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Geobear's solution to embankment stabilisation: SVR trial

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Introduction

- A section of railway track known as Alveley Wood in Shropshire on the Severn Valley Railway (SVR) is showing signs of distress, which resulted in 300mm deviation from design geometry and the introduction of a speed restriction (10mph)

- The distress, seen typically as a deformation of the track as a result of a slope of instability.

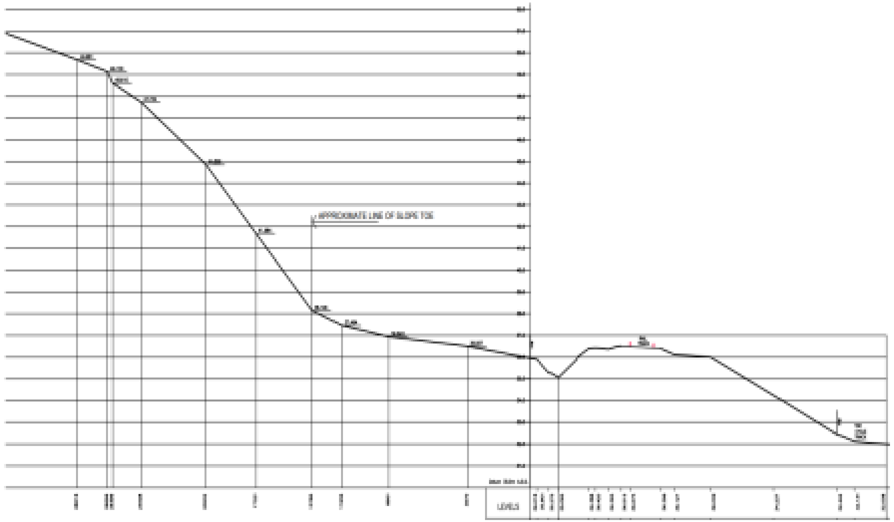
- Track deformation appears along an approximately 80m section of railway line on the western side of the River Severn.

Introduction

- The embankment, comprising ash fill with a mantle of track ballast at its crest, spreads to form a lobe at this position.

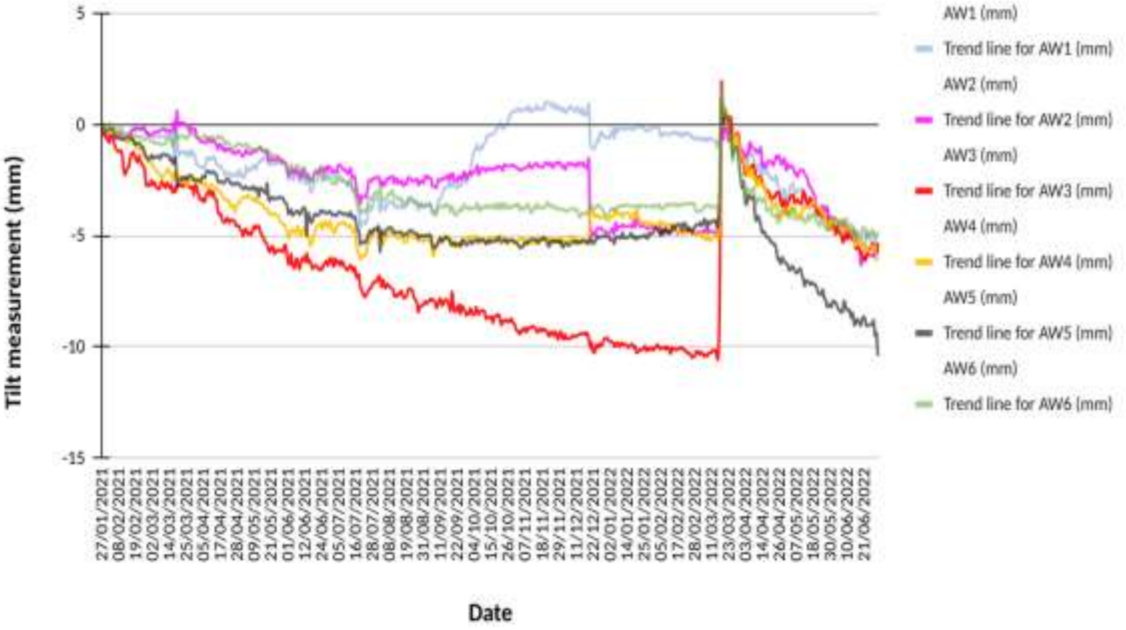
- There most of the embankment has little or no height on the western side.

- On the other hand, around 4.5m to 5.5m in height at its central point section on the eastern side. The deformation of the track is most pronounced where the embankment reaches maximum height.



Track tilt sensors

- Tilt sensors were installed in three locations / chainages:
  - 17660 (AW1-AW2)
  - 17684 (AW3-AW4)
  - 17708 (AW5-AW6)



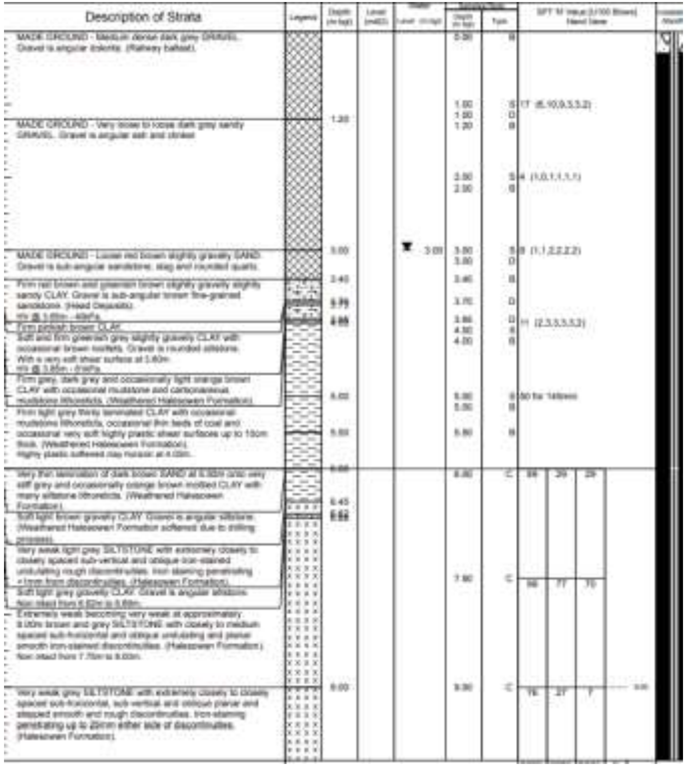
Ground model

Ground investigation - borehole data

- Made ground was identified in both holes to depths of between 3.4 and 4.6 metres and consisted of 1.2 metres of railway ballast underlain by mainly loose to medium dense ash fill. SPT N values ranged between 4 and 18 averaging around 10

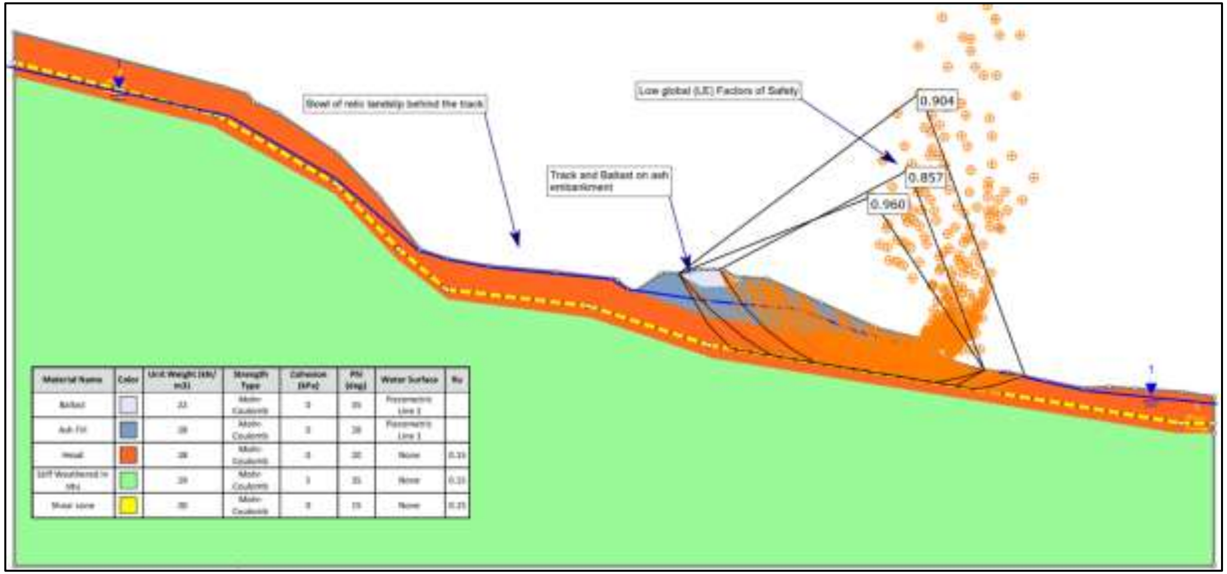
- Between the Made Ground and the solid geology, a layer described as Head Deposits were identified. These were generally described as firm gravelly clay, containing occasional very thin very soft shear surfaces.

- This was interpreted as a shear zone resulting from an ancient landslide, possibly arising at the end of the last ice age.



Slope Failure Mechanism

- Initial analysis of the site investigation data was done by Ground Investigation and Piling Ltd.
- They concluded movement of the track was due to slope instability.
- The lowest factor of safety occurred along a slip surface which migrated along the shear zone.
- The effective stress parameters of clay within the shear zone we assumed to be at residual conditions

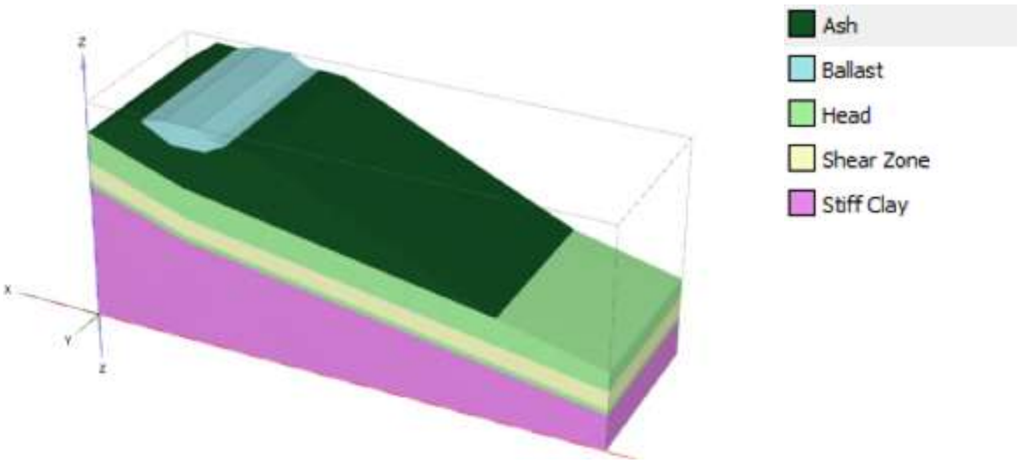


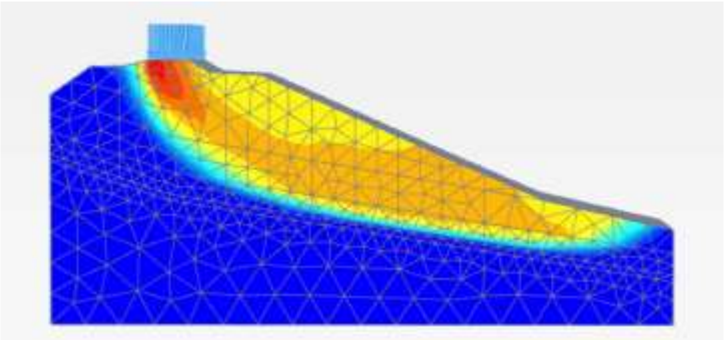
The original slope stabilization proposal was to soil nail through the shear zone into the competent bedrock.

Design

Existing Condition - PLAXIS Model

- In order to confirm the failure mechanism and to provide a model for remedial geopolymer treatment a PLAXIS model of the existing condition was developed by Geobear.
- This model analysis confirmed shear zone movement hypothesis as the underlying mechanism of failure.
- The treatment design would focus on strengthening this layer.





PLAXIS Design Parameters

- Back analysis of the slope failure using PLAXIS revealed the soil model parameters as defined in Table 1 with FOS=0.8-0.9
- In order to achieve a FOS >1 of the effective cohesion of the shear zone had to be increased from 0 to 10 kN/m^2
- The mass of geopolymer required to be injected is calculated on the assumption that for every 10 kN/m^2 increase in undrained cohesion (c_u) generates a 1 kN/m^2 increase in effective cohesion (c').

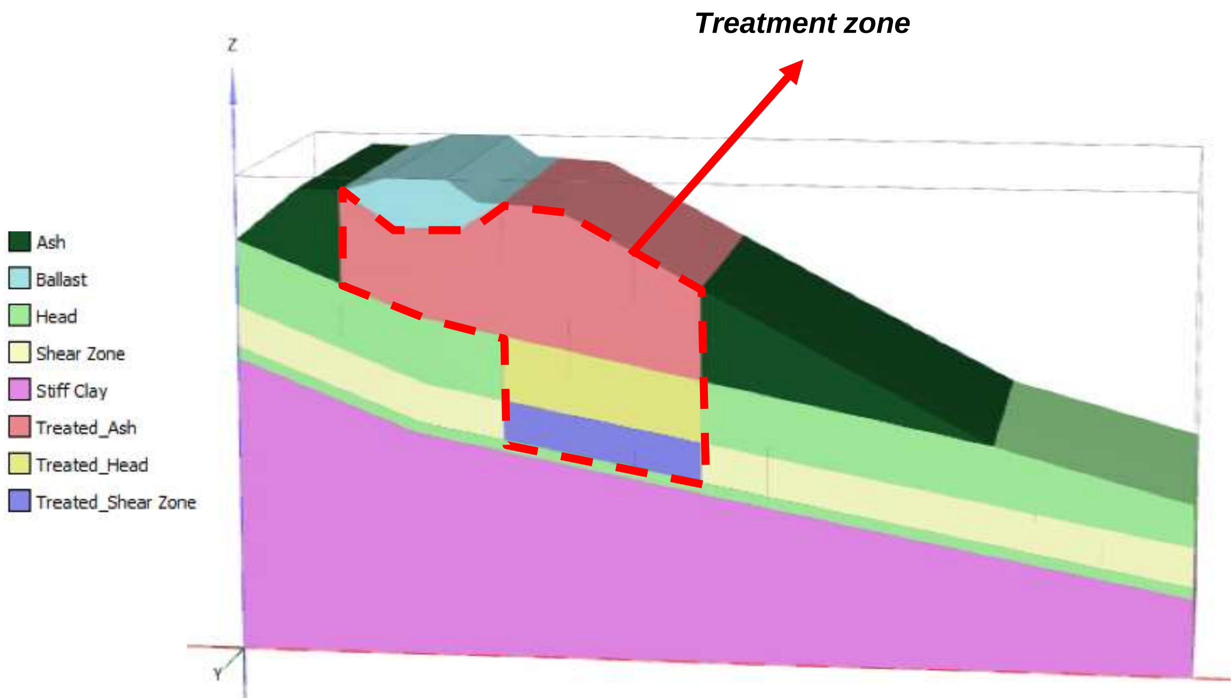
Table 1 PLAXIS Model Parameters

Stratum	Ø	c' (kN/m^2)	ɣ (kN/m^3)
Ballast	61	0	18
Ash Fill	27.5	0	19
Head (Clay)	21	6	20
Shear Zone	18	0	20
Mudstone/V. Stiff Clay	35	5	20

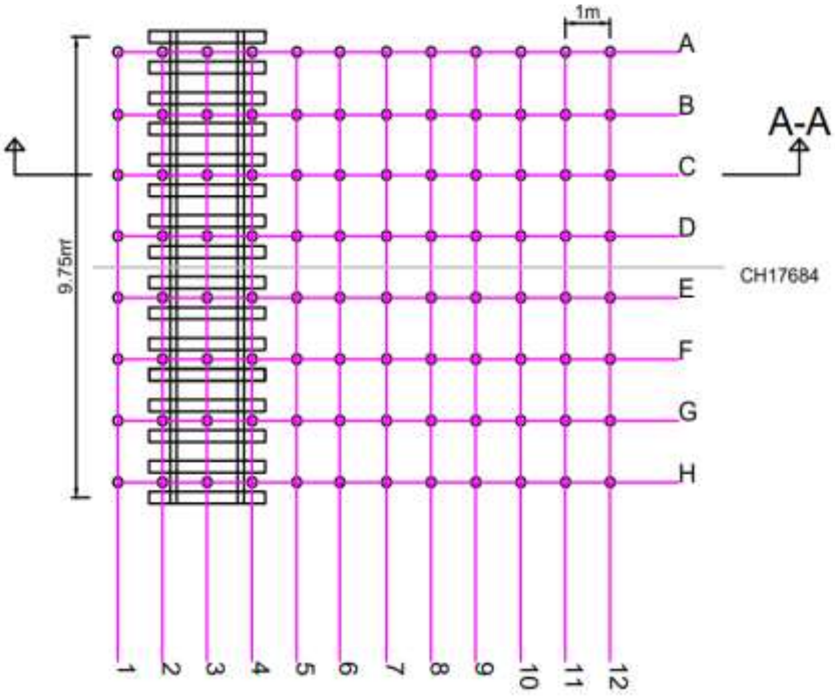
- Therefore, the treatment required an increase in of 100 kN/m^2 in the undrained cohesion of the shear zone.
- This increase could be measured in the field by in-situ penetration testing to confirm design parameters had been achieved

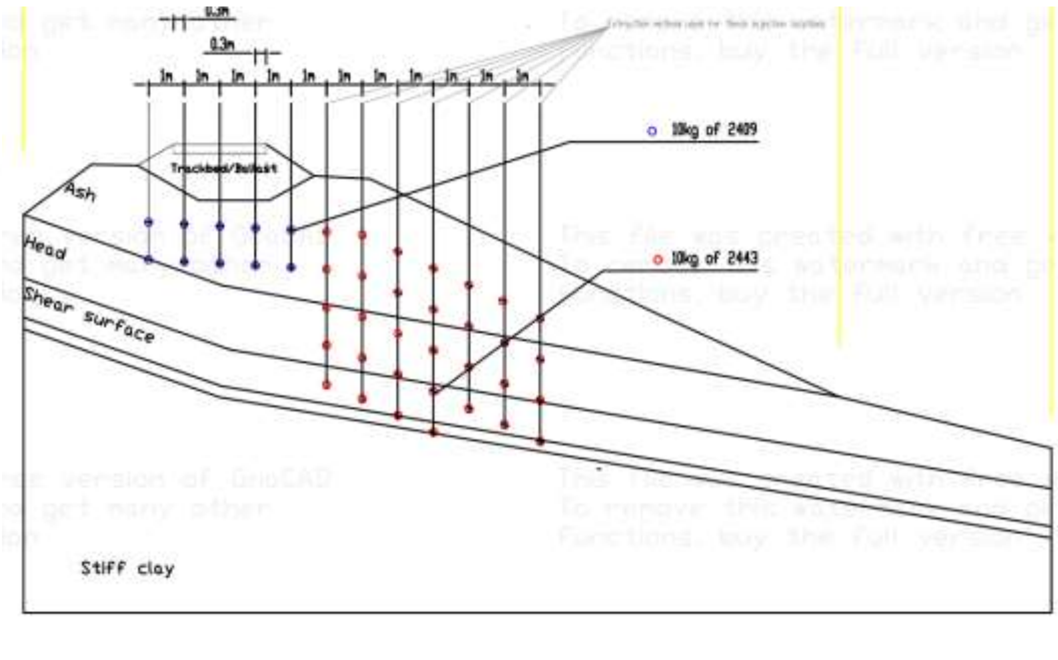
Design Solution Model

Using the developed PLAXIS model, a design solution was developed by incorporating the effect of the geopolymer injections into different sectors of the embankment. The configuration shown on the right handside shows the most cost-effective design where the treatment would yield maximum benefit



Injection design detailing





Section A-A

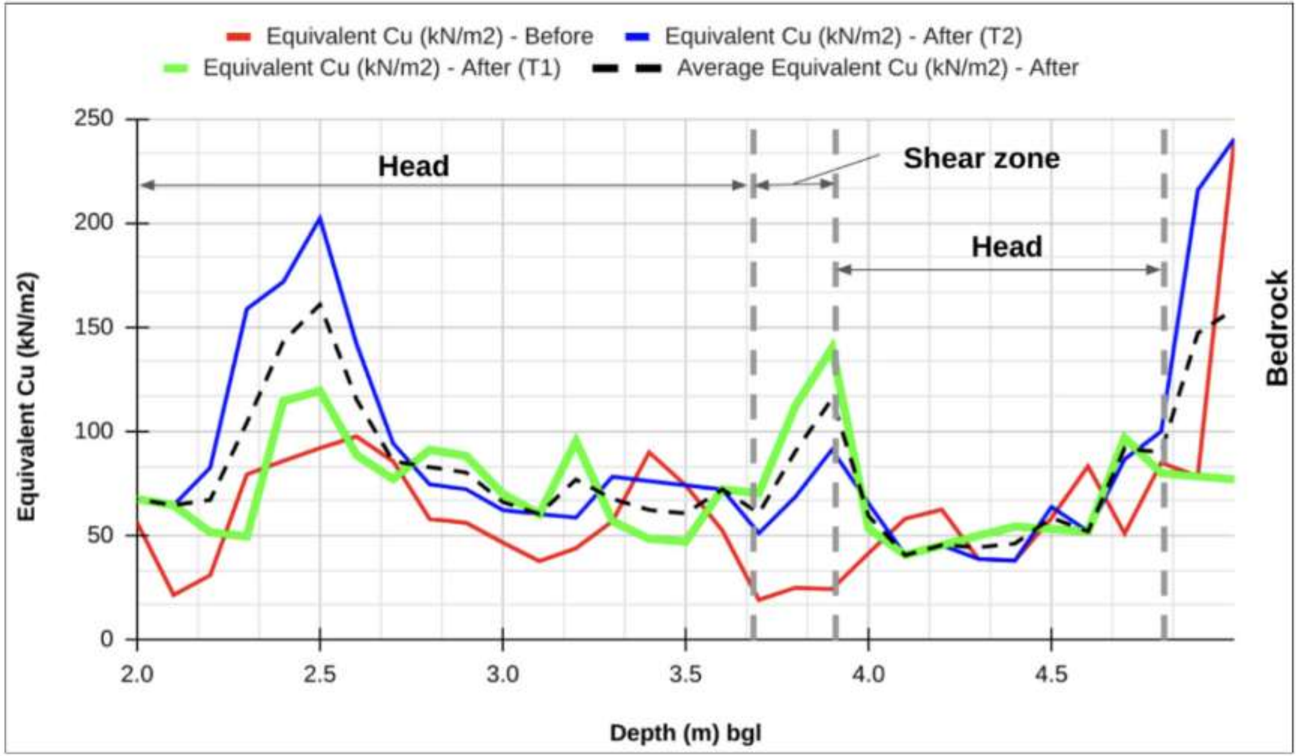
Installation

Installation

- The work has taken place on the 25th and 26th of July of last year (2022).
- Using injection mobile unit amounted a train wagon.
- 12mm diameter holes were drilled as per the injection plan.
- Injection tubes were be inserted in the drilled holes.
- A total of 136 tubes were installed.
- The injection was carried out using the extraction method.
- Approximately two and half tonnes of material was injected.
- Laser level was used to monitor track lift.
- Pre and post dynamic probing was carried out to validate the improvement in soil strength.
- Tilt sensors measurements were assessed for a period 6 months to verify performance.
- The work was completed in 2x10hr shifts

Performance

In-situ Penetration Test Results



Modelling post treatment performance

- Using Dominijanni A & Manassero M (2014), the effect of geopolymer compaction on the ash was estimated (improvement of 0.5 degrees to the angle of friction and cohesion of 5 kN/m^2)

- Using the probing data, it was assumed that the improvement in the cohesion in the Head and Shear Zone is equal to 10% of the measured undrained cohesion (c_u)

- The modelled FOS is approximately 1.2

Table 1 PLAXIS Model Parameters (post treatment)			
Stratum	Ø	c' (kN/m^2)	ɣ (kN/m^3)
Ballast	61	0	18
Ash Fill	28	5	19
Head (Clay)	21	15	20
Shear Zone	18	11	20
Mudstone/V. Stiff Clay	35	5	20

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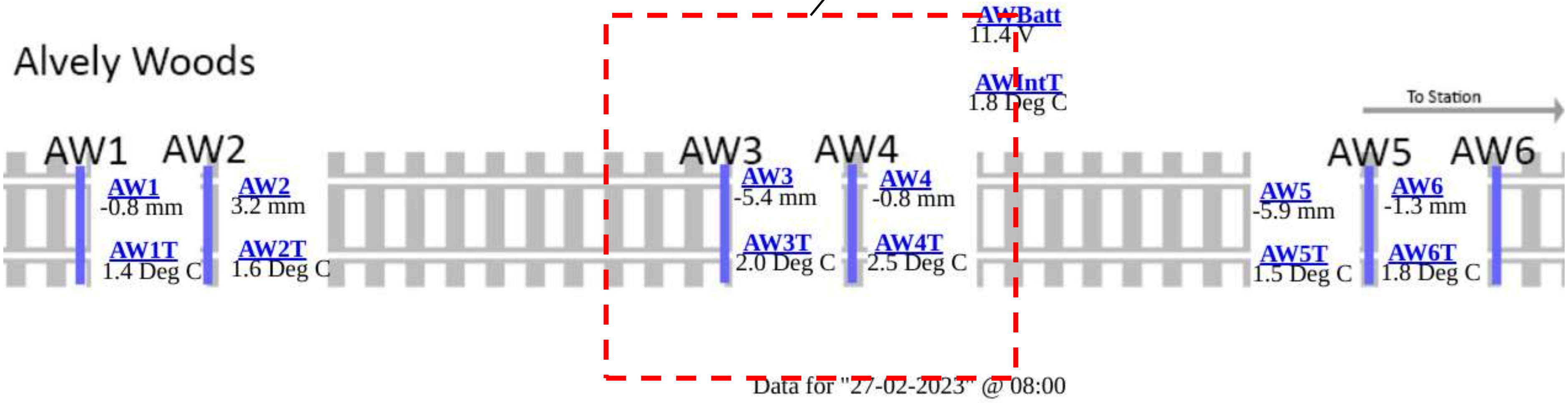
Long term performance

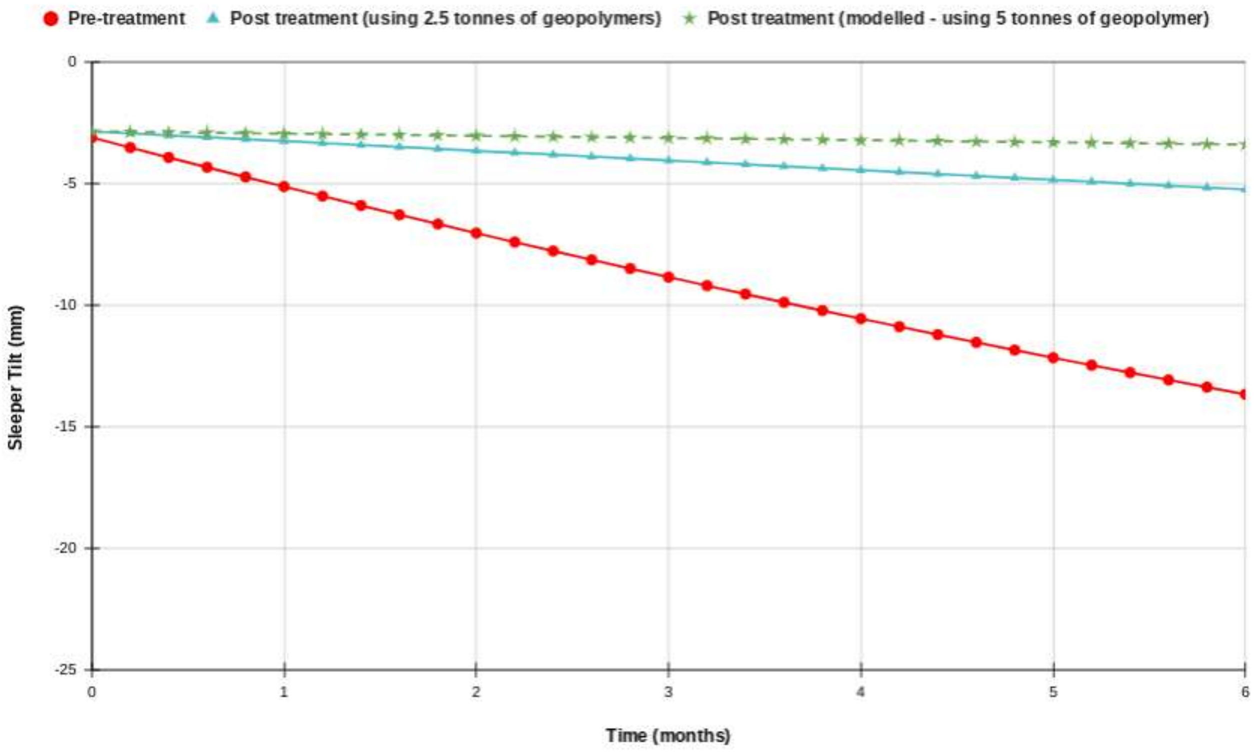
Existing title sensors was utilised to monitor track performance at the treated area and understand the long term impact the treatment



Long term performance

With discounting the effect of the start tilt value,

- the rate of deterioration **before** treatment is approx. 1.75mm/month.
- The rate of deterioration **after** treatment (2.5 tonnes of geopolymer injections) is approx. 0.39mm/month
- The rate of deterioration **after** treatment (5 tonnes of geopolymer injections **modelled**) is approx. 0.19mm/month

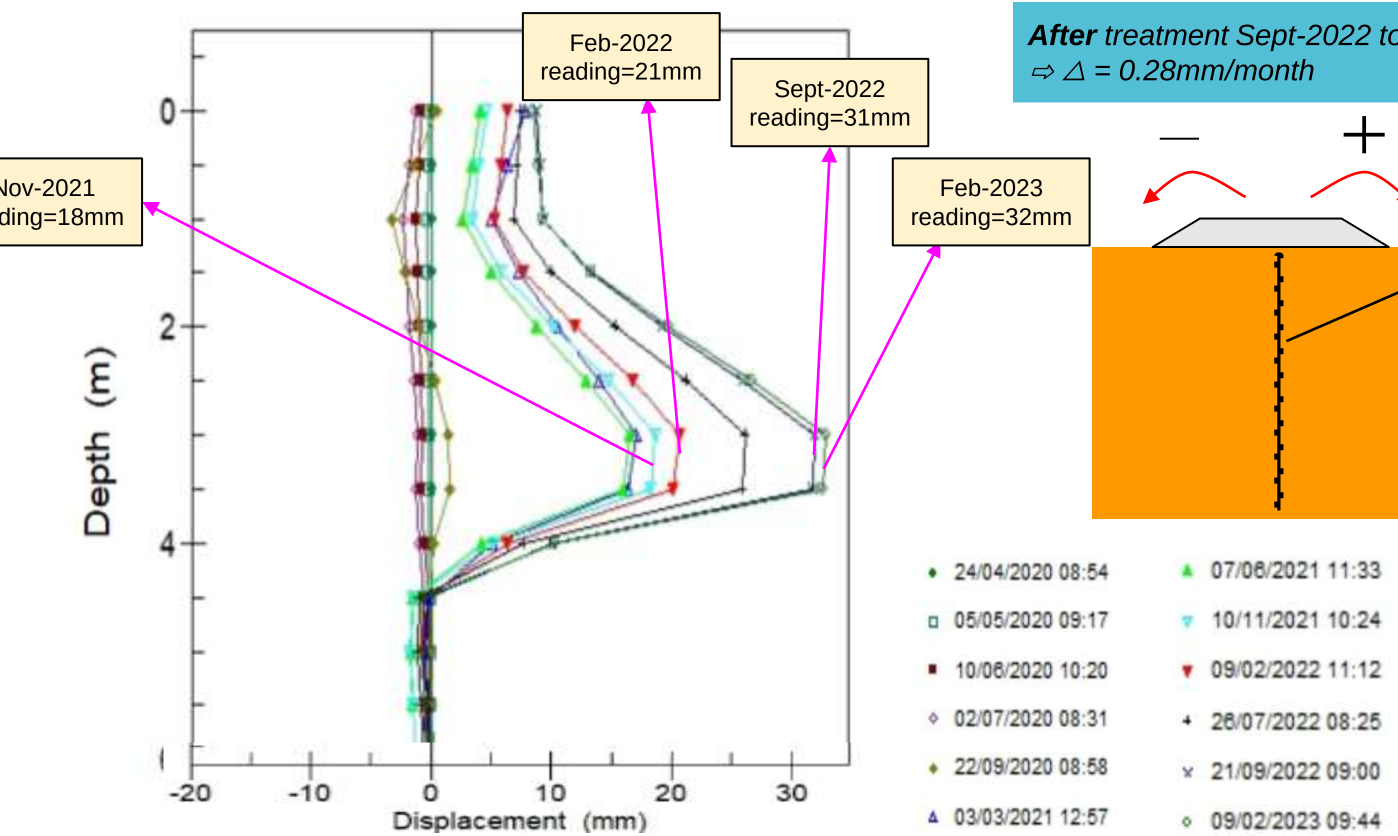


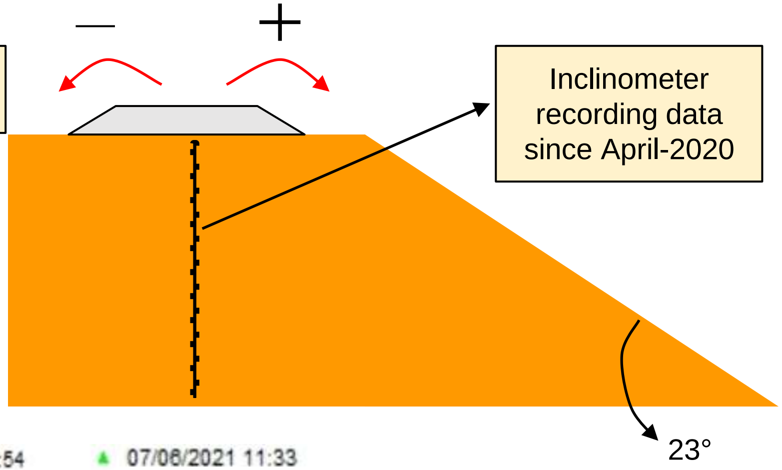
Long term performance

***Before** treatment Nov-2021 to Feb-2022*
⇨ △ = 1.01mm/month

***After** treatment Sept-2022 to Feb-2023*
⇨ △ = 0.28mm/month

72% reduction in rate of deterioration





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Rainfall data at the nearest weather station

Before *treatment period*
Sept-2021 to Feb-2022
Total rainfall = 342mm

After *treatment period Sept-2022 to Feb-2023*
Total rainfall = 369mm

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Findings

- The trial has demonstrated that geopolymer injections can be used to stabilise railway embankments slopes.

- Modelling was key to understand the underlying reason for deterioration and design solution optimisation.

- Before and after treatment probing has shown significant signs of improvement in the shear strength of the embankment material with an improvement of 50% and 340% for the Head and Shear zone materials, respectively.

- Long term monitoring, via tilt monitoring, has shown signs of the deterioration slowing down by up to 77%.

- Long term monitoring, via inclinometer monitoring, has shown signs of the deterioration slowing down by up to 72%.

- Results indicates that first of type trial has been successful.