



## TII268 OPEN RESEARCH CALL

# LOT 6: LIFESPAN OF STEEL SAFETY BARRIERS

### FACTUAL REPORT



MGT0613RP0002  
P02  
15 October 2024

**FACTUAL REPORT**

<b>Document status</b>					
<b>Version</b>	<b>Purpose of document</b>	<b>Authored by</b>	<b>Reviewed by</b>	<b>Approved by</b>	<b>Review date</b>
P02	Final	DT	PC	ROC	15/10/2024

<b>Approval for issue</b>	
ROC	15 October 2024

© Copyright R P S Group Limited. All rights reserved.

The report has been prepared for the exclusive use of our client and unless otherwise agreed in writing by R P S Group Limited no other party may use, make use of or rely on the contents of this report.

The report has been compiled using the resources agreed with the client and in accordance with the scope of work agreed with the client. No liability is accepted by R P S Group Limited for any use of this report, other than the purpose for which it was prepared.

R P S Group Limited accepts no responsibility for any documents or information supplied to R P S Group Limited by others and no legal liability arising from the use by others of opinions or data contained in this report. It is expressly stated that no independent verification of any documents or information supplied by others has been made.

R P S Group Limited has used reasonable skill, care and diligence in compiling this report and no warranty is provided as to the report’s accuracy.

No part of this report may be copied or reproduced, by any means, without the written permission of R P S Group Limited.

**Prepared by:**

**RPS**

**Prepared for:**

**TII**

Dublin | Cork | Galway | Sligo | Kilkenny  
 rpsgroup.com

RPS Group Limited, registered in Ireland No. 91911  
 RPS Consulting Engineers Limited, registered in Ireland No. 161581  
 RPS Engineering Services Limited, registered in Ireland No. 99795  
 The Registered office of each of the above companies is West Pier  
 Business Campus, Dun Laoghaire, Co. Dublin, A96 N6T7



## FACTUAL REPORT

---

# Contents

<b>1</b>	<b>INTRODUCTION .....</b>	<b>1</b>
1.1	Background .....	1
1.2	Project Scope .....	1
1.3	Project Team .....	1
<b>2</b>	<b>OBJECTIVES OF THE PROJECT .....</b>	<b>3</b>
2.1	Specific Aims .....	3
2.2	Context to Project Objectives .....	3
2.3	Challenges .....	3
<b>3</b>	<b>METHODOLOGY .....</b>	<b>5</b>
3.1	Literature Review .....	5
3.2	Identify VRS Test Locations .....	5
3.3	Testing .....	8
3.4	Output of Results & Analysis .....	9
<b>4</b>	<b>RESULTS .....</b>	<b>10</b>
4.1	Probe Test Results .....	10
4.2	SEM Test Results .....	11
<b>5</b>	<b>DISCUSSION .....</b>	<b>12</b>
5.1	Comparison of Positector Probe and SEM Results .....	12
5.2	Baseline .....	12
5.3	VRS Age: 20-25 Years versus 25+ Years .....	13
5.4	Urban, Rural, Coastal .....	13
5.5	Non-Motorway vs Motorway .....	13
5.6	Future Maintenance .....	14
<b>6</b>	<b>CONCLUSIONS .....</b>	<b>15</b>
<b>7</b>	<b>RECOMMENDATIONS .....</b>	<b>16</b>

**Appendix A** - Test Locations

**Appendix B** - TU Dublin Reports

**Appendix C** - Test Results

# 1 INTRODUCTION

This report summarises the findings of a research project carried out on behalf of Transport Infrastructure Ireland (TII) under their Open Research Call 2021 to assess the lifespan and residual durability of older steel vehicle restraint systems (VRS).

## 1.1 Background

The efficient management of the Irish national road network is of primary importance to ensure its ongoing functionality. With 5,300km of national roads under its management, TII is continually faced with challenging strategic decisions concerning the appropriate allocation of limited resources.

VRS (or safety barriers) play an integral part in delivering safe roads, which in turn contributes to one of TII's strategic goals – "safety: to reduce the risk and number of collisions, injuries and deaths on our... road infrastructure" (*TII's Statement of Strategy 2021-2025*).

While VRS systems come in different forms and materials, this study focusses on steel safety barriers systems (excluding wire rope). Currently there is approx. 1,600,000m of such barrier on the national road network. In order to more efficiently manage this particular asset, it is necessary to understand what lifespan these systems can achieve in Irish conditions.

In this era of the Construction Products Regulation, every CE marked barrier comes with a declared durability. Durability is an essential characteristic of VRSs in accordance with EN1317-5. It is declared indirectly in terms of galvanisation of the steel. Most manufacturers report on their certificates that their steel is galvanised in accordance with EN ISO 1461 and most of the barrier systems are marketed with serviceable life span of 20 years.

After 20 years in service, most VRS are still functional. However, it is unclear at what stage it becomes necessary to replace them as part of preventative maintenance. It is also not known whether prolonged exposure to Irish weather conditions affects durability, or if exposure to marine environments, such as on coastal roads, results in more degradation over time. These are questions which this study aims to answer especially given that VRSs play a crucial role in protecting road users from roadside hazards.

## 1.2 Project Scope

This research project was originally envisaged to comprise 3 separate studies:

1. **National study on zinc corrosion of old steel safety barriers** - to determine how much the galvanisation on steel barriers deteriorates over time as a result of atmospheric corrosion and at what stage should they be replaced in a preventative maintenance regime.
2. **Study of zinc corrosion in specific locations** - to determine if exposure to different environments (e.g. coastal, damp, under structures) affects the corrosion rate.
3. **Case study on the effect of exhaust fumes on galvanisation on high trafficked roads** - to determine the impact (if any) of exhaust fumes, and specifically sulphur dioxide, on the rate corrosion of zinc galvanisation.

Due to programme and budgetary constraints, the scope of the project and the proposed methodologies were refined. It was decided that Study 1 & 2 would be progressed and Study 3 would be omitted.

## 1.3 Project Team

The requirements set out by TII for the project required a Project Team comprised of highly experienced specialists from different fields within the industry who would work in partnership to deliver this unique piece of research. The Project Team which was selected for the delivery of this research is summarised as follows:



Figure 1.1 – TII Statement of Strategy 2021-2025 (TII)

## FACTUAL REPORT

**Table 1.1 – Project Team**

Team Requirements	Individuals	Provider
<b>Core Team</b>		
<b>Civil Engineer (CEng) with:</b>		
<ul style="list-style-type: none"> <li>- Specialist knowledge in road &amp; VRS design</li> <li>- Min. 10 years' experience incl design/ installation/ operation of VRS</li> <li>- Trained VRS designer</li> <li>- Familiar with TII's VRS design standards</li> <li>- Knowledge of Irish national road network</li> </ul>	<ul style="list-style-type: none"> <li>• Rowan O'Callaghan</li> </ul> <p><u>Supported by:</u></p> <ul style="list-style-type: none"> <li>• Padraic Culkin</li> <li>• Dylan Trant</li> <li>• Conall Boland</li> </ul>	<p><b>RPS</b>  <a href="http://www.rpsgroup.com">www.rpsgroup.com</a>            Highly experienced and trained in VRS design, specification, maintenance, project management, health and safety, with proven track record of working with TII and local authorities on VRS programmes and research projects for over 10 years.</p>
<b>Materials Specialist or Metallurgist with;</b>		
<ul style="list-style-type: none"> <li>- Min 10 years' experience</li> <li>- Specialist knowledge in galvanisation</li> <li>- Membership of Galvanisers Association UK and Ireland</li> <li>- Experience in research</li> </ul>	<ul style="list-style-type: none"> <li>• Dr Desmond Makepeace</li> </ul> <p><u>Supported by:</u></p> <ul style="list-style-type: none"> <li>• Iqbal Johal</li> </ul>	<p><b>Galvanizers Association</b>  <a href="http://www.galvanizing.org.uk">www.galvanizing.org.uk</a>            Representative body for hot dip galvanizing industry in UK &amp; Ireland, providing authoritative information and advice on hot dip galvanizing since 1949.</p>
<b>Support Team</b>		
<b>Team of Engineers &amp; Technicians &amp; Testing Specialists</b>		
	<ul style="list-style-type: none"> <li>• Brendan Duffy</li> <li>• Joseph Mohan</li> </ul>	<p><b>CREST, TU Dublin</b>  <a href="http://www.tudublin.ie">www.tudublin.ie</a>            Ireland's only dedicated surface coatings nationally approved laboratory with 60 years' experience and has worked with many Irish government bodies.</p>
<b>VRS Installer:</b>		
<ul style="list-style-type: none"> <li>- Current member of TII's VRS Installer Framework</li> </ul>	<ul style="list-style-type: none"> <li>• Michael Broderick</li> <li>• Kevin Torsney</li> </ul>	<p><b>Lagan O&amp;M</b>  <a href="http://www.laganoandm.com">www.laganoandm.com</a>            Specialist experienced VRS installer with knowledge/access to most VRS systems. On TII's VRS Framework. Maintenance contractor on TII's VRS regional term maintenance contract.</p>

## 2 OBJECTIVES OF THE PROJECT

### 2.1 Specific Aims

The aims of the research were:

1. To assess the residual durability of steel safety barriers after 20 years in operation and older;
2. To determine whether different environmental conditions affect this durability; and
3. To assist TII to maximising their existing VRS assets, planning for future maintenance, making the best use of resources, and reducing carbon emissions.

### 2.2 Context to Project Objectives

One of TII's stated goals is to operate, maintain and extend the life of national roads infrastructure to ensure the safety and efficiency of Ireland's road network, but also to ensure appropriate management of environmental resources and contribute to the transition to a low-carbon and climate resilient society (*TII Statement of Strategy 2021 to 2025*).

To achieve this goal, TII must maintain its existing assets to ensure function and safety (i.e. protecting road users from roadside hazards) while at the same time extending asset life to deliver a more sustainable network and a more efficient use of limited resources.

This research project (TII 268 Lot 6: Lifespan of Steel Safety Barriers) is closely aligned to this goal. By gaining an understanding of the lifespan of a network-wide asset such as steel safety barriers (over 1,600km on the network), and knowing when they reach the end of their functional life, TII can not only maximise the use of the asset but be more efficient in terms of planning future maintenance, expending resources, and reducing carbon emissions.

The specific focus of this research project is on older steel safety barriers which were installed prior to the introduction of European performance-based systems which now come with manufacturer-defined lifespans. Many of these older systems are non-proprietary British standard systems commonly referred to as open box beam, tensioned corrugated beam and untensioned corrugated beam (OBB, TCB and UCB). Some newer systems tested and specified to EN1317 may also fall into this age bracket. As these systems were installed on Irish roads from circa 1970 to 2002, many of them have been in place for between 20 and 50+ years.

The durability and therefore residual life of these old barriers is directly related to the condition of their galvanizing zinc coating. If this coating continues to provide protection to the steel components of the barrier system (e.g. beams, posts, bolts, washers, spacers, etc), then the system may be capable of providing more years of service. If the zinc coating has deteriorated, then the function will be affected, and preventative maintenance will need to be programmed to ensure road safety is not compromised.



Figure 2.1 – Examples of old Open Box Beam (OBB) and Tensioned Corrugated Beam (TCB) barriers

### 2.3 Challenges

The following challenges were anticipated at the outset of the project:

- **Locating barriers and identifying their age** - Identifying and sourcing sufficient numbers of VRS of the ages and categories specified in order to form a representative sample of the existing asset stock. It was a particular challenge to identify motorway sites in urban areas which were installed over 25 years ago and to identify motorway sites that could be classed as coastal.

## FACTUAL REPORT

---

- **Distinguishing between materials** - Ensuring the correct identification of the galvanised zinc layer and the steel substrate, such that measurements are accurate.
- **Galvanizing degradation profile** - Understanding of the profile of zinc coating given that testing samples start at 20-year-old installations.

Each of the above challenges and limitations were addressed by the methodology developed for the project by the Project Team.

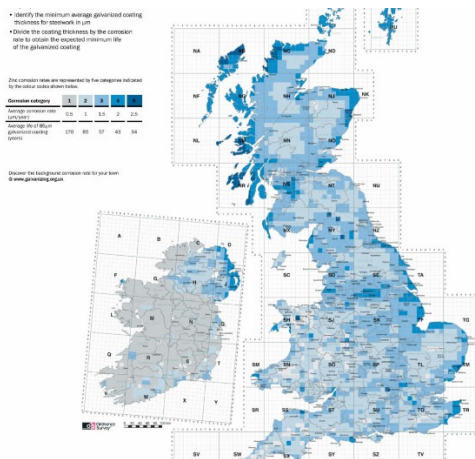
## FACTUAL REPORT

### 3 METHODOLOGY

The following is a summary of the approach taken to conduct Studies 1 and 2.

#### 3.1 Literature Review

- Previous relevant research on zinc degradation was identified and reviewed. This included a review of current standards, specifications, research papers and publications. Some of the key findings include:
  - For National Roads in Ireland, all components of metal VRS must achieve a serviceable life of not less than 20 years through galvanising to IS EN ISO 1461;
  - Atmospheric corrosion of galvanised steel is mainly influenced by the content of sulphur dioxide in the air in combination with humidity. Therefore, the durability of galvanised steel in outdoor applications is directly proportional to the thickness of the zinc coating;
  - Based on zinc corrosion rates for different environments (from BS EN ISO 14713) and the Zinc Millenium Map of Annual Average Atmospheric Corrosion of Zinc across the UK and Ireland (from the Galvanisers Association), the corrosion rates across large areas of the UK and Ireland are between 0.1 and 2µm/year. For the purposes of this research project the more conservative rate of 2µm/year will be assumed. However, in situations where de-icing salts are used, this could increase the corrosion rate;



**Figure 3.1 –Zinc Millenium Map of Annual Average Atmospheric Corrosion of Zinc: Galvanizers Association. Darker blue represents higher annual zinc corrosion rate.**

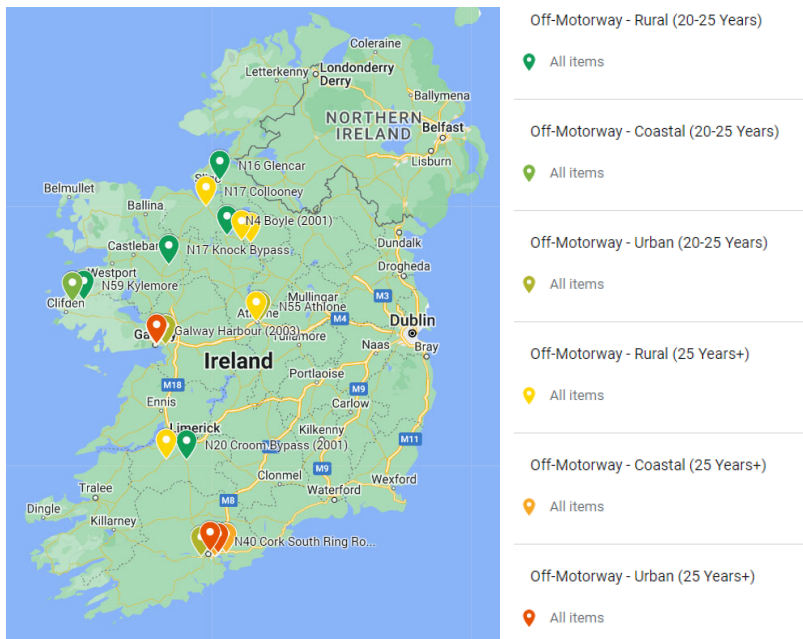
- Atmospheric corrosion rates have generally decreased due to improvements in air quality across Europe in recent decades, including significant reductions of sulphur dioxide. This enables a more economical use of zinc; and
- There is limited research available on the performance of zinc coatings on steel safety barriers or crash barriers globally. Most of the related research relates specifically to hot dip galvanising processes and galvanised steel for structural engineering applications.

#### 3.2 Identify VRS Test Locations

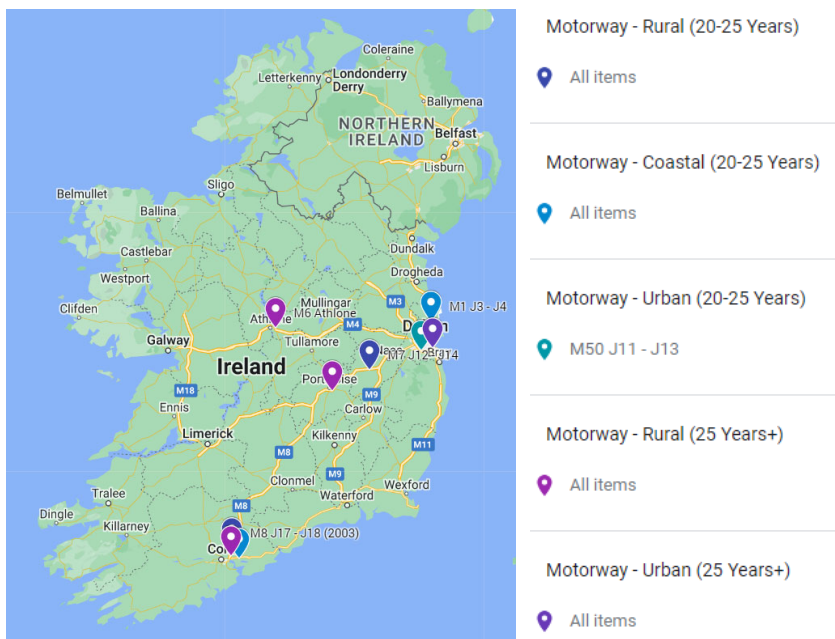
- All available existing VRS asset databases were obtained and forensically reviewed in order to identify schemes, locations and interventions with VRS of the appropriate age profile. This included:
  - TII's Pilot regional maintenance VRS database covering national roads in counties Sligo, Leitrim, Roscommon and Mayo;
  - Existing MMarC and PPP asset databases;
  - Local Authority data on historical road schemes where available;
  - Lagan O&M's database of previous VRS projects;

**FACTUAL REPORT**

- RPS’s database of previous VRS projects and historic road schemes.
- Based on their age profiles, candidate locations were shortlisted and mapped in GIS in order to identify their location, assess their environmental category (e.g. coastal, urban, rural, etc), and to plan site testing.



**Figure 3.2 - Non-Motorway VRS locations by age and location**



**Figure 3.3 - Motorway Locations by age and location**

- Site visits (both in-person or virtual) were carried out to confirm that old VRS were still in place and available/suitable for testing as necessary.
- 32 No. VRS locations were ultimately selected across the combined motorway and non-motorway networks for testing, all of which were aged between 20 and 25 years, or greater than 25 years. It should be noted that in the ‘greater than 25 years old’ category, there were a few sites that were likely significantly greater than 25 years old and possibly represent upwards of 40 years in service. However, for simplicity, it was decided to maintain the two distinct categories.

## FACTUAL REPORT

- Of these 32 No. locations, 5 No. were selected as sites from which samples would be extracted for laboratory testing. The type and performance of the VRS at these locations was confirmed and appropriate replacement components and materials were ordered.
- In order to set a baseline for VRS galvanisation, 4 No. reference VRS systems, manufactured by either Aximum or Vetex, were provided to TU Dublin's laboratory. These systems were to be analysed to provide a benchmark for galvanised coating. These included a brand-new barrier as well as 5 to 10 year old Aximum and Vetex systems.

**Table 3.1 - VRS test locations**

	Test Location	Location / Environment Type	Age
1*	N3 Cavan-0042	Rural	20-25
2	N4 Carrick-on-Shannon (east)	Rural	25 +
3	N4 Carrick-on-Shannon (west)	Rural	25 +
4	N4 (near Boyle)	Rural	20-25
5	N4 (N17)	Rural	25 +
6	N4 (N61 near Athlone)	Rural	25 +
7	N4 (R394)	Rural	25 +
8	N4 Junction 17 'south'	Urban	20-25
9	N4 Junction 14 'north'	Urban	20-25
10	N4	Rural	20-25
11	N7 Junction 3	Urban	20-25
12	M7 Junction 17	Rural	25 +
13	M7 Junction 13 (a)	Rural	20-25
14	M7 Junction 13 (b)	Rural	20-25
15	M8 Glanmire	Rural	25 +
16	M8 (Junction 18-to-17)	Rural	20-25
17	N20 Blackpool Bypass	Coastal	25 +
18	N20 Croom	Rural	20-25
19	N21 Rathkeale	Rural	25 +
20	N22 Ballincollig	Urban	20-25
21	N25 Cork (Site A)	Urban	25 +
22	N25 Cork (Site B)	Coastal	20-25
23	N25 Cork Harbour	Coastal	25 +
24	N28-Cork	Urban	20-25
25	N40 Douglas/Mahon Junction	Coastal	25 +
26	N40 Jack Lynch Tunnel (Site A)	Coastal	20-25
27	N40 Jack Lynch Tunnel (Site B)	Urban	20-25
28*	N55 Athlone	Urban	20-25
29*	N55 Limerick-RNo80	Coastal	25 +
30*	N59 Galway-SB09A	Coastal	20-25
31*	N59 KM-RNo78	Rural	25 +
32	N59 Galway-SB02	Coastal	20-25

\* Indicates locations selected for samples to be extracted from the site and brought to the laboratory for further analysis.

## FACTUAL REPORT

### 3.3 Testing

- The thickness of the galvanised zinc coating on the existing barriers was measured using two techniques:
  - Non-invasive probe tests:** These tests were carried out at all VRS locations using a handheld contact probe - a Positector 6000 Dual Probe. This was done either on site, or in the lab where components were removed from site for additional lab testing (see paragraph 2 below). Prior to taking a reading the area of the VRS component to be tested was marked and the surface was thoroughly cleaned to remove dirt/corrosion product.



Figure 3.4 – (Left) Illustration of Positector Probe; (Right) Test area markings and Positector Probe results

- Invasive laboratory testing:** These tests involved removing components from selected VRS installations on site, replacing them with like-for-like components, and then bringing them to the laboratory for testing. In the laboratory, small samples were cut from the VRS steel components using an angle grinder. These samples were then cleaned to ASTM standards and mounted in a clear set epoxy resin, before being ground and polished to a smooth surface finish suitable for electron microscopy. Each sample was then examined using a tabletop scanning electron microscope (SEM) – the Hitachi TM4000. As a secondary check, energy dispersive x-ray (EDX) analysis was also performed on each sample to ensure the correct identification of the galvanised zinc layer and steel substrate.

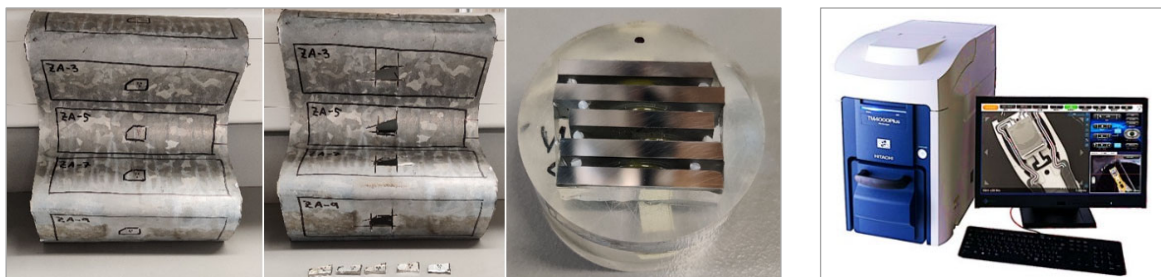


Figure 3.5 – (Left) Illustration of VRS samples and resin mounting; (Right) Tabletop Hitachi TM4000 scanning electron microscope

- For normal probe locations the coating thickness measurements were taken on three areas per beam face – the top, middle and bottom - and a minimum of five readings were taken per area. See Figure 3.5 above.
- The thickness of remaining zinc coating was measured for all test locations.
- For locations / systems analysed in detail the zinc coating of each VRS was measured in 10 different locations on the corrugated / 'W' profile (numbered 1-to-10) and in 6 different locations on the single Open Box Beam profile (numbered 1-to-6). Odd numbers were on the front of the profile (outward facing surface towards the road / traffic). Even numbers were on the back of the system's profile (inward facing surface, towards the road boundary). Sequential number pairs (e.g. 1 & 2 or 5 & 6) were opposite sides of the same area on the VRS component.

**FACTUAL REPORT**

---

### 3.4 Output of Results & Analysis

- Following all on-site and laboratory testing, the results were produced and compiled by TU Dublin into a number of distinct reports which cover general geographic locations. These reports as listed below are included at Appendix B.
  - 03923 Limerick Sites
  - 04823 N7 & M7 Sites
  - 04923 N4 Sites
  - 05023 Sligo Sites
  - 05223 Cork Sites
  - 05123 Rathcoole (Laboratory)

## FACTUAL REPORT

## 4 RESULTS

The following sections set out the results from all tests carried out as part of this research project. More detailed TU Dublin test reports are included at Appendix B.

### 4.1 Probe Test Results

**Table 4.1 - Probe Test Results: Reference VRS for Baseline Zinc Coating**

Test Location	Location / Environment Type	Age	Lowest Reading ( $\mu\text{m}$ )	Estimated Remaining Lifespan* (Years)
Aximum (New)	N/A	New	64	30-35
Aximum (5 years old)	N/A	5	90	45
Vetex C501 (New)	N/A	New	57	25-30
Vetex C501 (5 years old)	N/A	5	62	30+

\* Based on assumed zinc corrosion rate of  $2\mu\text{m}/\text{year}$

**Table 4.2 - Probe Test Results: Non-Motorway Sites**

Test Location	Location / Environment Type	Age	Lowest Reading ( $\mu\text{m}$ )	Estimated Remaining Lifespan* (Years)
N22 Ballincollig	Urban	20-25	65	30-35
N28-Cork	Urban	20-25	55	25-30
N40 Jack Lynch Tunnel (Site B)	Urban	20-25	51	25+
N55 Athlone	Urban	20-25	28	10-15
N25 Cork (Site A)	Urban	25 +	66	30-35
N3 Cavan-0042	Rural	20-25	21	10+
N4 (near Boyle)	Rural	20-25	35	15-20
N20 Croom	Rural	20-25	44	20-25
N4 Carrick-on-Shannon (east)	Rural	25 +	57	25-30
N4 Carrick-on-Shannon (west)	Rural	25 +	41	20+
N4 (N17)	Rural	25 +	29	10-15
N4 (N61 near Athlone)	Rural	25 +	12	5+
N21 Rathkeale	Rural	25 +	54	25-30
N59 KM-RNo78	Rural	25 +	35	15-20
N40 Jack Lynch Tunnel (Site A)	Coastal	20-25	69	30-35
N59 Galway-SB09A	Coastal	20-25	35	15-20
N59 Galway-SB02	Coastal	20-25	46	20-25
N20 Blackpool Bypass	Coastal	25 +	40	20+
N25 Cork Harbour	Coastal	25 +	55	25-30
N40 Douglas/Mahon Junction	Coastal	25 +	32	15+
N55 Limerick-RNo80	Coastal	25 +	28	10-15

\* Based on assumed zinc corrosion rate of  $2\mu\text{m}/\text{year}$

## FACTUAL REPORT

Table 4.3 - Probe Test Results: Motorway Sites

Test Location	Location / Environment Type	Age	Lowest Reading ( $\mu\text{m}$ )	Estimated Remaining Lifespan* (Years)
N4 Junction 17 'south'	Urban	20-25	62	30+
N4 Junction 14 'north'	Urban	20-25	62	30+
N7 Junction 3	Urban	20-25	68	30-35
N4	Rural	20-25	50	25+
M7 Junction 13 (a)	Rural	20-25	61	30+
M7 Junction 13 (b)	Rural	20-25	70	35+
M8 (Junction 18-to-17)	Rural	20-25	46	20-25
N4 (R394)	Rural	25 +	60	30+
M7 Junction 17	Rural	25 +	55	25-30
M8 Glanmire	Rural	25 +	56	25-30
N25 Cork (Site B)	Coastal	20-25	54	25-30

\* Based on assumed zinc corrosion rate of  $2\mu\text{m}/\text{year}$

## 4.2 SEM Test Results

Table 4.4 - SEM Test Results: Reference VRS for Baseline

Test Location	Location / Environment Type	Age	Lowest Reading ( $\mu\text{m}$ )	Estimated Remaining Lifespan* (Years)
Aximum (New)	N/A	New	75	35-40
Aximum (5 years old)	N/A	5	101	50+
Vetex C501 (New)	N/A	New	82	40+
Vetex C501 (5 years old)	N/A	5	96	45-50

\* Based on assumed zinc corrosion rate of  $2\mu\text{m}/\text{year}$

Table 4.5 - SEM Test Results: Non-Motorway Sites

Test Location	Location / Environment Type	Age	Lowest Reading ( $\mu\text{m}$ )	Estimated Remaining Lifespan* (Years)
N55 Athlone	Urban	20-25	86	40-45
N3 Cavan-0042	Rural	20-25	66	30-35
N59 KM-RNo78	Rural	25 +	68	30-35
N59 Galway-SB09A	Coastal	20-25	50	25+
N55 Limerick-RNo80	Coastal	25 +	72	35+

\* Based on assumed zinc corrosion rate of  $2\mu\text{m}/\text{year}$

## FACTUAL REPORT

## 5 DISCUSSION

This research measured the zinc coating on existing VRS at 32 different sites across the National Road Network: 21 site locations were on the non-motorway network and 11 were on the motorway network. The locations varied in terms of 'location / environment type', namely urban, rural and coastal.

All 32 sites were tested on site using a Positector Probe while samples of the barriers tested at five of the non-motorway sites were taken to TU Dublin for laboratory analysis using SEM.

### 5.1 Comparison of Positector Probe and SEM Results

The existing zinc coating thicknesses at five locations were measured using both the Positector Probe and SEM analysis techniques to allow both methods to be directly compared.

Figure 5.1 shows a plot of the measured coatings using SEM analysis plotted against the measurements taken using the Positector Probe for all five locations. If the two techniques were near identical, then a best fit line (shown in blue on the chart) would have a slope of '1' while passing through the origin. However, the slope of the line for these results is 1.2832 which indicates that the Positector Probe is a more conservative estimate of the galvanised zinc thickness.

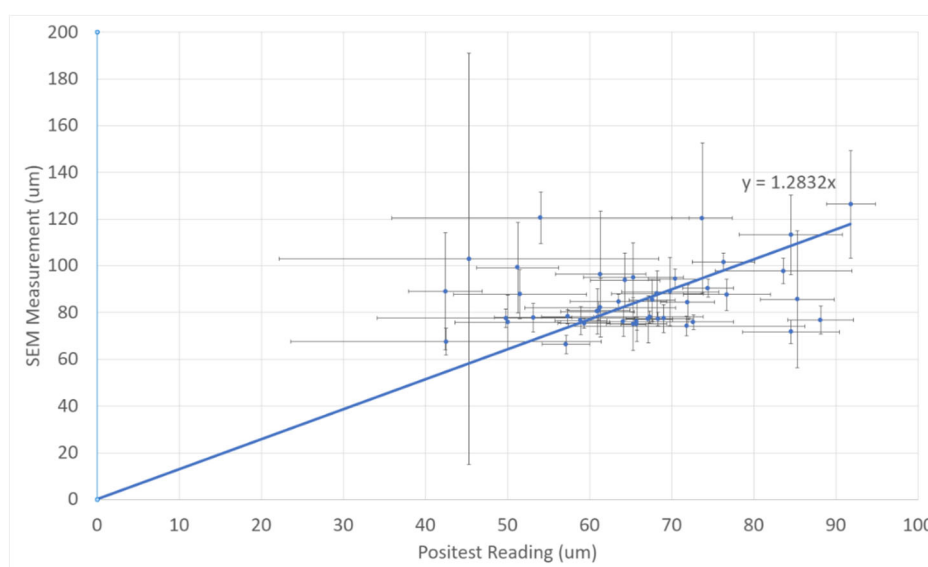


Figure 5.1 - Graph of SEM Measurement versus corresponding Positector Probe Reading

The Positector Probe is a much simpler and quicker 'non-destructive' measurement technique and can be performed on-site without damaging the barrier, while the SEM measurement technique can take several days in sample preparation and is a destructive test. The SEM data quoted included the full coating including the corrosion product while the Positector distinguished between the surface zinc and corrosion product. Therefore given that the Positector Probe results are more conservative, they will be used for analysis and discussion in the sections below.

### 5.2 Baseline

Four reference barriers, two Aximum (new and 5 years old) and two Vetex C501 (new and 5 years old), were sourced for detailed analysis in order to establish an acceptable baseline for new barriers. The lowest zinc thickness readings for the new Aximum and Vetex barriers were 64µm and 57µm respectively. However, the lowest readings for the same barriers but which were 5 years older were 90µm and 62µm respectively. This indicates that the newer barrier systems had a thinner zinc coating compared to the barriers that were five years old.

This corroborates to some extent the evidence found during the literature review that the galvanising industry is moving towards the use of thinner zinc coatings than traditionally used while still achieving the required

## FACTUAL REPORT

long-term corrosion protection as per the required standards (i.e. 20 years in the case of VRS in the EU). This could be considered a streamlining of the manufacturing process (when compared to older systems such as OBB, TCB, UCB), but also a more efficient, economical and sustainable approach to the use of zinc and to the galvanising of VRS components.

### 5.3 VRS Age: 20-25 Years versus 25+ Years

The results show a considerable overlap in the lowest measurements across all barrier age ranges with no clear difference between 20-to-25 and 25+ year old systems. In some cases, the 25+ barriers had thicker zinc coatings than 20-25 barriers. This indicates that age alone is not the only factor to consider when assessing the remaining lifespan of zinc coating thickness and therefore of the safety barrier systems.

Also, the data produced by this research suggests that the majority of barrier systems which are more than 25 years old have adequate zinc coating thickness additional years of serviceable life, ranging from 6 to 30+ years.

**Table 5.1 - Non-Motorway Sites**

Location / Environment Type	Age	Lowest Reading Range ( $\mu\text{m}$ )	Estimated Remaining Lifespan Range* (Years)
Urban	20-25	28-66	14-33
	25 +	66	33
Rural	20-25	21-44	10-22
	25 +	12-57	6-28
Coastal	20-25	35-69	17-34
	25 +	28-55	14-27

\* Based on assumed zinc corrosion rate of  $2\mu\text{m}/\text{year}$

**Table 5.2 - Motorway Sites**

Location / Environment Type	Age	Lowest Reading Range ( $\mu\text{m}$ )	Estimated Remaining Lifespan* (Years)
Urban	20-25	62-68	31-34
Rural	20-25	46-70	23-35
Rural	25 +	55-60	27-30
Coastal	20-25	54	27

\* Based on assumed zinc corrosion rate of  $2\mu\text{m}/\text{year}$

### 5.4 Urban, Rural, Coastal

The comparison of measurements from all three 'location/environment types' indicates that barriers in urban locations have slightly higher zinc coating thicknesses (average  $50.0\mu\text{m}$ ) compared to rural and coastal barriers (averages of  $36.4\mu\text{m}$  and  $43.6\mu\text{m}$  respectively). Rural barriers were shown to have the lowest zinc coating thicknesses (average of  $36.4\mu\text{m}$ , lowest thickness value measured of  $12\mu\text{m}$ ). While a larger data set would help to achieve a more definitive conclusion, the data from this research indicates that there is no dramatic difference in the zinc degradation between the three location/environment types, and the majority of barrier systems in all three have adequate zinc coating thickness for an estimated future lifespan of at least 10 years.

### 5.5 Non-Motorway vs Motorway

From the sites tested, those barriers on/adjacent to motorways typically have higher zinc coating thicknesses (average  $58.2\mu\text{m}$ ) when compared with the non-motorway sites (average  $41.7\mu\text{m}$ ). It is acknowledged that

## FACTUAL REPORT

---

we are dealing with a relatively small data set, and fewer tests were carried out on the motorway test sites due to the challenges of safely accessing and replacing test materials etc. In addition the motorway network is generally newer, has better road drainage, and barriers are set back further from the running lanes and therefore suffer less spray from passing traffic than on the tighter non-motorway and legacy networks.

### 5.6 Future Maintenance

Of the 32 existing barriers tested, all of which have been installed for 20 years or more, only three barriers were observed to be either approaching the end of their serviceable life or should be examined further:

- i. The first system, and the one with the lowest measured zinc coating thickness, was at test site N4 (N61 near Athlone) (non-motorway, rural, 25+) which had a 12µm coating. This equates to an estimated remaining lifespan of approx. 6 years (assuming a 2µm/year corrosion rate). While not an immediate concern, this system should be programmed for replacement in any upcoming replacement programmes for this area. It should be noted that while this particular barrier was included in the 25+ category, it is likely considerably older than that and possibly 40-to-50 years old. It is very much an outlier and not representative of other 25 year plus barriers.
- ii. The second barrier, N59-GY-SB09A (non-motorway, coastal, 20-25), had an acceptable zinc coating thickness as measured via the Positector Probe (min 35µm). However, there were signs of potential chemical staining at the bottom of the barrier. SEM analysis showed a non-homogeneous / non-continuous zinc layer. Therefore, barriers showing this feature could be monitored as part of any upcoming replacement programmes for this area.
- iii. The third barrier system was at N55 Athlone (non-motorway, urban, 20-25), and is an OBB system. The exterior surface of the OBB was in satisfactory condition from a visual inspection and had over 100µm of zinc coating remaining. However, the inside of the OBB beam (i.e. the surface facing away from the traffic) exhibited a layer of an unknown coating. Further EDX analysis revealed this layer contained the elements Calcium and Silicon, and resembled concrete. While the concrete did have a negative effect on the appearance of the galvanised layer, there was sufficient zinc remaining to protect the steel.

Of the three barriers identified as nearing end of life, only one is directly attributed to reduced zinc coating. The others appear to be affected due to either chemical staining or concrete contamination.

The results of this research indicate that there is no imminent requirement for an immediate targeted replacement of existing barriers based on age or location / environment. The majority of the older systems tested had zinc coating thicknesses which should give at least another decade of service. Most of these systems have close to 20 years lifespan remaining, which is comparable with the newer systems which were used to set the baseline (e.g. Aximum and Vetex C501). It should also be noted that these estimated remaining lifespans are based on the conservative assumption that zinc coatings corrode at a rate of 2µm/year, therefore the remaining serviceable life of many of these systems is likely to be longer.

However, it is clear that future planning is required to address those systems which are in their final years of service. In addition, the condition of each individual barrier system needs to be monitored in order to identify any visible signs of corrosion or other mechanisms of failure which would feed into the decision-making process for future maintenance and asset renewal.

## 6 CONCLUSIONS

The following conclusions can be drawn based on the research conducted and the results obtained during this project:

- For National Roads in Ireland, all components of metal VRS must achieve a serviceable life of not less than 20 years through galvanising to IS EN ISO 1461.
- The durability of galvanised steel barriers (i.e. its resistance to atmospheric corrosion) is directly proportional to the thickness of their zinc coating.
- Based on established zinc corrosion rates for different environments (BS EN ISO 14713) and the annual average atmospheric corrosion of zinc across the UK and Ireland (Zinc Millenium Map, Galvanizers Association), the corrosion rates across large areas of the UK and Ireland are between 0.1 and 2µm/year. Note that this corrosion rate does not take into account any potential influence of de-icing salts which would be expected to further increase the corrosion rate.
- The results indicate that there is no clear difference between 20-to-25 and 25+ year old barrier systems in terms of remaining lifespan.
- The test results indicate that the majority of existing barrier systems which are 20 to 25 years old, and some older, still have adequate zinc coating to allow them to function for an additional 10 to 20 years.
- The results do not indicate that the type of location/environment (i.e. urban, rural, coastal) in which the barrier is installed has a significant effect on the zinc corrosion.
- The mobile and non-destructive Positector 6000 Probe test yielded galvanised zinc thickness measurements which were more conservative than those measurements obtained using the destructive SEM laboratory test. This was a result of the SEM reading being based on the total layer that was observed on the safety barrier substrate. This included any corrosion products as well as the non-corroded HDG layer. If the non-corroded layer was separated from the SEM reading, it is likely that the Positector readings and SEM images may have been in better alignment.
- Zinc coating thicknesses were found to be thinner on new VRS beams than on equivalent beams manufactured five years ago for the same systems.
- Other types of corrosion may be taking place at some locations and therefore regular inspections should be carried out to identify any such corrosion which could accelerate the need for maintenance or replacement.
- Future asset planning is required in order to carry out renewals and replacements in a timely fashion as systems enter their final years of service.

## 7 RECOMMENDATIONS

Based on the findings of this research project the following recommendations should be considered:

- TII should start planning for future VRS asset renewals so that systems are replaced as they reach the end of their serviceable life. The age of the system will be an important factor to consider however this will need to be carefully considered as different systems (and particularly newer systems) will have different zinc coating thicknesses to start with and therefore will require earlier interventions in future maintenance programmes.
- Regular inspections of existing VRS are important in order to identify any visual signs of corrosion (other than zinc corrosion) which could result in the need for replacement.
- The findings and recommendations from this research project should be communicated those involved in maintaining VRS in Ireland (e.g. TII's VRS Regional Term Maintenance contractors).

# Appendix A

## Test Locations

## FACTUAL REPORT

## APPENDIX A - Test Locations

Specific locations, type and age profile of selected crash barriers. Google map location is also provided.

Location	Type	Age	Location
<b>Locations where Probe Testing done on-site</b>			
1	N4 Carrick-on-Shannon (east)	Rural	25 + <a href="https://goo.gl/maps/dD9theMGCx8DbNzY6">https://goo.gl/maps/dD9theMGCx8DbNzY6</a>
2	N4 Carrick-on-Shannon (west)	Rural	25 + <a href="https://goo.gl/maps/siNxoWmvGCKEXaW98">https://goo.gl/maps/siNxoWmvGCKEXaW98</a>
3	N4 (near Boyle)	Rural	20-25 <a href="https://goo.gl/maps/ksvYaZi8u1F2DcJk7">https://goo.gl/maps/ksvYaZi8u1F2DcJk7</a>
4	N4 (N17)	Rural	25 + <a href="https://goo.gl/maps/ptZ3uAq4W4434xsQ7">https://goo.gl/maps/ptZ3uAq4W4434xsQ7</a>
5	N4 (N61 near Athlone)	Rural	25 + <a href="https://goo.gl/maps/ahdaZB7Nq9grmwSt5">https://goo.gl/maps/ahdaZB7Nq9grmwSt5</a>
6	Rathkeale (N21)	Rural	
7	Croom (N20)	Rural	
8	N4 (R394)	Rural	25 + <a href="https://goo.gl/maps/fdRL2yJyPVofSZpk7">https://goo.gl/maps/fdRL2yJyPVofSZpk7</a>
9	N4 Junction 17 'south'	Urban	20-25 <a href="https://goo.gl/maps/SFXrFfhZfMtAtoML8">https://goo.gl/maps/SFXrFfhZfMtAtoML8</a>
10	N4 Junction 17 'north'	Urban	20-25 <a href="https://goo.gl/maps/e83x3sbqo1mLNou37">https://goo.gl/maps/e83x3sbqo1mLNou37</a>
11	N4	Rural	20-25 <a href="https://goo.gl/maps/3JAV9LF2h1JMnw4P7">https://goo.gl/maps/3JAV9LF2h1JMnw4P7</a>
12	N7 Junction 3	Urban	20-25 <a href="https://goo.gl/maps/unVRVDuwfNKdMQcJ8">https://goo.gl/maps/unVRVDuwfNKdMQcJ8</a>
13	M7 Junction 17	Rural	25 + <a href="https://goo.gl/maps/WAEULAzp5Knet9Jf6">https://goo.gl/maps/WAEULAzp5Knet9Jf6</a>
14	M7 Junction 13 (a)	Rural	20-25 <a href="https://goo.gl/maps/GQYaGtEg6oboXNaS7">https://goo.gl/maps/GQYaGtEg6oboXNaS7</a>
15	M7 Junction 13 (b)	Rural	20-25 <a href="https://goo.gl/maps/CVmuZxDdVEbtJsur7">https://goo.gl/maps/CVmuZxDdVEbtJsur7</a>
16	M8 Glanmire	Rural	25 + <a href="https://goo.gl/maps/ggigMyuwigCGPriH8">https://goo.gl/maps/ggigMyuwigCGPriH8</a>
17	M8 (Junction 18-to-17)	Rural	20-25 <a href="https://goo.gl/maps/7RerPoAZxFjTjedw9">https://goo.gl/maps/7RerPoAZxFjTjedw9</a>
18	N20 Blackpool Bypass	Coastal	25 + <a href="https://maps.app.goo.gl/izhq8aD7mHFz8SJu5">https://maps.app.goo.gl/izhq8aD7mHFz8SJu5</a>
19	N22 Ballincollig	Urban	20-25 <a href="https://goo.gl/maps/g29dri4tsawUMvrJ7">https://goo.gl/maps/g29dri4tsawUMvrJ7</a>
20	N25 Cork (Site A)	Urban	25 + <a href="https://goo.gl/maps/3VZR02cLyYNaz8vM6">https://goo.gl/maps/3VZR02cLyYNaz8vM6</a>
21	N25 Cork (Site B)	Coastal	20-25 <a href="https://goo.gl/maps/hbAds4R5ZftJNuz86">https://goo.gl/maps/hbAds4R5ZftJNuz86</a>
22	N25 Cork Harbour	Coastal	25 + <a href="https://goo.gl/maps/hbAds4R5ZftJNuz86">https://goo.gl/maps/hbAds4R5ZftJNuz86</a>
23	N40 Douglas/Mahon Junction	Coastal	25 + <a href="https://goo.gl/maps/Xj8xpokZYEK5AWTB8">https://goo.gl/maps/Xj8xpokZYEK5AWTB8</a>
24	N40 Jack Lynch Tunnel (Site A)	Coastal	20-25 <a href="https://goo.gl/maps/ku7MHLYSJJTtpoq7">https://goo.gl/maps/ku7MHLYSJJTtpoq7</a>
25	N40 Jack Lynch Tunnel (Site B)	Urban	20-25 <a href="https://goo.gl/maps/ku7MHLYSJJTtpoq7">https://goo.gl/maps/ku7MHLYSJJTtpoq7</a>
<b>Locations where Probe Testing done in Lab</b>			
26	N03-CN-0042	Rural	20-25
27	N55-ATH	Urban	20-25
28	N55-LK-RNo80	Coastal	25 +
29	N59-GY-SB09A	Coastal	20-25
30	N59-KM-RNo78	Rural	25 +
31	N28-Cork	Urban	20-25
32	N59-GY-SB02	Coastal	20-25
<b>Locations where SEM Testing done in Lab</b>			
33	N03-CN-0042	Rural	20-25
34	N55-ATH	Urban	20-25
35	N55-LK-RNo80	Coastal	25 +
36	N59-GY-SB09A	Coastal	20-25
37	N59-KM-RNo78	Rural	25 +

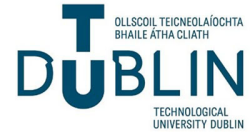
## Appendix B

### TU Dublin Reports



# CREST

## Centre for Research in Engineering Surface Technology



Focas Institute, TU Dublin Kevin St. Dublin 8, Ireland  
www.crestdit.com

Dr Irina Pascu  
Consultancy Manager  
+353 (1) 220 6911  
Irina/pascu@TUDublin.ie

Dr Brendan Duffy  
Centre Manager  
+353 (1) 220 6907  
brendan.duffy@TUDublin.ie



### Final Report

<b>Client:</b>	<b>RPS</b>	<b>Title:</b>	Evaluation of road barriers at Limerick sites
<b>Attn:</b>	<b>Rowan O'Callaghan Padraic Culkin</b>		
<b>Report ref:</b>	<b>03923</b>	<b>Order No:</b>	<b>TBC</b>
<b>Report by:</b>	<b>Brendan Duffy</b>	<b>Approved by :</b>	<b>Brendan Duffy</b>
<b>Date Recd:</b>	<b>08/06/2023</b>	<b>Issue date:</b>	<b>30/11/2023</b>

#### CONDITIONS: Terms and Conditions of Acceptance

1. Reports issued by Technological University Dublin are copyright and shall not be used, either in whole or in part, for the purposes of advertising, publicity or litigation without the consent of the Director of Research and Enterprise.
2. In accordance with laboratory accreditation requirements reports shall only be reproduced in full.
3. Non-perishable samples received for testing or laboratory work shall be disposed of after three months from completion of test unless claimed or unless instructions to the contrary have been notified by the client.
4. No action or legal proceedings shall be taken (except in the case of wilful neglect or default) against the University or any member of the University or the Board or any member of the Board or any Committee appointed by the Board or any employee of the University by reason of or arising out of the carrying out of any research, investigation, test or analysis in accordance with the Science and Technology Act 1987, or the publication of the results there in the name of the University.
5. Payment for work carried out shall be in accordance with the terms stated on the University invoices.
6. The laws of the Republic of Ireland shall apply.
7. The client is responsible for delivery to Technological University Dublin test items free of any duty, VAT, freight charges, etc. unless otherwise agreed.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
2

Evaluation of road barriers at  
Limerick sites

Report Ref:  
03923



## 1. INTRODUCTION

CREST was contracted by RPS to measure the levels of galvanised zinc on crash barriers at agreed locations in Limerick. The sites are classified as Rural and are outside of small inland towns.

2 sites were identified in Limerick:

- Rathkeale (N21)
- Croom (N20)

The measurement involved examining 3 adjacent barrier rails at 3 points, namely (a) Upper Front (b) Lower Front and (c) Rear.



Figure 1: Testing site in Rathkeale

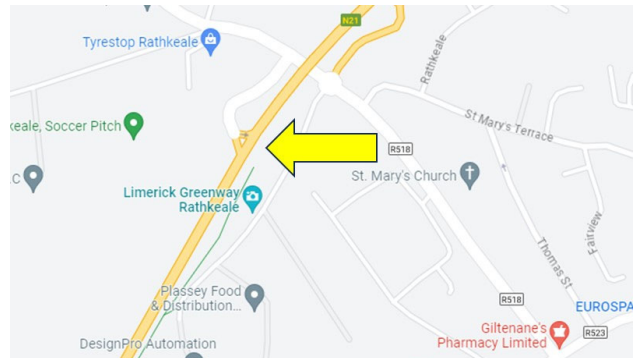


Figure 2: Location of testing in Rathkeale



Figure 3: Testing site in Croom

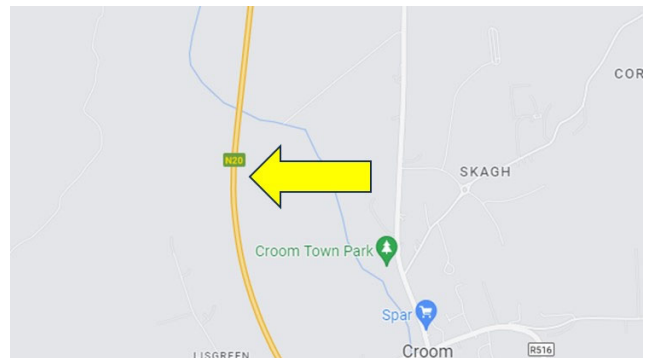


Figure 4: Location of testing in Croom

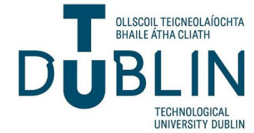
Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
3

Evaluation of road barriers at  
Limerick sites

Report Ref:  
03923



## 2. MEASUREMENT DETAILS

The zinc thickness measurement on the steel substrate was performed using a handheld contact probe (Positector Dual Probe). The area to be tested was marked on the barrier using a permanent marker and the surface was cleaned using wipes. After cleaning, the zinc thicknesses were measured using the probe. The measurements were then recorded by photograph and stored online.



Figure 5: Top Face Markings



Figure 6: Back Face Markings



Figure 7: Measurement Record

## 3. RESULTS

### 3.1 Rathkeale (N21) Results

	Top	Front	Back
Rail 1 (µm)	80 ± 8	73 ± 8	69 ± 8
Rail 2 (µm)	72 ± 4	54 ± 3	73 ± 8
Rail 3 (µm)	70 ± 6	62 ± 6	72 ± 8

### 3.2 Croom (N20) Results

	Top	Front	Back
Rail 1 (µm)	44 ± 2	70 ± 3	75 ± 6
Rail 2 (µm)	68 ± 2	73 ± 2	74 ± 4
Rail 3 (µm)	76 ± 5	78 ± 2	82 ± 5

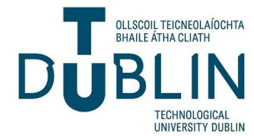
Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
4

Evaluation of road barriers at  
Limerick sites

Report Ref:  
03923



#### 4. **SUMMARY**

The results indicate that both sites have good zinc coatings on all rails tested. A general rule of thumb that has been established by the UK Galvanizers Association is that the zinc layer will be consumed at a rate of 1um/year<sup>1</sup>. Based on this estimate, all barriers examined in this report would have a remaining service life of 40 years. Even at a conservative rate of 2um/year, many of the barriers investigated in this report would have almost 20 years of service life remaining.

<sup>1</sup> <https://galvanizing.org.uk/sustainable-construction/galvanizing-is-sustainable/durability-service-life/#:~:text=With%20zinc%20corrosion%20rates%20normally,corresponding%20increases%20to%20coating%20life>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
5

Evaluation of road barriers at  
Limerick sites

Report Ref:  
03923



## ANNEXES

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu





# CREST

Centre for Research in Engineering Surface  
Technology



Focas Institute, TU Dublin Kevin St. Dublin 8, Ireland  
www.crestdit.com

Dr Irina Pascu  
Consultancy Manager  
+353 (1) 220 6911  
Irina/pascu@TUDublin.ie

Dr Brendan Duffy  
Centre Manager  
+353 (1) 220 6907  
brendan.duffy@TUDublin.ie



## Final Report

<b>Client:</b>	<b>RPS</b>	<b>Title:</b>	Evaluation of road barriers along the N7 & M7
<b>Attn:</b>	<b>Rowan O'Callaghan Padraic Culkin</b>		
<b>Report ref:</b>	<b>04823</b>	<b>Order No:</b>	<b>TBC</b>
<b>Report by:</b>	<b>Joseph Mohan</b>	<b>Approved by:</b>	<b>Brendan Duffy</b>
<b>Date Recd:</b>	<b>27/06/2023</b>	<b>Issue date:</b>	<b>30/11/2023</b>

### CONDITIONS: Terms and Conditions of Acceptance

1. Reports issued by Technological University Dublin are copyright and shall not be used, either in whole or in part, for the purposes of advertising, publicity or litigation without the consent of the Director of Research and Enterprise.
2. In accordance with laboratory accreditation requirements reports shall only be reproduced in full.
3. Non-perishable samples received for testing or laboratory work shall be disposed of after three months from completion of test unless claimed or unless instructions to the contrary have been notified by the client.
4. No action or legal proceedings shall be taken (except in the case of wilful neglect or default) against the University or any member of the University or the Board or any member of the Board or any Committee appointed by the Board or any employee of the University by reason of or arising out of the carrying out of any research, investigation, test or analysis in accordance with the Science and Technology Act 1987, or the publication of the results there in the name of the University.
5. Payment for work carried out shall be in accordance with the terms stated on the University invoices.
6. The laws of the Republic of Ireland shall apply.
7. The client is responsible for delivery to Technological University Dublin test items free of any duty, VAT, freight charges, etc. unless otherwise agreed.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu

 **TECHNOLOGY GATEWAYS**  
delivering solutions for industry  
an Enterprise Ireland network

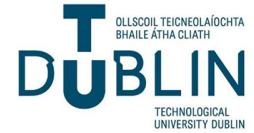
 **ENTERPRISE IRELAND**  
where innovation means business



Sheet No.  
2

Evaluation of road barriers  
along the N7 & M7

Report Ref:  
04823



## 1. INTRODUCTION

CREST was contracted by RPS to measure the levels of galvanised zinc on crash barriers at agreed locations along the N7 road and M7 motorway. The four locations examined in this report are shown in Table 1.

**Table 1: Specific locations, type and age profile of selected crash barriers. Google map location is also provided.**

Location	Type	Age	Location
N7 Junction 3	Urban	20-25 Years	<a href="https://goo.gl/maps/unVRVDuwfNKdMQcJ8">https://goo.gl/maps/unVRVDuwfNKdMQcJ8</a>
M7 Junction 17	Rural	25 Years +	<a href="https://goo.gl/maps/WAEULAzp5Knet9Jf6">https://goo.gl/maps/WAEULAzp5Knet9Jf6</a>
M7 Junction 13 (a)	Rural	20-25 Years	<a href="https://goo.gl/maps/GQYaGtEg6oboXNaS7">https://goo.gl/maps/GQYaGtEg6oboXNaS7</a>
M7 Junction 13 (b)	Rural	20-25 Years	<a href="https://goo.gl/maps/CVmuZxDdVEbtJsUr7">https://goo.gl/maps/CVmuZxDdVEbtJsUr7</a>

The measurement involved examining 3 adjacent barrier rails at 3 points, namely (a) Upper Front (b) Lower Front and (c) Rear.



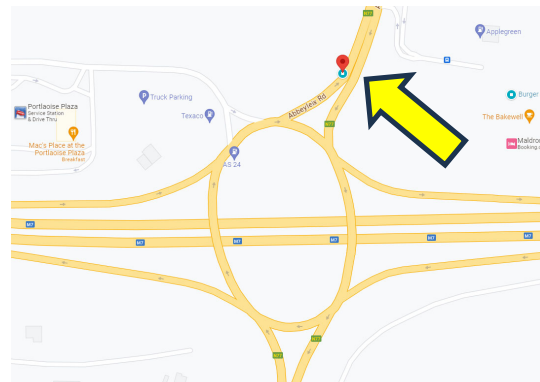
**Figure 1: Testing site on N7 Junction 3**



**Figure 2: Location of testing on N7 Junction 3**



**Figure 3: Testing site on M7 Junction 17**



**Figure 4: Location of testing on M7 Junction 17**

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
3

Evaluation of road barriers  
along the N7 & M7

Report Ref:  
04823

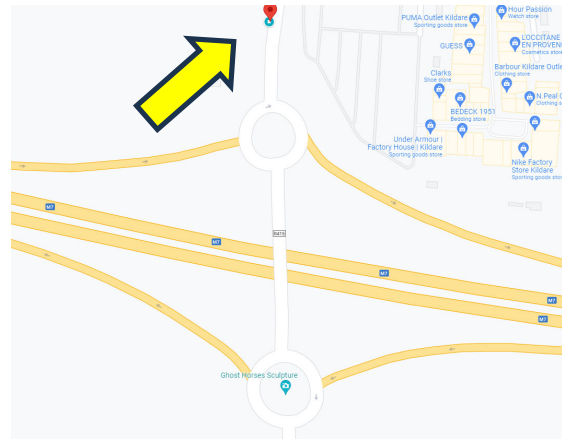


Figure 5: Testing site on M7 Junction 13 (a)

Figure 6: Location of testing on M7 Junction 13 (a)

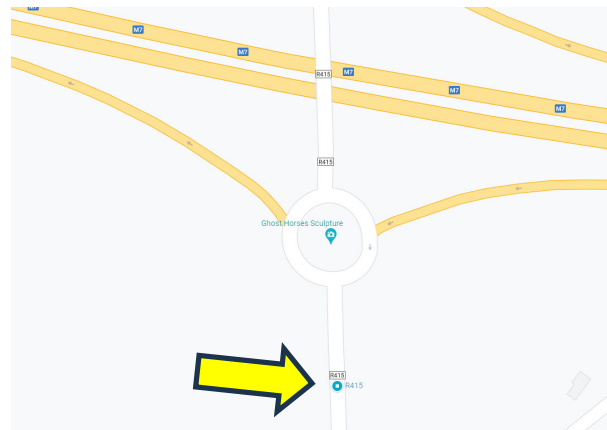


Figure 7: Testing site on M7 Junction 13 (b)

Figure 8: Location of testing on M7 Junction 13 (b)

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
4

Evaluation of road barriers  
along the N7 & M7

Report Ref:  
04823



## 2. MEASUREMENT DETAILS

The zinc thickness measurement on the steel substrate was performed using a handheld contact probe (Positector Dual Probe). The area to be tested was marked on the barrier using a permanent marker and the surface was cleaned using wipes. After cleaning, the zinc thicknesses were measured using the probe. The measurements were then recorded by photograph and stored online.



Figure 9: Top Face Markings & Record



Figure 10: Front Face Markings & Record

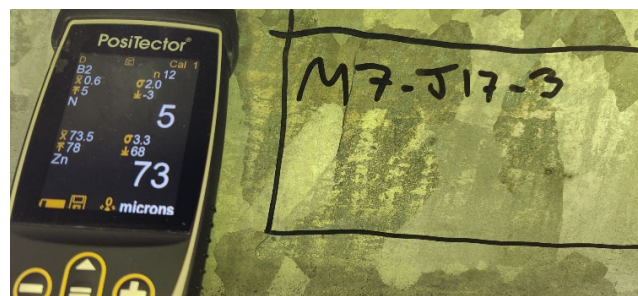


Figure 11: Back Face Markings & Record

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
5

Evaluation of road barriers  
along the N7 & M7

Report Ref:  
04823



### 3. RESULTS

#### 3.1 N7 Junction 3

	Top	Front	Back
Rail 1 (µm)	79 ± 5	76 ± 6	76 ± 3
Rail 2 (µm)	74 ± 6	69 ± 2	77 ± 4
Rail 3 (µm)	68 ± 4	79 ± 7	75 ± 2

#### 3.2 M7 Junction 17

	Top	Front	Back
Rail 1 (µm)	55 ± 4	68 ± 2	74 ± 3
Rail 2 (µm)	64 ± 3	69 ± 3	76 ± 3
Rail 3 (µm)	73 ± 3	73 ± 7	81 ± 2

#### 3.3 M7 Junction 13 (a)

	Top	Front	Back
Rail 1 (µm)	84 ± 6	80 ± 5	95 ± 7
Rail 2 (µm)	76 ± 4	61 ± 4	89 ± 4
Rail 3 (µm)	72 ± 7	78 ± 4	102 ± 7

#### 3.4 M7 Junction 13 (b)

	Top	Front	Back
Rail 1 (µm)	76 ± 4	79 ± 3	96 ± 7
Rail 2 (µm)	70 ± 3	77 ± 3	89 ± 7
Rail 3 (µm)	70 ± 3	72 ± 4	74 ± 3

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.



Sheet No.  
6

Evaluation of road barriers  
along the N7 & M7

Report Ref:  
04823



#### 4. **SUMMARY**

The results indicate that all four sites have good zinc coatings on all rails tested. A general rule of thumb that has been established by the UK Galvanizers Association is that the zinc layer will be consumed at a rate of 1um/year<sup>1</sup>. Based on this estimate, all barriers examined in this report would have a remaining service life of 50 years. Even at a conservative rate of 2um/year, many of the barriers investigated in this report would have almost 25 years of service life remaining.

---

<sup>1</sup> <https://galvanizing.org.uk/sustainable-construction/galvanizing-is-sustainable/durability-service-life/#:~:text=With%20zinc%20corrosion%20rates%20normally,corresponding%20increases%20to%20coating%20life>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
7

Evaluation of road barriers  
along the N7 & M7

Report Ref:  
04823



## ANNEXES

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

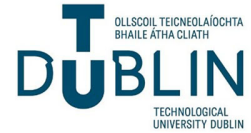
Owner: I.Pascu





# CREST

Centre for Research in Engineering Surface  
Technology



Focas Institute, TU Dublin Kevin St. Dublin 8, Ireland  
www.crestdit.com

Dr Irina Pascu  
Consultancy Manager  
+353 (1) 220 6911  
Irina/pascu@TUDublin.ie

Dr Brendan Duffy  
Centre Manager  
+353 (1) 220 6907  
brendan.duffy@TUDublin.ie



## Final Report

<b>Client:</b>	<b>RPS</b>	<b>Title:</b>	Evaluation of road barriers along the N4
<b>Attn:</b>	<b>Rowan O'Callaghan Padraic Culkin</b>		
<b>Report ref:</b>	<b>04923</b>	<b>Order No:</b>	<b>TBC</b>
<b>Report by:</b>	<b>Joseph Mohan</b>	<b>Approved by:</b>	<b>Brendan Duffy</b>
<b>Date Recd:</b>	<b>28/06/2023</b>	<b>Issue date:</b>	<b>30/11/2023</b>

### CONDITIONS: Terms and Conditions of Acceptance

1. Reports issued by Technological University Dublin are copyright and shall not be used, either in whole or in part, for the purposes of advertising, publicity or litigation without the consent of the Director of Research and Enterprise.
2. In accordance with laboratory accreditation requirements reports shall only be reproduced in full.
3. Non-perishable samples received for testing or laboratory work shall be disposed of after three months from completion of test unless claimed or unless instructions to the contrary have been notified by the client.
4. No action or legal proceedings shall be taken (except in the case of wilful neglect or default) against the University or any member of the University or the Board or any member of the Board or any Committee appointed by the Board or any employee of the University by reason of or arising out of the carrying out of any research, investigation, test or analysis in accordance with the Science and Technology Act 1987, or the publication of the results there in the name of the University.
5. Payment for work carried out shall be in accordance with the terms stated on the University invoices.
6. The laws of the Republic of Ireland shall apply.
7. The client is responsible for delivery to Technological University Dublin test items free of any duty, VAT, freight charges, etc. unless otherwise agreed.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu

 **TECHNOLOGY GATEWAYS**  
delivering solutions for industry  
an Enterprise Ireland network

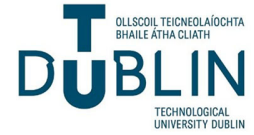
 **ENTERPRISE IRELAND**  
where innovation means business



Sheet No.  
2

Evaluation of road barriers  
along the N4

Report Ref:  
04923



## 1. INTRODUCTION

CREST was contracted by RPS to measure the levels of galvanised zinc on crash barriers at agreed locations along the N4 national road. The four locations examined in this report are shown in Table 1.

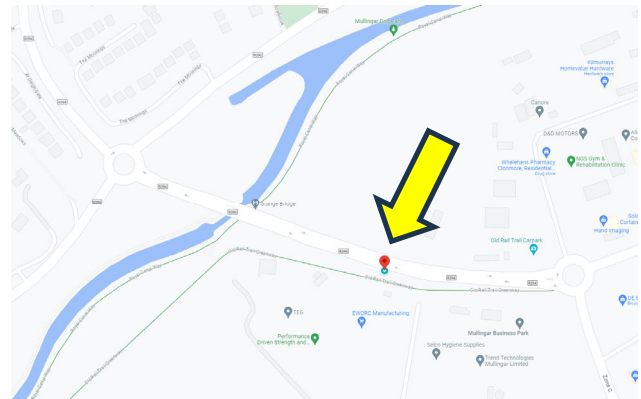
**Table 1: Specific locations, type and age profile of selected crash barriers. Google map location is also provided.**

Location	Type	Age	Location
N4 (R394)	Rural	25 Years+	<a href="https://goo.gl/maps/fdRL2yJyPVofSZpk7">https://goo.gl/maps/fdRL2yJyPVofSZpk7</a>
N4 Junction 17 'south'	Urban	20-25 Years	<a href="https://goo.gl/maps/SFXrFfhZfMtAtomL8">https://goo.gl/maps/SFXrFfhZfMtAtomL8</a>
N4 Junction 17 'north'	Urban	20-25 Years	<a href="https://goo.gl/maps/e83x3sbqo1mLNou37">https://goo.gl/maps/e83x3sbqo1mLNou37</a>
N4	Rural	20-25 Years	<a href="https://goo.gl/maps/3JAV9LF2h1JMnw4P7">https://goo.gl/maps/3JAV9LF2h1JMnw4P7</a>

The measurement involved examining 3 adjacent barrier rails at 3 points, namely (a) Top Face (b) Front Face and (c) Back Face.



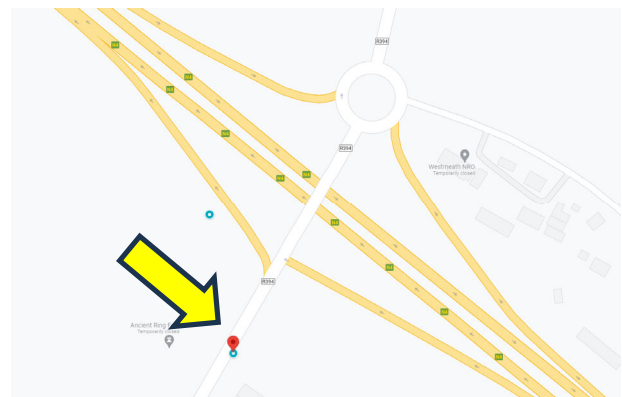
**Figure 1: Testing site on N4 (R394)**



**Figure 2: Location of testing on N4 (R394)**



**Figure 3: Testing site on N4 (Junction 17 'south')**



**Figure 4: Location of testing on N4 (Junction 17 'south')**

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
3

Evaluation of road barriers  
along the N4

Report Ref:  
04923



Figure 5: Testing site on N4 (Junction 17 'north)

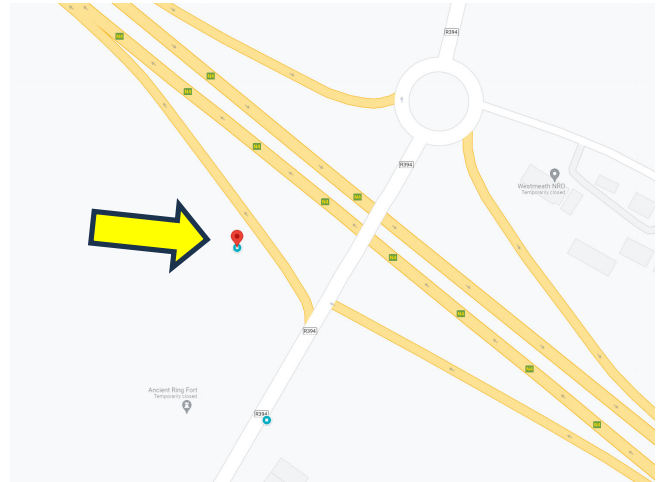


Figure 6: Location of testing on N4 (Junction 17 'north')



Figure 7: Testing site on N4



Figure 8: Location of testing on N4

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.



Sheet No.  
4

Evaluation of road barriers  
along the N4

Report Ref:  
04923



## 2. MEASUREMENT DETAILS

The zinc thickness measurement on the steel substrate was performed using a handheld contact probe (Positector Dual Probe). The area to be tested was marked on the barrier using a permanent marker and the surface was cleaned using wipes. After cleaning, the zinc thicknesses were measured using the probe. The measurements were then recorded by photograph and stored online.



Figure 9: Top Face Markings & Record



Figure 10: Front Face Markings & Record

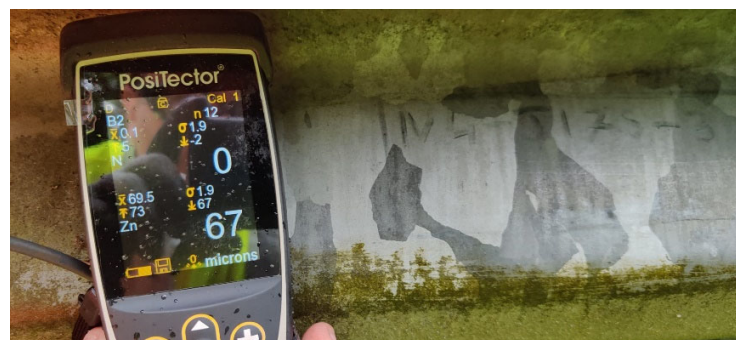


Figure 11: Back Face Markings & Record

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
5

Evaluation of road barriers  
along the N4

Report Ref:  
04923



### 3. RESULTS

#### 3.1 N4 (R394)

	Top	Front	Back
Rail 1 (µm)	66 ± 5	67 ± 3	81 ± 4
Rail 2 (µm)	60 ± 6	67 ± 2	80 ± 4
Rail 3 (µm)	70 ± 8	71 ± 7	80 ± 4

#### 3.2 N4 (Junction 17 'south')

	Top	Front	Back
Rail 1 (µm)	62 ± 3	70 ± 4	70 ± 2
Rail 2 (µm)	64 ± 3	70 ± 2	67 ± 3
Rail 3 (µm)	64 ± 2	72 ± 2	72 ± 3

#### 3.3 N4 (Junction 14 'north')

	Top	Front	Back
Rail 1 (µm)	62 ± 4	68 ± 3	70 ± 2
Rail 2 (µm)	62 ± 4	70 ± 4	72 ± 2
Rail 3 (µm)	84 ± 3	98 ± 3	98 ± 6

#### 3.4 N4

	Top	Front	Back
Rail 1 (µm)	55 ± 4	74 ± 4	62 ± 6
Rail 2 (µm)	51 ± 7	71 ± 7	66 ± 3
Rail 3 (µm)	50 ± 8	68 ± 3	59 ± 3

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
6

Evaluation of road barriers  
along the N4

Report Ref:  
04923



#### 4. **SUMMARY**

The results indicate that all four sites have good zinc coatings on all rails tested. A general rule of thumb that has been established by the UK Galvanizers Association is that the zinc layer will be consumed at a rate of 1um/year<sup>1</sup>. Based on this estimate, all barriers examined in this report would have a remaining service life of 50 years. Even at a conservative rate of 2um/year, many of the barriers investigated in this report would have almost 25 years of service life remaining.

<sup>1</sup> <https://galvanizing.org.uk/sustainable-construction/galvanizing-is-sustainable/durability-service-life/#:~:text=With%20zinc%20corrosion%20rates%20normally,corresponding%20increases%20to%20coating%20life>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
7

Evaluation of road barriers  
along the N4

Report Ref:  
04923



## ANNEXES

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

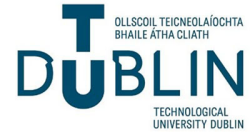
Owner: I.Pascu





# CREST

Centre for Research in Engineering Surface  
Technology



Focas Institute, TU Dublin Kevin St. Dublin 8, Ireland  
www.crestdit.com

Dr Irina Pascu  
Consultancy Manager  
+353 (1) 220 6911  
Irina/pascu@TUDublin.ie

Dr Brendan Duffy  
Centre Manager  
+353 (1) 220 6907  
brendan.duffy@TUDublin.ie



## Final Report

<b>Client:</b>	<b>RPS</b>	<b>Title:</b>	Evaluation of road barriers along the N4 towards Sligo
<b>Attn:</b>	<b>Rowan O'Callaghan Padraic Culkin</b>		
<b>Report ref:</b>	<b>04923</b>	<b>Order No:</b>	<b>TBC</b>
<b>Report by:</b>	<b>Joseph Mohan</b>	<b>Approved by:</b>	<b>Brendan Duffy</b>
<b>Date Recd:</b>	<b>04/07/2023</b>	<b>Issue date:</b>	<b>30/11/2023</b>

### CONDITIONS: Terms and Conditions of Acceptance

1. Reports issued by Technological University Dublin are copyright and shall not be used, either in whole or in part, for the purposes of advertising, publicity or litigation without the consent of the Director of Research and Enterprise.
2. In accordance with laboratory accreditation requirements reports shall only be reproduced in full.
3. Non-perishable samples received for testing or laboratory work shall be disposed of after three months from completion of test unless claimed or unless instructions to the contrary have been notified by the client.
4. No action or legal proceedings shall be taken (except in the case of wilful neglect or default) against the University or any member of the University or the Board or any member of the Board or any Committee appointed by the Board or any employee of the University by reason of or arising out of the carrying out of any research, investigation, test or analysis in accordance with the Science and Technology Act 1987, or the publication of the results there in the name of the University.
5. Payment for work carried out shall be in accordance with the terms stated on the University invoices.
6. The laws of the Republic of Ireland shall apply.
7. The client is responsible for delivery to Technological University Dublin test items free of any duty, VAT, freight charges, etc. unless otherwise agreed.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu

 **TECHNOLOGY GATEWAYS**  
delivering solutions for industry  
an Enterprise Ireland network

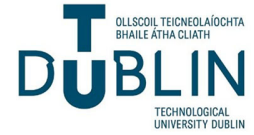
 **ENTERPRISE IRELAND**  
where innovation means business



Sheet No.  
2

Evaluation of road barriers  
along the N4 towards Sligo

Report Ref:  
05023



## 1. INTRODUCTION

CREST was contracted by RPS to measure the levels of galvanised zinc on crash barriers at agreed locations along the N4 national road towards Sligo (from Dublin). The five locations examined in this report are shown in Table 1.

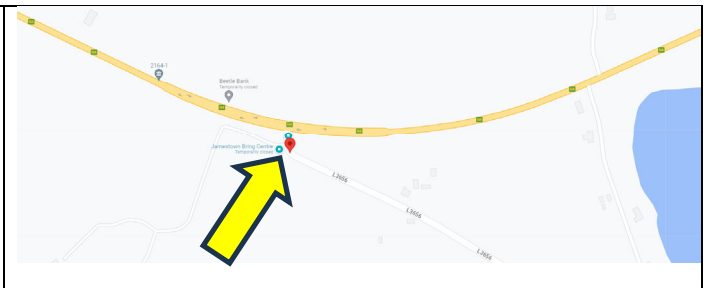
**Table 1: Specific locations, type and age profile of selected crash barriers. Google map location is also provided.**

Location	Type	Age	Location
N4 Carrick-on-Shannon (east)	Rural	25 Years +	<a href="https://goo.gl/maps/dD9theMGCx8DbNzY6">https://goo.gl/maps/dD9theMGCx8DbNzY6</a>
N4 Carrick-on-Shannon (west)	Rural	25 Years +	<a href="https://goo.gl/maps/siNxoWmvGCKEXaW98">https://goo.gl/maps/siNxoWmvGCKEXaW98</a>
N4 (near Boyle)	Rural	20-25 Years	<a href="https://goo.gl/maps/ksvYaZi8u1F2DcJk7">https://goo.gl/maps/ksvYaZi8u1F2DcJk7</a>
N4 (N17)	Rural	25 Years +	<a href="https://goo.gl/maps/ptZ3uAq4W4434xsQ7">https://goo.gl/maps/ptZ3uAq4W4434xsQ7</a>
N4 (N61 near Athlone)	Rural	25 Years +	<a href="https://goo.gl/maps/ahdaZB7Ng9grmwSt5">https://goo.gl/maps/ahdaZB7Ng9grmwSt5</a>

The measurement involved examining 3 adjacent barrier rails at 3 points, namely (a) Top Face (b) Front Face and (c) Back Face.



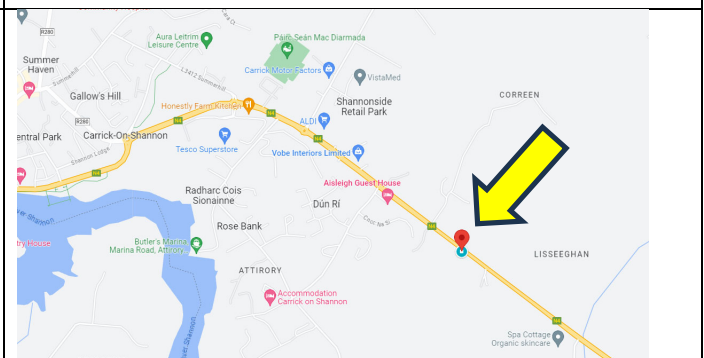
**Figure 1: Testing site on N4 Carrick-on Shannon (east)**



**Figure 2: Location of testing on N4 Carrick-on Shannon (east)**



**Figure 3: Testing site on N4 Carrick-on Shannon (west)**



**Figure 4: Location of testing on N4 Carrick-on Shannon (west)**

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
3

Evaluation of road barriers  
along the N4 towards Sligo

Report Ref:  
05023



Figure 5: Testing site on N4 (near Boyle)

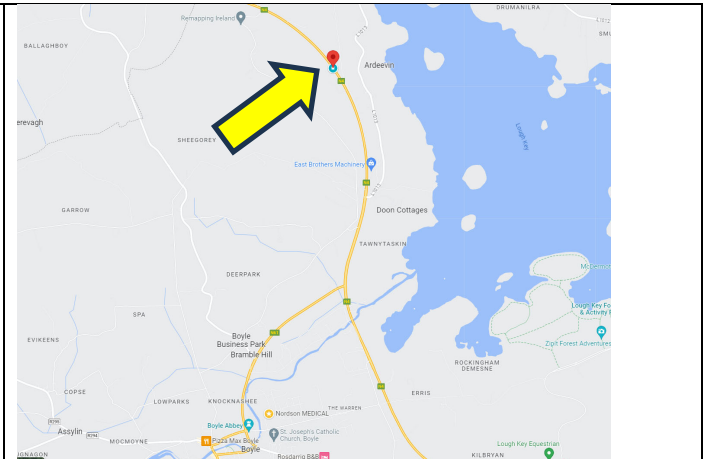


Figure 6: Location of testing on N4 Bypass



Figure 7: Testing site on N4 (near N17)

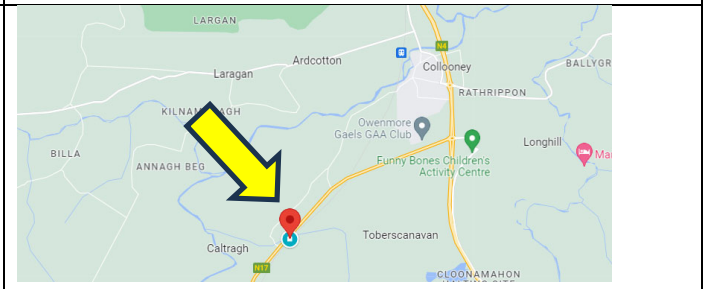


Figure 8: Location of testing on N4 (near N17)



Figure 9: Testing site on N4 (N61 near Athlone)

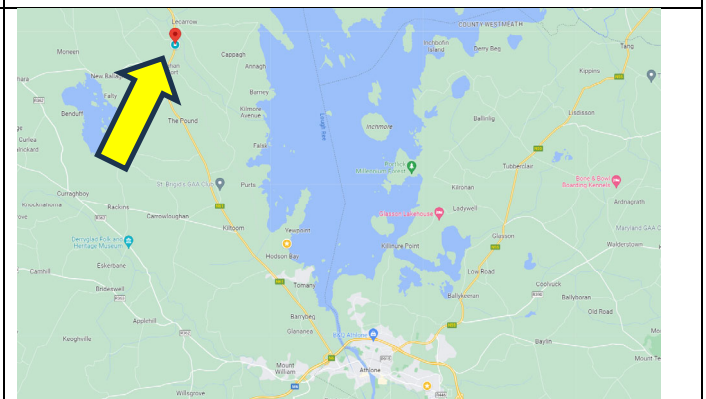


Figure 10: Location of testing on N4 (N61 near Athlone)

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
4

Evaluation of road barriers  
along the N4 towards Sligo

Report Ref:  
05023



## 2. MEASUREMENT DETAILS

The zinc thickness measurement on the steel substrate was performed using a handheld contact probe (Positector Dual Probe). The area to be tested was marked on the barrier using a permanent marker and the surface was cleaned using wipes. After cleaning, the zinc thicknesses were measured using the probe. The measurements were then recorded by photograph and stored online.



Figure 11: Top Face Markings & Record

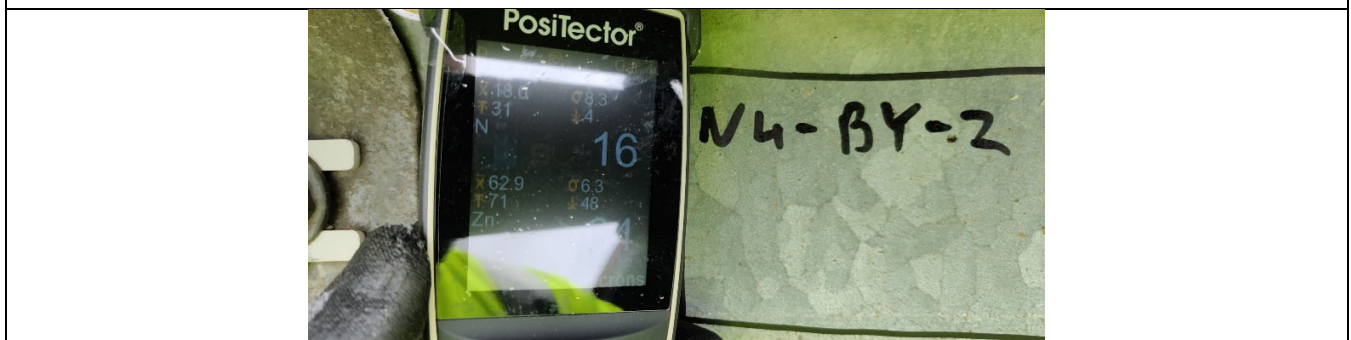


Figure 12: Front Face Markings & Record

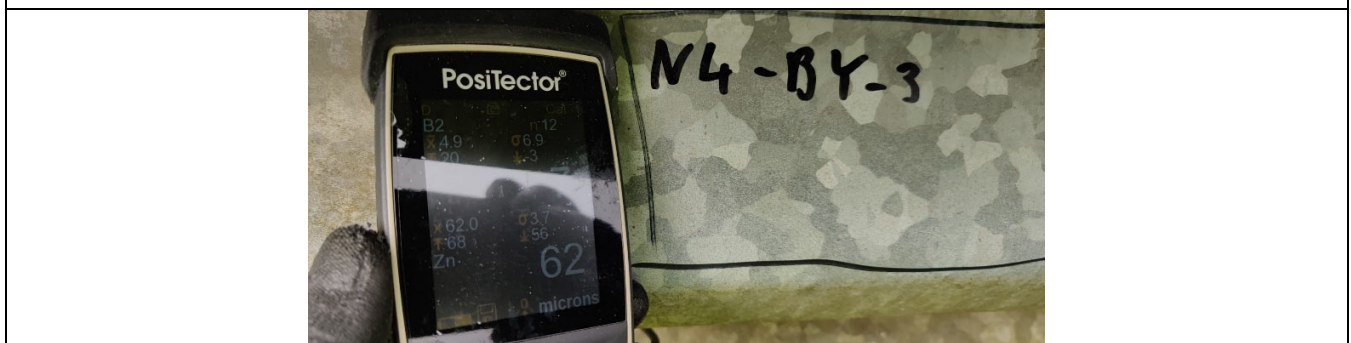


Figure 13: Back Face Markings & Record

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
5

Evaluation of road barriers  
along the N4 towards Sligo

Report Ref:  
05023



### 3. RESULTS

#### 3.1 N4 Carrick-on-Shannon (east)

	Top	Front	Back
Rail 1 (µm)	57 ± 5	70 ± 7	76 ± 4
Rail 2 (µm)	66 ± 5	69 ± 5	78 ± 5
Rail 3 (µm)	61 ± 7	76 ± 4	76 ± 4

#### 3.2 N4 Carrick-on-Shannon (west)

	Top	Front	Back
Rail 1 (µm)	75 ± 14	83 ± 4	72 ± 4
Rail 2 (µm)	41 ± 5	74 ± 14	58 ± 4
Rail 3 (µm)	96 ± 7	93 ± 4	95 ± 4

#### 3.3 N4 (near Boyle)

	Top	Front	Back
Rail 1 (µm)	35 ± 6	63 ± 6	62 ± 4
Rail 2 (µm)	41 ± 6	60 ± 6	63 ± 5
Rail 3 (µm)	46 ± 8	60 ± 3	65 ± 4

#### 3.4 N4 (near N17)

	Top	Front	Back
Rail 1 (µm)	60 ± 14	78 ± 5	64 ± 4
Rail 2 (µm)	29 ± 7	58 ± 2	60 ± 2
Rail 3 (µm)	33 ± 4	61 ± 2	67 ± 6

#### 3.5 N4 (N61 near Athlone)

	Top	Front	Back
Rail 1 (µm)	22 ± 21	28 ± 15	69 ± 11
Rail 2 (µm)	12 ± 43	45 ± 13	57 ± 13
Rail 3 (µm)	99 ± 34	115 ± 23	77 ± 11

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
6

Evaluation of road barriers  
along the N4 towards Sligo

Report Ref:  
05023



#### 4. **SUMMARY**

The results indicate that two sites (N4 Carrick-on-Shannon (east & west) have good zinc coatings on all rails tested with a minimum thickness of 40 microns. A general rule of thumb that has been established by the UK Galvanizers Association is that the zinc layer will be consumed at a rate of 1um/year<sup>1</sup>. Based on this estimate, these specific barriers would have a remaining service life of 40 years. Even at a conservative rate of 2um/year, the barriers would have almost 25 years of service life remaining. However, the remaining three locations had sections of the crash barriers with a zinc coating as low as 12 micron (e.g. N4/N61 near Athlone). These should be considered for replacing.

<sup>1</sup> <https://galvanizing.org.uk/sustainable-construction/galvanizing-is-sustainable/durability-service-life/#:~:text=With%20zinc%20corrosion%20rates%20normally,corresponding%20increases%20to%20coating%20life>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
7

Evaluation of road barriers  
along the N4 towards Sligo

Report Ref:  
05023



## ANNEXES

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu

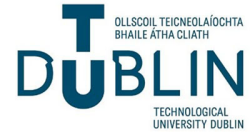
 **TECHNOLOGY GATEWAYS**  
delivering solutions for industry  
an Enterprise Ireland network

 **ENTERPRISE IRELAND**  
where innovation means business



# CREST

Centre for Research in Engineering Surface  
Technology



Focas Institute, TU Dublin Kevin St. Dublin 8, Ireland  
www.crestdit.com

Dr Irina Pascu  
Consultancy Manager  
+353 (1) 220 6911  
Irina/pascu@TUDublin.ie

Dr Brendan Duffy  
Centre Manager  
+353 (1) 220 6907  
brendan.duffy@TUDublin.ie



## Final Report

<b>Client:</b>	<b>RPS</b>	<b>Title:</b>	Evaluation of road barriers in Cork
<b>Attn:</b>	<b>Rowan O'Callaghan Padraic Culkin</b>		
<b>Report ref:</b>	<b>05223</b>	<b>Order No:</b>	<b>TBC</b>
<b>Report by:</b>	<b>Joseph Mohan</b>	<b>Approved by:</b>	<b>Brendan Duffy</b>
<b>Date Recd:</b>	<b>11/07/2023</b>	<b>Issue date:</b>	<b>30/11/2023</b>

### CONDITIONS: Terms and Conditions of Acceptance

1. Reports issued by Technological University Dublin are copyright and shall not be used, either in whole or in part, for the purposes of advertising, publicity or litigation without the consent of the Director of Research and Enterprise.
2. In accordance with laboratory accreditation requirements reports shall only be reproduced in full.
3. Non-perishable samples received for testing or laboratory work shall be disposed of after three months from completion of test unless claimed or unless instructions to the contrary have been notified by the client.
4. No action or legal proceedings shall be taken (except in the case of wilful neglect or default) against the University or any member of the University or the Board or any member of the Board or any Committee appointed by the Board or any employee of the University by reason of or arising out of the carrying out of any research, investigation, test or analysis in accordance with the Science and Technology Act 1987, or the publication of the results there in the name of the University.
5. Payment for work carried out shall be in accordance with the terms stated on the University invoices.
6. The laws of the Republic of Ireland shall apply.
7. The client is responsible for delivery to Technological University Dublin test items free of any duty, VAT, freight charges, etc. unless otherwise agreed.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu

 **TECHNOLOGY GATEWAYS**  
delivering solutions for industry  
an Enterprise Ireland network

 **ENTERPRISE IRELAND**  
where innovation means business



**1. INTRODUCTION**

CREST was contracted by RPS to measure the levels of galvanised zinc on crash barriers at agreed locations in the Cork area. The ten locations examined in this report are shown in Table 1.

**Table 1: Specific locations, type and age profile of selected crash barriers. Google map location is also provided.**

Location	Type	Age	Location
M8 Glanmire	Rural	25 Years +	<a href="https://goo.gl/maps/ggiqMyuwiqCGPriH8">https://goo.gl/maps/ggiqMyuwiqCGPriH8</a>
M8 (Junction 18-to-17)	Rural	20-25 Years	<a href="https://goo.gl/maps/7RerPoAZxFtJtedw9">https://goo.gl/maps/7RerPoAZxFtJtedw9</a>
N20 Blackpool Bypass	Coastal	25 Years +	<a href="https://maps.app.goo.gl/izhq8aD7mHFz8SJu5">https://maps.app.goo.gl/izhq8aD7mHFz8SJu5</a>
N22 Ballincollig	Urban	20-25 Years	<a href="https://goo.gl/maps/g29dri4tsawUMvrJ7">https://goo.gl/maps/g29dri4tsawUMvrJ7</a>
N25 Cork (Site A)	Urban	25 Years +	<a href="https://goo.gl/maps/3VZRo2cLyYNaz8vM6">https://goo.gl/maps/3VZRo2cLyYNaz8vM6</a>
N25 Cork (Site B)	Coastal	20-25 Years	<a href="https://goo.gl/maps/hbAds4R5ZftJNuz86">https://goo.gl/maps/hbAds4R5ZftJNuz86</a>
N25 Cork Harbour	Coastal	25 Years +	<a href="https://goo.gl/maps/hbAds4R5ZftJNuz86">https://goo.gl/maps/hbAds4R5ZftJNuz86</a>
N40 Douglas/Mahon Junction	Coastal	25 Years +	<a href="https://goo.gl/maps/Xi8xpokZYEk5AWTB8">https://goo.gl/maps/Xi8xpokZYEk5AWTB8</a>
N40 Jack Lynch Tunnel (Site A)	Coastal	20-25 Years	<a href="https://goo.gl/maps/ku7MHLYSJTTptq7">https://goo.gl/maps/ku7MHLYSJTTptq7</a>
N40 Jack Lynch Tunnel (Site B)	Urban	20-25 Years	<a href="https://goo.gl/maps/ku7MHLYSJTTptq7">https://goo.gl/maps/ku7MHLYSJTTptq7</a>

The measurement involved examining 3 adjacent barrier rails at 3 points, namely (a) Top Face (b) Front Face and (c) Back Face.



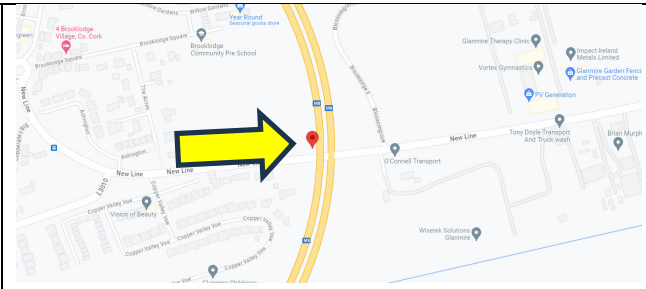
Sheet No.  
3

Evaluation of road barriers in  
Cork

Report Ref:  
05023



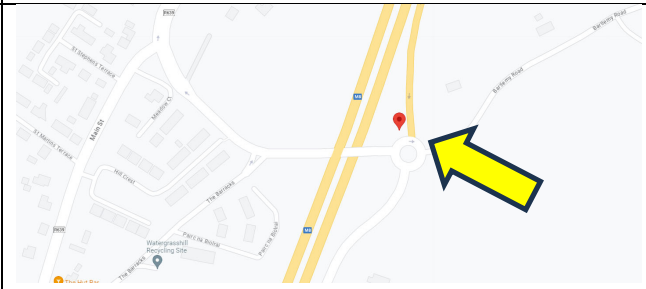
**Figure 1: Testing site on M8 Glanmire**



**Figure 2: Location of testing on M8 Glanmire**



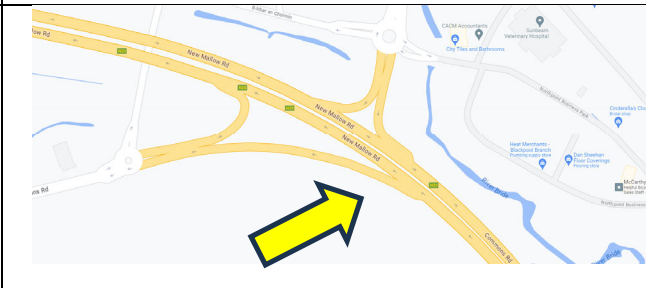
**Figure 3: Testing site on M8 (Junction 18-to-17)**



**Figure 4: Location of testing on M8 (Junction 18-to-17)**



**Figure 5: Testing site on N20 Blackpool Bypass**



**Figure 6: Location of testing on N20 Blackpool Bypass**

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
4

Evaluation of road barriers in  
Cork

Report Ref:  
05023



<p><b>Figure 7: Testing site on N22 Ballincollig</b></p>	<p><b>Figure 8: Testing site on N22 Ballincollig</b></p>
<p><b>Figure 9: Testing site on N25 Cork (Site A)</b></p>	<p><b>Figure 10: Location of testing on N25 Cork (Site A)</b></p>
<p><b>Figure 11: Testing site on N25 Cork (Site B)</b></p>	<p><b>Figure 12: Location of testing on N25 Cork (Site B)</b></p>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



<p><b>Figure 13: Testing site on N25 Cork Harbour</b></p>	<p><b>Figure 14: Location of testing on N25 Cork Harbour</b></p>
<p><b>Figure 15: Testing site on N40 Douglas/Mahon Junction</b></p>	<p><b>Figure 16: Location of testing on N40 Douglas/Mahon Junction</b></p>
<p><b>Figure 17: Testing site on N40 Jack Lynch Tunnel (Site A)</b></p>	<p><b>Figure 18: Location of testing on N40 Jack Lynch Tunnel (Site A)</b></p>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



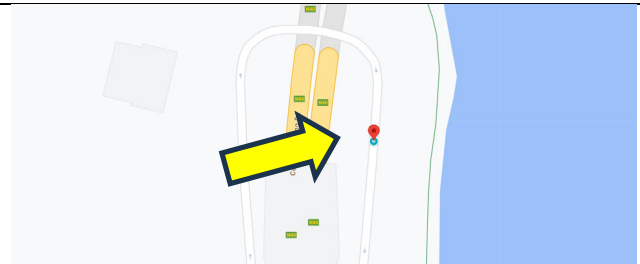
Sheet No.  
6

Evaluation of road barriers in  
Cork

Report Ref:  
05023



**Figure 19: Testing site on N40 Jack Lynch Tunnel (Site B)**



**Figure 20: Location of testing on N40 Jack Lynch Tunnel (Site B)**

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu

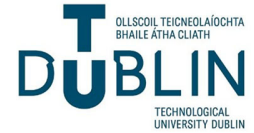




Sheet No.  
7

Evaluation of road barriers in  
Cork

Report Ref:  
05023



## 2. MEASUREMENT DETAILS

The zinc thickness measurement on the steel substrate was performed using a handheld contact probe (Positector Dual Probe). The area to be tested was marked on the barrier using a permanent marker and the surface was cleaned using wipes. After cleaning, the zinc thicknesses were measured using the probe. The measurements were then recorded by photograph and stored online.



Figure 21: Top Face Markings & Record

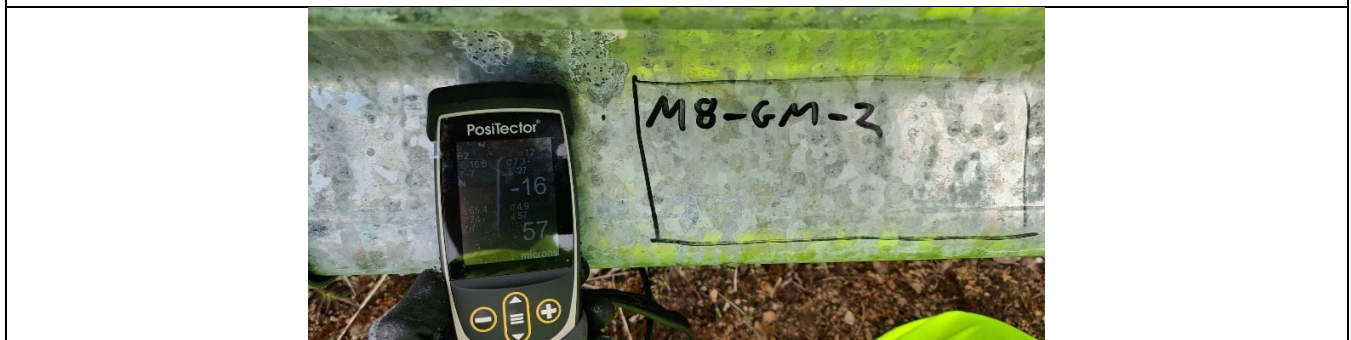


Figure 22: Front Face Markings & Record

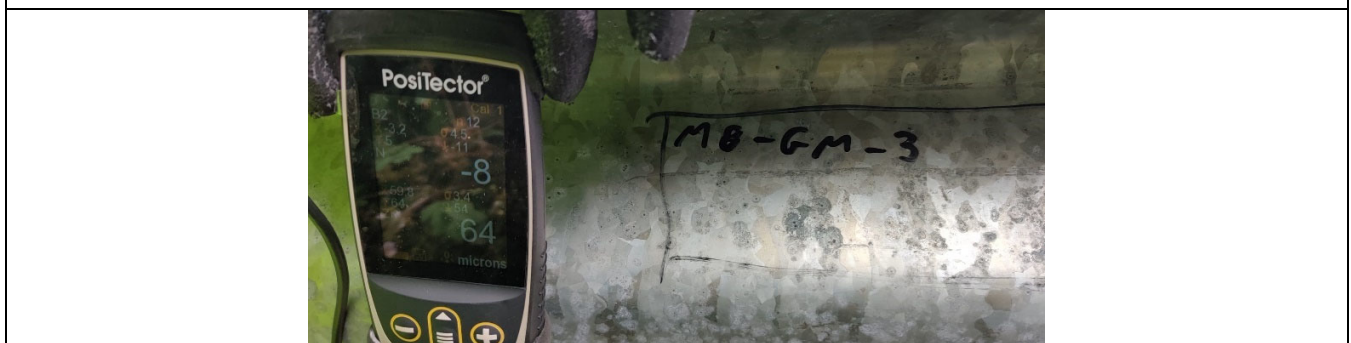
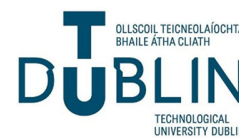


Figure 23: Back Face Markings & Record

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No. 8 Evaluation of road barriers in Cork Report Ref: 05023



### 3. RESULTS

#### 3.1 M8 Glanmire

	Top	Front	Back
Rail 1 (µm)	61 ± 3	65 ± 5	60 ± 3
Rail 2 (µm)	56 ± 6	61 ± 7	62 ± 5
Rail 3 (µm)	64 ± 8	72 ± 6	75 ± 2

#### 3.2 M8 (Junction 18-to-17)

	Top	Front	Back
Rail 1 (µm)	84 ± 4	81 ± 9	92 ± 4
Rail 2 (µm)	63 ± 8	46 ± 8	91 ± 9
Rail 3 (µm)	63 ± 5	59 ± 10	89 ± 8

#### 3.3 N20 Blackpool Bypass

	Top	Front	Back
Rail 1 (µm)	59 ± 6	64 ± 7	67 ± 4
Rail 2 (µm)	57 ± 5	71 ± 8	66 ± 4
Rail 3 (µm)	40 ± 9	62 ± 5	100 ± 5

#### 3.4 N22 Ballincollig

	Top	Front	Back
Rail 1 (µm)	80 ± 6	76 ± 3	68 ± 6
Rail 2 (µm)	65 ± 3	74 ± 5	67 ± 5
Rail 3 (µm)	94 ± 15	91 ± 13	71 ± 5

#### 3.5 N25 Cork (Site A)

	Top	Front	Back
Rail 1 (µm)	81 ± 5	72 ± 8	66 ± 13
Rail 2 (µm)	91 ± 4	97 ± 3	78 ± 6
Rail 3 (µm)	77 ± 10	76 ± 5	69 ± 4

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



**3.6 N25 Cork (Site B)**

	Top	Front	Back
Rail 1 (µm)	54 ± 15	80 ± 6	89 ± 3
Rail 2 (µm)	76 ± 3	77 ± 6	88 ± 4
Rail 3 (µm)	74 ± 6	85 ± 5	94 ± 9

**3.7 N25 Cork Harbour**

	Top	Front	Back
Rail 1 (µm)	60 ± 7	68 ± 3	70 ± 2
Rail 2 (µm)	55 ± 9	73 ± 4	65 ± 2
Rail 3 (µm)	64 ± 7	78 ± 5	63 ± 10

**3.8 N40 Douglas / Mahon Junction**

	Top	Front	Back
Rail 1 (µm)	61 ± 9	69 ± 9	32 ± 10
Bottom of Rail 1 (µm)	91 ± 4	73 ± 3	96 ± 5
Rail 2 (µm)	52 ± 10	71 ± 4	83 ± 8
Rail 3 (µm)	56 ± 4	72 ± 4	78 ± 2

**3.9 N40 Jack Lynch Tunnel (Site A)**

	Top	Front	Back
Rail 1 (µm)	73 ± 5	75 ± 5	114 ± 6
Rail 2 (µm)	76 ± 8	69 ± 5	88 ± 7
Rail 3 (µm)	95 ± 6	93 ± 6	136 ± 15

**3.10 N40 Jack Lynch Tunnel (Site B)**

	Top	Front	Back
Rail 1 (µm)	81 ± 8	91 ± 6	145 ± 11
Rail 2 (µm)	51 ± 6	61 ± 10	66 ± 7
Rail 3 (µm)	83 ± 15	82 ± 5	99 ± 11

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No. Evaluation of road barriers in Report Ref:  
*10* Cork 05023



#### 4. **SUMMARY**

The results indicate that most sites have a high level of zinc remaining on the barriers. A general rule of thumb that has been established by the UK Galvanizers Association is that the zinc layer will be consumed at a rate of 1µm/year<sup>1</sup>. Based on this estimate, the majority of barriers examined in this report would have a remaining service life of 50 years. Even at a conservative rate of 2µm/year, many of the barriers investigated in this report would have almost 25 years of service life remaining.

However, there were three locations that had crash barriers with a noticeably thinner zinc coating thickness, and these should be monitored or considered for replacing. These are:

- The open box beam at the N40 Douglas / Mahon Junction. The inside of the box had a thickness of approximately 30µm. See Figure 24 (a).
- One area of a barrier on the N20 near the Blackpool By-Pass had a relatively thin zinc layer of 40µm. This section should be monitored. See Figure 24 (b).
- One barrier on the M8 at the J18-to-J17 section had noticeable scratches on the surface and a relatively thin zinc thickness compared to other areas on the crash barrier. All other barriers at this site had at least approximately 60µm thick zinc. See Figure 24 (c).

<sup>1</sup> <https://galvanizing.org.uk/sustainable-construction/galvanizing-is-sustainable/durability-service-life/#:~:text=With%20zinc%20corrosion%20rates%20normally,corresponding%20increases%20to%20coating%20life>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
11

Evaluation of road barriers in  
Cork

Report Ref:  
05023

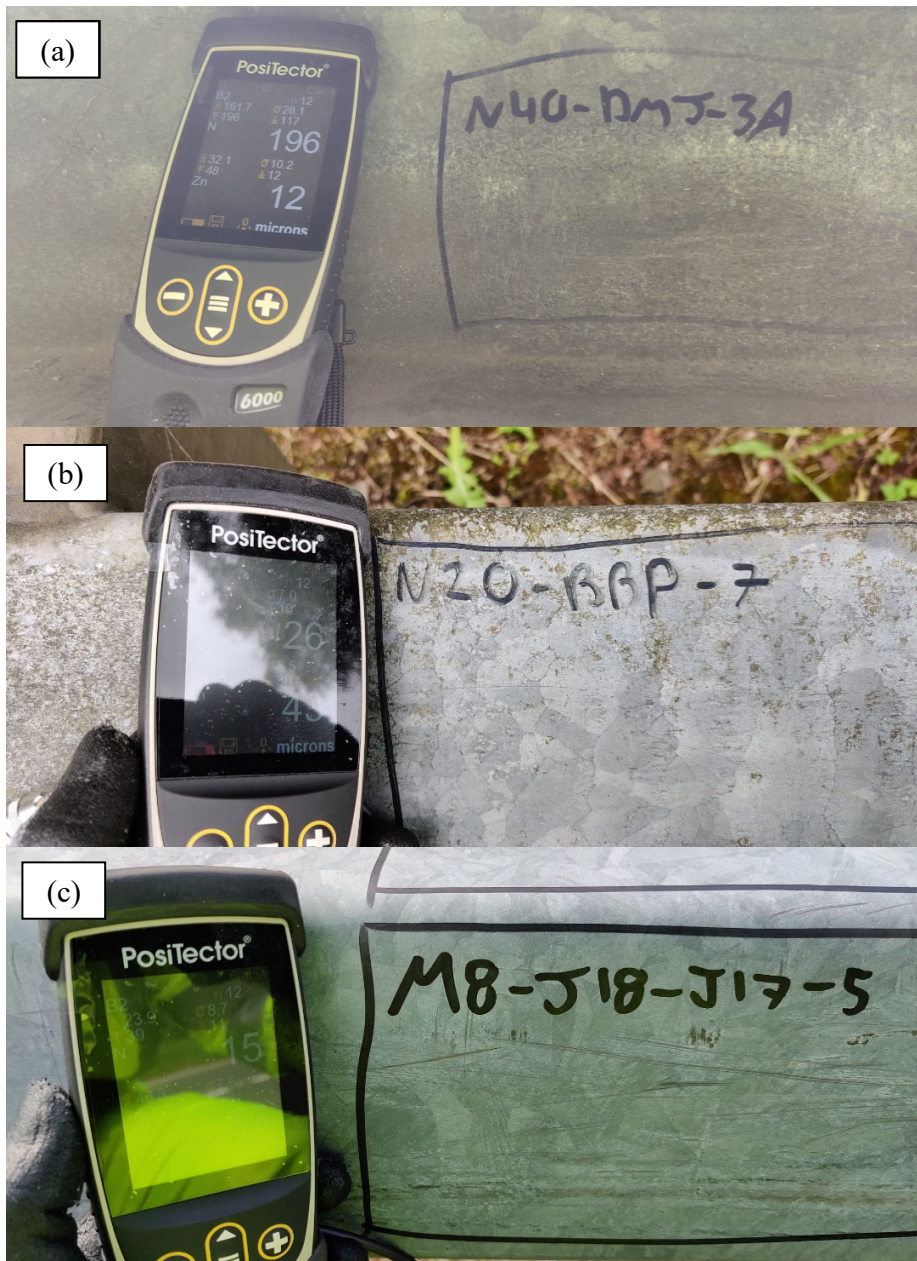


Figure 24: Three locations with relatively thin zinc coating. (a) N40 Douglas / Mahon Junction, (b) N20 Blackpool By-Pass & (c) M8 J18-to-J17 with noticeable impact damage (i.e. gouges and scratches).

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No.  
*12*

Evaluation of road barriers in  
Cork

Report Ref:  
05023



## ANNEXES

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

Rev. No: D

Issue Date:05/10/2021

Owner: I.Pascu

 **TECHNOLOGY GATEWAYS**  
delivering solutions for industry  
an Enterprise Ireland network

 **ENTERPRISE IRELAND**  
where innovation means business



# CREST

## Centre for Research in Engineering Surface Technology



Focas Institute, TU Dublin Kevin St. Dublin 8, Ireland  
www.crestdit.com

Dr Irina Pascu  
Consultancy Manager  
+353 (1) 220 6911  
Irina/pascu@TUDublin.ie

Dr Brendan Duffy  
Centre Manager  
+353 (1) 220 6907  
brendan.duffy@TUDublin.ie



### Final Report

<b>Client:</b>	<b>RPS</b>	<b>Title:</b>	Evaluation of road barriers for detailed analysis (Rathcoole)
<b>Attn:</b>	<b>Rowan O'Callaghan Padraic Culkin</b>		
<b>Report ref:</b>	<b>05123</b>	<b>Order No:</b>	<b>TBC</b>
<b>Report by:</b>	<b>Joseph Mohan</b>	<b>Approved by:</b>	<b>Brendan Duffy</b>
<b>Date Recd:</b>	<b>05/07/2023</b>	<b>Issue date:</b>	<b>30/11/2023</b>

#### CONDITIONS: Terms and Conditions of Acceptance

1. Reports issued by Technological University Dublin are copyright and shall not be used, either in whole or in part, for the purposes of advertising, publicity or litigation without the consent of the Director of Research and Enterprise.
2. In accordance with laboratory accreditation requirements reports shall only be reproduced in full.
3. Non-perishable samples received for testing or laboratory work shall be disposed of after three months from completion of test unless claimed or unless instructions to the contrary have been notified by the client.
4. No action or legal proceedings shall be taken (except in the case of wilful neglect or default) against the University or any member of the University or the Board or any member of the Board or any Committee appointed by the Board or any employee of the University by reason of or arising out of the carrying out of any research, investigation, test or analysis in accordance with the Science and Technology Act 1987, or the publication of the results there in the name of the University.
5. Payment for work carried out shall be in accordance with the terms stated on the University invoices.
6. The laws of the Republic of Ireland shall apply.
7. The client is responsible for delivery to Technological University Dublin test items free of any duty, VAT, freight charges, etc. unless otherwise agreed.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



**1. INTRODUCTION**

CREST was contracted by RPS to measure the levels of galvanised zinc on crash barriers from various locations for detailed analysis. Sections of crash barriers were collected from Lagan’s site in Rathcoole. The seven locations examined in this report are shown in **Table 1**. Note that ‘(DA)’ indicates that the barrier was selected for detailed analysis via scanning electron microscopy (SEM). Four reference barriers manufactured by either Aximum or C501 were also analysed to provide a benchmark of a galvanised coating. A brand-new barrier as well as a 5-to-10-year-old Aximum and C501 barrier were examined. Several locations were given a unique ID Code by TU Dublin to simplify the naming of samples.

**Table 1: Specific locations, type and age profile of selected crash barriers.**

Location	ID Code	Type	Age
Aximum (New)	AN	N/A	New
Aximum (5 years old)	A5	N/A	5 Years
C501	CN	N/A	New
C501	C5	N/A	5 Years
N03-CN-0042 (DA)	V	Rural	20-25 Years
N55-ATH (DA)	W	Urban	20-25 Years
N55-LK-RNo80 (DA)	X	Coastal	25 Years +
N59-GY-SB09A (DA)	Y	Coastal	20-25 Years
N59-KM-RNo78 (DA)	Z	Rural	25 Years +
N28-Cork	N/A	Urban	20-25 Years
N59-GY-SB02	N/A	Coastal	20-25 Years

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No. 3 Evaluations of road barriers for detailed analysis (Rathcoole) Report Ref: 05023



## 2. MEASUREMENT DETAILS

The thickness of galvanised zinc coating on the crash barriers were measured using two techniques. The first technique for zinc thickness measurement on the steel substrate was performed using a handheld contact probe (Positector 6000 Dual Probe). The area to be tested was marked on the barrier using a permanent marker and the surface was cleaned using wipes. After cleaning, the zinc thicknesses were measured using the probe at 12 different points (n=12). The measurements were then recorded by photograph and stored online. An example of this can be seen in **Figure 1** through **Figure 5**.

The zinc coating of crash barriers that were analysed in detail were measured in 10 different locations on the Corrugated / 'W' designs (numbered 1-to-10) and in 6 different locations on the single Open Box Beams (OBB's) design (numbered (1-to-6). Odd numbers are on the front of the crash barrier or outward facing surface towards the road / traffic while even numbers are on the back or inward facing surface. Sequential number pairs (e.g. 1 & 2 or 5 & 6) are opposite sides of the same area on the crash barrier. An example of the detailed areas for analysis on a corrugated barrier taken from the N59 location and labelled 'N59-GY-SB09A' by Lagan, are shown in **Figure 1** to **Figure 5**.

The second technique involved extracting small samples of the crash barrier using an angle grinder. These small samples were then mounted in a clear set epoxy resin prior to being ground and polished to a smooth surface finish. An example of this process can be seen in **Figure 6**. Once polished, the samples were then examined under a TableTop scanning electron microscopy (Hitachi TM4000 SEM) to determine the thickness of the galvanised zinc layer. Prior to any measurements under SEM, a calibration standard was checked to ensure all readings were accurate (see **Figure 7**). Thickness measurements were taken on both sides of the extracted samples (i.e. the front / back or odd / even numberd areas as previously discussed). Each microscopy sample was measured in three locations along the specimen and three measures were taken per location. This gave 9 measurements per sample (n=9). An example of an area that was analysed under SEM can be seen in **Figure 8**. In the left hand image, regions of interest are highlighted and include the dark grey area corresponding to the epoxy mounting resin used to prepare the samples. The light grey layer in the centre represents the galvanised zinc coating. The steel substrate of the crash barrier is a slightly darker shade of grey. Numerous samples also revealed corrosion products or contamination on the surface of the crash barrier and these have also been highlighted in **Figure 8**. On the right-hand side of **Figure 8**, a typical measurement is presented at three different locations.

As a secondary check, energy dispersive x-ray (EDX) analysis was also performed on each sample to facilitate the correct identification of the galvanised zinc layer and steel substrate. **Figure 9** shows the same SEM image from **Figure 8** alongside the EDX analysis that showed the presence of Iron (Fe) in the substrate and Zinc (Zn) in the galvanised coating correspond to the darker and lighter shades of grey respectively.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



**Figure 1: Example of measurement on area '1' (left) and '2' (right) for crash barrier labelled 'N59-GY-SB09A'.**



**Figure 2: Example of measurement on area '3' (left) and '4' (right) for crash barrier labelled 'N59-GY-SB09A'.**



**Figure 3: Example of measurement on area '5' (left) and '6' (right) for crash barrier labelled 'N59-GY-SB09A'.**

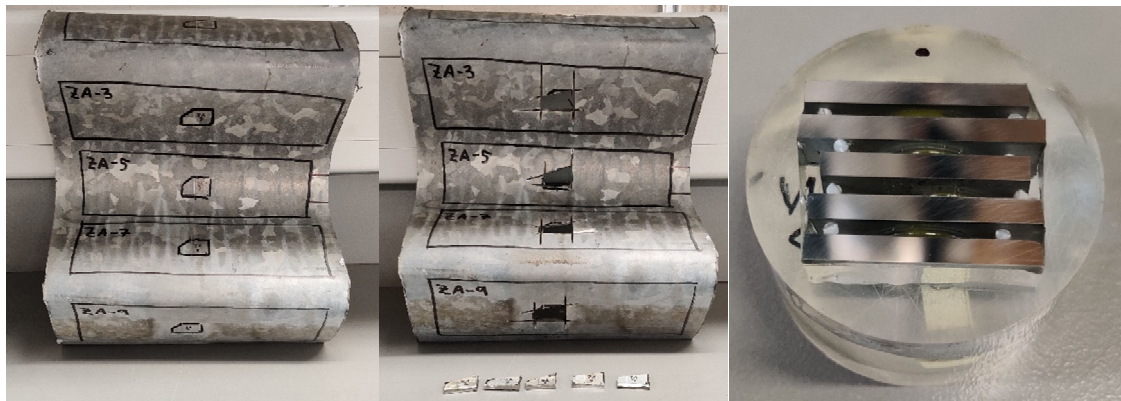


**Figure 4: Example of measurement on area '7' (left) and '8' (right) for crash barrier labelled 'N59-GY-SB09A'.**

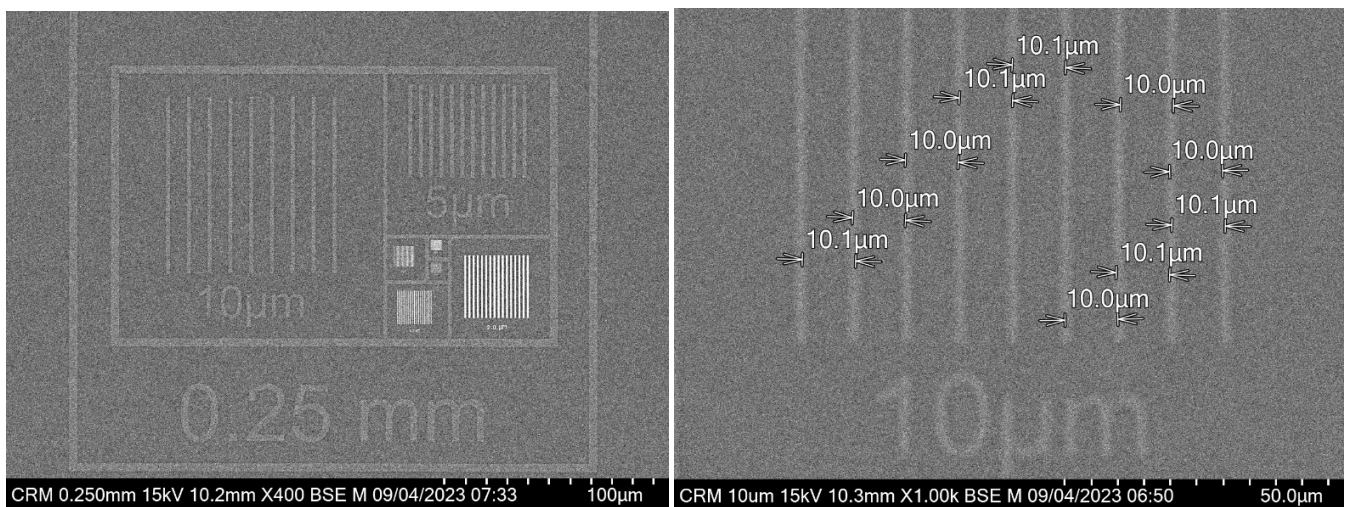


**Figure 5: Example of measurement on area '9' (left) and '10' (right) for crash barrier labelled 'N59-GY-SB09A'.**

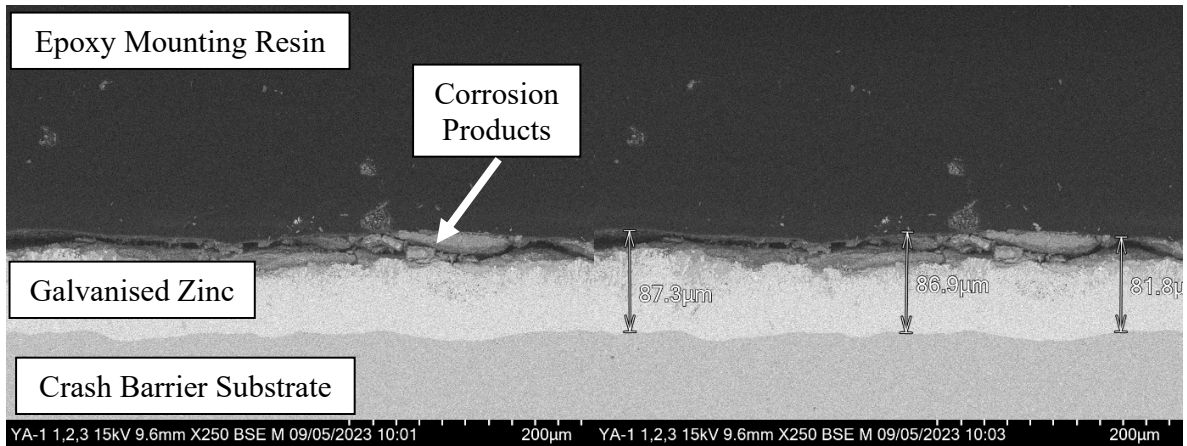
Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



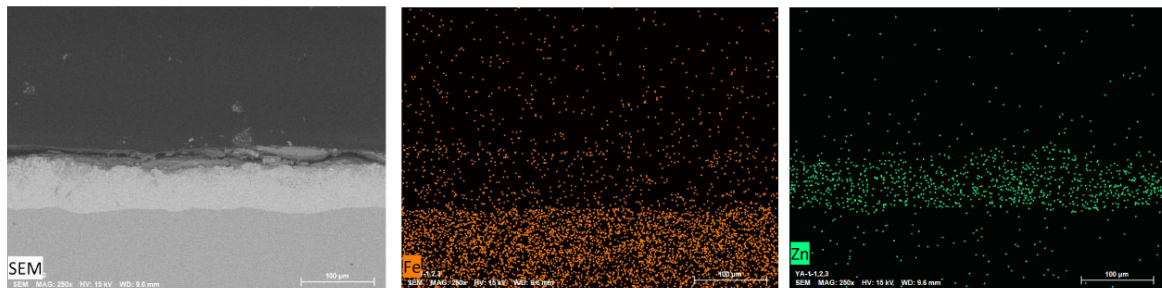
**Figure 6:** Example of crash barrier that was collected from Lagan's Rathcoole depot (left), after samples were extracted using an angle grinder (centre) and, finally, mounted in epoxy resin that was subsequently ground & polished (right).



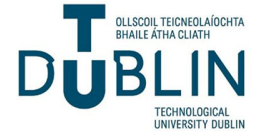
**Figure 7:** SEM calibration standard (left) and with several measurements taken at 10um scale (right).



**Figure 8:** Example of an SEM image taken from a section of crash barrier (left) and with galvanised zinc measurements in three separate locations (right).



**Figure 9:** Energy dispersive x-ray (EDX) analysis of SEM image (left) showing presence of Iron (Fe) in orange (centre) and Zinc (Zn) in green (right).



**3. POSITEST PROBE & SEM RESULTS**

After the measurements were taken from the Positector Probe and SEM methods, the results for each crash barrier were compiled and summarised into the following series of Tables for each site location as previously listed in **Table 1**. Note that for reported thicknesses per Section 1, 2 & 3, n=12 and for SEM measurements n=9. The reported values represent the averages plus or minus the standard deviation.

**3.1 Aximum New**

	Section 1	SEM
1 Top Front (µm)	64 ± 4	75 ± 4
2 Top Back (µm)	80 ± 7	85 ± 4

**3.2 Aximum 5-Year Old**

	Section 1	SEM
1 Top Front (µm)	90 ± 4	106 ± 6
2 Top Back (µm)	90 ± 6	101 ± 3

**3.3 C501 New**

	Section 1	SEM
1 Top Front (µm)	57 ± 10	92 ± 10
2 Top Back (µm)	64 ± 10	82 ± 10

**3.4 CS 5-Year Old**

	Section 1	SEM
1 Top Front (µm)	87 ± 7	133 ± 9
2 Top Back (µm)	62 ± 7	96 ± 9

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No. 8 Evaluations of road barriers for detailed analysis (Rathcoole) Report Ref: 05023



**3.5 N03-CN-0042 (DA) / V**

	Section 1	Section 2	Section 3	SEM
1 Top Front (µm)	59 ± 3	39 ± 7	21 ± 13	75 ± 2
2 Top Back (µm)	72 ± 14	68 ± 4	75 ± 4	74 ± 4
3 Near-Top Front (µm)	61 ± 4	63 ± 4	65 ± 6	81 ± 4
4 Near-Top Back (µm)	66 ± 4	70 ± 4	73 ± 3	75 ± 3
5 Middle Front (µm)	57 ± 3	64 ± 14	61 ± 8	66 ± 4
6 Middle Back (µm)	61 ± 9	75 ± 8	70 ± 9	82 ± 12
7 Near-Bottom Front (µm)	61 ± 6	59 ± 6	61 ± 8	96 ± 27
8 Near-Bottom Back (µm)	69 ± 4	70 ± 5	66 ± 7	77 ± 6
9 Bottom Front (µm)	67 ± 7	59 ± 10	67 ± 5	78 ± 3
10 Bottom Back (µm)	66 ± 6	72 ± 5	65 ± 5	76 ± 9

**3.6 N55-ATH (DA) / W**

	Section A	Section B	Section C	SEM
1 Top Front (µm)	76 ± 4	69 ± 7	72 ± 6	102 ± 4
2 Top Back (µm)	92 ± 3	62 ± 9	60 ± 6	126 ± 23
3 Near-Top Front (µm)	85 ± 6	66 ± 7	72 ± 6	113 ± 17
4 Near-Top Back (µm)	45 ± 23	65 ± 10	58 ± 6	103 ± 88
5 Middle Front (µm)	85 ± 5	62 ± 10	54 ± 4	86 ± 29
6 Middle Back (µm)	54 ± 18	28 ± 13	60 ± 8	121 ± 11

**3.7 N55-LK-RN080 (DA) / X**

	Section A	Section B	Section C	SEM
1 Top Front (µm)	50 ± 16	28 ± 17	45 ± 17	78 ± 4
2 Top Back (µm)	73 ± 5	73 ± 4	79 ± 7	76 ± 3
3 Near-Top Front (µm)	64 ± 2	66 ± 2	65 ± 2	76 ± 6
4 Near-Top Back (µm)	65 ± 6	73 ± 7	71 ± 5	95 ± 15
5 Middle Front (µm)	85 ± 6	84 ± 4	79 ± 3	72 ± 5
6 Middle Back (µm)	42 ± 5	42 ± 4	54 ± 5	89 ± 25
7 Near-Bottom Front (µm)	70 ± 3	72 ± 5	71 ± 6	94 ± 4
8 Near-Bottom Back (µm)	67 ± 3	65 ± 5	69 ± 5	77 ± 10
9 Bottom Front (µm)	57 ± 3	57 ± 4	61 ± 4	78 ± 3
10 Bottom Back (µm)	68 ± 6	66 ± 6	70 ± 2	88 ± 10

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



**3.8 N59-GY-SB09A (DA) / Y**

	Section A	Section B	Section B	SEM
1 Top Front (µm)	51 ± 5	37 ± 3	41 ± 4	99 ± 19
2 Top Back (µm)	74 ± 4	69 ± 3	70 ± 6	120 ± 32
3 Near-Top Front (µm)	50 ± 6	35 ± 5	45 ± 5	76 ± 12
4 Near-Top Back (µm)	61 ± 5	63 ± 14	57 ± 5	80 ± 10
5 Middle Front (µm)	70 ± 6	58 ± 6	60 ± 8	89 ± 15
6 Middle Back (µm)	64 ± 6	47 ± 6	49 ± 15	85 ± 3
7 Near-Bottom Front (µm)	53 ± 5	46 ± 9	36 ± 10	78 ± 6
8 Near-Bottom Back (µm)	65 ± 2	61 ± 3	63 ± 4	75 ± 11
9 Bottom Front (µm)	-130 ± 57	-247 ± 61	-278 ± 25	50 ± 10
10 Bottom Back (µm)	59 ± 3	56 ± 7	56 ± 5	77 ± 6

**3.9 N59-KM-Rno78 (DA) / Z**

	Section A	Section B	Section C	SEM
1 Top Front (µm)	64 ± 4	56 ± 5	62 ± 5	94 ± 12
2 Top Back (µm)	68 ± 4	60 ± 5	67 ± 4	77 ± 3
3 Near-Top Front (µm)	77 ± 5	73 ± 5	67 ± 8	88 ± 7
4 Near-Top Back (µm)	72 ± 3	70 ± 4	74 ± 6	84 ± 7
5 Middle Front (µm)	88 ± 4	87 ± 11	95 ± 29	77 ± 6
6 Middle Back (µm)	52 ± 8	45 ± 6	54 ± 6	88 ± 11
7 Near-Bottom Front (µm)	68 ± 3	59 ± 10	68 ± 3	85 ± 9
8 Near-Bottom Back (µm)	74 ± 3	64 ± 8	68 ± 7	90 ± 4
9 Bottom Front (µm)	43 ± 19	35 ± 19	19 ± 7	68 ± 6
10 Bottom Back (µm)	84 ± 8	84 ± 11	84 ± 5	98 ± 5

**3.10 N28-Cork**

	Top	Front	Back
Rail 1 (µm)	78 ± 10	60 ± 4	66 ± 18
Rail 2 (µm)	82 ± 6	55 ± 7	78 ± 6
Rail 3 (µm)	72 ± 5	55 ± 5	60 ± 30

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.

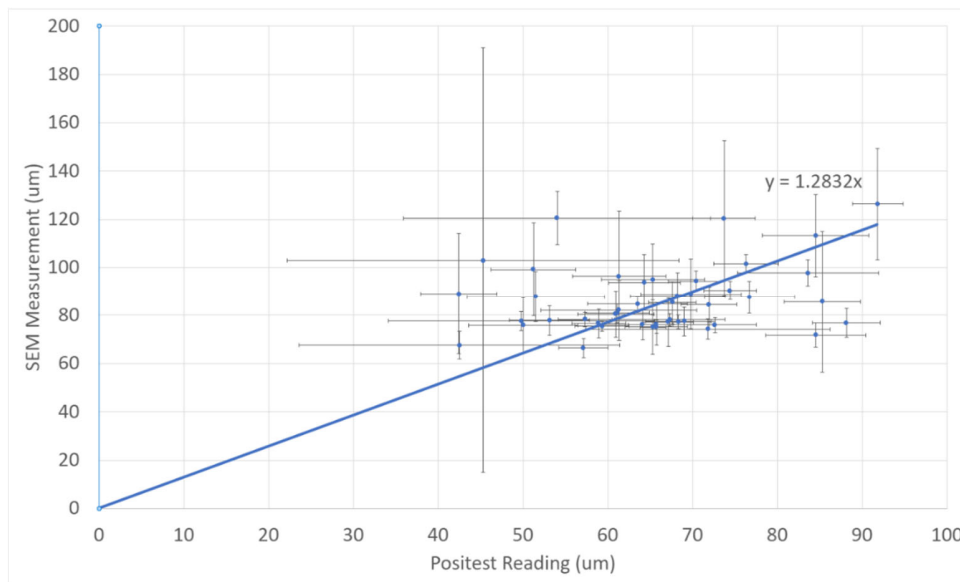


**3.11 N59-GY-SB02**

	Top	Front	Back
Rail 1 (µm)	46 ± 3	65 ± 5	62 ± 5
Rail 2 (µm)	56 ± 7	63 ± 3	58 ± 5
Rail 3 (µm)	66 ± 4	70 ± 8	71 ± 5

**3.12 Comparison of Measurements from Positector Probe versus SEM Analysis.**

Several crash barrier locations were measured using both the Positector Probe and SEM Analysis techniques and allowed both methods to be directly compared. Figure 10 shows a plot of the galvanised thickness as measured via SEM plotted against that measured via the Positector Probe for all such locations. If the two techniques were near identical, then a best fit line (shown in blue in Figure 10) would have a slope of '1' while passing through the origin. As was found, the slope of the line is 1.2832. This indicates that that Positector Probe is a more conservative estimate of the galvanised zinc thickness. The SEM measurement results in a thickness approximately 28% greater than that from a Positector Probe. Obviously, the Positector Probe is a much quicker measurement technique and can be performed on-site without damaging the crash barrier while the SEM measurement technique can take several days in sample preparation.



**Figure 10:** Graph of SEM Measurement versus corresponding Positector Probe Reading.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



The data presented in Figure 10 was further broken down into sub-categories that examined the effect of crash barrier age and environment as well as the side of the barrier (i.e. front versus back) and vertical position (i.e. top to bottom). The data is presented in Figure 11 and the variations in age, environment, side, and vertical position are highlighted via different colour codes.

**Figure 11 (a)** shows the data from Figure 10 broken down by Age. There was considerable overlap in the average data values with no clear difference between 20-to-25-year-old and 25+ year old barriers. It was interesting to note that the Aximum and C501 reference crash barriers had a noticeably thicker galvanised zinc coating on the older barriers (i.e. 5-to-10 Year Old / orange data points in **Figure 11 (a)**) versus the new barriers. **Figure 11 (b)** shows the data broken down by environment (i.e. Rural, Urban or Coastal). Once again there was considerable overlap in the data obtained via the Positest readings. The SEM measurements suggest that the Urban barriers had slightly higher zinc coating thicknesses compared to Rural or Coastal. However, more data points would be needed to form a more definite conclusion. **Figure 11 (c)** shows the data split between the Front (i.e. facing the road) and Back (i.e. facing away from the road). This split still contained an overlap between the front and back of the crash barrier. Finally, **Figure 11 (d)** shows the data divided by vertical position on the crash barrier. As with the other data segmentation, there was noticeable overlap in the data points with no clear influence on vertical position.



**Figure 11:** Data from previous graph (**Figure 10**) broken down by a) Age, b) Environment, c) Side and d) Vertical Position of Crash Barrier. For clarity, the error bars were removed.



Sheet No. Evaluations of road barriers for Report Ref:  
*12* detailed analysis (Rathcoole) 05023



#### 4. DISCUSSION

This report focused on 11 crash barriers across different site locations. This include x4 references barriers from Aximum and C501, x5 sites that were selected for detailed analysis and x2 additional sites that were included for analysis.

All average readings from these x11 crash barrier locations from the Positest Probe were above 40µm while all average measurements via SEM analysis were above 60µm (refer to **Figure 10**). However, there was significant variability (i.e. error bars) at several sites that resulted in areas with relatively thin zinc coatings (e.g. approximately 20µm on N03-CN-0042 (DA), see Section 3.5). There was also one barrier that produced an erroneous negative galvanised thickness (see Section 3.8 for the N59-GY-SB09A crash barrier). However, this was believed to be due to noticeable rust on the barrier. Several selected crash barriers will be discussed in more detail over the following Sections 4.1 to 4.6.

##### 4.1 Reference Crash Barriers

New and 5-year old crash barriers manufactured by Aximum and C501 were provided by Lagan to act as reference benchmark and also for developing the testing methodology. A total of x4 unique crash barriers were examined. It was noted that the newer crash barriers had a thinner zinc coating compared to the barriers that were 5-to-10 years old (see **Section 3.1 to 3.4**).

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection,  
Fundamental and Applied Industrial Research.

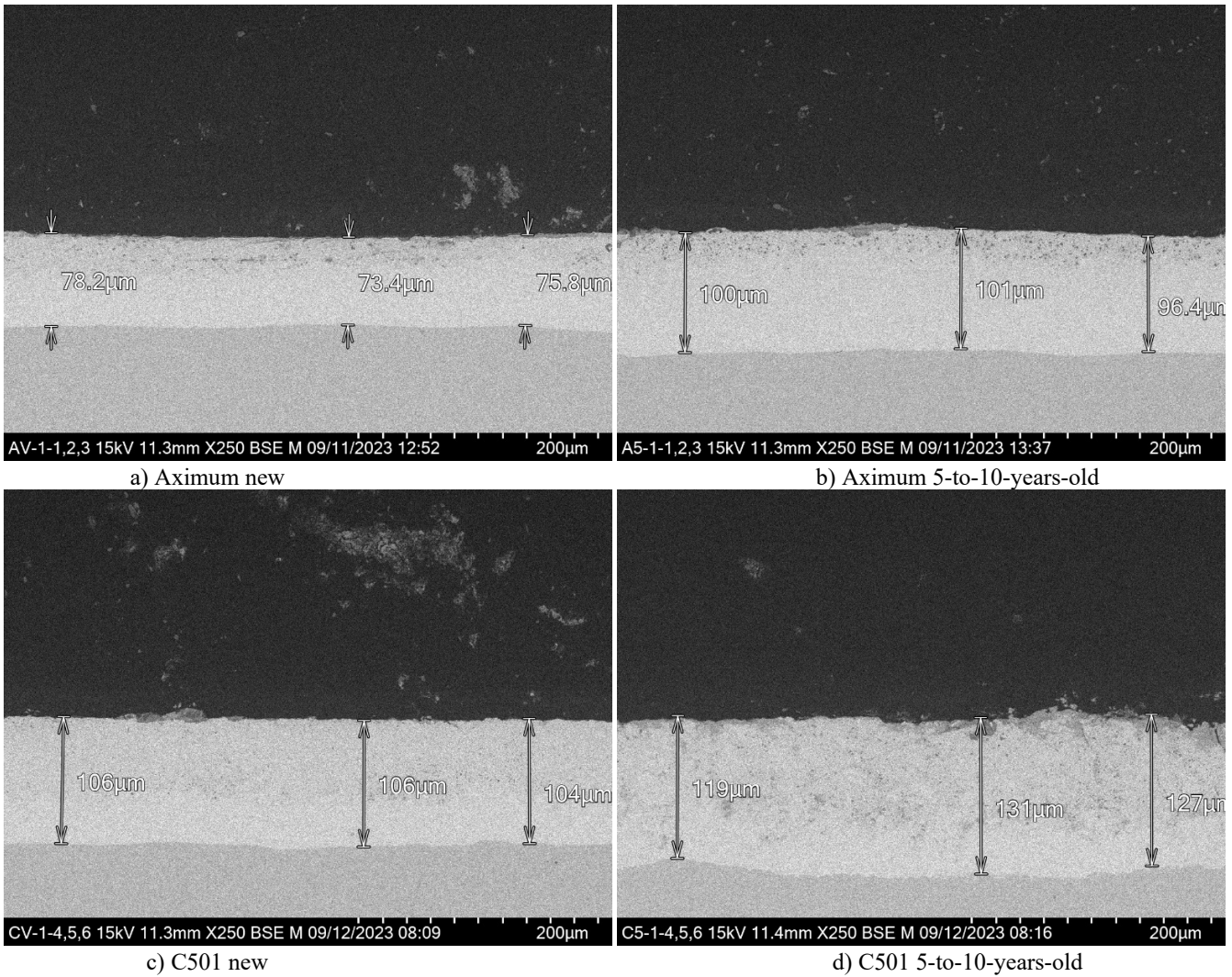
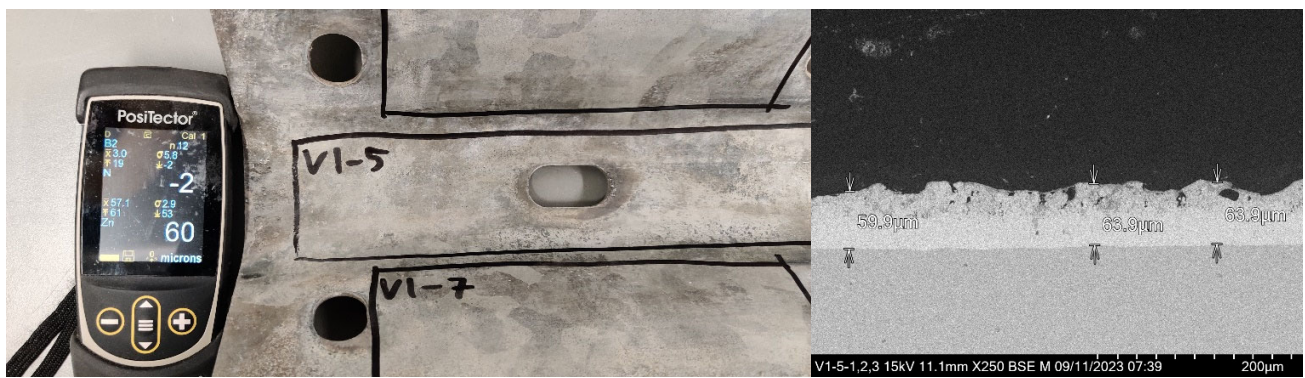


Figure 12: Reference crash barriers from Aximum, (a) new and (b) 5-to-10 years old, and C501, (c) new and (d) 5-to-10 years old.

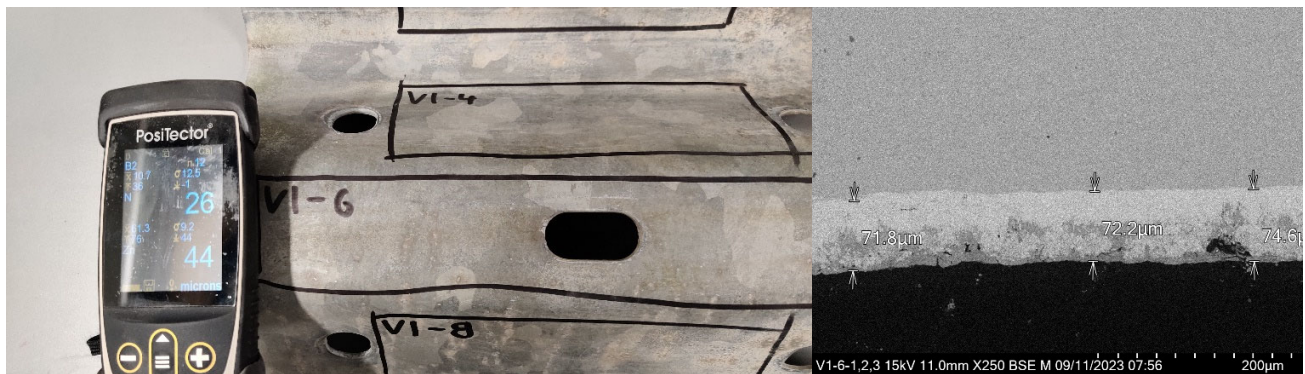


#### 4.2 N03-CN-0042 / V

The crash barrier taken from the N03 did not display the typical galvanised zinc coating surface pattern that was observed on other barriers (see Figure 15, Figure 19, Figure 21 & Figure 23). In general, it appeared ‘worn’, with very slight signs of rust, even after cleaning to remove any surface contamination. Figure 13 & Figure 14 show two such areas with a photograph on the left and SEM cross-section on the right. Despite the worn appearance, there was still approximately 60um of zinc coating remaining on the Front (Figure 13) and 70um on the Back (Figure 14).



**Figure 13:** Photograph of front area of N03-CN-0042 (V1-5) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at 12 points using the Positector and 9 points via SEM.



**Figure 14:** Photograph of back area of N03-CN-0042 (V1-6) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at 12 points using the Positector and 9 points via SEM.



### 4.3 N55-ATH / W

The crash barrier taken from the N55 was an Open Box Beam (OBB) construction. The exterior surface of the OBB was in good condition from visual inspection and had over 100um of zinc remaining (see Figure 15). However, the interior, or inside, of the OBB sections (i.e. surface facing away from the traffic) exhibited a layer of what appeared to be corrosion product. Further EDX analysis (Figure 17) revealed this layer contained the elements Calcium and Silicon.

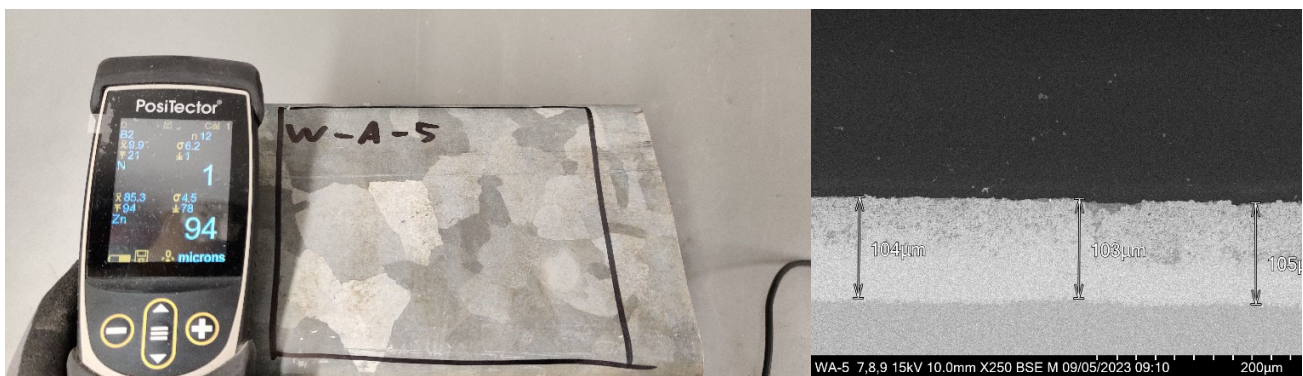


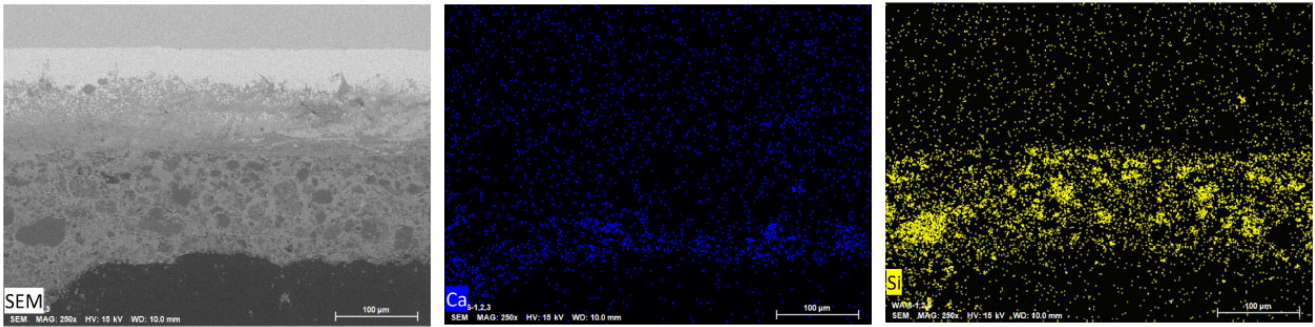
Figure 15: Photograph of front area of N55-ATH (WA-5) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at 12 points using the Positector and 9 points via SEM.



Figure 16: Photograph of front area of N55-ATH (WA-6) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at 12 points using the Positector and 9 points via SEM.



Sheet No. **16** Evaluations of road barriers for detailed analysis (Rathcoole) Report Ref: **05023**



**Figure 17:** Further EDX analysis of the SEM cross-section from **Figure 16** (right). In this Figure, the SEM image is on the left with Calcium elemental map in the centre and Silicon map on the right.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



#### 4.4 N55-LK-RN80 / X

It was interesting to note the difference in appearance between the Exterior / Front (**Figure 18**) and Interior / Back (**Figure 19**) of the section taken from the N55. The exterior surface was noticeable worn after cleaning. However, there was still a significant zinc layer on the barrier (see **Figure 18 (right)**).



**Figure 18:** Photograph of front area of N55-LK-RN80 (XA-9) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at 12 points using the Positector and 9 points via SEM.



**Figure 19:** Photograph of front area of N55-LK-RN80 (XA-10) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at 12 points using the Positector and 9 points via SEM.



#### 4.5 N59-GY-SB09A / Y

The crash barrier taken from the N59 had the most noticeable appearance of rust on the underlying side of the barrier (see Figure 20). While there was still a zinc coating that was approximately 40um thick in some areas, it was also observed that the rust permeated through the coating to the base steel substrate (see Figure 20 (right)). In this example, it would be strongly recommended that this barrier be replaced with a new beam. Despite this poor conditions on the outside, the interior surface appeared almost 'as new' (see Figure 21).

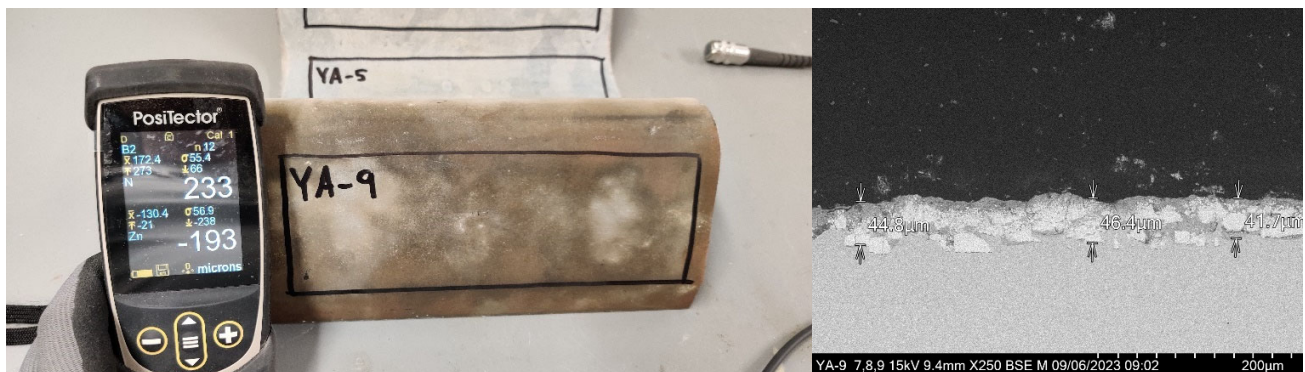


Figure 20: Photograph of front area of N59-GY-SB09A (YA-9) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at three points.



Figure 21: Photograph of front area of N59-GY-SB09A (YA-10) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at three points.



#### 4.6 N59-KM-RN078 (DA) / Z

The crash barrier taken from the N59 also exhibited signs of corrosion on the underlying surface (see Figure 22 (left)). Despite this, the thickness of the zinc coating was over 60um as measure via SEM (see Figure 22 (right)). Figure 23 (left and right) showed that the interior surface of the crash barrier had a zinc thickness of approximately 95um.

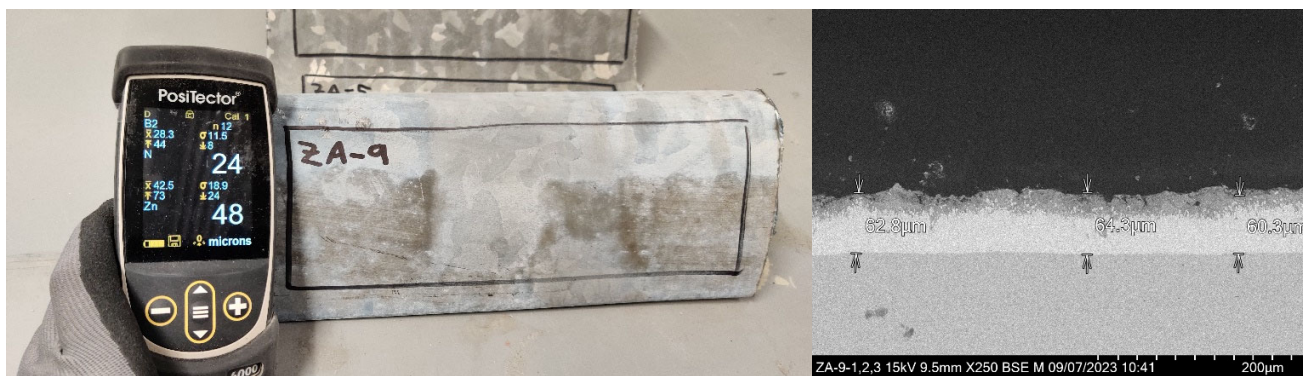


Figure 22: Photograph of front area of N59-KM-RN078 (ZA-9) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at three points.

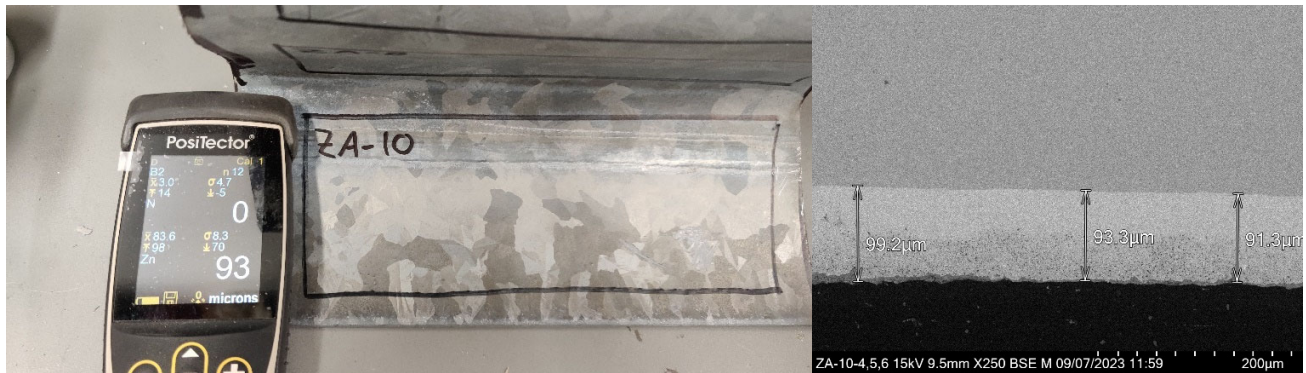


Figure 23: Photograph of front area of N59-KM-RN078 (ZA-10) (left) and correspond SEM image (right). Galvanised zinc coating has been measured at three points.

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.



Sheet No. Evaluations of road barriers for detailed analysis (Rathcoole) Report Ref:  
20 05023



## 5. SUMMARY

Based on the results presented in this report, the following main points can be made:

- The Positector 6000 Probe results in a slightly more conservative estimation of galvanised zinc thickness than via SEM. Positector zinc readings are approximately 30% higher than SEM. This indicates that a Positector Probe measurement is noticeable more conservative in estimating the remain thickness of the galvanised zinc layer.
- For the crash barriers examined in this report, the average measure of zinc thickness via SEM was greater than 60µm.
- For the crash barriers examined in this report, the average measure of zinc thickness via Positector Probe was greater than 40µm.
- A general rule of thumb that has been established by the UK Galvanizers Association is that the zinc layer will be consumed at a rate of 1µm/year<sup>1</sup>.
  - Using this as a guideline, many of the crash barriers examined in this report on detailed analysis as well as previous reports have over 40 years of service life remaining.
  - Even at a conservative rate of 2µm/year many of the barriers investigated in this report would have almost 20 years of service life remaining.
- There were several sites that had clear visual indications of thin zinc coatings. Throughout this detailed analysis and accompanying reports, it was observed that crash barriers that showed clear visual onset of rust or scale on the surface should be considered for replacing. In particular, the Open Box Beams (OBB's) and painted barriers on wooden posts should also be considered for replacement.

<sup>1</sup> <https://galvanizing.org.uk/sustainable-construction/galvanizing-is-sustainable/durability-service-life/#:~:text=With%20zinc%20corrosion%20rates%20normally,corresponding%20increases%20to%20coating%20life.>

Surface Coatings, Corrosion Control, Surface Analysis, Failure Investigation, Specification, Type Approval, Inspection, Fundamental and Applied Industrial Research.

## Appendix C

### Test Results

## FACTUAL REPORT

## APPENDIX C – Test Results

## Probe Test Results

VRS Location	Rail	Top	Front	Back
<b>N4 (R394)</b>	Rail 1 (µm)	66 ± 5	67 ± 3	81 ± 4
	Rail 2 (µm)	60 ± 6	67 ± 2	80 ± 4
	Rail 3 (µm)	70 ± 8	71 ± 7	80 ± 4
<b>N4 (Junction 17 'south')</b>	Rail 1 (µm)	62 ± 3	70 ± 4	70 ± 2
	Rail 2 (µm)	64 ± 3	70 ± 2	67 ± 3
	Rail 3 (µm)	64 ± 2	72 ± 2	72 ± 3
<b>N4 (Junction 14 'north')</b>	Rail 1 (µm)	62 ± 4	68 ± 3	70 ± 2
	Rail 2 (µm)	62 ± 4	70 ± 4	72 ± 2
	Rail 3 (µm)	84 ± 3	98 ± 3	98 ± 6
<b>N4</b>	Rail 1 (µm)	55 ± 4	74 ± 4	62 ± 6
	Rail 2 (µm)	51 ± 7	71 ± 7	66 ± 3
	Rail 3 (µm)	50 ± 8	68 ± 3	59 ± 3
<b>N4 Carrick-on-Shannon (east)</b>	Rail 1 (µm)	57 ± 5	70 ± 7	76 ± 4
	Rail 2 (µm)	66 ± 5	69 ± 5	78 ± 5
	Rail 3 (µm)	61 ± 7	76 ± 4	76 ± 4
<b>N4 Carrick-on-Shannon (west)</b>	Rail 1 (µm)	75 ± 14	83 ± 4	72 ± 4
	Rail 2 (µm)	41 ± 5	74 ± 14	58 ± 4
	Rail 3 (µm)	96 ± 7	93 ± 4	95 ± 4
<b>N4 (near Boyle)</b>	Rail 1 (µm)	35 ± 6	63 ± 6	62 ± 4
	Rail 2 (µm)	41 ± 6	60 ± 6	63 ± 5
	Rail 3 (µm)	46 ± 8	60 ± 3	65 ± 4
<b>N4 (near N17)</b>	Rail 1 (µm)	60 ± 14	78 ± 5	64 ± 4
	Rail 2 (µm)	29 ± 7	58 ± 2	60 ± 2
	Rail 3 (µm)	33 ± 4	61 ± 2	67 ± 6
<b>N4 (N61 near Athlone)</b>	Rail 1 (µm)	22 ± 21	28 ± 15	69 ± 11
	Rail 2 (µm)	12 ± 43	45 ± 13	57 ± 13
	Rail 3 (µm)	99 ± 34	115 ± 23	77 ± 11
<b>Rathkeale (N21) Results</b>	Rail 1 (µm)	80 ± 8	73 ± 8	69 ± 8
	Rail 2 (µm)	72 ± 4	54 ± 3	73 ± 8
	Rail 3 (µm)	70 ± 6	62 ± 6	72 ± 8
<b>Croom (N20) Results</b>	Rail 1 (µm)	44 ± 2	70 ± 3	75 ± 6
	Rail 2 (µm)	68 ± 2	73 ± 2	74 ± 4
	Rail 3 (µm)	76 ± 5	78 ± 2	82 ± 5
<b>M8 Glanmire</b>	Rail 1 (µm)	61 ± 3	65 ± 5	60 ± 3
	Rail 2 (µm)	56 ± 6	61 ± 7	62 ± 5
	Rail 3 (µm)	64 ± 8	72 ± 6	75 ± 2
<b>M8 (Junction 18-to-17)</b>	Rail 1 (µm)	84 ± 4	81 ± 9	92 ± 4
	Rail 2 (µm)	63 ± 8	46 ± 8	91 ± 9

## FACTUAL REPORT

	Rail 3 (µm)	63 ± 5	59 ± 10	89 ± 8
<b>N20 Blackpool Bypass</b>	Rail 1 (µm)	59 ± 6	64 ± 7	67 ± 4
	Rail 2 (µm)	57 ± 5	71 ± 8	66 ± 4
	Rail 3 (µm)	40 ± 9	62 ± 5	100 ± 5
<b>N22 Ballincollig</b>	Rail 1 (µm)	80 ± 6	76 ± 3	68 ± 6
	Rail 2 (µm)	65 ± 3	74 ± 5	67 ± 5
	Rail 3 (µm)	94 ± 15	91 ± 13	71 ± 5
<b>N25 Cork (Site A)</b>	Rail 1 (µm)	81 ± 5	72 ± 8	66 ± 13
	Rail 2 (µm)	91 ± 4	97 ± 3	78 ± 6
	Rail 3 (µm)	77 ± 10	76 ± 5	69 ± 4
<b>N25 Cork (Site B)</b>	Rail 1 (µm)	54 ± 15	80 ± 6	89 ± 3
	Rail 2 (µm)	76 ± 3	77 ± 6	88 ± 4
	Rail 3 (µm)	74 ± 6	85 ± 5	94 ± 9
<b>N25 Cork Harbour</b>	Rail 1 (µm)	60 ± 7	68 ± 3	70 ± 2
	Rail 2 (µm)	55 ± 9	73 ± 4	65 ± 2
	Rail 3 (µm)	64 ± 7	78 ± 5	63 ± 10
<b>N40 Douglas / Mahon Junction</b>	Rail 1 (µm)	61 ± 9	69 ± 9	32 ± 10
	Rail 1 (µm)	91 ± 4	73 ± 3	96 ± 5
	Rail 2 (µm)	52 ± 10	71 ± 4	83 ± 8
	Rail 3 (µm)	56 ± 4	72 ± 4	78 ± 2
<b>N40 Jack Lynch Tunnel (Site A)</b>	Rail 1 (µm)	73 ± 5	75 ± 5	114 ± 6
	Rail 2 (µm)	76 ± 8	69 ± 5	88 ± 7
	Rail 3 (µm)	95 ± 6	93 ± 6	136 ± 15
<b>N40 Jack Lynch Tunnel (Site B)</b>	Rail 1 (µm)	81 ± 8	91 ± 6	145 ± 11
	Rail 2 (µm)	51 ± 6	61 ± 10	66 ± 7
	Rail 3 (µm)	83 ± 15	82 ± 5	99 ± 11
<b>N7 Junction 3</b>	Rail 1 (µm)	79 ± 5	76 ± 6	76 ± 3
	Rail 2 (µm)	74 ± 6	69 ± 2	77 ± 4
	Rail 3 (µm)	68 ± 4	79 ± 7	75 ± 2
<b>M7 Junction 17</b>	Rail 1 (µm)	55 ± 4	68 ± 2	74 ± 3
	Rail 2 (µm)	64 ± 3	69 ± 3	76 ± 3
	Rail 3 (µm)	73 ± 3	73 ± 7	81 ± 2
<b>M7 Junction 13 (a)</b>	Rail 1 (µm)	84 ± 6	80 ± 5	95 ± 7
	Rail 2 (µm)	76 ± 4	61 ± 4	89 ± 4
	Rail 3 (µm)	72 ± 7	78 ± 4	102 ± 7
<b>M7 Junction 13 (b)</b>	Rail 1 (µm)	76 ± 4	79 ± 3	96 ± 7
	Rail 2 (µm)	70 ± 3	77 ± 3	89 ± 7
	Rail 3 (µm)	70 ± 3	72 ± 4	74 ± 3
<b>N28-Cork</b>	Rail 1 (µm)	78 ± 10	60 ± 4	66 ± 18
	Rail 2 (µm)	82 ± 6	55 ± 7	78 ± 6
	Rail 3 (µm)	72 ± 5	55 ± 5	60 ± 30
<b>N59-GY-SB02</b>	Rail 1 (µm)	46 ± 3	65 ± 5	62 ± 5
	Rail 2 (µm)	56 ± 7	63 ± 3	58 ± 5
	Rail 3 (µm)	66 ± 4	70 ± 8	71 ± 5

## FACTUAL REPORT

## SEM Test Results

## 1.1 N03-CN-0042 (DA) / V

	Section 1	Section 2	Section 3	SEM
1 Top Front (µm)	59 ± 3	39 ± 7	21 ± 13	75 ± 2
2 Top Back (µm)	72 ± 14	68 ± 4	75 ± 4	74 ± 4
3 Near-Top Front (µm)	61 ± 4	63 ± 4	65 ± 6	81 ± 4
4 Near-Top Back (µm)	66 ± 4	70 ± 4	73 ± 3	75 ± 3
5 Middle Front (µm)	57 ± 3	64 ± 14	61 ± 8	66 ± 4
6 Middle Back (µm)	61 ± 9	75 ± 8	70 ± 9	82 ± 12
7 Near-Bottom Front (µm)	61 ± 6	59 ± 6	61 ± 8	96 ± 27
8 Near-Bottom Back (µm)	69 ± 4	70 ± 5	66 ± 7	77 ± 6
9 Bottom Front (µm)	67 ± 7	59 ± 10	67 ± 5	78 ± 3
10 Bottom Back (µm)	66 ± 6	72 ± 5	65 ± 5	76 ± 9

## 1.2 N55-ATH (DA) / W

	Section A	Section B	Section C	SEM
1 Top Front (µm)	76 ± 4	69 ± 7	72 ± 6	102 ± 4
2 Top Back (µm)	92 ± 3	62 ± 9	60 ± 6	126 ± 23
3 Near-Top Front (µm)	85 ± 6	66 ± 7	72 ± 6	113 ± 17
4 Near-Top Back (µm)	45 ± 23	65 ± 10	58 ± 6	103 ± 88
5 Middle Front (µm)	85 ± 5	62 ± 10	54 ± 4	86 ± 29
6 Middle Back (µm)	54 ± 18	28 ± 13	60 ± 8	121 ± 11

## 1.3 N55-LK-RN080 (DA) / X

	Section A	Section B	Section C	SEM
1 Top Front (µm)	50 ± 16	28 ± 17	45 ± 17	78 ± 4
2 Top Back (µm)	73 ± 5	73 ± 4	79 ± 7	76 ± 3
3 Near-Top Front (µm)	64 ± 2	66 ± 2	65 ± 2	76 ± 6
4 Near-Top Back (µm)	65 ± 6	73 ± 7	71 ± 5	95 ± 15
5 Middle Front (µm)	85 ± 6	84 ± 4	79 ± 3	72 ± 5
6 Middle Back (µm)	42 ± 5	42 ± 4	54 ± 5	89 ± 25
7 Near-Bottom Front (µm)	70 ± 3	72 ± 5	71 ± 6	94 ± 4
8 Near-Bottom Back (µm)	67 ± 3	65 ± 5	69 ± 5	77 ± 10
9 Bottom Front (µm)	57 ± 3	57 ± 4	61 ± 4	78 ± 3
10 Bottom Back (µm)	68 ± 6	66 ± 6	70 ± 2	88 ± 10

## 1.1 N59-GY-SB09A (DA) / Y

	Section A	Section B	Section B	SEM
1 Top Front (µm)	51 ± 5	37 ± 3	41 ± 4	99 ± 19
2 Top Back (µm)	74 ± 4	69 ± 3	70 ± 6	120 ± 32
3 Near-Top Front (µm)	50 ± 6	35 ± 5	45 ± 5	76 ± 12
4 Near-Top Back (µm)	61 ± 5	63 ± 14	57 ± 5	80 ± 10
5 Middle Front (µm)	70 ± 6	58 ± 6	60 ± 8	89 ± 15
6 Middle Back (µm)	64 ± 6	47 ± 6	49 ± 15	85 ± 3
7 Near-Bottom Front (µm)	53 ± 5	46 ± 9	36 ± 10	78 ± 6

**FACTUAL REPORT**

8 Near-Bottom Back ( $\mu\text{m}$ )	$65 \pm 2$	$61 \pm 3$	$63 \pm 4$	$75 \pm 11$
9 Bottom Front ( $\mu\text{m}$ )	$-130 \pm 57$	$-247 \pm 61$	$-278 \pm 25$	$50 \pm 10$
10 Bottom Back ( $\mu\text{m}$ )	$59 \pm 3$	$56 \pm 7$	$56 \pm 5$	$77 \pm 6$

**1.2 N59-KM-Rno78 (DA) / Z**

	Section A	Section B	Section C	SEM
1 Top Front ( $\mu\text{m}$ )	$64 \pm 4$	$56 \pm 5$	$62 \pm 5$	$94 \pm 12$
2 Top Back ( $\mu\text{m}$ )	$68 \pm 4$	$60 \pm 5$	$67 \pm 4$	$77 \pm 3$
3 Near-Top Front ( $\mu\text{m}$ )	$77 \pm 5$	$73 \pm 5$	$67 \pm 8$	$88 \pm 7$
4 Near-Top Back ( $\mu\text{m}$ )	$72 \pm 3$	$70 \pm 4$	$74 \pm 6$	$84 \pm 7$
5 Middle Front ( $\mu\text{m}$ )	$88 \pm 4$	$87 \pm 11$	$95 \pm 29$	$77 \pm 6$
6 Middle Back ( $\mu\text{m}$ )	$52 \pm 8$	$45 \pm 6$	$54 \pm 6$	$88 \pm 11$
7 Near-Bottom Front ( $\mu\text{m}$ )	$68 \pm 3$	$59 \pm 10$	$68 \pm 3$	$85 \pm 9$
8 Near-Bottom Back ( $\mu\text{m}$ )	$74 \pm 3$	$64 \pm 8$	$68 \pm 7$	$90 \pm 4$
9 Bottom Front ( $\mu\text{m}$ )	$43 \pm 19$	$35 \pm 19$	$19 \pm 7$	$68 \pm 6$
10 Bottom Back ( $\mu\text{m}$ )	$84 \pm 8$	$84 \pm 11$	$84 \pm 5$	$98 \pm 5$

**Baseline Test Results****1.3 Aximum New**

	Section 1	SEM
1 Top Front ( $\mu\text{m}$ )	$64 \pm 4$	$75 \pm 4$
2 Top Back ( $\mu\text{m}$ )	$80 \pm 7$	$85 \pm 4$

**1.4 Aximum 5-Year Old**

	Section 1	SEM
1 Top Front ( $\mu\text{m}$ )	$90 \pm 4$	$106 \pm 6$
2 Top Back ( $\mu\text{m}$ )	$90 \pm 6$	$101 \pm 3$

**1.5 C501 New**

	Section 1	SEM
1 Top Front ( $\mu\text{m}$ )	$57 \pm 10$	$92 \pm 10$
2 Top Back ( $\mu\text{m}$ )	$64 \pm 10$	$82 \pm 10$

**1.6 CS 5-Year Old**

	Section 1	SEM
1 Top Front ( $\mu\text{m}$ )	$87 \pm 7$	$133 \pm 9$
2 Top Back ( $\mu\text{m}$ )	$62 \pm 7$	$96 \pm 9$