# A PROPOSED STANDARDISATION METHOD FOR THE INVESTIGATION OF BALLASTED TUNNEL FORMATIONS

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## SUMMARY

This paper examines a procedure to be used in investigating track geometry problems associated with severe mud pumping and seepage in ballasted tunnels in South Africa. The study seeks to develop and standardise a procedure that can be used within Transnet Freight Rail (TFR) to investigate and address the problems at comparable aforementioned environments. Currently there is no known previous work done successfully to investigate problematic ballasted tunnels. The objective of the standardised investigation procedure will be to establish a way of identifying the root cause of the seepage problem and thus enable depot personnel to have an audit specification template in order to initiate the geologic core logging investigation. The Beacon Hill and Lowlands tunnels are Case studies 1 and 2 respectively and are along the Natcor Line near Escourt in Kwa-Zulu Natal midlands. The tunnels are characterised by repetitive occurrence of track geometry loss, with regular manifestation of white ballast and mud pumping spots being the main indication of formation failure associated with poor drainage. The study introduces a proposed procedure of identifying, within the tunnel, meaningful information about the profile of the formation, root cause of water streams and any mud pumping that might be occurring, level of bedrock, quality of the bedrock and the rock material properties. This would then subsequently lead to adopting appropriate formation rehabilitation in the ballasted tunnels, standard waterproofing techniques that would work once conditions of drainage and respective affecting parameters have been established within TFR’s existing ballasted tunnels.

## 1 INTRODUCTION

Ballasted tunnels have a higher degree of seepage manifested on surface compared to slab track due to the porous nature of ballast. Ballasted tunnels within TFR have a similarity in that they are more than 30 – 50 years old and very little to no information is available as to the formation below track section, level of the bedrock, the rock material properties and drainage conditions. Most railway tunnels worldwide take these parameters into consideration in the conceptual design stage of the structure and most rehabilitation works take place in decommissioned tunnels which are being revived or are looking at the tunnel portal frame lining only. This study is unique as it is not focusing only on the portal frame, but focuses mainly on the substructure and bedrock on which the tunnel is constructed. In the current case studies, the challenge is that the existing portal frame structure and/or conditions, place limitations on the method used to determine the design parameters for rehabilitation works in that access for equipment is limited. Narrow working space is a reality and overhead track equipment is to be avoided. Thus highly specialised equipment, such as shown in ***Figure 1***, has to be developed such that in view of limited occupation times, assembling and disassembling time is to be kept at a minimum. Some of the other challenges include having a core drilling procedure that will work within rock that has disintegrated and is under saturated conditions.

**Figure 1: Tailor-made equipment for coring**

## 2 INVESTIGATION PROCEDURE

### 2.1 Visual Condition Assessment

During the visual inspection the tunnel length can be confirmed and testing positions of trial pits and core logging holes marked. In the two case studies discussed the tunnels measured to be 1159 m and 4050 m respectively and testing positions were spaced at 25 m and 50 m intervals respectively. The detailed visual inspection is more focused on assessing the condition and defaults of the track superstructure and surface drainage conditions. There are many parameters that can be observed from this exercise, such as defected sleepers, visible slacks and kinks, seepage of water from the tunnel portal roof, water runoff in concrete channels, etc., and in each case study, the most occurring defects should be noted and prioritised.

Their intensity or degree of occurrence along the tunnel should be recorded and rated from 0 – 3, where 0 indicates non-occurrence of defect at the particular chainage and 3 points for severe occurrence or high concentration of the problem around that particular chainage.

The recording of such data can then be used to plot a graph showing the distribution of defects along the track as shown in ***Figure 2***. In both these case studies seepage of water from the tunnel portal roof had little influence, as discussed later, and is not included in the plot below. This distribution was then used to prioritise tunnel into subsections grouped according to their deterioration level and information can be input into the programme planning and scheduling where detailed investigation work should be concentrated more on the critical sections. Detailed geotechnical investigation was carried out in 2013 by Technology Management - Track Technology [1, 2] for both tunnels.

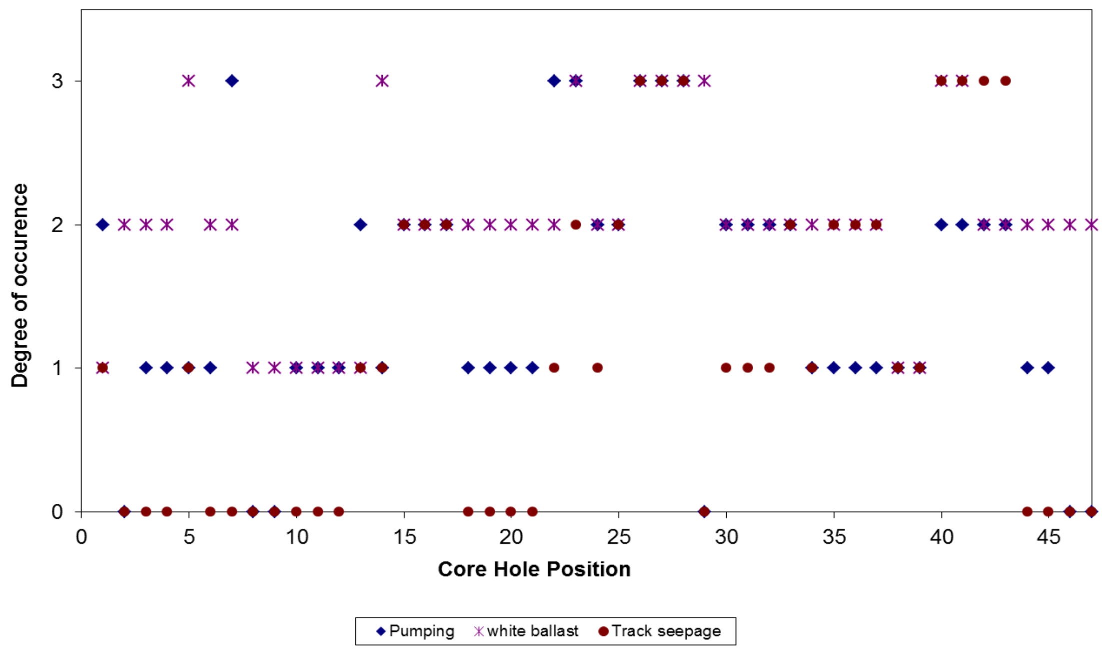


**Figure 2: Parameters observed during visual inspection and their relative distribution (Beacon Hill)**

## 2.2 Test Pitting and Formation Profiling

There is generally very little history of the tunnel construction that is readily available and thus no information regarding composition of materials and depth of formation profile. Establishing of bedrock level was achieved by opening ballast and test pit with hand tools between two sleepers within the track crib until refusal. The limitation here was that the space between the concrete channel and the rail was too small for efficient manual excavation of test pits in order to allow for staggering of test positions. This option should be explored where possible in future case studies. After excavating the imported material that forms the substructure of the track section, the longitudinal profile of the bedrock based on depths of the test pits can be assumed and represented as shown in ***Figure 3***. Average depth was 535 mm in case 1 and 472 mm in case 2, with minimum depths recorded to be 290 mm and 300 mm respectively, measured from beneath the sleeper up to the bedrock.

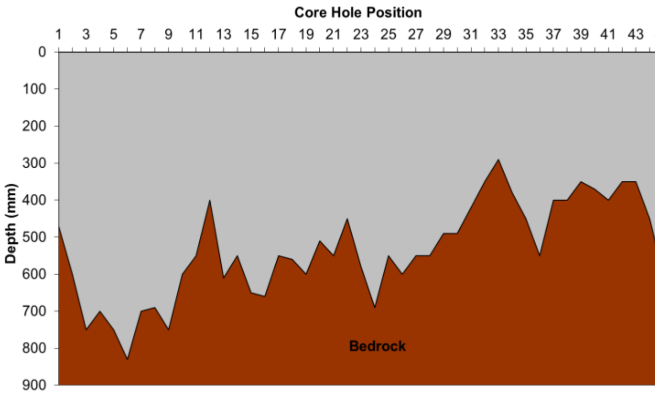


**Figure 3: Typical longitudinal profile of bedrock**

The track substructure materials were identified and profiled according to Jennings et al. [3] in order to check formation material composition and its integrity, and be graphically presented as in ***Figure 4***. The core logging reports revealed sedimentary decomposed shale rock and sandstones with occasional dolerite intrusions.

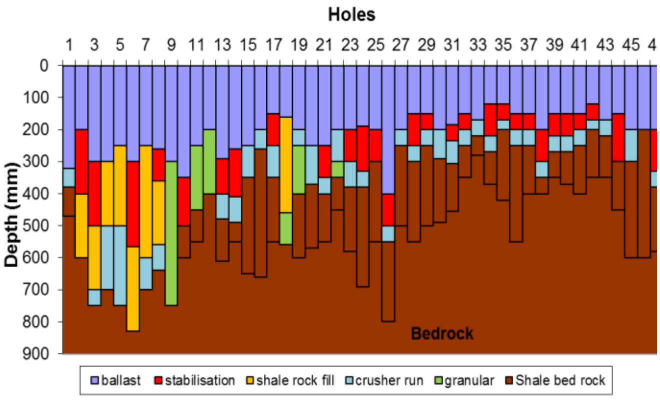


**Figure 4: Typical substructure material composition**

Any seepage that may occur is initially observed during test pitting. Direction of water seepage should be thoroughly observed, as to whether the water is transmitting through the ballast layer or flowing vertically up in a form of spring action under artesian pressures. The first points to a problem upstream, while the latter indicates permeability of bedrock and a fracture zone at that particular chainage position. The time it takes to fill the test pit, as shown in ***Figure 5***, can also be measured. The roof seepage had been restrained in the tunnels by installing rubber shields along the roof which divert water away from the track and into the surface runoff concrete channels.

**Figure 5: Seepage in test pits**

## 2.3 Rock Mass Permeability

Water pressure tests were carried out at each chainage position to determine the permeability of the existing rock mass using the Lugeon test. This test was to further establish the seepage characteristics of the rock mass as most of the seepage observed on the track was ascribed to upward ground water flow and horizontal runoff, since the roof seepage onto the track was restrained. Most positions of testing could not maintain the required pressure of 10 bars and the fluid disappeared into the ground, indicative of the extensiveness and connectedness of the cavities as small tributaries underground.

## 2.4 Core Logging

An external contractor can be commissioned to carry out geologic core logging investigations in order to determine the nature, integrity, and stability and strength parameters of the foundation structure bedrock within the tunnel. Quality assurance and site supervision are very critical at this stage.

Cores were recovered and a poor core recovery rate achieved was attributed to difficulty to drill cores through surface disturbance caused by the loose, fractured top part of the bedrock. A graphical representation of how conditions are likely to be underground within the bedrock can be deduced as shown in ***Figures 6 & 7*** as observed in the Beacon Hill and Lowlands tunnels respectively.

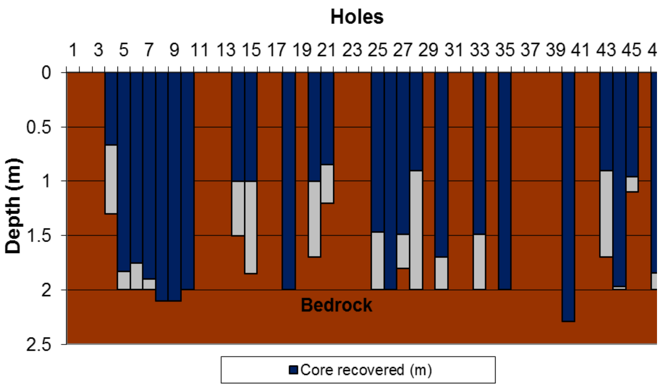


**Figure 6: Positions of cores recovered (B. Hill)**

It is important to note that the graph above only indicates that there are voids or highly fractured zones within the bedrock at that chainage but does not give the exact depth position of voids within the bedrock with reference to the top of the coring hole, which forms the base of the test pit. This graph can then be correlated with the Lugeon test results to confirm locations of cavities along tunnel.

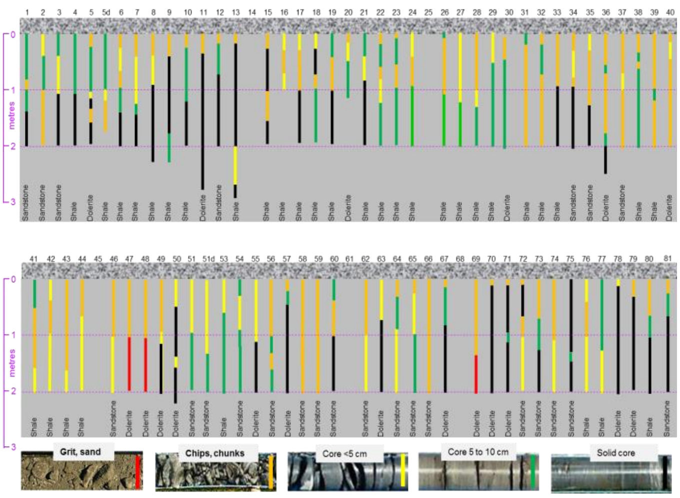


**Figure 7: Core condition and rock types**

### 2.5 RQD and UCS testing

Logging was done to gather useful information about bedrock material condition and integrity as a useful parameter affecting drainage conditions. Of most significance, amongst others, in the scope of this discussion is the rock quality designation (RQD) and unconfined compressive strength (UCS). The RQD gives an indication of core integrity. The RQD values in ***Figure 8*** show the top 1m to be severely fractured as compared to the bottom 1m – 2m of the bedrock. ***Figure 9*** shows the results of the unconfined compressive strength (UCS) testing of the bedrock. UCS values between 70 and 200 MPa indicates very hard rock and a value greater than 200 MPa denotes an extremely hard rock. The results can be compared to a good quality cemented material, C1 which yields a UCS of between 6 MPa and 12 MPa. Thus the rocks forming the foundation of the tunnel are still undamaged in terms of composition but are however weakened structurally by the extensive fractures within them. This severity of fracture within the bedrock mass then translates into increased permeability and poor bearing strength.

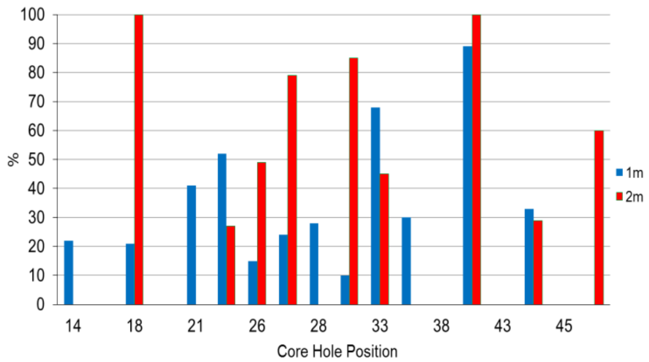


**Figure 8: Typical RQD values (Beaconhill tunnel)**

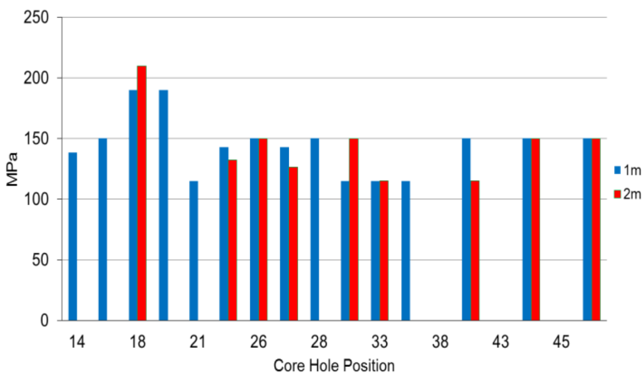


**Figure 9: Typical UCS values (Beaconhill tunnel)**

### 2.6 Ballast evaluation

***Table 1*** shows the ballast evaluation results taken randomly during test pitting. Laboratory ballast testing revealed that the entire section yielded highly fouled ballast. Fresh ballast is regarded as 0% fouled whereas highly contaminated ballast that has no voids is regarded as 100% fouled. The limit for ballast fouling is 75%. The ballast replacement condition (BRC) also appears to be critical at a few locations where the BRC value is above the threshold of 1.4. Here ballast cannot perform to its optimum in terms of drainage, resiliency, lateral and longitudinal resistance [4]. Practically it is very difficult to screen wet ballast and hence the drainage problem should be addressed before screening. Screening is ineffective in wet conditions. Ballast evaluation results revealed that ballast is highly fouled in this section.

**Table 1: Summary of ballast fouling test results**

| Position | Depth (mm) | BRC | Fouling (%) |
|---|---|---|---|
| 2 | 200 | 1.56 | 103.2 |
| 5 | 250 | 1.20 | 53.0 |
| 9 | 300 | 1.32 | 86.1 |
| 14 | 200 | 1.10 | 72.9 |
| 20 | 250 | 1.15 | 103.9 |
| 25 | 200 | 1.17 | 112.5 |
| 27 | 200 | 1.09 | 92.2 |
| 34 | 150 | 1.39 | 76.7 |
| 38 | 400 | 1.42 | 66.2 |
| 45 | 180 | 1.14 | 41.7 |

At Beacon Hill the railway track has been under speed restriction (30 km/h) for over 5 years; the normal design speed at Beacon Hill is 90 km/h. The 1950's design shows deviations compared to modern day best practice. Currently, regular screening of the ballast and tamping take place in order to ensure that derailments do not occur. As of year 2014, the Rail Network Department (Ladysmith Depot) spends **R91 607.00** on average on track maintenance per month at the affected section. A further **R4 million** is spent on ballast screening/cleaning every 4 years.

## 3 NUMERICAL ANALYSIS – ROCK MASS RATING (RMR)

A geologic core logging report is then obtained from the contractor from within a Rock Mass Rating classification can be deduced as a weighted index from several parameters as derived by Bieniawski [5]. The RMR System expresses the most significant geologic parameters of influence with one overall comprehensive index. The main input parameters that are used in the computation of rock mass classification system include: Rock Quality Designation (RQD), UCS, Joint attributes, and groundwater and excavation orientation. RMR values for the different core holes can be presented as shown in ***Figure 10***. Columns in blue represent cores found within depths between collar and 1m; while columns in red indicate values between 1m and 2m. The RMR rating between 0 and 20 indicates a very poor formation profile, between 20 and 40 indicates a poor formation profile whereas the RMR between 40 and 60 indicates fair profile. From gathered results it is clearly evident that most of the problem is within 1m of the formation profile.

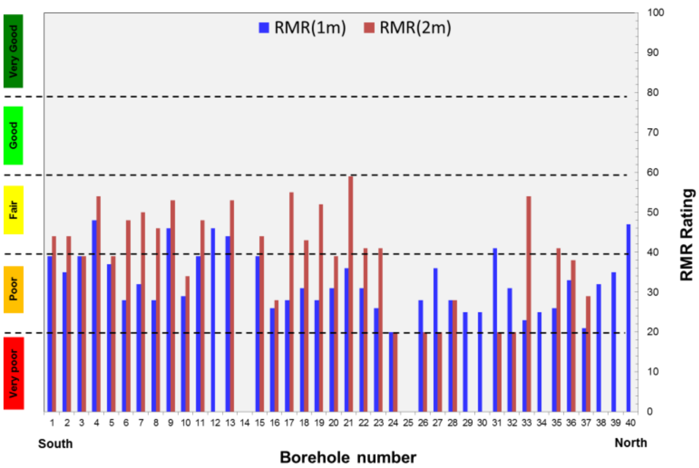


**Figure 10: Typical variation in RMR value**

## 4 CAMERA INSPECTION

Camera technology can then be employed to inspect holes and confirm position of voids and fractured zones. The camera inspection is desired because it shows the nature of in-situ condition, orientation and sizes of the fractures and cavities.

A typical hole from Beacon Hill tunnel was inspected and the clip, as shown in ***Figure 11*** as snapshot, shows that the rock there has alternating bands of solid intact and fractured structure zones.

**Figure 11: Typical camera inspection snapshot**

## 5 DISCUSSION

From the above investigation procedure, the following can be gathered:

The condition of drainage in the tunnel is very poor due to currently highly permeable rock mass within which the tunnel portals are founded coupled with lack of subsurface drainage. The deterioration of rock mass over the years has led to numerous interconnected underground streams to which the poor bedrock profile can be ascribed to. Bedrock failure resulted in underground water seeping on to the formation and mixing with fines, then causing pumping and also resultant superstructure failure (ballast deterioration, sleeper breakage, slacks and loose fastening system).

The cause of track geometry loss problem was clearly established, in this case not as originally suspected to be soft and very weak highly decomposed bedrock, but more to do with poor drainage conditions associated with fractures and cavities within the sedimentary profiles of bedrock mass. Mud pumping was the main indication on surface of formation failure associated with poor drainage. Rock type underlying the formation could also be described together with its properties. Formation profile material composition was also established and it could be drawn from the results that the non-uniformity of compaction and materials used contributed to the poor bearing strength to which the track geometry loss can be ascribed to.

During the water pressure tests and camera inspection activities the rock mass was proven to be highly permeable and also consisting of interconnected cavities as water seepage could be observed to large extents. The water disappeared into the ground when pumped in during the Lugeon testing. During camera inspections it quickly filled up (within seconds) an empty core hole that was pumped out completely at some chainage positions. Water samples were also collected for chemical and pH analysis but not much information was useful from the results, with the pH indicating neutrality ranging between 7.01 and 7.40.

The root cause of the water flowing inside the tunnel could also be confirmed as groundwater flowing under high artesian pressure within the mountain and the surface run off from the upstream cutting, as opposed to the initial suspicion that the water was due to the excess water from the portal frame roof experiencing leakages and hence causing lubrication of ballast.

Further modification of the available specialised equipment needs to be carried out in order to allow for a staggered core drilling pattern.

## 6 CONCLUSIONS

This paper described a procedure that can be used within TFR to investigate seepage and related track deterioration problems inside ballasted tunnels. Beacon Hill and Lowlands tunnels were used as case studies in collecting data and testing the viability of the work done which is proposed to be standardised as a procedure to be adopted within Transnet. This is only the first two case studies of listed ballasted tunnels with similar problem definition spread across the country, including the Cedara tunnel in the Natal midlands, Pieter tunnel near Ladysmith, the Kraal tunnel in the Highveld and numerous ones (approximately 10) in the Port Elizabeth regions.

As work is being planned for these other projects, more data will be collected and further modification of this proposed method is expected to unfold. This research work was motivated by the fact that most published work done within TFR consisting of the history of tunnel investigations was focused on slab tunnels. It is however to be emphasized that this research work seeks to standardize the method for investigation of the ballasted tunnels and not introduce a standardized solution.

The work done here has produced the desired result of parameters required to inform the design process for the remedial rehabilitation works of the tunnels. The procedure enables one to obtain information regarding the main source of water causing track deterioration and geometry loss, while different sources of the water inside the tunnel were determined. Subsurface and surface drainage including adequate impervious membranes and appropriate grouting if required can be incorporated into the design. All the results can then be combined to deduce the overall stability of the track inside the tunnel, adopting a Rock Mass Rating System of evaluating the integrity of the bedrock.

The procedure also enables one to do the program planning and scheduling for detailed investigation via a prioritisation method introduced from the visual inspection data. The research of the viability of this proposed procedure is ongoing as more tunnels are enlisted to be investigated. In addition to the above, a geological and hydrogeological study and finite element seepage modelling could be incorporated into the investigation method in the future anticipated projects [6]. Where there is sufficient flow, weir should be installed at the outlet in order to measure the amount of flow through the tunnel.

Innovative construction methods in rehabilitation of old ballasted tunnels can also be birthed from this research.

For the avid reader, the solution here included removing to spoil the substructure fill material and loose grit of highly fractured first meter of the bedrock mass, then sealing and water proof lining of the bedrock coupled with installation of subsurface drainage. The formation material will be replaced with mass concrete and track slab, with modifications to the surface drainage channel and tunnel portal wall lining. The details of design are beyond the scope of this paper and will therefore not be covered in depth.

## 7 RECOMMENDED FURTHER ADVANCES

Further advancements of this procedure will be to add the following tests for future test sites of this ongoing research:

- Petrographic analysis of the core samples to determine effects of weathering [7].
- Slake durability and ethylene glycol soak tests.
- In situ stress measurements are to be incorporated to inform recommendations related to excavation of rock mass during rehabilitation.
- Water seepage rate measurements and research into effect of ground water structures (eg. dykes and underlying streams) should be conducted.

## 8 ACKNOWLEDGEMENTS

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