic is also used but applied as discrete mounds approximately 80 x 150 mm in size at 100 mm spacings. This technique allows for surface drainage.

Raised pavement markers are another form of rumble strip that can be used for lane delineation or to mark the edge of the carriageway. When visibility is good, their visual properties are important. In poor visibility the audible and tactile stimulus they provide is much more significant.

3.6 Designs for Rumble Strips in Work Zones

The design of rumble strips for use in work zones is varied. Because of the temporary nature, raised bars are the more common form. Raised bars have been constructed from bituminous material or from prefabricated polycarbonate strips. In some cases grooved installations have been used. The height (or depth) of bars (or grooves) is generally slightly more than for similar permanent installations used on the carriageway. A study by Noel et al. (1989) summarises current US practices. The report notes that rumble strips are not widely used in work zones, though several states, e.g. Ohio, Maryland, Pennsylvania, have developed specifications for their use.

A more recent publication by Stout et al. (1993) summarises an investigation into the performance of a range of innovative work zone safety devices as part of the SHRP (Strategic Highway Research Program) project. The performance of three portable rumble strips is reported. The optimum placing of the devices across the roadway was found to be 500 ft (150 m) before the stop/go control. While the device produced only a small change in the average vehicle speed as recorded 30 ft (9 m) upstream and 30 ft (9 m) downstream of the device, a significant reduction in the average vehicle speed occurred as vehicles approached the rumble strip. The comment was made that drivers may have slowed because they saw the device across the carriageway in advance of seeing the road works signs.

Following some design modification undertaken as part of the investigation, one of the portable rumble strips reported by Stout et al. (1993) performed satisfactorily without flipping over during on-road use (the devices tested were not positively fixed to the roadway). However, another device that was trialled was a continuous strip some 20' (6 m) long with raised bars. It was intended to be laid along the length of the work zone to warn drivers that they were straying into the buffer zone between the roadway and the work zone. This device failed a skid test in the wet when the test vehicle rotated 90° after coming into contact with the device.

4. EFFECTIVENESS OF RUMBLE STRIPS AS WARNING DEVICES

The effectiveness of rumble strips as a warning device has been assessed by many researchers at numerous rumble strip installations by analysing indicators such as accident frequency, vehicle speeds, and driver compliance with traffic control devices.

4.1 Effectiveness Measured by Accident Frequency

Research into the effectiveness of rumble strips to decrease accident frequency has been carried out at rumble strip installations at intersection approaches and where rumble strips have been used along roadway shoulders. The accident reduction effectiveness of other rumble strip applications, such as rumble strips on the carriageway approaching toll plazas and lane reductions, or shoulder rumble strips at point locations (e.g. at entrance ramps, exit ramps and narrow bridge approaches), does not appear to have been evaluated.

Rumble strips on carriageways approaching horizontal curves were investigated in one UK study (Sumner & Shippey 1977). One early US study (Skinner 1971) reports on the effectiveness of rumble strip installations at railway grade crossings. Significant reductions in accidents and "near miss" reports were observed at the 30 grade crossings investigated over a 2-3 year period.

4.1.1 Rumble Strips on Carriageways

Operational experience of US highway agencies and the UK Department of Transport shows that rumble strips on the carriageway can be very effective in reducing accidents (Harwood 1993, Webster & Layfield 1993). Most of the available accident studies concern rumble strips placed at Stop-controlled approaches to T intersections, and at four-way intersections with Stop control on two approaches where the signage helped drivers react to the potential hazard.

Published safety evaluations generally show that the installation of rumble strips is effective in reducing accidents on intersection approaches by 14% to 100%, with characteristic values being 20% to 50% (Kermit & Hein 1962, Kermit 1968, Owens 1967, Sumner & Shippey 1977, Carstens 1983, Zaidel et al. 1986, Harwood 1993). Table 4.1 (after Harwood 1993) summarises the results of these and other studies. All the data in Table 4.1 relates to before and after studies, with "after" periods ranging from 10 months to four years. However, several involved only a few installations. Six of the 10 studies drew no conclusions on the statistical significance of the assessment. Few of the studies used control sites for comparative purposes, while only two of the studies took traffic counts before and after the treatment, though several commented that traffic volumes had not changed.

Table 4.1 Accident reduction effects of rumble strips installed on the carriageway (after Harwood 1993).

Study (date)	Location	Number of sites	Type of sites	Accidents recorded	% change in safety measure	Statistically significant?
Kermit & Hein (1962)	California	4	Intersection approaches	Total accidents	-59 to -100	Not stated
Kermit (1968)	California	1	Intersection approaches	Ran "Stop" sign accidents	-50	Not stated
Owens (1967)	Minnesota	2	Intersection approaches	Total accidents	-50	No
Illinois Division of Highways (1970)	Illinois	5	Intersection approaches	Total accidents Ran "Stop" sign accidents	+5 -50	Not stated Not stated
Sumner & Shippey (1977)	UK	10	Intersection approaches Roundabouts Horizontal curves Small towns	Total accidents Related accidents	-39 -50	No Yes
Virginia Department of Highways & Transportatiion (1981)	Virginia	9	Intersection approaches	Total accidents Fatal accidents Injury accidents PDO* accidents Total accident rate Related accident rate	-37 -93 -37 -25 -44 -89	Not stated Not stated Not stated Not stated Not stated Not stated
Carstens & Woo (1982)	Iowa	21	Primary highway intersection approaches Secondary highway intersection approaches	Total accident rate Ran "Stop" sign accidents Total accident rate Ran "Stop" sign accidents	-51 -38 -1 +3	Yes No No No
Zaidel, Hakkert & Barkan (1986)	Israel	1	Intersection approaches	Right angle accidents	-50 to -67	No
Moore (1987)	Louisiana	24	Intersection approaches	Total accidents Fatal and injury accidents Daytime accidents Night time accidents	-29 -14 -14 -50	Not stated Not stated Not stated Not stated
Taylor (1974)	Pennsylvania	8	Intersection approaches	Total accidents Ran "Stop" sign accidents	-40 -50	Not stated Not stated
Webster & Layfield (1993)	UK	13	Rural junctions Horizontal curves Small towns	Total accidents	-28	No

* PDO Property damage only

A further problem was lack of detail about the selection of sites. If the sites had high accident rates, some of the decrease could be simply regression to the mean. Two of the studies summarised in Table 4.1 had results statistically significant at the 95% confidence level. Despite the lack of rigorous statistical analysis, the results in the literature generally indicate that rumble strip installation on the carriageway can be effective in reducing accidents (Harwood 1993). Many authors caution against the over-use of installing rumble strips as the rarity of encountering them is suggested as a reason why rumble strips are effective in alerting inattentive drivers.

The data reported in the literature are insufficiently reliable to make a valid determination of the effectiveness of rumble strips to reduce accidents over a period of time. Some studies have found indications of greater effectiveness, others lesser effectiveness with time.

Almost universally the statement is made that rumble strip installation on the carriageway should be considered only where a documented accident problem exists, and only after more conventional treatments such as signage have been found to be ineffective.

A précis and analysis of the studies up until 1991 listed in Table 4.1 has been carried out in an extremely thorough and succinct manner by Harwood (1993), and for greater detail refer to this work.

Each of the published accident evaluations utilised slightly different rumble strip designs. Harwood (1993) comments that reliable conclusions that would allow comparison of the effectiveness of different designs cannot be drawn from the available data.

4.1.2 Rumble Strips on Road Shoulders

Shoulder rumble strips have been constructed over considerable distances in several states of the US. They are usually grooves or bars in the pavement shoulder outside the main carriageway.

Research on rumble strips placed continuously or at regular intervals along highway shoulders has shown that they can reduce run-off-the-road accidents by 20% to 50%. One study investigated continuous shoulder rumble strips constructed on rural freeways where monotonous driving conditions were believed to cause drivers to lose concentration. This study found that the run-off-the-road accident rate was reduced by 49% (Chaudoin & Nelson 1985). A second, more comprehensive study, covering a broader use of shoulder rumble strips constructed mainly on rural interstate highways, showed a 20% run-off-the-road accident reduction effect (Ligon et al. 1985). These two studies were based on accident rates, rather than on accident counts, and included control sites without rumble strips in their evaluation. Both are considered to be well designed investigations.

One of the more dramatic studies into the effectiveness of textured thermoplastic edge lines/rumble strips is an as-yet unpublished study of the M4 (Berkshire, UK). An accident rate of 62 injury accidents in the six years before the application of a road edge delineator rumble strip was reduced to seven injury accidents in the three year "after" period. P.T. Cairney (pers. comm.), however, advised caution in applying the results too broadly as this application involved use of a rumble strip/edge line in an ideal situation and the same gain may not be achievable in other situations. Though similar edge lines are known to have been used in Australia, information on their effectiveness for accident reduction was not available.

4.2 Effectiveness in Reducing Vehicle Speeds

Another measure of the effectiveness of rumble strips is their influence on vehicle speeds. The literature indicates that rumble strip installation at intersection approaches does result in a small reduction in vehicle speeds, although some vehicle types slow down more than other types. Reduction in vehicle speeds was observed at most of the 13 sites studied by Webster & Layfield (1993), with the average 85th percentile vehicle speed reduction after the rumble strips were installed being 3.1 mph (5 km/h). However, rumble strips, in conjunction with signage, were found to be ineffective in producing speed limit compliance in a study undertaken in a small town in the US (FHWA Maine Facility Research 1977).

In a study (Owens 1967) involving six rural highway intersections, the presence of rumble strips was found to reduce average speeds by 2-3 mph (3-5 km/h). A detailed study at one Israeli site showed that mean speeds were reduced by 5% to 43% on approaching the intersection, and that when rumble strips were present drivers generally began to slow down sooner and some drivers slowed more than others (Zaidel et al. 1986, Harwood 1993). The observation that drivers may have slowed down as a result of seeing the rumble strip across the roadway could be made here also.

An Australian study was made at three trial locations where rumble strips of 12 mm height were used in advance of a reduced speed zone. These strips reduced mean speeds by 1.9-3.2 km/h when compared to speeds at similar locations in a control site (Uber & Barton 1992). Its authors concluded, however, that speed reductions of this order are not significant in reducing the likelihood and severity of accidents, and that rumble strips are not a cost-effective solution for speed control.

4.3 Effectiveness on Driver Behaviour at Stop Signs

A further measure of rumble strip effectiveness that has been used was to analyse their effect on drivers' compliance with "Stop" signs, i.e. whether the driver made a full stop, a partial stop, or no stop. The effect of rumble strips on driver compliance with traffic control devices has been evaluated in five such studies, primarily for compliance with "Stop" signs at T and four-way intersections. Installation of rumble strips on an intersection approach generally increased the proportion of drivers who made a full stop. The percentage of drivers making a full stop has been reported as increasing from 46% to 76% (Kermit & Hein 1962), from 37% to 63% (Owens 1967), and from 91% to 95% (Zaidel et al. 1986).

4.4 Effectiveness for Work Zone Applications

Rumble strips have been used to supplement warning signs and other traffic control devices in advance of work zones on the open highway involving lane restrictions, width reductions or sharp detour transitions.

The results of five studies carried out in the US between 1985 and 1989 have been reviewed (Harwood 1993). One of the studies reviewed had indicated that only a limited number of applications of rumble strips in work zones had been investigated and that these had produced inconsistent results, while an earlier study in the review indicated that rumble strips were ineffective treatments for controlling work zone speeds. However, yet another study (Pigman & Agent 1986) reported a desired decrease in the percentage of traffic in the closed lane at 0.1 mile (160 m) in advance of the taper from 11% to 4%.

Evidence of the effectiveness of rumble strips as a speed control device in work zones is inconclusive. Generally, rumble strips are probably effective when they call a driver's attention to traffic control devices or to potential unseen hazards (Harwood 1993). Rumble strips do, however, appear to be effective at lane closures in work zones by encouraging drivers to leave the closed lane further upstream.

5. ADVERSE EFFECTS OF RUMBLE STRIPS

The potential adverse effects of rumble strips that have been reported include: noise, use of opposing lanes to avoid rumble strips, maintenance problems, concerns of motorists, cyclists and motorcyclists, and over-use of rumble strips.

5.1 Effect on Environmental Noise

The rumble strip is specifically designed to produce increased in-car noise levels as one component of the warning they give to the driver. This increased noise can be, however, a nuisance outside the car as well. One of the most common problems associated with the use of rumble strips is that the noise can disturb nearby residents. These residents may find the noise generated to be merely a nuisance during the day, but at night are likely to complain of interrupted sleep. Several rumble strip installations have been removed because of this problem (Gupta 1991, Webster & Layfield 1993).

Studies have been carried out to measure the noise generated by rumble strips. One study concluded that rumble strips (made by cutting grooves in concrete pavement) produce a low frequency noise that increases the noise level by as much as 7 dBA above the noise levels produced by traffic on normal pavement. They also found that noise outside the vehicle did not change with rumble strip configuration (Higgins & Barbel 1984). Another study which evaluated the effect of rumble strip spacing found that a 3 m spacing produced the lowest external noise levels (Pigman & Barclay 1981). A third study concluded that vehicles passing over rumble strips produced an increase in the external noise level of 6-8 dBA (Gupta 1991). (Note that an increase of 10 dBA corresponds approximately to the subjective impression of a doubling of loudness.)

Noise measurements carried out at a number of sites in the UK found noise levels increased by as little as 1.2 dBA for rumble strip devices made from coarse surface texture (Sumner & Shippey 1977) to as much as 6 dBA for rumble strips made from 18 mm high thermoplastic (Webster & Layfield 1993). The noise levels generated by heavy goods vehicles travelling over rumble strips has been reported to increase more (2.75 dBA) than for cars (1.25 dBA).

Noise generated by rumble strips is a serious problem, and in the US the use of rumble strips is restricted in residential areas, while in the UK they are not recommended within 250 m of any houses. The overall noise level resulting from a highway is recognised as needing to conform with normal guidelines. In the UK, a L_{10} (18 hour) level of not more than 68 dBA at the nearest affected residence is usually considered acceptable.

Rumble strips on shoulders are less likely to disturb nearby residents because noise is generated only by the few vehicles that stray from the carriageway and drift onto the shoulder area.

5.2 Effect on Driver Behaviour

Rumble strips installed across only the lanes leading in one direction may encourage some drivers to drive on the wrong side of the road to avoid crossing the rumble strips. This is obviously undesirable and may result in accidents. Typically this behaviour is shown by local residents or commuters who are familiar with the location and its potential hazard, and know that the rumble strips are present.

One potential solution to this problem is to extend the rumble strip across the full road width. However the disadvantages are increased noise generation and making traffic on the opposing lane unnecessarily traverse a rumble strip which has no associated potential hazard (Webster & Layfield 1993).

Another solution is the use of discontinuous rumble strips that extend across only the normal wheelpath areas of the lane. This allows drivers familiar with the installation to avoid the rumble strip without entirely leaving their lane. Some encroachment on the opposing lane or shoulder may still occur (Harwood 1993).

5.3 Maintenance Issues

An extensive survey of US state and local highway agencies and toll road authorities reported several types of maintenance problems with rumble strips (Harwood 1993). These include durability of rumble strips, snow ploughing concerns, and drainage erosion problems.

5.3.1 Durability of Rumble Strips

The durability of rumble strips, particularly raised rumble strips on the carriageway, is a reported concern. The most severe problems with rumble strip wear occur in areas where vehicles are normally braking at an intersection approach. Trucks particularly are a significant contributor to accelerated wear. Aggregate strips lose aggregate around the edges, and grooves in asphalt tend to flatten over time.

Raised pavement markers that are attached to the carriageway as rumble strips frequently had to be replaced because they had been damaged by heavy trucks. Failure rates of up to 75% within six months were reported by Harwood (1993).

Service life of rumble strips is discussed in more detail in Section 6 of this report.

5.3.2 Snow Ploughing Problems

Raised rumble strips on the carriageway have been reported to be damaged or displaced during snow ploughing (Harwood 1993).

5.3.3 Drainage and Erosion Problems

Shoulder rumble strips with grooves or raised strips can create drainage erosion problems by disrupting drainage patterns on the road shoulder and channelling water onto roadside slopes. This problem can be alleviated by ensuring the rumble strip does not extend to the outside edge of the shoulder. Longitudinal strips can possibly disrupt drainage from the pavement surface, thereby causing ponding on the road surface with attendant problems of loss of skid resistance, additional spray, and rogue reflections of street lights and oncoming traffic. Therefore strip design needs to allow for drainage.

In the UK the use of 13-19 mm stone chip, embedded in epoxy resin binder to form a rumble strip area on the carriageway, was found to create a rigid platform which did not allow the expulsion of water from the macadam by deformation under normal traffic loads. The build-up of water can lead to frost damage, potholing and other surface damage (Sumner & Shippey 1977).

5.4 Cyclist and Motorcyclist Concerns

The concern of cyclists and motorcyclists about rumble strips on the carriageway is largely related to the potential for loss of control if a rider strikes a rumble strip unaware of its presence. Concerns have also been expressed by cyclists about shoulder rumble strips as the shoulder is the preferred travel area for cyclists. No reliable information regarding these concerns is available and further research has been recommended.

5.5 Motorist Concerns

The survey by Harwood (1993) reported complaints from motorists who do not like rumble strips and from motorists who do not understand them.

Motorists who do not like rumble strips are generally concerned about vehicle vibration and potential vehicle damage. However, reliable data does not appear to be available on vehicle damage associated with rumble strips, and few instances of damage have been reported. Motorist acceptance of rumble strips will be increased if the bar height/groove depth/chip size is kept to a minimum, and yet sufficient audible and/or tactile sensation is generated. The most widespread compromise is to limit the maximum bar height/groove depth to ½" (12 mm), or to use 14-19 mm chips for rumble strip areas.

Some motorists did not understand the purpose of rumble strips and assumed that the noise/vibration generated by the rumble strip was related to a mechanical problem with their vehicle. A need for public education about the purpose of rumble strips has been reported, together with "Rumble Strip" warning signs where they are installed on the carriageway.

5.6 Over-Use of Rumble Strips

Many reports in the literature comment on the importance of avoiding the over-use of rumble strips. The effectiveness of rumble strips is believed to be associated with the rarity with which they are encountered on the road. This is primarily a concern where rumble strips are installed on the carriageway and must be crossed, but does not apply to their use on road shoulders where they are infrequently traversed.

6. INSTALLATION & MAINTENANCE COSTS OF RUMBLE STRIPS

Only a limited number of reports contain cost data for rumble strips, in part because in the US rumble strips are often not treated as a separate payment item in highway construction (Harwood 1993).

6.1 Rumble Strips on Carriageways

Costs that were reported in Harwood (1993) include those from one US highway agency which estimated that (at 1992 prices) raised rumble strips cost US$1.40 per linear foot (NZ$7.90 per metre), while reported costs for grooved rumble strips range from US$0.89 to US$2.23 per linear foot (NZ$5 to NZ$12.60 per metre). Another highway agency reported costs of US$400 (NZ$690) per intersection approach for grooved rumble strips, and US$500 (NZ$862) per intersection approach for raised rumble strips. A third US highway agency reported a cost of US$3,000 (NZ$5,170) per intersection approach for rumble strip installation.

Cynecki et al. (1993) reported trial installations of rumble strips for use as advance warning of pedestrian crossings as costing US$125 (NZ$215) for a single ceramic marker rumble strip traversing four lanes, and US$450 (NZ$775) when plastic rumble strips were used.

In the UK the typical price range for a thermoplastic rumble strip installation was £500 to £1,500 (NZ$1,310 to NZ$3,930) per site at 1992 prices. Sites which used a coarse aggregate were generally more expensive at £2,500 to £10,000 (NZ$6,550 to NZ$26,000) per site at 1992 prices (Webster & Layfield 1993). A typical cost of up to £5,000 (NZ$13,000) per site, depending on length of road treated at 1991 prices, has been recently reported (Webster 1993). An earlier series of trial installations utilising a coarse aggregate design reports an average installation cost of £400 (NZ$1,050) per site every three years, at 1975 prices (Sumner & Shippey 1977).

Australian trial installations of 12 mm-high thermoplastic rumble strips were estimated to cost (in 1992) A$1,000 (NZ$1,250) per lane for a single group of three (Uber & Barton 1992).

6.2 Rumble Strips on Road Shoulders

When rumble strips are rolled into an asphalt shoulder during re-surfacing, costs from US$150 to US$580 per mile (NZ$160 to NZ$620 per km) for a continuous 2 to 5 ft (0.6 to 1.5 m) wide rumble strip along one shoulder have been reported (Harwood 1993). In 1998 shoulder rumble strips that were installed along a 23 mile (37 km) section of interstate highway had an estimated cost of US$1,000 per mile (NZ$1,070 per km) for both shoulders (Tye 1988).

As at 1994, use of profiled thermoplastic rumble strip edge lines was very limited in New Zealand, and was mainly in the Auckland area. Prices were understood to be of the order of NZ$1,500 per km for each edge line.

6.3 Service Life of Rumble Strips

Only a limited number of reports are available on the service life of rumble strips installed on the carriageway. One early trial installation, incorporating coarse aggregate design with asphaltic bonding, experienced significant chip loss which necessitated considerable maintenance and periodic patching (Owens 1967). In comparison, another early trial utilising ¾" (19 mm) chips bedded in asphalt and held in place with polyester resin performed well, with no chip loss evident one year later. Chip loss was observed only in those rumble strips where no resin was applied (Kermit 1968).

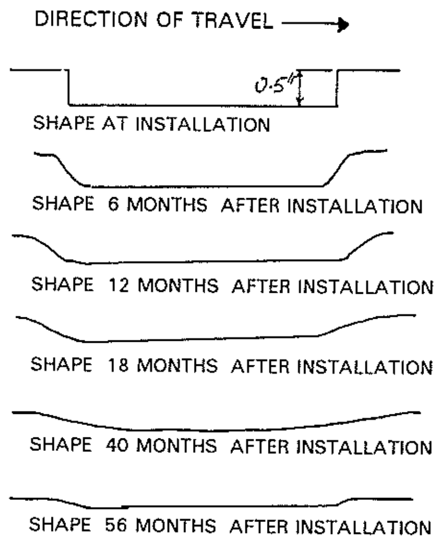
Sumner & Shippey (1977) report that three years is the effective life of a coarse aggregate rumble strip installation, after which extensive repairs or relaying is necessary. This service life has been confirmed recently at similar coarse aggregate trial installations (Webster & Layfield 1993).

Ceramic markers placed to form a rumble strip on the carriageway have not performed well with about 75% needing replacement every six months. Plastic rumble bars used at other locations during the trial had a similar maintenance history with 50% of the bars missing after six months. Both ceramic markers and plastic rumble bars were eventually replaced by 4" (100 mm) round white plastic markers. These provided a much longer service life and substantially eliminated most of the maintenance problems (Cynecki et al. 1993). One US toll road authority reported a service life of about five years for rumble strips on asphalt pavement on the carriageway approaching toll plazas (Harwood 1993).

For raised bar rumble strips, US highway agencies reported the need for periodic maintenance to build them up because they had worn down. Similarly, grooved rumble strips tend to wear at the edges of the grooves and the grooves tend to close up gradually over time, especially in asphalt pavements. Not unexpectedly the rate of wear of grooved rumble strips is affected by traffic volume (Harwood 1993). Figure 6.1 shows a characteristic wear pattern for a grooved rumble strip in an asphalt pavement. A similar wear pattern was predicted for grooved asphalt in Transit New Zealand Research Project PR3-0053 "Restoration of Skid Resistance" (Dravitzki 1995).

The service life of thermoplastic rumble strips is approximately four years, although their durability may be reduced if the ambient temperature during installation is above 25°C or below 5°C (Webster & Layfield 1993).

Figure 6.1 Change in shape over time of rumble strip grooves in asphaltic concrete (from Harwood 1993).



Because shoulder rumble strips are not subjected to continuous traffic wear, they are believed to perform adequately until the shoulder requires resurfacing. Those made of thermoplastic may need local repair where road curvature induces localised crossing of the edge line.

6.4 Other Maintenance

Concerns were expressed in the literature that grooved rumble strips would fill with silt and debris over a period of time and thus become less effective.

7. APPLICABILITY OF REVIEW FINDINGS TO NEW ZEALAND ROADS

Information from the technical literature on rumble strips in countries other than New Zealand generally applies to rumble strips being used over low textured pavement surfaces such as asphaltic concrete or concrete. This information is directly applicable to the low textured road surfaces used on New Zealand highways, namely asphaltic concrete and friction course. However, not all the information is relevant to the chipseal surfaces more commonly used in this country.

7.1 Use of Rumble Strips on Chipseal Surfaces

Techniques for forming rumble strips that involve grooving are unsuitable for chipseal because they would irreparably damage the surface.

From the literature it appears desirable that the rumble strip should provide a noise increase of about 6 dBA. As coarse chipseals produce road noise of around 2 dBA greater than that produced by fine chipseals (Barnes et al. 1994), the scope to produce additional noise by increasing the chip size used in strips of coarse aggregate or an overlay of coarse aggregate is limited. Because of this the suitability for chipseal of rumble strips formed using strips of coarse aggregate or an overlay of coarse aggregate is uncertain.

Also rumble strips formed from coarse aggregate, even on low textured pavements, are not desirable because the road maintenance philosophy in New Zealand involves patch repair of road surfaces. Thus the rumble strip could be confused with a repaired area. As changes in the visual appearance of the road surface are already accepted by drivers, such a rumble strip would not be identified visually as being different from a repaired area.

7.2 Environmental Noise Issues

One local issue that needs to be addressed is that of the external noise level. Transit New Zealand's draft guideline (dated 1994) indicates the use of a variable requirement rather than a single upper maximum. The requirement is based on the existing ambient sound level plus a margin which decreases as the ambient sound level increases. A 12 dBA margin is allowed for quiet areas. The effective permitted noise levels are a band from 55 dBA to about 70 dBA. These permitted levels may well restrict the use of rumble strips to a greater extent than the noise levels permitted in other countries.

7.3 Use of Raised Pavement Markers

The literature refers to the use of rumble strips on the carriageway consisting of raised pavement markers either in lines or as an array. This technique could be well suited to New Zealand roads where raised pavement markers are already extensively used for lane delineation on all road surface types. These pavement markers in effect act as longitudinal rumble strips. The literature also indicates that their limitation appears to be a high failure rate, with reports of up to 75% failing within six months. While the nature of the adhesive used for the markers is not stated, it is likely to be an epoxy adhesive. New Zealand experience is that good adhesion is achieved using thermoplastic-bituminous adhesives with which a higher retention rate could be reasonably expected.

The increase in noise levels provided by the raised pavement markers is not known, but they are know to provide sufficient visual and tactile stimuli. When used to form a rumble strip on the carriageway, use of an alternative colour to white (e.g. yellow) may be desirable to avoid any possible confusion with their normal longitudinal use as lane delineators.

7.4 Use of Thermoplastic Strips

An alternative successful treatment for rumble strips on the carriageway is likely to be the use of thermoplastic strip. In the UK these strips are used at thicknesses of about 12 mm, usually applied as a double application to give the desired slightly humped shape. In New Zealand, trials of thermoplastics applied as transverse strips over chipseals have demonstrated that they can achieve a life of up to four years under traffic volumes of about 10,000 vehicles per day.

If a thicker strip was used to produce a rumble effect, it could reasonably be expected to have at least as long a life. However performance will be dependent on the thermoplastic formulation used. The trials showed that some formulations have a tendency to flow and flatten under traffic loads, while others flaked in large sections from the road surface. Trials would be needed to establish optimum thicknesses on chipseal for noise and tactile effects. Their visual attributes have already been established as they have been used for lane delineation. Use could alternatively be made of thermosetting resin mixes. (Two part trowel-applied systems are already in use for intersection markings.)

7.5 Use of Rumble Strips on Road Shoulders

Rumble areas on the road shoulder are unsuitable for the narrow shoulders of many New Zealand roads. However, use could be made of raised pavement markers (commonly used in New Zealand for lane delineation) or discrete mounds of thermoplastic material (as used in Australia) to produce an edge line. An advantage over paint markings is that rumble strips for road edge delineation would provide discouragement to drivers from drifting over the edge line at corners. Their use would protect the shoulder and edge line from wear as well as provide increased safety for cyclists within the narrow shoulder area.

Use of a continuous thermoplastic edge line would have little acoustic or vibratory effect and would interfere with pavement drainage. The textured thermoplastic strip type, as shown in Figure 3.1(f), would probably be difficult to apply to a chipseal surface and there could be maintenance problems (P.T. Cairney, 1993, pers. comm.).

8. CONCLUSIONS

8.1 Rumble Strips for Carriageways

Although some preliminary conclusions can be drawn from the literature, further research is needed before the usefulness of rumble strips on New Zealand roads can be fully assessed.

The literature suggests that rumble strips used on the carriageway are an effective way of alerting drivers (attention conspicuity) to a road hazard, but much of the evidence does not have a sound statistical basis and many of the conclusions drawn in the literature are made without comparison to data obtained from control sites without rumble strips.

While there is evidence which points to the effectiveness of rumble strips in accident reduction at trouble spots on the road, and in increasing driver compliance with stop signs or traffic lights, the available evidence indicates that they are only partially effective in encouraging drivers to slow down.

A clear message provided in the literature is that rumble strips on the carriageway should be used with signage to ensure that the driver can identify the type of hazard to which he/she has been alerted (search conspicuity). A second clear message provided is that, if used, rumble strips should not be over-used as the rarity with which they are encountered adds significantly to their effectiveness in alerting drivers.

A general conclusion drawn is that rumble strips on the carriageway should only be used at well documented accident sites. They should be used only as a supplement to other methods of warning where those methods, e.g. adequate signage or bells at a railway crossing, have proved to be inadequate.

The literature notes a number of alternative designs of rumble strips in terms of their positioning ahead of a road hazard. The conclusion drawn is that there is no one preferred design available that assists in the siting of rumble strips to optimise their effectiveness.

Rumble strips consisting of strips of coarse aggregate or an area of coarse aggregate overlay are unlikely to be effective in New Zealand because (coarse) chipseal is commonly used and because the patch repair philosophy is applied to road maintenance. Rumble strips consisting of an array of raised pavement markers or discrete sections of thermoplastic strip are the type of rumble strip most likely to have general applicability on New Zealand roads.

Some experimentation with the thermoplastic formulation used to achieve long-term effectiveness for the (high built) thermoplastic strip would be needed. The high failure rate of raised pavement markers reported in the international literature is unlikely to be a problem in New Zealand given that such markers (fixed in place with a thermoplastic-bituminous adhesive rather than epoxy resin as used overseas) have a good long-term track record where used as lane delineators.

The environmental noise produced by rumble strips needs to be addressed in the terms of Transit New Zealand's noise guidelines.

8.2 Rumble Strips for Road Shoulders

In contrast to the variable evidence for the effectiveness of rumble strips on the carriageway, the literature clearly points to the effectiveness of longitudinal rumble strips to define the road shoulder. A reduction of 20%-50% in run-off-the-road accidents is reported in the literature and backed by thorough statistical analysis.

Rumble strips suitable for road shoulders in New Zealand are the types that can be incorporated as part of the road edge delineation.

The use of raised pavement markers as lane delineators is fairly common in New Zealand, but they are not commonly used to delineate the edge of the roadway. Adverse environmental noise considerations or over-use of rumble strips used for road edge delineation are less of a concern because the noise effect of running over the rumble strips will be produced only by those vehicles that stray off the roadway.

Rumble strips consisting of a line of discrete mounds of a high built (typically 12 mm) thermoplastic strip or raised pavement markers are considered to be more suitable than shoulder rumble areas that extend to the outside edge of the road shoulder. The latter may impede cyclists using the road shoulder and can result in channelling of rainwater which may result in erosion of roadside slopes. Use of rumble strips for road edge delineation would also reduce wear of the road edge delineation and of the road shoulder itself.

8.3 Public Information Programme

Motorists may need to be educated about the purpose of rumble strips. Some motorists, after traversing a rumble strip installation on the carriageway, have been observed to stop and check their vehicle, while others have complained of imperfections in the pavement surface.

8.4 Future Research

While the indications are that rumble strips do have beneficial effects, guidelines need to be prepared to minimise their adverse effects. To assist in the development of these guidelines for use of rumble strips both for carriageways and for road edge delineation, research is needed.

The following studies are recommended for future research:

- Establish the rumble strip designs that provide the desired levels of increased noise, vibration and visual intrusion on the coarse chipseal surfaces used on New Zealand roads.

- Determine that the external noise levels will be within Transit New Zealand's guidelines on road noise.

- Determine the minimum distance for placing a rumble strip from the nearest residence.

- Monitor the extent that rumble strips can be applied without over-use, and to ensure that driver safety is not compromised.

- Evaluate the durability of high build thermoplastic strips (on chipseal roads in particular), the optimum thermoplastic formulation, the thickness to use, and their layout pattern.

- Establish that rumble strips do not cause loss of control for cyclists (and possibly motorcyclists) using the road.

- Instal trials at accident black spots on carriageways where treatments such as cleared lines of sight or additional signage have not been effective, to research their effectiveness, evidenced by changes in driver behaviour and accident reduction, based on statistically rigorous before and after studies.

- Undertake public education and/or appropriate signage to accompany any installations of rumble strips on the carriageway to minimise driver confusion.

- Determine usefulness of textured thermoplastic lines, discrete mounds of thermoplastic, or raised pavement markers as these are much less commonly used in New Zealand for lane delineation than overseas.

- Assess effectiveness of road edge delineation strips for providing guidance to motorists who stray off the edge of the road, at sites where run-off-the-road accidents have frequently occurred.

- Establish effectiveness of temporary rumble strips at road work sites. While their effectiveness in reducing vehicle speed at road works is not supported by statistical data, they do appear to have had a beneficial effect in alerting drivers to lane changes and creating an awareness that unusual conditions lie ahead.

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