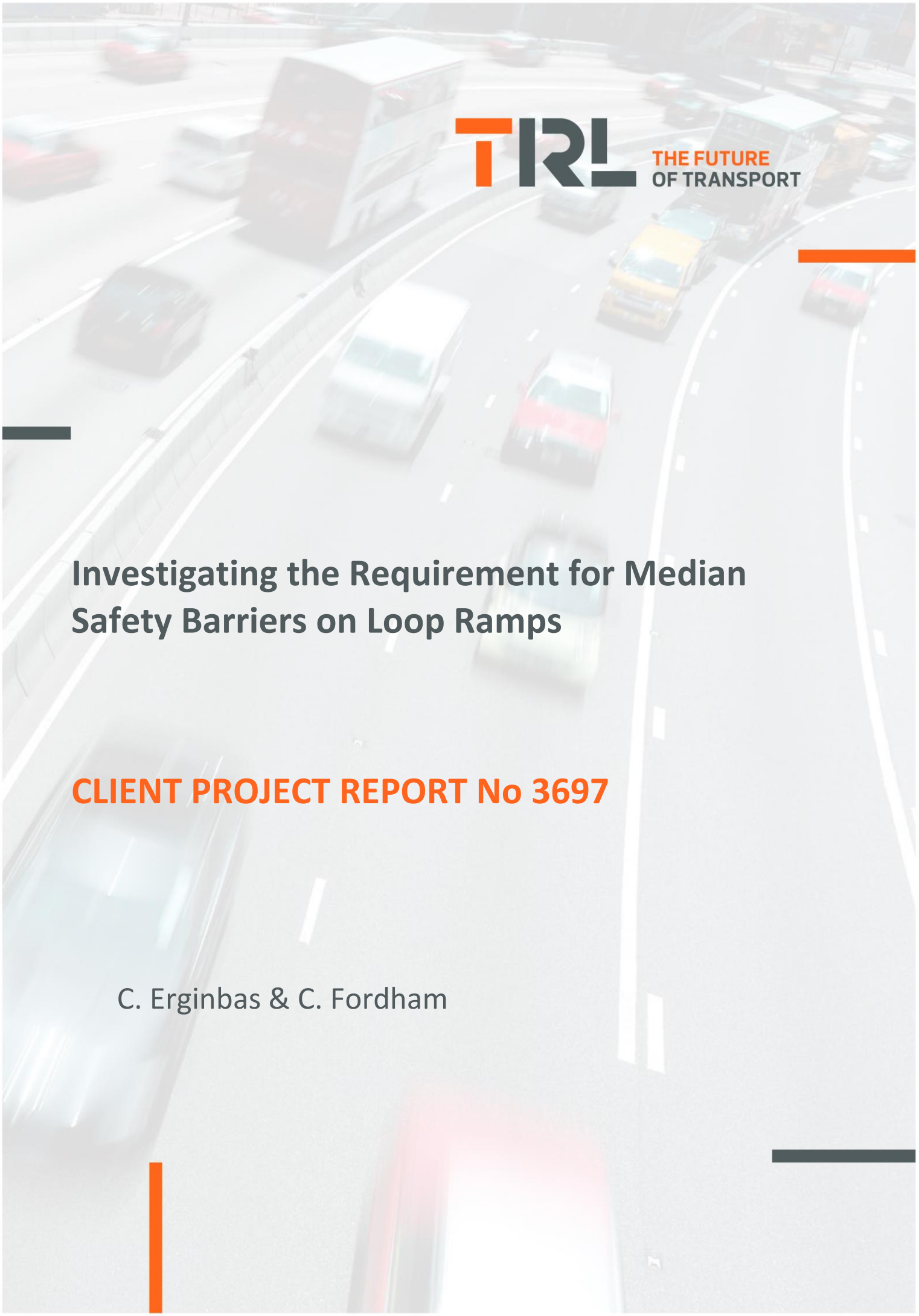

Investigating the Requirement for Median Safety Barriers on Loop Ramps

CLIENT PROJECT REPORT No 3697

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Contents

1 Introduction

1.1 Background

Potential Departures from Standard are currently being discussed for Transport Scotland's A9 and A96 Dualling Projects. These departures specifically relate to a requirement within TD22/06, Clause 5.27, for a physical central reserve with vehicle restraint system on two-way slip roads.

> **TD22/06, Clause 5.27:** "*Two way slip roads must be dual carriageway with opposing traffic separated by a physical central reserve with vehicle restraint system. Two way single carriageway slip roads are not permitted. Two way slip roads only occur at half-cloverleaf and trumpet junctions* (See Figure 1)*. Studies into the safety of tight loops for 2 way slip roads, as compared to one way, indicated that a physical barrier will improve safety and reduce cross-over accidents*." [1]

The aim of this research is to try to find the evidence behind this clause, and to review other studies and literature on the safety impacts of physical barrier provision on two-way loop slip roads, both in the UK and internationally. This has the purpose of forming an evidence base for safety critical design decisions when determining departures relating to this clause.

Figure 1 – Junction Types, Where Two-way Slip Roads Occur, i.e. Trumpet (left) and Half-Cloverleaf (right) [1]

2 Methodology

2.1 Overview

A number of different methods were utilised to help establish the aims of this research. These include:

- Consultation with local and international experts
- A review of international junction applications through satellite images
- An in-depth literature review

Following sections provide a detailed explanation for each of these methods.

2.2 Consultation with Local and International Experts

The search to establish the underlying research behind Clause 5.27 started with a series of consultations with local road safety professionals, who are internationally recognised as experts within their respective fields.

The project team have identified several TRL employees who have been involved in the development of highway geometric design and vehicle restraint system (VRS) standards. TRL have been providing the underlying research for many highway design standards for decades. Therefore, it was thought that one or more of the "studies" mentioned in Clause 5.27 may have been carried out by TRL. It was known to the project team that the Clause 5.27 was introduced in 2006 and therefore the efforts were focused on finding relevant employees who have been working at TRL during and before that time.

Furthermore, Clause 4.10 of TD22/06 refers to a research into loops, which was carried out from 1985 to 1994. It was assumed that the researches mentioned in Clauses 4.10 and 5.27 may be the same. And therefore, during the talks with the TRL experts, these dates were used as a potential reminder to help identify the underlying study.

The result of the consultations has shown that none of these TRL employees were aware of the underlying research or the exact reasons behind the addition of Clause 5.27 to TD22/06.

Further consultations took place with two Highways England employees; which are the current responsibility holders for keeping TD22 and TD19 up-to-date. It was understood that neither of these employees were aware of the underlying research or the exact reasons behind the addition of Clause 5.27 to TD22/06 either.

While carrying out the local consultations, the project team also contacted a number of international road safety professionals, who are one way or another involved in the development or implementation of their country's highway geometric or roadside design standards/guidelines. These consultations did not reveal anything significant to help identify the underlying research for Clause 5.27. However, they did lead to the identification of several concerns which may arise in the absence of a median barrier on a two-way slip road. These concerns were then fed into the literature review and are explained in Section 3 of this report.

2.3 Review of International Applications through Satellite Images

Before contacting a number of international road safety professionals to help identify any international best practice with regards to the installation of median barriers on two-way slip roads, the project team have also carried out a preliminary review of satellite images. The aim of this exercise was to establish an indicative idea about the common patterns with regards to median barrier application on two-way loop ramps, within the same country.

Popular map and geographical information programs were used to review grade separated junction designs through satellite and street level images at several countries, including Ireland, Norway, France, Spain & Italy. The result of this review was generally inconclusive as the project team managed to find examples of two-way loop ramps with and without a median barrier installation for the same type and size of junctions for each of the countries reviewed. Furthermore, the lack of key information such as the traffic volume and speed

limits associated with the junctions under review made it difficult to achieve any meaningful results through this method.

An interesting finding of this exercise was about the design of the junctions on M7 Motorway in Ireland. Substantial sections of the M7 Motorway were built as the result of the N7 dualling project, which was completed at 2010. This route bears similarities to the ones which constitute the A9 and A96 dualling projects. The review of several half-cloverleaf junctions on the newer parts of the route has shown that none of them had a median barrier installed on their two-way loops, even though the Irish National Roads Authority (currently known as the Transport Infrastructure Ireland) accepts TD22/06 as their national standard (with an addendum). A consultation with a TII representative has revealed that the above mentioned half-cloverleaf junctions were designed to TD40, instead of TD22/06. It was explained that the decision to use TD40 was made prior to M7 being confirmed as a motorway, although it was also stressed that such a decision would not be the norm.

2.4 Literature Review

The literature review started with an initial search within the TRL report database; with the hopes of finding the underlying research of Clause 5.27. The dates mentioned in Clause 4.10 of TD22/06 were also used as keywords to help identify any corresponding work. This search, which was carried out by the TRL library, did not reveal a TRL report which is likely to be the underlying research.

A second search was carried out to find any relevant work, which specifically considers the issue of median barrier need on two-way loop ramps. Prior to this second search and review, several areas of interest associated with loop ramps and median safety barriers were identified; these included:

- The effects of ramp type on accident frequency and severity
- The effects of ramp type on the accident type
- Accidents on diverge area
- Run-off-road accidents on loop ramps
- Wrong-way driving at loop ramp junctions
- The effects and safety implications median safety barriers have on different road users
- Alternative barrier installations.

This search also included the review of some of the leading highway geometric and roadside design guides/standards from around the world, including the likes of AASHTO Roadside Design Guide [2], A Policy on Geometric Design of Highways and Streets [3], Austroads Guide to Road Design [4], Norwegian VRS Manual [5], etc.

Unfortunately specific research concerning the use of median safety barriers on loop ramps could not be found, with the majority of the relevant research based on comparisons between several different junction types; the bulk of which was based on studies carried out in the United States.

At this point it was understood that a new approach would be required to be able to generate useful recommendations for SRRB, with regards to the safety effects of median barrier provision on loop ramps. This new approach was based on a pattern observed within the various reviewed literature. It was observed that majority of the literature divided loop ramps into different sections and focussed on specific types of accidents observed in different sections of a ramp. It was also observed that some of these accident types are more likely to be affected by the lack of a median barrier on the loop, than the others.

As a result, it has been decided to divide a two-way loop ramp into three sections of safety concern, as shown in Figure 2, and then to review the need for a median safety barrier for each. These sections are the diverge areas (or the off-ramps), the loop sections themselves and the at-grade junctions located at the end of the loops.

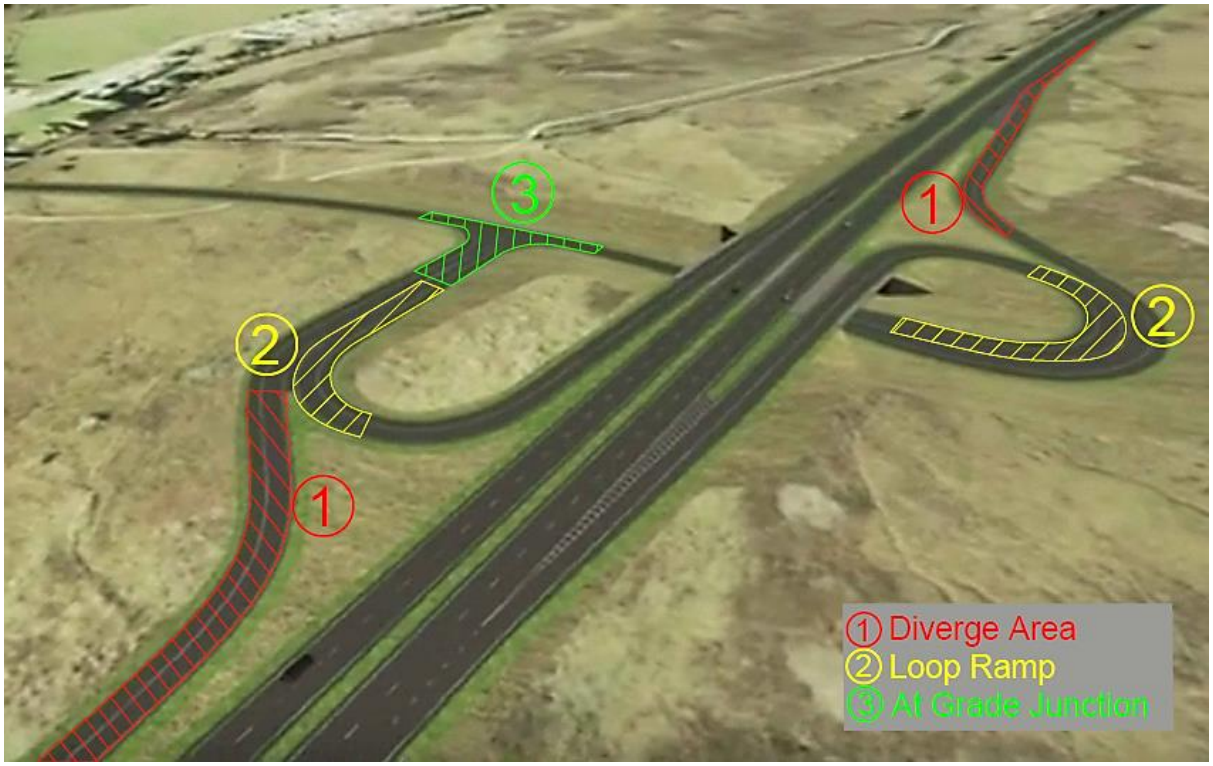

Figure 2 – Areas of Concern on Two-Way Slip Road Layouts from a Perspective of Median Barrier Provision[1]

The following Sections present a summary of the literature review for each of the three areas of concern, from the perspective of the potential effects of median barrier provision.

[1] The image on the background shows a potential layout for the Dalwhinnie Junction; as part of the A9 dualling project. [18]

3 Literature Review Summary on the Safety Implications of Applying Median Safety Barriers on Loop Ramps

3.1 Issues with Diverge Areas

Exit ramps have been shown to be prime locations for run-off-road accidents, over numerous studies. The common scenarios involve vehicles leaving the main dual carriageway with excessive speeds, fail to adapt the speed to the requirements of the ramp or the weather conditions and lose control at the first bend. This scenario often involves vehicles running off the road or hitting a roadside barrier, if one is positioned along the bend. In case of certain half-cloverleaf and trumpet junction layouts, the off ramp leads to the two way loop ramp. Therefore in such locations, the lack of a barrier clears the way of an errant vehicle to reach the traffic flowing on the opposite side. This in turn brings the risk of head-on or side-impact accidents, as shown in Figure 3. This risk would naturally increase or decrease depending on factors such as the traffic volume, junction geometry, surface friction, etc.

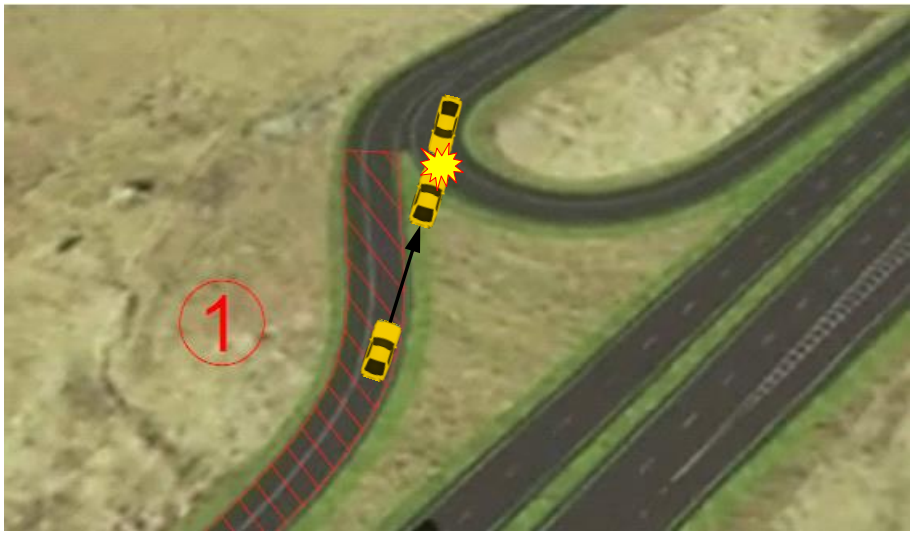

Figure 3 – A Potential Result of a Lack of Median Barrier around the Diverge Areas of Two-Way Slip Roads

In such locations, the common application is to elongate the median barrier placed in the middle of the loop to the diverge area and therefore offer protection to this section as well. One may argue, that the necessary protection for these areas can be provided with a separate barrier along the bend and this barrier can then be terminated with a crash-worthy terminal before reaching the two-way loop ramp; Thus eliminating the need for a median barrier provision on the loop. However, it should be remembered that such an application would be limited by the installation requirements of the VRS system, such as the minimum length of installation needed and the maximum impact angle a terminal is designed to safely contain.

This section provides a summary of the literature review findings, which are related to this specific area of concern.

Numerous factors affect road users' safety at diverge, or off-ramp, areas such as diverge or ramp type, design speed, traffic volume and lane length [6], and several earlier studies found that different ramp types can have significant and varying impacts on road user safety [7] [8] [9]

Data from the United States Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) from 2001 indicated that 83% of interchange crashes occurred on entrance or exit ramps [10]. However, Khorashadi [11] and Lundy [7] analysed crashes on urban and rural freeway ramps in California and found that exit ramps were more crash-prone than entrance ramps in terms of both frequency of crashes and average crash rates.

Chen, Lee and Lin [6] analysed motorcycle crash data at 419 different ramp sites in Florida from 2005 to 2010 and found that loop exits had one of the highest average crash frequencies of 1.44 crashes per site (See Table 1).

Table 1 - Summary of motorcycle crash frequency and crash rate by ramp exit type.

Ramp type	Number of sites	Crash Frequency (2005-2010)			Crash Rate (crashes per million vehicles per mile per day)	
		Total	Mean (Crashes/site)	Std.	Mean	Std.
Diamond Exit	178	213	1.19	0.52	0.55	0.55
Directional Exit	71	102	1.43	0.75	0.61	0.86
Loop Exit	85	122	1.44	0.64	0.97	1.23
Outer Connection Exit	85	136	1.60	0.97	0.77	0.71

Additional injury severity data showed that the highest percentage (6.56%) of fatal motorcycle crashes occurred on loop exits and this is supported by preliminary analysis undertaken by a research team in Florida from 2005 to 2010 who deduced that approximately 80% of reported motorcycle crashes at exit ramps resulted in injury or death. These findings would suggest that loop exit ramps are particularly hazardous for motorcyclists and may be attributed to the fact that, among other factors, motorcyclists have more difficulty reacting to and negotiating geometric changes at greater speeds [6]. The research undertaken by Chen, Lee and Lin also involved a motorcyclist web-based survey to understand motorcyclists' perceptions and attitudes towards the different exit ramp types. Of the 234 surveys, approximately 60% (145 respondents) of respondents deemed loop exits to be the most dangerous exit type.

McCartt, Northrup and Retting [10] examined a sample of 1,150 crashes that occurred on high flow, urban interstates in Northern Virginia and found that approximately 50% of all crashes occurred when at-fault drivers were in the process of exiting interstates. Three major crash types, run-off-road, rear-end, and sideswipe, accounted for 95% of crashes in the study and run-off-road crashes were most frequently associated with exiting interstates. This type of crash most commonly occurred when vehicles were exiting interstates at night,

in poor weather conditions or on curved ramp sections. Similarly, the most crash-prone situation took place when vehicles exited short, curved ramps (See Table 2).

Table 2 - Percentage of crashes on ramps and the distribution of crash types by ramp design [10]

Crash type	Ramp design				
	Cloverleaf (n=158)	**Short curve** (n=351)	**Long curve** (n=129)	**Partial loop** (n=83)	**Straight** (n=51)
Run-off-road	44	57	48	34	27
Rear-end	41	27	38	45	61
Sideswipe	10	11	8	14	10
Other	6	4	6	7	2
Total	100	100	100	100	100

One possible explanation for the high number of exit ramp crashes could be attributed to high vehicle speeds entering ramp curves [12] as well as possible ramp design issues. McCartt, Northrup and Retting's [10] study also examined the types of crashes on enter and exit ramps (See Table 3).

Table 3 - Percentage of crashes on ramps by travel direction and crash type [10]

Crash type	Travel direction	
	Exit (n=402)	**Enter** (n=284)
Run-off-road	54	42
Rear-end	31	48
Sideswipe	10	8
Other	5	2
Total	100	100

Run-off-road accidents were most prevalent on exit ramps, particularly on cloverleaf, short curve and long curve ramps. This emphasises the need for safety engineering treatments in such areas.

The effects different ramps types have on heavy goods vehicles (HGVs) has also been analysed by Janson et al. [13], who evaluated 644 ramps in Washington State where at least one HGV accident occurred during the study period (January 1993-March 1995); comparisons with limited data from ramps in Colorado and California were also made. Table 4 shows that almost 25% of HGV off-ramp accidents occurred on loop ramps, with the highest numbers occurring on directional ramps.

Table 4 - Numbers and percentages of Washington State HGV accidents by ramp type [13]

Ramp type	Number of off-ramp accidents	Percent of off-ramp accidents
Diamond	23	19
Loop	30	24.8
Outer Connection	12	9.9
Directional	48	39.7
Other	8	6.6

Table 5 shows that in terms of the number of off-ramp accidents by conflict area, the diverge ramp constituted the highest (28.3%) percent of accidents, with the downstream area also displaying a high figure (26.3%). The research also states that rollover accidents are most likely to occur at loop off-ramps which may be attributed to the greater curvatures witnessed on loop ramps.

Table 5 - Washington State HGV accidents by conflict area [13]

Off-ramp accidents	Number of accidents	Percent of accidents
Diverge ramp	131	28.3
Downstream of diverge	122	26.3
Off-ramp	91	19.7

3.2 Issues with the Loop Ramp

The second area of concern from the perspective of a median barrier need is the loop ramp itself. As shown in Figure 4, the concern in these areas is mainly associated with vehicles travelling in the inner section of the loop. A vehicle running off the road from the inner lane of the loop is expected to continue to the outer lane, in the case of a lack of median barrier. This in turn brings the risk of a head-on collision with another vehicle travelling on the outer lane. The risk of such a scenario would increase or decrease, depending on factors such as the traffic volume, speed, horizontal & vertical alignment of the loop and the surface condition.

The studies mentioned in the previous section have already shown that the loop ramps are areas of high accident concentration, with the most common type of accident being the run-off-road. This section provides further information from the literature review findings, which are related to this specific area of concern.

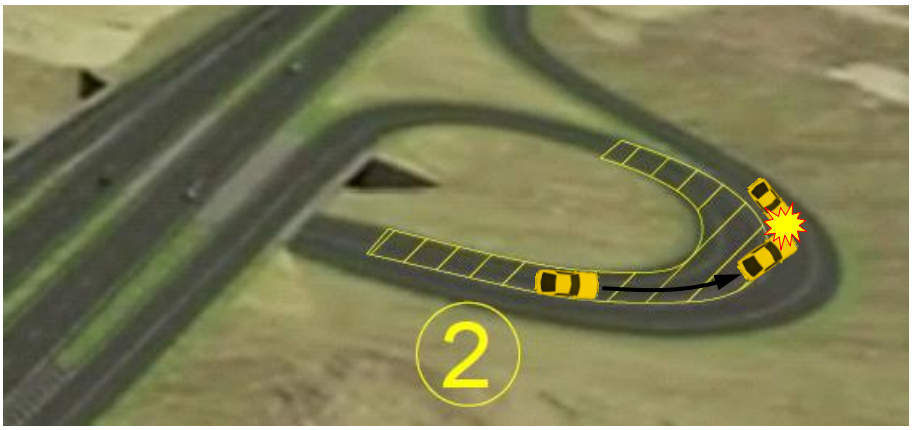

Figure 4 - A Potential Result of a Lack of Median Barrier along the Loop Section of Two-Way Slip Roads

A study by Erginbas and Williams [14] looked at the motorcycle-to-barrier impacts on the Highways England Network between 2010 and 2012. Analysis of all single vehicle run-off-road accidents within STATS-19 database has revealed a total of 173 cases where a motorcyclist hit the barrier. These accidents were then categorised and listed according to the type of road layout on which they occurred, as shown in Figure 5.

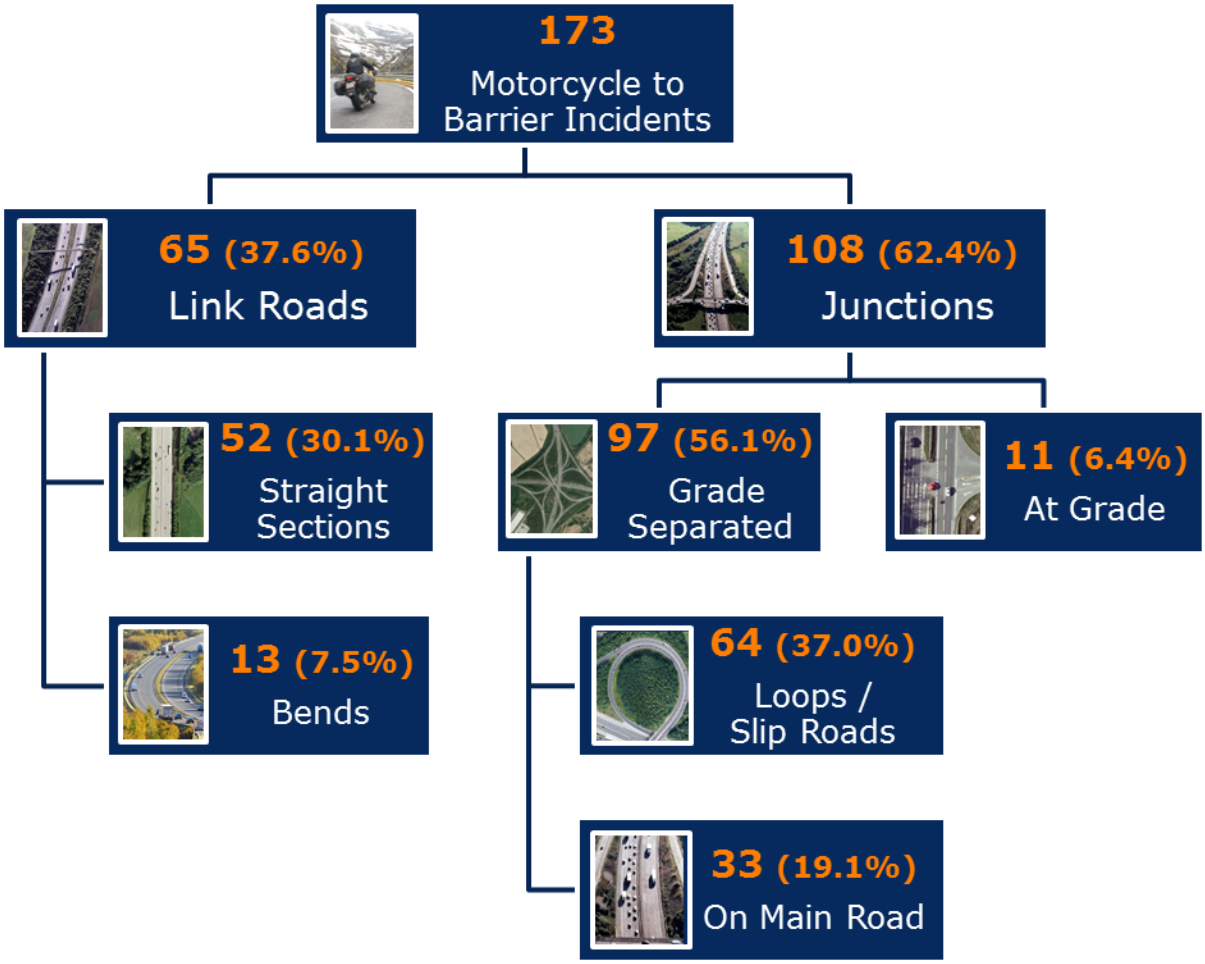

Figure 5 – Distribution of Injurious Motorcyclist-to-Barrier Accidents on Highways England Road Network (2010-2012) [14]

As can be seen from Figure 5, more than half (56%) of these incidents occurred on grade separated junctions, including the half-cloverleaf and trumpet designs, which incorporate a two-way loop ramp. Furthermore, it was shown that 37% of all single vehicle motorcycle-to-barrier type accidents on the Highways England Network happened on other slip roads, with a majority of them being loops. This supports the idea that slip roads, and especially loops, are prime locations for run-off-road incidents.

Erginbas and Williams [14] have also identified the incident clusters on the Highways England Network, where two or more motorcycle-to-barrier impact occurred within a 500m radius. The results have shown that 5 of 8 clusters identified were located on loops, with 3 of them being two-way loops.

Motorcyclists are more vulnerable, can react differently, and can also be more sensitive to grades and curvatures on ramps [8], [15]. At loop exits, there is a 50% probability of motorcyclist crashes occurring in the main ramp section [6].

From the perspective of a motorcyclist, who is sliding on the ground after losing control of the bike, a median barrier does not provide an ideal protection. Therefore one may argue that placement of median barriers on two way loops actually increase the risk for errant motorcyclists. The fairness of this argument would depend on the traffic volume on the loop and therefore the probability of another vehicle being on the outer lane while the errant motorist is crossing its path. It is not possible to protect an errant rider from a vehicle travelling on the opposite direction; however the median barrier can be made less dangerous for riders, by installing an appropriate motorcyclist protection system.

3.3 Issues with Loop Ramp Junctions

The third area of concern from the perspective of a median barrier need is the at-grade junction located at the end of the loop ramp for some half-cloverleaf designs. The main concern about these junctions is the potential issue of ‘wrong-way driving’, as shown in Figure 6. Partial cloverleaf interchanges (with their two-way entrance and exit ramps located close together) are among the interchanges most prone to wrong-way driving crashes [16]. Studies show that, the lack of a physical barrier on these junctions increase the risk of wrong-way driving. The provision of median barrier on two-way loops is therefore relevant from the perspective of these incidents. This section provides a summary of the literature review findings, which are related to this specific area of concern.

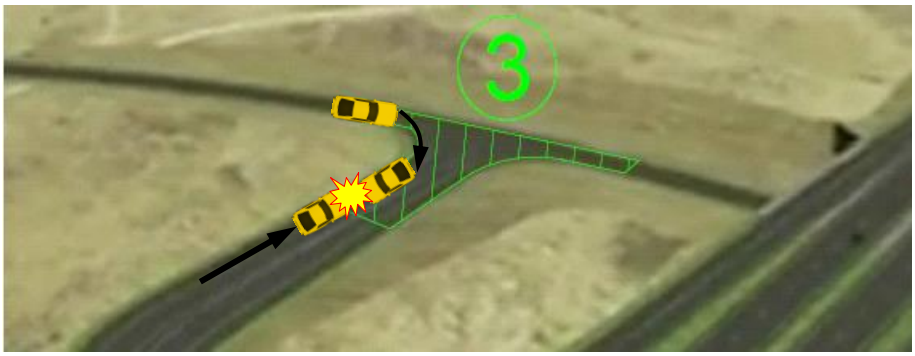

Figure 6 - A Potential Result of a Lack of Median Barrier around the At-Grade Junction Section of Two-Way Slip Roads

A study by the U.S. Federal Highway Administration and the Michigan Department of Transportation has identified 110 crashes caused by wrong-way-driving on the Michigan freeway system from 2005 to 2009. This study was later reported by Morena and Leix [17]. Of the 110 identified crashes, the wrong-way point of entry was known for 35 cases. In these 35 cases, the most common type of junction where the wrong-way entry occurred were the half-cloverleaf (21 cases) and the trumpet (4 cases); the types which are concerned within TD22/06 Clause 5.27.

Zhou and Pour-Rouholamin [16] collected and analysed a six-year period of crash data from 2004 to 2009 in an attempt to identify contributing factors regarding wrong-way driving crashes on Illinois freeways. From their study, a total of 217 wrong-way driving crashes were used to determine contributing factors. Based on their findings, a series of geometric considerations were offered to control access near interchange areas and to handle the wrong-way issues. The considerations included using raised medians and channelizing islands and increasing the distance from the gore of the exit ramp to the entrance ramp for partial cloverleaf interchanges. A non-traversable median on a crossroad is an effective treatment to discourage wrong-way left-turn entry onto diamond, partial cloverleaf, and full cloverleaf interchanges. This modification is sometimes implemented by narrowing median openings on arterial highways, making left-turn movements onto exit ramps extremely difficult.

The presence of raised medians or median barriers between two abutting exit and entrance ramps (i.e., in trumpet interchanges) can help avoid wrong-way entries. In addition, uniform lighting levels for both entrance ramps and exit ramps facilitate drivers' vision of the intersection, improve their perception of intersection configuration, and lessen, if not eliminate, the possibility of wrong-way movements. Three characteristics of medians are critical to their role in wrong-way driving mitigation, i.e., their type (traversable or non-traversable), their opening, and their width. While the first two characteristics are important for medians on a crossroad, the latter is of importance for the medians between two abutting exit and entrance ramps at partial cloverleaf interchanges.

From this perspective, the provision of a median barrier on the entrance of two-way loop ramp can be seen as way of delineating and channelizing the traffic to prevent wrong-way drivers. On the other hand, if not placed properly, it can also be a contributor of the wrong-way driving problem, as it would add to introduce visibility problems. The median barrier needs to be terminated before the stop line, i.e. the entrance of the junction, so that both entrance and exit lanes of the loop ramp are clearly visible, especially for the right-turning traffic, as shown in Figure 6. This helps prevent any confusion by the driver entering the loop.

Following their study, the Michigan Department of Transportation applied longitudinal channelization devices on the entry to a problematic the two-way ramp, identified in the study. This problematic area had 29 incidents in the year of 2010. There were no crashes the year following the installation of longitudinal channelization devices [16].

The problem of wrong-way driving on half-cloverleaf junctions was also raised by a representative of the Transport Infrastructure Ireland, during the international consultations for this research. Although exact numbers were not provided, it was mentioned that wrong-way driving is a very common problem in Ireland. When discussing the lack of median

barriers on the loops of the half-cloverleaf junctions located on M7, the Irish representative have pointed out that flexible bollards (similar to the channelization devices used in Michigan) were being used between the opposing lanes to increase delineation and help mitigate the risk of wrong-way driving in these locations. This is being seen as an effective and low-cost alternative to the provision of a median barrier.

4 Conclusions & Recommendations

The aim of this research was to try to find the underlying research behind Clause 5.27 of TD22/06 and any other literature, which would shed light onto the safety impacts of physical barrier provision on two-way loop slip roads.

Despite an extensive literature search and consultations with national and international road safety professionals, the project team could not identify the underlying research behind Clause 5.27.

However, considerable amount of information was found within the literature, with regards to the specific areas of safety concern, which occur on two-way loop ramps. The literature review has shown that the loop ramps are areas of higher accident concentration, with run-of-road being one of the most common types.

The three potential issues identified with regards to a lack of median barrier on a two way loop were:

- Cross-over incidents caused by vehicles running off the road from the end of the off-ramps, i.e. the diverge areas
- Cross-over incidents caused by vehicles running off the road from the inside lane of the loops
- Wrong-way driving incidents caused by a lack of delineation around the at-grade junctions located at the end of two-way loops

The project team believes that the provision of an adequately placed median barrier on a two-way loop ramp is likely to help mitigate these risks and provide a higher level of safety. However, it is also understood that the level of risk, and therefore the level of the increase in safety gained by median barrier provision on a two-way loop ramp, would vary considerably based on factors such as the traffic volume, speed and ramp geometry. For example with low traffic volumes, even if a vehicle runs off the road into the opposite lane, the chances of another vehicle being on the opposite lane at the same time would be low. Likewise, the chances of a cross-over accident increases with the increasing traffic volume. From this perspective, the cost effectiveness of median barrier provision on the two-way loop will also depend on the level of risk and hence the traffic volume, speed and road geometry. However, the literature review carried out as part of this research, did not yield any results into the levels of risk parameters, after which the provision of a median barrier would be justified. From this perspective, it is recommended for SRRB to carry out a research into quantifying the risks associated with these types of loops for the traffic

conditions observed in Scotland. One such study may include development of a safety performance function and a run-off-road prediction model.

Should Transport Scotland decides to go through with the departure from standard for their half-cloverleaf and trumpet junctions located on A9 and A96 dualling projects, it is recommended that they should at least consider the following safety precautions:

- Installation of a barrier should be considered along the bends located at the end of off-ramps. In case of such installations, consideration should be given to potential impact angles with the crashworthy terminal and the impact performance limitations of the system used.
- Delineation devices, such as flexible bollards, should be provided between the opposite lanes on the entrance to the at-grade junctions located at the end of the two-way loop. This should be done to help mitigate the risk of wrong-way driving.

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