# Caha Tunnel Rock Repairs and Improvements including Non-Destructive Testing

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ABSTRACT: This paper provides an overview of the recent short-term repair works by means of rock removal methods, and non-destructive testing (NDT) of Caha tunnel and thus providing an indication of suitable solutions in ensuring long-term structural validity of the tunnel.
The short-term repair works initially provides details of a hammer tap-survey, a geological mapping survey, a visual inspection as well as known historical rock fall locations which all give an indication of where immediate rock removal works were required. Following on from this, details of the rock removal operation works as well as associated site constraints are described.
The non-destructive testing describes the various methods such as ground penetrating radar (GPR), electrical resistivity tomography (ERT) and seismic refraction which were all undertaken at the tunnel to determine any weak underlying layers/zones. An interpretation of these results as well as suitable long-term strengthening measures required within the tunnel are also described.

KEY WORDS: Tunnel engineering, Geology, Non-destructive testing

## 1 INTRODUCTION

### 1.1 Background and History

Caha Tunnel is a rock tunnel located approximately 9km north of Glengarriff, Co. Cork and 18km south of Kenmare, Co. Kerry along the N71 through the Caha Pass on the Cork/Kerry border (Figure 1). The route is the primary link between the towns of Glengarriff and Kenmare and serves as a popular route amongst tourists, especially in the summer months.


Figure 1. Location of Caha Tunnel

As a result of reported rock falls within the tunnel, calls for improved safety within the structure were required. RPS were therefore commissioned in 2018 to undertake consultancy services relating to the rock repairs and removal works to the internal surface of the tunnel as well as non-destructive testing to determine any faults behind the intrados of the tunnel.

### 1.2 Description of Structure

Caha Tunnel is a 180m long rock tunnel of siltstone and sandstone formation. The tunnel was formed in the mid-19th century through blasting methods, thus giving it its inhomogeneous cross-sectional shape throughout and exposing the natural face of the rock. The tunnel varies in height and width throughout due to the rock profile however, it is approximately 4.0m high and typically 5.0m wide. A photograph of the elevation of the structure is provided in Figure 2.

Figure 2. Elevation view of Caha Tunnel

## 2 INSPECTION AND SURVEYS

### *2.1 Reported Rock Falls*

There have been reports of rock falls occurring within the tunnel intermittently in the past. The rock falls are generally noted to be occurring in the areas adjacent to the roof shaft, located 140m from the southern end.

As a result, TII required a visual inspection of the tunnel along with a hammer tap survey be undertaken in order to determine if the extent of any loose or friable rock which may exist along the internal surface of the tunnel.

### *2.2 Visual Inspection and Hammer Tap Survey*

In February 2018 RPS undertook a visual inspection and hammer tap survey of Caha Tunnel. The visual inspection was undertaken during daylight hours thus availing of the best opportunity to visually determine any defected zones along the length of the tunnel. A localised chainage system was marked out in advance of the inspection. Chainage 0 corresponding to the southern (Cork) end of the tunnel. The chainage system was used to identify defect locations and is presented in Figure 3.

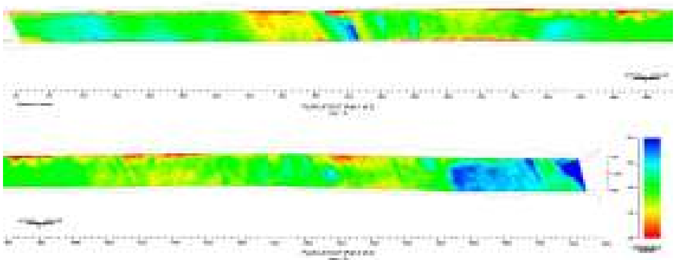

Figure 3. Chainage layout of Caha Tunnel

The hammer tap survey was carried out by four inspection engineers, including two Lead TII Principal Inspectors. The survey was conducted at night during a full temporary road closure. Temporary traffic management, diversion routes and the road closure application were finalised in advance of the inspection in conjunction with all affected stakeholders and statutory bodies.

Two scissor lifts, fitted with lighting, progressed in tandem through the tunnel with two inspectors per scissor lift. A full touch and hammer tap survey of the tunnel roof and side walls was undertaken. Existing sections of loose and friable rock, where safe to do so, were removed. Larger sections of loose rock were measured and recorded. An image of the hammer-tap survey set-up is provided in Figure 4.

Figure 4. Hammer-tap survey set-up

The findings of the inspection and survey were as follows:

- A large proportion of the tunnel walls & roof comprise sound rock;
- Due to the near vertical stratification of the rock localised sections of rock were loose & friable, particularly at sections of changes in height for example. Large stone sections had fallen from the tunnel roof in the past, and these were visible during the inspection.
- Where safe to do so, loose and friable sections of stone were removed, particularly where these appeared precarious or near falling.

Based on these findings RPS recommended that a works Contractor be appointed to remove the remaining loose sections of rock with suitable mechanical plant under a temporary road closure in order to reduce the hazards to road users on the N71.

## 3 ROCK REPAIRS AND IMPROVEMENTS

### *3.1 Geological and Rock Mass Inspection*

Prior to undertaking rock repairs and improvement works, RPS carried out a geological & rock mass inspection of the tunnel in July 2018, with the assistance of a Professional Geologist, in order to determine the following:

- Assess the rock mass condition with regard to the stability of material on the side wall faces and within the roof;
- Confirm locations where scaling work of loose material should be undertaken.
- Assess of how long it would take to undertake the rock removal and improvements works.

The tunnel was visually examined in this inspection while recording joint types, dip angles, dip direction and surface roughness to gain an added understanding of the natural behaviour of the rock masses throughout the structure. Geological profiles within the region, as obtained from the GSI website, were used to assist the desktop study. [1] [2]

Due to the tectonic history of the location, the rock mass can be highly and variably fractured due to blasting methods used for the initial tunnel excavation. It was noted that the possibility of longer-term relaxation of the rock mass around the tunnel such as falls of rock would be ongoing unless prevented.

A hammer-tap survey of the tunnel identified positions along its length where it is considered that there is a greater probability of material falling in the shorter term and therefore work should be undertaken to remove the loosest material and thus lower the probability of rock falls. [3]

### *3.2 Rock Repairs and Improvement Works*

P&D Lydon Ltd. were appointed as the Contractor to undertake the rock repair and improvement works for Caha Tunnel. The works were conducted at night during a full temporary road closure. Temporary traffic management, diversion routes and the road closure application were arranged in advance of the Works in conjunction with all affected stakeholders and statutory bodies. This operation was undertaken under 2 night-time road closures in October 2018.

The tunnel was marked out in advance using the conclusions of both the hammer-tap survey and the geological & rock mass inspection. Any sections of loose or friable rock which could not be previously removed by hand methods were done so using mechanical rock breakers. Adequate safety measures were in place for the site operatives and protection to the existing N71 was maintained with rubber matting. Upon completing rock removal works at each section, a hammer-tap inspection was carried out by the Engineer to ensure each section presented a stable surface without evidence of loose rock.

In addition, weep holes were installed in the walls of the tunnel in order to channel any water away where damp sections were noticed and could potentially lead to further softening of the rock mass within the tunnel. A steel grill was also installed above the roof of the tunnel over the shaft to prevent rock or debris from the areas above the tunnel falling through to the road surface.

Images of the rock repairs and improvement works are presented in Figures 5 and 6.

Figure 5. Mechanical breaker removing loose rock

Figure 6. Loose rock removed from an identified section

### *3.3 Conclusion after Rock Removal Works*

The rock repair and improvement works ensures the risk of rock falls within the next two years, from the date of the works is low and reduces the urgency for immediate works. Ongoing weathering and deterioration of the exposed surface will increase the probability of rock falls and therefore long-term remedial works should be undertaken within 2-5 years from the October 2018 rock repair and improvement works.

## 4 NON-DESTRUCTIVE TESTING

In advance of long-term remedial works being undertaken at Caha Tunnel, a further understanding of the condition of the rock mass behind the intrados was required. RPS' Geologist recommended that a geophysical contractor should engaged to undertake non-intrusive methods of investigation, which would identify fractures and faults behind the internal layer of the tunnel.

Apex Geophysics Ltd. were appointed as the Geophysical Contractor to undertake the non-destructive testing at Caha Tunnel in January 2019. The works were conducted over a period of 3 days, during daylight hours, and using a contraflow traffic management system when testing was undertaken within the tunnel. Traffic management was not required where testing was carried out on top of the tunnel.

The following tests were carried out in order to best determine if any defects were present:

1. Ground Penetrating Radar (GPR)
2. Electrical Resistivity Tomography (ERT)
3. Seismic Refraction

### *4.1 Ground Penetrating Radar (GPR)*

GPR works by sending radio waves into the ground and measuring the time of the reflected wave. Reflections occur where different material types exist. GPR was used here to determine where voids may exist along the tunnel and thus determine the condition of the tunnel at various sections.

Data collection was controlled by an EDM wheel attached to a frequency antenna, enabling a highly accurate, independent measuring system to ensure data was collected at specified intervals.

A time recording window of 60 – 300ns was used corresponding to a depth range of approximately 3 – 10m beyond surface level. The maximum usable depth of penetration before signal attenuation (the limit to where useful information was determined) for the site is approximately 5m.

4.1.1 Tunnel Walls

A single profile was recorded on both the east and west tunnel walls with data collected at 0.05m intervals at a height of 1.4m above the road surface. With a frequency of 400MHz these tests gave readings to a depth of 5.0m behind the face of the tunnel walls. The information obtained showed a zone of more 'fractured' rock immediately around the tunnel profile at a depth of about 2m at the southern portal increasing to a depth of around 3m at the northern portal.

Following on from the above results, three additional profiles were then recorded along the walls at heights of 0.80m, 1.20m and 1.60m above the road surface. These tests were undertaken at a frequency of 800MHz giving a depth of penetration of 3.2m behind the tunnel walls. Combining this information, the results are presented as a series of plots of depth intervals in 0.25m stages behind the tunnel walls showing anomalous features detected. An image displaying the GPR plots are shown in Figure 7.

Figure 7. GPR plot of western wall of the tunnel [4]

The plots produced indicate that the features typically penetrate to a depth of 0.75m behind the walls of the tunnel but extend to greater depths within the vicinity of the north portal. These are interpreted as indicating fracture planes which could act as release surfaces. In combination with other rock mass fracturing, this may result in future localised weakening of the rock with these features typically extending to a depth of 0.75m before the rock mass becomes tight. Towards the northern portal these fracture surfaces extend to greater depth on the east wall and there are fractured features to a depth of 1.25m.

4.1.2 Top of Tunnel

Three surface profiles were undertaken, and these show a layer of peat underlain by bedrock of good quality. The profiles also show the contact between the surface peat and the underlying bedrock. The peat has a thickness of up to 1.0m and is thicker towards the northern portal. Below this, the results show a relatively unweathered rock mass which are in good condition. The maximum depth of investigation achieved was 5.0m given the precision required to obtain concentrated defect zones within the rock mass.

### *4.2 Electrical Resistivity Tomography*

ERT images the resistivity of the materials in the subsurface along a profile to produce a cross-section showing the variation of resistivity with depth, depending on the length of the profile. Each cross-section was interpreted to determine the material type along the profile at increasing depth, based on typical resistivities for Irish ground materials. The testing was undertaken at ground surface above the alignment of the east and west wall of the tunnel.

Profiles were recorded using a Tigre resistivity meter, imaging software, two 32 takeout multicore cables and up to 64 stainless steel electrodes. Saline solution was used at the electrode/ground interface in order to gain a good electrical contact required for the technique to work effectively. The recorded data were processed and viewed immediately after surveying.

Based on the ERT values determined Apex made the following interpretation of the rock types along the tunnel line [4]:

- Sandstone/Siltstone between approximate chainages 0–40m and 60m–110m,
- Siltstone with minor sandstone as narrow bands between approximate chainages 40m -60m and 160m – 180m, and
- Shale band between approximate chainages 115m – 130m.

This interpretation concurs with the general assessment of rock types present made during the previous visual inspection of the tunnel side walls by RPS. [3]

### *4.3 Seismic Refraction*

Seismic Refraction profiling measures the velocity of the refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually higher seismic velocities while soft, loose or fractured materials have lower velocities. Readings are taken using geophones connected via multi-core cable to the seismograph. This method should allow profiling of the depth to the top of the bedrock, along profiles across the site.

A Geode high resolution 24 channel digital seismograph, 24 10Hz vertical geophones and a 10kg hammer were used to provide first break information, with a 24 take-out cable (1.5 – 2.0m spacing).

Reading are taken using geophones connected via multi-core cable to a seismograph. The depth of resolution of soil/bedrock boundaries is determined by the length of seismic spread, typically the depth of resolution is about one third the length of the profile. Shots from seven different positions were taken (2 x off-end, 2 x end, 3 x middle) to ensure optimum coverage of all refractors.

Two seismic profiles were investigated; one at ground surface above the west wall between approximate chainages 65m to 105m and one above the east wall between approximate chainages 135m and 170m. These tests identified four ground profiles as detailed in Table 1 below.

Table 1: Seismic Refraction Results [4]

| Layer | Thickness (m) | Interpretation | Stiffness/Rock Quality |
|---|---|---|---|
| 1 | Absent to 1.2 | Soil and completely to highly weathered Bedrock | Loose - Medium Dense or Very Poor |
| 2 | 0.4 – 1.7 | Highly to Moderately weathered Bedrock | Poor - Fair |
| 3 | 0.4 – 3.0 | Moderately to Slightly weathered Bedrock | Fair - Good |
| 4 | 3.0 – 5.0+ | Slightly weathered - Fresh Bedrock | Good |

These results indicate that the majority of the tunnel has been excavated within slightly weathered to fresh good quality rock. Towards the portals it has been excavated within moderately to slightly weathered fair to good rock.

### 4.4 *Conclusion after Non-Destructive Testing*

Upon establishing the rock types present at various locations as well as the anomalies present behind the internal layer of the tunnel, a more accurate indication of the long-term strengthening measures, at the required locations, were evaluated for the Caha Tunnel.

## 5 OPTIONS EVALUATION

Following on from the non-destructive testing, an evaluation of a suitable options for ensuring long-term suitable strengthening measures was required.

The following options were considered for future proofing the tunnel:

1. Fibre Reinforced Sprayed Concrete
2. Rock Fall Mesh and Bolting
3. Concrete Lining

### 5.1 *Fibre Reinforced Sprayed Concrete*

This would provide a sealed surface to the tunnel, prevent rock falls and would be applied along the full tunnel length to the walls and roof. Whilst a minimum thickness of 5cm is indicated, it is considered that due to the irregular profile of the tunnel walls and roof an increased thickness should be applied at locations where the roof profile is particularly irregular to smooth out the profile. This may require thicknesses of up to 10cm in places. At some locations this would be insufficient to infill all the irregularity and at these positions the sprayed concrete should be thinned on to the protuberance and the rock left exposed within the sprayed concrete.

Mesh may be incorporated between the initial and subsequent applications of sprayed concrete to provide additional strength to the concrete. However, due to the irregular profile of the roof and side walls at some locations within the tunnel it would be difficult to form the mesh to the irregular profile to ensure that the subsequent sprayed layers incorporate the mesh. Therefore, to strengthen the concrete, steel fibres may be incorporated into the sprayed concrete mix.

### 5.2 *Rock Fall Mesh Bolting*

To hold surface material and blocks that could fall with time, rock fall mesh could be placed over the rock surface and held in place by attaching short dowels/bolts. The hole spacing within the mesh would have to be selected to ensure that it holds the majority of material that potentially could become loose. This option could result in some smaller sized fragments becoming loose and passing through the mesh.

In that case a fine mesh could be placed to underlie a coarser mesh to trap smaller sized material with the coarser mesh providing primary support to the tunnel. To optimise the support of the mesh it will be necessary for this to be fixed close to the surface and follow the profile of the tunnel. Due to the irregular profile of parts of the tunnel, it is critical that sufficient fixing points for the mesh are used. This will be greater than for a tunnel of uniform and consistent profile along its length. The selected mesh size should be diamond chain link type mesh with openings no greater than 80mm x 80mm, such that rocks sizes of the order $0.2m^3$ can be contained at a minimum. Rocks of this volumes represents the minimum size of that which has been reported to have fallen or removed during both the hammer-tap survey and rock repair works.

### 5.3 *Concrete Lining*

The placement of a structural reinforced concrete lining within the tunnel would provide a permanent solution to the problem of rock falls and provide a smooth wall and low maintenance option. The side walls are unlikely to require a significant thickness of lining as they would not take any large loading from the rock mass. The most significant problem would be associated with the construction of the roof as this would require a flat arch due to the limited height of the tunnel. There are some significant areas of over break so it would require a relatively fluid concrete mix to ensure that it flows in and fills such voids.

The concrete would be placed behind shuttering which preferably should be pre-formed so that it can be moved along the tunnel to cast each segment of the roof lining. The roof should be cast after the wall lining has been placed. Where there is significant over break in the roof profile grouting holes should be incorporated within the concrete lining so that subsequent contact grouting can be undertaken to ensure that there are no voids between the roof and concrete lining.

Currently the road is a two-way single carriageway, however due to the existing size of the tunnel placement of a concrete lining is likely to require its reduction to a one-way single carriageway to meet Highway requirements for road tunnels. The reduction to a one-way single carriageway would require the installation of a stop/go traffic management system for vehicles passing through the tunnel. If it was required to maintain a two-way carriageway in the tunnel, it would be necessary to undertake further excavation along the full length of the tunnel to facilitate the installation of a concrete lining. Likewise, there are headroom restrictions within the tunnel, therefore the inclusion of a concrete lining may not be a viable option.

## 6 CONCLUSION

The geophysical investigations undertaken have confirmed the presence of a more fractured zone of rock immediately around the tunnel and to a shallow depth of about 0.5m with more deeply developed features toward the North Portal in particular.

It is considered that that no further non-destructive testing is required for the assessment of the rock mass around the tunnel however, periodic monitoring of the tunnel, via visual inspections, is recommended in order to gauge the frequency of rock falls.

With regard to the existing shape and to deal with the ongoing problem of rock falls within the tunnel a number of remedial options were presented. It is considered that due to the headroom issues in the tunnel, the application of sprayed concrete may not be viable at all the required locations. Therefore, with regard to ease of construction and providing long term stability, the application of mesh placement with rock bolting will provide the optimum solution for the long-term stability of the tunnel. This option will also minimise the requirement for long term maintenance.

To assist with the design of rock bolting it is advised that a further detailed visual inspection and mapping of the tunnel roof and shoulders is undertaken to take fracture orientation measurements along its full length. Detailed visual inspections will be required at the portals and around chainage 50m within the tunnel. This work should be done from a platform so that the orientations and continuity of the fracture surfaces can be accurately measured.

## ACKNOWLEDGMENTS

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