THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR995

Relationship between texture depth and collision risk on the Strategic Road Network

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Report details

Report prepared for:	Highways England		
Project/customer reference:	SPaTS 1-407		
Copyright:	© TRL Limited		
Report date:	30 April 2021		
Report status/version:	Issue 1		
Quality approval:			
Alison Kaminski (Project Manager)	Alison Kaminski	Martin Greene (Technical Reviewer)	Martin Greene

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Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1	30/04/21	Issued version	CW	MG

Document last saved on:	30/04/2021 10:37
Document last saved by:	Greene, M

Executive Summary

Road surface friction on the Strategic Road Network (SRN) is managed through the requirement to provide skid resistance and texture depth. The requirements have been in place since the 1980s and were previously reviewed prior to the 2004 update to the skid resistance standard (HD28/04) and reported by Parry and Viner (2005). Given the changes that have occurred in recent years to the SRN, including the introduction of Smart motorways and widespread adoption of negatively textured pavement surfacing materials, and to the vehicle fleet, for example anti-lock braking systems and electronic stability control systems are now widespread, a further review of the current approach was undertaken in 2016 and reported in TRL PPR806 (Wallbank et al, 2016).

The 2016 review focussed on the relationship between collision risk and skid resistance, and as part of this work a multivariate regression technique known as Generalised Linear Modelling was used to investigate the relationship between collisions and a number of variables including skid resistance and texture depth. The results showed that skid resistance was significant as an explanatory variable in most of the models for wet collisions, while texture depth appeared in all the models for all collisions with the exception of the gradients category. Thus, it appeared that, texture depth was not only associated with preventing vehicles skidding on wet roads, but may also be more generally associated with an increased road surface friction in all conditions.

The analysis may be confounded by the variety of surfacing types present on the SRN, since they have different properties, including different ranges of texture depth. Therefore to explore further the relationship between texture depth and collision risk, the surface type reported in Highways England's pavement management system (HAPMS) was added to the database that had been used in the work reported in TRL PPR806.

The methodology for the analysis followed that used by Wallbank et al (2016) with the collision risk characterised for different levels of texture depth within each of the site categories defined within HD28. The collision risk was assessed based on five categories, namely: "all collisions", "wet collisions", "wet-skid collisions", "dry collisions" and "dry-skid collisions".

The study focussed on the relationship between collision risk and in-service texture depth as measured by TRACs surveys, i.e. laser based measurements of Sensor Measured Texture Depth (SMTD). These measurements do not correlate directly to acceptance measurements of texture depth made at the time a surfacing is laid, such measurements being made using the volumetric approach. Information for as laid volumetric texture depths was not available for this study and therefore a link between initial and in-service texture depth cannot be made.

For the two materials that make up the majority of the non-event lengths on the SRN, i.e. Thin Surface Course Systems (TSCS) and Hot Rolled Asphalt (HRA):

- The collision rates are broadly similar in all, dry and wet conditions.
- There is a general trend for the all and dry collision rate to increase with decreasing texture depth. In the case of TSCS, the increase in collision risk tends to be more marked

at texture depths below 0.8mm. This finding is in broad agreement with that reported by Roe et al (1991).

- The trend for wet collisions is less strong with many cases where the relationship is quite flat at texture depths above 0.8mm. Although an increase in wet collision risk is generally seen for texture depths below 0.8mm the increase is not as great as for all or dry collisions. It therefore appears that the increase in collision risk at lower textures is associated with collisions in non-wet conditions. This finding is supported by the outcomes of the Generalised Linear Modelling reported by Wallbank et al. (2016) and in this report which indicate that texture depth is a stronger contributor to collision risk for all and dry collisions than for collisions in the wet.
- The proportion of skidding collisions, in both wet and dry conditions, does not increase as texture depth reduces. This finding and that the increase in collision risk at low texture depths is associated mainly with an increase in collisions in dry conditions, suggest that the increase is not associated with variations in friction. This assumption is supported by friction measurements that showed both locked wheel and peak friction values were consistent, and high, across a texture range from about 0.6mm to 1.4mm.

Concrete, as the material to make up the majority of the remainder of the non-event lengths on the SRN, generally has a texture depth of <0.8mm and therefore meaningful comparisons between concrete and TSCS/HRA at common texture depths are limited. However, the range of collision rates observed in all, dry and wet conditions for concrete is broadly similar to those for TSCS and HRA on motorways and non-event carriageways with one-way traffic.

Overall, the results of this investigation indicate that the current in-service condition category thresholds for texture depth defined in HD29/08 (DMRB 7.3.2) are still appropriate, with the potential exception of concrete. HD29 views texture <0.8mm as a concern for all materials types except High Friction Surfacings. However given that most of the concrete on the network has texture <0.8mm and this does not seem to result in higher risk than for TSCS or HRA above 0.8mm, there could be scope for a different threshold for concrete. However, any consideration of altering the threshold would need to consider other factors such as the influence of texture on skid resistance and high speed friction.

A lack of readily accessible as laid texture data for materials on the network meant it was not possible to establish if there is a link between initial volumetric texture depth and in service SMTD. Noting that > 55% of TSCS have texture depths in excess of 1.2 mm (HD29 condition category 1), it is not clear whether this is as a result of a high initial texture depth or is related to the ageing and deterioration of the surfacing by, for example, fretting. It is therefore recommended that this area is investigated further as there may be an opportunity to relax current as laid requirements for TSCS without compromising the in service levels of texture achieved. This could include reviewing how in service texture depths change with age for different proprietary TSCS and determining, where possible, how this relates to initial volumetric texture depths.

Given that the increase in collision risk at lower texture depths is associated mainly with collisions in dry conditions and that dry friction does not appear to vary with texture depth, further investigation is recommended to develop a better understanding of other factors that could be contributing to the increase in collision risk such as collision type, contributary factors or human factors. This understanding would then enable strategies to be developed to mitigate the increased risk.

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1 Introduction

Road surface friction on the Strategic Road Network (SRN) is managed through the requirement to provide skid resistance and texture depth. The requirements have been in place since the 1980s and were previously reviewed prior to the 2004 update to the skid resistance standard (HD28) and reported by Parry and Viner (2005). Given the changes that have occurred in recent years to the SRN, including the introduction of Smart motorways and widespread adoption of negatively textured pavement surfacing materials, and to the vehicle fleet, for example anti-lock braking systems and electronic stability control systems are now widespread, a further review of the current approach was undertaken in 2016 and reported in TRL PPR806 (Wallbank et al, 2016).

The 2016 review focussed on the relationship between collision risk and skid resistance, and as part of this work a multivariate regression technique known as Generalised Linear Modelling was used to investigate the relationship between collisions and a number of variables including skid resistance and texture depth. Models were developed for 'all collisions' and 'wet collisions', for each of the site categories by which skid resistance requirements are defined in HD28. While the models explain a rather low proportion of the overall variance in collision risk, skid resistance was found to be significant as an explanatory variable in most of the models for wet collisions. The results showed that texture depth appeared in all the models for all collisions with the exception of the gradients category.

Thus, it appeared that, texture depth was not only associated with preventing vehicles skidding on wet roads, but may also be more generally associated with an increased road surface friction in all conditions. Texture is needed on a pavement surfacing to maintain friction at high speed and a connection to collision risk has been observed in several studies. For example, Roe et al (1991) reported that "the texture level below which accident risk begins to increase is about 0.70mm sensor measured texture depth". However, high texture depth is undesirable in respect of tyre noise, rolling resistance (with user cost, air quality and carbon impacts) and durability (prevents reduction of void volume in specifications). As such there may be benefits in reducing the current texture requirements, although this cannot be at the expense of safety on the network.

The analysis may be confounded by the variety of surfacing types present on the SRN, since they have different properties, including different ranges of texture depth. Therefore to explore further the relationship between texture depth and collision risk, the surface type reported in Highways England's pavement management system (HAPMS) was added to the database that had been used in the work reported in TRL PPR806.

The methodology for the analysis followed that used by Wallbank et al (2016) with the collision risk characterised for different levels of texture depth within each of the site categories defined within HD28. The collision risk was assessed based on five categories, namely: "all collisions", "wet collisions", "wet-skid collisions", "dry collisions" and "dry-skid collisions".

2 Data sources

The following data sources have been used for this analysis:

- Stats19 (Collision data)
- HATRIS (Traffic data)
- HAPMS (Road network and condition data)

These are described in more detail below.

2.1 Collision data

The Stats19 database contains information on all reported collisions in Great Britain that involved injury. This includes details about the circumstances of the collision (including road, location and road surface condition) and the vehicles involved (including whether the vehicle skidded during the collision). The data include fatal, serious and slight collisions.

Data were extracted from Stats19 for all collisions on the Strategic Road Network (as defined using the 2010 network definition) between 2010 and 2013 inclusive (4 years). The following definitions were used for specific analyses:

- 'Dry collisions' were defined as: road surface condition = 1 'dry'
- 'Wet collisions' were defined as: road surface condition = 2 'wet/damp' (snow, frost/ice and flood are not included)
- 'All collisions' included dry, wet and other conditions such as flood, ice and snow
- 'Skidding collisions' were defined as: vehicle skidding = 1 'skidded', 2 'skidded and overturned', 3 'jack-knifed' or 4 'jack-knifed and overturned' (overturn alone was not included)

2.2 Traffic data

Highways England traffic data are stored in the HATRIS database. This includes average annual daily flows on each link of the SRN. A copy of the HATRIS database held at TRL was used to estimate the traffic on each section using data from 2010 to 2013; traffic was available for about 70% of the sections. Sections with no traffic data were excluded from the analysis since the collision rate cannot be calculated.

2.3 Road network data

Highways England's HAPMS database contains contextual information for each section, to allow analysis by environmental factors such as rural or urban, geometric factors such as radius of curvature, gradient and crossfall, and speed limit.

2.4 Road condition data

Pavement condition data were extracted from routine machine surveys stored in HAPMS, particularly skidding resistance by site category. Depending on site category, the road network is stored in 10m, 50m or 100m sections, with each section being surveyed to measure skid resistance once per year between 2010 and 2013[1]. Surface texture (SMTD) and rut depth were downloaded for each 100m length for the same period.

2.5 Surface type data

Data on the material type used in the surface layer were extracted from HAPMS construction tables. As with the condition data, this was limited to Lane 1 of each carriageway, in each direction. This represents a limitation of the analysis since the carriageway surface type and condition is not necessarily uniform across its width.

2.6 Aggregation of data

The network used in this analysis was defined by combining data into sub-sections of predetermined lengths within the ten site categories defined in HD28/15 (DMRB 7.3.1); A, B, C, Q, K, R, G1, G2, S1 and S2. The preferred lengths were selected to be 500m for motorways and 200m for all other roads; this aligns with the methodology used in the previous studies (Parry & Viner, 2005) and (Wallbank et al, 2016). However, categories Q (approaches to junctions and traffic signals) and K (approaches to pedestrian crossings) are generally used for the 50m approach to those features, therefore the typical length for analysis of these categories is shorter.

Data were combined (across all four years) from the different data sets to give the following data for each section[2] on the network:

- Length
- Annual Average Daily Traffic (AADT)
- Number of collisions
- Number of wet collisions
- Number of wet skid collisions
- Site category (consistent for each analysis length)
- Average skid resistance
- Average rut depth
- Average texture depth
- Average crossfall
- Maximum gradient
- Tightest radius

[1] 2013 data were the most recent available at the time of the study reported in TRL PPR806.

[2] For two-way roads, each direction was treated separately in the analysis.

3 Initial analysis – all surfacings

An initial analysis was undertaken that included all surface types on the SRN. For this initial analysis, the sub-sections were grouped based on the texture depth (SMTD) data into six bands with boundaries that corresponded approximately to the threshold levels given in HD29/08 (DMRB 7.3.2). The bands were defined as:

i. < 0.4 mm (HD29 category 4)

ii. ≥ 0.4 mm and < 0.8 mm (category 3)

iii. ≥ 0.8 mm and < 1.2 mm (approximately category 2 but note that HD29 threshold is 1.1mm)

iv. ≥ 1.2 mm and < 1.6 mm (band iv and above all correspond to category 1)

v. ≥ 1.6mm and < 2.0 mm

vi. ≥2.0 mm

3.1 Data available

The numbers of sub-sections and collisions within the dataset that fell within each of the six bands of texture depth are presented in Table 1 and Table 2 respectively.

Table 1: Number of sub-sections included within the analysis

Texture depth band	Number of sub-sections	Percentage of total
i (<0.4 mm)	65	0.1%
ii (0.4 - 0.8 mm)	2,923	6.5%
iii (0.8 - 1.2 mm)	14,359	31.9%
iv (1.2 - 1.6 mm)	18,393	40.9%
v (1.6 - 2.0 mm)	7,547	16.8%
vi (> 2.0 mm)	1,666	3.7%
Total	**44,953**	**100%**

The majority of sub-sections fell in the range 0.8 to 1.6mm (bands iii & iv), with only 6.6% of the sub-sections having texture depths of <0.8mm. Due to the very limited data for texture band i, most of the site categories did not contain any data within the band and consequently results for texture depths <0.4 mm are omitted from the analysis. About 20% of the sub-sections had texture depths greater than or equal to 1.6mm.

Table 2: Number of collisions included within the analysis

Texture depth band	Number of collisions				
	All	Dry	Dry Skid	Wet	Wet Skid
i (<0.4 mm)	23	18	6	4	2
ii (0.4 - 0.8 mm)	1,530	1,032	288	442	167
iii (0.8 - 1.2 mm)	7,701	5,255	1,658	2,121	957
iv (1.2 - 1.6 mm)	8,845	5,773	1,953	2,643	1,230
v (1.6 - 2.0 mm)	3,009	1,882	645	937	428
vi (> 2.0 mm)	560	333	120	187	89
Total	**21,669**	**14,293**	**4,670**	**6,334**	**2,873**
Proportion of all	**100.0%**	**66.0%**	**21.6%**	**29.2%**	**13.3%**

Approximately two thirds of all collisions (66%) took place in dry conditions and just under one third (29%) in wet conditions. 5% of collisions recorded took place in other conditions such as flood, ice and snow. The data from Table 2 also indicate that skidding is more likely in wet conditions: 45% of wet collisions involved skidding but only 33% of dry collisions did.

Further analysis presented in Figure 1 and Figure 2 shows that the proportion of collisions involving skidding, in either wet or dry conditions, did not increase on low-textured roads surfaced with Thin Surface Course Systems (TSCS) or Hot Rolled Asphalt (HRA); if anything, the trend may indicate a slight decrease. Similarly, the analysis also showed that the proportion of collisions in wet conditions appears to decrease rather than increase on low-textured roads with these surface types.

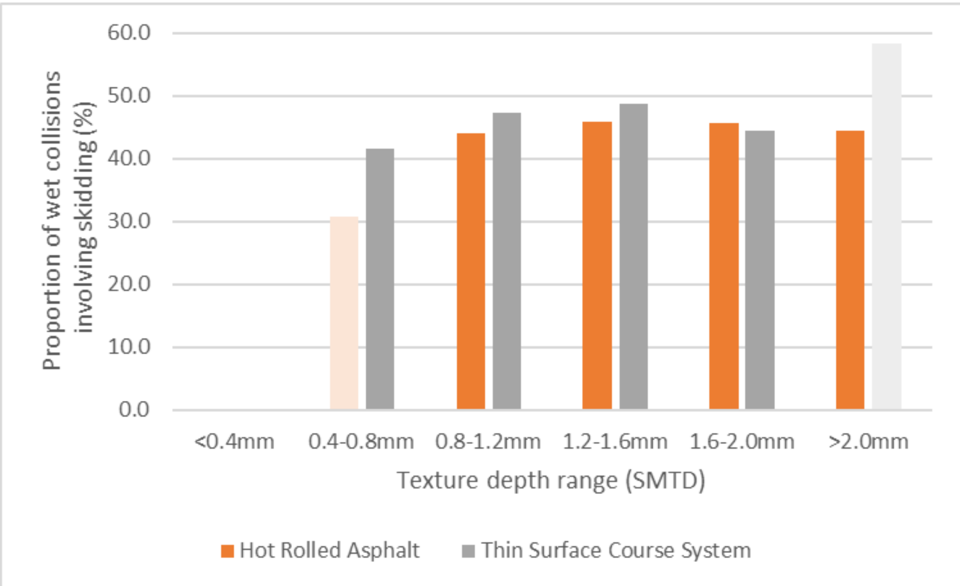

Figure 1 Proportion of collisions in the wet that involve skidding
(Note: lighter shading indicates analysis based on <100 collisions)

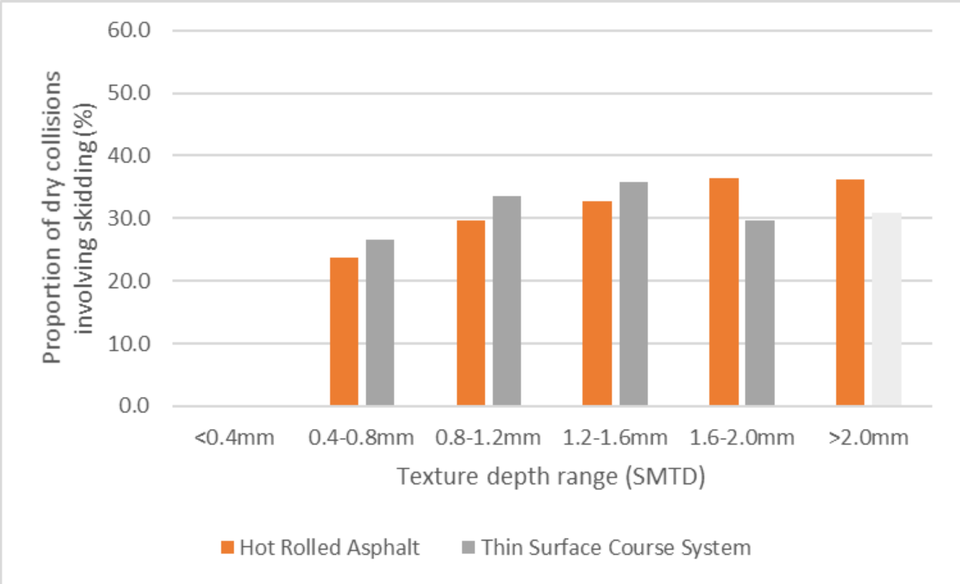

Figure 2 Proportion of collisions in the dry that involve skidding
(Note: lighter shading indicates analysis based on <100 collisions)

Table 3 shows the number of sub-sections within the dataset that were assigned to each of the site categories defined in HD28/15 (DMRB 7.3.1). No data were available for roundabouts as the TRACS survey does not include roundabouts and so no texture data were available. Also, due to the small amount of data available for categories K and Q it was decided to merge these categories in the subsequent analysis as both categories cover similar situations (vehicles braking on the approach to a feature). Similarly categories G1 and G2, and categories S1 and S2, were also merged into G and S categories respectively.

Table 3: Number of sub-sections within each HD28/15 site category

Site category		Number of sub-sections	Percentage of total
A	Motorway	9,916	22.1%
B	Non-event carriageway with one-way traffic	19,064	42.4%
C	Non-event carriageway with two-way traffic	9,023	20.1%
Q	Approaches to and across minor and major junctions, approaches to roundabouts and traffic signals	3,967	8.8%
K	Approaches to pedestrian crossings and other high risk situations	108	0.2%
R	Roundabout	0	0%
G1	Bend radius <500m – carriageway with one-way traffic	1,037	2.3%
G2	Bend radius <500m – carriageway with two-way traffic	23	0.1%
S1	Gradient 5-10% longer than 50m	606	1.3%
S2	Gradient ≥10% longer than 50m	1,209	2.7%
Total		**44,953**	**100%**

3.2 Collision risk by site category and accident condition

Figure 3 shows the results of the initial analysis and presents a graph for each of the site categories showing the relationship between collision risk (collisions per 100 million vehicle km) and texture depth. The analysis covered all collisions (all), collisions in the wet (wet), collisions in the dry (dry) and collisions in the wet and dry where one or more vehicles skidded (wet skid and dry skid respectively).

Note that for each texture band, the data point on the chart is placed at the mid-point for that band; for example, for textures 0.8 to 1.2 mm, the data point is at 1.0 mm.

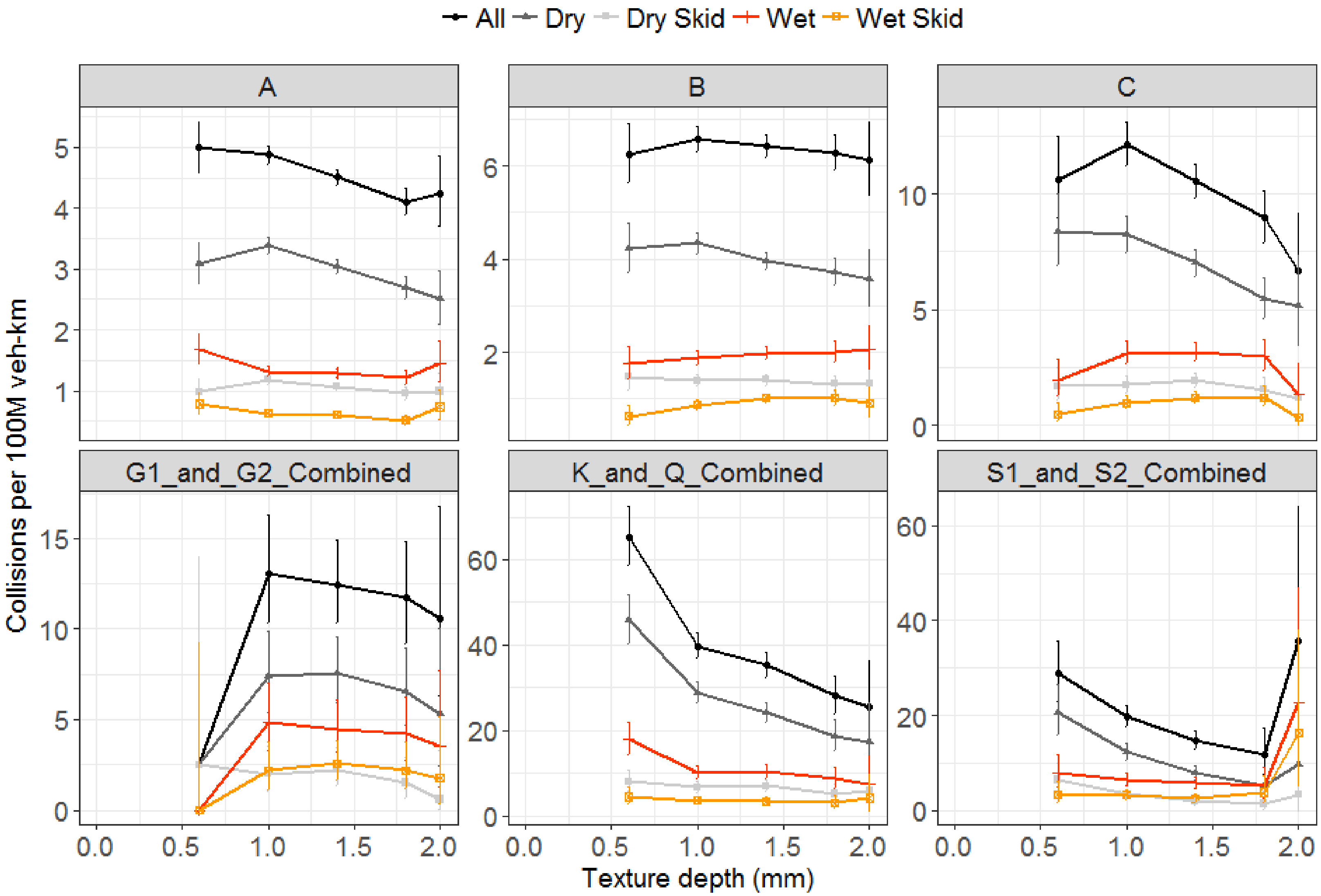

Figure 3: Collision risk against texture depth for each site category

3.2.1 All collisions

For texture depths of 0.8mm and above, all site categories show a decrease in collision risk with increasing texture depth. This trend appears strong for site categories A, C, K/Q and S1/S2; less so for B and G1/G2 (a line showing an increase in collision risk with increasing texture depth could be plotted within the limits of the error bars for B and G1/G2). Whilst the uppermost data point (>2.0 mm) appears variously above and below this trend, the error bars are large owing to the relatively small amount of data.

For categories B, C and G1/G2, the data point for 0.4 - 0.8 mm falls below the trend; for the other site categories (A, K/Q and S1/S2) it is consistent with it.

3.2.2 Wet and wet skid collisions

For texture depths of 0.8mm and above, the trends for wet and wet skid collisions are broadly flat for all site categories. Again, whilst the uppermost data point (>2.0 mm) appears variously above and below this trend, the error bars are large owing to the relatively small amount of data.

For category A and K/Q the rate of wet collisions for 0.4 - 0.8 mm is higher than for 0.8 mm and above. For categories B, C, and G1/G2 this band is associated with a lower risk of wet collisions, whereas for S1/S2 it is similar.

3.2.3 Dry collisions

The collision rate for dry collisions follows similar trends to all collisions.

For texture depths of 0.8mm to 2.0mm, all site categories show a decrease in collision risk with increasing texture depth. This trend appears strong for site categories A, B, C, K/Q and S1/S2, less so for G1/G2 (a line showing an increase in collision risk with increasing texture depth could be plotted within the limits of the error bars for G1/G2). The uppermost data point (> 2.0 mm) appears variously above (S1/S2) or below (all other site categories) trend with large error bars owing to the relatively small amount of data.

For site categories A, B, G1/G2, the data point for 0.4 - 0.8 mm falls below the trend with relatively large error bars; for the other site categories (C, K/Q and S1/S2) it is consistent with trend.

3.2.4 Dry skid collisions

The collision rate for dry skid collisions is relatively flat across all texture depths for all site categories.

3.2.5 Discussion

The results for wet and wet skid collisions are somewhat surprising given that the role texture depth is normally associated with is helping to remove water from the tyre-road contact patch, particularly at higher speeds. However, the results are consistent with the models reported in PPR806 (Wallbank et al, 2016) where texture did not appear strongly in the explanatory variables for wet collisions, as well as with earlier work (Roe et al., 1991). This implies that texture above 0.8 mm has no influence on collision risk in wet conditions. Possible explanations for this apparent lack of influence could include:

- The tread depth present on real vehicles - previous work has shown that texture depth has a lower effect on locked wheel friction when ribbed test tyres are used compared to smooth tyres. Also, Brittain and Greene (2007) demonstrated that the texture depth of a surfacing and tread depth of a tyre were somewhat interchangeable.
- An increase in the proportion of the vehicle fleet fitted with anti-lock braking systems (ABS) and Electronic Stability Control (ESC) – these systems maintain friction levels close to peak friction during braking and manoeuvring. Measurements have shown that peak friction with smooth tyres is less influenced by texture than locked-wheel friction, and peak friction with ribbed tyres even less so.

It is therefore possible that current 'worst case' measurements of wet friction have become unduly pessimistic given modern braking systems combined with non-zero tread depth.

The results for dry conditions imply that texture depths above 0.8 mm do have an influence on collision risk in dry conditions but not in cases of dry skid collisions. The trends observed for all collisions appear to be driven by those of dry collisions. These results are consistent with the models reported in PPR806 where texture did appear strongly in the explanatory variables for all collisions except those on gradients (G1/G2). As friction in dry conditions is generally assumed to be uniformly high, these results suggest that the influence of texture depth on collision risk may not be the result of variations in friction; this is explored further in Section 6.

3.2.6 Surface type

Some of the trends seen in the analysis may be linked to the different texture ranges associated with different surfacing material types. Typically concrete would have texture in the 0.4 – 0.8mm range (band ii), High Friction Surfacings (HFS) would fall in the 0.4 – 1.2mm range (band ii and iii), while texture depths for Thin Surface Course Systems (TSCS) are generally higher with Hot Rolled Asphalt (HRA) being higher again. Since it is very unlikely that there would be any HFS on motorways (category A), some of the trends seen at lower texture depths may be influenced by the presence of concrete surfacings.

To explore this possibility further, additional analyses were undertaken to investigate the relationship between accident risk and texture depth for each of the main surfacing types. These are presented and discussed at Section 4.

3.2.7 Collision type

The relationship of accident severity and road user involved with texture band was analysed to investigate whether similar collision types were happening at each texture depth or whether any variation could help explain the trends observed. This analysis is documented in Appendix A.

The proportion of collisions classified as fatal or serious was found to be relatively consistent across all texture bands. The proportion of collisions involving each road user type was also found to be relatively consistent across the texture bands.

4 Analysis of individual surfacing types

Information on surfacing type was extracted from HAPMS and incorporated into the database compiled for the initial analysis reported in section 3.

The surfacings were grouped into five material types, namely:

- Thin Surface Course Systems (TSCS)
- Hot Rolled Asphalt (HRA)
- Concrete
- High Friction Surfacing (HFS)
- Other

Note that the "other" category included materials that would not usually be permitted as a surfacing, for example DBM, as well as other surfacing materials such as surface dressing which are rare on the SRN. For this reason, no analysis of the data in this category was undertaken.

Where more than one surfacing type was linked with a sub-section in the database, the sub-section was assigned a material type only where 80% or more of the length was of a single surfacing material.

A visualisation of the distribution of texture depth and its probability density for each surface type is shown in Figure 4 in the form of a 'violin plot'. The width of the plotted shape for each surface type indicates the frequency of each texture depth.

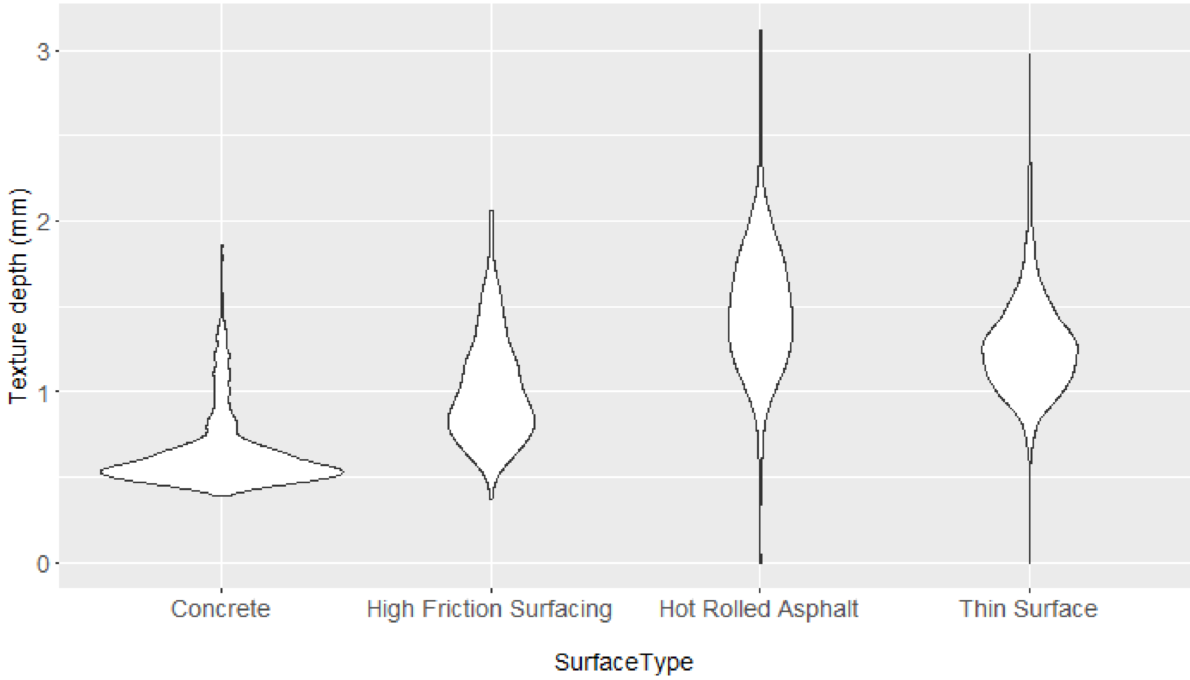

Figure 4: Distribution of texture depths for each surface type

As expected, the majority of concrete sections have a texture depth in the 0.4 – 0.8mm range, the HFS sections fall mainly in the 0.4 – 1.5mm range (some of the higher texture values are likely to be associated with deterioration of the HFS and exposure of the underlying material), while texture depths for TSCS are generally higher with HRA being higher again.

Given the nature of these distributions, revised texture bands for each surface type were defined for this individual analysis. Texture bands of size 0.4mm were used to analyse the HRA and TSCS sections whilst concrete and HFS were analysed in 0.1mm and 0.2mm bands respectively. The defined texture bands are shown in Table 4.

Table 4: Surface-specific texture band definitions

Texture Band	TSCS and HRA	Concrete	HFS
i	≥0 and <0.8 (‘0.4’)	≥0 and <0.5 (‘0.25’)	≥0 and <0.8 (‘0.4’)
ii	≥0.8 and <1.2 (‘1.0’)	≥0.5 and <0.6 (‘0.55’)	≥0.8 and <1.0 (‘0.9’)
iii	≥1.2 and <1.6 (‘1.4’)	≥0.6 and <0.7 (‘0.65’)	≥1.0 and <1.2 (‘1.1’)
iv	≥1.6 and <2.0 (‘1.8’)	≥0.7 and <0.8 (‘0.75’)	≥1.2 and <1.4 (‘1.3’)
v	≥2.0 (‘2.0’)	≥0.8 (‘0.8’)	≥1.4 (‘1.4’)

A summary of the number of sub-sections within each surface-specific texture band is provided in Table 5.

Table 5: Summary of sub-sections included within the analysis for each surfacing type in each surface-specific texture band

Texture band	TSCS		HRA		Concrete		HFS	
	No.	%	No.	%	No.	%	No.	%
i	447	2.6%	399	2.2%	260	19.8%	164	28.2%
ii	6,908	41.4%	3,605	20.1%	514	39.2%	160	27.5%
iii	7,611	45.6%	7,583	42.3%	251	19.1%	116	19.9%
iv	1,394	8.4%	5,182	28.9%	80	6.1%	69	11.9%
v	318	1.9%	1,177	6.6%	206	15.7%	73	12.5%
Total	**16,678**	**100%**	**17,946**	**100%**	**1311**	**100%**	**582**	**100%**

Some of the material types had only a small number of sub-sections within a given site category and in these cases the results of the analysis are not presented due to the uncertainty associated with the use of small amounts of data.

4.1 All site categories

Initially looking across all site categories, Figure 5 shows the collision risk with respect to texture depth for each surface type.

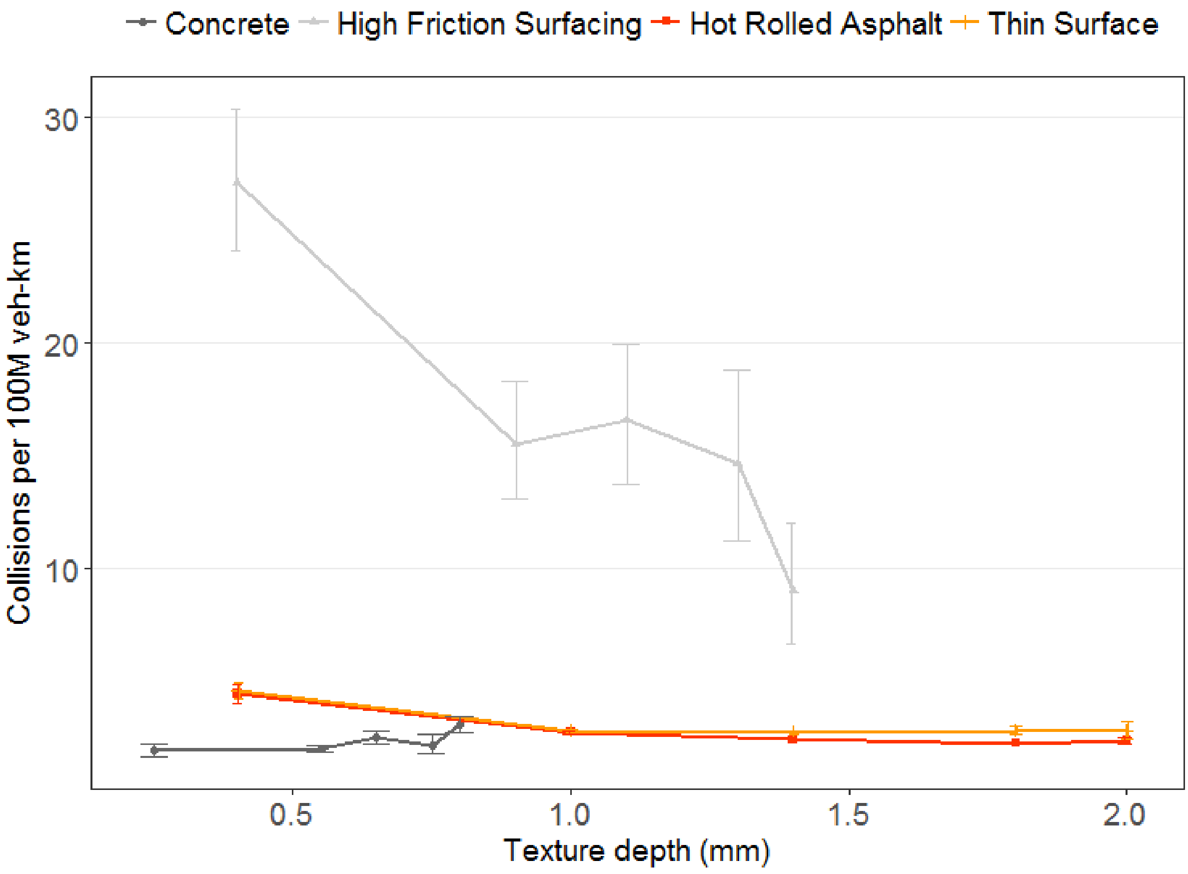

Figure 5: Collision risk against texture depth by surface type

The collision risk for HFS is clearly significantly higher than that for the other surfaces and shows a notable decrease, reducing by two thirds from 27 to 9 collisions per 100M veh-km between its lowest to highest texture band. In contrast the collision risk for concrete actually slightly increases across the texture bands from 1.9 to 3.1 collisions per 100M veh-km and any decreasing trend for HRA and TSCS is less pronounced, with the collision risk reducing by approximately one half and just over one third respectively between the lowest and highest texture bands for each material.

Figure 6 shows the collision risk against texture depth by both surface type and accident condition.

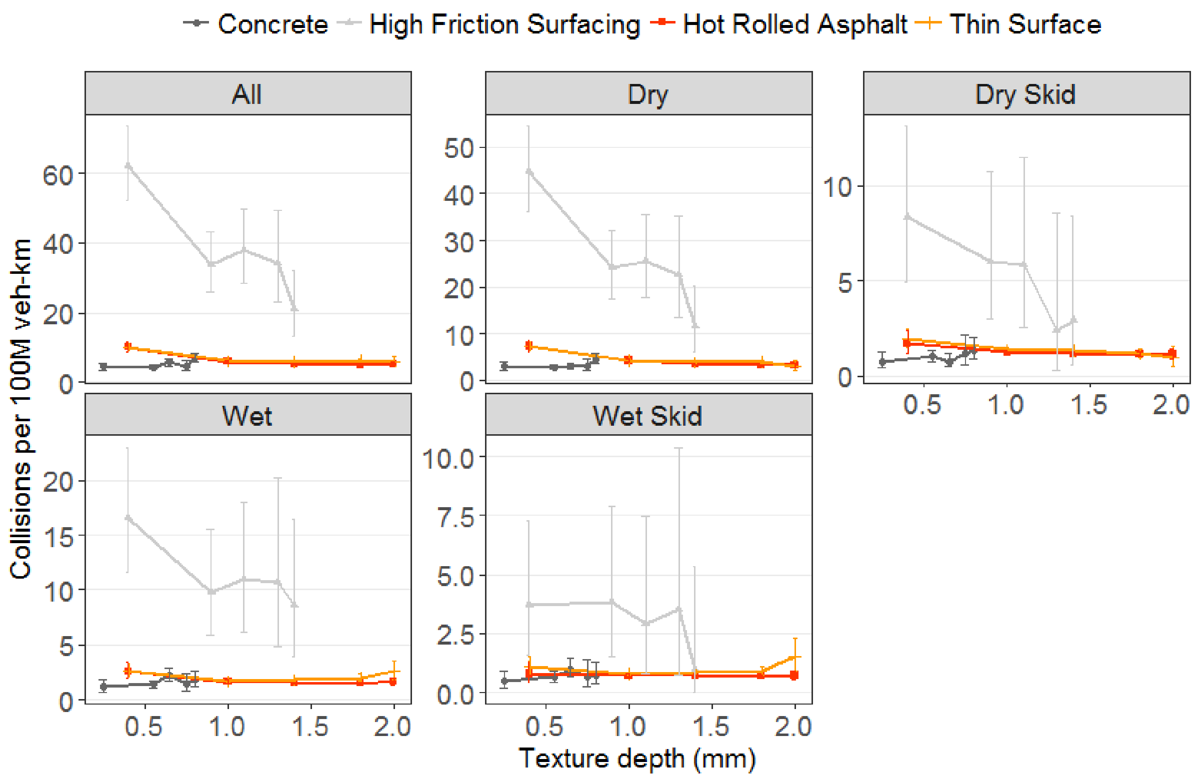

Figure 6: Collision risk against texture depth by surface type and accident condition

For HFS, there remains a significant decrease in collision risk between the lowest and highest texture bands in all, dry and dry skid conditions although in the case of dry skid, an increase in collision risk with increasing texture band could be plotted within the limits of the error bars. Any decreasing trend is less pronounced for wet and wet skid conditions and could also be on an upward trend within the limits of the error bars.

Differences between the trends for the different conditions are less pronounced for concrete, HRA and TSCS. However, the variation in collision risk between low and high texture bands is generally smaller in the cases of wet and wet skid conditions than in those of all, dry and dry skid conditions.

An analysis by surface type and site category is provided in sections 4.2 to 4.5. To enable the error bars for each accident condition to be visible on the graphs in these sections, the positions of the error bars for each texture band have been very slightly adjusted along the horizontal axis so that they do not overlap. The positions of the error bars on the vertical axis remain exactly as calculated.

4.2 Thin Surface Course Systems

4.2.1 Non-event lengths

Figure 7 to Figure 9 show the relationship between collision rates (per 10^6veh-km) and texture depth for non-event sites (A, B and C) surfaced with TSCS respectively.

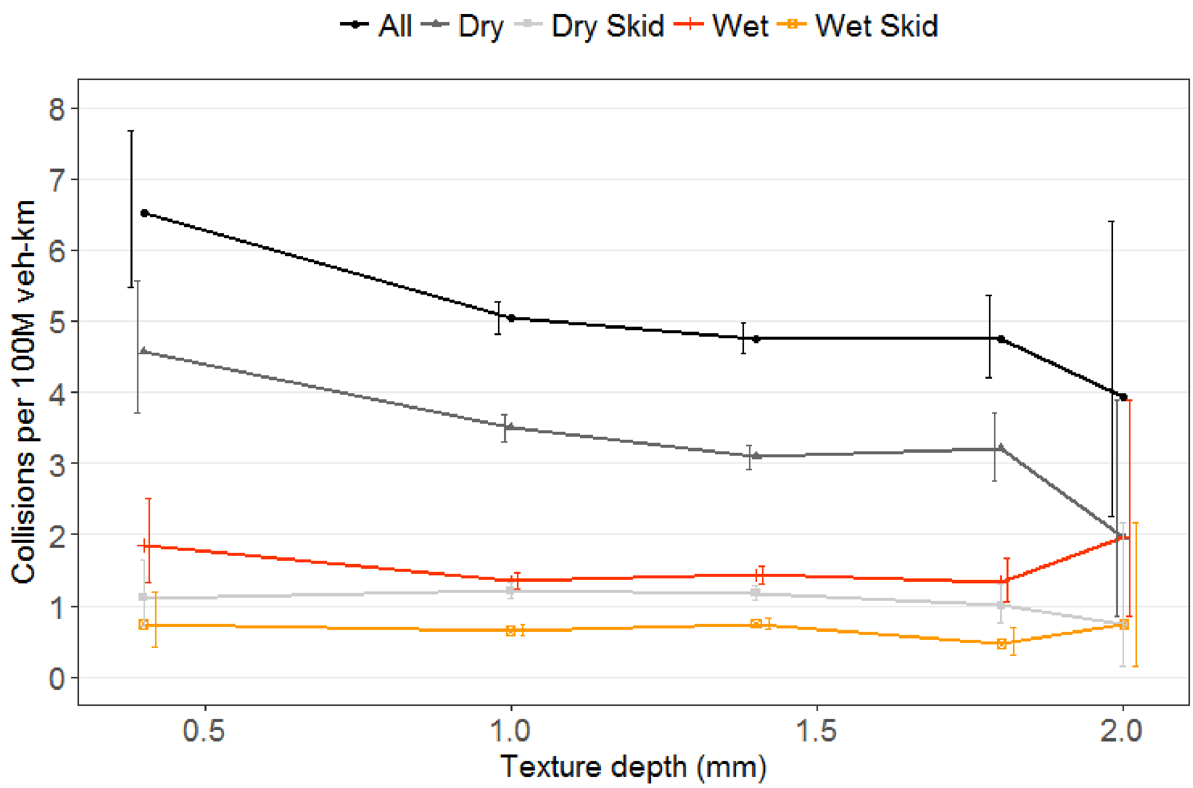

Figure 7: Collision risk against texture depth for motorways (site category A) surfaced with TSCS

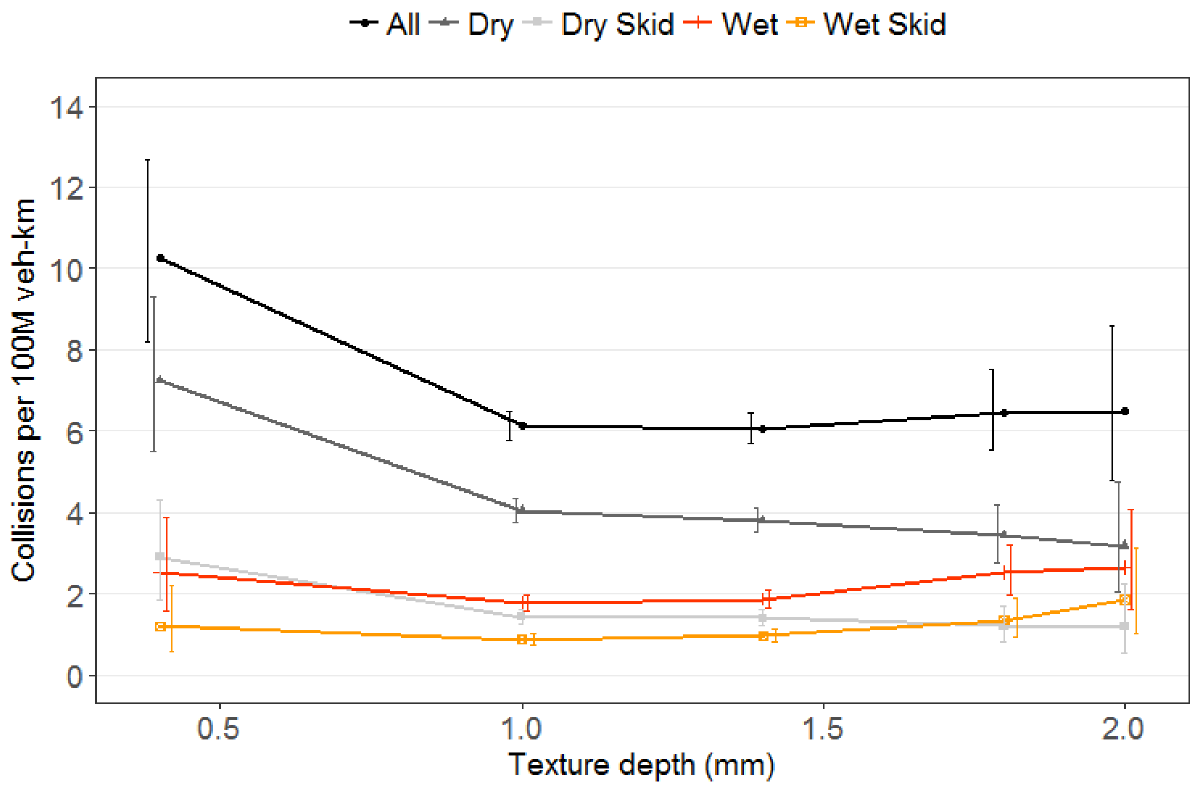

Figure 8: Collision risk against texture depth for non-event carriageways with one-way traffic (site category B) surfaced with TSCS

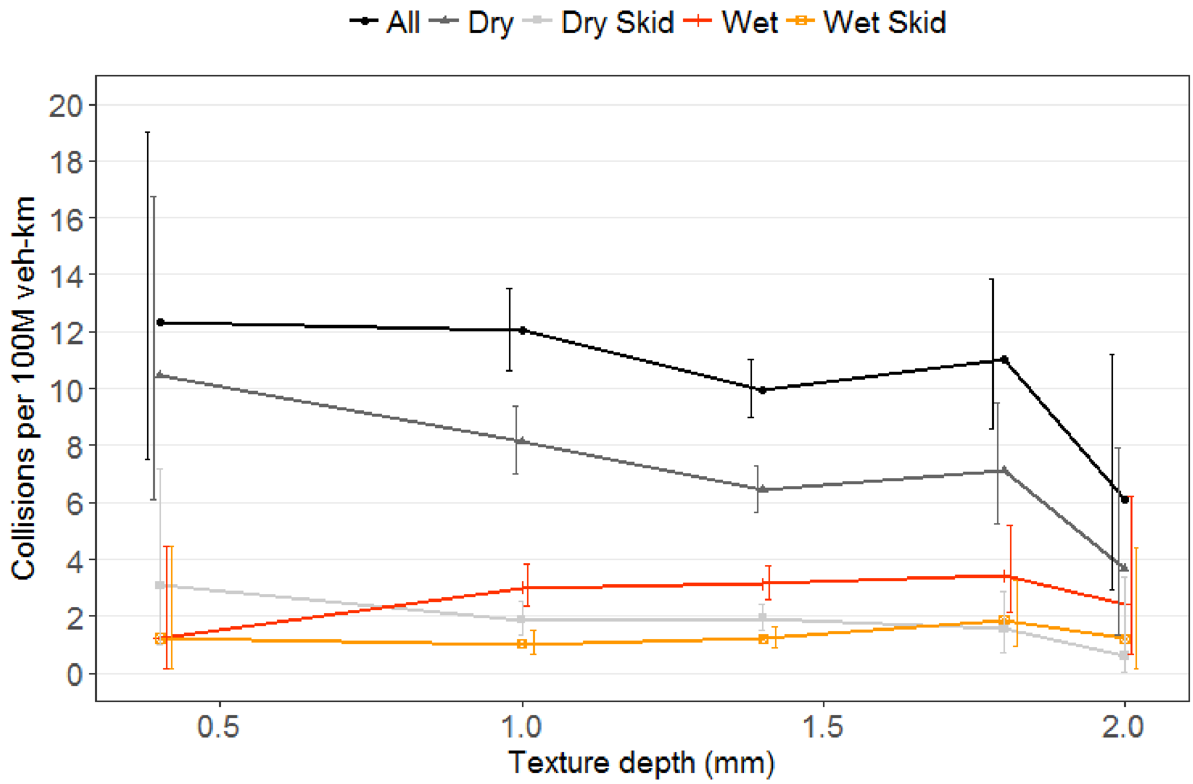

Figure 9: Collision risk against texture depth for non-event carriageways with two-way traffic (site category C) surfaced with TSCS

The results show that for texture depths above 0.8mm the trend in collision risk for all and dry collisions are broadly flat, within the range of the error bars. However at lower texture depths (0.4 - 0.8mm) all the non-event sites show an increase in collision risk with the trend being more marked for motorways and non-event carriageways with one way traffic (site categories A and B).

The trends for wet collisions also show a slight increase in risk for categories A and B at lower texture depths, but non-event carriageways with two-way traffic (category C) shows a decrease in risk albeit within the range of errors.

4.2.2 Event lengths

The trends of collision risk with texture depth for all collisions on approaches to pedestrian crossings and junctions (site categories Q and K) combined are shown in Figure 10.

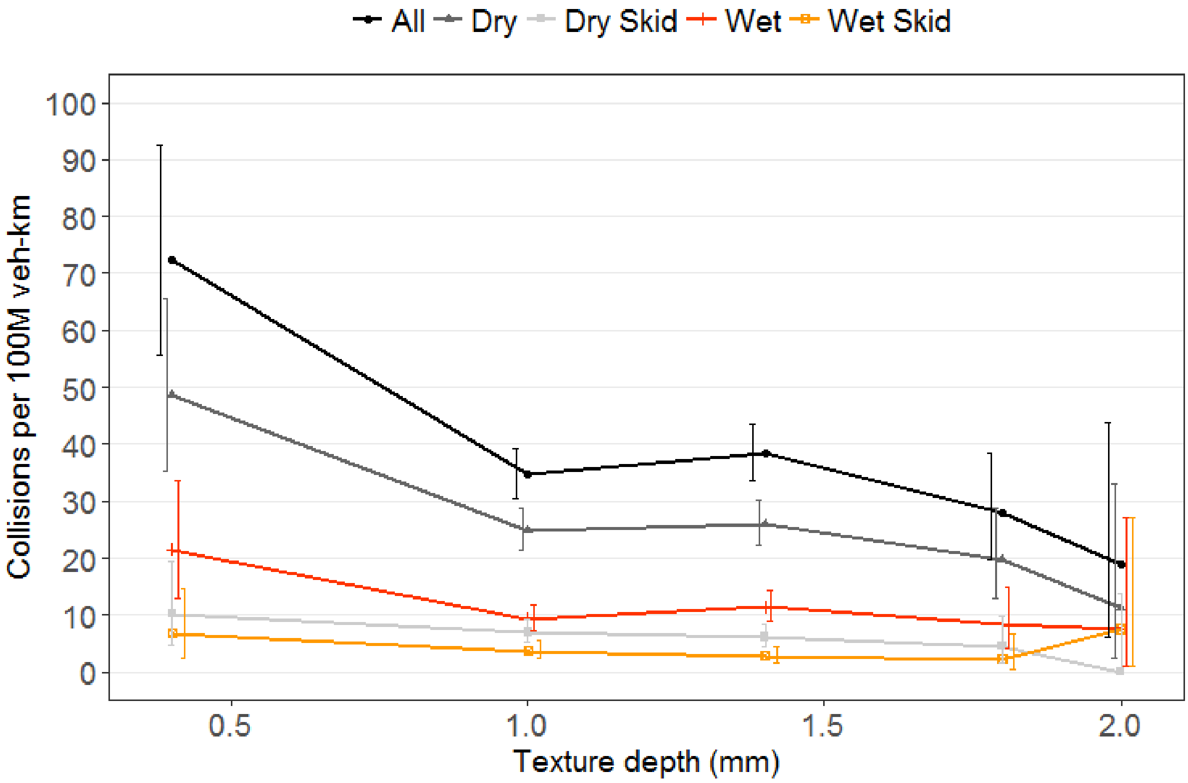

Figure 10: Collision risk against texture depth for all collisions for approaches to pedestrian crossings and junctions (site categories K and Q) surfaced with TSCS

The data show an increase in all and dry collision risk with reducing texture depths whilst the trend for wet collisions is reasonably flat for texture depths above 0.8mm but collision risk increases for texture depths in the 0.4-0.8mm range.

The results of the analysis for bends (site categories S1 and S2 combined) are shown in Figure 11.

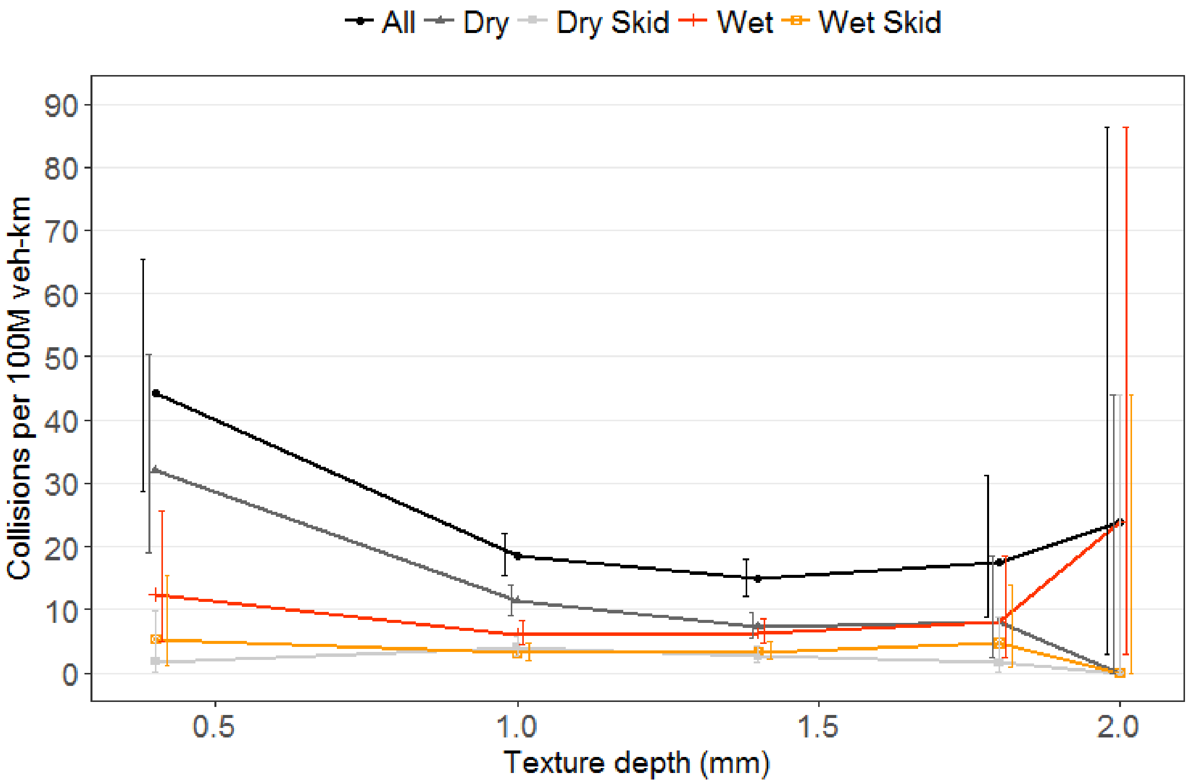

Figure 11: Collision risk against texture depth for all collisions for bends (site categories S1 and S2) surfaced with TSCS

The chart indicates that the collision risk for all, dry and wet collisions are reasonably constant for texture depths above 0.8mm. However, similar to the results for approaches to pedestrian crossings and junctions, there is an increase in collision risk at texture depths below 0.8mm.

The results for gradients (site categories G1 and G2 combined), presented in Figure 12.

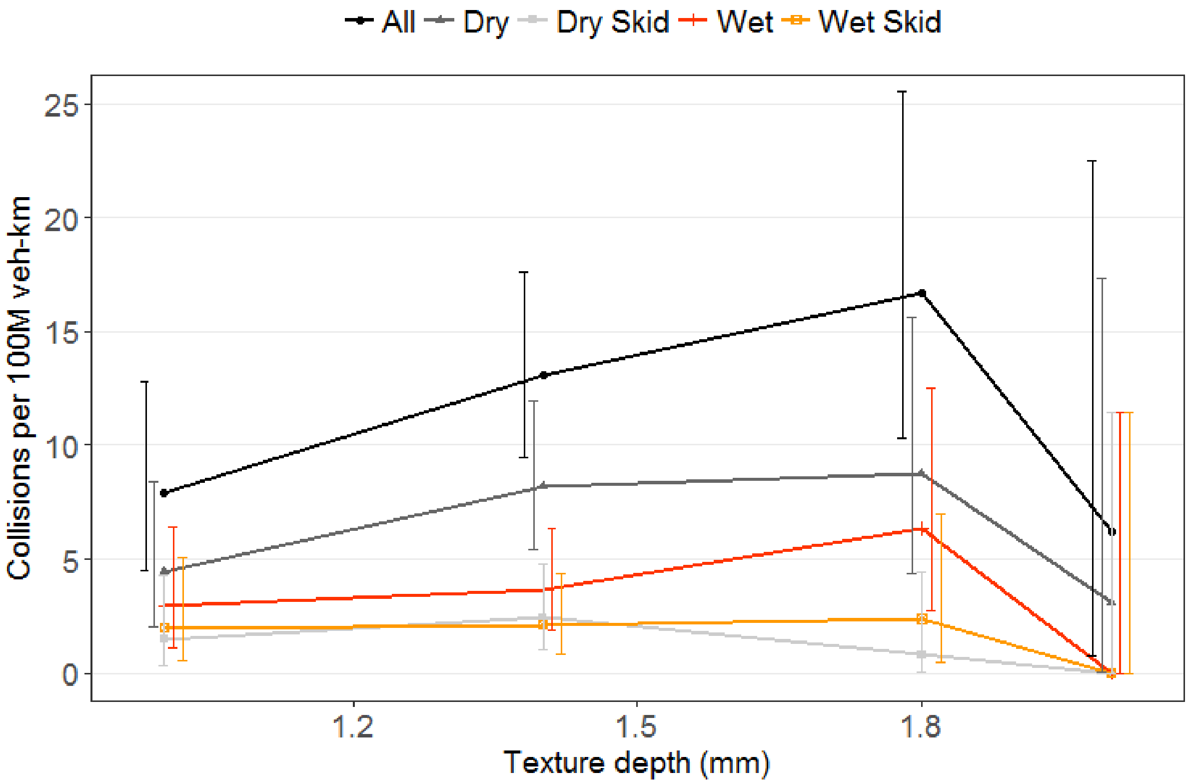

Figure 12: Collision risk against texture depth for gradients (site categories G1 and G2) surfaced with TSCS

The trend suggests a decrease in collision risk at lower texture depths. However the amount of data available at both the lower and higher texture depths is very limited and therefore the trends are unlikely to be robust.

4.2.3 Summary

The results for TSCS generally show a slight increase in risk for all and dry collisions with decreasing texture depth down to 0.8mm. At lower texture depths (0.4 - 0.8mm) the rate of increase in collision risk is more marked.

For wet collisions the trends in collision risk are generally flat for texture depths above 0.8mm but do show an increase in risk at lower texture depths.

These results suggest that the increase in collision risk at lower texture depths is largely associated with collisions that did not occur in wet conditions, a finding which is in agreement with the collision modelling reported by Wallbank et al (2016).

The data would therefore suggest that the current condition categories defined for texture depth in HD29 are still appropriate with condition category 3 (< 0.8mm) being defined as "moderate deterioration – warning level of concern".

4.3 Hot Rolled Asphalt

4.3.1 Non-event lengths

Figure 13 to Figure 15 show the relationship between collision rates (per 10^6veh-km) and texture depth for non-event sites (A, B and C) surfaced with HRA.

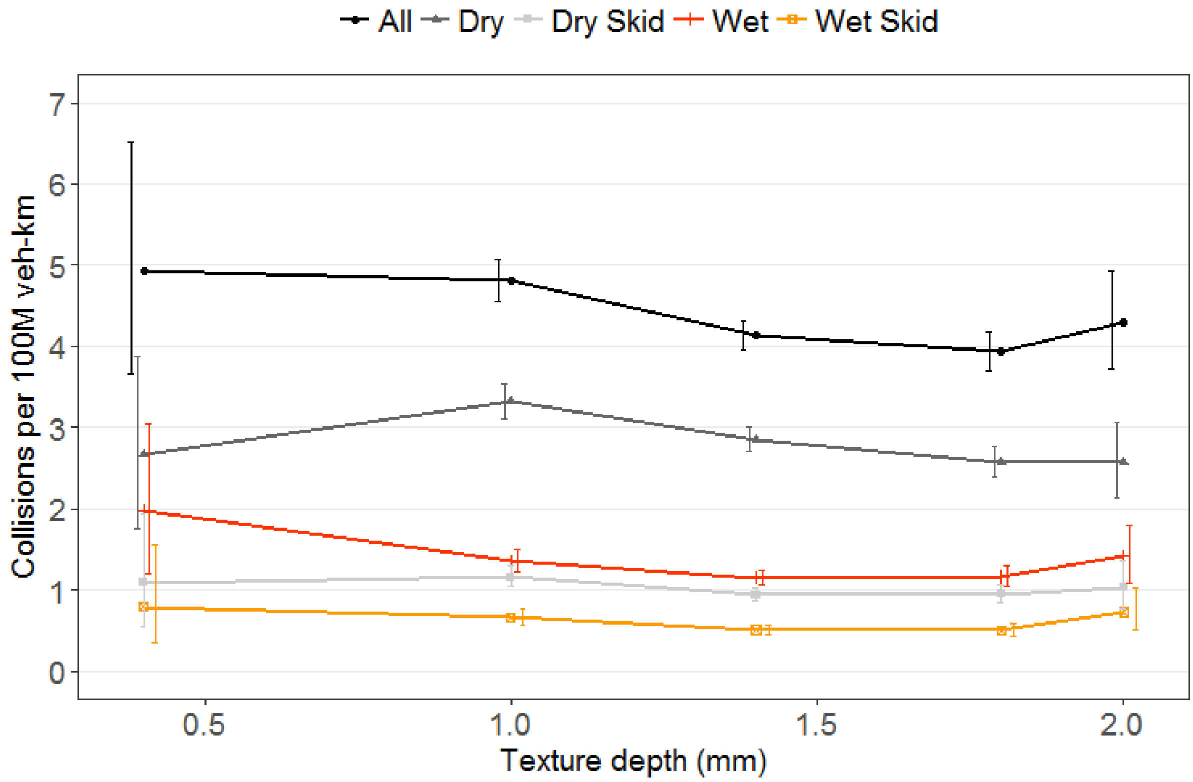

Figure 13: Collision risk against texture depth for motorways (site category A) surfaced with HRA

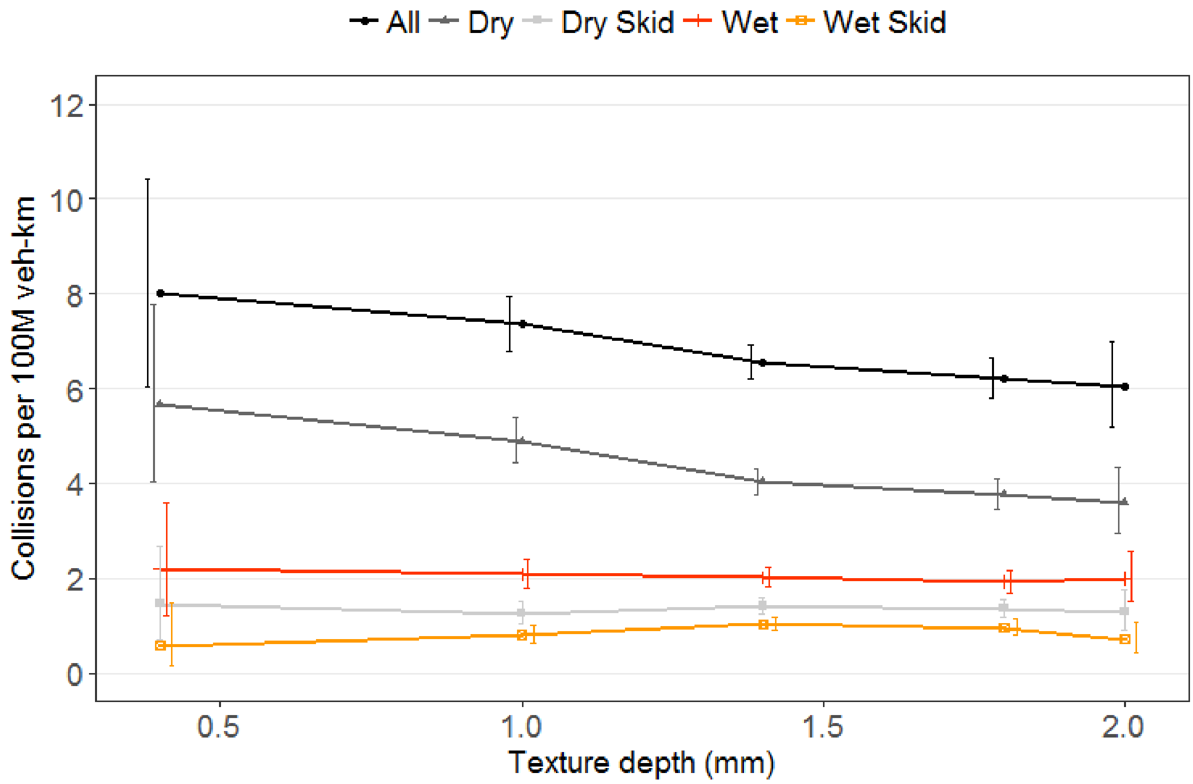

Figure 14: Collision risk against texture depth for non-event carriageways with one-way traffic (site category B) surfaced with HRA

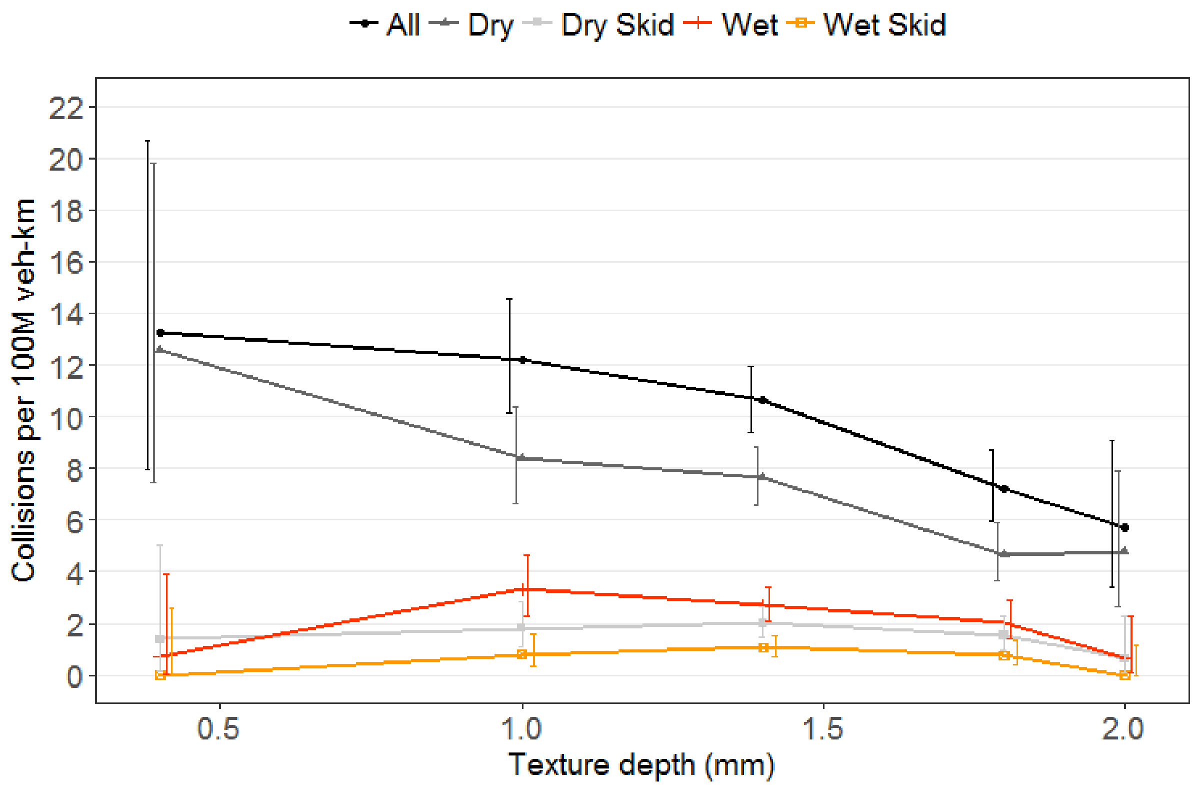

Figure 15: Collision risk against texture depth for non-event carriageways with two-way traffic (site category C) surfaced with HRA

All the non-event site categories (A, B and C) show an increase in collision rates for all and dry collisions with decreasing texture depth, this trend being more marked for non-event carriageways with two-way traffic (site category C). The only exception is for dry collisions on motorways (site category A), where the collision rate at < 0.8mm is below trend. The increase for texture depths below 0.8mm appears to be less than was observed for non-event lengths surfaced with TSCS for site categories A and B.

For wet collisions, the trends are generally quite flat, within the error bars, with site category A showing an increase in collision risk at textures below 0.8mm while category C shows the opposite trend, i.e. a reduction in risk at lower texture depths.

4.3.2 Event lengths

The trends of collision risk with texture depth for approaches to pedestrian crossings/junctions, bends and gradients (site categories Q/K, S1/S2 and G1/G2) are shown in Figure 16 to Figure 18 respectively.

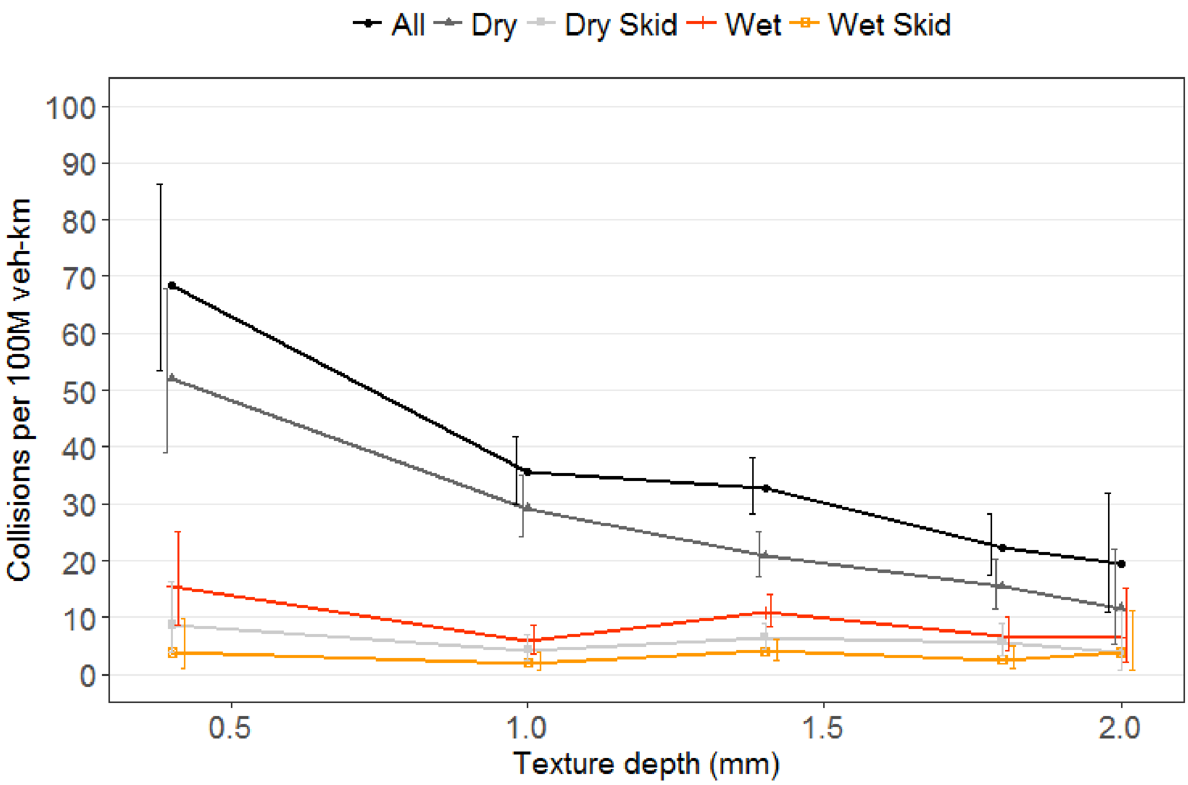

Figure 16: Collision risk against texture depth for approaches to pedestrian crossings and junctions (site categories K and Q combined) surfaced with HRA

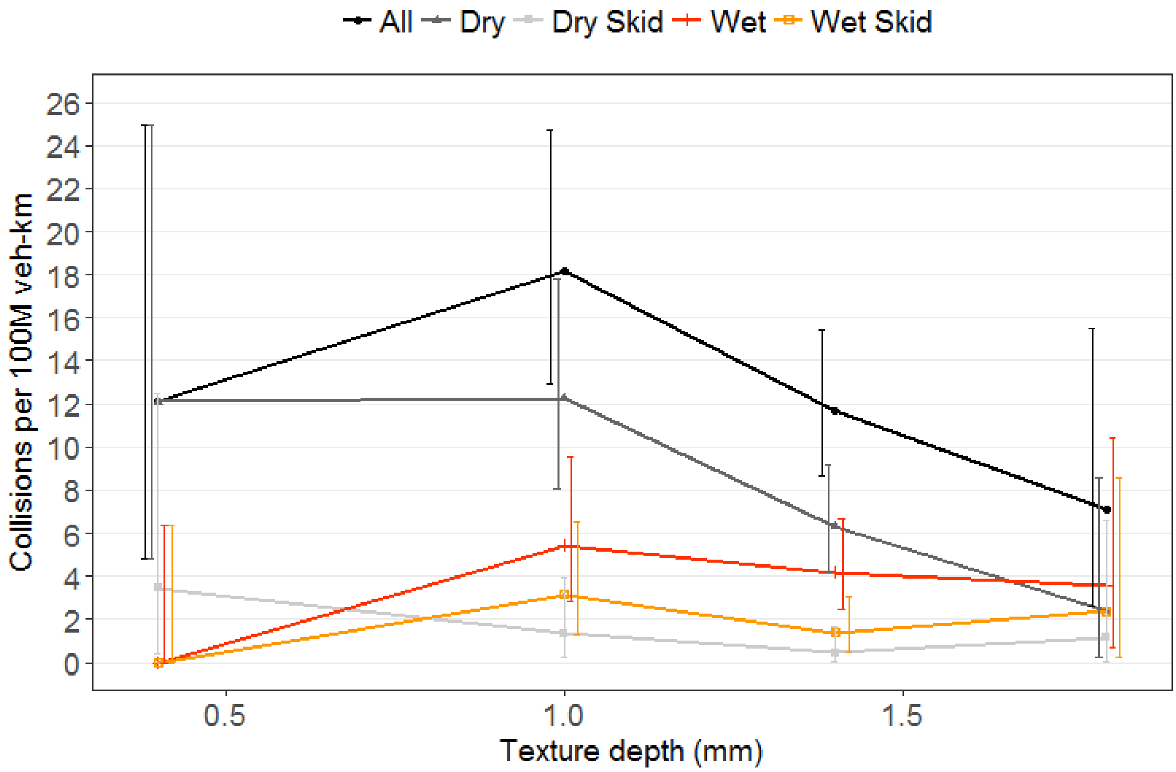

Figure 17: Collision risk against texture depth for site categories bends (S1 and S2 combined) surfaced with HRA

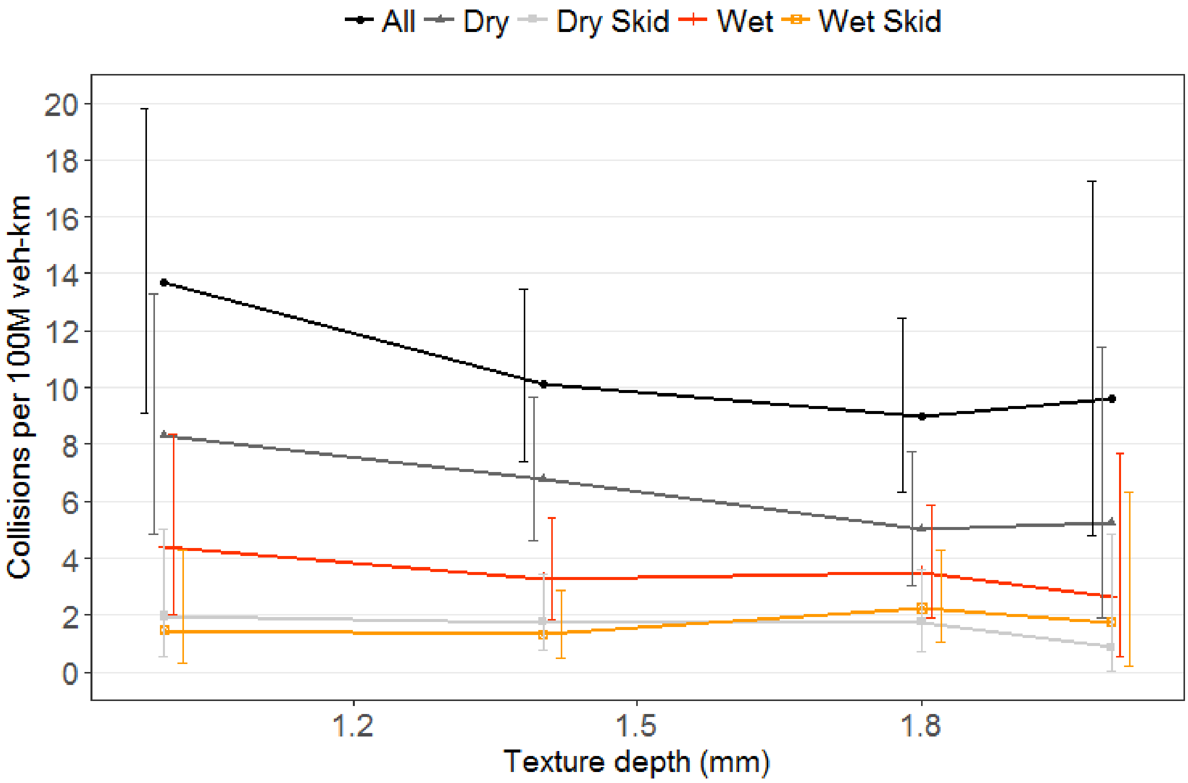

Figure 18: Collision risk against texture depth for gradients (site categories G1 and G2 combined) surfaced with HRA

All three categories demonstrate an increase in collision risk for all and dry collisions with decreasing texture depth; the exception is the bends category (S1 and S2 combined) that shows an increasing trend to texture depths in the 0.8 - 1.2mm range, but a reduction in the 0.4 - 0.8mm range.

The trends for wet collisions are less consistent but generally show a slight increase in collision risk as texture depths reduce down to 0.8mm. Below 0.8mm texture depth, the limited amount of data precludes any robust commentary on the results.

4.3.3 Summary

As with the results for TSCS, lengths surfaced with HRA tend to demonstrate an increase in collision risk with decreasing texture depth although the increase in risk at texture depths below 0.8mm generally appears slightly less marked for HRA than for TSCS. Also, similar to TSCS, the increase in collision risk appears to be linked mainly to collisions in dry conditions.

4.4 Concrete

The data for concrete surfacings indicated that the majority of these sections were present on motorways (site category A) and non-event carriageways with one-way traffic (site category B). Therefore only the results of the analysis for these two site categories are presented herein - see Figure 19 and Figure 20.

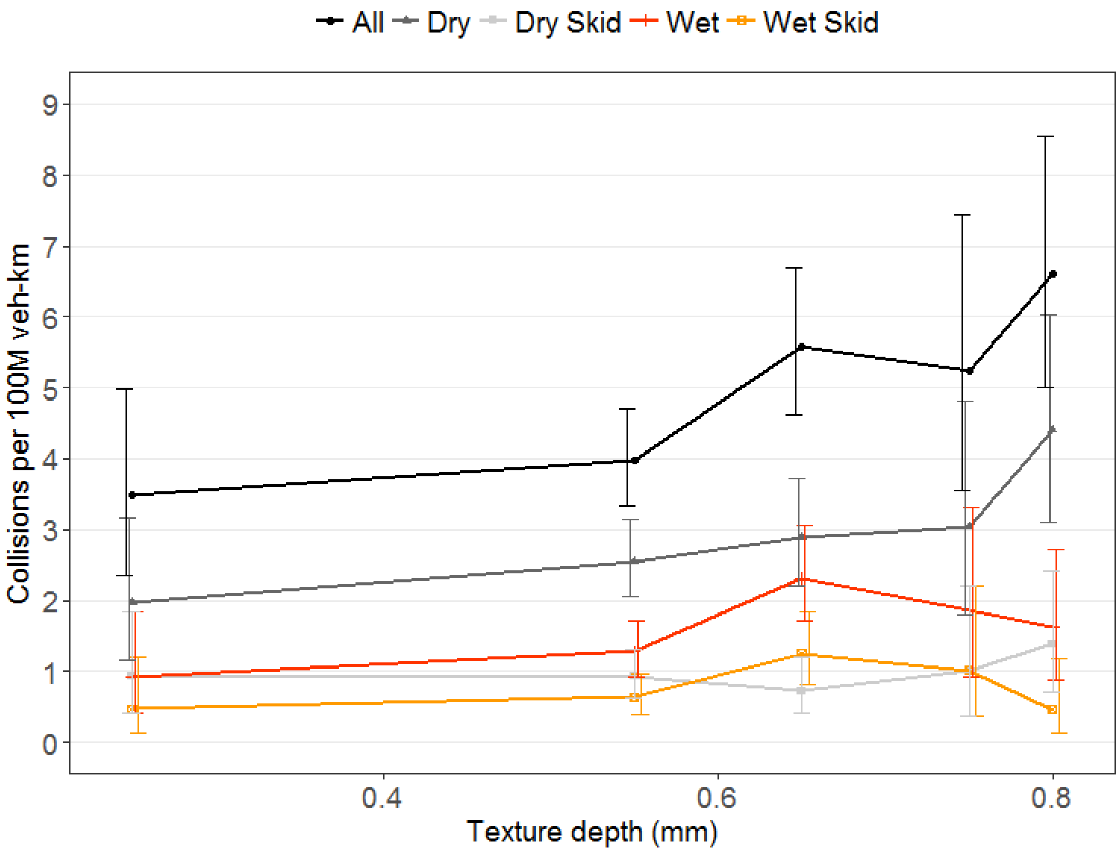

Figure 19: Collision risk against texture depth for motorways (site category A) surfaced with concrete

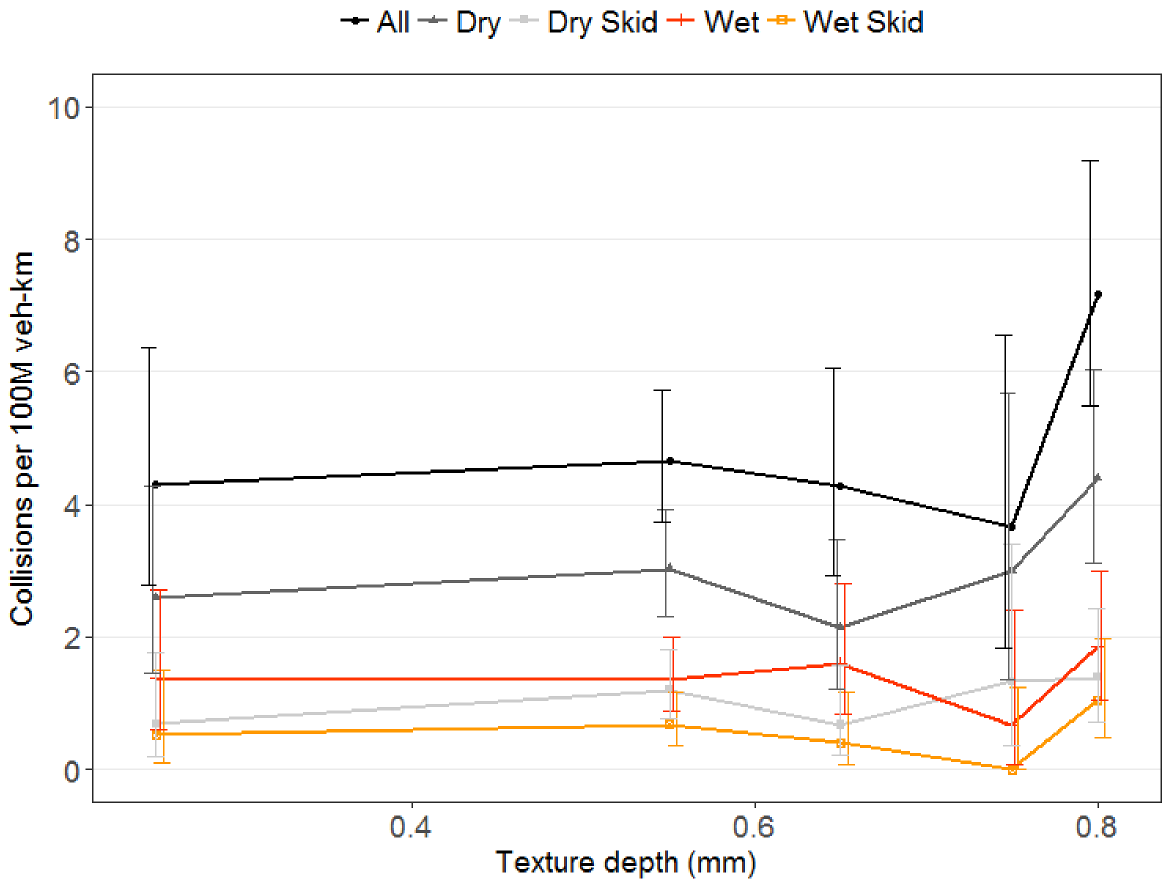

Figure 20: Collision risk against texture depth for non-event carriageways with one-way traffic (site category B) surfaced with concrete

In both cases, the collision risk generally decreases for all and dry collisions with decreasing texture depth; this trend is more pronounced for motorways (site category A) although relatively flat within the limits of the error bars. The collision risk for collisions in the wet is relatively flat across all texture bands.

4.5 High Friction Surfacing

Due to the fairly limited use of HFS on the SRN, there was only adequate data to provide results for the approaches to pedestrian crossings (combined site categories Q and K) and for bends (S1 and S2 combined); these are presented in Figure 21 and Figure 22 respectively.

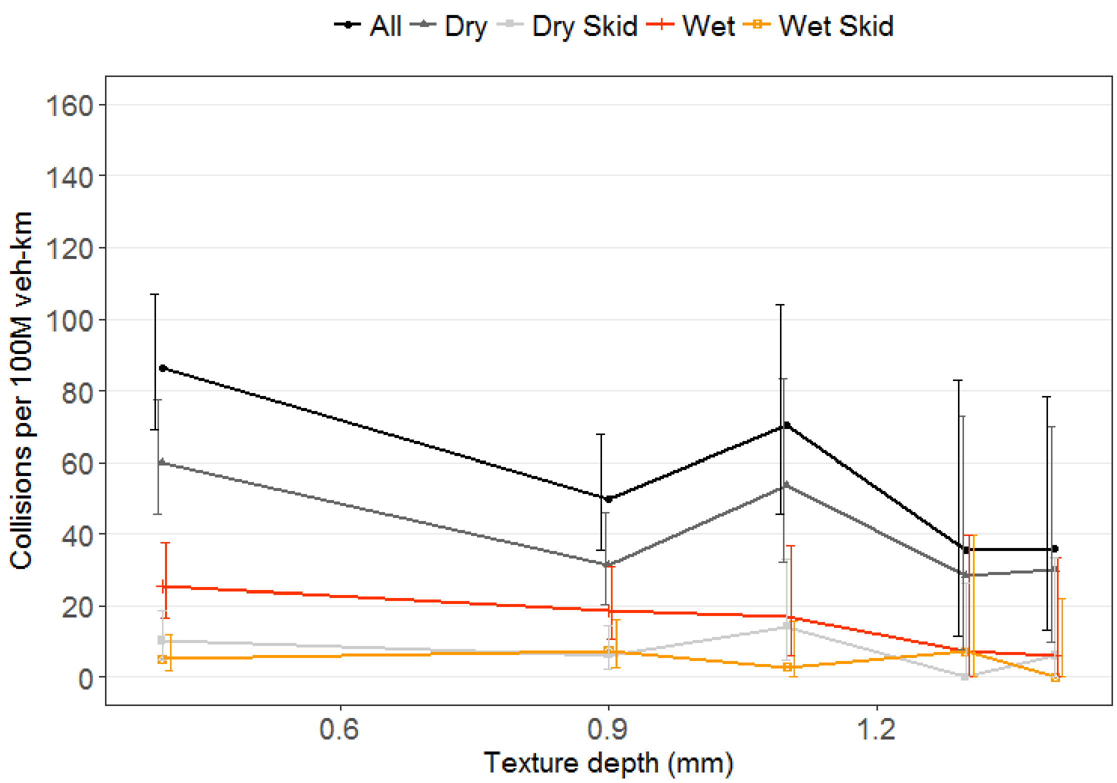

Figure 21: Collision risk against texture depth for approaches to pedestrian crossings and junctions (site categories K and Q combined) surfaced with HFS

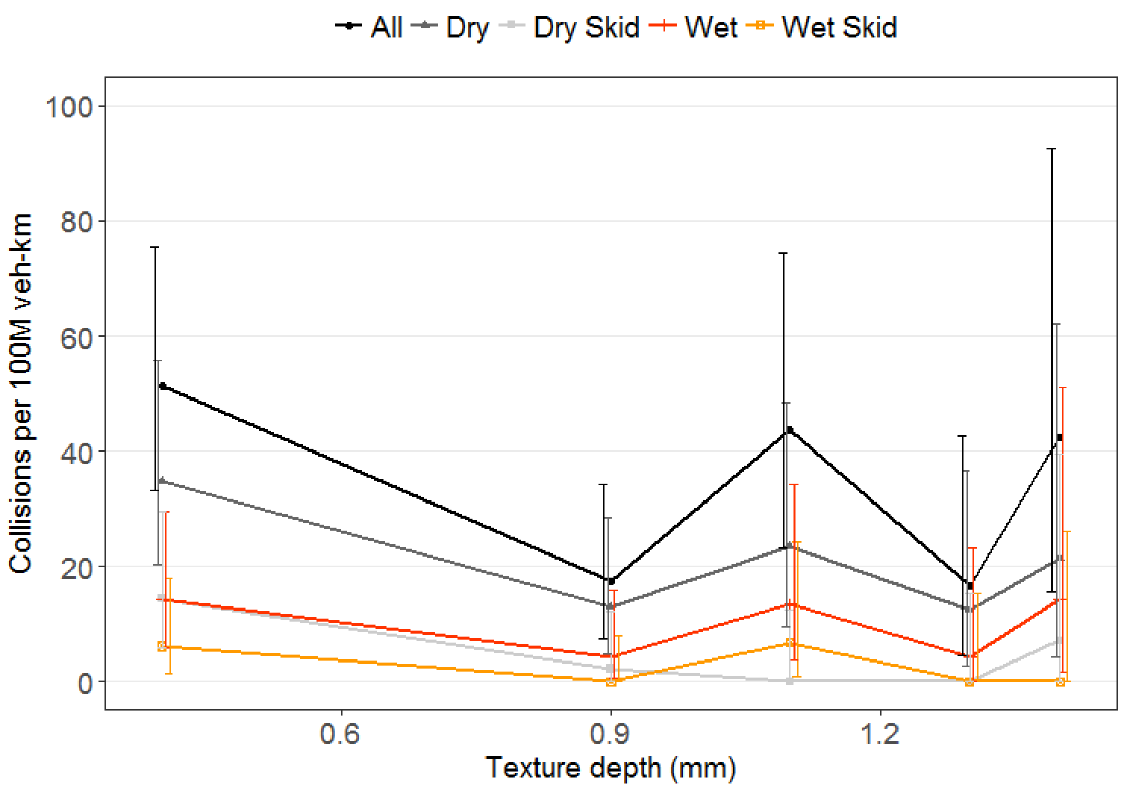

Figure 22: Collision risk against texture depth for bends (site categories S1 and S2 combined) surfaced with HFS

The trends are not consistent. The figures shows an increasing trend with reducing texture depth for all, dry and wet collision rates for approaches to pedestrian crossings/junctions (site categories K/Q) and all and dry collision rates for bends (S1/S2), but in all cases the trend is flat within the limits of the error bars.

The trend for wet collisions for bends is broadly flat. Although based on a limited amount of data, these results are somewhat unexpected given that HFS are specifically designed to provide high levels of friction at higher risk locations on the network. It may be that other risk factors at these sites are contributing to the higher collision rates seen.

The limited data available for this analysis combined with the fact that HFS can deteriorate in two distinctly different ways (loss of calcined bauxite chippings but with the HFS binder remaining resulting in potentially low texture depths and delamination failures where the HFS binder and aggregate is lost to expose the underlying material resulting in potentially higher textures associated with the underlying material) makes it difficult to draw any robust conclusions on whether the results at the lower and higher texture depths could be linked to the surfacings starting to deteriorate.

5 Modelling

5.1 Approach

The same multivariate regression technique known as Generalised Linear Modelling (GLM), used by Wallbank et al. (2016) to model all and wet collisions, was used to investigate the relationship between the number of collisions in dry conditions and a number of variables including texture depth[3].

For the purposes of these models, the number of collisions has been assumed to follow a negative binomial distribution (a common distribution used for modelling count data such as accidents). The models developed are of the form:

$$Collisions = Length.Flow^{\alpha}\exp\left(\beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n\right)$$

where α, β_0, β_1, …, β_n are coefficients estimated by the model and x_1, …, x_n are variables which are identified as being significant predictors of the number of collisions. A number of variables were tested for inclusion in the model[4]:

- Average skid resistance (average over years of data available)
- Average rut depth
- Average texture depth
- Curvature = 1/radius (based on the tightest absolute radius for each section)
- Gradient; each section was classified into uphill (maximum gradient > 5%), flat (maximum gradient between 5% and -5%) or downhill (maximum gradient < -5%)
- Average crossfall

Models have been developed for each of the site categories (A, B, C, Q/K combined, G1/G2 combined and S1/S2 combined). Where there is sufficient data, further models have been developed for each site category and surface type[5] combination.

[3] Comparisons are made to the results published for all and wet collisions in Wallbank et al. (2016); caution should be applied since there are differences in the processing of the raw data, for example how each section was defined and divided.

[4] The models developed here include only those sections with complete data for all significant predictors and with a known and specified surface type (i.e. sub-sections with a surface type of ‘other’ or ‘unknown’ were excluded. The number of sections (N) included in each model is shown in Appendix B.

[5] For each site category, ANOVA tests of surface type and each continuous predictor variable showed a relationship between surface type and one or more of the other variables. Surface type was therefore omitted from the list of predictor variables tested for inclusion in the site category models and instead surface specific models were produced for each site category where there was sufficient data.

The base model was developed which included an intercept term (β_0)[6] and the length of the sub-section as an offset[7] (i.e. the coefficient associated with this term was set to 1). This approach is consistent with that used in previous research and Wallbank et al. (2016).

Each explanatory variable was added to the base model in turn and was analysed to determine whether the inclusion of that variable reduced the unexplained variance in the number of collisions by a significant amount. The variable that improved the model most was then added. This process was repeated until it was deemed that no further variables improved the model significantly.

In addition to GLM, a Generalized Linear Mixed-effects Model (GLMM) was also fitted to each data set to investigate if controlling for any potential similarities between the collision numbers on each section notably changed the model fits. GLMM can be considered as an extension of GLM which allows multiple levels in the data to be modelled, e.g. in this case the hierarchical relationship between section (as defined within HAPMS) and sub-section (as defined by this analysis which disaggregates each section into smaller sub-sections). The same model fitting process as for the GLM was applied but with the section identifier added to the base model. Broadly similar coefficients for the same significant variables were found using both GLMM and GLM indicating that the insights provided by the GLM appear reasonably robust to any similarities within sections.

The results of the GLM for each site category and combination of site category and surface type inspected are presented in the following sections.

The proportion of variance explained by each GLM was also estimated. A value of 100% would indicate that the model perfectly predicts the number of collisions recorded for each sub-section of road. The values for the models presented in this report range from 1% to 15%, i.e. the majority of the variance in the number of collisions cannot be explained by the variables included in this analysis. The models for all and wet collisions presented in Wallbank et al. (2016) explained a similar range of 2% to 16%. This may be partly due to the nature of the analysis in which the road network has been disaggregated into short lengths to cater for localised changes in surface condition and, since collisions are rare events, there is a high degree of variability in the number of collisions occurring in any one analysed length.

Consequently, caution should be applied when interpreting these models. Whilst significant variables indicate there may be a relationship between numbers of collisions and the explanatory variable of interest, there may be other variables (e.g. weather, traffic composition, etc.) that have a greater influence on the number of collisions but which have not been considered in this analysis. As for the results for all and wet collisions presented in Wallbank et al. (2016), **the results presented here can be used to give an indication of the direction of the relationship between the number of collisions and significant variables** (e.g. increasing texture depth decreases the number of collisions), **but not to predict the number of collisions expected on any given section of road**.

[6] The log of the expected mean value of collisions when all explanatory factors equal 0 and length equals 1.

[7] The use of an offset variable allows different exposures (in this case section lengths) to be taken into account in derivation of the model.

The coefficients for each model are provided in Appendix B. In all cases, the level of traffic (log(AADT)) was included in the models.

5.2 Motorway non-event (A)

Crossfall and texture depth were identified as significant predictors of collision risk in dry conditions on motorways. The coefficient for crossfall was positive which suggests that higher values of crossfall are associated with larger numbers of collisions. In contrast, increasing texture depth decreases collisions. The proportion of variance explained by the model is 14%.

Wallbank et al. (2016) reported similar results for all collisions but with skid resistance as an additional significant variable. In the 2016 report, texture depth was also found to be significant for wet collisions. This relationship was in the same direction as those found here for dry collisions, and was of a similar magnitude.

Specific models were also fitted to concrete, HRA and TSCS sub-sections on motorways for dry collisions. The proportion of variance explained by the models was 14%, 15% and 13% respectively.

The significant variables varied for each surface type and included texture depth (concrete and HRA), crossfall (HRA and TSCS) and skid resistance (concrete and TSCS[8]).

5.3 Non-event carriageway with one-way traffic (B)

Texture depth and rut depth[9] were identified as significant predictors of collision risk on non-event carriageways with one-way traffic. The coefficients indicate that increasing texture depth is associated with decreasing collisions, whilst increasing rut depth is associated within increasing collisions. The proportion of variance explained by the model is 6%.

Wallbank et al. (2016) reported texture depth and rut depth as the only significant predictor of collision risk for collisions in all and wet conditions respectively. The direction of the relationship between collisions and texture depth for all conditions reported in Wallbank et al. (2016) was the same as that found here for dry conditions; the magnitude of the relationship for collisions in dry conditions is approximately double that previously reported for collisions in all conditions.

Specific models were also fitted to concrete, HRA and TSCS sub-sections on non-event carriageways with one-way traffic. No significant predictors (beyond level of traffic) were identified for concrete (which had a comparably small data set of 731 sub-sections), whilst texture depth was found as significant for HRA and TSCS. The direction of the relationship in all cases was such that increasing texture depth was associated with decreasing collisions. The magnitude of the relationship was larger for HRA and TSCS alone than for site category B overall.

[8] For TSCS, skid resistance was found to be significant in the GLM but not the GLMM.

[9] Rut depth was found to be significant in the GLM but not the GLMM.

5.4 Non-event carriageway with two-way traffic (C)

Texture depth was identified as the only significant predictor of collision risk (beyond level of traffic) on non-event carriageways with two-way traffic. The coefficient indicates that increasing texture depth is associated with decreasing collisions. The proportion of variance explained by the model is 5%.

Wallbank et al. (2016) reported texture depth and curvature as significant predictors of collision risk for collisions in all conditions. The direction of the relationship between collisions and texture depth for all conditions reported in Wallbank et al. (2016) was the same as that found here for dry conditions; the magnitude of the relationship for collisions in dry conditions is larger (0.52) that for collisions in all conditions (0.31). No significant predictors (beyond level of traffic) were identified in Wallbank et al. (2016) for collisions in wet conditions.

Specific models were also fitted to HRA and TSCS sub-sections on non-event carriageways with two-way traffic. Texture depth was found to be significant in both cases with skid resistance additionally significant in the case of TSCS[10]. The strength of the relationship with texture depth was largest with HRA.

5.5 Approaches to junctions and pedestrian crossings (Q and K)

Texture depth, skid resistance and rut depth[11] were identified as significant predictors of collision risk (beyond level of traffic) on approaches to junctions and pedestrian crossings. Increasing texture depth was found to be associated with decreasing collisions whilst increasing skid resistance and rut depth were found to be associated with increasing collisions. The proportion of variance explained by the model is 5%.

Wallbank et al. (2016) reported texture depth, skid resistance and crossfall as significant predictors of collision risk for collisions in both all and wet conditions and rut depth as an additional significant variable for collisions in all conditions. The direction of the relationships between collisions and each common significant variable for collisions in dry conditions were found to be the same as those for collisions in all and wet conditions.

5.6 Bends (S1 and S2)

Texture depth was identified as the only significant predictor of collision risk (beyond level of traffic) on bends[12]. The coefficient indicates that increasing texture depth is associated with decreasing collisions. The proportion of variance explained by the model is 8%.

Wallbank et al. (2016) reported texture depth and skid resistance as significant predictors of collision risk for collisions in all and wet conditions respectively. The direction of the relationship between collisions and texture depth for all conditions reported in Wallbank et

[10] Skid resistance was found to be significant in the GLM but not the GLMM.

[11] Skid resistance and rut depth were found to be significant in the GLM but not the GLMM. Curvature was found to be significant in the GLMM but not the GLM. Increasing curvature was found to be associated with increasing collisions.

[12] Curvature was additionally found to be significant in the GLMM.

al. (2016) was the same as that found here for dry conditions; the magnitude of the relationship for collisions in dry conditions is approximately double that previously reported for collisions in all conditions.

5.7 Gradients (G1 and G2)

No variables (beyond level of traffic) were identified as significant predictors of collision risk on gradients. The proportion of variance explained by the model is 4%.

In contrast, Wallbank et al. (2016) reported skid resistance and gradient as significant predictors of collision risk for collisions in all and wet conditions.

6 Friction testing

The analysis reported in Section 2 and 3, showed that the increase in collision risk with reducing texture depth was associated mainly with an increase in collisions in dry conditions and that the trends for wet collisions were broadly flat. Furthermore, the proportion of skidding collisions in both wet and dry conditions was not greatly influenced by texture depth; in fact, there may be a slight decrease in the proportion of skidding collisions as texture depth decreases. These findings suggest that the increase in collision risk with reducing texture depth may not be as a result of variations in friction. Therefore, to test the null hypothesis that "dry friction will be similar on low and high textured surfacings" a programme of friction testing was undertaken on surfacings with a range of texture depths.

Texture data available from HAPMS was used to identify sites with the same surface type (TSCS) that fell into each of the three central texture bands used in the analysis, i.e. 0.4-0.8mm, 0.8-1.2mm and 1.2-1.6mm. In addition, each site needed to have reasonably uniform texture depth along its length and to be >500m long.

As the testing was undertaken during Covid-19 restrictions, all the sites selected were within easy reach of TRL's head office in Berkshire to negate the need for overnight stays for the survey crew. Details of the sites are provided in Table 6.

Table 6 Details of the test sites

Site id	Route	HAPMS section(s)	General location	Texture depth (SMTD, mm)	
				Average	Standard Deviation
1	A34 SB	1700A34/185	Litchfield	0.65	0.09
2	A34 SB	1700A34/126 & 1700A34/124	Burghclere	1.00	0.06
3	A34 NB	3100A34/207	Snelsmore	0.99	0.05
4	A34 SB	3100A34/374	Chilton	1.29	0.11
5	A34 NB	3100A34/254	South Hinksey	1.35	0.10
7	A34 SB	3100A34/434	Islip	0.73	0.07
8	A34 SB	3100A34/460	Islip	0.72	0.07

The testing was undertaken using the Highways England Pavement Friction Tester (PFT); a locked-wheel road surface friction testing device comprising of a tow vehicle and trailer. The trailer holds the test wheel which is mounted on an instrumented axle. The test wheel can be independently braked and the forces acting upon it measured to determine the friction between the test tyre and road surface. The PFT can be used in a number of configurations; testing can be carried out under wet or dry road conditions using different test tyres and at a variety of test speeds. During testing, the load and drag forces on the tyre are measured every 0.01 seconds throughout the braking cycle and from this the peak[13] and locked-wheel[14] friction are determined.

Friction measurements were made in the nearside wheelpath of Lane 1 in dry conditions and with the PFT's automatic watering system turned off. The tests were conducted between 2nd and 6th November 2020 at a speed of 60km/h using the standard smooth PFT test tyre.

Both peak and locked wheel friction values were calculated for each site (based on a minimum of 5 valid measurements per site) and these are presented in Figure 23 and Figure 24. (in the figures, the green, yellow and orange markers indicate each of the three texture bands used in the analysis provided in earlier sections of this report).

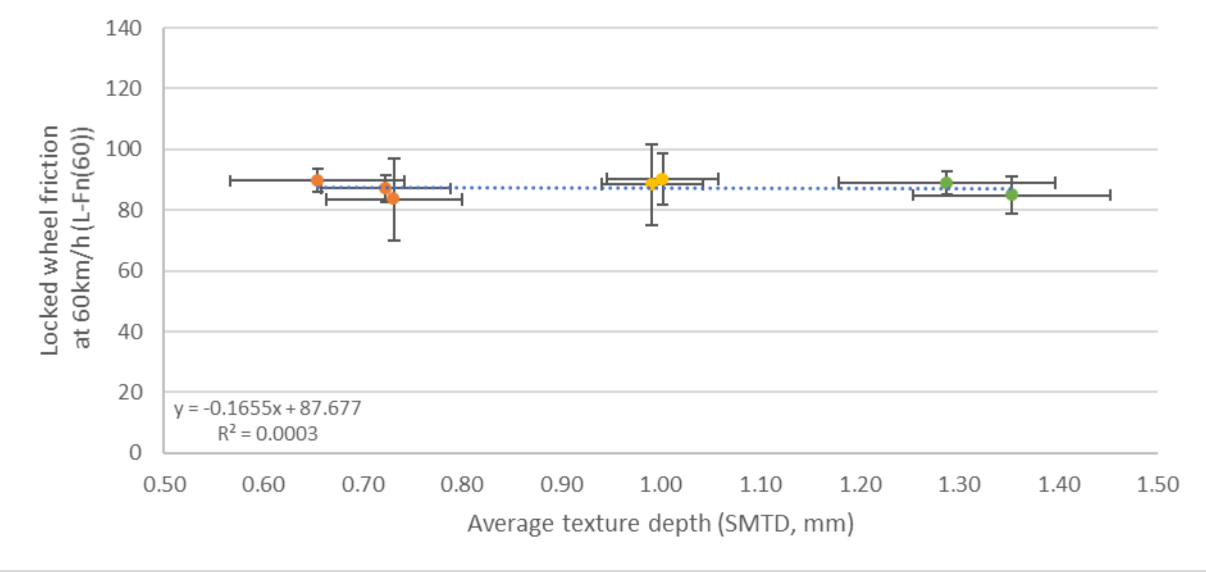

Figure 23 Locked wheel friction against texture depth

[13] Peak friction is the maximum friction value reached as the test wheel begins to slip.

[14] Locked-wheel fiction is the friction generated between the surface and test tyre when the wheel is locked.

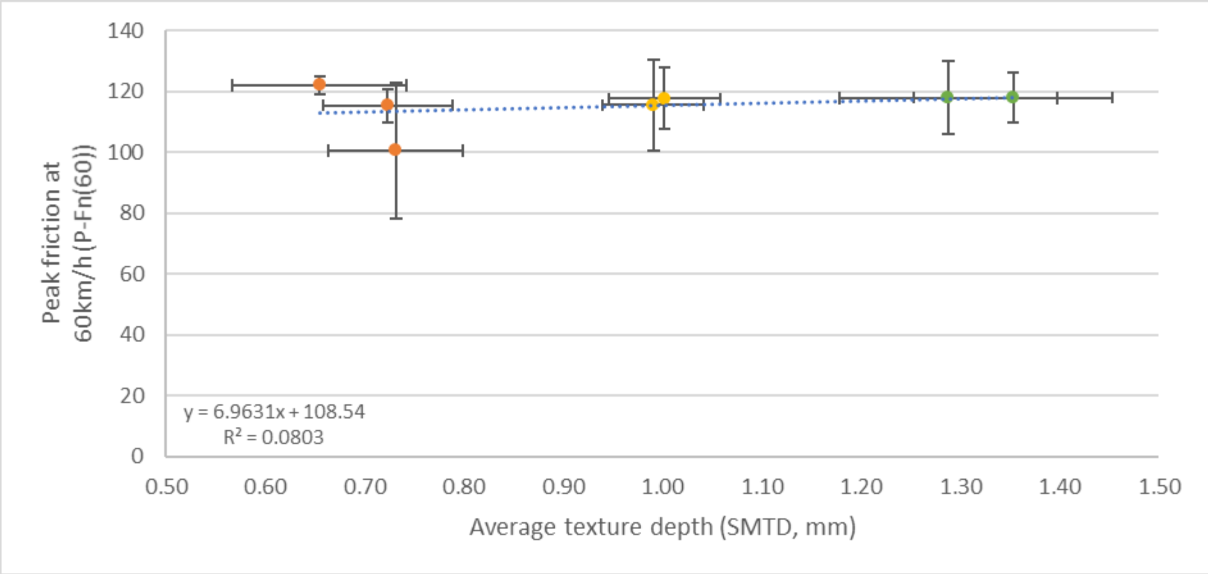

Figure 24 Peak friction against texture depth

The results show very little variation in either locked or peak friction with reducing texture depth and that the values are consistently high; this is demonstrated by the low R^2 values for the lines of best fit. It should be noted that peak friction measurements are generally more variable than locked wheel measurements due to the shorter period over which the forces on the tyre are measured. This may explain the slightly low value peak friction value for one of the lower textured surfaces in Figure 24.

Although limited to a relatively small number of sites, the results support the conclusions from the other analysis reported herein that the increase in collision risk at lower texture depths, mainly associated with collisions in dry conditions, is not arising from variations in dry friction.

7 Discussion, conclusions and recommendations

This study has focussed on the relationship between collision risk and in-service texture depth as measured by TRACs surveys, i.e. laser based measurements of Sensor Measured Texture Depth (SMTD). These measurements do not correlate directly to acceptance measurements of texture depth made at the time a surfacing is laid, such measurements being made using the volumetric approach. Information for as laid volumetric texture depths was not available for this study and therefore a link between initial and in-service texture depth cannot be made.

For the two materials that make up the majority of the non-event lengths on the SRN, i.e. TSCS and HRA:

- The collision rates are broadly similar in all, dry and wet conditions.
- There is a general trend for the all and dry collision rate to increase with decreasing texture depth. In the case of TSCS, the increase in collision risk tends to be more marked at texture depths below 0.8mm. This finding is in broad agreement with that reported by Roe et al (1991).
- The trend for wet collisions is less strong with many cases where the relationship is quite flat at texture depths above 0.8mm. Although an increase in wet collision risk is generally seen for texture depths below 0.8mm the increase is not as great as for all or dry collisions. It therefore appears that the increase in collision risk at lower textures is associated with collisions in non-wet conditions. This finding is supported by the outcomes of the Generalised Linear Modelling reported by Wallbank et al. (2016) and in this report which indicate that texture depth is a stronger contributor to collision risk for all and dry collisions than for collisions in the wet.
- The proportion of skidding collisions, in both wet and dry conditions, does not increase as texture depth reduces and may actually reduce slightly. This finding and that the increase in collision risk at low texture depths is associated mainly with an increase in collisions in dry conditions, suggest that the increase is not associated with variations in friction. This assumption was supported by friction tests that showed both locked wheel and peak friction values were consistent, and high, across a texture range from about 0.6mm to 1.4mm.

Concrete, as the material to make up the majority of the remainder of the non-event lengths on the SRN, generally has a texture depth of <0.8mm and therefore meaningful comparisons between concrete and TSCS/HRA at common texture depths are limited. However, the range of collision rates observed in all, dry and wet conditions for concrete are broadly similar to those for TSCS and HRA on motorways and non-event carriageways with one-way traffic.

Overall, the results of this investigation indicate that the current in-service condition category thresholds for texture depth defined in HD29/08 (DMRB 7.3.2) are still appropriate, with the potential exception of concrete. HD29 views texture <0.8mm as a concern for all materials types except HFS. However, given that most of the concrete on the network has texture <0.8mm and doesn’t seem to result in higher risk than for TSCS or HRA above 0.8, there could be scope for a different threshold for concrete. However, any consideration of altering the threshold would need to consider other factors such as the influence of texture on skid resistance and high speed friction.

As highlighted above, a lack of readily accessible as laid texture data for materials on the network meant it has not been possible to establish if there is a link between initial volumetric texture depth and in service SMTD. Noting that > 55% of TSCS have texture depths in excess of 1.2 mm (HD29 condition category 1), it is not clear whether this is as a result of a high initial texture depth or is related to the ageing and deterioration of the surfacing by, for example, fretting. It is therefore recommended that this area is investigated further as there may be an opportunity to relax current as laid requirements for TSCS without compromising the in service levels of texture achieved. This could include reviewing how in service texture depths change with age for different proprietary TSCS and determining, where possible, how this relates to initial volumetric texture depths.

Given that the increase in collision risk at lower texture depths is associated mainly with collisions in dry conditions and that dry friction does not appear to vary with texture depth, further investigation is recommended to develop a better understanding of other factors that could be contributing to the increase in collision risk such as collision type, contributary factors or human factors. This understanding would then enable strategies to be developed to mitigate the increased risk.

8 References

Note: this list of references contains unpublished reports (UPR) produced for Highways England. Please make a personal application to Highways England if you wish to obtain a copy.

Brittain S and Greene M J (2007). *Surface texture and tyre tread depth.* TRL Unpublished Project Report UPR/IE/071/07. Wokingham: TRL.

Design Manual for Roads and Bridges. The Stationery Office.

HD28/15 – Skidding resistance

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Appendix A Bias in accident types by texture band

A.1 Collision risk by texture band and accident severity

The number and proportion of collisions classified as fatal or serious and slight at each texture band is shown in Table A1.

Table A1: Collision risk at each severity level by texture band

Texture Band	Number of collisions		Proportion of collisions	
	Fatal or serious	Slight	Fatal or serious	Slight
ii (0.4 - 0.8 mm)	542	2,917	16%	84%
iii (0.8 - 1.2 mm)	2,817	14,875	16%	84%
iv (1.2 - 1.6 mm)	3,270	17,174	16%	84%
v (1.6 – 2.0 mm)	1,177	5,724	17%	83%
vi (> 2.0 mm)	215	1,074	17%	83%

The proportion of collisions classified as fatal or serious is relatively consistent across all texture bands. A chi-squared test of independence, which investigates if there is an association between accident severity and texture band, confirmed that there is insufficient evidence to suggest any relationship between these variables[15].

The variation in collision risk against texture depth for each collision condition is shown in Figure A1.

[15] A p-value of 0.23 indicated that there was insufficient evidence to reject the null hypothesis that texture band and accident severity are independent

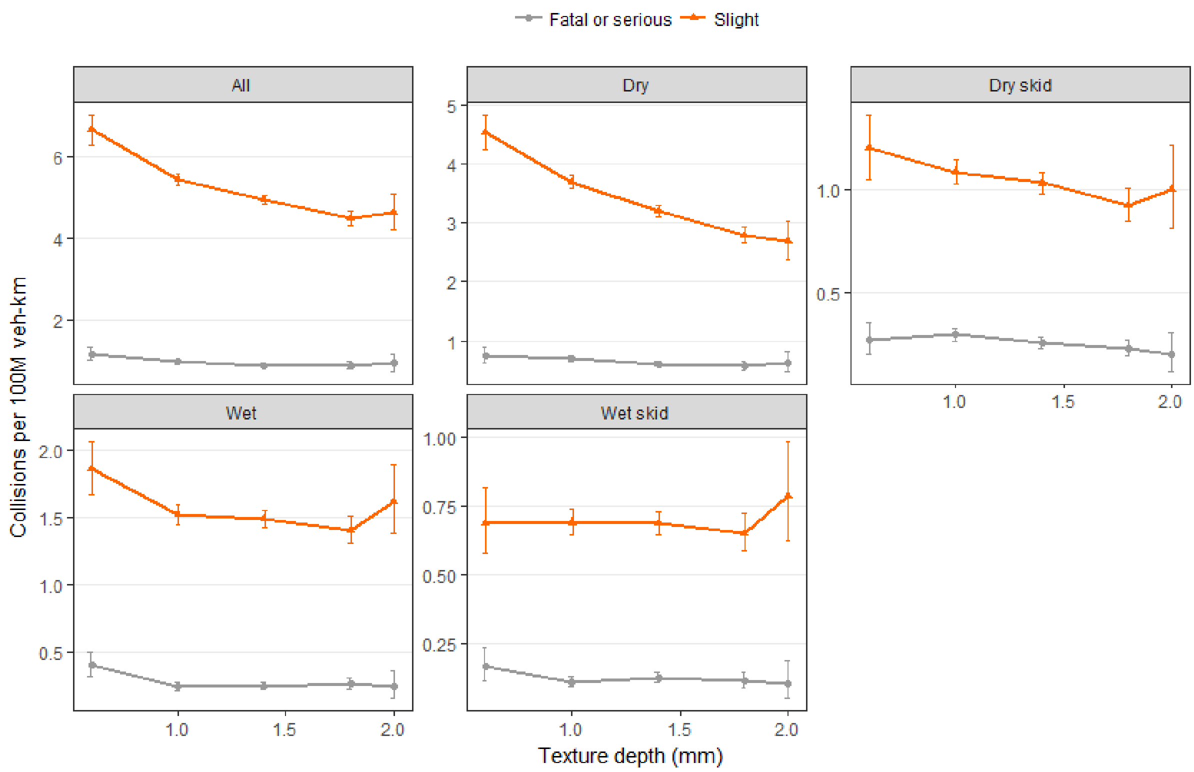

Figure A1: Collision risk against texture depth for each collision condition

In the case of fatal or serious severity collisions, in all and wet conditions, the collision rate for fatal or serious accidents is relatively flat for texture depths above 0.8mm, whilst for dry conditions, particularly dry skid, it increases with decreasing texture depth. In the case of slight severity collisions, the collision rate increases with decreasing texture depth for all and dry conditions but remains flat above 0.8mm for wet conditions. The trend is strong for all and dry conditions but relatively flat within the limits of the error bars for dry skid. The uppermost data point (>2.0 mm) appears variously above and below this trend with large error bars due to the relatively small amount of data.

In the case of dry conditions, the percentage reduction in collision risk with increasing texture band above 0.8mm is greater for slight collisions than it is for serious or fatal conditions.

A.2 Collisions by texture band and road users involved

Figure A2 shows the proportion of each type of road user involved in the collisions for each texture band.

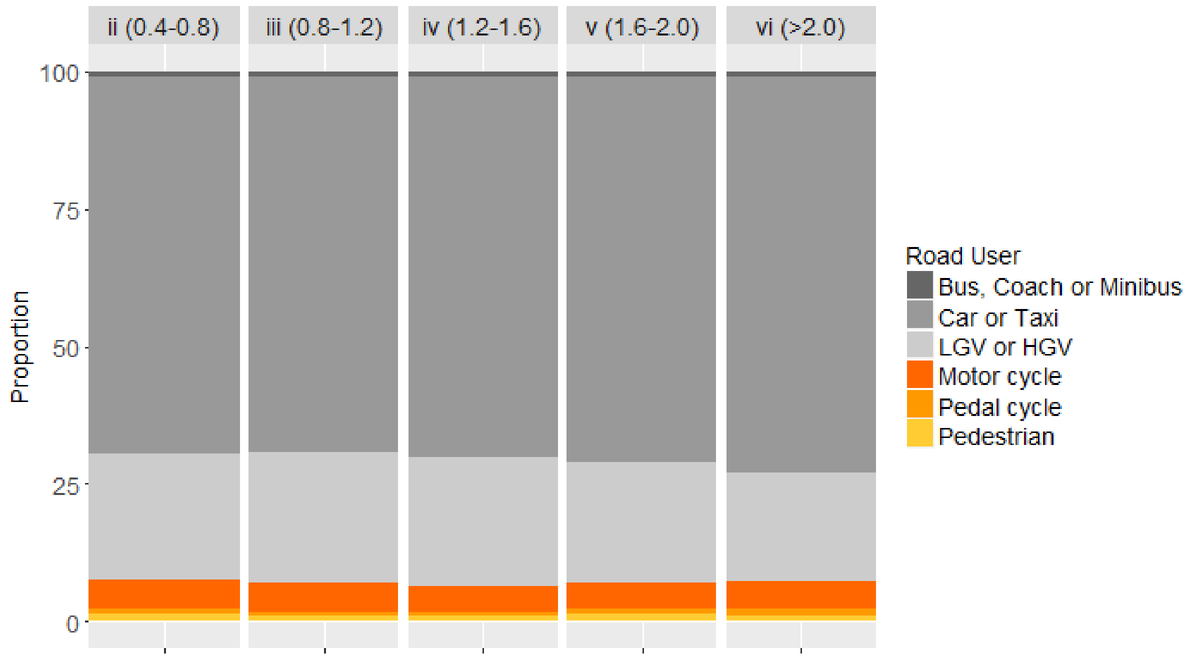

Figure A2: Proportion of each type of road user involved in the collisions for each texture band

A chi-squared test of independence, which tests if there is a relationship between texture band and road user involved, confirmed that there is no evidence of a significant relationship[16].

[16] A p-value of 0.21 indicated that there was insufficient evidence to reject the null hypothesis that texture band and other road user involved are independent.

Appendix B Model coefficients

This appendix presents the coefficients of the models described in Section 5. The order in which the variables are shown in the tables below is the order in which they were selected for inclusion in the model. Most variables were included in the models as continuous variables but one (gradient) was included as a factor (with three levels: up, down, flat[17]). Each model also included an intercept (constant) term and log(AADT) which was included as a measure of exposure to collision risk.

For each continuous variable (X), one coefficient is given. This coefficient can be interpreted as follows: for a one unit increase in X, the number of collisions will increase by a factor of exp(*coef of X*) if all else is held constant.

B.1 Motorway non-event (A)

Table B1: Model coefficients for motorway 'dry collisions' model (N=8,985)[18]

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-21.85	0.50	-22.00	0.56
Log(AADT)	1.31	0.04	1.31	0.05
Crossfall	0.03	0.01	0.03	0.01
Texture	-0.17	0.05	-0.14	0.05

Proportion of variance explained – 14%

B.1.1 TSCS

Table B2: Model coefficients for TSCS motorway 'dry collisions' model (N=3,859)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-21.26	0.76	-21.68	0.83
Log(AADT)	1.28	0.06	1.27	0.07
Crossfall	0.03	0.01	0.03	0.01
Skid resistance	-0.86	0.42	n/a	n/a

[17] Flat (gradient between -5 and 5), up (above 5) and down (below -5).

[18] N shows the number of sub-sections with complete observations for all predictor variables. This is the number of sections on which this model was run.

Proportion of variance explained – 13%

B.1.2 HRA

Table B3: Model coefficients for HRA motorway 'dry collisions' model (N=4,777)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-22.51	0.73	-22.66	0.80
Log(AADT)	1.36	0.06	1.36	0.06
Crossfall	0.02	0.01	0.02	0.01
Texture	-0.19	0.07	-0.15	0.07

Proportion of variance explained – 15%

B.1.3 Concrete[19]

Table B4: Model coefficients for concrete motorway 'dry collisions' model (N=344)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-13.77	2.61	-14.92	3.01
Log(AADT)	0.74	0.19	0.79	0.22
Skid resistance	-4.86	1.82	-3.98	1.99
Texture	0.76	0.30	0.81	0.34

Proportion of variance explained – 14%

[19] Gradient omitted from the model fit process as all concrete surfaces were flat

B.2 Non-event carriageway with one-way traffic (B)

Table B5: Model coefficients for non-event carriageway with one-way traffic 'dry collisions' model (N=16,307)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-17.42	0.51	-17.74	0.59
Log(AADT)	0.96	0.04	0.98	0.05
Texture	-0.23	0.05	-0.21	0.06
Rut	0.02	0.01	n/a	n/a

Proportion of variance explained – 6%

B.2.1 TSCS

Table B6: Model coefficients for TSCS non-event carriageway with one-way traffic 'dry collisions' model (N=7,107)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-18.33	0.76	-18.59	0.89
Log(AADT)	1.06	0.06	1.06	0.08
Texture	-0.36	0.11	-0.31	0.12

Proportion of variance explained – 8%

B.2.2 HRA

Table B7: Model coefficients for HRA non-event carriageway with one-way traffic 'dry collisions' model (N=8,411)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-15.97	0.75	-16.36	0.84
Log(AADT)	0.87	0.06	0.89	0.07
Texture	-0.41	0.08	-0.43	0.09

Proportion of variance explained – 6%

B.2.3 Concrete

Table B8: Model coefficients for concrete non-event carriageway with one-way traffic 'dry collisions' model (N=731)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-18.24	1.86	-18.08	2.16
Log(AADT)	1.00	0.16	0.97	0.19

Proportion of variance explained – 7%

B.3 Non-event carriageway with two-way traffic (C)

Table B9: Model coefficients for non-event carriageway with two-way traffic 'dry collisions' model (N=6,413)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-18.30	1.23	-17.92	1.40
Log AADT	1.15	0.12	1.10	0.13
Texture	-0.52	0.11	-0.55	0.13

Proportion of variance explained – 5%

B.3.1 TSCS

Table B10: Model coefficients for TSCS non-event carriageway with two-way traffic 'dry collisions' model (N=3,328)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-18.23	1.75	-16.98	1.89
Log(AADT)	1.95	0.15	1.02	0.18
Texture	-0.63	0.20	-0.63	0.22
Skid resistance	2.22	0.96	n/a	n/a

Proportion of variance explained – 4%

B.3.2 HRA

Table B11: Model coefficients for HRA non-event carriageway with two-way traffic 'dry collisions' model (N=2,755)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-18.40	1.90	-17.82	2.03
Log(AADT)	1.19	0.18	1.12	0.19
Texture	-0.73	0.18	-0.70	0.19

Proportion of variance explained – 6%

B.4 Approaches to junctions and pedestrian crossings (Q and K)

Table B12: Model coefficients for approaches to junctions and pedestrian crossings 'dry collisions' model (N=2,804)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-10.15	0.98	-9.44	1.02
Texture	-0.72	0.13	-0.81	0.13
Log(AADT)	0.44	0.08	0.43	0.13
Skid resistance	1.40	0.58	n/a	n/a
Rut	0.05	0.02	n/a	n/a
Curvature	n/a	n/a	1.26	0.58

Proportion of variance explained – 5%

B.4.1 TSCS

Table B13: Model coefficients for TSCS approaches to junctions and pedestrian crossings 'dry collisions' model (N=1,320)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-4.61	0.28	-5.26	0.30
Texture	-0.68	0.23	-0.61	0.23

Proportion of variance explained – 1%

B.4.2 HRA

Table B14: Model coefficients for HRA approaches to junctions and pedestrian crossings 'dry collisions' model (N=1,214)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-10.27	1.30	-9.98	1.49
Texture	-1.02	0.17	-0.97	0.18
Log(AADT)	0.57	0.12	0.50	0.14

Proportion of variance explained – 7%

B.5 Bends (S1 and S2)

Table B15: Model coefficients for bends 'dry collisions' model (N=1,241)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-10.44	1.34	-10.58	1.53
Texture	-1.54	0.28	-1.62	0.29
Log(AADT)	0.56	0.12	0.54	0.14
Curvature	n/a	n/a	5.10	2.10

Proportion of variance explained – 8%

B.6 Gradients (G1 and G2)

Table B16: Model coefficients for gradients 'dry collisions' model (N=764)

	GLM		GLMM	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-14.67	2.31	-15.58	2.74
Log(AADT)	0.74	0.22	0.76	0.25

Proportion of variance explained – 4%

Relationship between texture depth and collision risk on the Strategic Road Network

Road surface friction on the Strategic Road Network (SRN) is managed through the requirement to provide appropriate levels of skid resistance and texture depth. Th relationship between skid resistance and collision risk has been established in previous studies; this study focussed on the relationship between collision risk and in-service texture depth as measured by routine network surveys, i.e. laser based measurements of Sensor Measured Texture Depth (SMTD). The results showed that there was a general trend for collision rate to increase with decreasing texture depth, but that this increase was associated mainly with collisions in dry conditions; however, measurements show that dry friction does not appear to vary with texture depth. Therefore, further investigation is recommended to develop a better understanding of other factors that could be contributing to the increase in collision risk such as collision type, contributary factors or human factors. This understanding would then enable strategies to be developed to mitigate the increased risk.

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ISSN 2514-9652

ISBN 978-1-912433-48-3

PPR995