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Mud Hole Management Guideline

ETG-05-04

Applicability

ARTC Network Wide

SMS

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1.0	11 Dec 24	Standards	Stakeholders	Principle Track Engineer	Manager Engineering Services 18/12/2024

Amendment Record

Amendment Version #	Date Reviewed	Clause	Description of Amendment
1.0	11 Dec 24		Renumbered from ETH-10-01. To provide guidance to field staff in the management of mud holes.

Table of Contents

1 Introduction

1.1 Purpose

This guidance may be used by field staff in the management of mud holes. This guideline is not intended to be read as prescriptive.

1.2 Scope

This guideline applies ARTC network wide.

The guideline addresses:

- The causes of mudholes
- Inspection and Assessment of mudholes.
- The short- and long-term remedial actions.

1.3 Relevant Procedure

This guideline supports ARTC Track & Civil Code of Practice, Section 5.

1.4 Document Owner

The Manager Engineering Services is the Document Owner. Queries should be directed to standards@artc.com.au in the first instance

1.5 Reference Documents

The following documents support this guideline:

- ETS-05-00 Track Geometry

2 Introduction to Mud Holes

2.1 Mud holes

Mudholes in railway tracks are areas where the ballast becomes contaminated with fine materials like dirt or clay. This contamination causes the ballast to retain water, creating a muddy, slurry-like substance around the sleepers. This mud infiltration compromises the stability and integrity of the track structure, leading to uneven track surfaces, reduced load-bearing capacity, and potential safety hazards for train operations.

Characteristics of Mud holes

Ballast Contamination

- **Presence of Fines:** The ballast is often contaminated with fine particles, dust, or organic material, which reduces its drainage capacity and exacerbates mud formation.
- **Fouling:** The ballast may appear fouled, with a noticeable accumulation of mud and other contaminants

Water Saturation

- **Capillary Action**: Fine particles in ballast or subgrade materials can draw water upwards through small pore spaces, a process known as capillary rise. This action occurs especially in areas where drainage is inadequate, or the water table is high.
- **Persistent Wetness:** Mud holes are often waterlogged, with the track bed remaining wet long after rainfall has ceased.
- **Water Pooling:** Visible water may pool on the surface of the track, especially in areas with poor drainage

Failing Formation

- **Muddy Ballast:** The ballast, which should be free-draining and supportive, turns into a muddy, soft substance, losing its effectiveness in maintaining track stability.
- **Pumping Effect:** When trains pass over a mudhole, the water and mud may pump to the surface, creating visible, oozing mud around the sleepers and track.

Track Instability

- **Track Deformation:** The track may become uneven, with dips, bumps, or misalignment due to the loss of support from the ballast.
- **Reduced Track Integrity:** The overall stability and integrity of the track are compromised, increasing the risk of derailments or other safety issues.

Vegetation Growth

- **Weed and Plant Growth:** Mud holes often exhibit excessive vegetation growth, as the wet, muddy conditions provide an ideal environment for weeds and plants to thrive.

Figure 1:Sleepers covered with mud and visible gap present around the sleepers and evidence of pumping

2.2 Causes of Mudholes

Mudholes generally form due to a combination of factors, with three key contributors standing out. The first is the presence of water and inadequate drainage. Next, cyclic loading plays a significant role. Finally, excess fines in the underlying ballast layers—whether due to degradation of subgrade or fouling of the surface ballast.

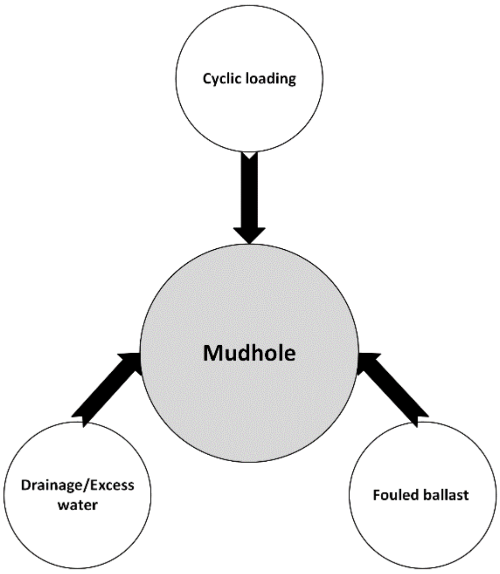


Figure 2: Factors contributing to the formation of mudhole

2.2.1 Drainage

In a properly drained track, surface water flows down through the ballast to the formation, where it is directed across the formation and out through the toe of the ballast. From there, the water drains across the formation cess, over the shoulder, or into a side drain. The side drain must remain free draining, eventually discharging into a natural creek.

Mudholes are closely tied to the presence of high-water content beneath the track. This occurs more frequently during heavy rainfall, as rising water tables and surface water accumulate. In this context, drainage issues are a major factor in the instability and shear failure of railway foundations. Poor drainage leads to undrained shear conditions, where trapped water accelerates the degradation of both ballast and subgrade.

Without adequate drainage, mud holes can form around sleepers, or the formation may become soft. Both surface and subsurface drainage must be considered when undertaking mud hole rectification work.

2.2.2 Cyclic loading

Cyclic loading from passing trains causes repeated stress on the subgrade, increasing capillary action in the soil. This pushes water and fine particles upward through the ballast layer and over time, these fine particles accumulate in the ballast, which reduces its ability to drain water effectively. Continuous stress and water infiltration degrade both the ballast and subgrade, leading to mud pumping.

In critical areas like switches and crossings, rail joints, insulated joints (IJs), defective welds and poor rail surface conditions (Squats and corrugations) intensify stresses under the rail. This heightened stress directly contributes to the accelerated degradation of the ballast and subgrade, often culminating in mud pumping.

- **Switches and crossing:** Mudhole formation at switches and crossings is primarily driven by the intensified dynamic forces and poor drainage conditions inherent to these complex track structures. The discontinuities in rail geometry, frequent wheel impacts, and high traffic loads concentrate stresses on the ballast and subgrade. Over time, this stress causes ballast degradation, creating fines that mix with water, often trapped due to insufficient drainage. Repeated train loads force this slurry-like mixture upwards, contaminating the ballast further and reducing its drainage capacity. The problem is exacerbated by water ingress from capillary action or surface runoff, which saturates the track bed and accelerates the pumping action.
- **Rail joint and IJ's**: Mudhole formation at rail joints and insulated joints (IJs) is a common issue due to the structural discontinuities and stress concentrations in these areas. Poor alignment or irregular geometry at the joints creates localized impacts as wheels traverse, generating high dynamic forces that are transmitted into the ballast and subgrade. These forces accelerate ballast degradation, producing fines that mix with water to form a slurry. Water ingress is often exacerbated by gaps or cracks in the joint area, as well as inadequate drainage. The repeated cyclic loading from passing trains pumps this slurry upwards, fouling the ballast and reducing its ability to drain effectively. Over time, this leads to persistent mudholes.
- **Defective welds**: Defective welds may have surface irregularities, such as dips, bumps, or uneven surfaces, where the two rail sections are joined. These irregularities disrupt the smoothness of the rail surface and creates a localized weakness in the track. When trains pass over the defective weld, the irregularities cause the wheels to experience uneven impact forces. The uneven impact generates increased vibrations, which cause the axles to bounce, leading to cyclically increased loading until settled. This, in turn, propagates the formation of mud holes further down the track. *Refer to Section 1, table 1-10 for tolerances of finished rail welds and 1-13 for existing welds.*
- **Squats**: Squats are localized depressions or cracks on the rail surface caused by fatigue or plastic deformation under repeated heavy loads. These defects generate sharp dynamic impact forces as wheels pass over them, transferring high loads to the track structure. This leads to ballast breakdown and increased particle movement in the subgrade, producing fines. Repeated impacts compact the subgrade, creating depressions that trap water. The combination of water and fines forms a slurry, fouling the ballast and ultimately resulting in mudhole formation.

- **Corrugations**: Corrugations are wave-like irregularities on the rail surface caused by wear, vibration, and wheel-rail interaction. These defects generate oscillatory forces during wheel passage, destabilizing the ballast layer and concentrating energy at specific wavelengths, which accelerates ballast degradation and subgrade deformation. Vibrations from corrugations intensify the pumping of water and fines, forming a muddy slurry. Additionally, these forces compact the ballast in localized areas, obstructing drainage and leading to prolonged saturation, which contributes to mudhole formation.

2.2.3 Fouled Ballast

Fouled ballast refers to ballast that has become completely contaminated with fine particles such as dirt, dust, clay, coal dust, or organic matter. This contamination reduces the ballast's effectiveness, leading to various track maintenance issues, including poor drainage and the formation of mudholes. Ballast can become foul through various means, including subgrade degradation, ballast breakage, and contamination from external sources like dust and waste materials.

- **Subgrade degradation:** Subgrade mud pumping primarily occurs due to the migration of fines from the subgrade layer. As trains travel over the tracks, the repeated cycles of loading and unloading generate excess pore-water pressure in the subgrade. This pressure forces water and fine particles to move upward. Over time, these fine particles accumulate in the ballast, diminishing its drainage capacity and stability. This results in the formation of mudholes, which are essentially pockets of mud within the ballast.
- **Ballast breakage:** The breakdown of ballast over time is caused by the action of train loading, particularly from heavy and frequent traffic. Rail surface defects such as dipped and peaked welds, rail mechanical joints, wheel burns, and shelling can lead to ballast breakage, and generating fine particles within the ballast layer. Maintenance activities like tamping also contribute to this issue. Unlike fines from the subgrade, ballast breakage is usually unavoidable.
- **External sources:** This type of fines originates from external sources affecting the rail ballast, as opposed to those generated internally. External sources can include coal, ore dust, and other waste from freight train operations, dust carried by wind and rain, and fines resulting from the wear and tear of the superstructure, such as the degradation of sleeper.

As ballast degrades due to the factors mentioned above, gaps or voids begin to emerge between the sleepers and ballast. A moderately or partially fouled ballast site is one where sleepers are not yet completely surrounded by mud and there are no visible gaps around the sleepers at this stage. Water can still drain away after rainfall, and the area does not remain wet long after the rain has stopped. As the gaps between ballast grains continue to fill with contaminants, the site can become a fully fouled ballast site, significantly reducing the drainage capacity of the ballast bed. Water is retained even with minimal rainfall and stays wet long after the rain has stopped, turning the site into soft formation, or an active mudhole with visible dry or oozing mud.

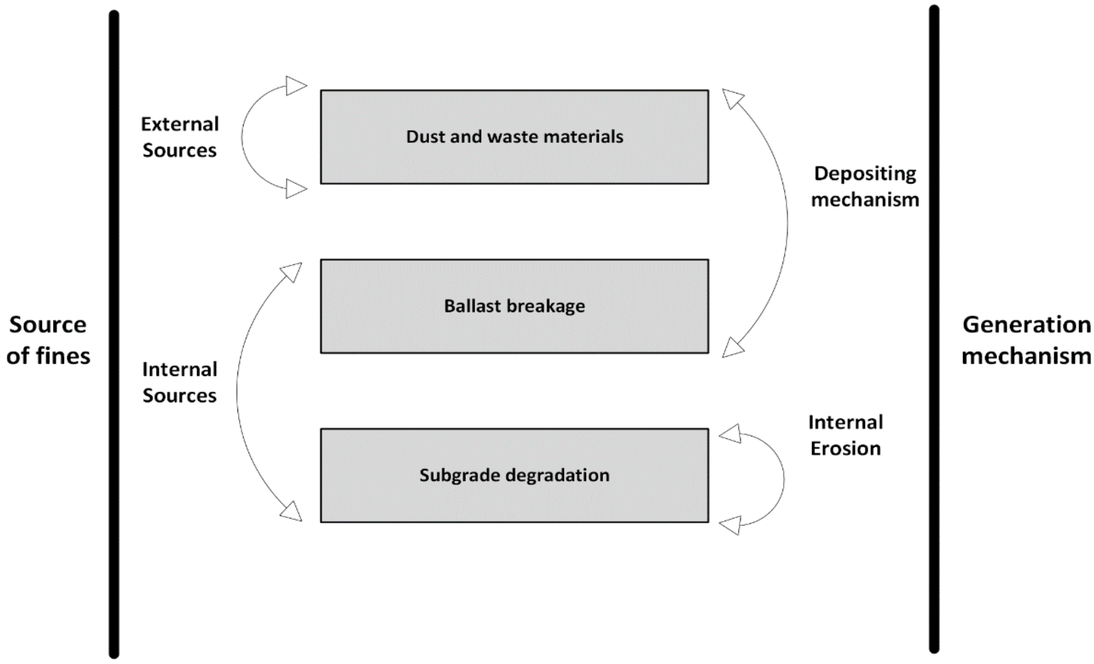


Figure 3: Sources and generation mechanism of mudholes fines

Prevention

It is inevitable that ballast will become fouled over time. There are however steps that can reduce fouling:

- Purchase ballast in accordance with specification and in particular reject ballast with excessive fines.
- Avoid excessive tamping to reduce the risk of ballast breakdown. If only a few hundred metres require tamping, then do not tamp the whole km. This avoids unnecessary ballast degradation
- Clean out silt from cuttings. The long-term effect of delaying such work is that the ballast becomes fouled with the silt.
- When ballast regulating
  - avoid grading the formation shoulder up into the ballast.
  - ensure the side ballast plough does not put a groove in the formation at the ballast toe.
- When grading the formation ensure the toe of the ballast is allowed to drain freely.
- Provide adequate ballast under sleepers.
- Control vegetation at the toe of the ballast limiting drainage.
- Address dips in the weld to prevent the escalation of ballast breakdown and contamination issues.

2.3 Type of Mud holes

2.3.1 Fouled ballast Mud hole

In severely fouled ballast, the sleeper will be surrounded by mud that retains a pool of water (or sloppy mud) around the individual sleepers. This puddle can be “perched” around the sleeper with dryer ballast beneath. Alternatively, the mud can extend down to a solid formation (this often occurs when there is inadequate ballast depth above a rock formation). In both cases the problem is fouled ballast. The resulting geometry faults are often short sharp faults.

Figure 4:Fouled ballast mud hole (This is a perched type with water and mud in pockets around the sleepers)

Causes

When ballast is fouled the water is trapped in the ballast around the sleeper. The fines in the ballast appear as mud surrounding the sleeper and in some cases the sleeper “pumps” up and down in the mud when under train loading. The actual geometry under the load of a train can be worse than the unloaded geometry due to voids under the pumping sleepers. This pumping can become severe enough that the track geometry fails to meet the track geometry standard.

Prevention

1. Pick out sleeper ends to allow water to drain from sleeper bay.
2. Avoid recovery of foul ballast by Ballast regulators during resurfacing operations.
3. Clean the ballast shoulder. It is important to ensure the toe of the ballast is not left foul. If left foul, the formation will not drain properly and may become soft
4. Short sections of foul ballast can be simply graded out and discarded. This is appropriate when the cost of screening either by portable screen or ballast cleaner is not justified for small sections
5. Distribute new clean ballast and give the track a high lift.

2.3.2 Grey mudhole

In this type of mudhole, the ballast is contaminated with fine particles, commonly consisting of coal and degraded ballast material. This condition can be identified through visual inspection, characterized by the presence of fine material and moisture around the sleepers, as well as voids beneath them. The fouling material typically appears grey, closely resembling the ballast.

Causes

The primary cause of grey mudhole is a combination of train loading, ballast fouling beneath the sleepers, and moisture retention within the ballast layer. Train loading imposes repeated cyclic forces on the track, which intensifies stress on the ballast. Over time, ballast breaks down into fine particles, which combines with moistures, leading to a mudhole. This type of mudholes are commonly found where there is a poor weld geometry such as dips.

Figure 5:Sleepers enveloped in grey mud, a clear sign of ballast degradation

2.3.3 Soft Formation

It is important to clearly distinguish between these two conditions as the treatment is dependent on the problem. Sometimes both conditions exist at the one location, and in these cases the remedial actions must address both conditions. In all cases however, the drainage of the track should be addressed.

On soft formation, the track overall becomes wavy with repetitive loss of faults. There may however be a single fault and it is generally longer and gentler than for the fouled ballast mudhole. The single soft formation fault is often referred to as a ballast pocket. The formation outside the toe of the ballast may be soft and muddy to walk on. In severe cases the shoulders of the formation may “heave” outside the toe of the ballast, as the track sinks.

Figure 6:Soft formation mud hole

Causes

Inadequate drainage systems can cause water to accumulate in the track bed, saturating the ballast and subgrade. When these materials become waterlogged, they lose their strength and become soft and depress to form a puddle under the ballast. The ballast sinks into the formation and this leads to loss of track geometry.

Another cause is the permanent plastic deformation of the formation and/or subgrade due to cyclic train loading, which gradually increases the depth of the ballast under sleeper.

Prevention

The remedial actions for fouled ballast also can be used to address soft formation. Collecting and diverting surface water away from the track structure may be the most cost-effective portion of any maintenance program. By intercepting and diverting more water, less of it infiltrates the ground, reducing the risk of weakening the track structure. The recommended maintenance practices include:

- Enhance track drainage
    - Ensure runoff flows away and does not accumulate.
    - Maintain surface water as surface water – prevent it from pooling or infiltrating the embankment or the ground upslope of the embankment.
    - Deepen cess drains to 300 millimetres below the bottom of the top formation, ensuring they are not deepened to the extent that the track section is undercut.
    - Grade the bottoms of cess drains to enhance runoff.
    - Clean cess drains and culverts.
    - Inspect culverts to ensure they are in good condition, free from rust, and properly aligned.
    - Install a trench drain at, and upslope of the heave location as a short-term solution to address the heaving and ballast pocket issues.
- Reconstruct the formation for long term solution

2.3.4 Brown Mudhole

A type of soft formation mudhole. In this mudhole, the ballast layer contains formation and/or subgrade material, along with moisture present around the sleepers. Visible features include voids around the sleepers and the presence of material that resembles the capping, formation, or subgrade, typically brown or red brown in colour. This material, along with the moisture, indicates the migration of fines from the underlying layers into the ballast, compromising track stability and drainage.

Causes

The causes of brown mudholes can be attributed to excessive moisture and poor drainage, combined with overstressing of the formation and/or capping layer. Additionally, the absence of a proper filter layer beneath the ballast exacerbates the issue, allowing fine particles from the underlying layers to migrate into the ballast.

Figure 7: Brown mud accumulating on the surface of the ballast, signalling potential issues with the formation or capping layer, and early signs of drainage failure

3 Assessment of Mudholes

3.1 General inspections

Each mud hole found during normal patrol inspection, reported by train crews or otherwise identified, should be inspected as specified in ETS-05-00 clause 5.4.1

A general inspection should be carried out at specific locations when suspected defects are identified from conditions determined during patrol inspections and as defined by the responses in ETS-05-00 Table 5-15 and Table 5-16 The geometry at the location should be measured and compared with specified limits. The cause, restrictions and repair work should be determined taking into account the local conditions at the site that may affect deterioration rates. General inspections should also identify the need for further specialist inspection.

At locations with mudholes, visual inspections should include assessments of track geometry deterioration, drainage effectiveness, and any initiator that’s causing mudhole

3.1.1 Assessment of geometry and the void under sleepers during general inspection

Measurement of track geometry shall be in accordance with the ARTC Track & Civil Code of Practice Section 5: Track Geometry.

The loaded condition can be measured by:

- The AK car or other measuring system with axle load above 5 tonnes.
- During front of train inspection.
- Measuring the unloaded track geometry and then adding the extent of depression under load. Examples of measuring unloaded track geometry are:
    - Measurement by manual means using stringline, track gauge, cant gauge, and straightedge.
    - Use of light weight measuring trolley.
- The extent of depression can be measured by:
    - Use of depression pegs.
    - Digging out the ballast from the end of the sleepers and measuring the void under the sleepers.
    - Use of void meter.
    - Observing the passage of trains.

3.1.2 Initial assessment of mudholes during general Inspection

When performing initial assessment, mudholes should be classified into A, B, and C response categories, *Refer to table 1 for response categories*.

- The minimum length to be recorded is 1 meter. If there is a series of mudholes within close proximity, they can be grouped and registered as one defect, provided the distance between them is less than 20 meters. If the distance is 20 meters or greater, they should be recorded as separate defects.
- The extremities of mudholes should be marked in the field to monitor their longitudinal growth over time.

- The root cause of the mudhole should be recorded. For example: fouled ballast, ineffective drainage, broken sleeper, or poor rail condition.
- For geometry exceedances, a separate defect should be recorded in Ellipse.
- If a geometry fault exists at the location, the response, including inspection intervals and any speed restrictions, should follow the Geometry Standard. If formation failure has occurred or is suspected, a separate defect should also be recorded in Ellipse.

Refer to the flow chart in Figure 8 for a detailed process on the initial assessment of mudholes.

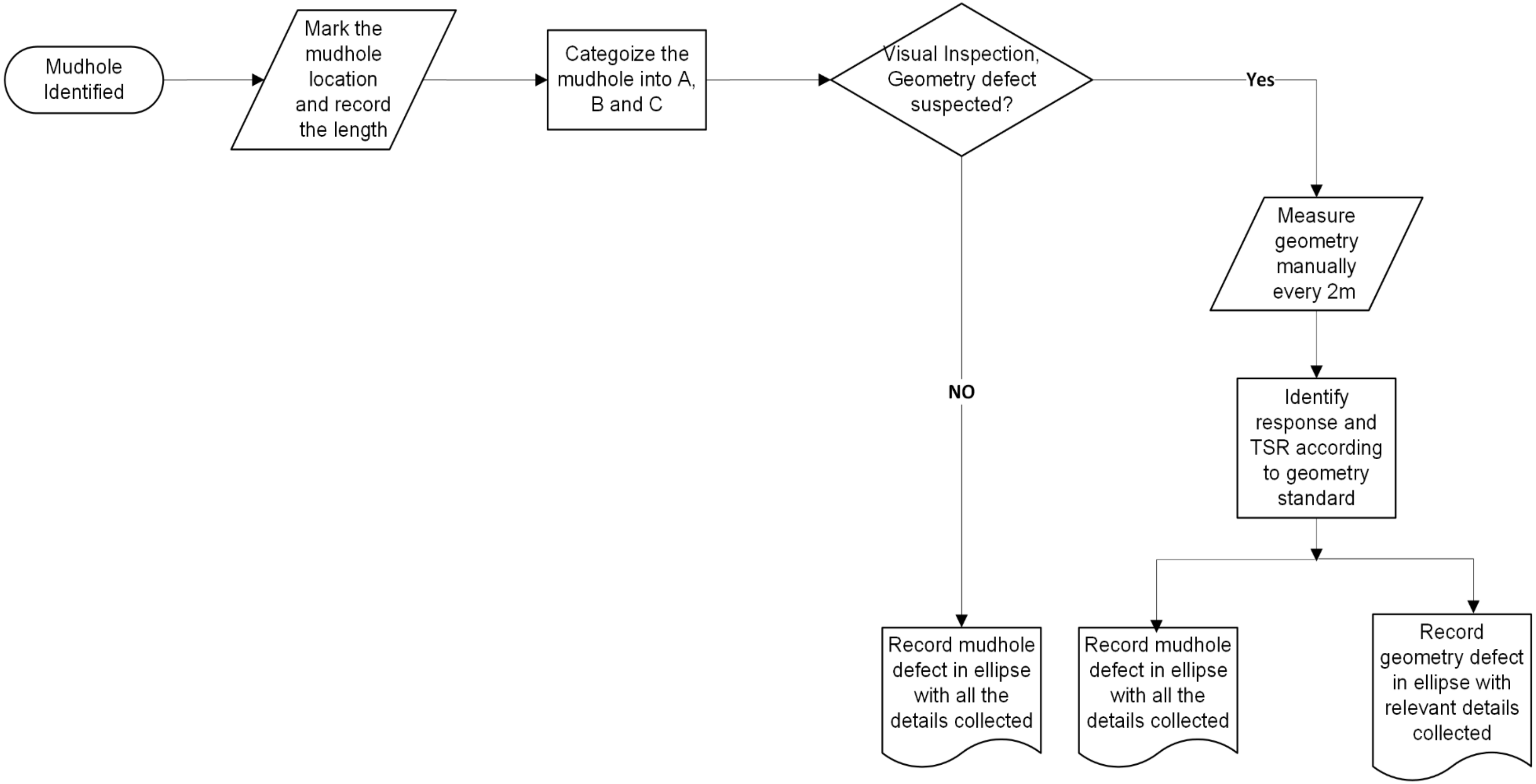


Figure 8: Flow chart for initial assessment of mudhole.

Measure geometry manually every 2m*: Refer to Appendix B for instructions on measuring track top under loaded conditions using depression pegs.*

Table 1: Mudhole classification and Alarms & Defect Response Categories.

Response Code	Description	Reinspection Interval	Work Order Std Job
A	**Band A General Inspection of Mudholes – e.g.:** • In transition of a curve • Partial mud hole • Water ponding • Within 25 metres of a fixed point with rail condition • The Shoulder excavated below bottom of sleeper • Tunnel, Overbridge etc	Within 90 days PR	MUD001: Band A General Inspection of Mudholes
B	**Band B General Inspection of Mudholes – e.g.:** • With rail condition being the primary initiator • Within 25 metres of a fixed point • On Curve	Within 6 Months P3	MUD002: Band B General Inspection of Mudholes
C	**Band C General Inspection of Mudholes – e.g.:** • Mud evident but no reportable geometric defects present	Within 1 Year P4	MUD003: Band C General Inspection of Mudholes

3.2 Reassessment of mudholes

Reinspection of mudholes is performed to assess the deterioration of the mudhole and track geometry. When a reinspection of mudhole is undertaken, the following results may occur:

- No further deterioration of mudhole:
  - In this case, there is no requirement to measure the length of the mudhole or the track geometry.
- Further deterioration of mudhole:
  - The length of the mudhole needs to be measured if it has extended beyond the previously marked location.
  - Measure track geometry and compare against Section 5 Geometry Defects – Response Category Maintenance Limits. This ensures that any deviations from the standard are accurately identified.
  - Use depression pegs to measure voids under a sleeper in the track while it is under load. This method is useful for determining the relative change over time.

Refer to the flow chart in Figure 9 for a detailed process on the reassessment of mudholes.

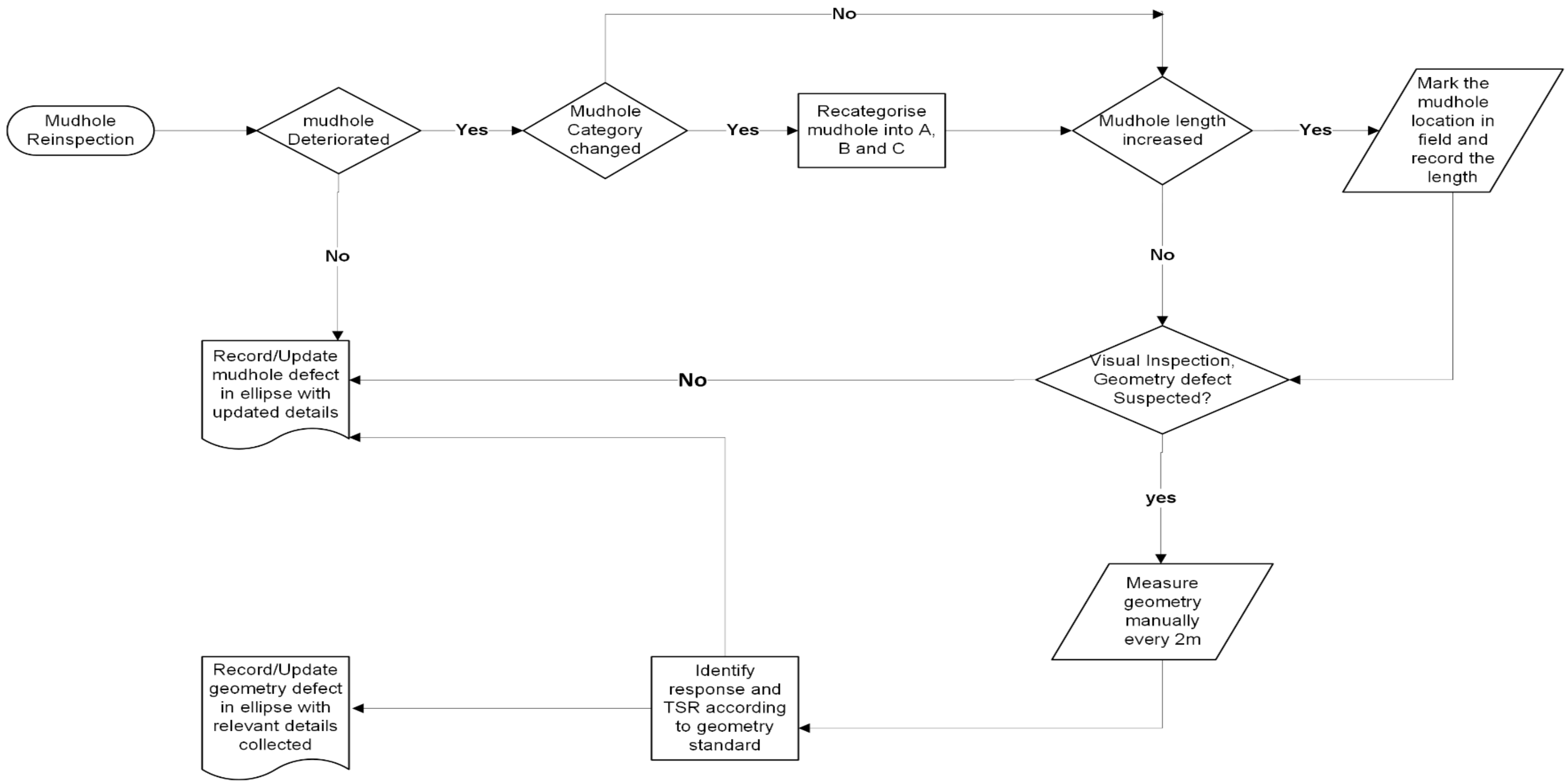


Figure 9: Flow chart for reassessment of mudholes

Measure geometry manually every 2m*: Refer to Appendix B for instructions on measuring track top under loaded conditions using depression pegs*

Appendix A: Solutions and Treatment

Numerous solutions for treating mudholes are available, it is crucial to identify the root cause and initiators of mudhole. Understanding these factors allows for more targeted and effective rectification. Mudhole solutions can be categorized into Interim solution and Permanent solution

Interim treatment

While waiting for a final treatment to be implemented, several interim measures can be taken to mitigate the effects of mudholes. These methods provide temporary relief and stabilize the affected area. Examples are:

- **Shoulder ballast cleaning:** Shoulder ballast cleaning involves removing and cleaning the fouled ballast located at the toe of track shoulders. The cleaning can be performed at specific spots using excavator equipment or on a larger scale with on-track shoulder ballast cleaners. The method chosen depends on the extent of contamination and the area to be addressed. Surface drainage from the bottom of the cleaned section to the side drains should prevent any ponding. Sufficient make-up ballast should be provided to maintain the required total ballast depth for the sleepers. Regardless of the total ballast depth after shoulder cleaning, a minimum tamping lift of 50mm is necessary.

  Shoulder cleaning is significantly cheaper than full section cleaning and causes less disruption to train operations. This process can be repeated as needed, as the shoulder may become fouled again by fines leaching out from around the sleepers.

  A speed restriction should be imposed, and the track should be closely monitored during consolidation after shoulder ballast cleaning. The process is often more effective when combined with cleaning or replacing the ballast in the cribs, as this addresses the full extent of potential issues and enhances overall track stability. In the case of small mud holes, an alternative to shoulder cleaning is to remove the shoulder entirely and replace it with new ballast. This method is often preferred when the use of specialized equipment is not cost-effective.
- **Narrow drains:** A common interim measure is to create narrow drains from the ends of the affected sleepers, extending from the bottom level of the sleeper past the shoulder. This allows the perched water pocket to drain effectively.
- **Gravel packing:** In addition to draining the sleeper ends, 20mm gravel can be used to pack the void under the sleeper. This method provides support without disturbing the mud beneath the sleeper.
- **Ballast removal:** Removing the ballast from the end of each sleeper affected by the mudhole can help alleviate pressure and reduce pumping. However, care should be taken not to excessively undermine the ballast underneath the sleeper, as this could lead to a complete collapse of support**.**
- When sleeper ends are exposed, a precautionary speed restriction more conservative than that prescribed in the Track and Civil Code of Practice. From November to March, a stability analysis should account for the disturbance to the ballast, as the risk of track buckling increases during warmer months**.**
- **High lift tamping:** High lift tamping can be employed as an interim solution. Its effectiveness should be monitored closely, and it is often more successful when following shoulder ballast cleaning.

- **Shoulder and Crib Excavation:** Digging out shoulders and cribs with small excavators can serve as an interim measure. In some cases, this may even be a permanent solution

Long term treatment

There are many options for long term treatment to address the mudholes and improve track stability over time. The treatments are:

- **Full section ballast cleaning:** Full section ballast cleaning involves the thorough removal of fouled ballast from the entire track section, including beneath the sleepers and the shoulder. It is also recommended to create a cross fall on the new bed to support proper drainage for the cleaned and make-up ballast. Sufficient make-up ballast should be added to maintain the required total ballast depth. Surface drainage across the new bed must prevent any ponding beneath the track, ensuring free drainage with no pooling toward the side drains. Proper drainage is essential to maintaining the integrity and longevity of the track structure.
- **Sledding:** Where the fouling of ballast is extreme, full section ballast cleaning or shoulder cleaning becomes uneconomic as the cost increases due to clogging of the screens and the percentage of returned ballast is low. Sledding or full section replacement should then be considered. Sledding involves placing new, free-draining ballast beneath and around the sleepers to create a durable foundation. This method ensures long-term drainage and structural integrity.
- **Fixing Track issues:** Adress any contributing factors that may exacerbate the problem, such as dipped or peaked welds, excessively worn rail, or skewed or broken sleepers. Rectifying these issues helps prevent the recurrence of mud holes and ensures a more stable and long-lasting track structure. Addressing these underlying initiators is essential for the overall effectiveness of mud hole rectification efforts.
- **Improve Drainage:** Improving drainage systems, such as installing sub-surface drains, trenches, or upgrading existing drainage infrastructure to ensure water is effectively removed from the track bed.
- **Subgrade improvement:** Strengthening or stabilizing the subgrade to prevent degradation and migration of fines. Techniques such as soil stabilization, and adding geosynthetics can provide lasting support to the track structure. The use of geosynthetics plays a vital role in preventing the recurrence of mudholes by addressing two key issues: the migration of subgrade fines and the reduction of pressure on the ballast and subgrade degradation. Subgrade fines can migrate into the coarser track layers due to an upward hydraulic gradient, contributing to mudhole formation and recurrence. Geosynthetics, especially those functioning as filter layers, effectively block this migration, preserving the integrity of the track structure. Additionally, geosynthetic composites help reduce pressure on both the ballast and subgrade by distributing loads more evenly, mitigating layer degradation, extending their lifespan, and decreasing the likelihood of mudhole formation.

Where the extent and severity of mud holes in an area is beyond the resources of the local maintenance staff to control, a plan should be prepared to address the mud hole problem and submitted for approval and funding

Appendix B – Use of Depression Pegs

When a train passes over a mudhole, it causes pumping due to the voids beneath the sleeper. Depression pegs are tools used to measure these voids under the sleeper while it's under load. There are two main types:

- **Type 1**: Equipped with a slide-able stopper. To set up, position the peg in the centre of a sleeper bay at the location of concern, ensuring that the fixture base and slide stopper are in contact, as shown in Figure 1.
- **Type 2**: A simple assembly with a sharp spike and horizontal pin. To setup, position the peg in the centre of the sleeper bay and ensure the horizontal pin is in contact with the rail foot.

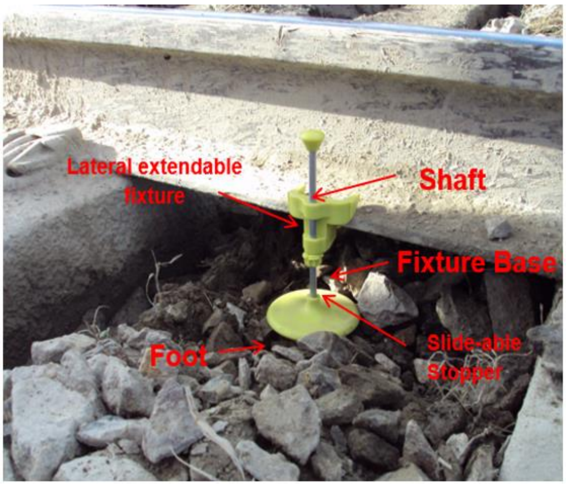


Figure 10: On the left is the Type 1 depression peg, featuring a slideable stopper; on the right is the Type 2 depression peg, a simpler assembly with a sharp spike.

Under load, the amount of void or pumping can be determined by measuring the distance between the bottom of the fixture base and the top of the slide-able stopper for Type 1, or by measuring the gap between the rail foot and the horizontal pin for Type 2.

The use of depression pegs in track varies depending on the length of the mud-hole, the defect location, and the track's characteristics. Measurements must be taken on both rails of the track for accurate assessment. For each measurement location, a minimum of six pegs is required: four for the reference baseline (two on each rail) and two for measuring depression (one on each rail), as shown in figure 10.

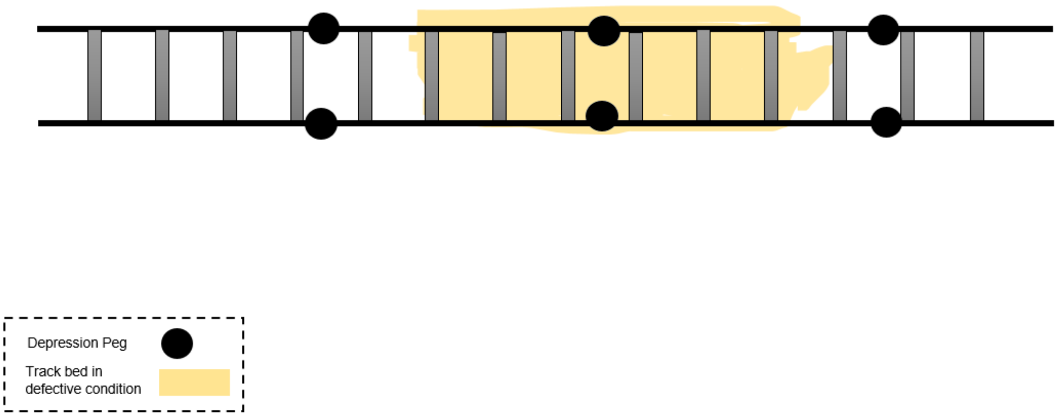
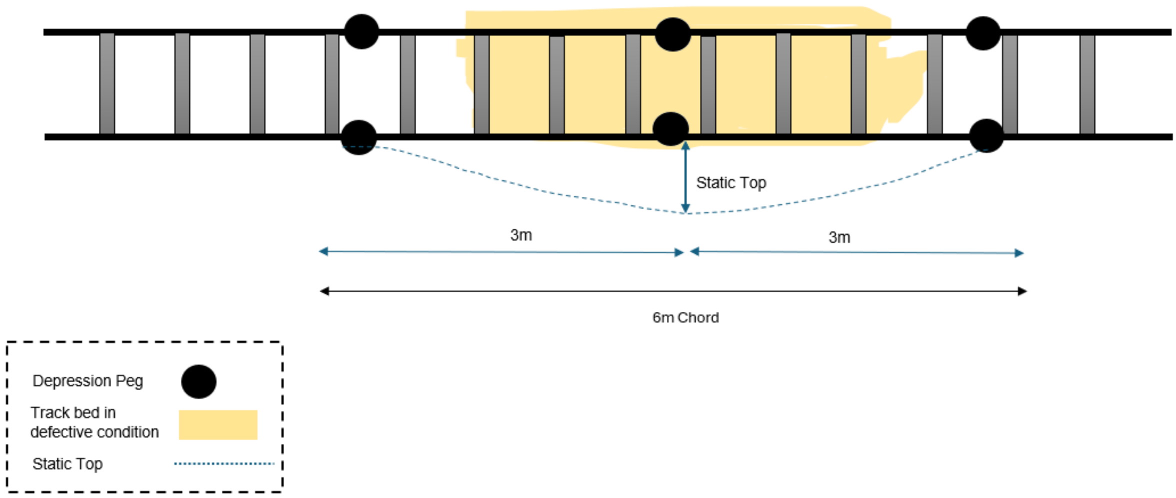


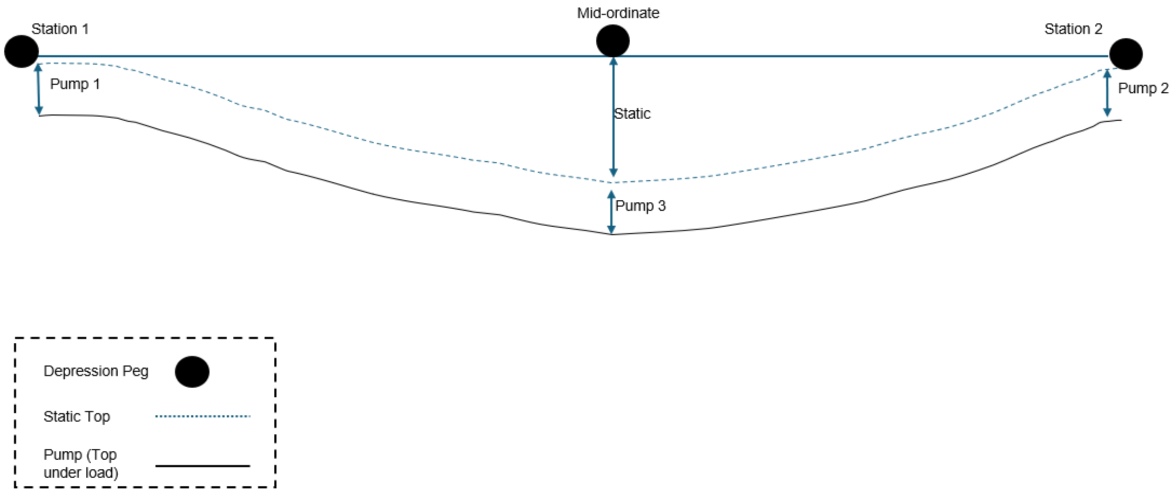
Figure 11: Track bed with a mudhole, showing six depression pegs: four as reference baselines (two on each rail) and two for measuring depression (one on each rail).

For mud hole lengths shorter than 10 sleeper bays, the following approach should be applied:

- Identify the section of track affected by pumping or poor top.
- Visually inspect the track to find the approximate area of greatest top deterioration and mark it with a paint line.
- Measure the static top using 6m chord manually or light weight measuring trolley over the defect section.



- Under load, take measurements for the three parameters shown in the image below: Pump 1, Pump 2, and Pump 3, as shown in the figure below.

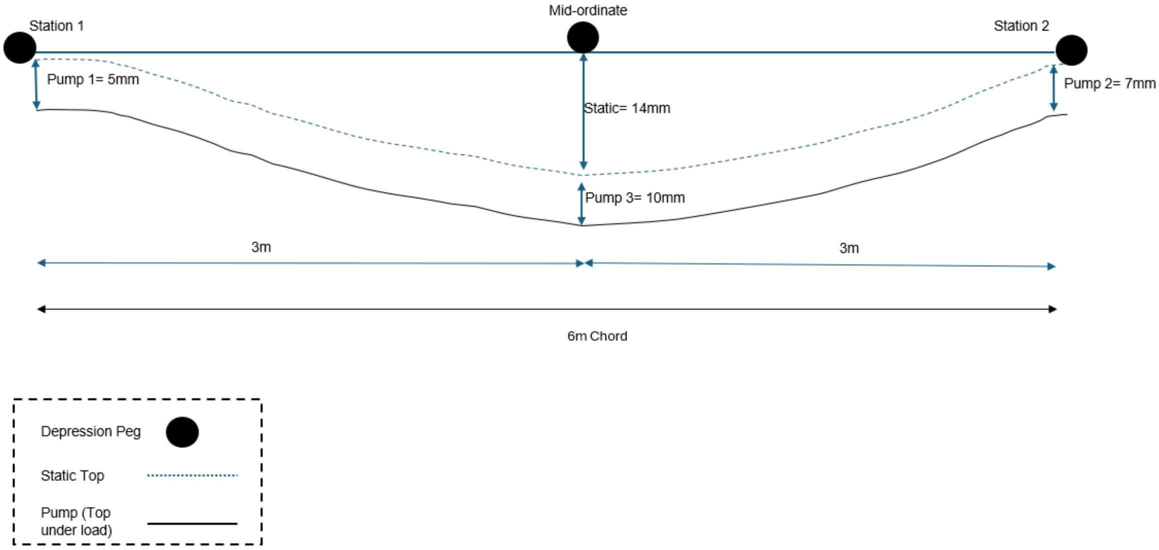


- Once the measurements have been recorded, use the following equations to calculate the total pump and actual top value.

$$Total\ Pump = Pump\ 3 - \left(\frac{Pump\ 1\ +\ Pump\ 2}{2}\right)$$

$$Top = Total\ Pump + Static\ top$$

An example of the measurement and calculation for the 6-meter chord is provided below. The static top is measured at 14mm, with a pump reading of 10mm at the centre and measurements of 5mm and 7mm at the ends of the chords.



$$Total\ Pump = Pump\ 3 - \left(\frac{Pump\ 1\ +\ Pump\ 2}{2}\right)$$

$$Total\ Pump =\ 10 - \left(\frac{5\ +\ 7}{2}\right)$$

$$Total\ Pump =\ 10 - 6$$

$$Total\ Pump =\ 4mm$$

Now Top,

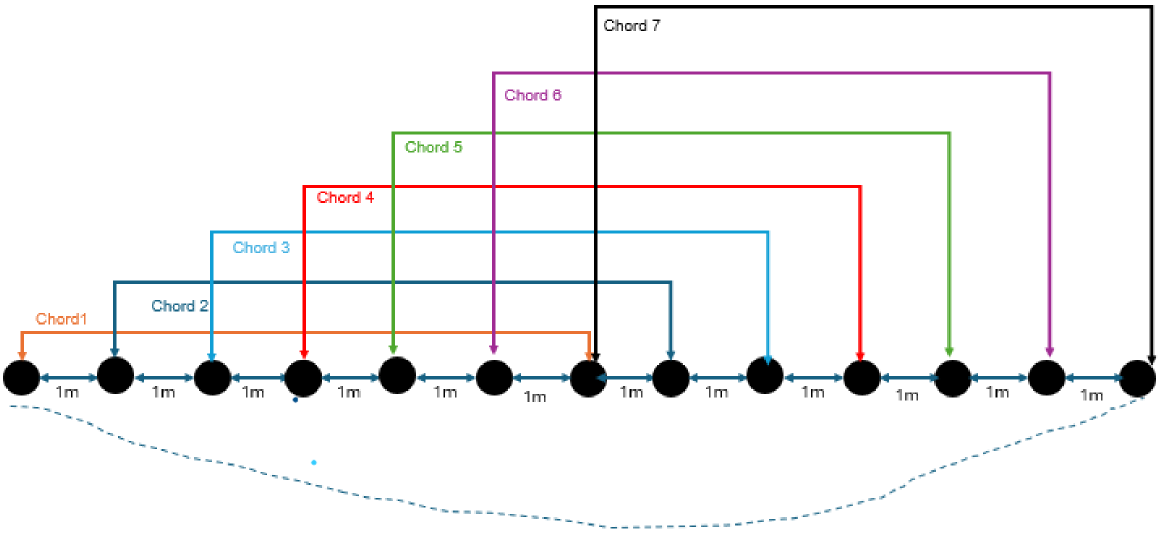
$$Top = Total\ Pump + Static\ top$$

$$Top = 4mm + 14$$

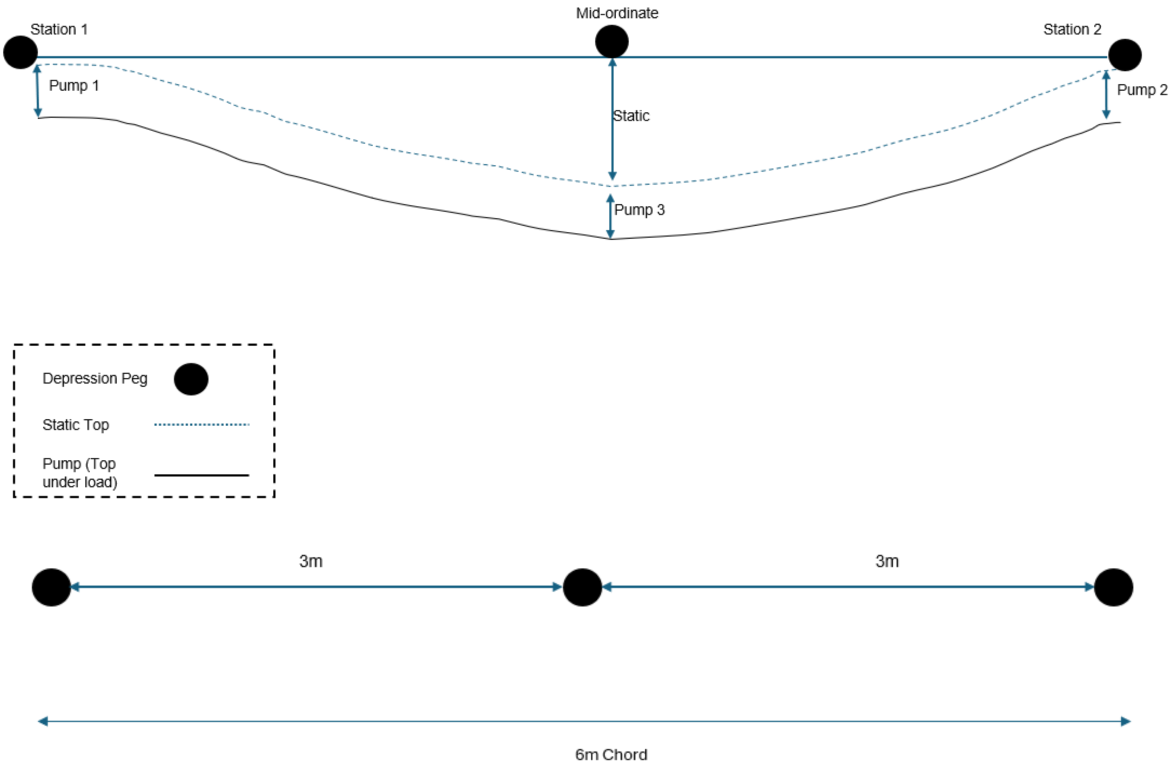
$$Top = 18mm$$

For mud hole lengths longer than 10-20 sleeper bays, a detailed application of depression pegs should be applied:

- Identify the section of track affected by pumping or poor top.
- Visually inspect the track to find the approximate area of greatest top deterioration and mark it with a paint line.
- Measure the Top with a lightweight measuring trolley or manually.
- For manual measurement, place paint marks at 1-meter intervals along the entire defective section of track, ensuring the entire area with poor top is included, as well as some additional length at each end to capture the worst-affected location. A conceptual diagram of 6-meter chords is provided below.



- Measure the static top for all the chords over the defect section.
    - Static Top for Chord 1
    - Static Top for Chord 2
    - Static Top for Chord 3
    - Static Top for Chord 4
    - Static Top for Chord 5
    - Static Top for Chord 6
    - Static Top for Chord 7
- At the location with the worst static top, place depression pegs at both ends of the chord and in the middle at the location of static pump.
- Under load, take measurements for the three parameters shown in the image: Pump 1, Pump 2, and Pump 3.



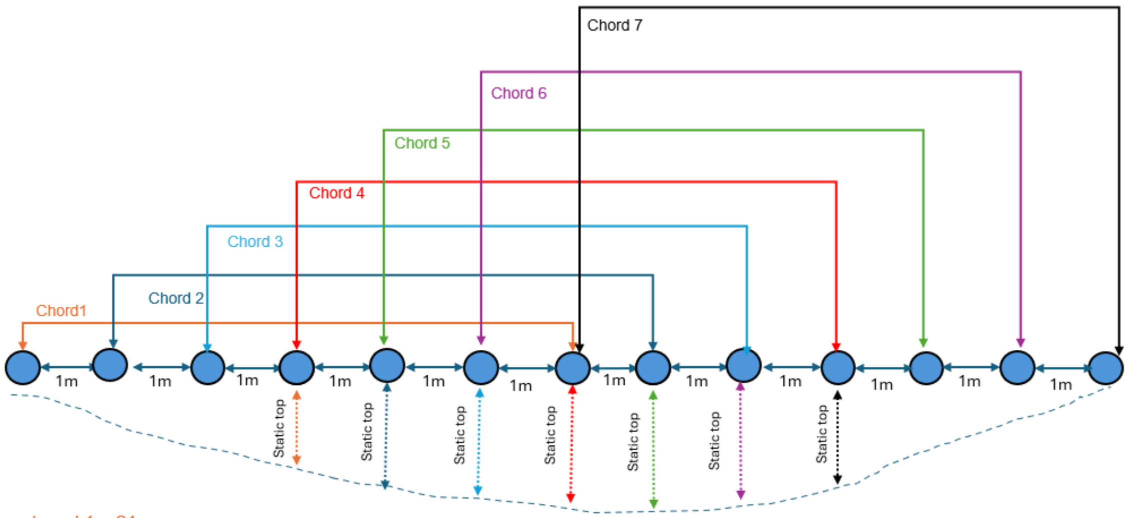
- Once the measurements have been recorded, use the following equations to calculate the total pump and actual top value.

$$Total\ Pump = Pump\ 3 - \left(\frac{Pump\ 1\ +\ Pump\ 2}{2}\right)$$

$$Top = Total\ Pump + Static\ top$$

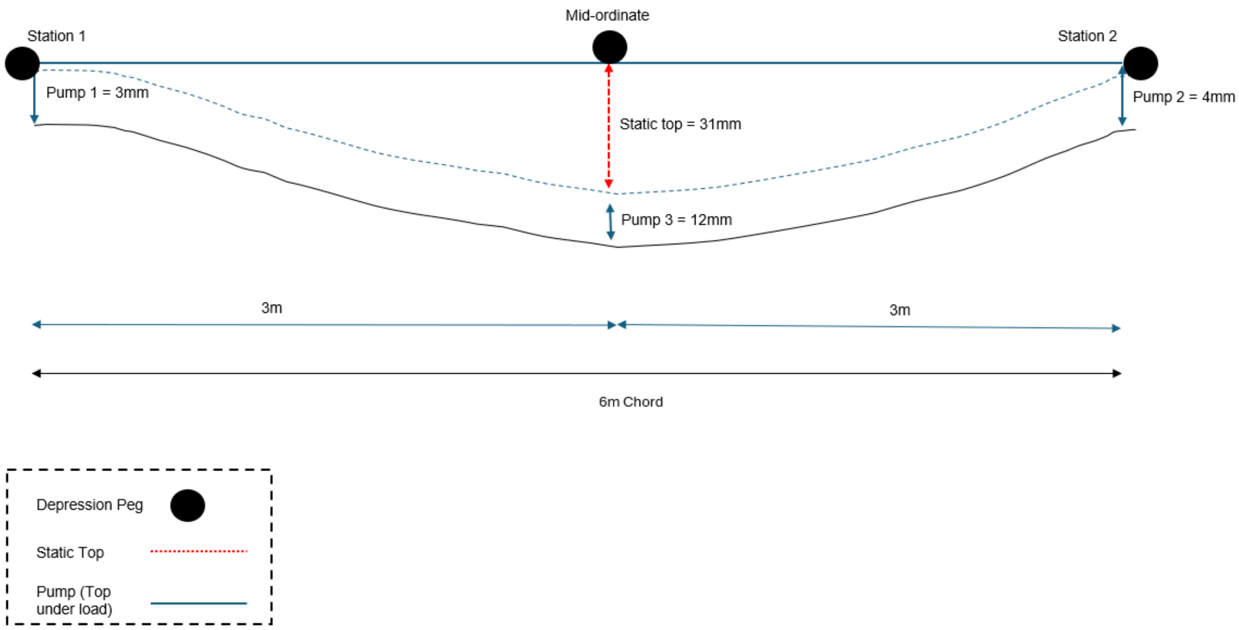
- Using the top measurement results, refer to the Track & Civil Code of Practice to determine the defect priority and the appropriate Temporary Speed Restriction (TSR) response.

An example of the measurement and calculation for the 6-meter chord is provided below. The top was measured at 7 locations and let's say the worst static top is measured at cord 4, 31mm, with a pump reading of 12mm at the centre and measurements of 4mm and 3mm at the ends of the chords.



- Static Top at cord 1 = 21
- Static Top at cord 2 = 24
- Static Top at cord 3 = 28
- Static Top at cord 4 = 31
- Static Top at cord 5 = 28
- Static Top at cord 6 = 26
- Static Top at cord 7 = 25

As the worst static top is **31mm**, so place the depression pegs at cord 4, one in the middle and two on each end.



$$Total\ Pump = 12 - \left(\frac{3+4}{2}\right)$$

$$Total\ Pump = 12 - (3.5)$$

$$= 8.5mm$$

$$or\ say\ 9mm$$

Now Top,

$$Top = Total\ Pump + Static\ top$$

$$Top = 31mm + 9mm$$

$$40mm\ Top$$

Loaded Top is now 40mm Band B E1 at (115kph)