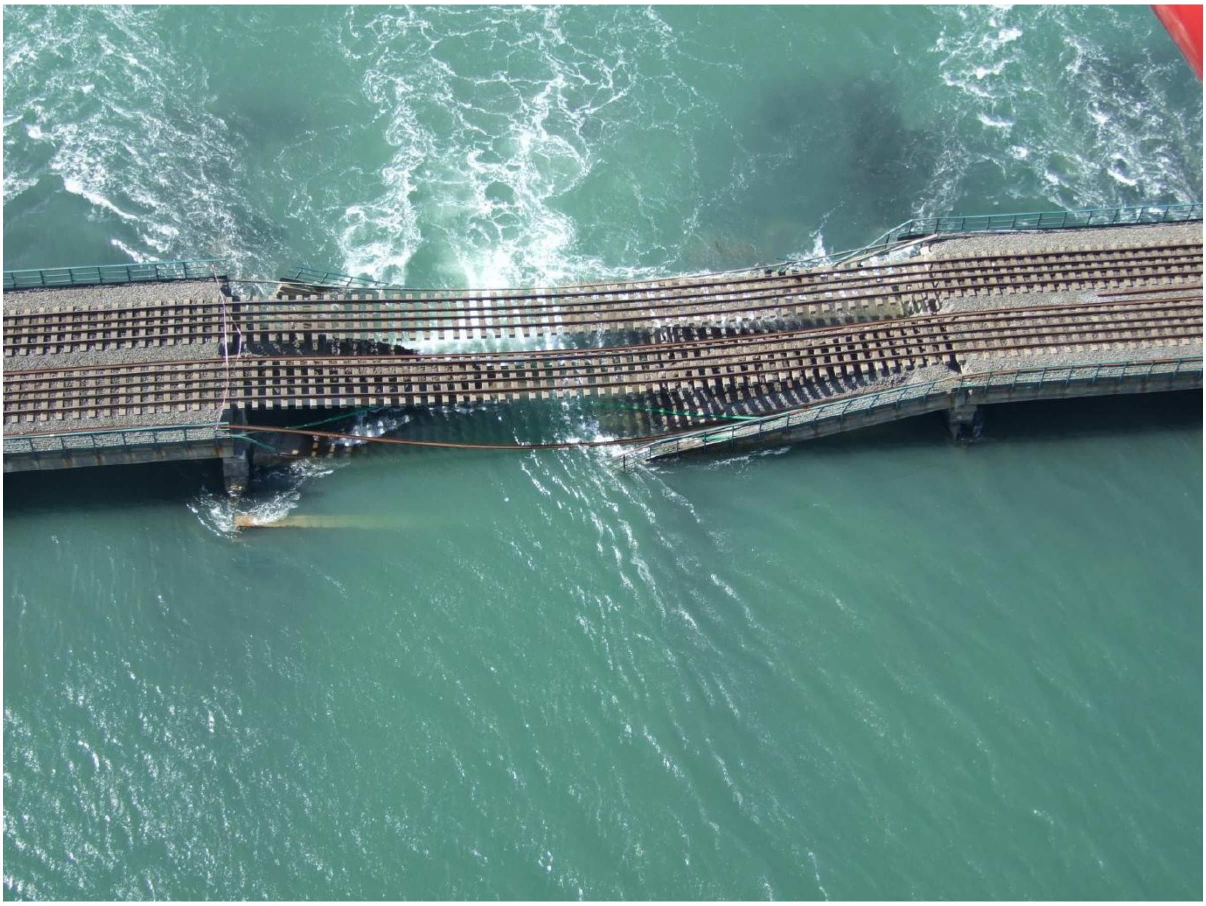
Railway Accident Investigation Unit

Investigation Report No. 2010 – R004

August 2010



Malahide Viaduct Collapse on the Dublin to Belfast Line,

on the 21st August 2009

Document History

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1	17/08/2010	Photograph 3 caption change
2	20/10/2010	Report and footers renumbered. Typographical error correction in paragraph 5 of Section 11. Figure 19 is now Figure 22, Figures 20 – 22 renamed. Additional RAIU and RSC terms added to Section 46.1.

Role of the Railway Accident Investigation Unit

The Railway Accident Investigation Unit (RAIU) is an independent investigation unit within the Railway Safety Commission (RSC). The RAIU conducts investigations into accidents and incidents. The purpose of an investigation by the RAIU is to improve railway safety by establishing, in so far as possible, the cause or causes of an accident or incident with a view to making safety recommendations for the avoidance of accidents in the future, or otherwise for the improvement of railway safety. It is not the purpose of an investigation to attribute blame or liability.

The RAIU's investigations are carried out in accordance with the Railway Safety Act 2005 and European railway safety directive 2004/49/EC.

Any enquiries about this report should be sent to:

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Executive Summary

On the 21st August 2009 as an Iarnród Éireann passenger service, travelling from Balbriggan to Pearse, passed over the Malahide Viaduct the driver witnessed a section of the viaduct beginning to collapse into Broadmeadow Estuary. The driver reported this to the controlling signalman who immediately set all relevant signals to danger ensuring no trains travelled over the viaduct. Within minutes of the report of the accident, by the driver, Pier 4 of the Malahide Viaduct had collapsed into the Broadmeadow Estuary. All post accident emergency procedures were properly employed by the operating staff resulting in no fatalities or injuries to any members of the public or staff.

At the time of the accident, the Malahide Viaduct piers were formed on a grouted rock armour weir, with stones intermittently discharged along this weir to maintain its profile.

The immediate cause of the collapse of Pier 4 was as a result of the undermining of the weir that surrounds and supports Pier 4 through the action of scouring. This was as a result of a combination of factors:

- An inspection carried out on the Malahide Viaduct three days before the accident did not identify the scouring defects visible at the time;
- A scour inspection undertaken in 2006 did not identify the Malahide Viaduct as a high-risk structure to the effects of scouring;
- Iarnród Éireanns likely failure to take any action after an independent inspection carried out on the Malahide Viaduct in 1997 identified that scouring had started at the base of Pier 4 and that the rock armour weir was “too light for the job”;
- The historic maintenance regime for the discharge of stones along the Malahide Viaduct appears to have ceased in 1996, resulting in the deterioration of the weir which was protecting the structure against scouring.

The above factors were necessary for the accident to happen. Contributory to the accident happening were the following factors:

- Iarnród Éireann had not developed a flood/scour management plan at the time of the accident, despite the IRMS Implementation Review (2001) and the AD Little Review (2006) recommending that this plan be developed. Contributory to Iarnród Éireann not developing this flood/scour management plan was the fact that the Railway Safety Commission closed this recommendation in 2008;
- Engineers were not appropriately trained for inspection duties, in that the inspections training course they completed was an abridged version of the intended format, and there no formal mentoring programme, for Engineers on completion of this course;

- There was a shortfall in Iarnród Éireann's suite of structural inspection standards in that a standard which provided guidance for inspectors in carrying out inspections was not formalised;
- There existed an unrealistic requirement for patrol gangers to carry out annual checks for scour, as they do not have access under the structure and in addition, they did not have the required specialist training/ skills to identify defects caused by scouring;
- A formal programme for Special Inspections for structures vulnerable to scour was not adopted, as per Iarnród Éireanns's Structural Inspections Standard, I-STR-6510, at the time of the accident.

Underlying factors to the accident were:

- There was a loss of corporate memory when former Iarnród Éireann staff left the Division, which resulted in valuable information in the relation to the historic scouring and maintenance not being available to the staff in place at the time of the accident;
- There was a dearth of information in relation to the Malahide Viaduct due to Iarnród Éireanns failure to properly introduce their information asset management system;
- Iarnród Éireanns inadequate resourcing of Engineers for structural inspections to be carried out at the Malahide Viaduct;
- Iarnród Éireanns failure to meet all the requirements of their Structural Inspections Standard, I-STR-6510, in that:
    - Visual inspections were not carried out for all visible elements of structures;
    - Bridge Inspection Cards, for recording findings of inspections, were not completed to standard or approved by the relevant personnel;
    - A formal programme for systematic visual inspections of all elements of a structure, including hidden or submerged elements, despite an independent review recommending that Iarnród Éireann implement this programme in 2006.

Immediately after the accident, Iarnród Éireann carried out inspections on over a hundred viaducts on the network. Iarnród Éireann have now reinstating the Malahide Viaduct, ensuring that the overall structure has been significantly strengthened, that the weir profile has been restored and improved.

Iarnród Éireann are currently reviewing all the Civil Engineering technical standards in order to improve the content, readability and practicable implementation of these standards. Improved control mechanisms are being introduced to ensure compliance with these standards. A competency management system is also being implemented to ensure the appropriate training is received by Engineers.

In relation to tracking recommendations made by independent organisation, the Railway Safety Commission has formalised their system for closing recommendations, and is now, in conjunction with Iarnród Éireann developing an action plan to close all outstanding recommendations.

As a result of the findings of this RAIU investigation, the RAIU have made fifteen safety recommendations. Thirteen safety recommendations have been made to Iarnród Éireann, one safety recommendation has been made to the Railway Safety Commission, and one joint recommendation has been made to Iarnród Éireann and the Railway Safety Commission.

Recommendation 1

Iarnród Éireann should put appropriate interface processes in place to ensure that when designated track patrolling staff (who report to two or more divisional areas) are absent from their patrolling duties, that appropriate relief track patrolling staff are assigned to perform these patrolling duties.

Recommendation 2

Iarnród Éireann should amend the Track Patrolling Standard, I-PWY-1307, to remove the requirement for track patrollers to carry out annual checks for scour.

Recommendation 3

Iarnród Éireann should formalise their 'Civil Engineering and Earthworks Structures: Guidance Notes on Inspections Standard', I-STR-6515, which should include guidance for inspectors on conducting inspections and identifying structural defects. On formalising this document Iarnród Éireann should re-issue, in the appropriate format, to all relevant personnel.

Recommendation 4

Iarnród Éireann should introduce a verification process to ensure that all requirements of their Structural Inspections Standard, I-STR-6510, are carried out in full.

Recommendation 5

Iarnród Éireann should ensure that a system is put in place for effective implementation of existing standards and to manage the timely introduction of new and revised standards.

Recommendation 6

Iarnród Éireann should ensure that a programme of structural inspections is started immediately in accordance with their Standard for Structural Inspection, I-STR-6510, and ensure that adequate resources are available to undertake these inspections.

Recommendation 7

Iarnród Éireann should carry out inspections for all bridges subject to the passage of water for their vulnerability to scour, and where possible identify the bridge foundations. A risk-based management system should then be adopted for the routine examination of these vulnerable structures.

Recommendation 8

Iarnród Éireann should develop a documented risk-based approach for flood and scour risk to railway structures through:

- Monitoring of scour risk at sites through scour depth estimation, debris and hydraulic loading checks, and visual and underwater examination;
- Provision of physical scour / flood protection for structures at high risk;
- Imposing of line closures during periods of high water levels where effective physical protection is not in place.

Recommendation 9

Iarnród Éireann should adopt a formal process for conducting structural inspections in the case of a report of a structural defect from a member of the public.

Recommendation 10

Iarnród Éireann should introduce a training, assessment and competency management system in relation to the training of structural inspectors, which includes a mentoring scheme for engineers to gain the appropriate training and experience required to carry out inspections.

Recommendation 11

Iarnród Éireann should review their network for historic maintenance regimes and record this information in their information asset management system. For any future maintenance regimes introduced on the network, Iarnród Éireann should also record this information in their information asset management system.

Recommendation 12

Iarnród Éireann should incorporate into their existing standards the requirement for the input of asset information into the technical database system upon completion of structural inspections.

Recommendation 13

Iarnród Éireann should carry out an audit of their filed and archived documents, in relation to structural assets, and input this information into their information asset management system.

Recommendation 14

The Railway Safety Commission should review their process for the closing of recommendations made to Iarnród Éireann by independent bodies, ensuring that they have the required evidence to close these recommendations. Based on this process the Railway Safety Commission should also confirm that all previously closed recommendations satisfy this new process.

Recommendation 15

The Railway Safety Commission, in conjunction with Iarnród Éireann, should develop an action plan in order to close all outstanding recommendations in the AD Little Review (2006) and the IRMS Reviews (1998, 2000, 2001). This action plan should include defined timescales for the implementation and closure of all these recommendations.

Contents

The Accident

This section of the report details the:

- Parties involved;
- Location of the accident;
- Infrastructure;
- Rolling stock;
- Malahide Viaduct structure;
- Narrative of events preceding, during and after the accident.

1 Parties involved

1.1 Iarnród Éireann

Iarnród Éireann[1] (IÉ)[2], a subsidiary of *Córas Iompair Éireann* (CIÉ), is the owner and operator of the national mainline rail service in Ireland.

The IÉ railway network is approximately 1,919 route kilometres (km) in length, with seven routes radiating from the two main railway terminals in Dublin (Connolly Station and Heuston Station). Physical assets include in excess of 6,000 safety critical infrastructure assets on the network, such as track, structures, rolling stock, signalling and telecommunications, electrification and level crossings. There are 1,204 *overbridges*, and 1,926 *underbridges* on the network, and of the 1,926 underbridges, 780 are *viaducts.* IÉ is responsible for managing the design, installation, testing, maintenance and renewal of these physical assets

IÉ operates the *Intercity, Commuter, DART* and freights services, as well as the *Enterprise* service from Belfast to Dublin which is operated in conjunction with Northern Ireland Railways (NIR).

1.1.1 Drivers

Two trains (identification numbers D820 and P711) passed over the Malahide Viaduct close to the time of its collapse. Both drivers of these trains were *competent* to drive trains. After the *accident*, the driver of P711 called the *controlling signalman* to report the partial collapse of the Malahide Viaduct and carried out the appropriate emergency procedures correctly.

1.1.2 Controlling signalman

The controlling signalman, who received the report of the partial collapse of the Malahide Viaduct from the driver of P711, is based at *Central Traffic Control* (CTC) at Connolly Station. The controlling signalman was competent. Upon notification of the accident, the controlling signalman carried out the appropriate emergency procedures correctly.

[1] Terms which appear in italics, the first time they appear in the report, are explained in the 'Glossary of Terms' section of this report.

[2] Abbreviations are defined in the 'List of Abbreviations' section of this report.

1.1.3 Civil Engineering Department

The Chief Civil Engineer (CCE) directs the Technical Support, Business Support and Safety sections within the Civil Engineering Department of IÉ.

This Department carries out the inspections and maintenance of track and structures and is divided into three different geographical areas, with offices based at Dublin, Athlone and Limerick Junction.

The Dublin Divisional Engineer (DE) is the *Person Responsible* for the inspections and maintenance of all fixed infrastructure such as bridges, including the Malahide Viaduct, for the Dublin area. The DE may nominate an ADE to be the Person Responsible for certain tasks.

The Assistant Divisional Engineers (ADEs) are responsible for the track and structures and the conduct of structural inspections for the fixed infrastructure in designated areas, known as Divisions, and report to their respective DEs. There are three Dublin Division ADEs, with two ADEs involved in the accident:

- ADE 1 (East) is responsible for the area that falls from the 9 ½ milepost in Malahide to the 17 ¼ milepost in Greystones, along with Glasnevin Junction (Division 1);
- ADE 2 (West) is responsible for the East Coast network (excluding the DART), of which Malahide Viaduct is included (Divisions 5, 7, 8, 11). ADE 2 has been in this post since March 2005.

Engineers carry out the inspections on the instruction of the ADE. When carrying out inspections, Engineers are referred to as Inspectors. The Inspectors involved, both from the East Coast Division, in this accident were the:

- Senior Engineer (SE) who carried out a planned inspection on Malahide Viaduct in 2007;
- Assistant Engineer (AE) who carried out the inspection after a reported defect at the Malahide Viaduct by a member of the public.

*Patrol Ganger*s carry out continuous systematic examination of the track to locate conditions that are unsafe. The Patrol Ganger for the Malahide Viaduct is one of seventy patrol gangers in Divisions 1 and 5. As the area around the Malahide Viaduct is split into two Divisions (Division 1 and 5) the Patrol Ganger reports to two *Permanent Way Inspectors* (PWIs), who in turn report directly to the ADEs (Division 1 and 5). The regular Patrol Ganger for the Malahide Viaduct patrolling section was on leave at the time of the accident.

1.1.4 New Works Department

The Principal Structural Engineer, the Structural Engineer and a Programme Manager within the Structural Design Division of the New Works Department, on the instruction of ADE 2, carried out the a Programme of Scour Inspections between 2005 – 2007, which included a Scour Inspection for the Malahide Viaduct in 2006.

1.2 The Railway Safety Commission

1.2.1 Functions set out by the Railway Safety Act 2005

The RSC has three main functions set out in Section 10 of the Railway Safety Act 2005. These are as follows:

- To foster and encourage railway safety;
- To enforce the Railway Safety Act 2005 and other legislation relation to railway safety;
- To investigation and report on railway incidents.

Other secondary functions of the RSC under the Railway Safety Act 2005 are as follows:

- Assess the Safety Cases of railway undertakings and issue a safety certification on acceptance of the Safety Case (Sections 45 & 46);
- Carry out safety assessments of new works and rolling stock (Sections 42 & 43);
- To make regulations in relation to specified aspects of railway safety (Part 6);
- Take enforcement proceedings against a railway undertaking, where necessary (Part 7).

Under the Railway Safety Act 2005 there is no requirement for the RSC to carry out inspections of infrastructure assets. However, the RSC may carry out inspections of infrastructure assets where there is deemed to be a specific risk in relation to safety.

1.2.2 Mission Statement

Functions identified in the RSC's mission statement, of assuring the safety of railway services and affected persons which are as follows:

- Safety approval;
- Safety auditing and monitoring;
- Safety enforcement.

1.2.3 Tracking safety recommendations

As the RSC is a railway safety enforcement body one of the roles of that the RSC undertake is to track and close recommendations made by the RAIU or other independent bodies in relation to safety.

1.3 International Risk Management Services

Following the instigation of the five-year Railway Safety Programme, the Minister for Transport[3] commissioned the International Risk Management Services (IRMS) Review. This was a strategic review of the IÉ network and operations to determine whether the risk posed to passengers, staff and the public were acceptable, and to highlight where action and investment was required to address shortfalls. The review entitled "A Review of Railway Safety in Ireland" was completed in October 1998.

This study was commissioned to include a review of IE's Safety Management System (SMS), the safety adequacy of its infrastructure and rolling stock, an assessment of the risks on the system and criteria by which their control should be judged, a review of the railway safety regulation system and an assessment of the implications for safety regulation from the implementation of EU Directives on railway open access. The study was required to investigate the physical and management systems that existed to achieve acceptable standards of safety on the present IÉ network. It was not asked to establish the historical background for any deficiencies found but was required to focus recommendations on actions necessary to secure safety on the Irish railway system in the future.

Based on the recommendations identified in this report, IRMS suggests that a full time Implementation Project Manager will be required to lead the implementation plans. It is suggested that implementation plans are formulated and agreed between the Department of Transport (DoT), CIÉ and IÉ within three months and that the necessary resources allocated to commence work within six months of the report's acceptance with an initial audit of the completion of these implementation plans at the end of that six months' period and a further audit of progress should undertaken a year later, i.e. eighteen months from acceptance of the report.

IRMS implementation reviews of "A Review of Railway Safety in Ireland" were carried out in 2000 and 2001.

[3] At the time of the commissioning of the IRMS Review, in 1998, the Minister for Transport was referred to as the Minister for Public Enterprise. For this report the term Minister for Transport will be used, in all cases, for ease of reading.

1.4 Arthur D. Little Limited consultants

In 2006, the RSC commissioned Arthur D. Little Limited (AD Little), a global management consultancy specialising in strategy and operations management, to carry out an independent safety review of IÉ's network and operations, the role and function of the RSC and the oversight provided by the DoT. The final report was submitted to the RSC in July 2006, titled "A review of railway safety and of the role and function of the Railway Safety Commission". Based on the findings of this review, the AD Little Review made recommendations on safety which were ranked as follows:

- Urgent – action needed immediately to reduce unacceptable risk;
- High – action needed as high priority to control a safety risk (commence within one month);
- Medium – action needed to control risk (commence within three to six months);
- Low – action suggested to support longer term improvement in safety management (within 12 months).

The review included a suggested timescale, indicating the timescales for the implementation of the recommendations. The final section of the AD Little Review, 'Proposed Action Plan', sets out the high level action plan for implementing the recommendations and includes a suggestion that more detailed plans to be prepared by IÉ.

1.5 Department of Transport

The DoT is responsible for implementing an integrated transport policy for Ireland. Following the instigation of the five-year Railway Safety Programme, the Minister for Transport commissioned the IRMS Review.

1.6 CEI Collins Engineers Consultants

CEI Collins Engineers (Collins Engineers) provides engineering services in structural analysis and design and underwater engineering to IÉ. Collins Engineers carried out a scour inspection on Malahide Viaduct in 2006.

1.7 East Coast Diving Services

In 1997 East Coast Diving Services removed a derelict barge that was lodged against the Malahide Viaduct and after its removal carried out an inspection of the structure.

2 Location of the accident

Malahide Station is located nine miles north of Connolly Station (Dublin) on the Dublin to Belfast line. Donabate is located a further two and a half miles north of Malahide Station. The Broadmeadow Estuary and Malahide Viaduct are approximately located at the 9 ½ *Mile Post* (MP), (see Figure 1).

Figure 1 – Location Map of accident site

Eighty-two passenger services travel over Malahide Viaduct every weekday, with one additional train travelling on a Friday. In addition, six freight trains travel over Malahide Viaduct every weekday.

3 Infrastructure

3.1 Track

The Malahide – Donabate route is *double track, Continuous Welded Rail* (CWR) on concrete *sleepers*. The maximum permitted *line speed* over the viaduct is 145 kilometres per hour (kph). As a result of tight clearances through the Malahide Station Down Platform there is a *permanent speed restriction* of 110 kph from the 8 ¾ MP to the 9 ¼ MP, and for the same reason (i.e. tight clearances), there is a permanent speed restriction of 80 kph through the Malahide Station Up Platform.

3.2 Rolling stock

The 17.50 hrs train from Pearse to Dundalk is an eight-*car* Class 29000 *Diesel Multiple Unit (DMU).* On the 21st of August 2009, car numbers 29117, 29217, 29317, 29417, 29407, 29307, 29207 and 29107 were assigned to this service and the train identification number was D820.

The 18.07 hrs train from Balbriggan to Pearse is a four-car Class 29000 DMU (see Photograph 1). Car numbers 29128, 29228, 29328 and 29428 (*leading end*) were assigned to this service and the train identification number was P711.

Photograph 1 – 29000 Class DMU

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Each four-car set is 81.46 metre (m) long, 3.985 m high and 2.9 m wide and weighs a total of 160.8 tonnes. An eight-car set comprises of two four-car sets. Both four-car and eight-car sets have a *maximum permitted speed* of 110 kph.

Passenger capacity for a four-car set is 185 seated and 455 standing.

3.3 Signalling and communications

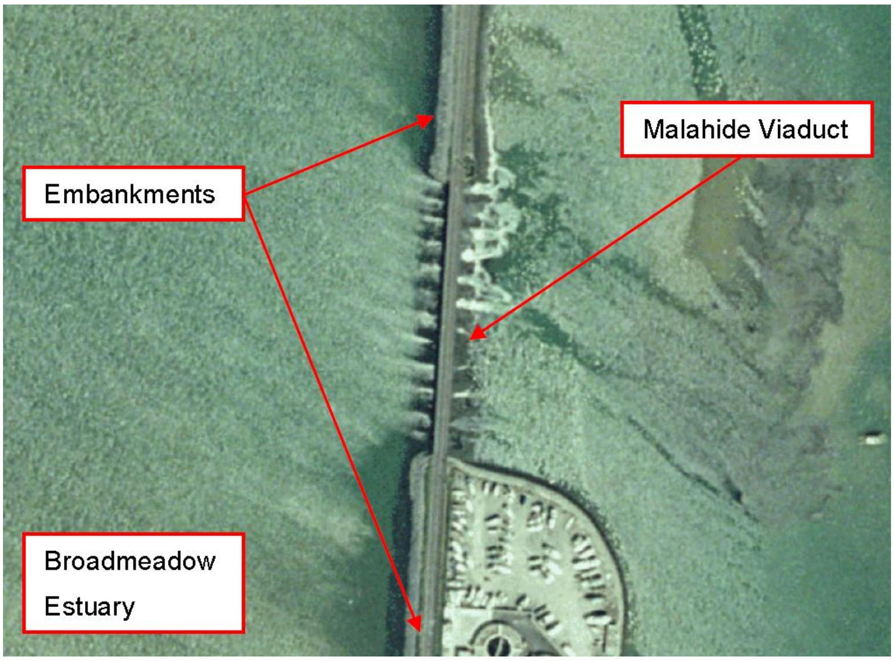
The double track route from Malahide to Donabate is signalled using *three and four aspect signals.* This route is controlled by the Suburban Signalman (controlling signalman) based in the CTC building at Connolly Station. The *Track Circuit Block* (TCB) regulations apply to this route.

The means of communication between train drivers and controlling signalmen on the route is through *Mode A train radio*. *Lineside telephones* are provided as an alternative means of communication.

4 Malahide Viaduct

4.1 General description

The Dublin to Belfast railway line crosses the Broadmeadow Estuary, a tidal estuary, by means of *embankment* and a 176 m railway viaduct, see Photograph 2. This section of the report details the initial construction of the Malahide Viaduct (IÉ asset number UB30) and the subsequent major *capital projects* carried out on the Malahide Viaduct.



Photograph 2 – Malahide Viaduct and embankments

4.2 Original construction completed in 1844

The embankments and viaduct were originally constructed as part of the Dublin and Drogheda Railway which opened in 1844. Embankments were first constructed on either side of the estuary, north and south. The spoil for the construction of the southern embankment were supplied from the now disused quarry that located to the south of Malahide Station; with the spoil for the northern embankment supplied from *cuttings* on the approach to Donabate.

The Journal of the Irish Railway Records Society (IRRS), article on Malahide Viaduct (2000), indicates that the original Malahide Viaduct was constructed as an eleven *span* timber structure, measuring approximately 175 m in total length (with each span measuring 15.85 m), supported on ten timber piles driven into the bed of the estuary. A historic drawing, taken from this article, of the original viaduct is illustrated in Figure 2.

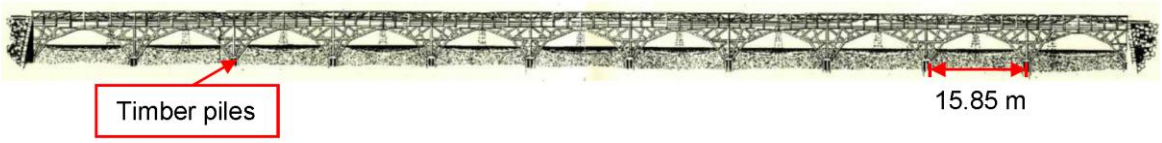


Figure 2 – Original timber structure with timber piles

4.3 Weir construction 1846

A tidal estuary, with a relatively narrow opening for a viaduct, meant that as the tide rose and fell, large volumes of water were travelling through the viaduct. This movement of water resulted in *scouring* around the viaduct piers. In 1846, to overcome the problem of scouring, large stones were placed around the viaduct piers. In addition, stones were discharged along the line following its construction, forming a virtual *permeable* stone *'weir'* over the length of the entire viaduct, see Figure 3).

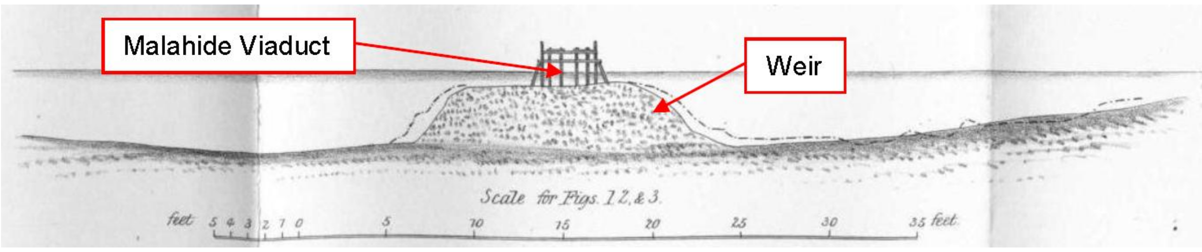


Figure 3 – Malahide Viaduct on weir construction

The *silting* of the stones reduced the flow of water in and out of the estuary by maintaining a constant water level in the estuary at all states of tide to reduce the effect of scouring.

4.4 Malahide Viaduct Replacement 1860

In 1860 the viaduct was replaced by wrought iron *lattice girder beams* supported by eleven masonry piers founded on two stone fill foundation courses, each approximately 0.3 m each in depth, constructed on the weir traversing the estuary, (see Figure 3).

The new piers were built at the mid-spans of the original structure, as there were concerns at the time that the new construction could affect the safety of the timber structure which was still carrying rail traffic. There were now eight number 15.85 m spans and four number 12.9 m spans totalling twelve spans, (see Figure 4).

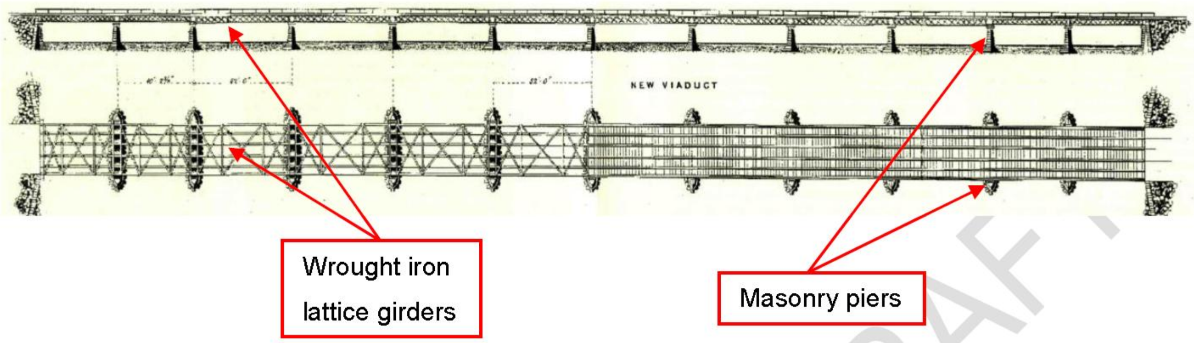


Figure 4 – New masonry and wrought iron Malahide Viaduct constructed in 1860

The new masonry piers acted as gravity structures, meaning the piers weight held the structure securely on the weir without the need for piling, (see Figure 5).

The superstructure was composed of wrought iron lattice girders, six per span, four girders under the rails of the double track and two outside parapet girders. The girders ranged between 0.92 m to 1.83 m in depth.

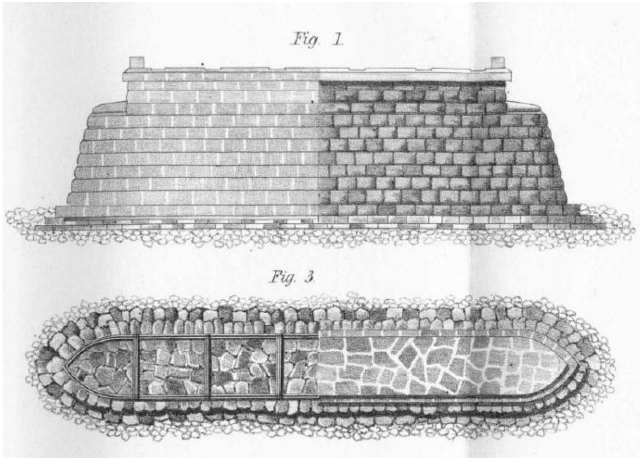


Figure 5 – Elevation and plan of the masonry piers

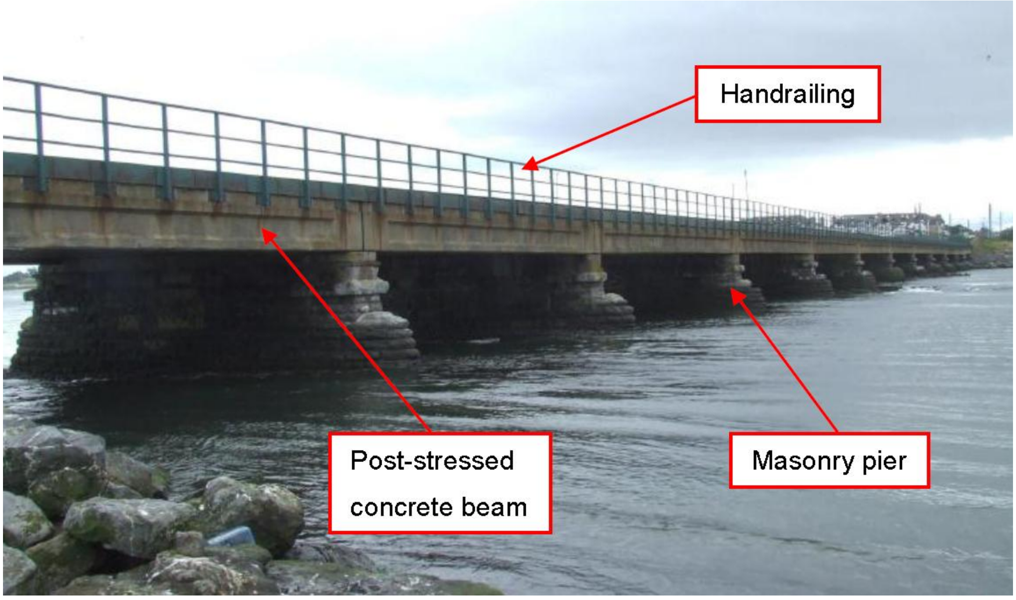
4.5 Renewal of Viaduct 1965

After a century of service the lattice girder viaduct began to shows signs of deterioration, due to the exposure to the sea environment and, by 1965, it was decided to renew the viaduct for a third time. Design criteria had to be met for the renewal of the viaduct included the following:

- The speed of erection was a major design driver as it was essential to continue rail services during the renewal;
- The use of ballasted deck**,** used to support normal sleepered track for open type bridge decks as opposed to traditional fixing of the rails to longitudinal sleepers, was a requirement. The use of ballasted deck was railway policy at the time of construction – the rationale for this was that it was more economical and more low maintenance than the longitudinal sleepers, especially for the 110 kph speeds;
- The load capacity for the viaduct was also designed for 20 ton axle load. The locomotives at the time of renewal weighed less than 17 ton axle load, but CIE were following British Rail practice of the day;

- The requirement for the discharge of stone was a special requirement for Malahide Viaduct, the viaduct handrailing was formed so that complete handrails sections could be removed to facilitate the tipping of stone pitching over the side of the bridge in the event of a section of the weir being scoured away.

New *precast post-tensioned concrete* beams were used to replace the lattice girders. New pre-cast *bedstones* were designed and placed on the existing stone piers – these varied in height for adjustments for the difference in span heights of the old structure and some pier settlement. The *wing walls* of the 1860 construction were retained. Over 2,000 tons of concrete was used, as well as over sixty-nine km of post-tensioning wire. The new structure is illustrated in the 2009 photograph below (see Photograph 3).



Photograph 3 – Post-stressed concrete beams on original masonry piers

4.6 Grouting scheme 1967 - 1972

A major grouting scheme was undertaken in 1967 and 1968, in an attempt to stabilise the weir. Further grouting occurred in 1972, with ten of the twelve spans being grouted at this stage. This grouting scheme formed a grout apron (grouted rock armour) extending approximately two metres in depth into the weir.

5 The accident

5.1 Events preceding the accident

At 18.20.59 hours (hrs) on the 21st August 2009, the eight-car Class 29000 DMU, 17.50 hrs passenger service from Pearse to Dundalk (train identification number D820) passed over the viaduct in the *Down* direction, towards Belfast, without incident.

At 18.22.21 hrs, the four-car Class 29000 DMU, 18.07 hrs passenger service from Balbriggan to Pearse (train identification number P711) approached the viaduct in the *Up* direction, (i.e. approaching Malahide Station from the Belfast direction). As P711 approached the Malahide Viaduct, the driver observed water splashing over the viaduct as the D820 passed over the viaduct.

5.2 Events during the accident

At 18.22.35 hrs, as train P711 passed over the viaduct, the driver witnessed a section of the viaduct was beginning to collapse. On seeing this, the driver put the train's *power controller* into the *coast* setting and continued towards Malahide Station. At 18.22.42 hrs the driver informed the controlling signalman, by radio, of the partial collapse of the viaduct.

5.3 Events after the accident

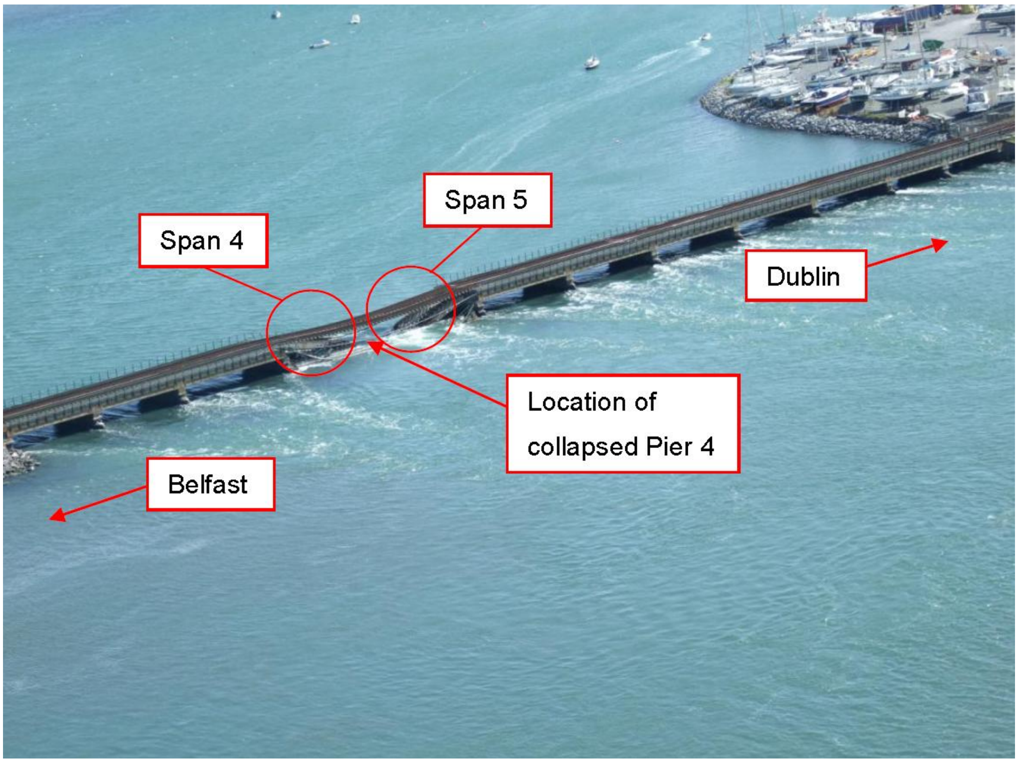
The controlling signalman set all relevant signals to *Danger* at 18.22.58 hrs to ensure no trains travelled over the viaduct. All traffic over the Malahide Viaduct was stopped at this time.

At 18.23.37 hrs, the driver of train P711, carried out on unscheduled stop at Malahide Station and *detrained* all passengers.

At approximately 18.28 hrs, once the driver received verification that the viaduct was protected by the signals, he placed a *track circuit operating device* on the Down line[4] before walking back along the track to the viaduct. The driver then observed that Pier 4 had collapsed and the *post-tensioned concrete beams* of Span 4 and Span 5 had collapsed into the estuary (see Photograph 4).

The controlling signalman maintained the signals at Danger to protect the accident site.

[4] It should be noted, that this was an additional safety measure, as all traffic over Malahide Viaduct was stopped by the controlling signalman.



Photograph 4 – Collapsed Malahide Viaduct

5.4 Numbering of the piers at the Malahide Viaduct

For the purposes of this report, the numbering of the piers begins at Pier 1 at the Belfast end (north end) and increased numerically to the Dublin end (south end), (see Figure 6). It should however be noted that historically the IÉ numbering system is the reverse, with Pier 1 at the Dublin end and increasing numerically to the Belfast end. Other historical documents may also use this convention.

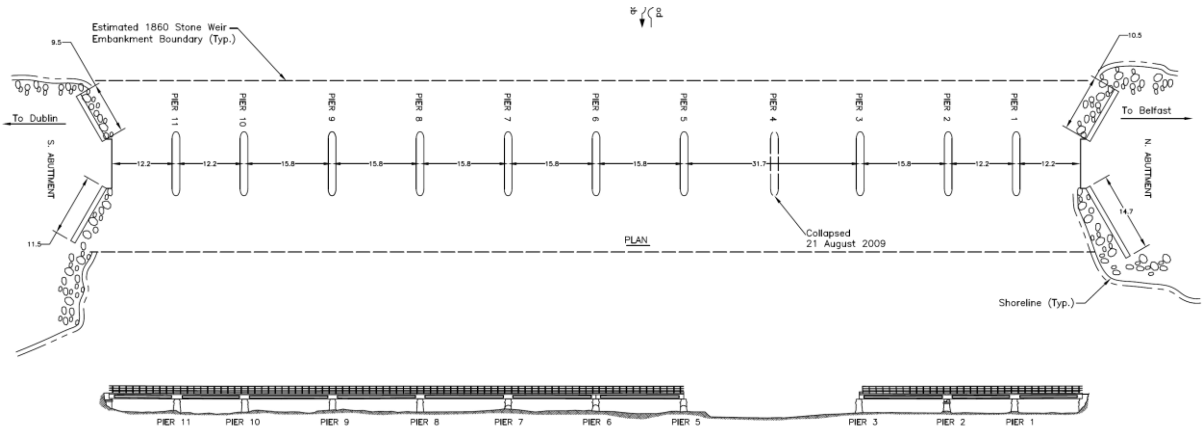


Figure 6 – Plan and elevation illustrating pier numbering

5.5 Summary of events

Events preceding, during and following the accident are summarised below (see Table 1).

Events preceding, during and following the accident on the 21st August 2009	
18.20.59 hrs	The 17.50 hrs passenger service from Pearse to Dundalk (D820) passes over the Malahide Viaduct without incident.
18.22.21 hrs	The driver of the 18.07 hrs passenger service from Balbriggan to Pearse (P711), notices splashing over the Malahide Viaduct as D820 passes over the Malahide Viaduct.
18.22.35 hrs	The driver of P711 witnesses a section of the viaduct beginning to collapse as he passes over the Malahide Viaduct.
18.22.40 hrs	The driver of P711 puts the unit's power controller into the coast setting and continues towards Malahide Station.
18.22.42 hrs	The driver of P711 calls the controlling signalman, by radio, and informs him of the partial collapse of the Malahide Viaduct.
18.22.58 hrs	The controlling signalman sets all relevant signals to Danger, stopping all traffic over the Malahide Viaduct.
18.23.37 hrs	The driver of P711 carries out an unscheduled stop at Malahide Station and de-trains all passengers.
18.28 hrs	The driver of P711 walks towards the viaduct and observes that Pier 4 has collapsed and the post-tensioned beams of Span 4 and Span 5 have collapsed into the estuary.

Table 1 – Events preceding, during and following the accident on the 21st August 2009

6 External factors

6.1 Weather

At the time of the accident the weather conditions were dry with good visibility.

6.2 Tidal information

The tidal times recorded by Malahide Marina for the day of the accident are as follows (see Table 2):

Date	Times	Level	Tide
21st August 2009	00.24hrs	4.36m	High Tide
	06.19hrs	0.17m	Low Tide
	12.58hrs	4.07m	High Tide
	18.28hrs	0.50m	Low Tide

Table 2 – Tidal records for Malahide Marina on the 21st August 2009

The accident occurred close to the time of the second low tide.

The August records for Malahide Marina show that the low tide level of 0.17m, on the morning of the 21st August 2009, was the lowest low tide for that month. The *tidal range* for that day was also one of the largest for the month of August.

The Investigation

This section of the report details the:

- Investigation process;
- Scope of the investigation;
- Sources of evidence.

7 Investigation Process

7.1 On-site investigation

The RAIU was notified of the accident at 18:45 hrs on the 21st August 2009 and immediately mobilised to the accident site.

The on-site investigation included:

- On-site photographic evidence at the location of the accident on the 21st August 2009, and the subsequent days following the accident;
- Detailed surveys, which commenced on the 22nd August 2009, were carried out of the viaduct and weir.
- A *bathymetric survey,* which commenced on the 22nd August 2009, of the estuary was also carried out to the east and west of the weir.

On completion of the on-site photography and surveys, the collapsed post-tensioned concrete beams were removed from site, which the intact beams were removed to a testing facility, with the testing of beams being carried out on the 14th October 2009.

Following release by the RAIU of the accident location on the 24th August 2009, the re-construction of the Malahide Viaduct began.

7.2 Off-site investigation

Off-site investigation included:

- The intact beams were loaded and tested by IÉ, and independently monitored by the RSC, on the 14th October 2009;
- University College Cork (UCC) were commissioned to prepare *two-dimensional* (2D) and a *three-dimensional* (3D) models for purposes of *simulation* of the hydraulic mechanisms involved in the collapse;
- The RAIU reviewed the IÉ structural standards, and compliance levels with the requirements of these standards;
- The RAIU reviewed historic articles and drawings relevant to the Malahide Viaduct;
- The RAIU reviewed records of correspondence between the RSC and IÉ;
- The RAIU interviewed IÉ staff directly and indirectly involved in the accident (past and present).

8 Scope of investigation

The scope of the RAIU investigation is as follows:

- Establish the sequence of events that led to the collapse of Malahide Viaduct;
- Establish the immediate cause, contributory factors and underlying causes that lead to the failure of Malahide Viaduct;
- Review the management of inspections and maintenance arrangements for the Malahide Viaduct;
- Review relevant historical documents relating to the Malahide Viaduct;
- Review the role of the RSC in relation to enforcing safety recommendations made by independent safety reviews.

9 Sources of evidence

All evidence was collated by the RAIU during the investigation process, and recorded in an evidence log. The evidence included:

- On-site photographic and survey records;
- UCC Technical Papers on the mechanism of collapse of Malahide Viaduct;
- Historic engineering articles on the construction of Malahide Viaduct;
- Witness testimony from the driver of P711;
- Other testimonies from members of the public, with information pertaining to Malahide Viaduct;
- Inspection records for inspections carried out on Malahide Viaduct;
- IÉ structural standards;
- Data from the IÉ's Track Recording Vehicles (TRVs);
- "A Review of Railway Safety in Ireland" produced by IRMS in 1998, with implementation reviews in 2000 and 2001;
- "A review of railway safety and of the role and function of the Railway Safety Commission". produced by AD Little;
- Safety audits carried out by the RSC;
- IÉ's document management system.

The Failure Mechanism of Malahide Viaduct

This section of the report details the:

- Modelling of the Malahide Viaduct;
- Long terms events leading to the failure Malahide Viaduct;
- Medium terms events leading to the failure Malahide Viaduct;
- Short terms events leading to the failure Malahide Viaduct;
- Evaluation of other possible causes of failure for the Malahide Viaduct.

10 Modelling the failure mechanism

To understand the mechanism of collapse it is important to consider the combination of the long, medium and short term events leading up to the date of the accident.

To aid this understanding of events, 3-D and 2-D physical models were created at UCC, as well as mathematical and hybrid models, in order to simulate the hydraulic mechanisms involved in the collapse.

10.1 Physical models

A 3-D, 1:80 scale model was created and set at a prototype flow-rate of 400 *cubic metres per second* (m^3/s), which simulates the high spring *ebb-tide* flowrate, (see Photograph 5). The model was also used to determine the discharge characteristics of the weir. It was also used in the process of developing a mathematical representation of three-dimensional surfaces via specialised software.

Photograph 5 – 3-D model (viewed from east to west)

A 2-D 1:40 model was also created to simulate the Broadmeadow estuary level, at 2m *Ordnance Datum* (OD) at Malin Head. It is a depth averaged model that assumes uniform velocity and *hydrostatic pressure* along water depth, and considering vertical velocities and accelerations to be negligible. Simulated 0.3m – 0.4m cobbles were placed along the full length of the simulated pier, (see Photograph 6). The model was used to determine the hydraulic characteristics of the weir.

Photograph 6 – 2-D model in laboratory flume

10.2 Mathematical and hybrid modelling

Appropriate mathematical models were set-up using specialised software. The physical and mathematical models were used to determine hydraulic characteristics of the historic (pre-failure) weir (and subsequently used for the final design of the new enhanced weir).

11 Weir hydraulics

The Malahide Viaduct is made up of a permeable stone weir, with masonry piers constructed on this weir, as illustrated in Figure 7. The figure also illustrates the direction of tide, ebb tide occurs between high and low tide where the water flows back to the sea; and flood-tide occurs between low and high tide where the water flows into the estuary.

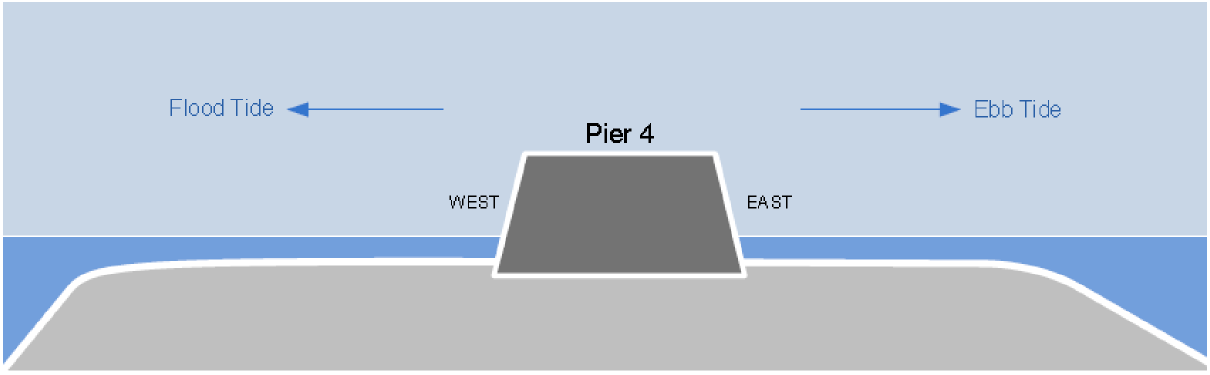


Figure 7 – Original Malahide Viaduct construction

For sub-critical flow, the weir acts as a step up from the bed of the estuary. This water level drop (depth decrease) resulting from the step up reduces the flow area through the viaduct, causing a drop in pressure, which in turn increases the velocity of the flow of water as the *kinetic energy* increases (see Figure 8), thus increasing scour potential.

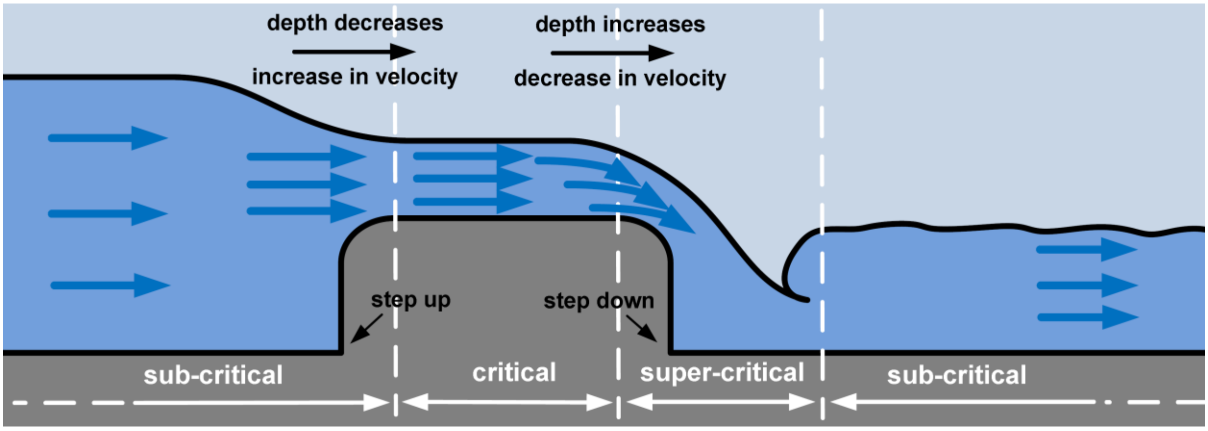


Figure 8 – Increase in velocity as a result of the water flowing over the weir

For super-critical flow, the weir acts as a step down. This water level increase (depth increase) from the step down increases the flow area, causing an increase in pressure which in turn decreases the velocity of the water flow (see Figure 8).

For sub-critical flow to convert to super-critical flow, the flow must go through critical flow (see Figure 8).

When the initial flow goes from sub-critical to super-critical, it does so smoothly as the water surface curves rapidly but smoothly through the critical flow. The change from super-critical to sub-critical is not so smooth. Hydraulic jump occurs as the depth of water increases abruptly due to downstream boundary condition, which causes a vigorous turbulent mixing action (see Figure 9).

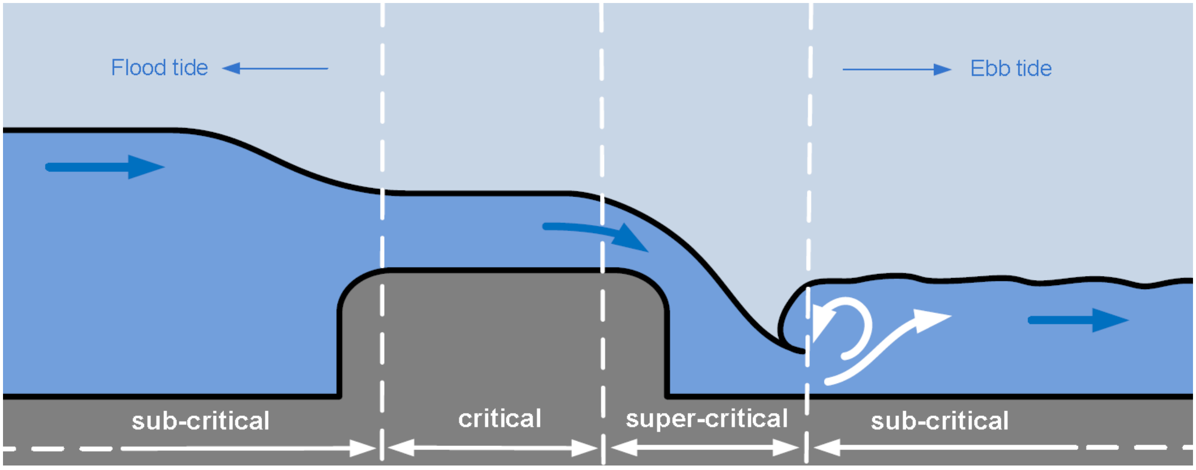
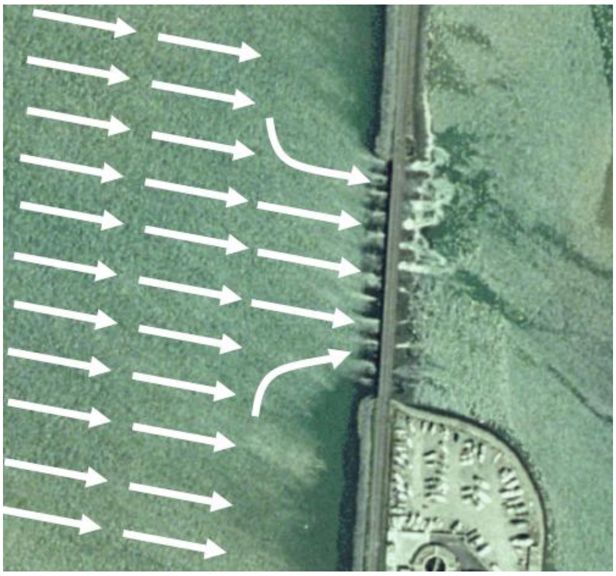


Figure 9 – Water flow over a weir

As illustrated above, when the water level drops the flow of water (over the weir, through the viaduct) increases in velocity. There is an additional drop as the viaduct structure itself causes the water level to drop further as a result of the reduced width of the estuary exit, further increasing the velocity through the viaduct.

The viaduct construction allowed for even flows through all twelve spans of the viaduct (see Photograph 7).


Photograph 7 – Even flows through all twelve spans (during ebb flow)

12 Long term events leading to the collapse

The 2-D 1:40 laboratory moveable model was created to simulate the sediment transport between the piers for the Broadmeadow estuary level (west), at 2.7m, 2.0m and 1.5m OD. Simulated 300 – 400mm stones were placed along the full length of the simulated pier. The model showed that these stones were unstable and moved even when slightly dislodged, suggesting that the stones were close to the *threshold of movement* when velocities are high, as occur during high ebb tides, Figures 10 and 11 illustrate this movement. The velocity measurements were taken from the model and scaled up to give prototype velocities ranging from 3.48m/s to 4.9m/s.

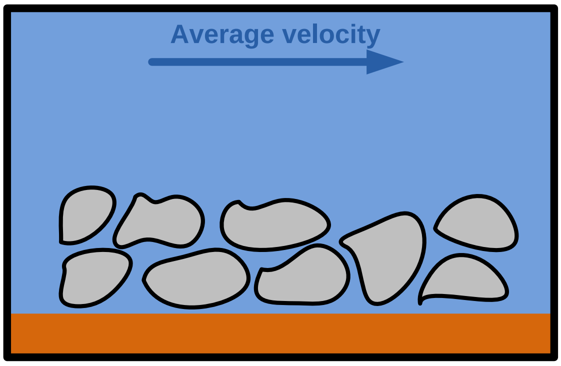


Figure 10 – Stable cobbles during average velocities

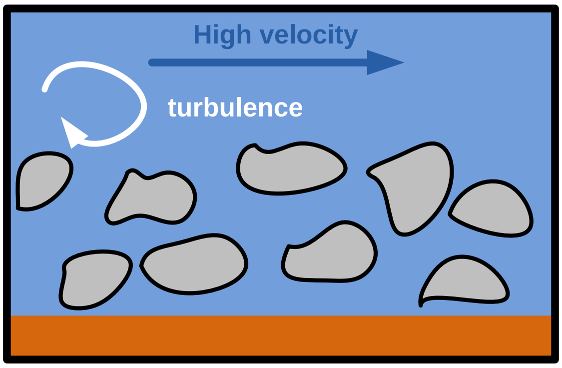


Figure 11 – Unstable and moving cobbles during turbulence caused by high velocities

This movement of stones, simulated over a period of many years, resulted in the material being eroded from the crest of the weir; this process is generally referred to as *winnowing*. This erosion resulted in the weir's profile changing over the years from the original weir profile, illustrated in Figure 7, to a more elongated weir on the eastern side, illustrated in Figure 12.

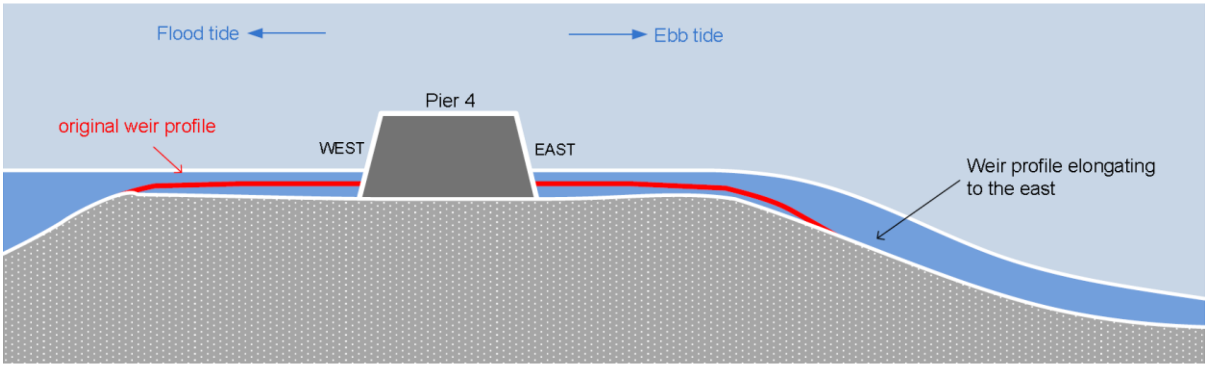


Figure 12 – Weir elongating to the east due to erosion

This would have been magnified by the fact that there was more materials to be eroded as the weir crest was being replaced by IÉ.

The historical records, Malahide Viaduct article in ICE Session 68-9 Volume 95, shows an original placement of 90,000 tonnes of stone were discharged along the line in the early years after construction with stones being continually discharged under the viaduct to maintain the weir. Great Northern Railway Ireland (GNRI) records show that 5,730 tons were discharged along the viaduct in 1922, while CIÉ discharged 2,000 tons from CIÉ wagons after a storm in 1965.

13 Medium term events leading to the collapse

ICE Session 68-9 records that the weir crest was *grouted* in 1967 and 1968, in an attempt to stabilise for a period the weir; this formed a grouted rock armour extending approximately two metres in depth (see Figure 13). The Malahide Viaduct article in ICE Session 68-9 Volume 95, noted that "the surface of the stone 'weir' varied from crest level to the west side sloping steeply to about 100 feet (30m) out from the pier on the seaward side.", (see Figure 13).

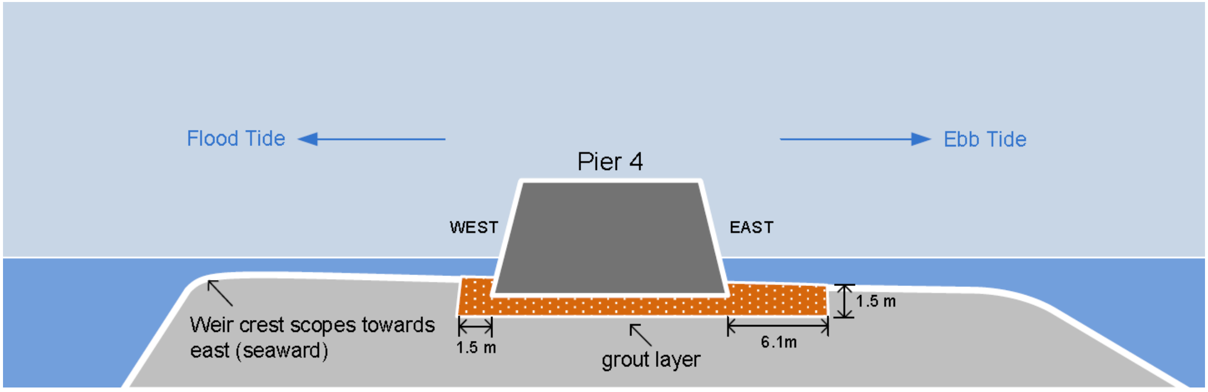


Figure 13 – Grout layer (grouted rock armour) inserted in 1967 – 1968

The Malahide Viaduct article in ICE Session 68-9 Volume 95, also noted, in relation to the grouting scheme, that "the general longitudinal profile dipped between piers to concentrate the main flow away from the piers while providing optimum protection to the piers foundations". These features were retained for the grouting (see Figure 14).

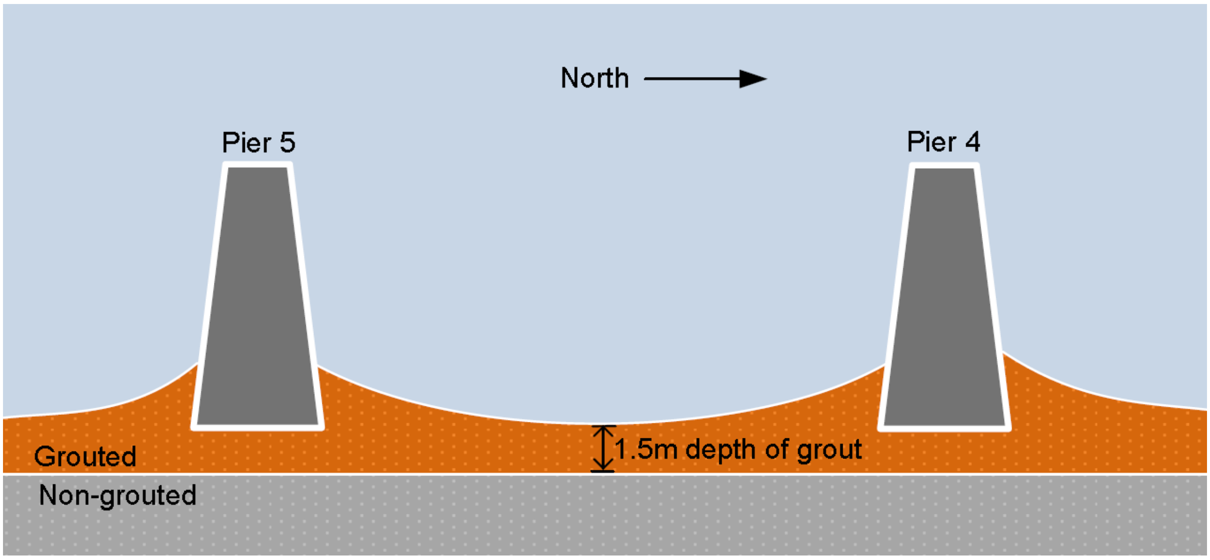


Figure 14 – Elevation illustrating the dipped profile between the piers

The stabilisation by the grouted rock armour was proved successful by the absence of observed scouring or potholing after the storms in February 1969, and the elongated profile on the east remained, (see Figure 15).

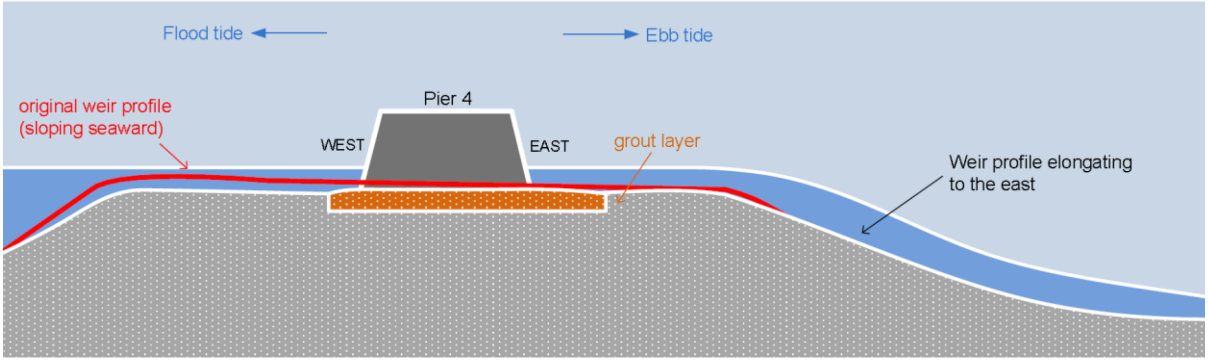


Figure 15 – Weir profile remains elongated to the east, with the grout layer (rock armour) stabilising the scouring

However, the grouted rock armour began to break down as a result of degradation of the grout (the grout on the west side remained semi-intact). This led to further transport of cobble and grout from the weir crest. However, with the non-replacement of materials to the crest of the weir further erosion resulted under the eastern side of the pier, (see Figure 16).

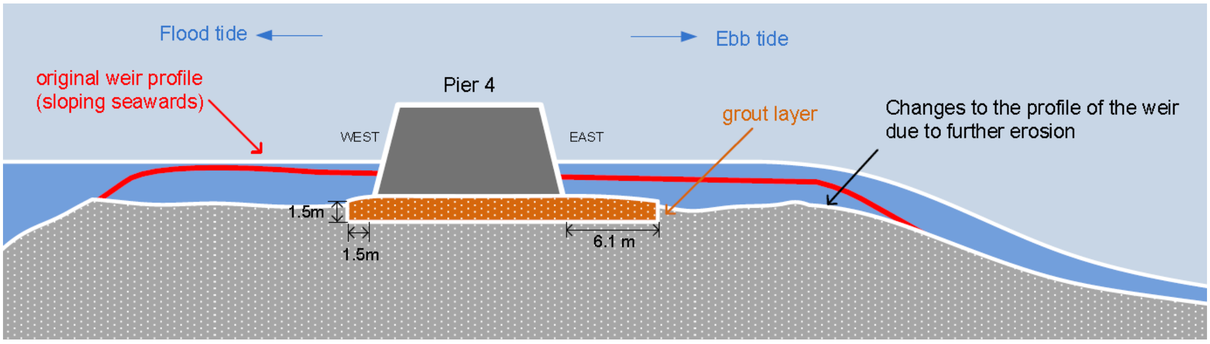


Figure 16 – Erosion of the eastern side of the weir

Referring back to Figure 8, the hydraulic jump should be downstream of the weir, a safe distance from the bridge pier foundations. This is also illustrated in Figure 17 for what should happen at Malahide Viaduct.

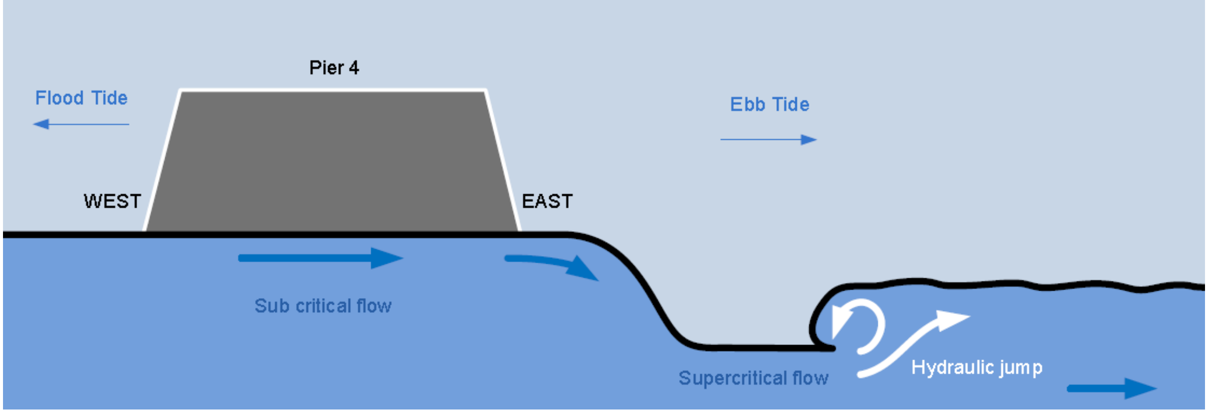


Figure 17 – Malahide viaduct original hydraulic jump

However, the 3-D 1:80, simulating the high spring *ebb tide* flowrate, showed that when the tide reached certain critical levels on the eastern side, a hydraulic jump formed between Pier 4 and Pier 5, the location of the collapsed pier (see Figure 18 and Photograph 8). Velocity measurements were taken from the model at the mid-point of the pier to the downstream side of the weir. These measurements were recorded in the model and scaled to the prototype giving values in the range of 4m/s to 5.5m/s.

Photograph 8 – 3-D model of movement of hydraulic jump

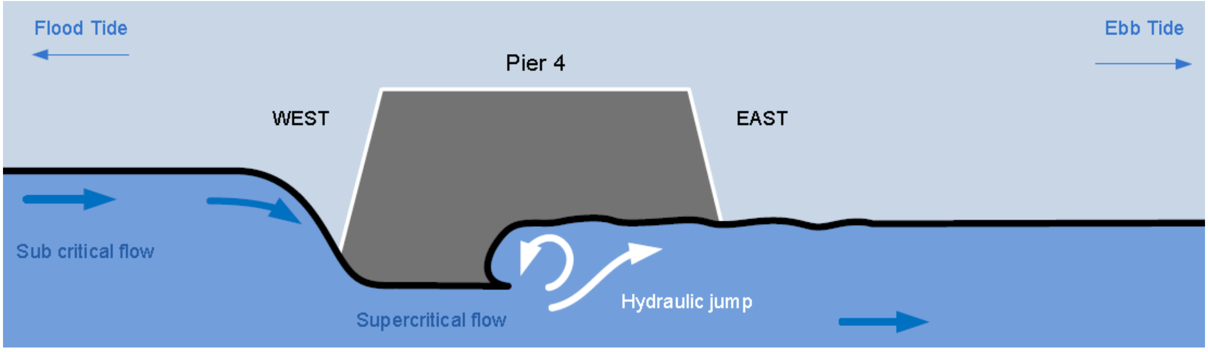
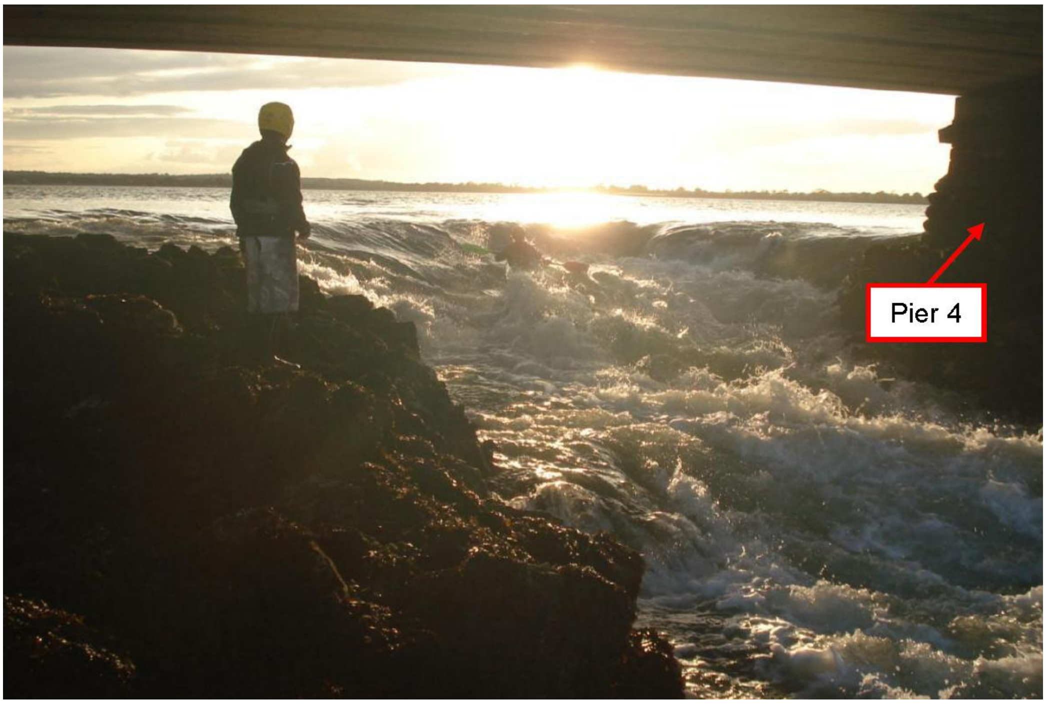


Figure 18 – New position of hydraulic jump, between piers 4 and 5

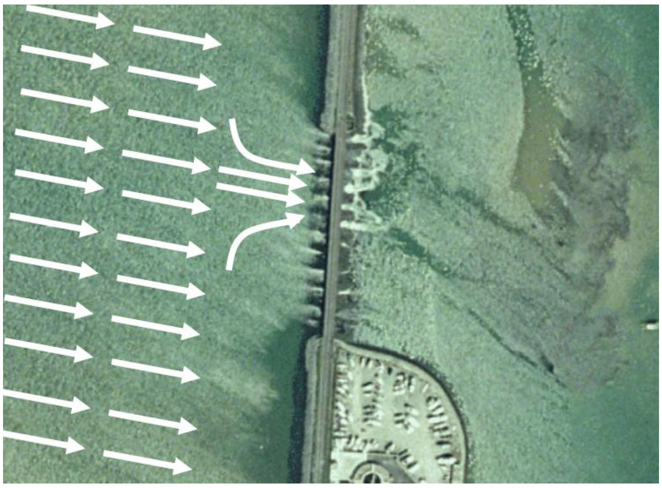
The turbulence from the hydraulic jump at the mid-point of Pier 4 would have meant that the materials were at the threshold of movement, and started being transported from the crest of the weir, with the materials being deposited on the eastern side of the weir, creating an even more elongated weir profile.

This erosion resulted in the area between Pier 4 and Pier 5 to deepen forming a channel (see Photograph 9). This resulted in changes to the water flow under the structure, with the flow of water no longer being evenly distributed through all twelve spans.



Photograph 9 – Deepened channel between Pier 4 and Pier 5

Now, for the latter part of the ebb tide cycle, the majority of the water was flowing through this deepened channel between Pier 4 and Pier 5 (see Photograph 10) and the flow path through the permeable weir was reduced.



Photograph 10 – Majority of water flow between Piers 4 and 5

As a result of the deepened flow path, through Pier 4 and Pier 5; and the increased hydraulic gradient resulting from the erosion of the crest of the weir, the potential for the winnowing of smaller stones from the weir was increased.

Figure 19 illustrates the grouted and un-grouted zones of the weir, as well with the red lines indicating the general westward propagation of the hydraulic jump where the grouted and non-grouted weir material has been removed by the scour action.

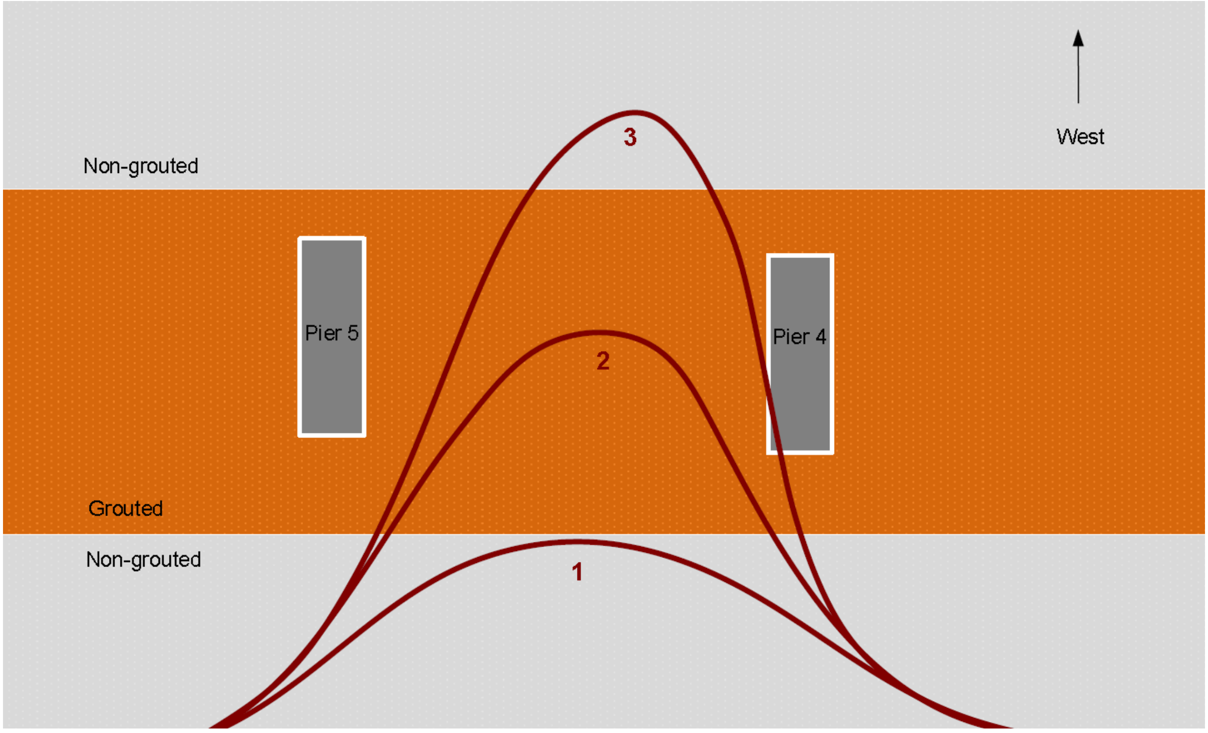
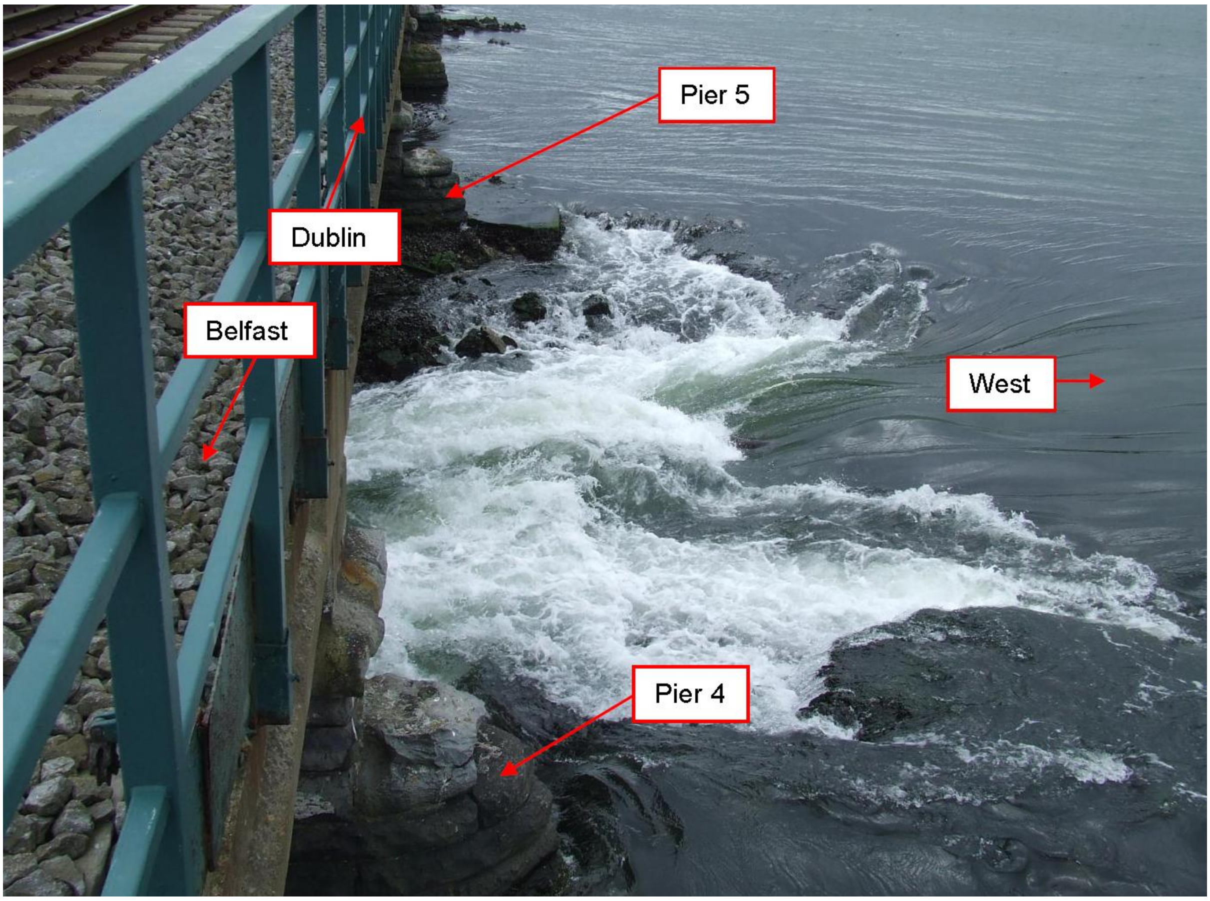


Figure 19 – Westward propagation of the hydraulic jump and erosion due to scour action

14 Short term events leading up to collapse

On the morning of the 17th August 2009, a group leader from the Malahide Sea Scouts, who had been a regular canoeist in the Broadmeadow Estuary, noticed that some of the 'stones' around the base of Pier 4 had been washed away, and he reported this to IÉ on that day. While he did not consider the structure unsafe, he was concerned about the changing conditions at Pier 4.

The reported washing away of 'stones' would indicate that the erosion mechanism had accelerated and the stones close to the foundations of Pier 4 had started to be displaced on the western side of the weir. This can be verified from the photograph taken by IÉ during the structural inspection on the 18th August 2009 (see Photograph 11). It can be seen, from the photograph, that the ebb flow hydraulic control point had moved further west at Piers 4 and 5. This suggests that serious erosion was occurring in the months leading up to the collapse of the viaduct, confirming the flow was accelerating over the crest, resulting in high velocities upstream of the western foundations of Pier 4.



Photograph 11 – Photograph taken during inspection of Viaduct on the 18th August 2009

The narrowed flowpath and the remaining semi-intact grout rock armour on the western side meant there was an increased potential for *piping*. Piping occurs when there is a sub-surface formation and progression of a continuous 'pipe-like' tunnel. The material is eroded by the flow of water through the tunnel, which then carries way these eroded particles, (see Figure 20).

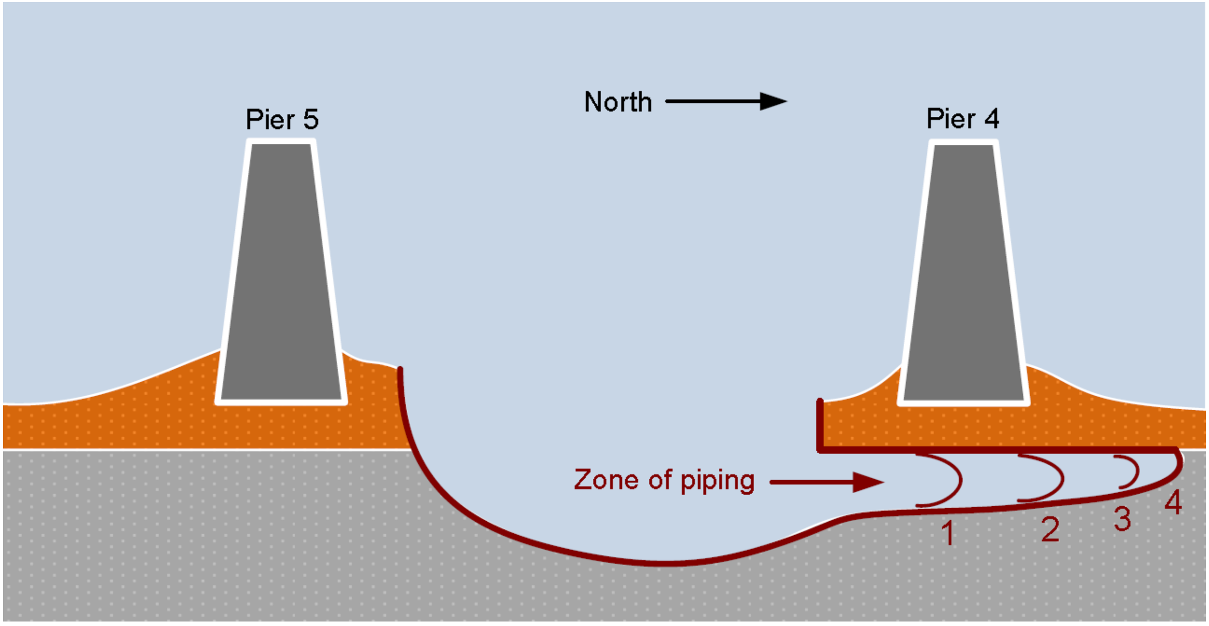


Figure 20 – Piping under Pier 4.

The piping flowpath was under the remaining grout layer on the west side of the weir with the grout layer acting as an upper boundary to the flow pipe, causing undermining of Pier 4 (see Figure 21).

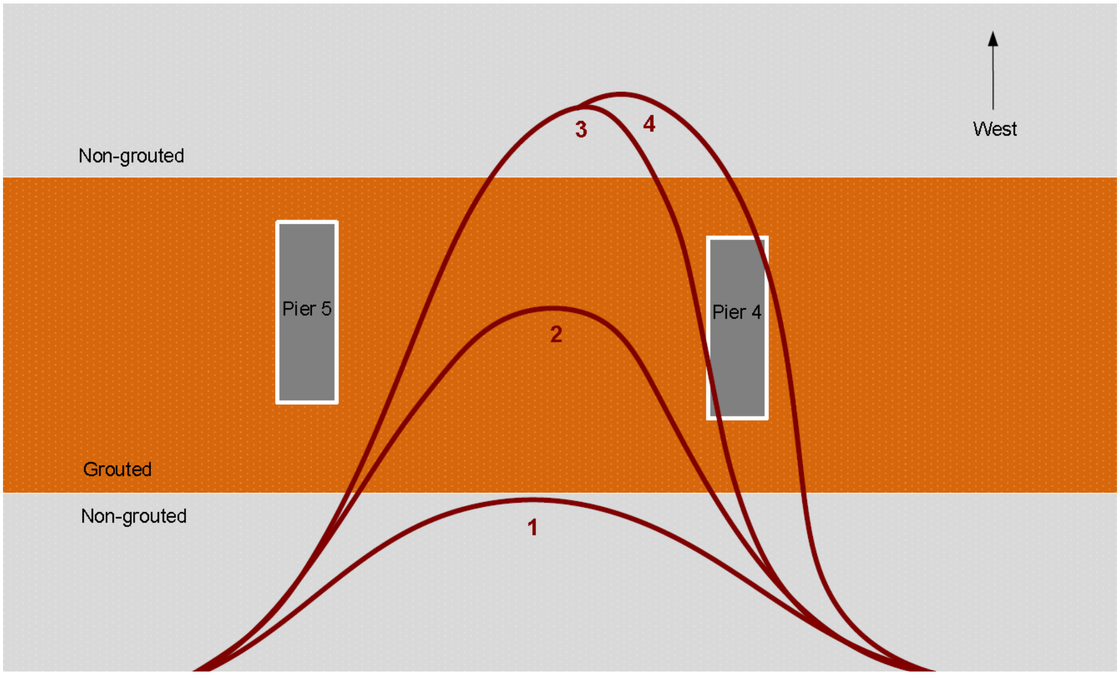


Figure 21 – Undermining of Pier 4 as a result of piping

The red lines 1 – 3 in Figure 20 and 21, illustrate the general westward propagation of the hydraulic jump where the grouted and non-grouted weir material has been removed by the scour action (as occurred in the medium term events), the addition of red line 4 indicates the post collapse zone of the 'piped' scour that undermined the grout apron. Figure 22 clearly illustrates this undermining.

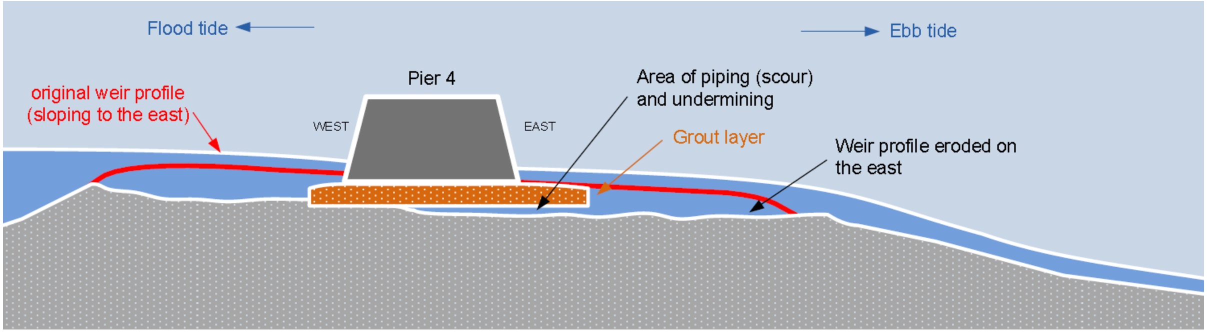
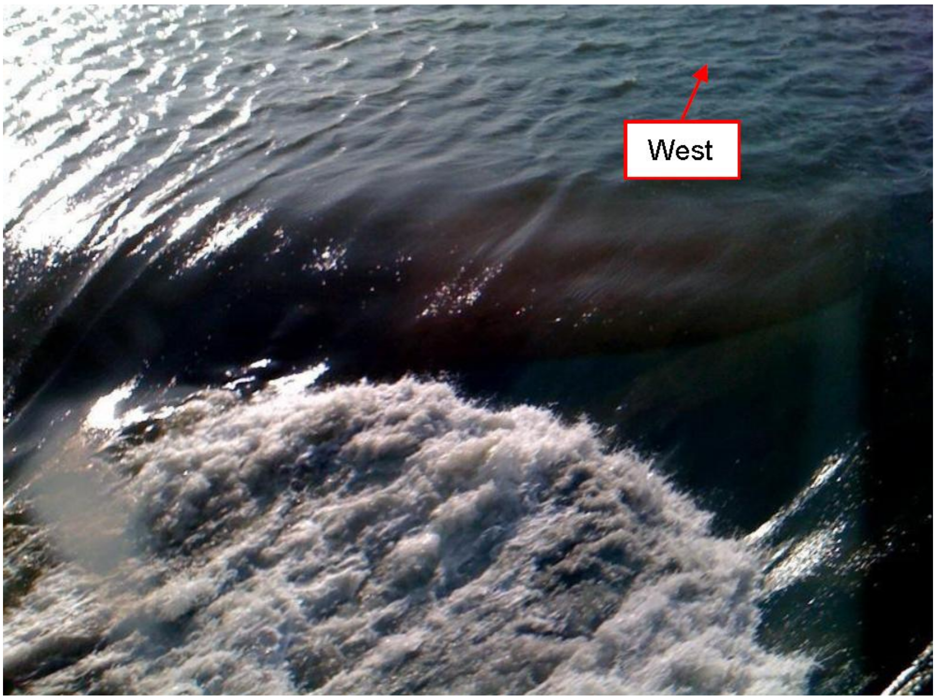


Figure 22 – Transport of materials after the movement of the hydraulic jump

This has been verified by a photograph taken by a passenger travelling over the viaduct at 9.35 hrs on the 21st August 2009, the day of the collapse. He observed a whirpool of approximately 3 m diameter on the western side of the viaduct. From the passenger's position on the train, the whirpool would have been located approximately 4 – 5 m from the viaduct. The passenger again observed and photographed this whirpool at approximately 17.55 hrs, (see Photograph 12). This passenger's travel over the viaduct coincided with the ebb tide flow for the day.



Photograph 12 – Vortex, photograph taken 30 minutes before the collapse

Removal of the weir material was now the result of the flow over (by hydraulic jump) and through (by piping) the weir. The vortex size (approximately 3m diameter) indicates that the piping flow rate was high, resulting in the high potential of the removal of materials.

From a post accident survey (see Figure 23) an asymmetrical form can be observed. The significance of this observation is that the cause of scour is unlikely to be solely a result of '*local scour'*, further reinforcing the cause of the undermining to be as a result of piping scour.

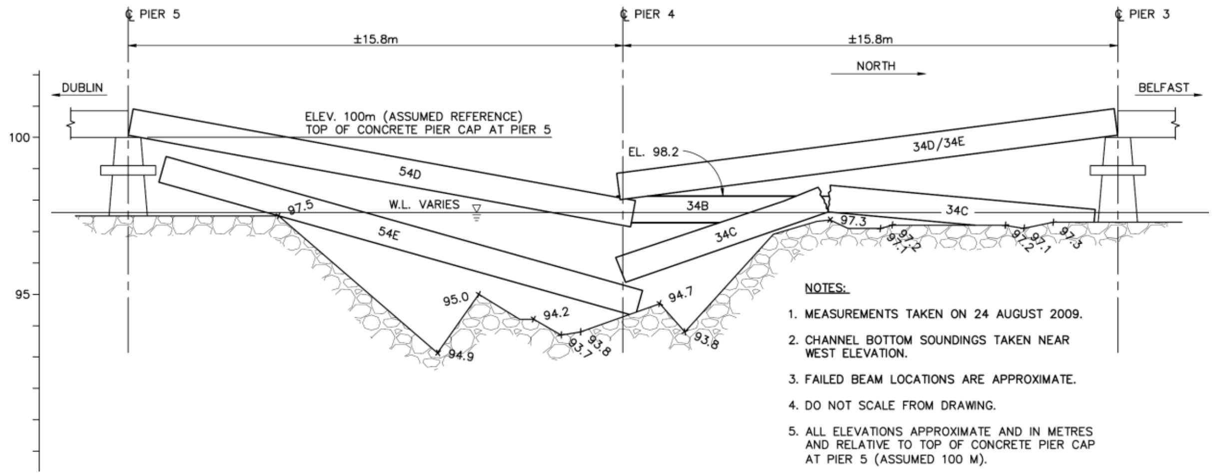


Figure 23 – Post accident survey illustrating asymmetrical scour hole

15 Evaluation of other possible causes of failure

15.1 Drag and lift forces

Lift forces on the piers are most likely to have been negligible at the time of the collapse due to the good alignment of flow under the structure (see Photograph 7). Drag and lift forces though are likely to have been contributory to the gradual collapse of the weir.

15.2 Impact loading or debris

Impact of debris on a bridge pier, or the resulting turbulence resulting from the debris, can lead to increased local scour, which can be an important contributor to some bridge pier failures. It is not possible for the RAIU to establish conclusively that the piers had not sustained impact forces from floating debris. The evidence gathered by the RAIU, in conjunction with the fact that the piers would be expected to be relatively clear of floating debris, due to the width of the estuary and the high velocity of flow through the main viaduct spans suggests there was no significant debris trapped at the piers, and therefore not a contributory factor to the failure mechanism.

15.3 Impact of live loading

The collapse of Pier 4 occurred whilst the 18.07 hrs Balbriggan to Pearse, four-car DMU was travelling over the viaduct, the 17.50 hrs Pearse to Dundalk eight-car DMU had travelled over the viaduct seconds earlier. The impact of the live loading to Pier 4 was likely to be a **contributory factor** to the loss of masonry or support bed material to the already undermined Pier 4, this can be verified by the driver of the P711 service witnessing the water splashing over the viaduct as the D820 service travelling over the viaduct.

15.4 Condition of the concrete beams

The intact concrete beams were removed from the Broadmeadow Estuary and loaded and tested at a testing facility. The beams passed the required loading for the requirements of the structure, and therefore were fit for purpose and not contributory to the accident.

Track Inspections: Factual and Analysis

This section of the report details:

- The standard for track inspections;
- The track patrolling carried out over Malahide Viaduct;
- The track recording vehicle runs over;
- Analysis of the RAIU's findings.

16 Track inspections – Factual

16.1 Track patrolling inspections – Factual

The track over the viaduct is patrolled by a designated Patrol Ganger. The regular patrolling length for the section of track which includes the Malahide Viaduct is from the 7 ¼ *milepost* to the 9 ½ milepost which is in Division 1, and from the 9 ½ milepost to 13 ¾ milepost is Division 5. This means that the Patrol Ganger was working across two separate Divisions, reporting to two separate PWIs, and must, therefore, keep two separate patrolling books.

IÉ's standard for track patrolling, Standard for Track Patrolling, I-PWY-1307, states that the "patrol gangers must carry out continuous systematic examination of the track to locate conditions that are unsafe, potentially unsafe or likely to cause delay to trains"; and that the "patrol ganger must be alert for any signs of unsafe conditions developing in adjacent assets which can be observed from the track, as well as for any unusual events inside or outside the railway boundaries that could affect safety". In relation to rail underbridges over rivers or waterways, the same standard states that the patrol gangers must "check underneath for scour at least once a year" in a "dry weather spell".

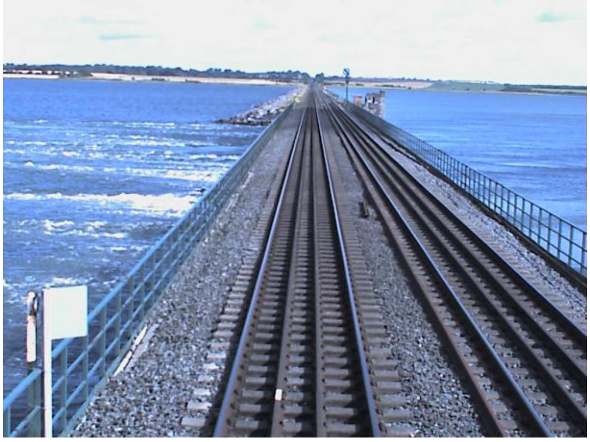
Work on the track relaying of CWR on concrete sleepers was completed in 2002, which was laid on a ballasted deck. As CWR has few joints, this form of track is very strong, gives a smooth ride, and needs fewer inspections than the previous *jointed track.* IÉ's standard for track patrolling stipulates that CWR has a minimum inspection frequency rate of once a week, as opposed to the three times a week stipulation for jointed track. The new frequency rate had not been introduced in this section at the time of the accident, therefore the track continued to be patrolled three times a week (usually on Mondays, Wednesdays and Fridays).

It would, therefore, have been expected that the last track patrol over the Malahide Viaduct would have been on Friday, 21st August 2009. The last patrol on Malahide Viaduct was actually carried out on the 10th August 2009, for which the Patrol Ganger noted no faults in relation to the structure.

16.2 Track recording vehicle inspections – Factual

IÉ's track and structures inspection requirements standard, Track and Structures Inspection Requirements, I-PWY-1107, states that the *Track Recording Vehicle (TRV)* has a six monthly track inspection rate. The TRV has travelled over the Malahide viaduct eight times, in each direction, since its first run in May 2007. The last run on the viaduct (both directions) was the 20th August 2009, the day before the collapse, at which time it recorded the track to be in a good condition (i.e. no defects were found and no significant changes in the vertical and horizontal *alignment*, *cross level* or *twist* which would have indicated that the viaduct was close to failure were recorded for the run or in any of the previous eight runs). Still photographs from the TRV video taken on the day before the collapse are illustrated below in Photographs 13 and 14.

Photograph 13 – TRV still towards Dublin



Photograph 14 – TRV still towards Belfast

17 Track inspections – Analysis

17.1 Track patrolling inspections – Analysis

The track section which included the Malahide Viaduct was not patrolled in the eleven days prior to the accident – no relief Patrol Ganger was assigned patrolling duties, for the Malahide Viaduct section, when the designated Patrol Ganger for the area was on annual leave. Confusion arose about assigning a relief ganger as there was an overlap in the Patrol Ganger's patrol length over Divisions 1 and 5. A track patrol should have been carried out on the day of the accident. However, reviewing the still photographs from the TRV which was carried out on the 20th August 2009 (see Photographs 13 and 14) there is some doubt that the Patrol Ganger would have identified any precursors to the failure of the viaduct in from a track level inspection.

As noted earlier, IÉ's track patrolling standard states that, in relation to rail underbridges (i.e. bridges over rivers or waterways), the patrol gangers must "check underneath for scour at least once a year". The RAIU has not found any records to show that the Patrol Ganger carried out an annual check for scour for the Malahide Viaduct.

As the track patrols are conducted at track level, a track patroller would not be expected to go under the bridge to carry out an inspection for scour.

The conduct of an inspection for scour requires specialist training/skills and there are no records to suggest that the Patrol Ganger patrolling the Malahide Viaduct track had received any training in the identification of scour.

17.2 Track Recording Vehicle inspections – Analysis

The last run over the viaduct was the 20th August 2009, the day before the collapse, for which it recorded the track to be in a good condition. It should be noted that the TRV inspections relate mainly to track geometry and it is likely that only severe track geometry changes would alert staff to any faults with the viaduct structure. There is no suggestion from the findings described in the 'The Failure Mechanism of Malahide Viaduct' sections that there would be any severe track geometry changes prior to the collapse of Pier 4.

Structural Inspections: Factual and Analysis

This section of the report details the:

- Requirements set out in the structural inspections standard;
- Types of inspections carried out on bridges;
- Process of inspections;
- Inspection reporting;
- Independent report recommendations in relation to structural inspections;
- Analysis of the RAIU findings.

18 Structural Inspections Standards – Factual

IÉ's Structural Inspections Standard, I-STR-6510, was introduced on the 5th July 2005. A revised issue, Issue No. 2, has been in operation since 23rd October 2008, and was in operation at the time of the accident. The standard provides guidance on the types of inspections to be carried out, their frequency and the process of carrying out inspections.

In relation to the frequency of inspections to be carried out on bridges, there is conflicting requirements. I-STR-6510 categorises Bridges as Category A1 structures, which therefore require Thorough Inspections every two-years, however, the Bridge and Culvert Inspection Card (Bridge Inspection Card), states that Bridges are subject to Ground Level Inspections (every two years) and Thorough Inspections (every six years).

From the evidence provided, IÉ had adopted the frequency requirements of I-STR-6510 for Ground Level Inspections to be carried out every two-years and Thorough Inspections to be carried out every six years.

The standard states that the 'Civil Engineering and Earthworks Structures: Guidance Notes on Inspections Standard', I-STR-6515, which provides guidance on procedures for inspections and identification of defects, must be read in conjunction with the Structural Inspections Standard, I-STR-6510. However, in the course of this investigation, IÉ has confirmed that standard I-STR-6515, due to be adopted at the time as I-STR-6510, was not developed.

19 Types of structural inspections – Factual

19.1 Inspections carried out prior to the introduction of the Structural Inspection Standard

Prior to the introduction of the Structural Inspection Standard, I-STR-6510, a Maintenance of Way (MW) document, MW41, 'Maintenance of Bridges'. This standard specified that "all bridges and culverts should be thoroughly inspected at two year intervals" in a thorough inspection.

Bridge Inspection Cards for the Malahide Viaduct, based on MW41, have been retrieved for the following dates 30/01/1998, 11/11/1988, 19/09/1985, 28/01/1982, 19/02/1975 and 19/11/1972.

19.2 Ground Level Inspections

Structural Inspections Standard, I-STR-6510, (introduced on the 5th July 2005), specifies that a 'Ground Level Inspection' is an inspection of all visible elements of a structure undertaken from ground or water level, with the assistance of binoculars where necessary. If significant elements of the structure are not visible, the relevant inspector must make arrangements for access. This level of inspection is intended to monitor the general condition of the structure on a regular basis without the need for special access. Ground Level Inspections should be carried out on a 2-year cycle.

I-STR-6510 provides a template of a Bridge and Culvert Inspection Card (Bridge Inspection Card) which should be used for reporting on Ground Level Inspections, (see Figure 24). I-STR-6510 states that the following details must be included on the Bridge Inspection Card for Ground Level Inspections:

- Date of inspection;
- Type of inspection;
- Description of the structure;
- Photographs of the structure including each defect observed;
- Description of any defects observed and evidence of most likely cause;
- Deterioration in condition since previous inspection;
- *Condition ratings* of each component of the structure;
- Recommended action to be taken;
- Name and title of the person carrying out the inspection;
- Recommended date for the next inspection.

The Bridge Inspection Card, when completed, must be submitted to the Person Responsible (in the case of Malahide Viaduct – ADE 2) for approval.

Iarnród Éireann CCE Department

A.1 Bridges and Culverts Inspection Card

(Page 1 of 2)

Reports must be submitted for each individual bridge and culvert structure inspected and issued for approval to the person responsible for maintaining the asset (Person Responsible). Reports must contain the minimum information required, as outlined in Section 5 of this standard, together with the additional information listed below. The condition ratings in the table below apply to all inspection cards.

Bridges and Culverts *(Ground Level and Thorough Inspection)*

- Adequacy of drainage
- Ballast retention
- Evidence of water seepage
- Live load deflections
- Track alignment on the approach

Condition Ratings Table

Condition	*Rating*
Good (no faults or minor faults well within tolerance)	1
Fair (tolerable faults, no restriction in use necessary)	2
Poor (significant structural defects, i.e. out-of-tolerance faults)	3
Very poor (seriously deficient, mitigation measures necessary)	4

Iarnród Éireann CCE Department
Bridges and Culverts Inspection Card
(Page 2 of 2)

IÉ Bridge No		Line Name		Location/Bridge Name	
Up or Down		Warning Signs/ Reflective Panels		Restriction No on Headroom-Restricted Bridges	
Footbridge(FB) /Subway (SUB)		Type of Inspection		Division	

Inspection Date: ________________ Bridge Description: ______________________________
Usage: ________________ No of Spans: _______ Form of Construction: ________________ Services Present: ________________
Access Arrangements: ______________________________ Weather Conditions: ______________________________

Type	Masonry, Brick or Concrete Work													
Component	Abutments	Piers/Columns	Jack Arches	Wingwalls	Arch Rings	Arch Soffit	Parapets	Copings	Bedstones	Invert	Beams	Slab	Decking	Foundation, where visible
Condition														
Photo Ref														

Type	Steel or Iron Work														
Component	Columns	Girders, Main	Girders, Outside (parapet)	Girders, Cross	Stringers Under Waybeam	Brackets Under Waybeam	Troughing	Plating	Bracing	Bedstones	Cast Iron Ornamentation	Rods & Stools Under Trussed Beam	Handrail	Painting Dates	Gutters & Drainage
Condition															
Photo Ref															

Type	Timber Work							
Component	Beams, Main	Beam, Outside (parapet)	Waybeams & Fastening	Decking	Bridge Support & Trestles	Wall Plates & Packing	Handrail	Packs & Transoms
Condition								
Photo Ref								

Deterioration Evident Since Previous Inspection: ______________________________

Likely Cause of Deterioration: ______________________________

Recommended Remedial Works: ______________________________

Recommended Date for Implementing Remedial Works: ________________

Inspector's Name & Title: ______________________________ **Signature:** ______________________________

Person Responsible Name: ______________________________ **Signature:** ______________________________

Recommended Date of Next Inspection: ________________

Figure 24 – Bridge Inspection Card Template

The last Ground Level Inspection for Malahide Viaduct was carried out on the 5th October 2007. There was also one other Ground Level Inspection carried out since the introduction of I-STR-6510 on the 19th July 2005. The recommended date for the next inspection was in October 2009.

19.3 Thorough Inspections

A 'Thorough Inspection', as states by I-STR-6510' is a "systematic visual inspection of all elements of a structure, including submerged elements (e.g. bearings and elements susceptible to scour)."

"Thorough Inspections are undertaken at a suitable distance from the component of the structure under investigation such that defects or the deterioration of defects may be detected. It may be necessary for the inspector to remove non-structural components of the structure in order to obtain access to some elements as part of this type of inspection. This level of inspection is intended to provide a detailed evaluation of the current condition of a structure and to identify the cause, extent and severity of specific defects noted throughout." Thorough Inspections should be carried out on a six-year cycle.

"Where the inspector considers that elements of a structure may be subject to defects which cannot be determined without special access (e.g. hidden structural elements, scour, steel lamination), then he or she must inform the person responsible for maintaining the asset (Person Responsible)." The Person Responsible must record necessity for a Special Inspection and arrange.

The Bridge Inspection Card, illustrated in Figure 24, should also be used for reporting the results of Thorough Inspections. I-STR-6510 states that the following details must be included on the Bridge Inspection Card for Thorough Inspections:

- Date of inspection;
- Type of inspection;
- Description of the structure;
- Photographs of the structure including each defect observed;
- Photographs of each element of the structure as well as each significant defect observed;
- Materials incorporated within the structure;
- Structural form;
- Access requirements;
- Description of any defects observed and evidence of most likely cause;
- Deterioration in condition since previous inspection;
- Condition ratings of each component of the structure;
- Recommended action to be taken;
- Name and title of the person carrying out the inspection;
- Recommended date for the next inspection.

Again, as for Ground Level Inspections, the Bridge Inspection Card when completed, must be submitted to the Person Responsible for maintaining the asset for approval.

Thorough Inspections have not been carried out on the Malahide Viaduct, since the introduction of the Structural Inspections Standard, I-STR-6510, in 2005. The first planned Thorough Inspection for Malahide Viaduct is in 2011.

The AD Little Review carried out in 2006, specifically refers to Thorough Inspections stating:

> *"In addition to the two-yearly visual inspection regime, 'Thorough Inspections' should be carried out at a six-yearly frequency. However, these do not appear to occur at present, and there has been no programme established which would enable this is become part of the way of working. Appropriate resources and budget must be identified and assigned for this requirement from the Inspection Standard to become a reality. Competence of staff to carry out the inspections will also need to be considered."*
>
> \- AD Little, 2006, A review of railway safety and of the role and function of the Railway Safety Commission, p 85

This AD Little Review finding led to Recommendation S2:

> *"In accordance with the Standard for Structural Inspections (July 2005), ensure that a programme of 'Thorough Inspections' is started immediately and that adequate resources are available to undertake the exercise. This should include reviewing the competency and training requirements necessary to carry out such a programme of inspections."* (p 86)
>
> - AD Little, 2006, A review of railway safety and of the role and function of the Railway Safety Commission, p86

Recommendation S2 was ranked a high priority rating (i.e. action to commence within one month of the publishing of the AD Little Review, with a timescale of three months for completion).

19.4 Special Inspections

19.4.1 General description

A 'Special Inspection', according to Structural Inspections Standard, STR-6510, is "any inspection that requires specialist access, knowledge or testing, or; requires a specific element of a structure to be examined in very close detail due to a particular area or defect that may be causing concern for the person responsible for maintaining the asset (Person Responsible)."

This level of inspection is conducted on more complex structures (whether due to size, condition or accessibility) where it is deemed that a Thorough Inspection is "not considered appropriate", however, a Special Inspection may form part of a Thorough Inspection. A Special Inspection may also be required following an incident that may have affected the integrity of the structure (e.g. *bridge strike* or flooding incident).

I-STR-6510 specifies that Special Inspections are carried out "at the discretion of the Person Responsible" for maintaining the asset but not greater than a maximum six year interval between inspections is permitted.

I-STR-6510 also states that Special Inspection reports should be written in a form agreed between the Inspector and the Person Responsible and should address any concerns relating to the defect or area under inspection (e.g. scour), and the report should include the minimum requirements as set out for Thorough Inspections.

19.4.2 Bridge scour inspections

A bridge scour inspection is categorised by IÉ as a Special Inspection as it requires specialist access, knowledge and testing.

The IRMS report makes specific reference to bridge scour inspections in the 1998, 2000 and 2001 reviews. Some extracts from the reviews are included below:

> *"Inspections for scour (the undermining of bridge foundations by water) are not formalised except that they form part of the standard bridge inspection procedures. However, frequently, the danger areas are under water and cannot be easily inspected. There is a need for divers to go under the surface to carry out proper inspection."*
>
> - IRMS, 1998, A Review of Railway Safety in Ireland, p 30

> *"Bearing in mind the large number of bridges that could potentially be affected by scour, a structured approach to its management is needed. It is noted that scour is the subject of one of the standards that IE's consultants GNC (Gibb, Nifast and Curry & Brown) will be producing. This should address not just the assessment of vulnerability of a structure to scour and its routine examination but also how times of flood are dealt with."*
>
> - IRMS, 2000, A Review of Railway Safety in Ireland – Implementation Review, p 37

> *"IE should identify all structures potentially vulnerable to scour action and undertake an engineering risk assessment of them. Develop a remedial works programme resulting from that assessment."*
>
> - Recommendation made to IÉ, A Review of Railway Safety in Ireland – Second Implementation Review, IRMS, 2001, p 64

> *"Develop a flood/scour management system to ensure safety of structures at times of flood, including the conditions under which the track must be closed and may be re-opened."*
>
> - Recommendation made to IÉ, A Review of Railway Safety in Ireland – Second Implementation Review, IRMS, 2001, p 64

The AD Little Review also specifically refers to scour management its 2006 Review, stating:

> *"The Second implementation Review of Structures' (March 2001) made recommendations concerning structures vulnerable to scour action. IÉ are currently in the second year of a three-year programme of inspections of bridges vulnerable to scour. This will ensure that all remedial works are identified and programmed accordingly. However, based on interviews at Divisional level, there does not appear to be progress with developing a flood/scour management system to ensure safety of structures at times of flood."*
>
> - AD Little, 2006, A review of railway safety and of the role and function of the Railway Safety Commission, p 85

This led to Recommendation S3:

> *"Develop a flood/ scour management system to ensure safety of structures at times of flood, including the conditions under which the track must be closed and may be re-opened."*
>
> - AD Little, 2006, A review of railway safety and of the role and function of the Railway Safety Commission, p 86

Recommendation S3 was given ranked a high priority rating (i.e. action to commence within one month, with a timescale of three months for completion).

Collins Engineers carried out a Bridge Scour Inspection[5] on Malahide Viaduct on the 18th September 2006, at the request of IÉ's Structural Design Section of the New Works Department, on behalf of ADE 2.

19.5 Inspection after reported structural defect from member of the public

The Structural Inspections Standard, I-STR-6510, (or any other standard) does not specify a formal process for the follow up of reports of structural asset defects by members of the public. Three days prior to the accident, a telephone call was received by IÉ in relation to a structural defect, and actioned as described below.

A group leader from the Malahide Sea Scouts, who was a regular canoeist in the Broadmeadow Estuary, noticed "structural damage" and "eroding down to the base of the pillar" at Malahide Viaduct. At 10.46 hrs on the 17th August 2009, he decided to report this to IÉ even though he did not consider the structure unsafe, however, was concerned about the changing conditions at the viaduct. The telephone call was taken by a member of IÉ's administration staff who noted the reported concerns (i.e. the "structural damage" and the "eroding down to the base of the pillar") in an email to ADE 1

[5] Iarnród Éireann, 2006 Bridge Scour Inspection of UB 30 / Dublin – Belfast Line 9 miles & 902 yards

(The Malahide Viaduct does not fall into this ADE 1's area, however, ADE 2 – the ADE responsible for the Malahide Viaduct, was on leave).

Acting on the contents of this email, at 14.58 hrs on the 17th August 2009, ADE 1 contacted, by telephone, the group leader from the Malahide Sea Scouts. ADE 1, in the course of this telephone call, established that the reported defect related to the "5th span from the Belfast end".

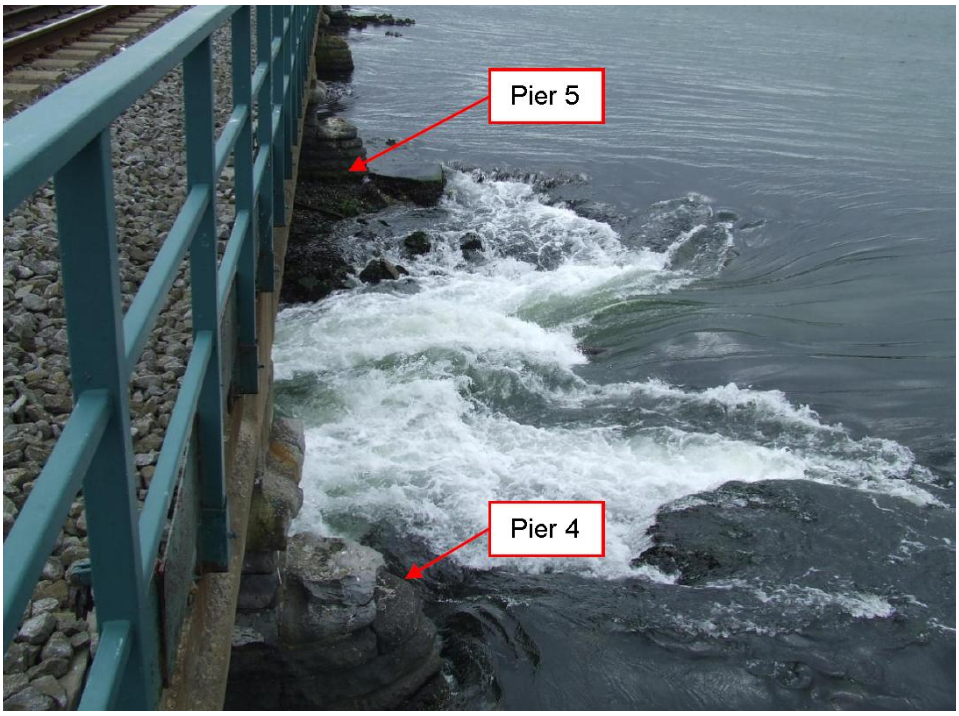
Following on from this telephone conversation, ADE 1 forwarded the email from the member of the administration staff (which noted the "structural damage" and "eroding down to the base of the pillar"), adding to this email, that it was the 5th span from the Belfast end. The AE was in the area of Malahide Viaduct carrying out other inspections and offered, by return email to the ADE 1, to inspect the viaduct the following day.

Prior to the AE carrying out an examination of Malahide Viaduct at 14.10 hrs on the 18th August 2009, the AE had not carried out an inspection of the Malahide Viaduct and was not familiar with the structure or the tidal conditions of the Broadmeadow Estuary. The AE recorded the examination with photographs and found defects in the piers' stonework, such as the piers' required repointing and found that some of the stones on a number of the piers were cracked or missing, (see Photograph 15).

Photograph 15 – Photograph taken by the AE on the 18th August 2009, showing defects to piers' stonework

On finding these defects the AE assumed that these were the faults reported by the Malahide Sea Scouts group leader. The AE also had no previous knowledge of the structure and assumed that the piers had a "sound footing", with the piers founded on bedrock, incorrectly assuming that the weir was not structural.

The AE also photographed (see Photograph 16) the base of the piers on the fifth span of the Malahide Viaduct (i.e. the span reported by the Malahide Sea Scouts group leader to IÉ as the span with the erosion at the base of the piers) and determined that there were no indications of erosion at the base of the piers.



Photograph 16 – Span 5 (between Pier 4 and Pier 5) of the Malahide Viaduct

On the 19th August 2009, the AE contacted ADE 1, by telephone, to inform him that he found no major structural defects at Malahide Viaduct.

No further action was taken by ADE 1 or the AE in relation to the report from the Malahide Sea Scouts group leader.

20 Structural Inspections Standard – Analysis

Structural Inspections Standard, I-STR-6510, defines the types of inspections to be carried out and their required frequency.

The Civil Engineering and Earthworks Structures: Guidance Notes on Inspections Standard, I-STR-6515 provides guidance on procedures for inspections and identification of defects. The standard should, it is stated, be read in conjunction with the Structural Inspections Standard. However, as previously stated, this standard is not in place. It was found that the notes from the "Civil Engineering Earthworks and Structures – Inspection Guidance" training course had been informally referred to as this standard.

21 Types of inspections – Analysis

21.1 Inspections carried out prior to the introduction of the Structural Inspections Standard

Prior to the introduction of the Structural Inspection Standard in 2005, MW41, Maintenance of Bridges document was in place for bridges which specified that "all bridges and culverts should be thoroughly inspected at two year intervals".

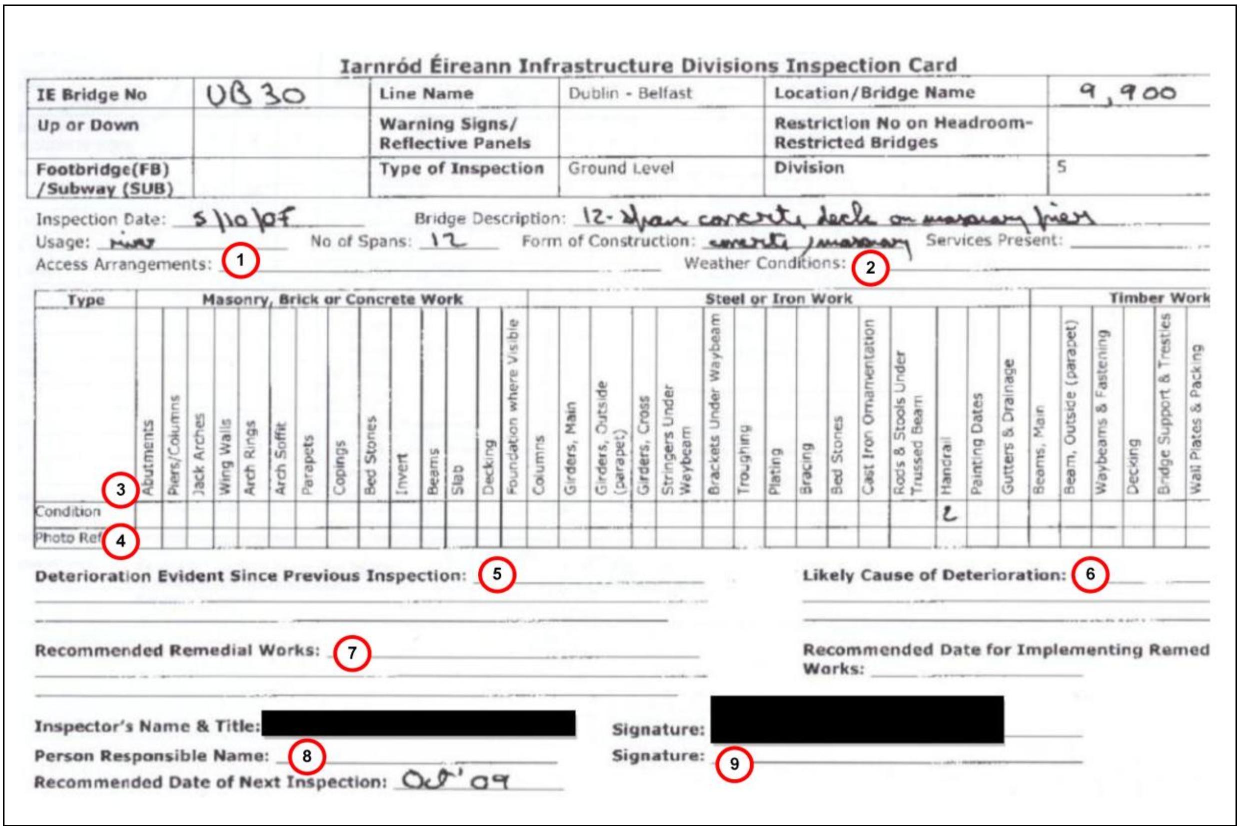
Given that the only Bridge Inspection Cards made available were for the following dates, 30/01/1998, 11/11/1988, 19/09/1985, 28/01/1982, 19/02/1975 and 19/11/1972, there is an apparent failure to meet the requirements of MW41 as there are inspection intervals greater than the required two-yearly inspections (e.g. no inspection was carried out on Malahide Viaduct for ten years between 1988 and 1998). IÉ have confirmed to the RAIU that there is some doubt that all DEs and ADEs would have been aware of the existence of MW41, and therefore did not carry out the requirements of the document in full.

Given that the Structural Inspections Standard, I-STR-6510, was the standard in place at the time of the accident, the RAIU investigation will focus on the inspections carried out after the introduction of this standard.

21.2 Ground Level Inspections

The most recent Ground Level Bridge Inspection Card available for Malahide Viaduct was completed on the 5th October 2007 by an SE within Division 5, who reports to ADE 2. This was the first inspection to be carried out using the new format of Bridge Inspection Card, introduced in 2005 as part of the original Structural Inspection Standard, I-STR-6510. One other inspection had been carried out since the introduction of I-STR-6510 Bridge Inspection Cards which was carried out on the 19/07/2005.

The Bridge Inspection Card completed for the 5th October 2007, is shown below (see Figure 25).



Iarnród Éireann Infrastructure Divisions Inspection Card

IE Bridge No	UB 30	Line Name	Dublin - Belfast	Location/Bridge Name	9,900
Up or Down		Warning Signs/ Reflective Panels		Restriction No on Headroom-Restricted Bridges	
Footbridge(FB) /Subway (SUB)		Type of Inspection	Ground Level	Division	5

Inspection Date: 5/10/07 Bridge Description: 12-span concrete deck on masonry piers

Usage: [illegible] No of Spans: 12 Form of Construction: concrete / masonry Services Present:

Access Arrangements: (1) Weather Conditions: (2)

Type	Masonry, Brick or Concrete Work														Steel or Iron Work																Timber Work					
(3)	Abutments	Piers/Columns	Jack Arches	Wing Walls	Arch Rings	Arch Soffit	Parapets	Copings	Bed Stones	Invert	Beams	Slab	Decking	Foundation where Visible	Columns	Girders, Main	Girders, Outside (parapet)	Girders, Cross	Stringers Under Waybeam	Brackets Under Waybeam	Troughing	Plating	Bracing	Bed Stones	Cast Iron Ornamentation	Rods & Stools Under Trussed Beam	Handrail	Painting Dates	Gutters & Drainage	Beams, Main	Beam, Outside (parapet)	Waybeams & Fastening	Decking	Bridge Support & Trestles	Wall Plates & Packing
Condition																											2								
Photo Ref (4)																																			

Deterioration Evident Since Previous Inspection: (5)

Likely Cause of Deterioration: (6)

Recommended Remedial Works: (7)

Recommended Date for Implementing Remed Works:

Inspector's Name & Title: [redacted] Signature: [redacted]

Person Responsible Name: (8) Signature: (9)

Recommended Date of Next Inspection: Oct '09

Figure 25 – Ground Level Inspection carried out in on the 5th October 2007

The 2007 Bridge Inspection Card was not fully completed in that:

1. Access arrangements were not identified, so it is not clear from the Bridge Inspection Card where the inspection was carried out;
2. The weather conditions were not included;
3. Condition Ratings were not applied to all applicable elements of the Viaduct, (the sole item to be given a condition rating was the handrail, which was given a condition rating of 2 (fair));
4. Photographs of the structure or of any defects indentified were not taken;

5. No comments were made on the deterioration of the structure since last inspection, (the 2005 Inspection Card in the old format, suggested a check for scour, and the handrails to be painted);
6. No description of the handrails defects or the likely cause of deterioration was given;
7. No suggested date was included for the implementation of remedial works;
8. The name of the Person Responsible was not provided on the card;
9. Sign off of the Bridge Inspection Card for approval was not shown.

Further information on the actions of the inspector of the 2007 Ground Level Inspection was retrieved by the RAIU during the course of this investigation. It was found that the inspector:

- Conducted the inspection at track level and could not, therefore, carry out a visual inspection of each of the components on the bridge;
- Did not conduct the required visual inspection of the base of the piers as he was aware, through carrying out a desk top study, prior to the inspection, that a scour inspection was planned / or had been carried out for Malahide Viaduct.

In summary, the inspection did not meet all the requirements of I-STR-6510 with stated requirements in that:

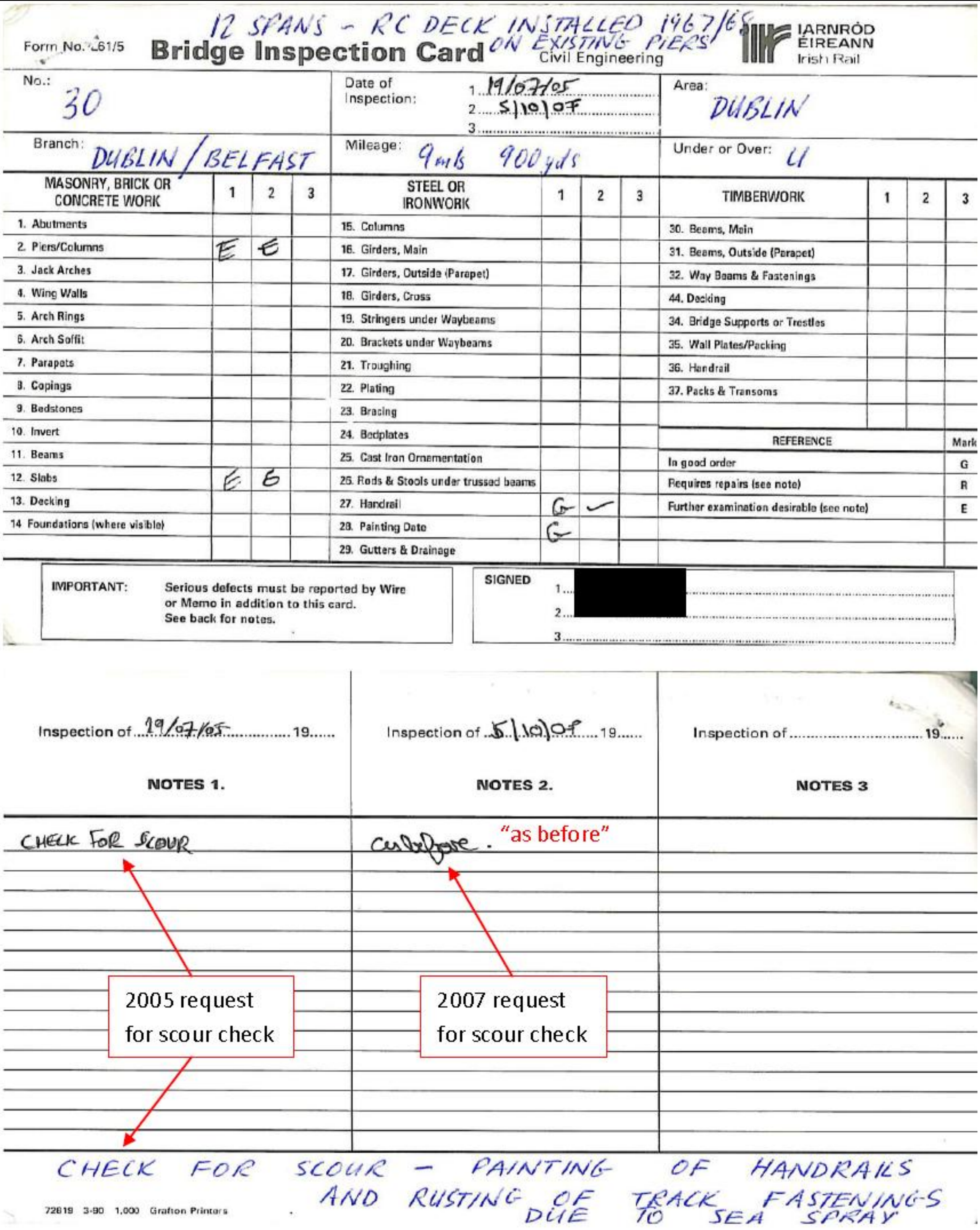
- No visual inspection was conducted on all elements of the structure;
- Condition ratings for elements of the structure were not assigned (e.g. the 'Foundation where visible' element was left blank, as there had been no visual checks of the foundations, as the inspection had been conducted from track level);
- Photographs or sketches were not provided with the inspection, (which if recorded could be compared by the next inspector and the deterioration of the structure could be determined);
- Name for the Person Responsible was absent, in this case ADE 2. Together with the absence of a signature by ADE 2, indicates that the Bridge Inspection Card was not reviewed for approval, a requirement of I-STR-6510.

The lack of approval of the Bridge Inspection Card by ADE 2, which is a formal requirement of I-STR-6510, was replaced with informal approach, where Inspectors "highlighted" any issues to ADE 2 in relation to the "major issues" arising from the inspections. This informal approach, may also led to a less formal approach to the carrying out inspections as there was no formal verification by ADE 2 that the inspections were being carried out. With inspections only forming part of the Engineers day-to-day duties the Engineers appear to be under no obligation to conduct inspection to the full requirements of the Structural Inspection Standard, I-STR-6510.

As mentioned previously, there is a conflict in relation to the required frequency of inspections to be carried out on bridges. I-STR-6510 categorises Bridges as Category A1 structures, which therefore require Thorough Inspections every two-years, however, the Bridge and Culvert Inspection Card (Bridge Inspection Card), states that Bridges are subject to Ground Level Inspections (every two years) and Thorough Inspections (every six years). In the 2007 Bridge Inspection Card, Figure 25, the Type of Inspection inserted is a Ground Level Inspection, illustrating that IÉ adopted the Ground Level Inspection and Thorough Inspection regime. This demonstrates that the new Structural Inspection Standard, I-STR-6510, may not have been fully adopted since its introduction in 2005.

During the course of the inspection, the SE, as well as completing the new Bridge Inspection Card template, filled in details on the old Bridge Inspection Card (see Figure 26) marking the piers and slabs an "E" mark which indicates that the Inspector considers "further examination required" for both these elements, details which the SE has omitted in the new Bridge Inspection Card. The inspector also requested a check for scour (as mentioned previously, the inspector was aware that there was an inspection planned or carried out for the Malahide Viaduct), which again was not included on the new Bridge Inspection Card. This demonstrates that the new Structural Inspection Standard, I-STR-6510, was not fully adopted since its introduction in 2005.

In relation to the Ground Level Inspection carried out on the 19th July 2005, illustrated in Figure 26, the old format Bridge Inspection Card is used, (the new format was introduced two weeks previously, on the 5th July 2005) indicating that the new format Bridge Inspection Card was not fully adopted. It should be noted, also, that there was a request for a scour inspection to be carried out, however, the card does not indicate if there is any evidence of scouring.



Form No. L61/5 **Bridge Inspection Card** 12 SPANS – RC DECK INSTALLED 1967/68 ON EXISTING PIERS

Civil Engineering

IARNRÓD ÉIREANN Irish Rail

No.: 30

Date of Inspection: 1. 19/07/05 2. 5/10/07 3. ....

Area: DUBLIN

Branch: DUBLIN / BELFAST

Mileage: 9 mls 900 yds

Under or Over: U

MASONRY, BRICK OR CONCRETE WORK	1	2	3
1. Abutments			
2. Piers/Columns	E	E	
3. Jack Arches			
4. Wing Walls			
5. Arch Rings			
6. Arch Soffit			
7. Parapets			
8. Copings			
9. Bedstones			
10. Invert			
11. Beams			
12. Slabs	E	E	
13. Decking			
14 Foundations (where visible)			

STEEL OR IRONWORK	1	2	3
15. Columns			
16. Girders, Main			
17. Girders, Outside (Parapet)			
18. Girders, Cross			
19. Stringers under Waybeams			
20. Brackets under Waybeams			
21. Troughing			
22. Plating			
23. Bracing			
24. Bedplates			
25. Cast Iron Ornamentation			
26. Rods & Stools under trussed beams			
27. Handrail	G	✓	
28. Painting Date	G		
29. Gutters & Drainage			

TIMBERWORK	1	2	3
30. Beams, Main			
31. Beams, Outside (Parapet)			
32. Way Beams & Fastenings			
44. Decking			
34. Bridge Supports or Trestles			
35. Wall Plates/Packing			
36. Handrail			
37. Packs & Transoms			

REFERENCE	Mark
In good order	G
Requires repairs (see note)	R
Further examination desirable (see note)	E

IMPORTANT: Serious defects must be reported by Wire or Memo in addition to this card. See back for notes.

SIGNED 1. [redacted] 2. 3. ....

Inspection of 19/07/05 ....19.... NOTES 1.	Inspection of 5/10/07 ....19.... NOTES 2.	Inspection of ....19.... NOTES 3
CHECK FOR SCOUR	as before. "as before"	

2005 request for scour check

2007 request for scour check

CHECK FOR SCOUR – PAINTING OF HANDRAILS AND RUSTING OF TRACK FASTENINGS DUE TO SEA SPRAY

72819 3-90 1,000 Grafton Printers

Figure 26 – 2005 Ground Level Inspection Bridge Card

This non-use the new Bridge Inspection Card system (in the 2005 and 2007 Ground Level Inspections) is consistent with the findings of the 2006 AD Little Review which stated:

> *"Divisions appear to be still operating the old 'bridge card' system and are not fully engaged with the new standard and its contents."*
>
> - AD Little, A review of railway safety and of the role and function of the Railway Safety Commission, p 84

21.3 Thorough Inspections

The RAIU has found no record of a Thorough Inspection being carried out on Malahide Viaduct since the introduction of the Structural Inspections Standard, I-STR-6510, in 2005, which has conflicting frequencies for Thorough Inspections, at either two-yearly or six-yearly frequencies.

However, it should be noted that the Scour Inspection carried out in 2006, may form part of a Thorough Inspection, but does not however, substitute for a comprehensive examination of all elements of the structure.

The RAIU has been informed that a Thorough Inspection is scheduled to be carried out in 2010. A formal Thorough Inspection Programme has not been submitted to the RAIU suggesting that this programme is not in place and it is not clear if the decision to conduct a Thorough Inspection in 2010, on the Malahide Viaduct, is as a result of the accident.

The absence of a formal programme for Thorough Inspections suggests that Thorough Inspections may not to be conducted to the standard. This is consistent with the findings of the AD Little Review, which assumes a six-year frequency, which states:

> *"In addition to the two-yearly visual inspection regime, 'Thorough Inspections' should be carried out at a six-yearly frequency. However, these do not appear to occur at present, and there has been no programme established which would enable this is become part of the way of working. Appropriate resources and budget must be identified and assigned for this requirement from the Inspection Standard to become a reality. Competence of staff to carry out the inspections will also need to be considered."*
>
> - AD Little, A review of railway safety and of the role and function of the Railway Safety Commission, p 85

The AD Little Review findings led to Recommendation S2:

> *"In accordance with the Standard for Structural Inspections (July 2005), ensure that a programme of 'Thorough Inspections' is started immediately and that adequate resources are available to undertake the exercise. This should include reviewing the competency and training requirements necessary to carry out such a programme of inspections."* (p 86)
>
> - AD Little, A review of railway safety and of the role and function of the Railway Safety Commission, p 86

As mentioned previously, this recommendation was not closed by the RSC at the time of the accident, indicating that the RSC did not consider that IÉ had completed this recommendation.

Recommendation S2 also requires for "adequate resourcing" for these inspections. As part of the investigation the RAIU reviewed the workload of inspectors in relation to the East Coast Division (which includes the Malahide Viaduct). At the time of the accident the AE and ADE 2 were responsible for carrying out the inspections of infrastructure assets, (the SE who carried out the 2005 Ground Level Inspections, had left this Division at the time of the accident), with the support of two members of technical staff (these were not full-time inspection resources).

The RAIU have reviewed the job descriptions for both the AE and ADE 2. In the case of the AE, the carrying out of inspections is only one task of twelve specified in the AE's job description. For ADE 2, the inspection of assets only forms one of the eighteen tasks specified in ADE 2's job description.

From the RAIU investigation, it was found that between the AE and ADE 2, there were inspections to be carried out on an estimated 2,150 civil infrastructure assets (519 of these were bridges). Given that these 2,150 assets all require different frequencies of inspections, the RAIU have calculated that the AE and ADE 2 each have approximately 800 (including 130 bridge inspections) inspections to carry out each year.

21.4 Special Inspections

21.4.1 General description

As mentioned previously, a Special Inspection is "any inspection that requires specialist access, knowledge or testing, or requires a specific element of a structure to be examined in very close detail due to a particular area or defect that may be causing concern for the person responsible for maintaining the asset." And normally conducted on more complex structures where it is considered that a Thorough Inspection is "not considered appropriate".

Scour inspections are considered to be Special Inspections. Again, it should be noted that the Scour Inspections are comprehensive inspections, which may form part of a Thorough Inspection. However, they do not constitute a Thorough Inspection as not all the elements of structures are comprehensively inspected (e.g. a precast post-tensioned concrete beam deck).

21.4.2 Bridge Scour Inspections

The necessity for bridge scour inspections has been consistently highlighted to IÉ since 1998 in the IRMS Reviews.

In 1998 the IRMS review highlighted that there was no formalised approach for the inspection of structures for scour, and suggested that divers should go under the water surface to carry out "proper inspections" of structures. IÉ took no apparent action in relation to this IRMS finding.

In 2000, the requirement for a formalised approach for the inspection of structures for scour was re-iterated. IÉ took no apparent action in relation to this IRMS finding.

Then in 2001, IRMS made the following recommendation:

> *"IE should identify all structures potentially vulnerable to scour action and undertake an engineering risk assessment of them. Develop a remedial works programme resulting from that assessment."*
>
> - Recommendation made to IÉ, IRMS, 2001, A Review of Railway Safety in Ireland – Second Implementation Review, p 64

Based on this recommendation made in the 2001 IRMS review, IÉ implemented a three-year programme for the inspection of bridges that were vulnerable to scour. This review was led by the Chief Engineer (Infrastructure), and carried out by the Structural Design Section, with lists of bridges susceptible to scour provided by the ADEs.

There is no documented evidence that the ADEs carried out risk assessments as a basis for the identification of structures vulnerable to scour to compile these lists. The only documentation submitted to the RAIU is the email correspondence which contains the lists of structures provided by the ADEs to the Programme Manager in the Structural Design Section of the New Works Department. There is mention in this email correspondence that structures that could not be inspected, for access reasons, were included in these lists.

ADE 2 did identify Malahide Viaduct as one of these structures to be included in the three-year inspection programme (in total 20 bridges were inspected in 2005, with a further 44 inspected in 2006). There are no records available for the reasons ADE 2 included this structure, however, the "check for scour" request on the 2005 Ground Level Inspection may have been contributory to this decision.

Tender documents were issued by IÉ to specialist engineering diving companies for the conduct of underwater inspections for scour. The specification included, in the tender documents requested the completion of visual and tactile examination of the channel bottom and substructure surfaces up to 1m above evident high water level, noting the type of channel bottom material, the location of scour holes, the confirmation of the presence or absence of *rip-rap* (in this case the grout apron), the location of any foundation undermining, the condition of the substructure units, and the presence of any drift or debris.

The specification did not include a requirement to establish the foundation depths of the abutments and piers. However, it should be noted that the IRMS reports did not specify that this was a requirement. The contract was awarded to CEI Collins Engineers, Ltd., who carried out these underwater inspections, including the inspection of the Malahide Viaduct in September 2006.

21.4.3 Malahide Viaduct scour inspection

On the 18th September 2006, Collins Engineers carried out a Bridge Scour Inspection[6] on Malahide Viaduct. The inspection methodology consisted of a team of engineers carrying out an underwater inspection and taking soundings from the bottom of the channel using a digital *fathometer* and a *sounding rod*. The underwater inspection consisted of visual and tactile examination of the channel bottom and substructure surfaces up to 1.0 m above the evident high water level. Particular attention was directed to observed areas of deterioration or apparent distress.

The purpose of this inspection was to gather data on:

- Type of channel bottom material;
- Location of any scour holes;
- Presence or absence of riprap;
- Location of any foundation undermining;
- Condition of the substructure units;
- Presence of any drift or debris.

Overall, the viaduct was found to be in fair condition, with the piers protected and the primary flow being directed through the mid-span channel. The inspection found that the difference in waterline elevations upstream and downstream of the structure due to the tides resulted in high water velocities

[6] Iarnród Éireann, 2006 Bridge Scour Inspection of UB 30 / Dublin – Belfast Line 9 miles & 902 yards

through the spans of the structure. As a result of the large amount of tidal activity in the area surrounding the viaduct, the report concluded that the structure was susceptible to scour.

The report includes, as an appendix, the soundings from the sounding rod and digital fathometer. However, the report does not interpret these results for the reader, only suggesting that these soundings should be taken as part of the thorough inspections and during or soon after major flood occurrences.

The inspection found that the channel bottom near the viaduct comprised of random areas of grout aprons and large pieces of grout placed at the piers for scour protection. The remainder of the channel bottom was typically grout from the piers and aprons and riprap or rocks 0.4 m in diameter. It was also covered in a layer of mussels approximately 200 mm deep over 50% of the channel bottom. The channel bottom dropped off to approximately 2 to 2.5 m deep between 15 and 20 m upstream and downstream of the bridge.

As there was no requirement by Collins Engineers to establish the foundations they did not therefore establish the foundations. Had this been a requirement, the inspection may have resulted in IÉ discovering that the foundations were not formed on bedrock but on the weir – highlighting that the weir was a crucial structural element to the integrity of the Malahide Viaduct. The only reference to the foundations was in an attachment to the report which awarded the foundations "good" condition rating, however, the report does not elaborate on how it came to this conclusion.

The focus of the report was on the condition of the piers, with defects identified including damage to the noses of the piers, missing or cracked stones and mortar loss in the pier noses. The inspection report concluded that the piers were in fair condition, with the masonry not in need of timely repair but recommended that their condition be monitored during future inspections. There was little information provided in relation to the weir.

The report recommended the substructure units be inspected underwater at intervals not exceeding six years.

21.4.4 IÉ's Scour Interpretation Report

The findings of the three-year programme for the inspection of bridges that were vulnerable to scour were summarised by IÉ in the 'Scour Inspections 2006 Interpretation Report' in order to prioritise the works required for the repair of the effects of scouring.

The results of the scour inspections details structural and riverbed conditions, and identified mitigation works are therefore categorised into substructure and riverbed. Structures with the greatest reported damage due to scour were prioritised for works under the Safety Budget over the following 5 years and those that required maintenance were included under the normal maintenance budget within the same period. The letter S (Scour) or M (Maintenance) was placed beside each of the ratings according to the nature of the repair required. Within these Scour and Maintenance ratings, the structures requiring the most urgent works received an ascending numerical value, with 1 indicating the most urgent.

Malahide Viaduct included in the Maintenance budget and was ranked number 34 out of these structures. Works to be completed were listed as “washed out joints in pier or abutment walls to be repointed depending on the flow of water and missing stones should be replaced and monitored”, as the report stated: “Overall, UB 30 (Malahide Viaduct) was found to be in fair condition. The pier noses had areas of 100% mortar loss and some of the stones were either missing or cracked.”

Works with no major defects or suggested mitigation works were recommended for another inspection in five years time. No documents have been provided to the RAIU that this recommendation of carrying out another inspection for scour on structures has been programmed.

21.4.5 Scour Inspection Programme

Structural Inspections Standard, I-STR-6510 states that Special Inspections can be carried out at any time, at the discretion of the Person Responsible, in the case of Malahide Viaduct, ADE 2. There was no evidence of any assessment in relation to the appropriate frequency of inspections and the Special Inspection frequency was defaulted to the minimum required frequency (i.e. a six-year cycle).

The three-year programme implemented by IÉ was a ‘one-off’ programme. At the time of the accident, scour inspections on the remainder of the bridges, or the conduct of repeat scour inspections on the bridges captured in the three-year programme were not formally scheduled.

The absence of risk assessments as a basis for the compiling of the lists of structures to be inspected has not been addressed and it is not evident, at this stage, whether the ADEs included the appropriate bridges to be inspected.

21.4.6 Scour/ flood management plan

The IRMS implementation reviews and the AD Little review make reference to a scour/ flood management plan.

The IRMS implementation review of 2000 states:

> "*It is noted that scour is the subject of one of the standards that IE's consultants GNC (Gibb, Nifast and Curry & Brown) will be producing. This should address not just the assessment of vulnerability of a structure to scour and its routine examination but also how times of flood are dealt with."*
>
> - IRMS, 2000, A Review of Railway Safety in Ireland – Implementation Review, p 37

It was found that IÉ's consultants GNC did not produce this standard.

The 2001 IRMS implementation recommended that IÉ:

> *"Develop a flood/scour management system to ensure safety of structures at times of flood, including the conditions under which the track must be closed and may be re-opened."* (p 64)

This flood/scour management system was not produced.

In 2006 the AD Little Review acknowledged that the inspections of bridges vulnerable to scour was in its second year of the three-year programme, but highlighted that there was no progress on developing a scour management system, as recommended in the 2001 IRMS implementation review, and again recommended (Recommendation S3) that IÉ:

> *"Develop a flood/ scour management system to ensure safety of structures at times of flood, including the conditions under which the track must be closed and may be re-opened."* (p 85)

This flood/scour management system was not produced, despite being assigned a high priority rating (i.e. action to commence within one month, with a timescale of three months for completion).

The above evidence demonstrates that IÉ were aware of the request for the development of a scour/ flood management plan since 2001, however, no flood/scour management plan was ever produced by IÉ.

As mentioned previously, the RSC hold regular progress tracking meetings to monitor the implementation of recommendations made by the AD Little Review. The RSC confirmed to the RAIU that they do not hold regular progress meetings to monitor the implementation of recommendation made by the IRMS Reviews (these are monitored by IÉ internally).

The RSC provided a letter from the RSC to IÉ's Safety Performance Manager, dated the 9th April 2008 which documented that at that time the RSC considered the Recommendation S3 (i.e. to develop a flood/scour management system) closed "based on the evidence provided" by IÉ at the regular progress tracking meetings.

Part of the evidence provided to the RSC was the Structural Inspections Standard, I-STR-6510, which requires that the inspector, when conducting a Thorough Inspection, carry out a "systematic visual inspection of all elements of a structure, including submerged elements (e.g. bearings and elements susceptible to scour)." It further states that: "Where the inspector considers that elements of a structure may be subject to defects which cannot be determined without special access (e.g. hidden structural elements, scour, steel lamination), then he or she must inform the person responsible for maintaining the asset (Person Responsible)."

I-STR-6510, states that Special Inspection "may also be required" following an incident that may have affected the integrity of the structure (e.g. *bridge strike* or flooding incident). However, there is no formal parameters defining "flood incidents", and therefore the standard does not require a Special Inspection, they are conducted at the discretion of the ADE. I-STR-6510, also does not include *"the conditions under which the track must be closed and may be re-opened"* after flooding.

On the 7th April 2008 IÉ informed the RSC that scour inspections are conducted every six years as set out in I-STR-6510, however, this is not the case, as the inspections are at the discretion of the Person Responsible (i.e. the ADE 2) and that inspections were carried out after flooding incidents, which again is not the case.

IÉ also informed the RSC that they "envisaged that within two years a management system will be in place" for the management of structures vulnerable to scour. However, no documentation was provided to the RSC, at the time, to verify that this management system was in place.

On the closure of this recommendation, by the RSC, IÉ took no further action in producing or adopting a flood/ scour management plan.

Structural Inspections (Continued): Factual and Analysis

This section of the report details the:

- The submission to the RAIU of the East Coast Diving Services Inspection;
- The results of this inspection;
- Analysis of the RAIU findings.

22 Submission of the East Coast Diving Services Inspection to the RAIU – Factual

After the collapse of the Malahide Viaduct on the 21st August 2009, the RAIU requested that IÉ conduct an extensive search for all documentation, including inspections, which refer to the Malahide Viaduct. This search was conducted and the information provided to the RAIU within one month of the accident.

Nearing the completion of the RAIU investigation on the 4th August 2010, IÉ submitted an inspection carried out in 1997 on the Malahide Viaduct, to the RAIU. This document was only found by IÉ on the 30th July 2010 while carrying out a search of CCE offices in Pearse Station.

23 East Coast Diving Services Inspection – Factual

In 1982 a derelict barge, approximately 27m long, was abandoned against the seaward side of the Malahide Viaduct, (see Photograph 17). The barge was lodged against Piers 5, 6, 7, and at certain tides, the barge rubbed against these piers.

Photograph 17 – Derelict barge

In 1997, IÉ were granted permission to remove the barge, and in the same year hired North East Diving Services to remove the barge.

After the removal of the barge, East Coat Diving Services carried out an inspection of the Malahide Viaduct in March 1997. A summary of the inspection findings are as follows:

- The pointing was generally in "okay condition";
- Scouring and undercutting can be "found on a few piers where rock armour and concrete have been washed away";
- "Underwash and undermining of concrete pour due to hole and tidal flow" at Pier 7;
- The inspection diver concludes that the rock armour is "too light for the job it is to do";
- The rock armour grout has diminished by approximately 80% on the west side of the Malahide Viaduct and 70% on the east side;
- Evidence of cracking and *spalling* of the concrete deck;
- "Scouring starting at the base" of Pier 4 (the Pier which collapsed);
- Debris (twisted metal and old railway sleepers) recorded between Piers 4 and 5.

24 Submission of the East Coast Diving Services Inspection to the RAIU – Analysis

The late submission of this report to the RAIU is discussed in the ‘Knowledge Management’ sections of this report as part of this investigation into IÉ’s knowledge management systems.

25 East Coast Diving Services Inspection – Analysis

The inspection results of Malahide Viaduct carried out by North East Diving Services after they removed the derelict barge, highlights that defects of diminishment of the rock armour, scouring and undermining at the Malahide Viaduct.

The inspection found a large number of defects in relation to the condition of the Malahide Viaduct, with signs that by 1997, the rock armour was deteriorating, with some areas of the rock armour being completely depleted.

The inspection diver who carried out the inspection, did not consider that the weir protection to be substantial enough stating “the rock armour itself is in my opinion too light for the job it is to do”, which indicates that further strengthening works to the rock armour was required in order to protect the weir. Also, in direct reference to Pier 4, the report states that scouring had started at the base.

There is no evidence available to the RAIU to suggest that any works were carried out on the weir post inspection, and therefore it can only be assumed that the weir was allowed to degrade further as described in the ‘The Failure Mechanism of Malahide Viaduct’ sections of this report.

Considering that this inspection directly refers to scouring starting at the base of Pier 4, and no works recorded, it is a major concern that IÉ took no remedial actions to carry out any maintenance works.

Competency of Inspectors: Factual and Analysis

This section of the report details:

- Qualification of inspectors;
- Training of inspectors;
- The competence of inspectors;
- Competency management of inspectors;
- Analysis of the RAIU findings.

26 Inspectors Competencies – Factual

The Structural Inspections Standard I-STR-6510 does not define formal qualifications for inspectors, however, inspectors are generally qualified Civil Engineers.

There is also no formal training scheme for Inspectors, but all Engineers complete the 'Civil Engineering and Earthworks Structures: Guidance Notes on Inspections' training course. The purpose of the training course is to:

- Give further knowledge of inspection procedures;
- Describe the type of structures to be inspected;
- Describe the defects typical of these types of structures;
- Give guidance on how to assign condition ratings to structures.

This is a stand-alone training course with no further training of inspectors provided by IÉ.

IÉ have not adopted a competency management system for Engineers carrying out inspectors.

27 Inspector Competencies – Analysis

The Structural Inspection Standard, I-STR-6510, does not define the qualifications or training required by the Inspector position. Competencies are therefore analysed separate from the Structural Inspections Standard.

The inspectors are required to complete the ‘Civil Engineering Earthworks and Structures – Inspection Guidance’ training course, for which the training notes are available to the inspectors. This training course had been designed to be carried out over a three day period. However, the course was subsequently cut to a period of one and a half days, and some elements of the course were skipped or only mentioned, meaning attendees were reliant on the training notes provided. The RAIU has found that the training notes provided to the attendees were “black and white, and in small print”. There was also no practical element to this course, with no on-site training which would have provided the inspectors with practical experience on how to conduct inspections.

The RAIU reviewed the notes provided to the attendees. Under the bridges section of the training notes, one of the main defects identified for masonry bridges is scouring which can undercut the substructure foundations, resulting in instability and, if allowed to continue, collapse of the structure. The training notes also stress the effects of scouring on masonry structures “is exacerbated due to the shallow foundations typical of that type of structure”.

In relation to the inspections carried out where scouring may be an issue, the training recommends that “the inspector should probe the integrity of the foundations to identify any scour holes” and, that if scour is suspected an engineering diving survey should be carried out. The training notes also highlight the need for defect photographs to be taken for the inspection, suggesting that defects should be sketched. The training notes include, by way of example, different condition ratings of scour defects illustrated in photographs (see Figure 27), which are rated between condition ratings 2 to 4.

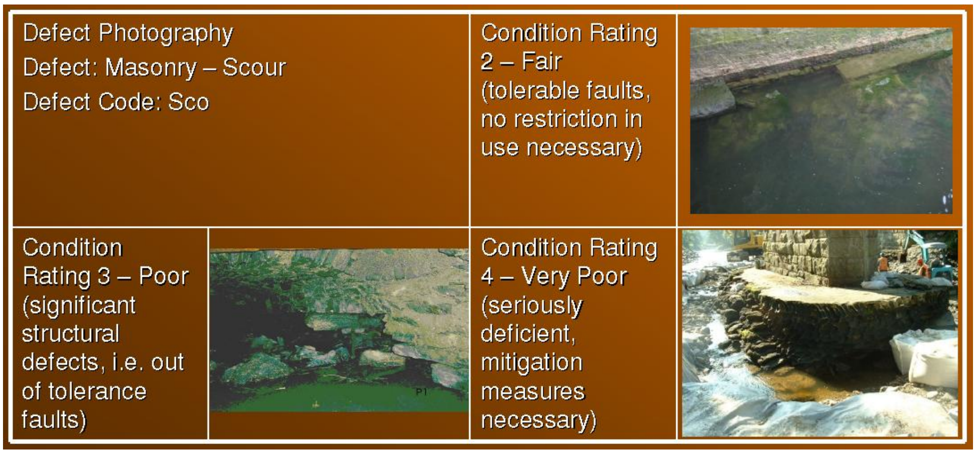


Figure 27 – Defect photography and condition ratings for scour

These condition ratings are defined as follows:

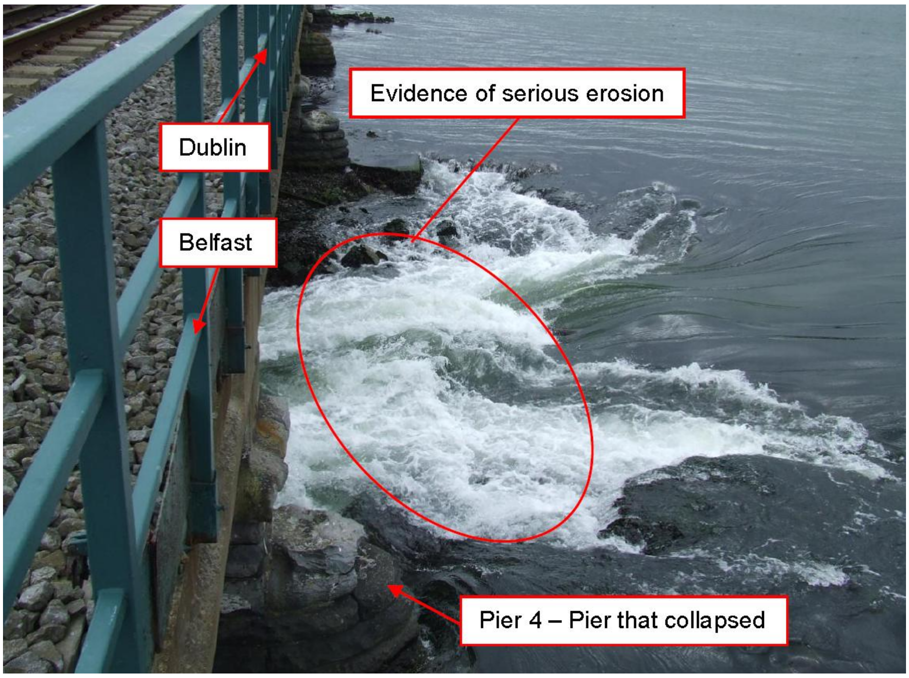
- Condition Rating 2 – evidence of void;
- Condition Rating 3 – debris within area and voids present – requires diving survey;
- Condition Rating 4 – undercut of apron slab - at this location undercut of the slab was suspected and remedial undertaken.

As mentioned above, the training notes were provided to the attendees were in black and white and in small print, therefore, making the scour defect photographs (illustrated in Figure 27) difficult to decipher.

As the training was an abridged version of the intended full course, the RAIU have not been able to establish conclusively whether the section relating to scouring was covered in the amended course, however, attendees on this course do not recall "any in-depth discussion into scour".

The AE who visually examined Pier 4 on the 18th August 2009 was not able to apply any lessons learnt from the training course. Even though the AE was unfamiliar with the structure's construction, he did not recall that, in general, scouring on masonry structures "is exacerbated due to the shallow foundations typical of that type of structure", and incorrectly assumed that the viaduct had a "sound footing".

Reviewing the photograph (Photograph 18) taken by the AE, there is evidence of serious erosion, however, the AE, being unable to recall any information from the training, unable to decipher the training notes provided, and not experiencing any practical element to the training, did not conclude that there was any evidence of scouring at Malahide Viaduct. Reviewing the condition ratings, provided in the training notes, Condition Rating 4 illustrates where undercutting of the rock armour had occurred, similar to the failure mechanism of the collapse of Pier 4.



Photograph 18 – Photograph taken during inspection of Viaduct on the 18th August 2009

Additional structured training or mentoring is not provided to these inspectors after the completion of this course. The RAIU found that the ADEs adopted an informal mentoring system for the new inspectors, where the new inspector would observe the ADE carrying out inspections, the inspector then carries out inspections under the supervision of the ADE; until the ADE is satisfied the inspector is able carry out inspections without the supervision of the ADE. As there was no structured approach to this mentoring system, there would be no consistency in training of inspectors.

Both the AE and SE who carried out the inspection on the 18th August 2009 and the 2007 Ground Level Inspection, respectively, had been mentored by different ADEs which may result in different competency levels for inspectors.

Maintenance: Factual and Analysis

This section of the report details:

- Historic and recent maintenance of the weir and viaduct;
- Analysis of the RAIU findings for the maintenance of the weir and viaduct.

28 Maintenance of the Malahide Viaduct Weir – Factual

28.1 General information

'The Malahide Viaduct' section of this report discussed the original construction of the Malahide Viaduct and all subsequent capital projects. This section of the report reviews the maintenance regime of the Malahide Viaduct and weir.

The RAIU have reviewed all available IÉ documentation in relation to the Malahide Viaduct maintenance regime. This documentation includes internal IÉ correspondence, correspondence with members of the public and contract documentation for maintenance works.

There is no additional information available in relation to maintenance of the Malahide Viaduct *superstructure*, piers or abutments of the capital project apart from the information previously stated in relation to capital projects (i.e. the replacement of the piers).

There is also relatively little information available to the maintenance of the Malahide Viaduct weir, however, as the immediate cause of the collapse of Pier 4 was as a result of the undermining of the remaining grout apron of the weir, the RAIU have reviewed this information in detail.

28.2 Maintenance of the Malahide Viaduct

As discussed previously, in 1846, to overcome the problem of scouring, large stones were placed around the viaduct piers. Stones were then discharged along the viaduct following its initial construction, forming a virtual stone 'weir' over the length of the entire viaduct.

Historic IÉ records show that, as part of the routine maintenance for Malahide Viaduct, large rocks were brought out to the viaduct and discharged around the base of the piers, with IÉ maintenance staff then placing the rocks into their final position using mechanical diggers and by hand.

There was recorded evidence, through engineering articles, of the discharge of stones, in 1922 by GNRI.

In 1957 where IÉ, in correspondence with a local farmer whose land north of the Broadmeadow Estuary, refers to the discharge of stones "carried out as a protection against scour". The farmer is concerned with the levels of water in the Estuary as his land is flooding as a result of the discharge of stones. IÉ initially dispute that the discharge of stones affects the levels of the Broadmeadow Estuary, however, in 1961 IÉ agree to "remove some of the pitching stones from the centres of the spans at Malahide viaduct to the sides of the spans in order to lower the water level" to satisfy the request of the farmer. This work was commence on the 29th May 1961, there is no documentation available to confirm the work was carried out, however, the correspondence with the farmer ceased at this time, and therefore likely that the work was carried out.

In 1965, there is a request from the "Penguin Water-ski Club" who use the Broadmeadow Estuary as an amenity, to discharge stones along the Malahide Viaduct as "the level of water here changes by about 2 feet between high tide levels". IÉ respond by referring to landowner concerns in relation to the levels at the Broadmeadow Estuary. It is not clear from the correspondence how this issue was resolved. However, as previously mentioned there was a recorded discharge of stones by CIÉ, through an engineering article in 1965.

The renewal of the viaduct for a third time in 1965 required, as part of its design criteria, a special requirement for the viaduct handrailing to be easily removed to facilitate the tipping of stone over the side of the viaduct in the event of a section of the weir being scoured away.

A major grouting scheme was undertaken in 1967 – 1968, where concrete was injected into the weir, to protect the weir against scouring, this was proved successful in 1969 when the weir remained intact after major flooding. Further grouting of the weir was undertaken in 1972.

In 1972, IÉ internal correspondence states that IÉ would not carry out any further works on the Malahide Viaduct weir "as it is important that we do not change the level by any grouting we have recently done".

In 1974 "Swords Community Council" contacted IÉ on behalf of the landowners to resolve the issues of the high levels of water at the Broadmeadow Estuary and polluting the land. IÉ investigate and dispute that there is pollution as a result of the Malahide Viaduct and suggest that Swords Community Council seek an independent survey. This correspondence continues into 1976, with no apparent resolution.

In February 1976 internal IÉ correspondence captures a further discharge of stones along the weir "to fill the voids" as "at the moment scouring has taken place".

Between 1982 and 1997 correspondence between IÉ and third parties (such as the Department of Marine, Revenue Commissioners, Fingal County Council) refers to the ownership and removal of a the derelict barge. However in on the 22nd June 1992 the DE notes that the derelict barge is now causing scouring *"This boat is causing severe scouring to the foundations of the bridge and as such constitutes a danger to life and the safe running of the railway."* Correspondence similar to this, in relation to scouring, continues until 1997, when the barge is removed. However, there is no record of any maintenance carried out while this barge is lodged against the Malahide Viaduct until 1995.

In 1995, there is correspondence between the DE and the Malahide Sea Scouts. The Malahide Sea Scouts are concerned about the discharge of stones as their canoeing amenity has been removed as a result of the maintenance works. The DE responds by saying that: “This work is carried out in an effort to protect the viaduct pier from serious scouring due to the wave action associated with tidal movement”. Correspondence, similar to this continued into 1996, as the maintenance works progressed.

There is no documented correspondence, in relation to the discharge of stones after 1996. However, the DE, who was in the East Coast Division until 2002, stated that the decision to discharge the stones along the weir occurred when it became apparent that scouring had occurred, through inspections carried out by the DE, ADE, or the Patrol Gangers, and was not recorded.

The inspection carried out by North East Diving Services, in March 1997, records considerable diminishing of the rock armour, with evidence of scouring and undermining at some pier locations. The inspection diver states that “the rock armour itself is in my opinion too light for the job it is to do”. This report was forwarded to the East Coast Division.

There is no documentation to illustrate whether any repair works were carried out based on the finding of this inspection. The DE cannot recall, with any certainty, whether any action was taken to repair the rock armour on receipt of the inspection report from North East Diving Services.

In 1998, IRMS carried out infrastructure site surveys on structures on the IÉ network. Each surveyed structure was assigned a safety inadequacy rating, measured as a percentage of the maximum score possible – a score of 0% (safe) is considered to be ideal or the target, whereas 5% is considered to be ‘best practice’. A score in excess of 5% indicates a decrease in safety below that of ‘best practice’. While the average safety inadequacy for structures was 33%, IRMS assigned a safety inadequacy score of 40% to the Malahide Viaduct structure. No information is available in relation to the score of 40% and the RAIU was unable to verify how or why this score was awarded.

Since 2002, when the DE left the East Coast Division, there have been two DEs and two ADEs for this Division.

The DEs and ADEs from 2002 to the time of the collapse of the Malahide Viaduct, have confirmed to the RAIU, that they had no knowledge of the requirement to discharge stone along the viaduct or were they aware of any issue of scouring at the Malahide Viaduct.

In 2006, the Scour Inspection carried out by Collins Engineers stated that the piers were in fair condition, with the masonry not in need of timely repair but recommended that their condition be monitored during future inspections. No scouring was identified. The foundations were not established.

28.3 Summary of inspection and maintenance events

Table 3 below, summarises the maintenance events, including the key capital project and inspection events, in relation to the Malahide Viaduct:

Malahide Viaduct capital projects, maintenance and inspection events	
Year	**Event**
1844	The original Malahide Viaduct, constructed as an eleven *span* timber structure supported on ten timber piles driven into the bed of the estuary.
1844 – 1860	In the early years of construction, stones were discharged along the line forming a virtual stone *'weir'* over the length of the entire viaduct which reduced the flow of water in and out of the estuary by maintaining a constant water level at all states of tide to reduce the effect of scouring. Stones were continued to be discharged under the viaduct to maintain the weir for sixteen years until it was necessary to replace the viaduct.
1846	In 1846, to overcome the problem of scouring, due to the large volumes of water flowing into and out of the Broadmeadow Estuary, large stones were placed around the viaduct piers.
1860	The viaduct was replaced by wrought iron *lattice girder beams* supported by eleven masonry piers founded on two stone fill foundation courses, constructed on the weir.
1922	GNRI records show that 5,730 tons being discharged along the viaduct in 1922.
1965	Renewal of the viaduct with precast post-tensioned concrete beams place on the existing stone piers. The availability to discharge stones from the viaduct was a special requirement for the new Malahide Viaduct design.
1965	CIÉ discharged 2,000 tons from CIÉ wagons after a storm in 1965. IÉ continued to discharge stones onto the weir as part of the routine maintenance until 1996.
1967 – 1968	A major grouting scheme was undertaken in 1967 – 1968, where concrete was injected into the weir (which had been estimated to have 40% voids in the stone fill) in order to stabilise the weir.
1969	The stabilisation by the grout apron was proved successful by the absence of observed scouring or potholing after the storms in February 1969.
1972 – 1973	Additional grouting in between piers, as a result of the weir being washed away by high tides.
1976	Internal IÉ correspondence indicates that a discharge of stones has occurred at the Malahide Viaduct to fill the voids caused by scouring.
1982 – 1997	A derelict barge is abandoned and rests against the viaduct. The DE at the time notes that the barge is causing severe scouring until its eventual removal in 1997.
1996	The last known discharge of stones along the Malahide Viaduct.
1997	North East Diving Services carry out an inspection of the Malahide Viaduct, noting there is evidence of scouring, undermining and deterioration of the rock armour.

1998	IRMS assigned a safety inadequacy score of 40% to the Malahide Viaduct structure.
2005	Ground Level Inspection requests painting of the Malahide Viaduct handrailing. (The inspection also requests a check for scour).
2006	The 2006 scour inspection stated that the piers were in fair condition, with the masonry not in need of timely repair but recommended that their condition be monitored during future inspections. No scouring was identified.
2007	Ground Level Inspection repeats request for painting of the Malahide Viaduct handrailing.
2009	A reported defect from a member of the public results in an inspection by an AE, who does not observe any evidence of scouring.

29 Maintenance of Malahide Viaduct – Analysis

Historical data indicates that the Malahide Viaduct has been susceptible to the defect of scouring since its original construction in 1844, the RAIU have reviewed correspondence in which IÉ directly refers to this issue of scouring in 1957, 1972, 1992, 1995, 1996 and 1997. The correspondence was in relation to IÉ's response to third party complaints about the level of water at the Broadmeadow Estuary, with some third parties wanting the levels of the water to remain high for leiasure purposes and other third parties wanting the level of the water to remain low to prevent flooding of the adjacent land.

In 1967, there was a major grouting programme commenced, with further grouting in 1972. It is understood, by the RAIU, from correspondence in relation to this programme that IÉ considered this programme to be a success, with no recorded discharge of stones until 1976.

In 1982, when the derelict barge was lodged against the Malahide Viaduct, there was no initial concern in relation to the degradation of the weir. However, from 1992 until the barges eventual removal in 1997, the DEs concern in relation to scouring is apparent. This may have resulted in the recorded discharge of stones in 1996, prior to the barge being removed. This is the last recorded discharge of stones along the Malahide Viaduct. However, the DE at this time stated that there may have been further discharges of stones while he was in the Division (until 2002).

In 1997, East Coast Diving Services carried out an inspection of the Malahide Viaduct after the removal of the barge, recording that the rock armour has diminished, with approximately 20% of the rock armour remaining. Considering, stones were discharged one year previous, this indicates removal of materials at the Malahide Viaduct.

There is no record of any maintenance carried out as a result of the findings of this report. However, the condition rating of 40% (best practice is 5%) awarded to the Malahide Viaduct by IRMS in 1998, suggests either:

- Repair works were carried out in 1997 and deteriorated by the time the IRMS inspection was carried out in 1998;
- No repair works were carried out.

In 2006, when Collins Engineers carried out a Scour Inspection at Malahide Viaduct, the previous DE and ADE had left the Division. And as the present DE and ADE were unaware of any scouring or scouring issues at the Malahide Viaduct, when the results for the inspection were returned to IÉ with no record of any scouring having taken place, the DE and ADE assumed that the Malahide Viaduct was not susceptible to scour and therefore took no additional measures to address scouring at the Viaduct.

IÉ had not requested Collins Engineers to establish the foundation depths for the Malahide Viaduct. Had IÉ requested this to be carried out the importance of the weir and the consequences of its degradation would have been established.

Therefore, with the inspection not highlighting any requirement to monitor scouring at the viaduct and no recorded discharges of stones along the Malahide Viaduct from 1996 onwards, the rock armour and weir continued to deteriorate, as described in 'The Failure Mechanism of Malahide Viaduct' sections of this report, until Pier 4 was eventually undermined and collapsed.

Knowledge Management: Factual and Analysis

This section of the report details:

- Knowledge management for inspections;
- Knowledge management for maintenance;
- Analysis of the knowledge management systems.

30 Knowledge management – Factual

30.1 General information

Through IÉ's history, there have been informal and formal knowledge management systems for the sharing of company knowledge through individuals, Divisions and the company.

Historically, IÉ's knowledge was passed from individual to individual through word of mouth and written documentation. More recently, IÉ developed an electronic information asset management system, IAMS.

This section of the report will review IÉ's systems for retaining information in relation to the Malahide Viaduct.

30.2 Knowledge management

30.2.1 Structural knowledge

In relation to the Malahide Viaduct, IÉ provided the RAIU with construction drawings for the Malahide Viaduct, these included the construction drawings for the viaduct renewal in 1965 (with no foundation drawings) and the grouting works carried out in 1967. These drawings were archived by IÉ and therefore not immediately available to Engineers within the Division.

Further information in relation to the construction of Malahide Viaduct and other capital projects was not archived by IÉ. The information retrieved to aid the investigation, post accident, were articles published by engineering organisations.

In January 2005, when IAMS, the asset database, was introduced there was a view to the uploading of civil asset information (including historic documents) into the system for future use, this had not occurred.

In specific relation to the scouring issue at Malahide Viaduct, it is evident from the RAIU investigation, that the fact that the Malahide Viaduct weir was prone to scouring was known by former IÉ staff members, as it has been recorded in IÉ correspondence with third parties (i.e. Penguin Water-ski Club, a local farmer, Department of Marine) as discussed previously. This knowledge in relation to the scouring appears to continue until 2002, until the Person Responsible for the Malahide Viaduct left the Division.

The Persons Responsible for the Malahide Viaduct at the time of the accident (the DE for the Division and ADE 2) were not aware of any issue of scouring at Malahide Viaduct. Nor were they aware of the necessity to continuous maintain the weir (through discharging stones along the weir) in order to uphold its structural integrity of the viaduct.

30.2.2 Inspections knowledge

Historically, upon completion of bridge inspections, inspectors completed Bridge Inspection Cards for the Ground Level, Thorough or Special Inspections and filed these Bridge Inspection Cards in the Divisional offices, this was not a formal system.

When IAMS was introduced it was intended to upload Bridge Inspection Cards onto the system for future use. However, no standard has been adopted for the updating of information on IAMS, or assigning responsibilities for uploading of these inspections. This had not occurred, for the Malahide Viaduct, the RAIU found that limited information in relation to Malahide Viaduct had been uploaded with only the bridge number and bridge mileage being recorded.

The East Coast Diving Services inspection, carried out in 1997, was fortuitously found as a consequence of cleaning out an office at Pearse Station, and had not been filed with the other Bridge Inspection Cards. It should be noted that IÉ carried out an extensive search of documents after the accident, and the East Coast Diving Services inspection had not been discovered at that time.

30.2.3 Maintenance knowledge

The RAIU in have received no formal documentation in relation to maintenance works carried out on the Malahide Viaduct. All information provided to the RAIU in relation to maintenance works has been as a consequence of IÉ correspondence with third parties, with the exception of some tender documents in relation to the grouting in 1967 – 1972.

The process for recording maintenance works to civil assets is also not formally defined in any of IÉ standards.

Again, as in the case for inspections, no standard has been adopted for the updating of maintenance information of correspondence on IAMS, or assigning responsibilities for uploading of the details of maintenance works.

30.3 Knowledge sharing

As previously mentioned, there are no responsibilities assigned for the uploading of information onto IAMS. There is also no formal process for sharing information when staff members leave the Division. Knowledge in relation to works carried out in companies, is sometimes referred to as *corporate* *memory,* which refers to knowledge and information from the company's past which can be accessed and used for present and future company activities.

31 Knowledge management – Analysis

31.1 Structural knowledge management

As no construction drawings were readily available to Engineers in relation to the Malahide Viaducts foundations, IÉ Engineers did not know that the masonry piers were supported by the weir and therefore the weir was pertinent to the structural integrity of the Malahide Viaduct. The Engineers had assumed, incorrectly, that the piers were formed on bedrock.

The Engineers, at the time of the accident, were also not aware of the design requirement that had been introduced in 1965 for the handrailing to be removed to facilitate the discharge of stones along the weir.

This information was not available through IAMS, which may have alerted Engineers to the construction of the Malahide Viaduct and the maintenance regime that had been adopted.

In specific relation to the scouring issue at Malahide Viaduct, it is evident from the RAIU investigation, that the knowledge that the Malahide Viaduct weir was prone to scouring was known by former IÉ staff members (as it has been recorded in IÉ correspondence with third parties – Penguin Water-ski Club, a local farmer, Department of Marine). This knowledge is part of IÉ's corporate memory.

Whatever method this corporate memory had been forwarded in the past, it appears that when Persons Responsible for the Malahide Viaduct left the Division in 2002 they took this corporate memory with them. And with no system in place to capture it, and no asset information management system, this information was inaccessible to the next Persons Responsible.

The information in relation to the Malahide Viaduct was therefore lost and resulted in the Persons Responsible at the time of the accident not carrying out any maintenance works to the weir in order to uphold its structural integrity of the Malahide Viaduct piers.

31.2 Bridge Inspection Cards document management

Bridge Inspection Cards (from Ground Level Inspections and Thorough Inspection) for inspections carried out on the Malahide Viaduct were stored in the East Coast Division offices, and were available to Engineers carrying out inspections on Malahide Viaduct. From the Bridge Inspection Cards provided to the RAIU there is little information available here that would have indicated to Engineers that there was an issue of scouring at the Malahide Viaduct.

The fact that the East Coast Diving Services Report (1997) was fortuitously located almost one year after the accident occurred, after IÉ had apparently carried out an extensive search after the accident in August 2009, further emphases the inadequacy of the document system. This finding also raises questions in relation to other documentation that may exist, but cannot be located due to the condition of IÉ's document management system.

Had this information been located, prior to the accident, and uploaded onto IAMS the Engineers again would have been made aware of the issue of scouring at the Malahide Viaduct. However, with only limited information, Engineers did not utilise IAMS to its full potential. As mentioned previously, only limited information was uploaded onto IAMS in relation to the Malahide Viaduct.

31.3 Maintenance document management

As there is an absence of information in relation to the formal recording of maintenance of the Malahide Viaduct, Engineers again were unaware of the requirement to discharge stones along the weir. The only information available to the RAIU, in relation to the maintenance that was carried out at the viaduct, is as a consequence of IÉ correspondence with third parties.

This highlights IÉs lack of any requirement to record any maintenance works carried out on civil assets, and therefore for the passing of corporate memory in relation to maintenance is reliant on individuals verbally passing this information onto new staff. However, there is some doubt that this occurred either, as the Persons Responsible for the Malahide Viaduct were completely unaware of the maintenance regime that had been adopted for the prevention of scouring at the Malahide Viaduct.

As above, the correspondence in relation to maintenance at the Malahide Viaduct was not uploaded on IAMS and again Engineers were not therefore made aware of any maintenance regimes carried out at the structure.

31.4 Knowledge sharing

The technical asset database system, IAMS, had only limited information in relation to Malahide Viaduct, with the bridge number and bridge mileage only being recorded. No records of any inspections, maintenance works or correspondence in relation to the Malahide Viaduct was uploaded onto the system.

As there was no formal requirement for Engineers to upload information on IAMS and with so little information recorded on IAMS, Engineers did not reference this database for inspection or maintenance purposes nor did they upload any works they themselves had carried out. This illustrates a reluctance of IÉ to adopt IAMS, even though it has been available for use since 2005.

Had IAMS been adopted successfully, all information in relation to the Malahide Viaduct would have been uploaded, and the Persons Responsible for the Malahide Viaduct would have been made aware of the issue of scouring and may have carried out the appropriate maintenance requirements to maintain the structural integrity of the Malahide Viaduct. This would have also eliminated the more informal method of sharing corporate memory verbally.

Roles of the RSC: Factual and Analysis

This section of the report details:

- The role of the RSC in relation to tracking recommendations;
- The role of the RSC in auditing and monitoring IÉ's safety case.

32 Role of the RSC – Factual

32.1 Tracking recommendations

As mentioned previously, the RSC hold regular tracking meetings to monitor the implementation of recommendations made by the AD Little Review (2006).

The RSC do not hold regular tracking meetings to monitor the implementation of recommendations made by the IRMS Reviews (1998, 2000, and 2001).

32.2 Auditing and monitoring IÉ's Safety Case by the RSC

The RSC were aware of their duty to audit and monitor IÉ's Safety Case. The RSC's 2008 Annual Report states that new additional resources, recruited in 2008, would enable the RSC to implement a comprehensive audit and monitoring programme in relation to IÉ's Safety Case.

33 Roles of the RSC - Analysis

33.1 Tracking safety recommendations

The RSC hold regular progress tracking meetings to monitor the implementation of recommendations made by the AD Little Review. As discussed previously, the RAIU discovered that the RSC closed Recommendation S3 (for the reasons discussed in Section 21.4.6), made in the AD Little Review in relation to the development of a flood/scour management system by IÉ which may have contributed to IÉ not formulating this flood/ scour management plan.

The RSC have confirmed to the RAIU that they do not hold regular progress meetings to monitor the implementation of recommendation made by the IRMS Reviews (1998, 2000, and 2001) as the IRMS Review was commissioned by the DoT, and therefore understood by the RSC that these recommendations would continue to be tracked by the DoT.

The DoT have confirmed to the RAIU that the tracking of safety recommendations made by the IRMS Reviews (1998, 2000, 2001) was carried out by the DoT until 2005. However, after the establishment of the RSC this task of tracking of recommendations would have been included in the transferring of all administration and business to the RSC.

When the RSC commissioned the AD Little Review, it was understood by the RSC that the IRMS Review recommendations were now superseded as AD Little did review the IRMS reviews as part of its own review. Based on this assumption, the RSC did not carry out any recommendation tracking meetings in relation to the recommendations made in IRMS after the AD Little Review was published.

However, IÉ do not believe that the AD Little Review recommendations encompasses all the recommendations made by the IRMS Reviews, and therefore IÉ continue to action and close the recommendations made by the IRMS Reviews. At the time of the accident, of the 286 recommendation made to IÉ in the IRMS Review (2001), 80 of these recommendations remained open.

33.2 Auditing and monitoring IÉ's Safety Case by the RSC

The RSC has confirmed to the RAIU that there was no audit and monitoring programme planned in 2009 for IÉ's bridge inspection and maintenance processes as the basis for selecting areas to audit is on accident/incident trends, statistical analysis, engineering judgement and experience, representations and known areas of risk.

Conclusions and Recommendations

This section of the report details:

- The conclusions made by the RAIU in relation to the investigation;
- The safety recommendations[7] made by the RAIU as a result of these conclusions.

[7] Recommendations shall be addressed to the safety authority and, where needed by reason of the character of the recommendation, to other bodies or authorities in the Member State or to other Member States. Member States and their safety authorities shall take the necessary measures to ensure that the safety recommendations issued by the investigating bodies are duly taken into consideration, and, where appropriate, acted upon. (Railway Safety Directive, 2004/49/EC)

34 Failure Mechanism of the Viaduct

The **immediate cause** of the collapse of Pier 4 was as a result of the undermining of the remaining grout apron (constructed in 1967 – 1972) that surrounds and supports Pier 4 through the action of piping (scour).

Contributory factors to the failure of the Malahide Viaduct resulted from:

- The long term gradual elongation of the weir in the ebb tide direction (eastwards);
- The medium term degradation of and partial removal of the 1.5m thick layer of grout that extends 1.5m in the flood tide direction (westwards) and 6.1m in the ebb tide direction (eastwards). The gradual elongation process, through erosion, implies a general lowering of the entire weir crest profile. The propagation of scour to the grouted rock armour weir continued in a westerly direction and was concentrated in between Piers 3 – 5. More especially the losses were most severe in between Piers 4 and 5. The concentration of flow in this area resulted in a positive feedback mechanism that increased scour depth and allowed further propagation of the hydraulic jump in a headward direction (westwards);
- The short term propagation of the hydraulic jump, resulting in substantial removal of the grouted and non-grouted rock armour weir material in between Pier 4 and Pier 5 which resulted in the hydraulic jump migrating to a position westward (upstream under ebb flow conditions) of the bridge piers. This would also have progressively exposed the foundation material beneath Pier 4 forming the piping action that occurred under the remaining weir apron.

35 Track Inspections – Conclusion

35.1 Track patrolling inspections

The track section which included the Malahide Viaduct was not patrolled in the eleven days prior to the accident (which is normally patrolled three times a week) as no relief Patrol Ganger had been assigned patrolling duties by Division 5, which includes the Malahide Viaduct, when the designated Patrol Ganger for the area was on annual leave. Confusion arose about assigning relief patrol gangers as there was an overlap in the designated Patrol Ganger's patrol length over Divisions 1 and 5, which meant two patrol gangers from the two Divisions should have been assigned to ensure the entire patrol length was inspected.

As a result the RAIU make the following safety recommendation:

> **Recommendation 1**
> IÉ should put appropriate interface processes in place to ensure that when designated track patrolling staff (who report to two or more divisional areas) are absent from their patrolling duties, that appropriate relief track patrolling staff are assigned to perform these patrolling duties.

On review of the still photographs from the TRV inspection which was carried out the day before the accident (20th August 2009) there is some doubt that the Patrol Ganger would have identified any precursors to the failure of the viaduct from a track level inspection. The RAIU therefore concludes that the absence of track patrolling, in this case, was **not contributory** to the accident.

The requirement of the Track Patrolling Standard, I-PWY-1307, for patrol gangers to "check underneath for scour at least once a year" was not carried out by the patrol gangers. Patrol gangers carry out inspections at track level and therefore have no access under the structure to carry out these checks, in addition, they did not have the required specialist training/ skills to identify defects caused by scouring. As a result of these findings, the RAIU concludes that this requirement for checking for scour by the patrol gangers was an unrealistic requirement which may have been a **contributory factor** to the accident. Therefore the RAIU make the following safety recommendation:

> **Recommendation 2**
> IÉ should amend the Track Patrolling Standard, I-PWY-1307, to remove the requirement for track patrollers to carry out annual checks for scour.

See Recommendation 7 for a further recommendation in relation in relation to scour inspections.

35.2 Track Recording Vehicle inspection

The last run over the viaduct was the 20th August 2009, the day before the collapse, for which it recorded the track to be in a good condition. It should be noted that the TRV inspections relate mainly to track geometry and it is likely that only severe track geometry changes would alert staff to any faults with the viaduct structure. Therefore the RAIU concludes that there are **no contributory factors** identified which may have alerted TRV staff to the accident at the time of the TRV inspection.

36 Structural Inspections Standards – Conclusion

Structural Inspection Standard, I-STR-6510, states that the ‘Civil Engineering and Earthworks Structures: Guidance Notes on Inspections Standard’, I-STR-6515, which provides guidance on procedures for inspections and identification of defects, must be read in conjunction with I-STR-6510.

However, in the course of this investigation, IÉ has confirmed that standard I-STR-6515, due to be adopted at the time as I-STR-6510, was not developed. This resulted in the Engineers not having the complete suite of Structural Inspections Standards to carry out inspection to the required specifications. This finding may have been a **contributory factor** in the inspector’s lack of ability to identify any scouring defects at the Malahide Viaduct and therefore the RAIU make the following safety recommendation:

> **Recommendation 3**
> IÉ should formalise their ‘Civil Engineering and Earthworks Structures: Guidance Notes on Inspections Standard’, I-STR-6515, which should include guidance for inspectors on conducting inspections and identifying structural defects. On formalising this document IÉ should re-issue, in the appropriate format, to all relevant personnel.

37 Types of inspections

37.1 Inspections carried out prior to the introduction of the Structural Inspection Standard

The requirements of MW41, Maintenance of Bridges, were not met in full, in that the required two-yearly inspections were not always carried out, which might have been as a result of the DEs and ADEs unfamiliarity with the document. Given that this document had been superseded at the time of the accident by Structural Inspections Standard, I-STR-6510, these findings are therefore **not an underlying factor** to the accident.

37.2 Ground Level Inspections

The Structural Inspections Standard, I-STR-6510, implemented with effect from in 5th July 2005, has conflicting requirements for the frequency of inspections, however, IÉ have adopted that Ground Level Inspections to be conducted on a two-year cycle. Bridge Inspection Cards have been submitted to the RAIU, which confirms these inspections were carried out at the required two-year cycle frequency since the introduction of this standard (with Bridge Inspection Cards available for 2005 and 2007).

The requirements of I-STR-6510 for Ground Level Inspections were not meet in their entirely in that:

- A visual inspection of all elements of the structure was not carried out;
- Bridge Inspection Cards were not completed in full;
- Bridge Inspection Cards were not approved by the Person Responsible (ADE 2).

This lack of approval of the Bridge Inspection Card by ADE 2, which is a formal requirement of I-STR-6510, was replaced with informal approach, where Inspectors “highlighted” any issues to ADE 2 in relation to the “major issues” arising from the inspections. This informal approach, may also led to a less formal approach to the carrying out inspections as there was no formal verification by ADE 2 that the inspections were being carried out. With inspections only forming part of the Engineers day-to-day duties the Engineers appear to be under no obligation to conduct inspection to the full requirements of the Structural Inspection Standard, I-STR-6510. This may have been a **contributory factor** resulting in the dearth of information provided on the Bridge Inspection Cards as there was no verification by ADE 2 on the quality of these Bridge Inspection Cards. Therefore the RAIU make the following safety recommendation:

Recommendation 4

IÉ should introduce a verification process to ensure that all requirements of their Structural Inspections Standard, I-STR-6510, are carried out in full.

The SE also entered details on the superseded, old format, Bridge Inspection Card (i.e. a request for the check of scour and a further request for the examination of the piers). This was also found to be the case for the 2005 Ground Level Inspection, where the Engineer also, did not adopt the new Bridge Inspection Card (which was introduced two weeks previous to the inspection).

This continued use of the old Bridge Inspection Card and the lack of compliance with the requirements of I-STR-6510, demonstrates the reluctance to move to the new Bridge Inspection Card system and the requirements of I-STR-6510. This gives the indication that the standard was introduced with little thought for the effect it would have on the day to day operations of the division. These findings concur with one of findings of the AD Little Review which states: *“All Divisions appear to be still operating the old ‘bridge card’ system and are not fully engaged with the new standard and its contents.”*

Therefore the RAIU make the following safety recommendation:

Recommendation 5

Iarnród Éireann should ensure that a system is put in place for effective implementation of existing standards and to manage the timely introduction of new and revised standards.

37.3 Thorough Inspections

The RAIU has found no record of a Thorough Inspection being carried out on Malahide Viaduct since the introduction of the Structural Inspections Standard, I-STR-6510, in 2005. There are conflicting frequency requirement in the standard, however, IÉ appear to have adopted a six-yearly frequency. It should be noted that a Special Inspection, similar to the 2006 Scour Inspection carried out by Collins Engineers, may form part of a Thorough Inspection but does not substitute the requirement for an extensive inspection of all elements of the structure, as the Thorough Inspection specifies.

A formal Thorough Inspection Programme has not been submitted to the RAIU suggesting that this programme was not in place at the time of the accident. A recommendation made to IÉ in July 2006 by the AD Little Review, called for IÉ to *"ensure that a programme of 'Thorough Inspections' is started immediately".* Despite the recommendation being awarded a high priority ranking, indicating the necessity to close this recommendation by November 2006 IÉ did not effectively action this recommendation, and it remained open by the RSC (who track the progress of recommendations) at the time of the accident.

In addition, given the high workload on the AE and ADE 2 to carry out inspections, (approximately 800 each per year), and considering these inspections only form part of their day-to-day duties, there is some doubt that the resourcing provided for structural inspections is adequate, which may have been an **underlying factor** in relation to the lack of Thorough Inspections carried out on Malahide Viaduct. Therefore the RAIU make the following safety recommendation:

> **Recommendation 6**
> IÉ should ensure that a programme of structural inspections is started immediately in accordance with their Standard for Structural Inspection, I-STR-6510, and ensure that adequate resources are available to undertake these inspections.

37.4 Special Inspections

37.4.1 Identification of structures susceptible to scour

A formal six-yearly programme for Special Inspections for structures vulnerable to scour was not established as per the Structural Inspections Standard, I-STR-6510. In its place, the New Works Department led the 'one-off' three-year programme for the inspection of structures vulnerable to scour, with the ADEs from the Divisions providing lists of structures vulnerable to scour. It was found during the course of this investigation that ADEs from different Divisions took different approaches to identifying the structures, with no evidence of any risk assessments being carried out in order to compile this list. There is also no evidence on why particular structures were left off this list. However, a Scour Inspection was carried out on Malahide Viaduct in 2006, which did not identify any evidence of scouring, however, it did highlight that the structure was vulnerable to scour. This inspection did not establish the foundations of the Malahide Viaduct, which may have been a **contributory factor** to IÉ taking no further action in relation to inspections at Malahide Viaduct, as had the foundations been established IÉ would have discovered that the masonry piers were formed on the weir and therefore the importance of the weir maintenance may have been recognised, thus awarding the Malahide Viaduct with a higher risk ranking in relation to vulnerability to scouring.

As a result of the conclusions above, the RAIU make the following safety recommendation:

> **Recommendation 7**
> IÉ should carry out inspections for all bridges subject to the passage of water for their vulnerability to scour, and where possible identify the bridge foundations. A risk-based management system should then be adopted for the routine examination of these vulnerable structures.

37.4.2 Flood / scour management plan

No flood/ scour management plan had been developed by IÉ at the time of the accident despite the IRMS Implementation Review (2001) and the AD Little Review (2006) recommending *"Develop a flood/scour management system to ensure safety of structures at times of flood, including the conditions under which the track must be closed and may be re-opened."* Contributory to IÉ not developing this flood/scour management plan was the fact that the RSC closed this recommendation in 2008.

As a result of the non-implementation of a flood/scour management plan there existed no risk-based approach to the management of flood and scour risk to railway structures. Therefore the RAIU make the following safety recommendation:

> **Recommendation 8**
> IÉ should develop a documented risk-based approach for flood and scour risk to railway structures through:
>
> - Monitoring of scour risk at sites through scour depth estimation, debris and hydraulic loading checks, and visual and underwater examination;
> - Provision of physical scour / flood protection for structures at high risk;
> - Imposing of line closures during periods of high water levels where effective physical protection is not in place.

37.5 Inspections after reported structural defects from members of the public – Conclusion

No formal system is in place for conducting structural inspections after a report from the public. There is no information available to IÉ inspectors in relation to the type of inspection to be conducted in the instance where a member of the public reports a structural defect. In the case of the inspection carried out on the 18th August 2009 the inspector did carry out an extensive visual inspection of the structure, but did not follow a formal process, as there was no formal process adopted by IÉ to deal with reported structural defects from members of the public. Therefore the RAIU make the following safety recommendation:

> **Recommendation 9**
> IÉ should adopt a formal process for conducting structural inspections in the case of a report of a structural defect from a member of the public.

38 Structural Inspections (Continued) – Conclusion

The East Coast Diving Services inspection carried out in 1997 highlighted the deterioration of the rock armour at the Malahide Viaduct, and estimated that only 20% of the rock armour remained, concluding that the rock armour was “too light for the job it is to do”. The diving inspector also noted that there was considerable scouring and undermining occurring at the Malahide Viaduct in 1997, and specifically refers to scouring starting at Pier 4. It is difficult to determine what action IÉ took on receipt of this inspection report, however, with no records of any maintenance works, or any discharges of stones after 1996, it is likely that IÉ took no actions as a result of the findings of this inspection, this therefore this would have been a **contributory factor** in the continued deterioration of the weir and the eventual collapse of Pier 4. **See Recommendation 7.**

39 Competencies of inspectors – Conclusion

On the 18th August 2009, an AE in Division 5 (who reports to ADE 2) carried out an inspection on the Malahide Viaduct after a report of “erosion at the base of the pillars” from a Malahide Sea Scouts group leader. The AE carried out a detailed visual inspection of the Malahide Viaduct, carrying out the inspection from the track and sea levels. From the photographs taken by the AE it is evident that the AE saw the evidence of scouring, however, the AE did not have the appropriate training or experience to identify this evidence of scouring.

The investigation found that the training course for inspectors, ‘Civil Engineering Earthworks and Structures – Inspection Guidance Training Notes’ was not completed in the format intended as it was abridged, and the RAIU have not been able to establish whether the section relating to scouring was covered in detail. It is, therefore, not clear if the inspectors gained the knowledge required to become an inspector.

This training course, when completed in full, ensures that the engineers carrying out these inspections have an appreciation and knowledge of the defects in structures. This training does not provide the experience that should be gained by engineers through carrying out the inspections under supervision. This is particularly important for inspectors that have no prior experience of carrying out inspections or are not familiar with IÉ structures.

The lack of a formal mentoring programme for inspectors on completion of this course also means there is a lack of consistency with the competencies of the inspectors is provided to these inspectors after the completion of this course. With the absence of a formal training and mentoring system, consistency on the training and mentoring is not assured for different ADEs. Therefore the RAIU make the following safety recommendation:

Recommendation 10
IÉ should introduce a training, assessment and competency management system in relation to the training of structural inspectors, which includes a mentoring scheme for engineers to gain the appropriate training and experience required to carry out inspections.

40 Maintenance of Malahide Viaduct – Conclusion

The dearth of documents available to the current DE and ADE meant they were not fully aware of the construction of the Malahide Viaduct, and incorrectly assumed that the structure was founded on bedrock.

The DE and ADE, at the time of the accident, were unaware of the routine discharge of stones along the viaduct as this process was not formally recorded, and there was an apparent loss of corporate memory of knowledge from former DEs and ADEs.

The lack of recording of maintenance and the loss of corporate memory was a **contributory factor** into why the current DE and ADE were unaware of the issue of scouring at the Malahide Viaduct and therefore were not carrying the required scouring maintenance works or inspecting for scour. Had these maintenance regimes been formalised and available to the current DE and ADE, the issue of scour and the requirement to maintain the weir would have been available to IÉ staff.

The lack of discharging the stones was a **contributory factor** to the deterioration of the weir. This discharge of stones was not recorded formally through any IÉ information management system, therefore the RAIU make the following safety recommendation:

> **Recommendation 11**
> IÉ should review their network for historic maintenance regimes and record this information in their information asset management system. For any future maintenance regimes introduced on the network, Iarnród Éireann should also record this information in their information asset management system.

41 Knowledge management – Conclusion

41.1 Structural knowledge management

As there was little documentation available to the Engineers who carried out Structural Inspections, the Engineers had very little information in relation to the construction of Malahide Viaduct and therefore incorrectly assumed that the piers were formed on bedrock.

In an effort to record information, IÉ introduced IAMS in 2005. During the course of the investigation, it was found that IAMS was continually not used by Engineers. This reluctance to use IAMS maybe have been the result of no formalised procedure for the requirement to upload information post inspection, and the high workload of the Engineers who may not have had the spare time to carry out this additional duty.

41.2 Inspections knowledge management

There is a dearth of historic data in relation to the Malahide Viaduct, which results from the lack of a formal process for the filing of records within IÉ. The finding of the East Coast Diving Services inspection, almost one year after IÉ had carried out an extensive search for all documents relating to Malahide Viaduct, reinforces the poor quality document management system adopted by IÉ.

The technical asset database system, IAMS, was not used to its full potential, with only limited information being recorded on the database. The lack of clarity in relation to who was responsible for inputting the data may have led to a situation where little information was recorded in the database. Therefore the RAIU make the following safety recommendation:

> **Recommendation 12**
> IÉ should incorporate into their existing standards the requirement for the input of asset information into the technical database system upon completion of structural inspections.

Had IAMS been adopted successfully the East Coast Diving Services inspection carried out in 1997, which referred directly to scouring at Pier 4, would have been available to the Persons Responsible and would have highlighted the issue of scouring and the deterioration of the weir. **See Recommendation 13.**

41.3 Maintenance document management

No information was made available to the RAIU in relation to the formal recording of maintenance of the Malahide Viaduct. The information retrieved by IÉ and provided to the RAIU relating to the discharge of stones along the viaduct is only a consequence of complaints being made by members of the public in relation to the discharge of stones resulting in changing levels of the Broadmeadow Estuary.

As above, IAMS had only limited information and no information in relation to maintenance at the viaduct, which may have highlighted the issue of scouring at the Malahide Viaduct. Therefore the RAIU make the following safety recommendation:

> **Recommendation 13**
> IÉ should carry out an audit of their filed and archived documents, in relation to structural assets, and input this information into their information asset management system.

This recommendation would avoid the more unreliable informal verbal handover of information by word of mouth, as all documentation would be available to the Persons Responsible.

42 Role of the RSC – Conclusion

42.1 Tracking recommendations

The recommendation made by AD Little (2006) was closed by the RSC on the 9th April 2008 based on Structural Inspections Standard, I-STR-6510, and other information provided by IÉ. On the closure of this recommendation by the RSC, IÉ took no further action to adopt a flood /scour management plan.

> **Recommendation 14**
> The RSC should review their process for the closing of recommendations made to IÉ by independent bodies, ensuring that they have the required evidence to close these recommendations. Based on this process the RSC should also confirm that all previously closed recommendations satisfy this new process.

It must be also noted that this recommendation was ranked a high priority rating (i.e. action to commence within one month, with a timescale of three months for completion). However, at the time of the accident (three years after the issue of the review), of the 58 recommendation made to IÉ in the AD Little Review, the RSC had closed 46 of these recommendations, with 12 remaining *complete* or open.

The RSC were not carrying out regular recommendation tracking meeting with IÉ in relation to recommendations made by the IRMS Reviews (1998, 2000, 2001) as there was confusion in relation to the transfer of functions from the DoT to the RSC under the Railway Safety Act.

Therefore IÉ were solely responsible for the implementation of recommendations made to them, with no independent review that the recommendations have been satisfied, which may have contributed to the recommendations made by IRMS not being completed. Therefore the RAIU make the following safety recommendations:

> **Recommendation 15**
> The RSC, in conjunction with IÉ, should develop an action plan in order to close all outstanding recommendations in the AD Little Review (2006) and the IRMS Reviews (1998, 2000, 2001). This action plan should include defined timescales for the implementation and closure of all these recommendations.

Actions taken or in progress since the accident

This section of the report details:

- Actions taken by IÉ since the accident;
- Actions taken by the RSC since the accident.

43 Actions taken or progress by Iarnród Éireann

43.1 Rebuilding the Malahide Viaduct

The initial damage resulting from the collapse of Pier 4 and the collapse of the spans to the two adjacent piers caused very significant damage. Immediately after the collapse IÉ put an extensive rebuild programme into motion in order to return the viaduct to full operational service by 16th November 2009. This programme of work has now been completed to a significant extent with only a few activities still in progress and the Malahide Viaduct has been returned to its full integrity and normal service duty.

IÉ immediately put an extensive programme of water level and water flow surveying (i.e. hydrographical surveying) in place in order to provide on-going information on the estuary bed levels close to the weir, on the weir itself while works were being carried out, and also as far as the motorway bridge at the western end of Broadmeadow Estuary. This information gathering programme enabled the UCC to model the estuary and determine the effect that IÉ's rebuilding of the weir would have on water levels in the estuary across the entire tidal range.

An extensive programme of structural monitoring was also put in place with survey targets on the east and west side of every pier together with vibration and tilt monitors on the bridge spans. The damage to the weir at Pier 4 was repaired with rock armour and twenty-two vertical steel piles (20 m in length) were installed to support the re-constructed pier (see Figure 28).

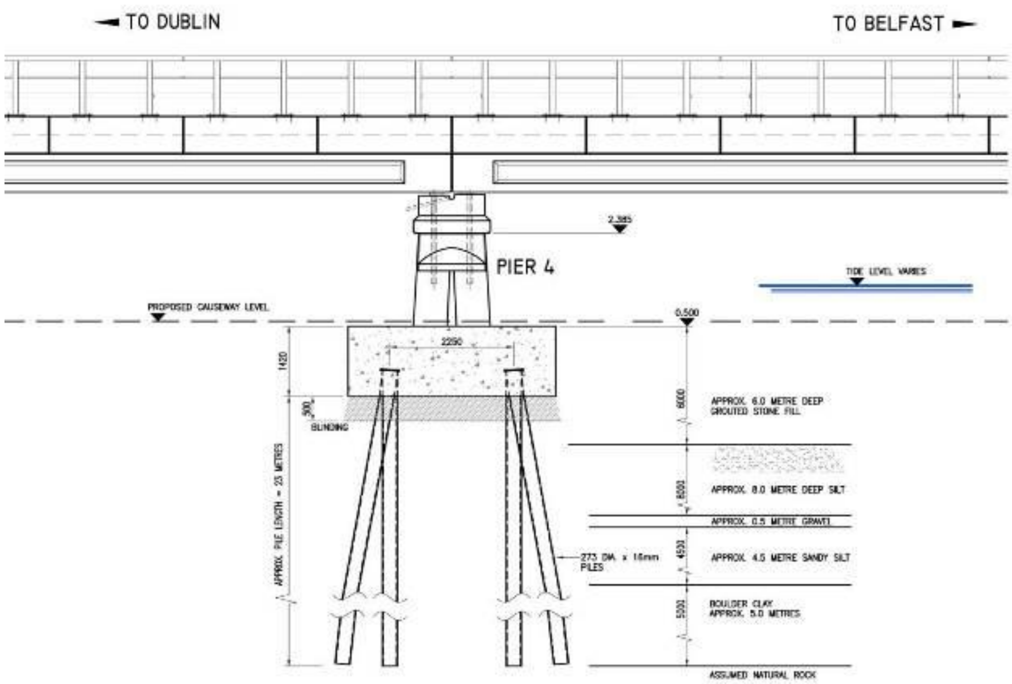


Figure 28 – Piles in Pier 4

All of the other piers were strengthened with the installation of fifteen additional piles at every pier and abutment. This further enhances the load bearing capacity of every pier. All the stonework on the piers were re-pointed and stainless steel reinforcing rods were use to strengthen each pier.

The two collapsed spans were re-constructed using twelve pre-cast concrete beams with in-situ concrete infill applied in each span. Handrails on all the viaduct spans were renewed and the track was reinstated.

Several technical studies (e.g. geotechnical and hydrographical studies) were conducted and a programme of works to strengthen and maintain the weir has been completed (see Photograph 19).

Photograph 19 – New weir profile

The Broadmeadow Estuary is a significant wetlands area with a very important conservation and a natural heritage contribution to our community. It is a designated Special Protection Area (SPA) and it is also designated under the Ramsar Wetlands Convention. Throughout the rebuild programme IÉ worked closely with all the interested parties to ensure that the weir will, on the completion of the rebuild works, be returned to the same environmental and hydrological conditions that prevailed before the accident. In this regard, extensive ecological surveys have been carried out to consider terrestrial and inter-tidal habitats, impacts on flora and fauna, ornithological habitats and the effects on marine mammals.

In conclusion, in reinstating the Malahide Viaduct, IÉ has also ensured that the overall structure has been significantly strengthened, that the weir profile has been restored and improved, and that these works have been undertaken with sensitivity to the local environment both from an ecological and amenity point of view.

43.2 Civil Engineering Department Review

In line with the same principles adopted in a previous re-organisation of another IÉ engineering department and with regard for the circumstances surrounding this accident, IÉ's Civil Engineering Department has been substantially re-organised during 2010. Five fundamental changes, each with intended wide ranging benefits, have been implemented since January 2010:

- A detailed Safety Management System (SMS) has been develop and implemented in the Civil Engineering Department. The SMS specifically describes the roles and responsibilities for managers, supervisors and engineers where these roles affect workplace safety and the safety of the Iarnród Éireann track and structures. In addition, the SMS also describes the procedures that must be followed and the review/control mechanisms that is exercised to ensure that those procedures are followed. One example of the impact of this change is that a formal programme for the inspection of bridges by specific personnel is now established and is maintained in an automated asset management system;

- The Civil Engineering Department has been re-organised and re-staffed in a manner significantly different to the Department structure that previously existed. Following a vacancy arising for the position, a new Chief Civil Engineer has been appointed, as well as a new Technical Manager (for Civil Engineering). The Technical Manager has full accountability for the safety of track and structures and is supported by a team of engineers dedicated to this accountability. This change establishes the unambiguous ownership for the safety of the Iarnród Éireann infrastructure and assigns the appropriate resources to the Technical Manager to achieve that accountability;

- A thorough review of all the Civil Engineering technical standards is being conducted in order to improve the content, readability and practicable implementation of these standards;

- The Civil Engineering Department has adopted a 'compliance verification' process to regularly audit and check that the new processes are continuously followed in practice. For example, greatly improved control mechanisms are in place to ensure that structural inspections are undertaken in accordance with standards and at the specified frequency;

- The Civil Engineering Department has now implemented a competency management process that is resourced with a Competency Manager who is, in turn, supported by Assessors. This team will implement, over the coming months, different programmes of assessments of Civil Engineering staff competencies. Assessments will be preceded with training modules and will be supported by briefings and follow-up refresher training sessions. The first example of this assessment programme is the training and assessment of track patrollers.

44 Review of specific actions taken by Iarnród Éireann

44.1 Track inspections

The confusion that arose because of the overlap in the track patrolling staff's patrol length over Division 1 and Division 5 has been rectified by the removal of that overlap. In addition, all the Divisions in IÉ have been reviewed for similar overlapping of patrol lengths and nowhere else was this practice found. With the overlap removed, the standard practice whereby a supervisor assigns a relief track patroller when another employee is on leave will operate as normal. **IÉ response to Recommendation 1.**

The Track Patrolling Standard, I-PWY-1307, has been reviewed and the requirement for a track patroller to carry out annual checks for scour has been removed. The standard has now been re-issued and re-briefed to the appropriate staff. **IÉ response to Recommendation 2.**

44.2 Structural Inspections Standards

As mentioned previously, IÉ has developed and implemented a robust SMS for Civil Engineering which specifically assigns the responsibilities for developing, owning and for the timely implementation of all technical standards to a new Technical Manager. In addition, a programme of comprehensive review of all sixty-three technical standards for practicability was initiated in February 2010 and will conclude with the re-implementation of these standards from October 2010 onwards.
IÉ response to Recommendation 5.

One of the documents reviewed was the 'Civil Engineering and Earthworks Structures: Guidance Notes on Inspection Standards', to assist inspectors in conducting inspections and identifying structural defects. The document was updated and formally issued as "Guidance Notes". **IÉ response to Recommendation 3.**

This new SMS for Civil Engineering assigns very specific responsibilities to line managers to adhere to the issued technical standards. The SMS also assigns a specific responsibility to the new Technical Manager to verify the Civil Engineering Department's compliance, through compliance checks, to ensure that the line managers are adhering to the technical standards. **IÉ response to Recommendation 4.**

44.3 Structural Inspections

The Structural Inspections Standard, I-STR-6510, has been reviewed, updated and re-issued. Ground Level, Thorough and Special Inspections have been replaced with General Engineering Inspections (GEIs) and Specialist Inspections.

IÉ has now implemented, within the automated Infrastructure Asset Management System (IAMS), a cyclical inspection regime for all the bridge structures according to the specific frequency as defined in the revised Structural Inspections Standard. This is a significant improvement in the scheduling and control of these structural inspections. IAMS is an automated asset management system ensures that cyclical inspections are part of formal schedules and inspection plans and that it is executed in a timely manner. **IÉ response to Recommendation 6.**

In addition, a Coastal Defence Inspector has been appointed with the specific responsibility to review scour inspection information and to develop/co-ordinate formal scour action plans. **IÉ response to Recommendation 6.**

The new SMS System for Civil Engineering assigns a specific responsibility to the new Technical Manager to verify, according to the “Safety Tours and Compliance Verification” standard (CCE-SMS-008), that the inspection regime is achieved at the correct frequency. **IÉ response to Recommendation 4.**

44.4 Inspections for structures vulnerable to scour

IÉ has identified 105 bridge structures that are potentially susceptible to scour and has conducted detailed surveys (including dives for assessing scour) on the 105 bridge structures and has not found any scour related risks with any of these bridge structures. A risk-based condition rating for scour has been assigned to each of the 105 bridge structures. **IÉ response to Recommendation 7.**

IÉ has implemented, within IAMS and within the new Structural Inspections Standard, a cyclical scour inspection regime for the 105 bridge structures at a three-yearly frequency. This represents a more stringent inspection regime than that detailed in the appropriate international standard “Defects in railway bridges and procedures for maintenance and strengthening” (UIC 778-4), which specifies inspections at a six-yearly frequency. **IÉ response to Recommendation 7.**

Based on the findings of future scour inspections, the scour inspection frequency will be adjusted to be appropriate to any risks that may emerge.

44.5 Flood/scour management plan

IÉ is developing both technical solutions and a supporting technical standard (“Floods and Scour Management Standard”) that will establish a documented, risk-based management system for floods and scour. This management system will be based on risk ratings for flood or scour susceptible bridge structures, the frequency of inspections, the use of measurement sensors to provide pre-cursor warnings of scour-related phenomena, the use of visual and underwater examinations and specific remedial action plans (e.g. in the case of floods of unprotected structures). This technical standard will be issued in March 2011. **IÉ response to Recommendation 8.**

IÉ has initiated a project that will verify and support the use of measurement sensors (to monitor water flow rates, water levels and river bed levels). **IÉ response to Recommendation 8.**

Specific operational mitigations for abnormal weather conditions such as extensive flooding will also be described in this standard. **IÉ response to Recommendation 8.**

44.6 Inspection after a report from a member of the public

IÉ’s new Safety Management System for Civil Engineering specifically assigns the responsibility for managing live Structures Risk Registers to Senior Track & Structures Engineers (who reports to the new Technical Manager) by way of a new standard for “Hazards and Risk Assessments” (CCE-SMS-006).

Any report received by the CTC, from a member of the public or other sources, is distributed to all parties. The Senior Track & Structures Engineers are accountable for recording the report, doing a Risk Assessment and for initiating and tracking the corrective actions. **IÉ response to RAIU Recommendation 9.**

44.7 Training and competency management

IÉ has implemented a new standard for “Competency Assessments and Training” (CCE-SMS-004) in Civil Engineering. This standard establishes the competency management and training management systems for Civil Engineering. The training management and competency management of structural inspections will be incorporated into this standard by December 2010. **IÉ response to Recommendation 10.**

The training management and competency management of track patrollers is already incorporated into this standard. **IÉ response to Recommendation 10.**

44.8 Recording of information on IAMS

IÉ's new Safety Management System for Civil Engineering specifically assigns the responsibility for inputting data into the IAMS to line managers, while the responsibility for maintaining the integrity of IAMS is assigned to the new Technical Manager. Ensuring information is recorded on IAMS is part of the compliance verification accountability of the new Technical Manager and will be tracked and managed on an on-going basis. **IÉ response to Recommendation 12.**

A project to achieve the recording of data and to improve the use of IAMS was initiated in January 2010 and will be complete by November 2010. This project, led by the new Technical Manager, will ensure that maintenance regimes are scheduled and implemented on IAMS in accordance with the revised technical standards. **IÉ response to Recommendation 11.**

IÉ has now initiated a project whereby the current paper-based information systems are being converted to an electronic format for referencing by IAMS and for ease of access and use by engineers. **IÉ response to Recommendation 13.**

44.9 Closing recommendations made in independent safety reports

IÉ has met with the RSC to agree a programme to develop an action plan to close all the recommendations in the AD Little Review (2006) and the IRMS Reviews (1998, 2000, and 2001). **IÉ response to Recommendation 15.**

45 Actions taken or in progress by the RSC

45.1 Monitoring of IÉ's response to the accident

Post incident, RSC Inspectors accompanied IÉ Engineers as they inspected a number of bridges identified as been vulnerable to scour. The interim train operations put in place following the incident was monitoring through RSC Inspectors cab-riding and witnessing the degraded mode operations.

The RSC have tracked IÉ's progress of inspection of the 105 bridges identified as being potentially vulnerable to scour through regular direct correspondence with the Structural Engineer responsible for overseeing the project.

45.2 RSC Compliance Audit

The RSC produced "RSC Compliance Audit – Following the Partial Collapse of the Broadmeadow Viaduct" in March 2010. This compliance audit focused on IÉ's inspection regimes for track and structures to identify any non-compliances in relation to these regimes and make recommendations based on the findings of this audit. This involved the review of numerous documents, records and the interview of Civil Engineering Departmental personnel. Based on these activities the RSC identified four non-compliances and made sixteen recommendations.

An 'Improvement Plan' was requested under Section 76 of the Railway Safety Act 2005 and IÉ submitted this to the RSC at the end of April 2010. The RSC reviewed and accepted this plan and has had two meetings with IÉ's Assistant Chief Executive to monitor progress against the recommendations.

45.3 Tracking recommendations

The RSC are currently reviewing the AD Little Review recommendations previously closed by the RSC to ensure that all documentation has been provided by IÉ. If gaps are identified the RSC will request evidence to be submitted. **RSC response to Recommendation 14.**

In relation to RSC supervision activities the RSC has published guidance on its website for RSC staff, Railway Undertakings and Infrastructure Managers. This guidance document entitled 'Guidance on the RSC Supervision Activities' includes a section on the tracking of recommendations. **RSC response to Recommendation 14.**

The RSC have undertaken a follow up audit and had thirteen meetings with IÉ's Safety Performance manager since 2007. At the time of writing there are seven recommendations 'open/in progress'. The RSC have requested that IÉ provide an implementation plan for the closure of the remaining open recommendations made in the AD Little Review. This plan is expected imminently. Once received it will be reviewed and monitored. **RSC response to Recommendation 15.**

Additional information

This section of the report details:

- List of abbreviations in report;
- Glossary of terms;
- References.

46 Additional information

46.1 List of abbreviations

ADE	Assistant Divisional Engineer
AE	Assistant Engineer
CIÉ	Córas Iompair Éireann
CWR	Continuous Welded Rail
DE	Divisional Engineer
GNRI	Great Northern Railway Ireland
hrs	Hours
ICE	The Institution of Civil Engineers of Ireland
IÉ	Iarnród Éireann (translated into English – Irish Rail)
IRMS	International Risk Management Services
kph	Kilometres per hour
Km	Kilometre
m	Metre
MP	Milepost
MW	Maintenance of Way
p	Page
PWI	Permanent Way Inspector
RAIU	Railway Accident Investigation Unit
RSC	Railway Safety Commission
SE	Senior Engineer
SMS	Safety Management System
TCB	Track Circuit Block

46.2 Glossary of terms

*Terms with * are taken directly from Ellis' British Railway Engineering Encyclopaedia*

Accident	Unwanted or unintended sudden event or a specific chain of such events which have harmful consequences including collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others.
Alignment	The longitudinal direction, vertically or laterally, of a section of track.
Ballasted deck*	A bridge deck that is designed to support and has a layer of ballast laid on is, onto which the track is placed.
Bathymetric Survey	A study of underwater depth of lake or ocean floors, usually through depth sounding.
Bedstone*	The masonry block placed at the top of an abutment or pier, which in turn supports one end of a single bridge girder.
Bridge Strike	The term used for a road vehicle, or less commonly, a ship, colliding with the deck of an underbridge.
Cable Route	The designated cable management system laid alongside the railway.
Cant	The design amount by which one rail of a track is raised above the other rail, measured over the track centres.
Capital project	Long-term investment project , requiring relatively large sums of money, for the development or improvement of infrastructure assets.
Car	Car is an abbreviation of carriage, and refers to a single vehicle in a multiple unit train.
Coast*	Removing the power from the traction unit to allow the train to continue under its own momentum.
Commuter	Commuter services are suburban rail services running in Dublin, Cork and Limerick.
Corporate memory	Knowledge and information from the company's past which can be accessed and used for present and future company activities.
Competent	In relation to staff, means that the person is qualified, trained and capable of undertaking the duties for which he/ she is employed.
Condition Rating	Numerical value to describe the condition of an IÉ asset.
Continuous Welded Rail	Rails welded together, utilising flash butt welding, to form one continuous rail that may be several kilometres long, or thermite welding to repair or splice together existing CWR segments.
Contributory factors	Any factor(s) that affects, sustains or exacerbates the outcome of an occurrence. Eliminating one or more of these factor(s) would not have prevented the occurrence but their presence made it more likely, or changed the outcome.
Controlling signalman	A person employed by IÉ to supervise and operate a signalling system for

	a particular section of line.
Córas Iompair Éireann	Córas Iompair Éireann is a statutory corporation and wholly owned by the Irish Government. CIÉ has three wholly owned subsidiary limited liability companies established under the Companies Acts, as provided for in the Transport (Reorganisation of Córas Iompair Éireann) Act 1986. Iarnród Éireann is one of these subsidiary companies.
Critical Point	The critical depth is the point where the velocity becomes the critical velocity and the depth becomes the critical depth.
Crosslevel	The measured distance between the two running rails of a track. This value should be equal to the designed value of cant for the location.
Cubic metres per second	A unit of flow rate equal to that of a cube with sides of one metre in length moving each second, which is commonly used for water flow calculations.
Cutting	An area excavated to permit a railway to maintain its level and gradient through high ground to avoid excessive deviation from a straight course.
Danger	Universal railway term for Stop Aspect (Red Aspect) on a colour light signal.
DART	An electrified heavy rail system that runs north - south on Dublin's eastern coast.
Detrain	The action of getting passengers off a train.
Diesel Multiple Unit*	A multiple unit train whose source of power is a diesel engine.
Double track	A route with two tracks.
Down Line	North-bound railway line.
Easement	A right held to make use of the land of another for a limited purpose, e.g. a right of railway network for IÉ over land.
Ebb-tide	The period between high and low tide where the water flows back to the sea.
Embankment	An embankment is a filled area permitting the railway to maintain its level and gradient. In the case of Malahide, the embankments allow the railway to travel over the estuary.
Enterprise	The Dublin – Belfast service route which is operated in conjunction with Northern Ireland Railways.
Fathometer	A brand of sonic depth finder.
Fixed infrastructure	Infrastructure that is not movable, e.g. bridges, coastal or river defences, culverts, cuttings, drainage, embankments, platform and loading banks, retaining walls and tunnels.
Flood-tide	The period between low and high tide where the water flows into the estuary.
Four Aspect Signalling	An arrangement of colour light signals which provide red, double yellow, yellow and green aspects.
Girder	A large or principal beam of steel, reinforced concrete, or timber; used to

	support concentrated loads at isolated points along its length.
Great Northern Railway Ireland	An Irish railway company formed in 1876 by a merger of the Irish North Western Railway, Northern Railway of Ireland, and Ulster Railway.
Grout	A mortar poured into cavities, such as rock fissures, to fill them and consolidate the adjoining objects into a solid mass.
Hydrostatic pressure	The pressure at a point in a fluid at rest due to the weight of the fluid above it.
Iarnród Éireann	A wholly owned subsidiary of Córas Iompair Éireann. IÉ is the owner and operator of the national mainline service in Ireland.
Immediate Cause	The situation, event or behaviour that directly results in the occurrence.
Incident	Any occurrence, other than an accident or serious accident, associated with the operation of trains and affecting the safety of operation.
Infrastructure Asset Management System	A database maintained by IÉ to record details of IÉ's track and structure assets. It also encompasses a condition monitoring module, a fault management system, work order processing and geographical information system. The system was introduced in January 2005.
Intercity	Long distance routes, generally travelling from Dublin.
Jointed track	Track made using lengths of rail, usually around 20 m in length, which are bolted together using perforated steel plates known as fishplates.
Kinetic energy	Energy created as a result of the movement of water flowing – the faster the water flows, the greater is the kinetic energy.
Lattice girder beam	An open girder in which the web consists of diagonal pieces arranged like latticework.
Leading end	The front end of a train in the direction of travel.
Lineside Telephone	Telephone provided within the boundary of the railway.
Line speed	The maximum speed at which trains may run when not subject to any other restrictions.
Local scour	Local scour is the process where bed levels change locally around a structure such as a bridge pier due to a local distortion of the field flow causing patterns of higher and lower shear velocities on the bed.
Maximum permitted speed	The maximum speed at which trains may safely negotiate a section of track.
Milepost	A post placed at one mile intervals along the railway, (quarter mile intervals similarly marked).
Mode A train radio	IÉ's discrete train radio system which communicates voice and telegram messages between signalling centres and trains.
Ordnance Datum	A vertical datum used by an ordnance survey as the basis for deriving altitudes.
Overbridge*	A road that allows passage of road vehicles over the railway.
Patrol /patrolling	A visual inspection by the patrol ganger of the track (and a superficial

	visual inspection of other lineside items).
Patrol ganger	A person who is trained and competent to undertake patrolling duties on a specified length of track on behalf of IÉ.
Permanent speed restriction	A speed restriction applied permanently to a length of track because it has a maximum permissible speed lower that the line speed for that route.
Permanent Way Inspectors	A person responsible for the day to day track inspection and maintenance activities for both track and structures. They must ensure that their patrol gangers undertake their inspections to the required frequency and submit defect reports.
Permeable	In the case of the weir, permeable is a term used to describe how the water is permitted to flow through openings in the stones.
Person Responsible	Structural Inspection Standard, I-STR-6510, states that the Person Responsible is responsible ensuring the requirements of the standard are satisfied in relation to inspection of assets. He/ she is also responsible for maintaining an asset.
Post-tensioned concrete	Post-tensioning wires set in the concrete, but not bonded to the concrete, allowing tensioning to occur at the job-site.
Power controller	The driver's device for the application of power to the traction unit to allow the train to travel.
Precast	Concrete (block or slab, etc.) cast in a place other than where it is to be installed in a structure.
Relief Patrol Ganger	A person designated by a local Permanent Way Inspector as competent to undertake patrolling duties on specified lengths of track in place of the designated Patrol Ganger.
Rip-rap apron	Rock or other material used to armour shorelines, streambeds, bridge abutments, pilings and other shoreline structures, against scour, water or ice erosion.
Scour	The process by which material is eroded and transported away from the bed of a river causing a lowering of bed level.
Silting	The deposition of fine materials on the river bed.
Simulation	A technique of representing the 'real world' by a computer or physical model.
Sounding rod	A rod used to ascertain the depth of water.
Spalling concrete	Where pieces of concrete separate from the concrete structure as a result of the concrete deteriorating due to weathering, temperatures or pressure.
Span	The distance between to supports (piers) on a bridge.
Superstructure	Portion of a bridge above the piers and abutments.
Threshold of movement	The point at which a material crosses from a condition of stability to instability and the movement of materials begins.
Three aspect signalling	An arrangement of colour light signals which provide red, yellow and green

	aspects.
Thorough Inspection	A Thorough Inspection is a systematic visual inspection of all elements of a structure including submerged elements, for example bearings and elements susceptible to scour.
Tidal range	The tidal range is the vertical difference between high water and the succeeding low water levels.
Track	An assembly of metal rails supported by sleepers and placed in ballast, used for the passage of vehicles fitted with rail wheels.
Track circuit	An electrical train detection system, based on proving the absence of a train.
Track Circuit Block	A method of signalling to trains in a section of line where safety is ensured by the use of track circuits or other means of automatic train absence detection system and without the use of block instruments.
Track circuit operating device	A mechanism to short out track circuits in times of emergency.
Track Recording Vehicle	A specially adapted Diesel Multiple Unit, equipped with measuring and recording equipment, it is used to measure track geometry and create a video of the infrastructure.
Twist fault	A rapid change in cant or crosslevel.
Underbridge	A bridge that allows passage of road or marine vehicles under the railway.
Underlying factors	Any factor(s) associated with the overall management systems, organisational arrangements or the regulatory structure.
Up line	Southbound railway line.
Viaduct	A series of spans or arches to carry a road or railway over a wide valley, water or over other roads and railroads.
Wayleave	A right of way over or under another's ground or property, e.g. rail line.
Weir	A small overflow-type dam commonly used to raise the level of water in a river, estuary or stream.
Wing walls	The wing walls are adjacent to the abutments on a bridge and act as retaining walls.
Winnowing	A process whereby a water flow removes lighter stones from within a weir structure – the heavier stones remain but large voids are created.

46.3 References

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