Materials and Trackbed Design for Heavy Haul Freight Routes : Case Study

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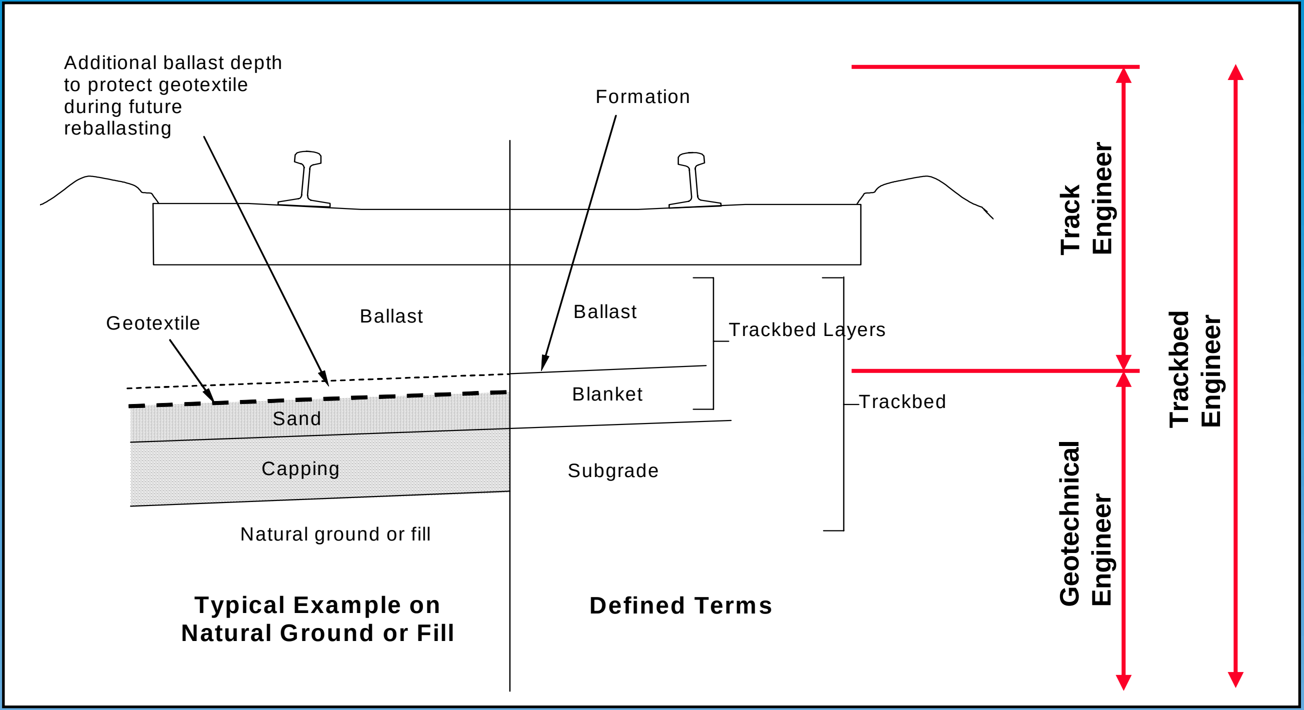
Trackbed Design : The basics

- ## Definitions



Trackbed Design : The basics

- ## Failure Mechanisms

TYPE	CAUSES	FEATURES
Progressive shear failure	•Repeated over-stressing of subgrade •Fine-grained subgrade soils •High water content	•Squeezing near subgrade surface •Heaves in crib and/or shoulder •Depression under ties
Excessive plastic deformation (ballast pocket)	•Repeated loading •Soft or loose soils	•Differential subgrade settlement •Ballast pockets
Attrition with mud pumping	•Repeated loading of subgrade by ballast •High ballast:subgrade contact stress •Clay rich rocks or soils •High water contact at subgrade surface	•Muddy ballast •Inadequate sub ballast •Poor ballast drainage
Liquefaction	•Repeated loading •Saturated silt and fine sand	•Large displacement •More severe with vibration •Can happen in sub-ballast
Massive shear failure (slope stability)	•Weight of train, track and subgrade •Inadequate soil strength	•High embankment and cut slope •Caused by increased water content
Consolidation settlement	•Embankment weight •Saturated fine-grained soils	•Increased static soil stress as in newly constructed embankment
Frost action (heave and softening)	•Periodic freezing •Frost susceptible soils	•Occurs in winter/spring period •Rough track surface
Swelling/Shrinkage	•Highly plastic soils •Changing moisture content	•Rough track surface
Slope erosion	•Running surface and sub-surface water •Wind	•Soil washed or blown away
Soil collapse	•Water inundation of loose soil deposits	•Ground settlement

Trackbed Design : The basics

- **Methods of Site Investigation**
- **Desk Study**
  - **Walkover Survey, Site History, Asset condition, Geology**
- **Non Intrusive Techniques**
  - **Geophysics (e.g. Ground Probing Radar [GPR])**
  - **NDT (e.g. Falling Weight Deflectometer [FWD])**
- **Intrusive Techniques**
  - **Trial Pitting ([TP] including Materials Sub-sampling, Shear Vane, DCP, Plate Bearing Test)**
  - **CPT/SPT**
  - **Automatic Ballast Sampling (ABS) / Window Sampling**
- **Monitoring**
  - **Piezometers, Accelerometers**
- **Modelling**

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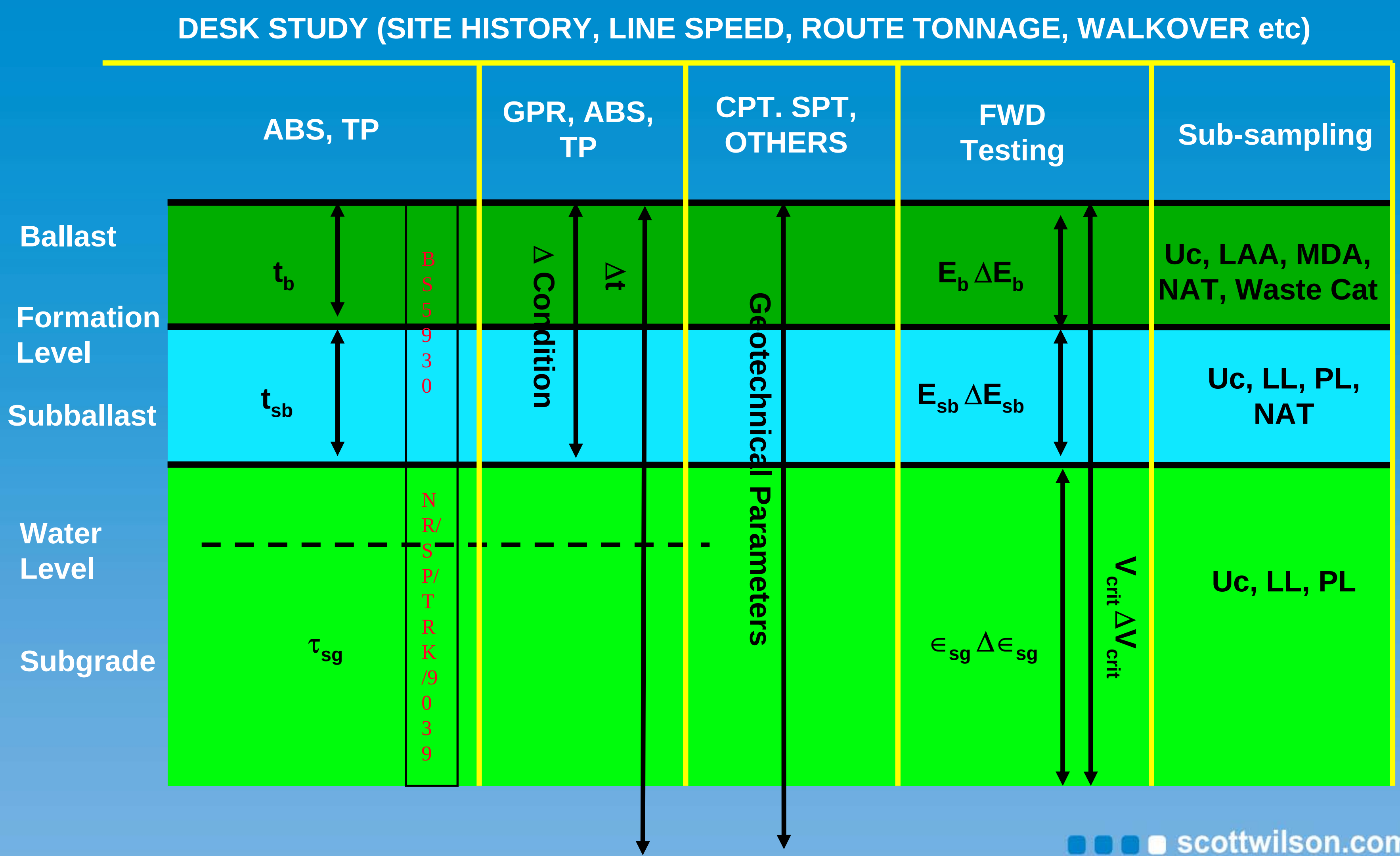
Trackbed Design : The basics



Network Rail Requirements (CAT 1A)

- High Line Speeds (>125 mph)
- Mixed passenger / freight traffic (25t axle loads)
- Track quality and component driven
- Needs to be maintainable and make use of existing assets where possible
- Design life (25 to 30 years? – not always)
- 300mm ballast (minimum or maximum)
- Geotextiles / geogrids / geocomposites

Heavy Haul Freight Requirements

- Reduced Line Speeds (15 to 50 mph)
- Freight Traffic (30 to 40t Axle loads)
- Freight tonnage, production (line speed) and safety driven (derailment)
- Needs to be maintainable (reactive maintenance)
- Design Life (10 years or life of resource?)
- ?mm ballast (300mm minimum)
- Geotextiles / geogrids / geocomposites

Case Study : The Brief

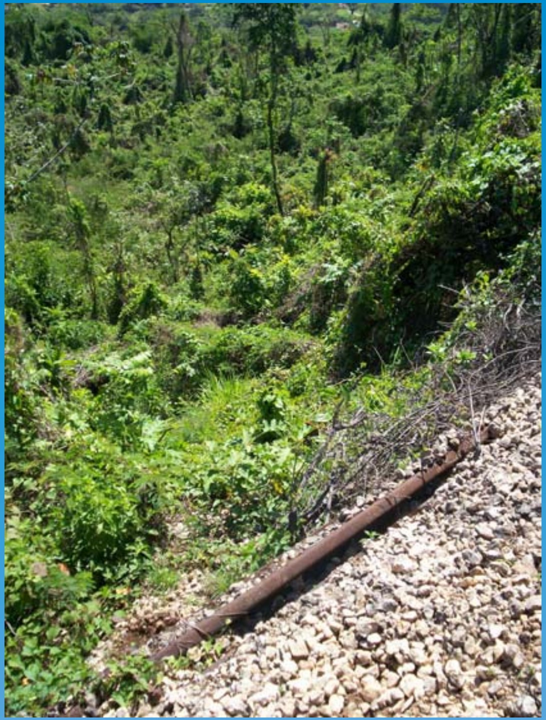
- Alternative Bauxite source identified to replace current source
- Major infrastructure required including 22 miles route upgrade (comprising 10 miles operational, 8 miles mothballed, 4 miles new build)
- Doubling of Freight Traffic Volume and Axle Loading
- Needs to use local materials, staff and resources where possible

Case Study : Design Parameters

- Static Axle Load of 32 tonnes, becoming 38 tonnes when dynamic factor accounted for
- 15 to 20 MGTPA
- Maximum line speed 40mph
- Equivalent to CAT 3 / CAT 2 line
- Design Life of 10 years
- Local Stone specified for ballast use
- Timber sleepers and Jointed Rail

Case Study : Desk Study

- Topography – Rock cutting, steep embankments and sidelong ground



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Case Study : Desk Study

- **Geology**
  - **Newport Limestone Formation**
  - **Highly voided due to chemical dissolution (Karstification)**
  - **Variable bedrock profile with characteristic Sinkholes, subterranean caves, open joints and solution cavities**

  - **Terra Rossa Soils**
  - **Extremely high plasticity red/brown gravelly clay (PI > 70)**
  - **Occurs as an incomplete and variable soil cover and as solution cavity infilling within the limestone**

Case Study : Desk Study

- **Drainage generally absent or inadequate where present comprising cess trenches and undertrack box culverts**

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Case Study : Desk Study

- **Major flooding events and significant washout of ballast affect the area of track in the river valley on an annual basis.**

Case Study : Desk Study

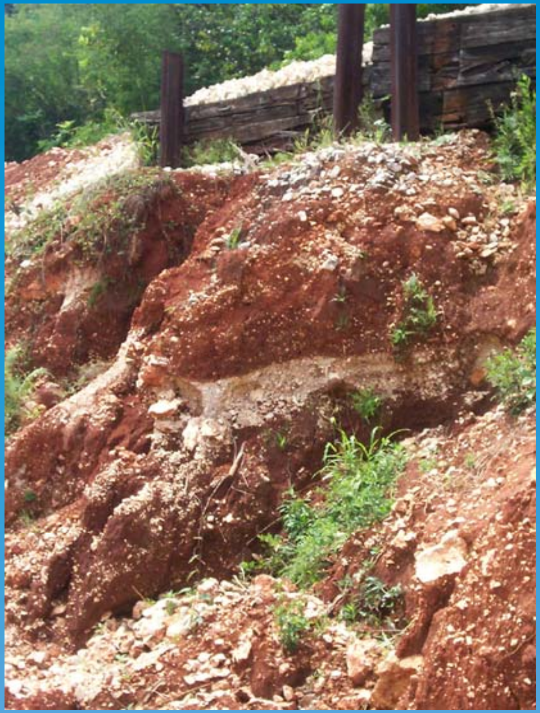
- **The majority of the trackbed and components are at the end of their design life**

Case Study : Desk Study

- **Structures**

Case Study : Desk Study

- **Maintenance and spot renewal occur on a reactive rather than a proactive basis, generally at the end of the wet season where washouts occur.**



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Case Study : Desk Study

- **Reballasting and 'topping up' ballast levels where problems occur has resulted in significant raising of the track and excessive ballast depth.**

Case Study : Desk Study

- Overview
  - Derailment is common;
  - Most components life expired;
  - Geology / Hydrology / Topography is a major factor influencing Trackbed Design;
  - Reactive maintenance and renewal;
  - Historic Problems with ballast deterioration.

Case Study : The Ballast

- Ballast Characteristics
  - Limestone ballast with fines generation a problem;
  - Ballast grading typically finer, more uniform and quality control a potential issue;
  - Flakiness and angularity not deemed to be a problem;
  - Regardless of properties, material has been specified for use.

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Case Study : The Ballast

- Ballast Functions
  - Resist vertical, lateral and longitudinal forces to retain track in its required position;
  - Provide voids for fouling material storage, and movement of particles through the ballast;
  - Facilitate maintenance operations to adjust track geometry;
  - Provide immediate drainage of water falling onto the track;
  - Reduce pressures from the sleeper to acceptable stress levels for the underlying material.

Case Study : The Ballast

- Tests for Particle Characteristics
  - Durability Tests (LAA, WAV, MD, ACV);
  - Shape Tests (Flakiness, Elongation);
  - Gradation;
  - Environmental (e.g. Freeze thaw);
  - Identification and Composition (Petrographic / Chemical analysis);
  - Performance (Stiffness testing).

- Problem in assessment is that the effects of particle characteristics can have both positive and negative effects on performance (in relation to ballast function)

Case Study : The Ballast

- Design for this material, however implications of material use need to be identified (compare with NR spec ballast)
- The specification has been used as a benchmark, and the implications of non-compliance on performance of ballast functions discussed.
  - Resistance to fragmentation - Los Angeles Abrasion (LAA)
  - Resistance to wear – Micro-Deval Abrasion (MDA)
  - Grading BS 812 Section 103.1 (1985).
- Further testing was also performed to assess the ballast resilient stiffness, and effect of compaction and dynamic loading on ballast degradation using the Springbox test:
  - Springbox Testing (Design Manual for Roads and Bridges Volume 7 Section 2 HA25/06 (IAN) Appendix C: Stiffness Testing).

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Case Study : The Ballast

Ballast Test or analysis	Case Study Ballast	UK Ballast	NR/SP/TRK/006 requirements	Case Study:UK Ballast Ratio
LAA (fragmentation)	27	8	Must not exceed 20	3.4
MDA (Wear)	20	7	Must not exceed 7	2.9
Spring Box (SB) Testing - Hardins Total Breakage (B_t) - after compaction	0.05	0.00	Not applicable	Negligible breakdown for UK ballast
SB Testing - Hardins Total Breakage (B_t) - after compaction and loading	0.09	0.00	Not applicable	Negligible breakdown for UK ballast
Abrasion Number (AN) = LAA + 5MDA	127	43	Not applicable	3.0

Ballast Life

- Dependant upon aggregate strength and durability properties, grading characteristics, shape and loading environment to name but a few;
- Importantly dependant upon the ballast failure criteria (when is ballast classed as life expired for the user? When choked with fines, when track quality affected, when the track does not respond to tamping or when there is risk of derailment?);
- One method of assessing ballast life using the AN is that specified by Canadian Pacific Railroad (ballast classed as life expired due to fouling due to traffic loading)

Can we improve?

Ballast life (using CPR approach) – assuming 20MGTPA	< 2 years	>35 years	Not applicable	or the UK ballast lasts 16 times longer than the Case Study ballast

Case Study : The Ballast

Grading Number	Max Size	Percent by weight smaller than specified sieve								
	mm	64	51	38	25	19	13	9.5	4.8	0.075
2	50	-	100	90-100	70-90	50-70	25-45	10-25	0-3	0-2
3	50	-	100	90-100	70-90	30-50	0-20	0-5	0-3	0-2
4	50	-	100	90-100	20-55	0-5	-	-	0-3	0-2
5	62.5	100	90-100	35-70	0-5	-	-	-	0-3	0-2

Grading	Max size	Percent by weight smaller than specified sieve					
Network Rail Spec	mm	63	50	40	31.5	22.4	32-50
	n/a	100	70-100	30-65	0-25	0-3	>=50% to be within these limits

Ballast gradings 2 and 3 shall be used for crushed gravel

Ballast gradings 4 shall be used for crushed gravel, crushed rock or slag

Ballast gradings 5 shall be used for crushed rock or slag

Taken from Klassen *et al.* (1987)

Case Study : The Ballast

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Gradation	4 Coarse Uniform (20-32mm) >90%	5 Coarse Uniform (20-50mm) >90%	>=50% within 32-50mm	NR Ballast mean size coarser and broader Grading

More research needed, spec needs to be performance based

Effects of Gradation

- Broadening the gradation should decrease cumulative plastic strain, decrease particle degradation and increase strength / stiffness properties of the ballast;
- However, coarser, more uniform grading should increase ballast life because of an increased voids storage capacity and less restriction to downward movement of fines

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Case Study : The Ballast

- **Resilient Stiffness**
  - Resilient stiffness increases with bulk stress;
  - Case Study ballast has slightly higher resilient stiffness than the Case Study ballast (post immersion in water) and the dry UK ballast;
  - Many variables in the determination of resilient stiffness;
  - Although resilient stiffness equivalent, the layer stiffness will potentially deteriorate due to reductions in the layer's ability to freely drain with fines production;
  - Case Study Ballast produced 3 times more fines than NR Ballast, however fines non-plastic.

Case Study : The Ballast

- **Overview**
  - **The Case Study ballast is considerably poorer than the typical UK Network Rail ballast tested.**
    - **more susceptible to degradation and fracture with significant effects on the perceived ballast life due to fines accumulation in the voids.**
    - **Although stiffness is comparable, aggregate degradation is likely to result in stiffness reductions, influenced by local factors such as drainage.**
  - **Although this may result in a maintenance liability for the purposes of this project this may not be a cause for concern to the client.**

Case Study : Trackbed Design

- Ongoing
  - Ballast source has been specified – Design for the materials available
  - Ballast depth will be critical – several methods being considered including
    - Network Rail Line Standards – Minimum Depth
    - International Methodologies (French, American)
    - Simple Linear Elastic Models
  - Washout a major problem - Lineside Drainage key;
  - Stiffness transitions and underlying earthworks / geology a major consideration – geogrids, geowebs

Case Study : Overview

- Materials and Trackbed Design Methodology required for Heavy Haul Freight Routes;
- Revised Specifications required to be more performance based;
- Detailed in Paper to be presented at conference later in the year (Railfound 06);