

PREDICTION OF BALLAST RETURN FROM HIGH OUTPUT BALLAST CLEANERS (HOBC)

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ABSTRACT

Network Rail has recently acquired High Output Ballast Cleaners (HOBC) to increase the effectiveness and output of track renewals in the UK. One of the most important criteria to ensure efficient programming, correct application and utilisation of the HOBC plant is to accurately predict the volume of ballast returned to track and the subsequent amount of new ballast required for the renewal. Therefore, the rate of return of ballast to the track needs to be determined accurately prior to any renewal using HOBC.

This paper presents an extensive site investigation to evaluate ballast return on a planned HOBC site. Current recommended site investigation methods to evaluate ballast return, utilising trial pitting and sub-sampling are discussed. It was considered that a more rigorous approach should be adopted to identify locations along the track that give a more representative sample for ballast return assessment. It was also noted that pitting and sub-sampling is time consuming and is subject to human error. Thus, Automatic Ballast Sampling (ABS) was conducted in addition to the more traditional methods of sample recovery in a closely monitored site investigation. The predicted ballast recovery results based on both the ABS and trial pitting are compared and discussed, and the relative merits of both techniques identified.

INTRODUCTION

HOBC renewal involves specialised plant in order to produce consistent and high quality renewals in a very efficient manner over several kilometres of track in each possession. This type of renewal is being adopted by Network Rail to increase productivity on main lines which generally have limited track access. One of the most important criteria to ensure efficient programming, correct application and utilisation of the HOBC plant is to accurately predict the volume of ballast that will be returned to track and the subsequent amount of new ballast required for the renewal. This means that there is a need to accurately determine the rate of return of ballast to the track prior to any renewal using HOBC. This involves identifying suitable trackbed investigation techniques and producing a methodology to analyse trackbed investigation data.

This paper presents an extensive site investigation to evaluate ballast return on a planned HOBC site, which is 14 track miles long. Current recommended site investigation methods to evaluate ballast return, utilising trial pitting and sub-sampling are discussed. It was considered that a more rigorous and repeatable approach should be adopted to identify locations along the track that give a more representative sample for ballast return assessment. This approach requires an analysis of the track history such as the volumes of traffic, type of ballast material and maintenance history, and Ground Probing Radar (GPR) data. It was also noted that pitting and sub-sampling is time consuming and is subject to human error because it relies on engineering judgement. In addition, there is an inherent error in trial pitting and sub-sampling because the accuracy of the evaluation depends on the ballast condition or material. Thus, Automatic Ballast Sampling (ABS) was conducted in addition to the more traditional methods of sample recovery in a closely monitored site investigation. In order that the two methods

could be compared appropriately, both methods were performed in the same ballast cribs with trial pitting being performed after ABS. The predicted ballast recovery results based on both the ABS and trial pitting were compared, and the relative merits of both techniques identified. It should be noted that this is not the first time ABS has been used to evaluate ballast return. Matharu (1990) used ABS to evaluate ballast return on various section of track and found correlation with the actual ballast cleaner return. It is hoped to validate the analysis of the data summarised in this paper, with actual ballast returns from the HOBC where the works are performed.

CURRENT PRACTICE TO EVALUATE BALLAST RETURN

For decades, ballast cleaners have been in operation in the UK in a smaller production unit utilising Medium Output Ballast Cleaners (MOBC). Site investigation prior to renewal has concentrated on determining the type of renewal or suitability of renewal using ballast cleaners. Traditionally, an examination of the track foundation materials down to, and including, the subgrade has been carried out from a series of cross track trenches or trial pits (Selig & Waters, 1994). The evaluation of ballast return is then performed on these trial pits visually and/or by sub-sampling of a representative sample comprising material from the full depth of the excavation and including a relative proportion of all the different types of material encountered.

This gives a subjective evaluation as it relies on engineering judgement and the quality of this technique is not auditable. In addition, there is an inherent error in the evaluation of ballast return from trial pits where the accuracy of the evaluation depends on the ballast condition or material. For example, Figure 1 shows two sets of colour coded vertical bars representing materials encountered in a Trial Pit (TP) and an Automatic Ballast Sampler (ABS) conducted in the same crib (or adjacent cribs) at 2 different sites. The colour coded vertical bars correspond to a simplified materials key according to Network Rail’s Code of Practise (RT/CE/C/039, 2003) to identify and present typical trackbed materials (as shown in Figure 2). The ABS is an intrusive trackbed investigation technique consisting of a steel sampling tube with cutting shoe, which is driven into the trackbed using a hydraulically powered hammer as shown in Figure 3 (Sharpe, 1999; Middleton et al., 2005).

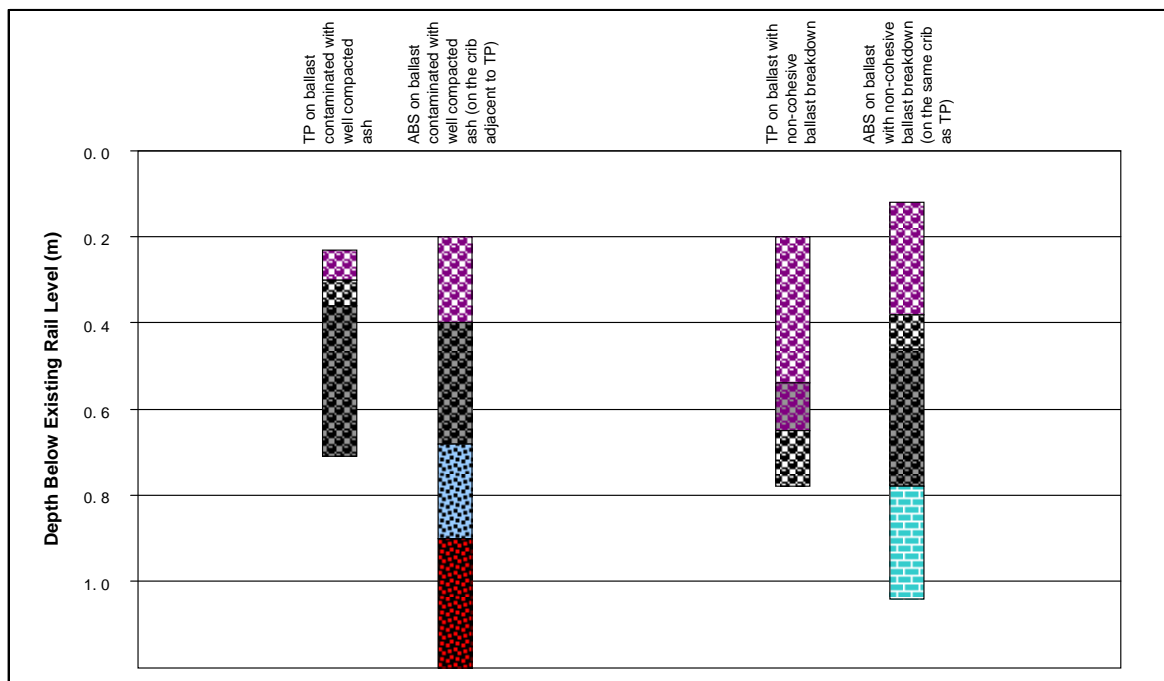






Figure 1: Colour coded vertical bars representing materials encountered in Trial Pit (TP) and Automatic Ballast Sampler (ABS) at two different sites.

1 BALLAST

a) With no subgrade erosion







- 1  Clean Ballast
- 2  Slightly Dirty Ballast
- 3  Dirty Ballast
- 4  Very Dirty Ballast (non-cohesive)
- 5  Very Dirty Ballast (cohesive)

b) With subgrade erosion

- 6  Slurried Ballast - recently placed
- 7  Slurried Ballast - old ballast
- 8  Ballast - Voids filled with silt/fine sand
- 9  Ballast - Voids filled with soft/firm clay

2 TRACKBED/FILL



a) Aggregates derived from naturally occurring sands and gravels (quoted sizes indicative only)

- 10  Fine Sand D = 0.06 to 0.20mm
- 11  Medium Sand D = 0.20 to 0.60mm
- 12  Coarse Sand D = 0.60 to 2.00mm
- 13  Sand and Gravel
- 14  Clayey Sand and/or Gravel
- 15  Slurried Sand and/or Gravel

b) Aggregates formed from crushed stone and industrial by-products


- 16  Well compacted weak rock - e.g. chalk
- 17  Well compacted crushed stone 90% <40mm
- 18  Stone dust - 90% <5mm
- 19  Chipping, <30mm single sized
- 20  Fine Ash (sand sized)
- 21  Coarse ash &/or slag/clinker (<50% coarse gravel size)
- 22  Coarse ash &/or slag/clinker (>50% coarse gravel size)
- 23  Other well-graded granular fill
- 24  Other poorly-graded granular fill
- 25  Any of the above in clay matrix
- 26  Any of the above contaminated with clay slurry

c) Formed from pitching stone

- 27  Clean Pitching
- 28  Slurried Pitching






3 EARTHWORKS

Fill patterns below can be used for embankment, made ground or cuttings





 Use legend with bold outline to indicate natural ground

Where appropriate use fill patterns given in Section 2 - Trackbed/Fill



a) Organic soils, clays and silts

- 29  Organic Soil
- 30  Soft Clay/Silt Cu < 40kN/m²
- 31  Firm Clay/Silt Cu = 40 to 75kN/m²
- 32  Stiff Clay/Silt Cu = 75 to 150kN/m²
- 33  Very Stiff/Hard Clay/Mudstone Cu > 150kN/m²

b) Hard Ground

- 34  Interbedded rocks, including clay or silt layers
- 35  Weathered, or weakly cemented fine grained rock
- 36  Weathered, or weakly cemented coarse grained rock
- 37  Hard rock

4 SAMPLE LOSS IN ABS

- 0x  Soil penetrated by ABS, but not recovered
- 0d  Soil displaced by ABS - indicative of very soft soil

5 ADDITIONAL INFORMATION

- g permeable geotextile separator
- c permeable geocomposite
- m reinforcing mesh (geogrid)
- p impermeable membrane (polythene)
- h heavy duty/composite membrane
- w water strike
- ws water standing
- 34 shear strength kN/m²
- e likely chemical contamination
- l >10% limestone ballast
- hs evidence of historical slurring

Figure 2: Simplified trackbed materials key (RT/CE/C/039, 2003).



Figure 3: Intrusive trackbed investigation - Automatic Ballast Sampling (ABS).



(a)



(b)

Figure 4: (a) Photograph of TP on ballast contaminated with well compacted ash; (b) Photograph of TP on ballast with non-cohesive ballast breakdown.

The first set of data in Figure 1, which represents the TP and ABS performed on ballast contaminated with well compacted ash, shows a consistent material log for both the TP and ABS (although the TP is slightly dirtier than the ABS [i.e. shallower clean ballast]). It should be noted that the material log from the TP is expected to show dirtier ballast because it represents ballast underneath the sleeper whilst the ABS represents ballast in the crib.

However, for the second set of data in Figure 1, the material log from the TP shows cleaner ballast than the material log from the ABS. The reason for this different outcome can be seen in Figures 4a and 4b, which show photographs from TP's on ballast with well compacted ash and ballast with non-cohesive ballast breakdown respectively. It can be seen in Figure 4a that the fine ash underneath the sleeper still adheres to the coarse ballast whilst in Figure 4b the non-cohesive fine ballast breakdown materials underneath the sleepers do not. TP's performed on ballast with fines that do not adhere to the coarse ballast would produce an artificially cleaner ballast assessment and result in an overestimation of ballast return.

Another potential problem with the traditional approach to examine ballast return using TP's is that these are generally performed along the track at wide spacings which may not give accurate interpretation of the ballast return for a section of track. Assessing ballast return visually and/or sampling ballast at TP performed at well spaced locations may not be truly representative and only show localised ballast condition. For example, a TP may be excavated in an area of localised formation migration, a wet bed, or a recently dug out wet bed area, which would give the wrong impression about the actual ballast return for a section of track.

IDENTIFYING LOCATIONS THAT GIVE REPRESENTATIVE SAMPLES FOR BALLAST RETURN ASSESSMENT

In order to perform ballast return assessment on a section of track, a systematic process is required to identify locations along the track that would provide sample from the average ballast condition of a section of track can be estimated. This process involves consideration of the track history (i.e. the volumes of traffic, type of ballast material and maintenance history) and analysing the Ground Probing Radar (GPR) trace.

The information on track history is important because ballast degradation for a section of track is a function of the volumes of traffic, the type of ballast material or ballast year, and the frequency of maintenance (Selig & Waters, 1994; Lim, 2004; McDowell et al., 2005). Figure 5 shows a 5 ¾ mile section of a track displaying the volumes of traffic, ballast year and the last 4 years of maintenance history for that section of track. The volumes of traffic and the ballast year were obtained from the Network Rail Engineering, Innovation and Examination (EIET) Database and the maintenance history was obtained from the local Network Rail track engineer. It can be seen in this plot that the track history varies along the track and sections of track with similar track history can be identified easily from this plot. It is likely that ballast return would vary from one section to another because of the different track history.

The GPR trace is also important to identify locations along the track that provide representative samples for the average ballast condition of a section of track because it provides the ballast profile and highlights localised problems such as areas with potential formation migration. The GPR is a non-intrusive trackbed investigation technique designed to identify anomalies in the trackbed so that targeted intrusive trackbed investigation can be performed (Sharpe, 1999; Middleton et al., 2005). Figure 6 shows a typical GPR trace with the heavier black/white/black interface representing the base of ballast (or at least clean granular material). It can be seen that ballast condition at location A is likely to represent the condition for around 660 yards of track whilst ballast condition at location B would not. It should be noted that ABS would still be performed at location B in Figure 6 to confirm ballast condition and investigate the source of shallow trackbed depth, but the sample would not be used to assess likely rates of return.

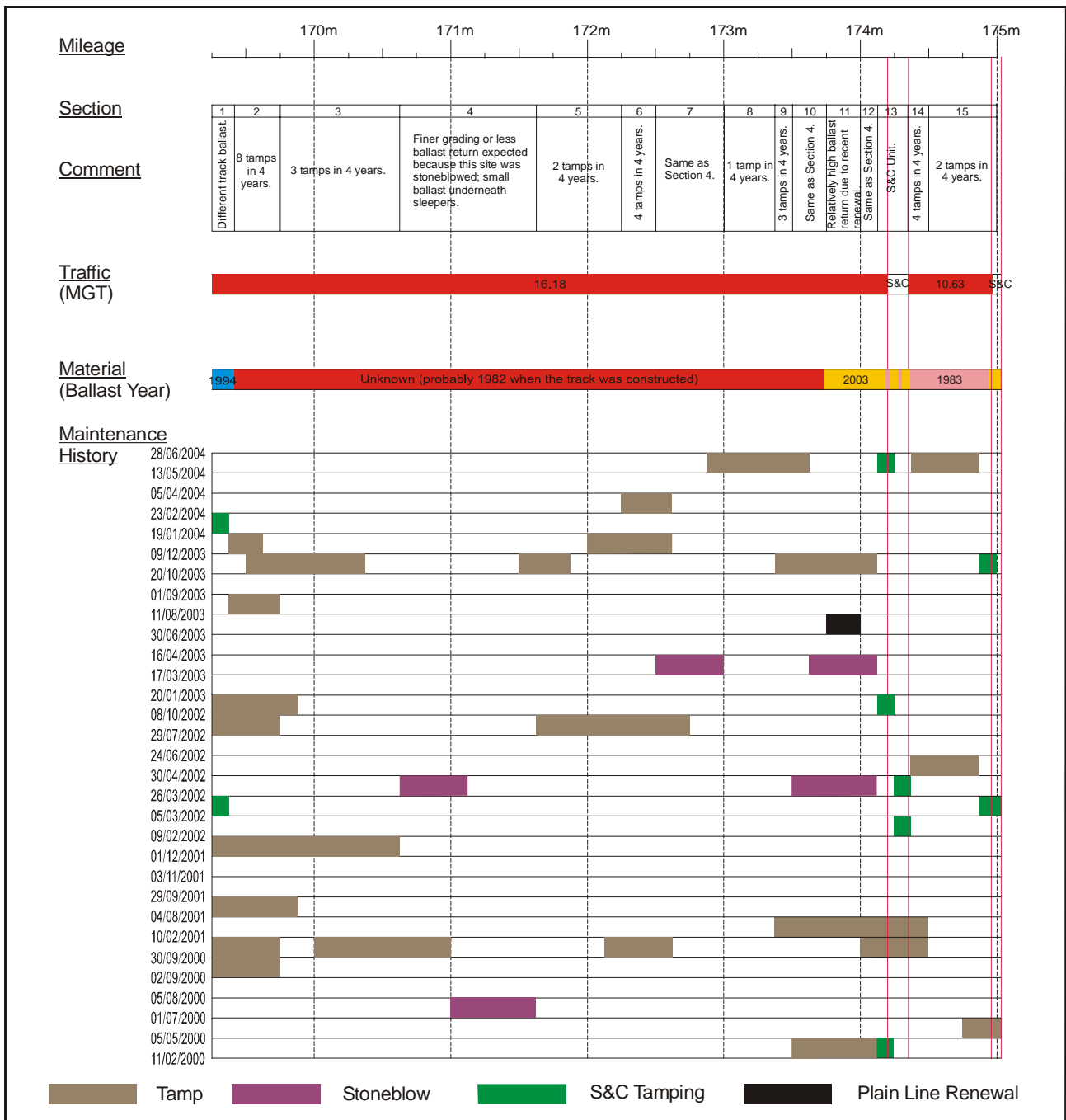


Figure 5: Example of section of a track displaying track history.

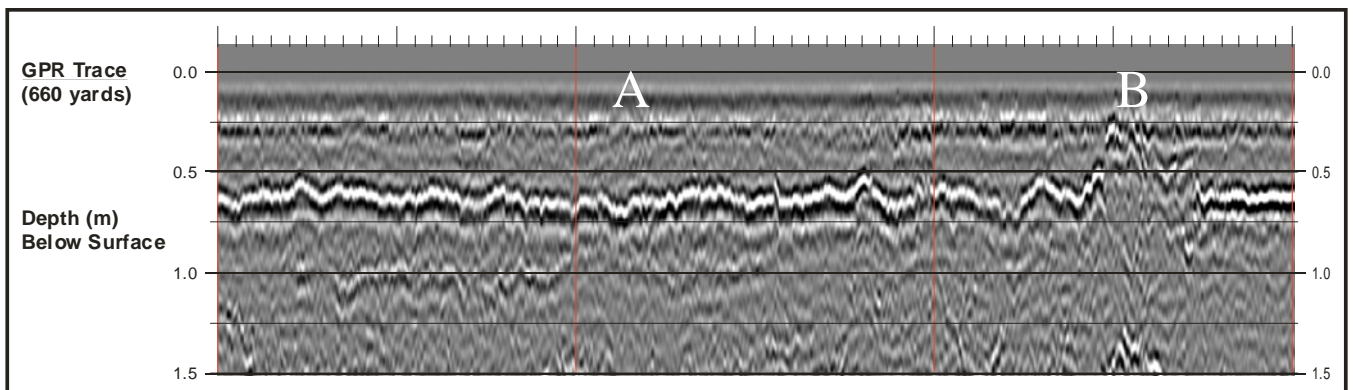


Figure 6: Typical GPR trace.

SITE INVESTIGATION

An extensive site investigation to evaluate ballast return on a planned HOBC site was performed recently by Scott Wilson Pavement Engineering (SWPE). The site investigation involved sampling ballast using ABS in addition to the traditional method of TP's so that both sampling techniques could be compared. For this purpose, both the ABS and TP's were performed on the same crib (Note: TP's were performed after ABS). Track history and the GPR trace were analysed as discussed in the previous section to identify locations along the track for trackbed investigation.

A total of 14 track miles were investigated over a 4 month period with all the site investigation performed during weekend night shifts. The technical advantages and disadvantages of using TP and ABS for ballast return analysis identified during this site investigation are presented in Table 1. It can be seen that ABS is a more reproducible and efficient method of sampling ballast which provides consistent data for ballast return analysis. However, it is noted that TP's are still the most appropriate and efficient method in assessing large ballast particles and variation of ballast condition across the crib.

The ballast return results from 81 sets of TP and ABS samples are presented in Figures 7 and 8, which show the percentage of ballast return using 28mm and 37.5mm sieves respectively. It should be noted that each sample was briefly hand sieved the next working day after sampling to minimise change in moisture content in each sample and allow loose fines to pass through, but some fines still adhere to the retained coarser particles. This sieving method was adopted to imitate the coarse ballast screening on the HOBC.

The results show ballast return from TP varies more than ballast return from ABS. The reason for this could be due to the subjective nature of sampling ballast from TP's, where different engineers that work on various shifts throughout the project would have a different judgement as to a 'representative sample'. Nevertheless, it is reasonable to conclude that the true ballast return at each location is somewhere between the ballast return from the TP and ABS (since it is likely that TP would overestimate ballast return and ABS would underestimate ballast return as discussed earlier).

Sampling Technique	Advantage	Disadvantage
TP	<ul style="list-style-type: none"> • Able to assess large particle size ballast; • Able to assess variation of ballast condition across the crib; • Large sample retrieved for ballast return analysis – approximately 30kg 	<ul style="list-style-type: none"> • Difficult to sample fines properly – may overestimate ballast return; • Inconsistency in retrieving “representative sample” for ballast return analysis; • Low output i.e. maximum 9 per shift; • Technique is difficult to audit for quality assurance
ABS	<ul style="list-style-type: none"> • Able to retrieve fines properly; • Consistent method in retrieving sample for ballast return analysis; • High output i.e. 25 samples per shift; • Good permanent record from recovered sample that can be audited 	<ul style="list-style-type: none"> • Difficult to sample large particle size ballast – may underestimate ballast return; • Only assess ballast condition at discrete area; • Small sample retrieved for ballast return analysis – approximately 3kg

Table 1: Advantages and disadvantages of sampling ballast using TP's and ABS.

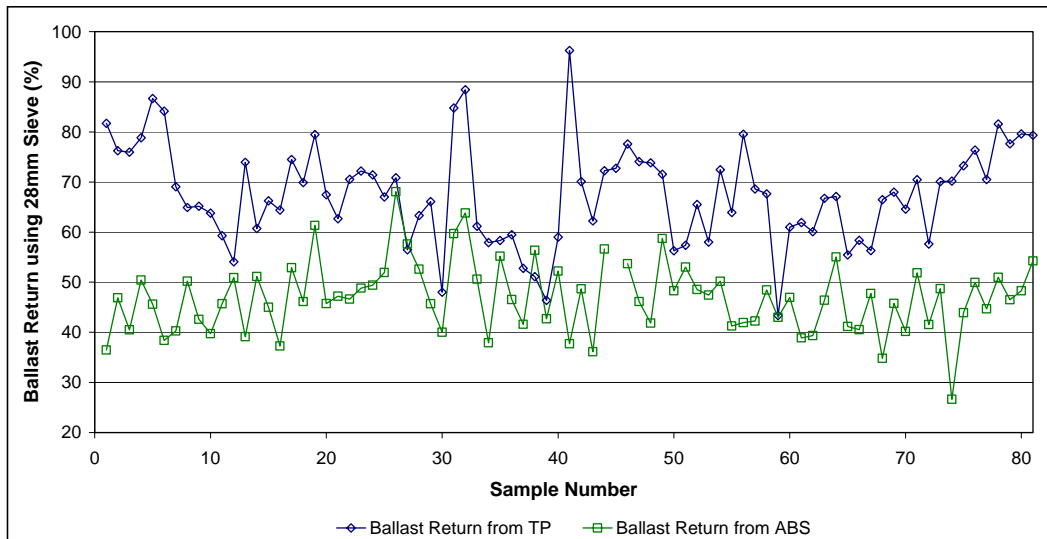


Figure 7: Ballast return from TP's and ABS using 28mm sieve.

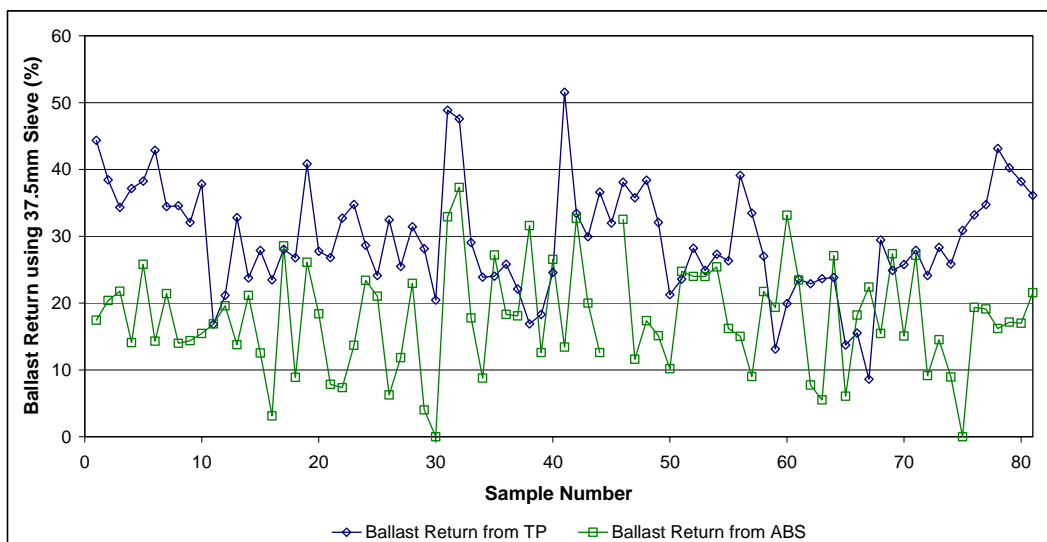


Figure 8: Ballast return from TP and ABS using 37.5mm sieve.

CORRECTED BALLAST RETURN FROM ABS

It has long been noted by many experienced SWPE personnel that the degree of sample loss in ABS is generally related to the amount of coarse ballast in the trackbed i.e. higher sample loss is expected when drilling ABS on a trackbed with large amount of coarse ballast particles. Sample loss is a term used to describe the difference in depth between the samples retrieved using the ABS and the actual ABS drill depth e.g. 0.1m of sample loss recorded if only 0.4m of sample retrieved when drilling to a depth of 0.5m. This is thought to be due to the size of the ABS tube (65mm diameter) which is too small to sample coarse ballast particles properly. Therefore, it can be assumed that sample loss is a measure of “lost” coarse ballast particles (e.g. that would be retained on a 28mm sieve).

From this, a methodology which utilizes the measured sample loss recorded during each ABS has been produced to correct the ballast grading obtained from the ABS. The corrected ballast return from ABS results together with the ballast return from the TP and the raw ABS results are shown in Figures 9 and 10. It can be seen that the corrected ballast return generally falls within ballast return from the TP and the raw ABS (previously suggested as the upper and lower limits).

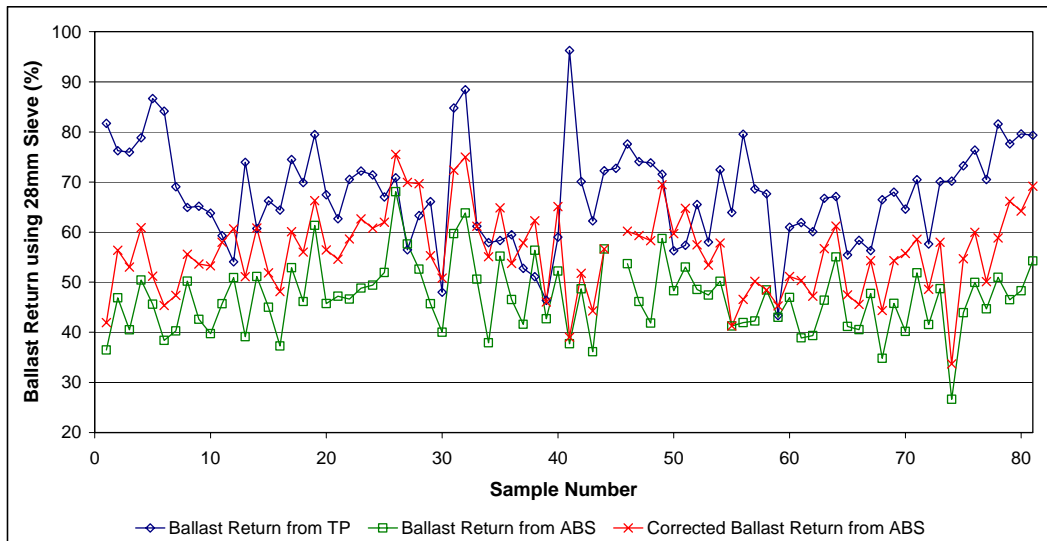


Figure 9: Ballast return from TP, raw ABS and corrected ABS using 28mm sieve.

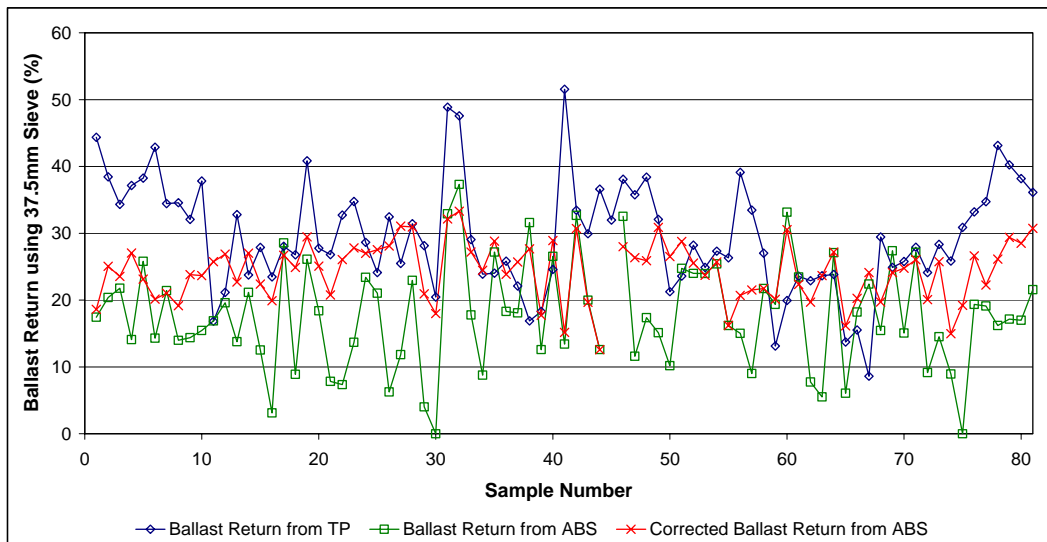


Figure 10: Ballast return from TP, raw ABS and corrected ABS using 37.5mm sieve.

It is noted that the difference between the corrected ballast return from one sample to another is generally small, which is consistent with the visual ballast return assessment as shown in Figures 11 and 12. The visual ballast return assessment is based on a subjective assessment of the ABS material log to produce a score that evaluates ballast return. It can be seen in Figures 11 and 12 that the majority of the samples recovered during this work were in the Moderate ballast return category (that is, slightly dirty to dirty ballast).

It is noted that there is a good correlation between the visual ballast return assessment and the corrected ballast return from ABS. For example, the average corrected ballast return from ABS using 28mm sieve for all the High ballast return, Moderate ballast return and Low ballast return are 65%, 54% and 45% respectively; and for the average corrected ballast return from ABS using 37.5mm sieve are 28%, 24% and 14% respectively. It is also noted that the predicted ballast returns are reasonable compared to the expected ballast return from new track ballast specified in RT/CE/S/006 (2000) as shown in Table 2. It can be seen that the average ballast returns for new ballast is around 50% for ballast cleaning using a 37.5mm sieve and around 90% for ballast cleaning using a 28mm sieve.

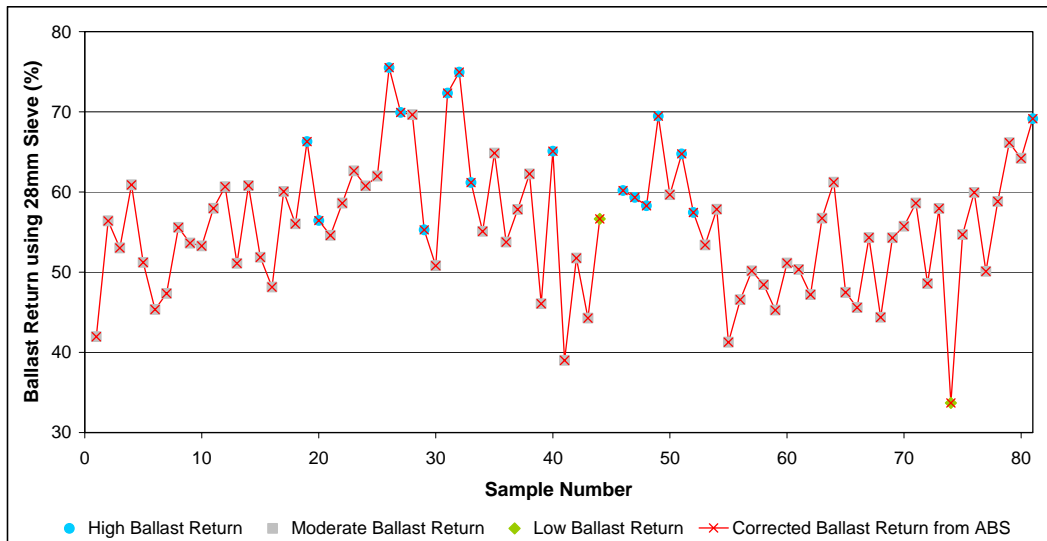


Figure 11: Visual ballast return assessment and corrected ballast return from ABS using 28mm sieve.

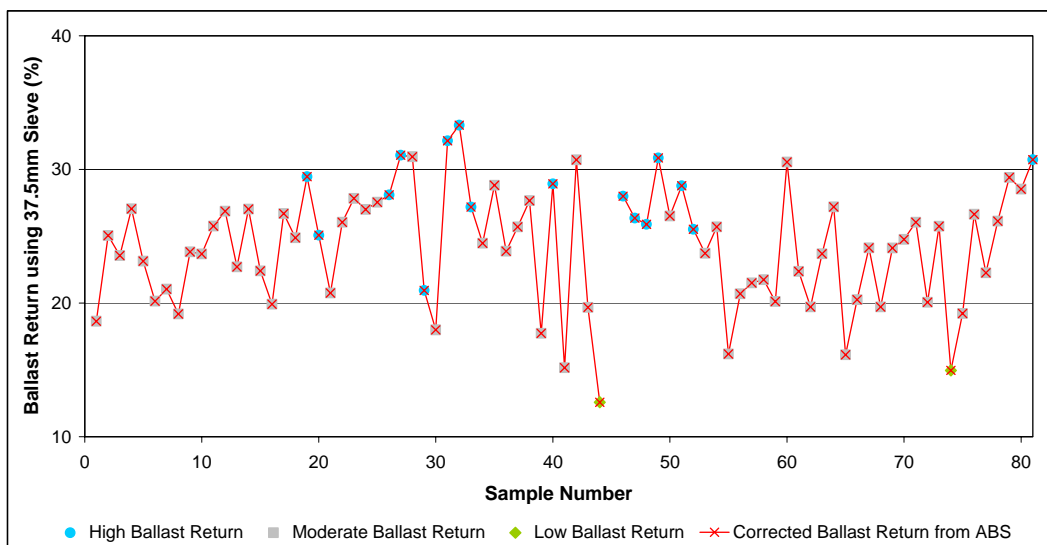


Figure 12: Visual ballast return assessment and corrected ballast return from ABS using 37.5mm sieve.

Square Mesh Sieve (mm)	Cumulative % by weight passing BS sieve
63	100
50	100-97
37.5	65-35
28	20-0
14	2-0
1.18	0.8-0

Table 2: Specification for new ballast particle size distributions (RT/CE/S/006 Issue 3, 2000)

TRUE BALLAST RETURN

The true ballast return for a section of track will only be known if all ballast in that section of track is sieved i.e. after ballast cleaning. The sources of ballast fouling are well documented in Selig & Waters (1994) which shows that variation in ballast condition or ballast return along the track is inevitable. Trackbed investigations are limited to investigating trackbed at specific or targeted locations and provide

best evaluation of ballast return for a section of track. It should also be noted that ballast return obtained from a sample depends on the ballast condition i.e. moisture content of ballast. For example, a lower ballast return would be obtained from sieving a dryer sample because fewer fines would adhere to the retained coarser particles. Therefore, the predicted ballast return obtained from the site investigation would inevitably be different from the ballast return from the actual ballast cleaning, if weather conditions varied significantly from site investigation dates to actual renewal dates.

Due to the expected variation of ballast return results, a consistent and reliable site investigation technique is crucial to minimise further variation. Therefore, ABS is considered a better sampling technique for ballast return analysis than TP because of the consistent method of sampling ballast, which does not require engineering judgement. In addition, ABS is also the most economical because of high output (i.e. 25 ABS compared to 9 TP per shift – see Table 1) and can be carried by technicians with relatively little trackbed experience. (Note: materials still need to be logged by experienced trackbed staff in the laboratory).

The method of predicting ballast return from HOBC presented in this paper is not an attempt to predict the absolute ballast return from the HOBC, but the relative ballast return for a section of track or route. For example, Figure 13 shows the final product of the ballast return analysis for the 14 track miles investigated. This analysis involved the corrected ballast return from ABS for all those sampled locations except where problems such as formation migration were evident. The figure shows the average percentage of ballast return for the preceding 880 yards using 28mm sieve e.g. ballast return at 172 miles 0 yard is the average ballast return from 171 miles 880 yards to 172 miles 0 yard. From Figure 13, it can be said in general that the ballast return from 171 miles 880 yards to 174 miles is approximately 10% higher than ballast return from 169 miles 0 yard to 171 miles 880 yards.

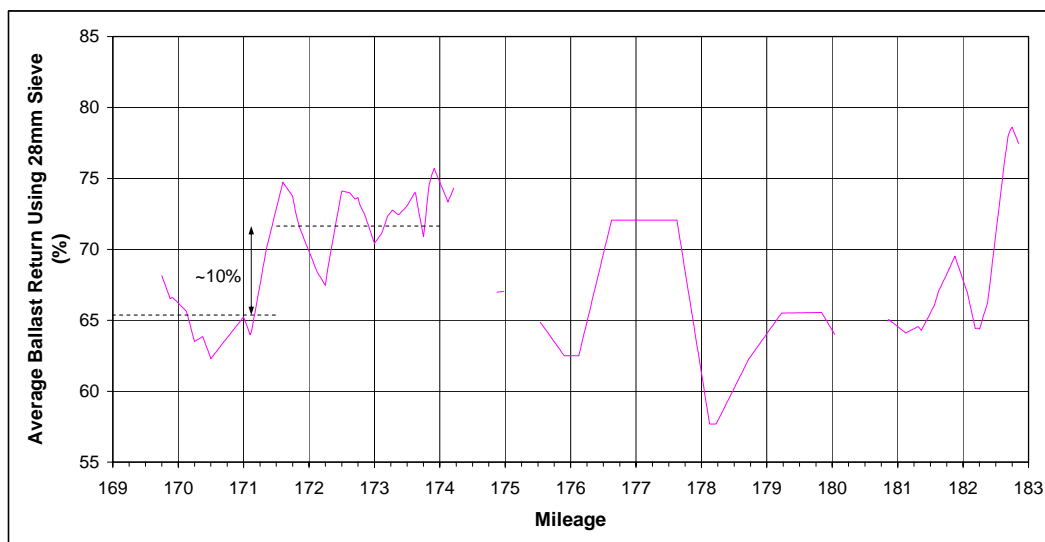


Figure 13: Average percentage of ballast return for the preceding 880 yards using 28mm sieve.

SUMMARY

HOBC renewal produces a consistent and high quality renewal in a very efficient manner. This type of renewal is being adopted by Network Rail to increase the renewal productivity on main lines which generally have limited track access. One of the most important criteria to ensure efficient programming, correct application and utilisation of the HOBC plant is to accurately predict the volume of ballast returned to track and the subsequent amount of new ballast required for the renewal. Therefore, suitable trackbed investigation techniques need to be identified to estimate the rate of return of ballast to the track prior to using HOBC.

Traditionally, evaluations of ballast return have been performed through examination of trial pits, visually and/or by sub-sampling of a representative sample. The main drawback of this technique is the subjective nature of the evaluation, as it relies on engineering judgement which may vary from one engineer to another.

A systematic and repeatable approach needs to be adopted to identify locations along the track that give a more representative sample for ballast return assessment. This approach involves consideration of the track history to identify sites which are likely to have similar ballast return. This analysis also includes use of GPR data to identify locations within a site that would give a representative sample for that site.

A site investigation recently performed to evaluate ballast return on a planned HOBC site noted that ballast return from TP's is likely to be an overestimate and ballast return from ABS is likely to be an underestimate. From this, it is reasonable to conclude that the true ballast return at a specific location will fall between the ballast return from the TP's and ABS.

A methodology that utilizes the sample loss recorded on each ABS has been produced to correct the ballast grading obtained from the ABS. The main concept behind this methodology is that sample loss is a measure of the "lost" coarse ballast particles (e.g. that would be retained on a 28mm sieve) during ABS. The ballast return obtained through this methodology is encouraging because it generally falls within the upper and lower limits of ballast return from the TP and the raw ABS.

The true ballast return for a section of track cannot be accurately identified through trackbed investigation because it is limited to investigating specific or targeted locations. In addition, the varied ballast condition during the site investigation and during renewal (specifically moisture content of the materials) means that the predicted ballast return will be different during these scenarios. The method of predicting ballast return from HOBC presented in this paper is not an attempt to predict the absolute ballast return from the HOBC, but the relative ballast return throughout a route. ABS is considered a more consistent sampling technique for ballast return analysis than trial pits for this purpose.

ACKNOWLEDGEMENTS

This Paper is dedicated to the memory of Richard Allen.

REFERENCES

- 1) Lim, W. L (2004). *Mechanics of Railway Ballast Behaviour*. Ph.D. dissertation, The University of Nottingham.
- 2) Matharu, M. S. (1990). The Effect of Ballast Grading on Ballast Cleaner Return and Track Level Following Cleaning. *British Rail Research Technical Memorandum* TM TD 051, December 1990.
- 3) McDowell, G. R., Lim, W. L., Collop, A. C., Armitage, R. & Thom, N. H. (2005). Laboratory simulation of the effects of train loading and tamping on ballast performance. *Proceedings of the Institution of Civil Engineers – Transport*. Volume 158, Issue TR2, pp. 89-95.
- 4) Middleton, S., Brough, M. & Armitage, R. (2005). Maintenance Liability Sites: Earthworks & Subgrade Failure Case Studies Newham Bog & Haywood Level Crossing. *Paper submitted to the 8th International Conference on Railway Engineering, 29-30 June 2005*.
- 5) Network Rail Code of Practice (2003). RT/CE/C/039. *Formation Treatments*.
- 6) Railtrack Line Specification (2000). RT/CE/S/006 Issue 3. *Track Ballast*.

- 7) Selig, E. T. & Waters, J. M. (1994). *Track Geotechnology and Substructure Management*. Thomas Telford. London.
- 8) Sharpe, P. (1999). Trackbed Investigation. *Journal and Report Proceedings of the Permanent Way Institution*. Volume 118, Part 3, pp. 238-255.