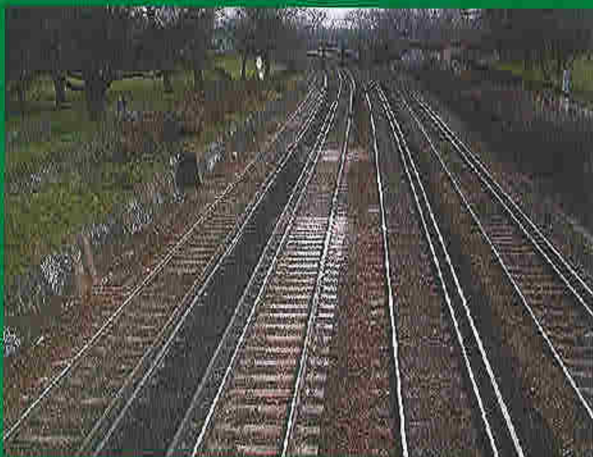
BALLAST, DRAINAGE AND FORMATION

GOOD PRACTICE GUIDE



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Railtrack PLC (in Railway Administration)

Alan Bloom, Chris Hill, Scott Martin and Mike Rollings were appointed Joint Special Railway Administrators of Railtrack PLC on 7th October 2001

The Joint Special Railway Administrators act as agents of the company and without personal liability

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Railtrack PLC (in Railway Administration) have produced a video "Repair of Wet Beds" which should be used in conjunction with this book.

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FOREWORD

The substructure is the foundation of the track and is critical to its performance, quality and safety. Due to the high cost of remedial work, whether manual maintenance or renewal, it is always economical to carry out the investigations and assessments described in this book. Ground Probing Radar is the normal method of assessing the depth and variation of substructure layers. This will be supplemented by Automatic Ballast Sampling, Trial Holes and Sample Grading as appropriate.

Treatment of Wet Beds should be carried out early in their development, preferably when they are first showing as voids or are affecting one sleeper. This will avoid reduction in asset life as well as poor geometry and potential safety risks. If the techniques in this book are adopted, long lasting repairs will be achieved.

Drainage is the most important aspect of track maintenance. Attention to cleaning, maintenance and effectiveness of drainage will be repaid with future good geometry and reduced costs.

DAVID VENTRY, B.Eng., C.Eng., FICE, FPWI

HEAD OF TRACK ENGINEERING

1. TRACK SUBSTRUCTURE COMPONENTS

1.1 DEFINITIONS

1.1.1 Track Substructure

The track substructure comprises all layers of materials between the underside of the sleepers and the top of the subgrade. This includes the ballast, sub-ballast, blankets and any geosynthetic materials.

1.1.2 Sub-Ballast (Bottom Ballast)

Sub-ballast is a layer of granular material sometimes placed immediately beneath the main ballast layer. It is sometimes known as 'Bottom Ballast'.

1.1.3 Blanket

A blanket is a layer, usually of carefully graded sand, interposed between the ballast and the subgrade, particularly if the latter is clay. The subgrade can, in some circumstances, also act as a blanketing layer.

1.1.4 Geosynthetics

Geosynthetic is the generic name given to a man-made polymer sheet in the form of either a geogrid, geotextile or geomembrane which may be incorporated into the track substructure.

1.1.5 Subgrade

The subgrade is the material supporting the track substructure and may be either the naturally occurring ground or comprise one or more layers of imported fill material. In either case the top surface in contact with the track substructure will have been prepared or profiled at the construction stage of the track.

1.1.6 Capping Layer

This is a layer of material, usually hard and impervious, applied to the top surface of the subgrade during the construction of the track.

1.2 FUNCTIONS

1.2.1 General

The subgrade and each layer in the track substructure have their own specific functions, although some overlapping may occur.

If problems are to be correctly diagnosed and treated, senior track staff must understand the function of each element of the track supporting structure.

1.2.2 Ballast

The ballast has four main functions. It must:

a) Provide vertical and lateral stability to the track substructure.

b) Permit the track level to be adjusted by manual or mechanical means.

c) Be free draining.

d) Adequately spread load to the next layer in the track substructure.

1.2.3 Sub-Ballast (Bottom Ballast)

The sub-ballast, where present, has two main functions. It:

a) Reduces the traffic induced stresses at the surface of the subgrade.

b) Provides a frost protection barrier to a susceptible subgrade, when necessary.

In addition the presence of sub-ballast may:

- prevent penetration of the subgrade by the ballast
- prevent upward migration of the subgrade particles into the ballast
- prevent attrition of the subgrade

The complete specification for ballast to be used on Railtrack Infrastructure is given in Company Standard RT/CE/S/006.

1.2.4 Blanket

The primary role of a blanket is to prevent upward migration into the ballast of fine particles originating from clay subgrades. Whilst this role can sometimes be effectively achieved by the sub-ballast, if present, this will often result in the sub-ballast becoming contaminated by fines and ultimately allow these to penetrate the ballast.

A blanket can be effective if provided by a layer of well graded sand laid to a thickness of 100mm, with a geotextile separator between ballast and blanket, so long as the blanket has been laid accurately. Thicknesses usually range from 150mm to 200mm to allow for some unevenness at the bottom of the cut surface.

The current Railtrack Company Standard for blanketing sand is RT/CE/S/033.

Sand Blanket

1.2.5 Geosynthetics

1.2.5.1 Geogrid:

A geogrid, consisting of a semi rigid, ribbed, open grid polymer, may be incorporated in the lower part of the ballast, below the level reached by the tines of tamping machines, to improve the shear resistance of the lower layers of the ballast. It achieves this by providing a mechanical interlock between the otherwise unbound aggregate which enhances the local bearing capacity of the ballast layer and reduces the ballast settlement under load.

1.2.5.2 Geotextile:

A geotextile is a permeable polymer membrane in sheet form. It may be laid directly on the subgrade but it is preferable to incorporate it as a separator between the ballast and the blanket.

The current Railtrack Company Standard for geotextiles is RT/CE/S/010.

1.2.5.3 Geomembrane

A geomembrane is an impervious polymer membrane in sheet form. It may be incorporated in the track substructure to assist drainage above the level of the geomembrane or to separate two layers in the track substructure.

Geotextile

1.2.6 Capping Layer

The role of the capping layer is to provide an impervious protection to the subgrade. Capping layers were installed usually as part of the initial construction of the track and, when correctly selected, could very effectively provide dual roles of preventing subgrade particle migration and protect the subgrade from the effects of water.

Unfortunately in the quest for deeper ballast depths, required with the introduction of concrete sleepers and CWR, many of these capping layers have been damaged and have lost their effectiveness.

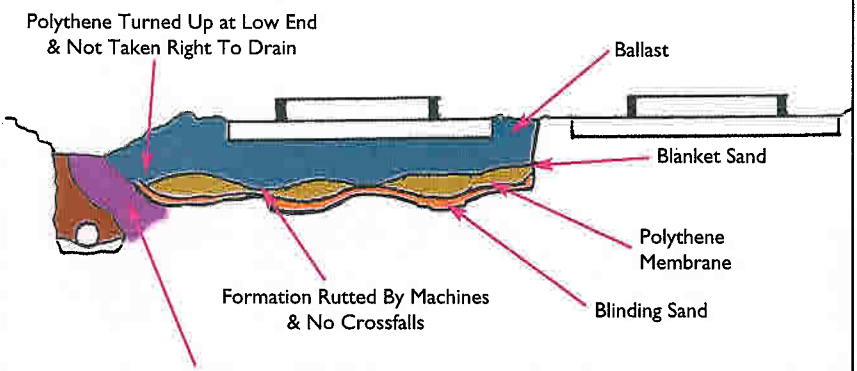
1.2.7 Subgrade

The subgrade must be capable of withstanding the static and dynamic loads imposed on it by the track structure and traffic.

2. TRACK SUBSTRUCTURE RENEWALS

2.1 MACHINE DIGS

How Not To Do It!



Wet Plastic Clay Squeezed Over Drain & Not Dug Out.
Even when this does not happen a 'Lip' of clay is often left between the Dig & the drain.
In both cases water is ponded under the track as it cannot flow into the drain.

2.1.1 Crossfall

On deep reballasting (excavating) and blanketing works it is essential that a clean plane bottom is attained, with a proper crossfall, over the whole width of the subgrade right to the drain. Excavating the dig initially level and then forming the cross level is seldom satisfactory. Best results will be obtained if machines are made to work on the crossfall from the beginning. Unless it is free draining, the sub-grade should have a crossfall of between 1 in 20 and 1 in 40 to permit the dispersal of water from the track.

2.1.2 Track Substructure

Prior to new construction, or renewal involving ballast replacement, explicit consideration shall be given to the design of the Track Substructure.

The design shall take account of the criteria in:

a) RT/CE/S/101 Track design requirements.

b) RT/CE/C/039 Track substructure treatments.

2.1.3 Ramping

Excavations by machine should be ramped at the ends so that when the track is re-instated there is no sudden change from well compacted to less well compacted conditions under the sleepers or bearers. This should normally be at a rate of 1 in 400 for temporary run outs. With a rate of 1 in 720 for permanent run out.

Compaction Plate / Vibrating Plate

2.1.4 Compaction

When track is laid on new uncompacted ballast, considerable settlement takes place under traffic, no matter how much fettling and machine tamping has been done, though use of a Dynamic Track Stabiliser (DTS) may have a significant effect.

The settling occurs as the stones gradually fit into each other with the vibration of passing trains.

There are tremendous advantages in compacting blanket sand and ballast with a vibro-roller or vibrating plate. These machines do not have to be large or cumbersome, it is the vibration that matters. In the past, vibratory rollers have been shown to be prone to leave an uneven compacted surface. Vibrating plates have been found to be less prone to this and are therefore preferable to rollers.

The benefits of compaction are:

a) Less distortion of track substructure interfaces and and the top surface of the ballast when locomotives and hoppers run across the site. Hence a reduction in the need for laborious lifting.

b) A firm level surface for laying out sleepers and timbers with subsequent ease and speed of clipping up - of particular benefit when laying S&C.

c) Subsequent accurate ballast distribution and marking up for final tamp.

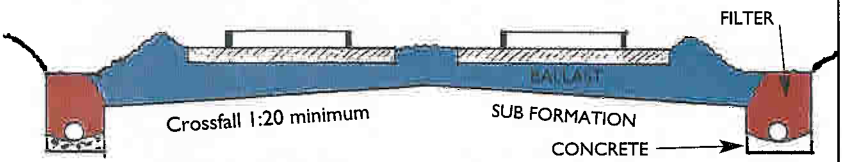
In addition to the advantages gained during the actual work, the result is a firm consolidated bed with long term benefits:-

1) Less initial tamping and kangoing required.

2) Possible earlier lifting of temporary speed restrictions.

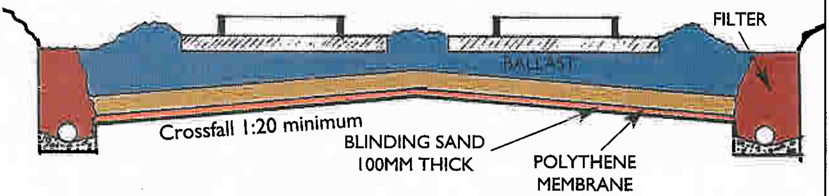
3) Track will then hold its top and line for longer.

2.1.5 The Completed Job - Some Examples

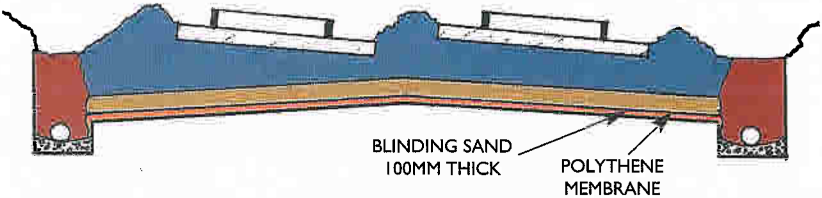


RE-BALLASTING - TYPICAL CROSS SECTION

The depth of dig may be increased dependent on ground and traffic conditions but the Crossfall right to the drain MUST be attained.



SAND BLANKET - TYPICAL CROSS SECTION
FOR UNCANTED TRACK



SAND BLANKET - TYPICAL CROSS SECTION
FOR CANTED TRACK

Depth of sand and ballast and therefore the dig must be taken from the lowest end of sleeper. It will be helpful to remember that 75mm cant = 1:20

2.1.6 Table Showing Minimum Ballast Depth To Be Provided At Renewal

Track Category (see note (i))	Sleeper Type	Minimum Ballast Depth mm (see note (iv))
Cat 1A	New concrete	300mm
Cat 1	New concrete or new hardwood (ii) or new steel (iii)	300mm
Cat 2	Serviceable concrete or serviceable hardwood or new steel (iii)	250mm 250mm (steel only) (v)
Cat 3, 4, 5 and 6	Serviceable concrete or serviceable hardwood or serviceable steel	200mm 150mm (steel only) (v)

Notes to Table:

(i) The track categories are defined in Railtrack Company Standard RT/CE/S/102.

(ii) Hardwood sleepers may be used at speeds over 110mph only with the approval of Railtrack PLC (in Railway Administration).

(iii) Steel sleepers may be used only with the approval of Railtrack PLC (in Railway Administration) which will depend on compatibility with track circuits. Steel sleepers shall have spade ends and welded-on housings and shall be separated from concrete sleepers by not fewer than four wood sleepers.

(iv) Ballast depths shown are measured from the bottom of the sleeper and are MINIMA: Crossfall of the formation will require additional ballast. For concrete and wood sleepers, ballast shall be new or clean recycled; for steel sleepers, existing ballast may be retained subject to Railtrack PLC (in Railway Administration) approval.

(v) Where steel sleepers are used the ballast depth shown is to be measured from the base of the sleeper side wall and not from the underside of the sleeper top.

2.2 MACHINE BALLAST CLEANING

2.2.1 Site Suitability

Ballast cleaning is appropriate when ballast has become life expired through contamination from breakdown of the ballast particles or through wind-borne debris or wagon spillage. If the ballast has become contaminated through any other cause, the source of the contamination must also be eliminated. Otherwise the ballast cleaning will only provide a temporary improvement.

Ballast cleaning can be used for complete excavation of ballast, but cannot be used in any case where ballast has become cohesive due to clay or silt contamination. This will clog the ballast cleaner

2.2.2 Preparation

Prior to the work the site must be inspected to assess the integrity of the track fastenings, and all obstructions to the cutter bar must be identified.

Ballast cleaning often leaves the ballast shoulder still polluted so that a canal is formed in the trackbed.

A clean shoulder is most important and can be achieved with the use of a shoulder ballast cleaner (Trac Gopher) or a vacuum machine, or by the use of a cutter bar shoulder extension on the ballast cleaner.

Disposal of the spoil must also be considered carefully in the light of current legislation regarding disposal of waste products. The maximum amount of ballast spoil that can be disposed of at the lineside is 10 tonnes per metre of track.

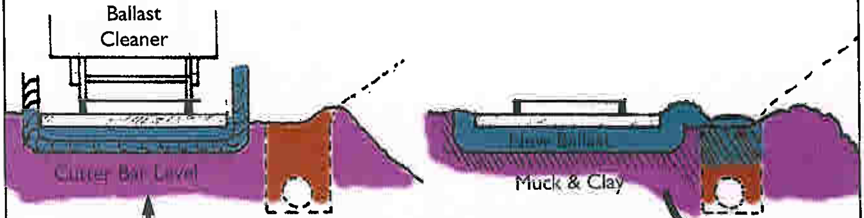
If excavated material is to be distributed on site, the effect of additional loading on embankments and cutting slopes must be carefully assessed.

For accurate control of the process, the cutter bar height and crossfall must be laser controlled. To avoid an abrupt change in conditions at the beginning and end of the job the work must be ramped in and out. This can be achieved by progressively lifting the sleepers over the first and last length beyond the ballast cleaned section to effectively reduce the depth of cut over these lengths.

High output machines can be set up very quickly, without the need for excavation to accommodate the cutter bar or for the track to be lifted, and can normally operate under a live catenary.

These machines are designed to work in conjunction with single line spoil handling and ballast distribution systems, to facilitate re-ballasting in a single line occupation.

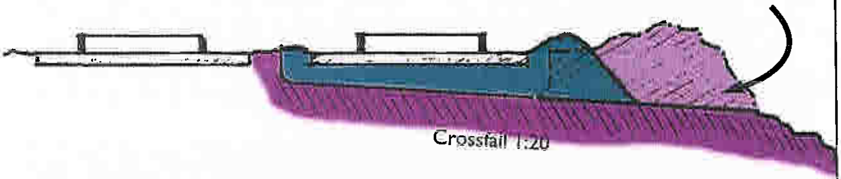
Ballast cleaning machines will not work effectively if the ballast is contaminated with clay.



1. A canal full of ballast
2. Water will not drain away therefore formation will fail. Slip plane can form at A

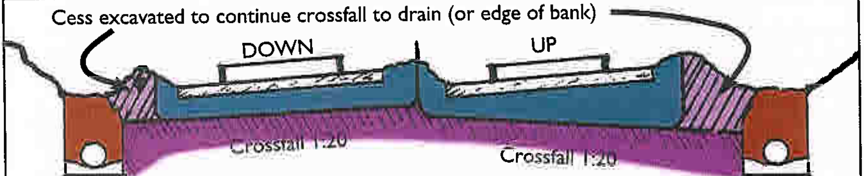
DOING IT LIKE THIS...
LEADS TO THIS

Cess lowered to continue crossfall to edge of bank



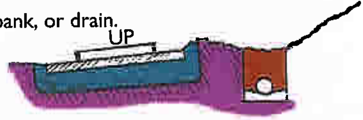
BALLAST CLEANING UN-CANTED TRACK
Cutter bar must be set to give crossfall to edge of bank, or drain.
Note: Joints should be avoided in the immediate vicinity of start and finish of ballast cleaning

Cess excavated to continue crossfall to drain (or edge of bank)



BALLAST CLEANING CANTED TRACK
Cutter bar must be set to give crossfall to edge of bank, or drain.
Even if this is against the cant as in up line above.

NOT LIKE THIS



Note: Joints should be avoided in the immediate vicinity of start and finish of ballast cleaning

3. TRACK DRAINAGE

3.1 NEED FOR DRAINAGE SYSTEMS

Many stretches of line where the subgrade is free draining do not require the installation of drainage systems. Where the subgrade does not drain freely, and this may often be the situation in cuttings, drainage systems have usually been installed in the past.

However many of the problems which arise in trackbed layers occur where such drainage systems are not operating with adequate efficiency. Or it may be that recent changes in the position of the water table have created the need for additional drains.

It should be part of every trackbed renewal to include remedial work to the drainage at the site if it is not functioning as intended. In most instances all that will be required is for the existing drains to be cleared of silt or other debris.

If more substantial work to renew or extend the drainage in the area is required, this should be undertaken in advance of the track renewal work, making sure that the drainage levels and out-falls are compatible with the new works.

3.2 FUNCTION OF DRAIN

A good drain should be at an adequate depth and have an adequate fall. Most importantly, the water from the track bed must be able to freely enter the drain. The first two requirements are not always easy to attain due to factors like adverse track gradients, shallow or no suitable out-fall.

3.3 WATER ENTRY

Track drains are catchment drains as distinct from carrier drains. A catchment drain is one that collects and removes water from the ground, and to do this it must have open joins, perforations or other means to allow water to enter.

3.4 FILTER

Clay soil is made up of very fine particles and the pipe must be surrounded with filter materials to prevent these entering the drain. The filter has to be porous to allow the passage of water and fine grained enough to reduce the amount of silt particles entering the drainage system. Chippings and ballast are not suitable. Filter material consists of correctly graded non-cohesive granular material.

Varying with type of soil, filters may fail after some year's in use and an otherwise satisfactory drain becomes ineffective and must be refiltered.

3.5 MANHOLES (CATCHPITS)

'Manholes' or 'catchpits' are normally provided every 25 to 30m to enable access for maintenance purposes. Most have sumps to act as silt traps and these must be emptied with adequate frequency to prevent blockage of the pipes. This can be done using a drainage ladle, and the resulting silt and debris must be spread evenly on the cutting / embankment slope. Care must be taken not to place it where it will be washed back into the drain or cause instability of the bank or cutting slope.

Catchpit

3.6 DRAINAGE: GENERAL GUIDELINES

Unless it is free draining, the top of the sub grade shall have a crossfall of between 1 in 20 and 1 in 40 to permit the dispersal of water from the track.

Where natural drainage is not adequate a drainage system shall be installed in any new or renewed track and should be considered for existing track. The following requirements apply:

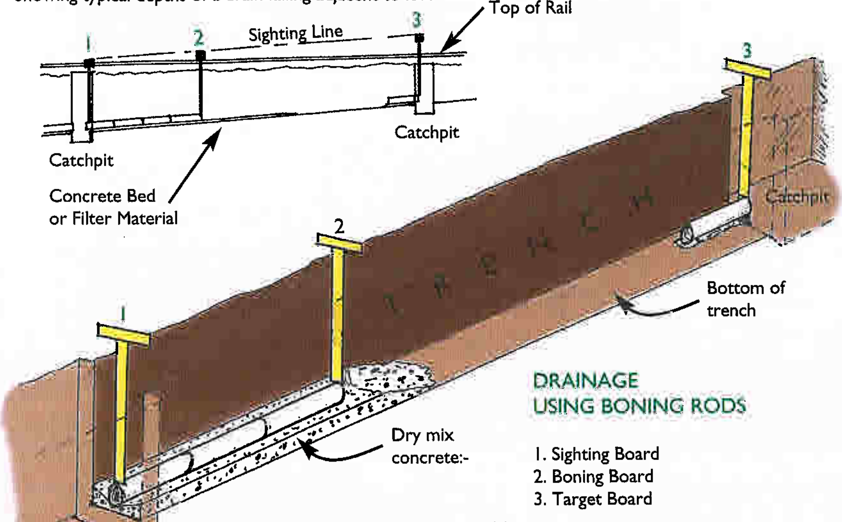
- The invert of a lineside track drain shall be at least 100mm below the base of the ballast;
- The drain shall fall towards the out-fall at a self cleaning gradient where practicable. The gradient shall be no flatter than 1in1000 and preferably no flatter than 1in500;
- Material used for backfilling a catchment drain must permit free passage of water;
- Catchpits shall be provided at intervals that will permit maintenance of the drain to be undertaken (a maximum interval of 30m is recommended). They shall also be provided at each turn or junction in the drainage system.
- Catchpits shall be covered to prevent ingress of debris and to prevent accidents to staff. The covers shall be capable of carrying a person's weight.
- Cross-track drains shall be laid deep enough to avoid damage from future maintenance and renewal operations and shall comprise pipe of sufficient strength to resist train loading. No part of such drain shall be less than 1100mm below the top of the lowest rail unless approved by Railtrack Plc (in Railway Administration).

See also RT/CE/S/044 Undertrack Crossings.

Guidance on drainage practice is given in RT/CE/C/006 Design, Installation and Maintenance of Drainage.

LONGITUDINAL SECTION OF DRAIN IN PROGRESS

Showing typical depths of a drain falling adjacent to level track



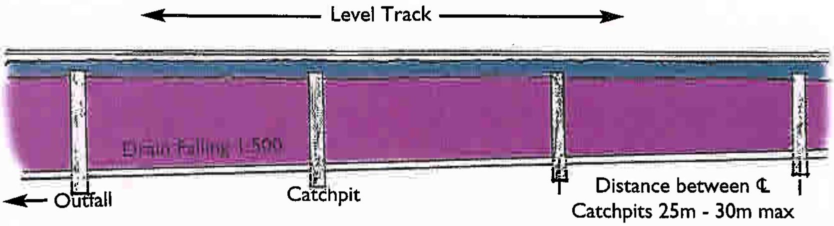
1 cement : 12 filter (open jointed pipes only).

Plastic pipes with slots or perforations to be bedded on filter material, not concrete.

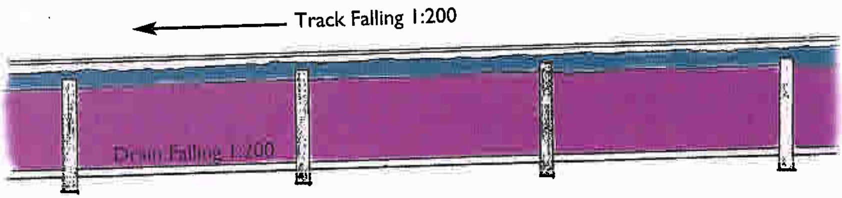
One pipe is laid at each catchpit position at the given depth below rail level by measuring down from a cross level board.

Boning rods 1 & 3 are set up at these pipe levels and the drain laid uphill, each pipe levelled in by sighting with the intermediate boning boards.

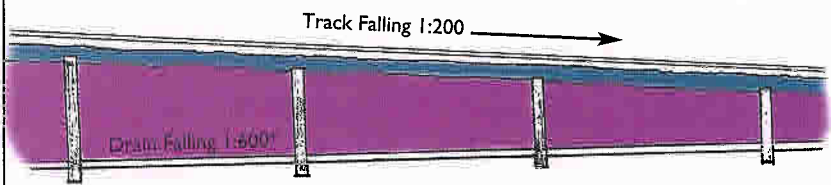
3.7 DEPTH OF DRAINS



Drain must fall towards its outfall. When it is adjacent to level track it will, therefore, gradually become deeper in relation to the track. On a long drain or where the outfall is shallow, it may be necessary to start the drain at a very shallow depth and make the fall flatter than the minimum desirable 1:500



In most cases the outfall is in the direction of the down gradient and the drain can follow the track gradient at a constant depth.



Considerable problems can arise when the only outfall is in the direction of a rising track gradient. Even when the drain is started at too shallow a depth it can rapidly become too deep in relation to the track. Sometimes the only answer is to make the fall of the drain flatter than the minimum 1:500 e.g. the 1:600* shown here.

4. WET BEDS: CAUSES

4.1 DIRTY BALLAST FAILURE

4.1.1 Mechanism

To perform well, ballast needs to be clean, angular and free draining. During its service life ballast deteriorates because of the wearing away of contact points between individual stones under load, creating fines (ie fine material) and causing loss of angularity. This is known as ballast attrition. It can occur slowly as a result of traffic loading, but very much more rapidly as a consequence of tamping and Kangoing. There may also be abrasion of concrete sleepers where they transfer their loads into the ballast.

Ballast can also be contaminated by fine particles from outside the track structure, such as may be carried on the wind, or from wagon spillage, especially coal.

Groups of wet beds can develop where drainage is inadequate and excess water forms a slurry with the contaminating fine material described above. However they usually develop where loads are also locally higher than usual due to a dipped rail joint or weld, or some other rail discontinuity.

4.1.2 Prevention

Wet beds can occur on long established track and newly installed track. Patrol / inspection staff are required to report any they see, but like all defects which are not corrected immediately, there is a tendency to avoid repeat reporting, which may lead to failure to report new occurrences.

To avoid or postpone the development of wet beds we must:-

- Report all wet beds; new or worsening/deteriorating.
- Find out the depth of ballast before doing routine maintenance (tamping etc) and do not damage the subgrade.
- Treat dipped joints
- Treat dipped welds
- Clean out weld debris after welding.
- Replace badly worn/missing pads.
- Remove vegetation growth in and around the ballast.
- Keep the cess clear of spent ballast.
- Clean out drains and catchpits on an annual basis.

Pads out on a weld. Onset of a wet bed.

4.2 SUBGRADE EROSION FAILURE

4.2.1 Mechanism

Subgrade Erosion Failure should not be confused with Dirty Ballast Failure, since the methods of rectification of the two types of problem are completely different.

Subgrade erosion occurs most commonly when the subgrade is composed of fine grained material such as silt or clay. In the absence of a subgrade protection layer, dynamic loading from traffic transmitted directly to the subgrade through the ballast particles and the exposure of subgrade to water, combine to produce a slurry effect at the interface between the ballast and the subgrade, under the packing area of the sleepers.

In time the slurry accumulates within the ballast layer and ultimately penetrates the ballast to reach the sleepers.

As with Dirty Ballast Failure, groups of wet beds are likely to develop, but these groups may be much larger, and they may eventually cover a long length of track.

4.2.2 Prevention

Upward migration of fines from the subgrade can only be prevented by incorporating an effective blanket. Ideally this is done at the time of construction or renewal of the track, but it may be necessary at some sites before renewal is due.

4.2.3 Bearing Capacity Failure

Bearing Capacity Failure, or strength failure, is a different mode of subgrade failure which may not lead to wet spots. It is characterised by a continuous loss of rail level which starts some days after the onset of wet weather. The treatment for this type of failure will probably require redesigning the track substructure and such redesign will not necessarily include a blanket.

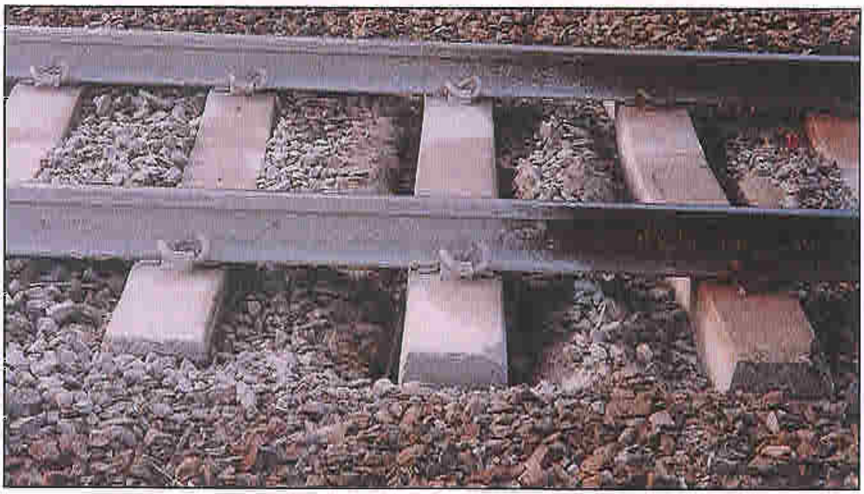
4.3 CONSEQUENCES

4.3.1 Single Groups of Wet Beds

The development of a group of wet beds leads to voids and vertical movement of the track under traffic, an increase in the rate of settlement of the track, and ultimately an inability to hold the track geometry, especially after tamping.

The water pumping action caused by passing traffic can wash out ballast and fines. Where ballast has been washed away from the sides and ends of sleepers the resistance of the track to buckling is reduced.

Wet beds can cause twist faults if they develop unevenly across the sleepers.



Voids: Water under pressure washes out ballast

Wet Bed Site: Ballast removed to allow "Drying Out". This causes track distortion or buckling in hot weather

4.3.2 Cyclic Top

Cyclic Irregularities in track geometry are able to excite natural harmonics in a variety of vehicles leading to a risk of derailment. If groups of wet beds develop close to one another, there is the potential for the creation of cyclic top or twist.

If such faults are identified action will need to be taken as defined in the Company Specification Track Maintenance Requirements (RT/CE/S104, appendix D in particular). This Company Specification does not detail action for the combination of severity, extent of grouping that is typical of wet beds. Speed restrictions may be necessary at all times, not only during hot weather. Each site must be considered on its merits in determining the minimum action. In case of any doubt guidance must be sought after first taking an adequate level of precaution.

Typical top fault on wet bed site showing a single irregularity

5. WET BEDS: MAINTENANCE TREATMENT

5.1 ASSESSMENT

5.1.1 Identification

Visual inspection will detect signs of slurry forming around sleepers/bearers. however, inspection should also be looking for root causes e.g. poor drainage, pools of surface water and voiding. Additionally, the output data from track recording vehicles can be evaluated to identify trouble spots.

Locations particularly sensitive to failure include welds, rail joints and other rail discontinuities, areas of poor drainage (especially those with weak sub grades), transitions to non-ballasted track and sites where the ballast condition is poor / clogged.

Sites should be reported as soon as any slurry is observed.

5.1.2 Cause

Before the treatment of wet beds can be undertaken it is necessary to assess their cause, severity and extent in terms of number of beds affected and over what length.

If the wet beds are caused solely by ballast attrition the colour of the slurry produced is usually similar to concrete, being the product of sleeper and ballast materials breaking down. At wood or steel sleeper sites or where the ballast is red granite, this may not be the case. Voiding may or may not have occurred and the track top may remain good with little visible vertical movement under the passage of trains.

If the wet beds are the result of subgrade failure, the colour of the material can be matched to the colour of the material found in the track drainage. Voiding is likely to occur and may do so before fines are visible at the surface.

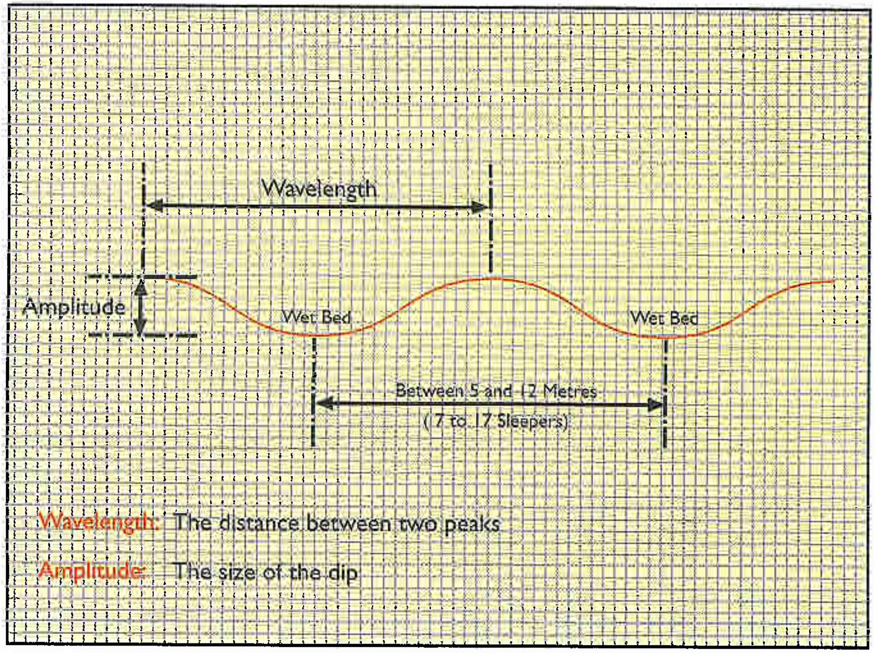
If the wet beds are the result of the spillage from trains, the oil, sand, coal or aggregate dust will be obvious on top of the ballast.

These causes may be present in combination, but note ballast attrition may accelerate subgrade failure, or vice versa.

5.1.3 Cyclic Top Severity

Once voiding occurs, track geometry (top and line) can deteriorate rapidly. Single irregularities can develop into cyclic irregularities.

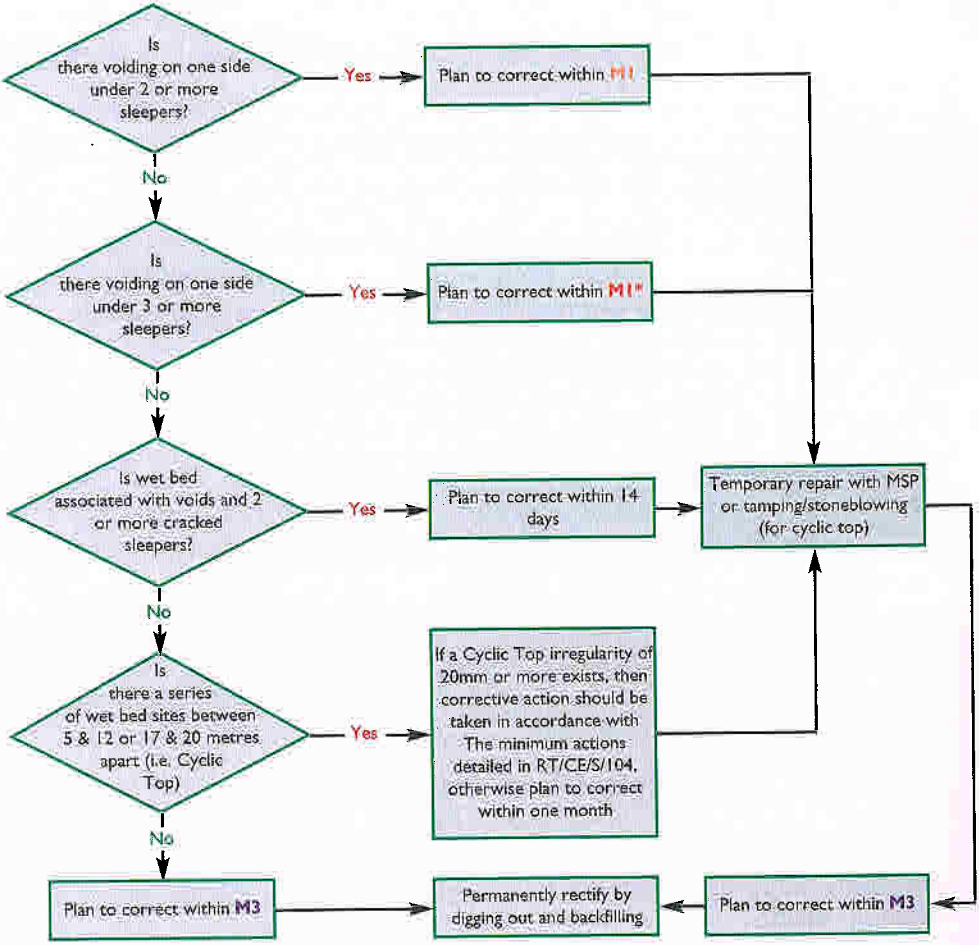
Significant cyclic top can occur when dips are at intervals (wavelength - see diagram) of between 5 and 12 metres (7 to 17 sleepers). To pose a serious risk of derailment two or more evenly spaced dips (amplitude) of 5mm or more are thought to be required, although one significant dip can cause a derailment. The dips may not be immediately obvious because of voiding under the sleepers. Dynamic readings can be taken using voidmeters to give an accurate assessment of the severity of the problem. Train speed is also a factor. It is unlikely that cyclic top derailments will occur at 30mph or less.



Wavelength and Amplitude of Cyclic Wet Beds

5.1.4 Planning Remedial Action

The decision tree set out below suggests some guidance timescales, for more detailed guidance, refer to the inspection tables in the Track Inspection Handbook.



* Safety Limit Exceedence (SLE) Rectification work to be undertaken as quickly as practicable.

5.2 MINIMUM ACTION TO PROTECT TRAFFIC

Wet beds reduce the stiffness of track and the support given to trains, cause geometry deterioration and reduce resistance to buckling. It is always necessary to ensure track safety is maintained.

Because some wet beds may have been present for a long period of time, the appearance of new wet beds nearby (or worsening of existing wet beds) does not mean they can be tolerated until corrective action can be arranged.

Once voiding occurs, track geometry (top and line) can deteriorate rapidly as increased impact loading occurs as trains pass. Single irregularities can develop into cyclic irregularities further along the track.

If action is not taken at an early stage to repair wet beds, with increasing severity of the wet beds it can be expected that action will be necessary to protect traffic including:

- Imposition of an Emergency or Temporary Speed Restriction
- Reduced intervals between visual inspections
- Placing of watchmen in hot weather
- In hot weather, action may need to be taken at a critical rail temperature appropriate to severe shortage of ballast between sleepers.

Company Specification Continuous Welded Rail (CWR) Track is applicable RT/CE/S/011, (section 14 in particular.)

5.3 MANUAL TREATMENT

Railtrack PLC (in Railway Administration) have produced a video "**Repair of Wet Beds**" which should be used in conjunction with this book.

5.3.1 General

Methods available range from wholly manual repair to complete renewal of the subgrade.

Small numbers of wet beds of light or moderate classification may be corrected under traffic by manual repair only if the subgrade is not damaged.

5.3.2 Tools and Equipment

For Removing Voids:

Cross Level

Sighting Boards

Void Meters

MSP Canisters

Opening Out Shovels

Packing Shovel

Ballast Forks

Hydraulic Track Jacks

Kango Equipment fitted with audible warning device for red zone working.

For Wet Bed Removal:

Shovels

Ballast Forks

Panpuller / Pansetter / Other tools appropriate to the fastenings

Pad Scraper

Pick Axe

Pinch Bar

Kango Hammer with clay spade and compaction plate

with compressor or generator

Associated packing tools used for removing voids.

Drainage Scoops / Ladles

Safety Note:

When Measured Shovel Packing, do not remove the hydraulic track jack handles during the work process as this has led to chippings filling the release mechanism, preventing hydraulic pressure release under traffic.

5.3.3 The Process Step by Step (See diagram on Page 30)

Stage 1: Cess Lowering

The first task is to provide a drainage path for water to get away from the bearing area of the sleeper. The drainage path needs to be continuous through the ballast shoulder and into the cess and any associated drains. This process is known as 'cess lowering' and is essential in achieving a quality job.

Stage 2: Remove Voids

Pack all sleepers in the section of the track to be treated to eliminate voids, by Shovel or Kango Packing. During this process visually check the sleeper depth for erosion or steel reinforcement breaking out, or housings working loose, then arrange to replace the sleeper as part of the task.

Stage 3: Excavation:

Excavate all ballast from between sleepers 1 and 2 and open out the crib between 2 and 3 to just below the bottom of sleeper level for the complete length of the sleeper.

Contaminated ballast removed from the cribs and cess must be spread evenly onto the cutting slope or embankment slope and not left in the cess or mounded adjacent to the track drain.

Spoil must not be left where it may be washed into drains, nor where it may lead to instability in bank or cutting slopes.

Contamination and Spent Ballast left in the cess and not removed causes bad drainage

The base of the excavation between the first and second sleepers must fall towards the drain.

It is worth mentioning that when opening out is being undertaken it is good practice to remove contaminated ballast with a shovel and return clean ballast with a fork. This will prevent fine materials being returned to the track.

Stage 4: Compaction

Backfill the crib between the sleepers 1 and 2 with clean stone to the bottom of the sleeper level, consolidating the ballast using a Kango compaction plate in 50mm to 75mm layers for a distance of 375mm either side of each rail.

Unclip sleeper 2, remove pads and insulators and move the sleeper onto the clean compacted stone, between first and second sleeper positions. Fit pads, insulators and clips and pack sleepers.

Remove the remaining ballast from crib 2-3 and the original support to sleeper 2. Repeat stage 4 for this crib and return sleeper 2 to its original position.

Stage 5: Repeat the Process

Repeat the relevant stages above for the remaining sleepers which require treatment, starting with the moving of sleeper 3 to its temporary position.

Contamination after flooding which if not cleared will lead to drainage failure

Stage 6: Profiling

Excavate the ballast at the sleeper ends in the interval between the tracks, in lengths not exceeding 1.5m, to the same depth reached as when the cribs were evacuated. Backfill with clean ballast and consolidate before moving to the next 1.5metres section.

Excavate the ballast shoulder in 1.5m lengths, and replace with clean stone, ensuring the consolidated shoulders are to the correct profile.

Carry out this process throughout the affected length of track.

The appropriate dimensions are as follows

CWR track:
Minimum width of Ballast shoulders measured from sleepers ends:

Straight track and curved track over 200m radius	375mm
Curved track 200m radius or less	450mm
At any discontinuity	450mm

(Discontinuities include Insulated Joints, adjustment switches and Catch points. The wider shoulder shall apply over not fewer than 10 bays/beds each side of the discontinuity.)

In CWR track including S&C the shoulders must be heaped 125mm above the top of the sleeper level.

Jointed track:

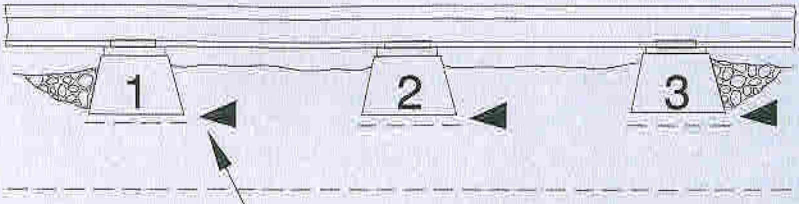
Minimum width of ballast shoulder from sleeper ends (straight or curved track) = 300mm.

Stage 7: Clean up / Follow Up

On completion of the work leave the track and walkways clean and tidy, check the drains (Pipe or U. channel) and catchpits for blockage and clear as necessary.

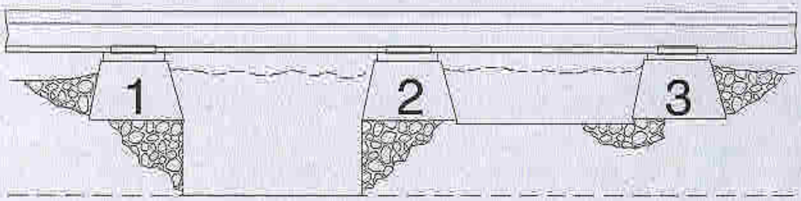
Replace drain/catchpit lids.

Follow Up : Observe traffic passing over the newly repaired site for vertical movement check and correct longitudinal top and cross-level before leaving site and make a follow up visit to the site within 2 to 5 days. It is likely that further kangoing work may be necessary then.



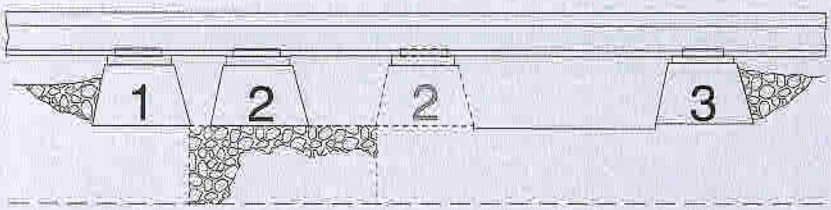
Shovel pack all sleepers to eliminate voids.

Stage 2



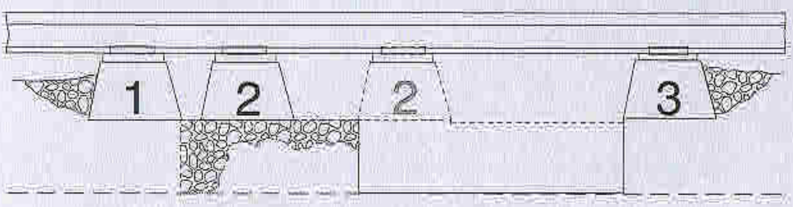
Remove ballast as shown ensuring that crib between sleepers 1 and 2 has a fall of approx. 1 in 20 to 1 in 30 towards the drain.

Stage 3



Backfill crib 1-2 with clean ballast, consolidated in 50-75 mm layers. Move sleeper 2 onto the clean ballast and pack.

Stage 4



Remove remaining ballast from crib 2-3 including original support to sleeper 2. Repeat stage 4 for this crib and return sleeper 2 to its original position.

Stage 5

5.3.4 A Note on Opening Out Under Traffic

To avoid impairing the stability of the track, the following requirements should be observed when opening out:-

Jointed Track: No more than 6 consecutive cribs to be opened out except with Railtrack PLC (in Railway Administration) approval. (ESR/TSR likely to be needed)

CWR Track: No more than 6 consecutive half cribs or 2 consecutive full cribs to be opened out within a 9m length.

Injury/Damage To Traffic: Ballast must be kept clear of rails during the opening out process to avoid being thrown up by the wheels of passing trains or causing damage to pipes or other associated train equipment.

Railhead Ballast Scars: Ballast must not be thrown onto the running surface of the rails where it may be rolled into the steel producing ballast scars. This can ultimately lead to rail failures.

Signalling Equipment: Excavated ballast must not be allowed to interfere with the signalling equipment, nor should it be thrown onto cable troughing.

5.3.5 Cyclic top

Wet bed sites where the end of one site falls between 5 and 15 metres (7 to 22 sleepers) of the end or the beginning of the next site must not be rectified at the same time.

Each site must be rectified, consolidated and capable of maintaining crosslevel and longitudinal top, before dealing with the next site in the cycle.

This process will reduce the risk of cyclic top developing during settlement.

5.3.6 Extremes of Weather:

Repairs to wet beds should:

- Not be undertaken when rail temperature is above 32°C.
- Not be under undertaken when rail temperature is below 0°C .

Done in a Fashion ... Ballast pyramid not excavated!

Wet Beds Done with Passion ... Wet beds dug out and correctly treated.

ENGINEERS NOTES: ASSESSMENT METHODS

1. GRADING REQUIREMENTS

1.1 Ballast

The grading requirement for track ballast to be used on Railtrack infrastructure is given in the table below:

Ballast Grading	
Square Mesh Sieve Size mm	Percentage to Pass %
63	100
50	97-100
28	0-20
14	0-2
1.18	0-0.8

The complete specification for ballast to be used on Railtrack infrastructure is given in Railtrack Company Standard RT/CE/S/006.

1.2 Blanket Sand

A Typical Sand Blanket Grading:	
Size mm.	% Passing by Weight
14	100
2.36	80-100
1.18	70-90
0.60	50-75
0.30	25-60
0.15	5-40
0.075	0-10

The current Railtrack Company Standard for Blanketing Sand is RT/CE/S/003.

1.3 Subgrade

The subgrade must be capable of withstanding the static and dynamic loads imposed on it by the track structure and traffic. The bearing capacity of subgrades is assessed by classification into one of five 'Soil Quality Categories' together with an assessment of its geotechnical properties, and the local hydrogeological and hydrological conditions at the particular site.

For the purposes of this handbook, subgrades may simply be assessed as poor, average or good, and, depending on the traffic loading, may need to be enhanced by the importation of stronger and more suitable materials in order to function correctly.

2. TRIAL HOLES OR TRENCHES

2.1 Limitations

For many years the excavation of trial holes or trenches was the only method used to assist in the decision making process prior to proposing particular sites for ballast cleaning, total excavation or complete track renewal.

Assessments were subjective and relied on the experience of the inspecting engineer to formulate the correct proposal for the site.

Even today this is often the only method used before many thousands of pounds are committed to track renewal work.

The limitations of this approach are obvious.

Trial holes or trenches can, at best, only provide a visual indication of the condition of the ballast. They give no clue as to the likely further life of the ballast, it's intrinsic properties or it's ability to withstand further traffic loading and retain adequate track geometry in the future.

Furthermore, because only a limited number of samples can be taken at any one site, they cannot provide a comprehensive overview of the condition of the whole site proposed for renewal, nor, more importantly, identify the optimal extent of the work site.

Trial trenches are better than trial holes since they give some indication of any differences in the condition of the ballast between the loaded and unloaded areas. For this reason they should extend the full length of the sleeper.

2.2 The Process

It is recommended that for relaying and/or ballast cleaning proposals, one trial trench is excavated every 100m, and where subgrade failure is suspected, one trench is excavated every 50m, with additional excavations as considered necessary at each end of the proposed site, to confirm that the proposed extent of the work is correct.

Trial trenches are usually used only to assess the ballast, since it is generally impractical to extend their depth down to the subgrade.

If any existing sand blanket is disturbed, care must be taken to avoid damage to any geotextile which may be present.

Trial trenches should be inspected as soon as possible after excavation to avoid ballast from adjacent sleepers falling into the excavation. If this is not possible, the trial trenches should be protected by filling them with bags of sand or small ballast, until the day of the inspection. They should be backfilled with clean ballast immediately following the inspection.

If a sand blanket has been removed it must be reinstated prior to replacing the ballast.

2.3 Sample Grading.

The excavated samples from trial holes or trenches may be assessed as to their grading relative to the initial specification or degree of contamination, by undertaking a grading analysis in the laboratory. If this is to be done, separate samples shall be taken from the unloaded and loaded areas.

3. GROUND PROBING RADAR (GPR)

Ground probing radar (GPR) is a very effective and relatively quick technique for assessing the depth and thickness variation of the ballast and sub-ballast layers.

It allows changes in the depth and extent of these layers to be identified easily and therefore identifies the probable extent of any remedial work needed. It also identifies those locations at which changes are taking place, including the development of possible future pumping problems, and can be used to target areas for more detailed examination.

Several miles of track data can be collected in a day and, because the equipment is portable and the antennae used are compact, it can be used within a red zone. Alternatively, the equipment can be trolley mounted and used in a possession. Data collection rates are typically up to 1 mile per hour.

The technique is non-destructive and employs electromagnetic radar waves to identify the presence of interfaces between the various layers making up the track bed. A single reading is taken in each crib in the centre of the four-foot and the successive results are combined to provide an effectively continuous record.

The technique works by measuring the strength of the reflected signal during a fixed time period, typically several nanoseconds and, knowing the time of travel and the dielectric constant of the ballast/sub-ballast, the depth of the interfaces can be assessed.

The output is in the form of a continuous longitudinal section of the track showing the reflected signals from the various layers beneath the sleepers. For most effective use of the data, an expert commentary should be supplied by the specialist sub-contractor on the interpretation of the various features of the trackbed shown in the trace.

Although interpretation of the trace can appear somewhat daunting to those unfamiliar with the system, some readily comprehensible features usually become clear after a little practice.

For example, if the ballast is reasonably clean a strong signal identifies the interface between the top ballast and the sub-ballast so that any variation in depth of the top ballast can be identified. Conversely, if the top ballast is soiled through contamination with clay slurry, the extent of the slurry penetration can be seen and estimates made of the likely time to penetrate the ballast completely.

The presence of the sub-ballast layer or the existence of a blanket can also be readily identified.

However, one of the most beneficial features of the GPR trace is the ability to accurately identify locations where changes in the track substructure are occurring. This is invaluable for two reasons:

a) It enables the optimum length of any proposal remedial work to be determined before work commences.

b) It identifies locations where further investigation of the underlying materials would be beneficial.

Thus, with proper use, GPR can eliminate the all too frequent occurrences where job sites are not long enough to deal with the original problem, which then re-emerges some time later at the ends of the treated length.

It also enables random selection of the trial investigations to be replaced by a focussed approach to this time consuming task, steered scientifically to pinpoint those locations which are likely to reveal the most useful information.

It is often possible to link sections of poor quality track geometry to the information provided in the GPR trace. The track engineer is thus provided, for the first time, with an understanding of the cause of his track quality problem.

Whilst ground probing radar is often quite useful as a stand alone investigative tool, particularly when its findings clearly relate to the track geometry, in many instances a complete understanding of the causes of a problem needs the GPR information to be supplemented by further detailed investigations at specific locations, using the techniques described below.

4. AUTOMATIC BALLAST SAMPLING (ABS)

Automatic ballast sampling is a more effective tool than trial holes or trenches for providing detailed information about the actual materials making up the track substructure at any location.

Unlike trial holes or trenches, the automatic ballast sampler enables useable samples of all the supporting materials, ballast, sub-ballast and subgrade to be obtained.

The automatic ballast sampler consists of a steel sampling tube lined with a 65mm diameter clear plastic tube in which the sample is collected. The steel tube is capped with a hardened steel cutting shoe and the whole unit is driven into the trackbed, using a hydraulically powered hammer, to a depth of up to 1metre.

Additional smaller diameter tubes can, if necessary, be driven even deeper into the subgrade.

The samples are sealed in their plastic tubes for subsequent photographing, logging and appropriate material testing. The latter can include:

a) Grading and measurement of the fine content of the ballast.

b) Measurement of the water content of the sample.

c) Assessment of the shear strength of the subgrade material.

d) Measurement of the cohesiveness of the subgrade material.

The equipment must be operated in a Green Zone. However all equipment is portable and can be stored on a trolley.

Typical sampling rate is of the order of ten 1m samples per hour using a four man team. This compares very favourably with the time taken to excavate trial holes or trenches.

The use of ABS in conjunction with GPR is particularly beneficial in permitting most track substructure problems to be diagnosed.

The ABS samples can be useful in 'calibrating' the GPR profiles and assisting in their interpretation.

The output is presented in the form of a photograph of the samples and a legend for each location in the longitudinal direction of sampling.

The legend is presented using a standard reference key for the materials.

The excavated sample holes are backfilled immediately after extraction with clean ballast.

5. FALLING WEIGHT DEFLECTOMETER (FWD)

It has been demonstrated that many irregularities in the vertical track geometry (top) are related directly to variations in the stiffness properties of the trackbed layers.

The ***F***alling ***W***eight ***D***eflectometer (FWD) is a piece of equipment capable of measuring directly the variation in trackbed stiffness in situ.

It was originally developed for the road construction industry but has now been adapted for use in the railway environment.

The FWD is a non-destructive device which applies a predetermined impulse load to the sleeper close to the rail seat areas. The response to this load in terms of transient deflections produced in the sleeper and the surrounding ballast are very accurately measured using an array of sensors called geophones.

Each sleeper is disconnected from the rails in turn and a load of 12.5tonnes, which equates approximately to a typical vehicle axle load, is applied three times to the sleeper. Measurement of the load and displacements are recorded simultaneously.

The deflections of the loaded sleeper (D_0), the ballast in the adjacent crib (D_{300}) and the ballast in the next crib (D_{1000}) are interpreted as corresponding to the sleeper deflection, the deflection of the loaded ballast and the deflection of the subgrade respectively.

These values are then combined and interpreted as:

a) The sleeper deflection (D_0).

b) The compression of the upper trackbed (D_0-D_{300})

c) The compression of the lower trackbed (D_{300}-D_{1000})

d) The deflection of the subgrade (D_{1000})

The data is presented as a continuous longitudinal trace showing the variation of these properties along the track.

This can often be related to the corresponding track recording unit trace of the longitudinal profile (top) and the source of the track geometry irregularities, where this is attributable to variations in the stiffness of the track substructure, identified.

The data can also be used to calculate the velocity of surface wave propagation along the track - the so-called critical velocity. On soft formations, this can often be the limiting factor on operating speeds, since unacceptably high vertical displacements of the track arise once train speeds approach about 70% of the critical velocity.

6. REMEDIAL ACTIONS

6.1 Work Planning.

The assessment methods described can, when used sensibly, either alone, or more effectively, in combination, provide the basis for identifying the most appropriate remedial actions to overcome perceived problems attributable to the trackbed layers.

They also enable the most appropriate extent of any work to be identified at an early stage in the planning process.

The most appropriate assessment should always be carried out in advance of any proposed remedial work on the track substructure.

It is only when the cause of any track substructure problem is identified clearly and understood that the most appropriate remedial action can be selected and detailed planning of the extent and nature of the work can commence.

6.2 Total Route Evaluation.

A combination of the assessment methods described earlier should be used to assist in developing a plan of the likely track renewal activities on a route for, say, the next 10 years. This is called 'Total Route Evaluation'.

However, before any additional site assessment is undertaken, a 'desk study' should be carried out to enable all existing information about the route and its problems to be gathered together.

This should include:

a) Track recording data.
b) Records of recent work carried out and when.

c) Details from the GEOGIS database.
d) Comments on maintainability from the track maintenance contractor.
e) Any planned upgrading schemes or line speed improvement plans.

The 'desk study' should then be supplemented by:

a) A detailed route walk-over.
b) A ground probing radar survey.

The route walk-over should include details of the :

a) Visual condition of the track structure including the track geometry.
b) Location of track features such as insulated joints, dipped welds, under track cable crossings, AWS inductors and/or ATP balises.
c) Type and visual condition of the top ballast.
d) Location and condition of drainage.
e) Extent of cuttings and embankments.
f) Evidence of slips or areas of instability.
g) General geological features.

The ground probing radar trace and commentary should be combined with track recording data and the results of the walk-over survey, to identify proposed locations for further investigation by means of automatic ballast sampling, slip monitoring, falling weight deflectometer measurements or other site specific investigations.

Following this, all the relevant data for the route should be combined, and a dated renewal programme for the route drawn up.