

# Subgrade ground improvement using in-situ stabilisation for track formation in Melbourne

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## ABSTRACT

The Southern Program Alliance (SPA) is one of the alliances formed in Melbourne to remove level crossings, construct track duplications and upgrade the rail network as a part of the Victorian government initiative to improve rail infrastructure. An integral component of a rail infrastructure project is the construction of track formation. The essential requirement for rail formation is to satisfy the bearing capacity (strength) and settlement (serviceability) requirements for rail loading. The strength and serviceability requirements are a function of track design, axle-load, speed, and, notably, subgrade characteristics. For the SPA projects to date, where existing subgrade conditions could not satisfy these requirements, either the weaker subgrade was excavated and replaced by structural fill material, or subgrade improvement using in-situ stabilisation was explored. Subgrade improvement typically minimises the excavation and earthworks required for the construction of track formation and provides significant sustainability, cost, and time benefits to the project, without compromising the functional requirements. Subgrade stabilisation methods using admixtures (lime and cement) were considered and/or adopted for differing surficial geological deposits, including alluvial deposits, residual soil of Silurian origin and Tertiary sediments of South-East Melbourne. The design strategy was to verify the applicability of admixture ratios through laboratory testing, whilst further undertaking quality assurance (QA) measures through the construction phase. To assess the depth of stabilisation required, both empirical and finite element analysis design methods were undertaken. This paper summarises key design, laboratory testing and construction considerations for subgrade improvement works undertaken for a rail track duplication between Diamond Creek and Wattle Glen in Melbourne's North-Eastern suburbs.

**Keywords:** Subgrade ground improvement, in-situ stabilisation, rail/track formation, sustainability

## 1 INTRODUCTION

The Victorian State Government initiated a program to remove at least 110 level crossings across Melbourne by 2030. Removing level crossings improves safety by separating trains from road traffic, while also reducing congestion by upgrading the road network, connecting communities and supporting urban regeneration. The Southern Program Alliance (SPA) comprises the Level Crossing Removal Project (LXRP), Acciona, Coleman Rail, WSP, and Metro Trains Melbourne (MTM). SPA is delivering level crossing removal works, rail line upgrades, track duplications, station upgrades and mechanical service upgrades.

As part of the Hurstbridge line upgrade, SPA constructed duplication of tracks for a length of approximately two kilometres between Diamond Creek and Wattle Glen, in Melbourne's North-Eastern suburbs. Three types of track formation were predominantly adopted between Diamond Creek and Wattle Glen: at grade track formation on soil subgrade, at grade track formation on rock subgrade and track formations supported by earthworks structures (including earthwork embankments, geogrid reinforced soil embankments or selected fill behind retaining walls). The location and extent of track duplication of the Hurstbridge rail line is shown in Figure 1.



Figure 1. Diamond Creek to Wattle Glen rail line duplication (LXRP, 2021)

The type and condition of the subgrade is an essential factor in the maintenance life of track structures, as it is the source of the majority of cumulative permanent deformation associated with the deterioration of track.

For the section of track duplication along the Hurstbridge line between Diamond Creek and Wattle Glen from chainages CH 33660 to CH 34010, the improvement of the subgrade condition using lime stabilisation was proposed as a more economically feasible solution than the removal of subgrade and replacement with structural fill.

This proposed design approach would contribute to adhering to Infrastructure Sustainability Council of Australia (ISCA) sustainability target requirements, support to achieve the targeted project sustainability certifications using the Infrastructure Sustainability (IS) rating tool by the ISCA, and the Green Star tool for stations and associated aspects by the Green Building Council of Australia. These requirements are as follows:

- ISCA Sustainability Targets Requirement 22: Monitoring and modelling are to be conducted to demonstrate a reduction in materials lifecycle impacts compared to a base case footprint.
- ISCA Sustainability Targets Requirement 38: Measures to minimise materials to be removed and disposed into landfill during construction. Measures to minimise the volume of materials to be imported to the site.

This paper reports on work undertaken by SPA to improve subgrade for new track formation where the track formation is founded on a soil subgrade. The benefits of subgrade stabilisation as compared to removal and replacement of material are highlighted in relation to ISCA sustainability targets.

## 2 TRACK FORMATION DESIGN

Typical track formations consist of a ballast layer, capping layer and structural fill layer, which distributes the rail loading from the underside of the sleeper to the top of the subgrade to prevent shear failure and excessive settlement under repeated loading. The design bearing pressure can be obtained by factoring the subgrade ultimate bearing capacity by a load factor and a settlement factor to arrive at an allowable bearing pressure (design limit) which is used to estimate the bearing pressure for design purposes (Jefferies and Tew, 1991). The allowable bearing pressure using this methodology is as follows:

The safe average bearing pressure ( $\sigma_{safe}$ ):

$$\sigma_{safe} = X_L \times \sigma_{ult} \quad (1)$$

The ultimate bearing capacity ( $\sigma_{ult}$ ) of the subgrade for a fine-grained soil based on Meyerhof (Meyerhof, 1951) is given by the following equation:

$$\sigma_{ult} = C_u \times N_c \quad (2)$$

Where  $C_u$  is the undrained shear strength and  $N_c$  is the bearing capacity factor ( $N_c = 5.14$ ).

The allowable bearing pressure or design limit of the subgrade pressure ( $\sigma_{allow / des}$ ):

$$\sigma_{allow / des} = X_s \times \sigma_{safe} \quad (3)$$

Where,  $X_L$  is the load factor of 0.6 and  $X_s$  is the settlement factor of 0.5 (Jefferies and Tew, 1991).

### 2.1 Rail loading

The following design axle load and design speeds were used for the track formation design.

- 25 tonne axle load (static) in accordance with Project Requirements Specification.
- Design speed of 80km/hr.
- Wheel diameter of 0.9m.

To account for the dynamic nature of the loading, a corresponding dynamic wheel load ( $P_{di}$ ) was calculated using the methodology presented by Li and Selig (1998b).

$$P_{di} = (1 + 0.0052 V/D) \times P_{si} \quad (4)$$

where  $V$  is train speed in km/h,  $D$  is wheel diameter in meters and  $P_{si}$  is static wheel load.

The train load acting on the rail and sleeper is assumed to be distributed uniformly over a length of four axles, as shown in Figure 2. This uniformly distributed load is transferred to the top of the capping layer, as shown in Figure 5.

For calculating the uniformly distributed load underside of rail capping layer, the following has been assumed.

- No. of axles = 4 with axle spacings in accordance with AS5100.2 (2017).
- Length of sleeper = 2.6m (low profile concrete sleepers).
- Length of rail = 6.5m for four axles, allowing for 2 No. close coupled bogies. The 6.5m length includes the standard axle spacing in accordance with AS5100.2 (4.5m overall) and allows an additional 1m length of distribution along the rails at each end of the bogies, as shown in Figure 2 below.
- Ballast depth = 300mm minimum beneath sleeper.
- Capping layer thickness = 150mm.

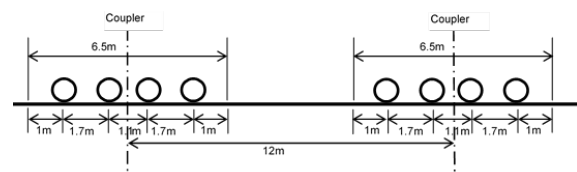


Figure 2. Axle Group Spacings for Load Distribution Longitudinally (AS5100, 2017)

The pressure distribution of 1V:2H as given in Indraratna et al. (2011) has been adopted to estimate the rail loading at rail capping layer level. Figure 3 shows typical wheel load distribution below the tracks,

Figure 4 shows the adopted contact length of sleepers for pressure distribution, and Figure 5 illustrates the adopted pressure distribution.

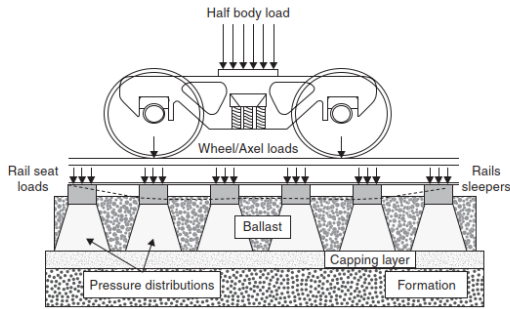


Figure 3. Illustration of typical wheel load distribution in tracks (Indraratna et al., 2011)

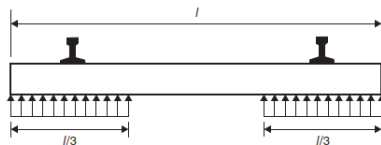


Figure 4. Illustration of adopted contact length of sleepers for pressure distribution

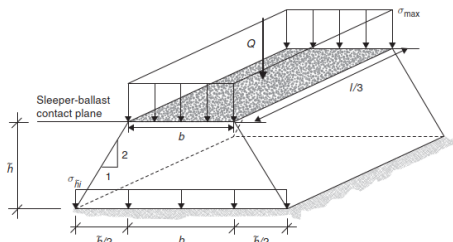


Figure 5. Illustration of adopted 1H:2V pressure distribution

Based on the train loading, train speed and load distribution, the estimated uniformly distributed loading underside of the rail capping layer and at top of structural fill is 74kPa.

### 2.2 Subgrade condition

The natural subgrade condition between Diamond Creek and Wattle Glen comprises surficial sands, silts, clays and minor gravels of the Quaternary Alluvium deposits inferred to be associated with flooding of Diamond Creek. Underlying the Alluvium deposits (and outcropping to the North and South of the railway line), is the Silurian age Anderson Creek Formation.

The design level of the underside of capping layer was noted to be below the existing ground surface level within the section identified for subgrade stabilisation and is therefore nominated as an “at grade” track formation.

From the test results of natural subgrade within this section of track formation, the minimum California Bearing Ratio (CBR) is 2.5%, the maximum CBR swell is 1.0% (remoulded samples soaked for 4 days, with

a 4.5kg surcharge) and plasticity index ranged between 10% and 40%. It is noted that these values represent the typical values of the residual soil of Silurian origin.

### 2.3 Track formation composition

As with many rail authority standards, the MTM earthworks and formation specification and standard (Document numbers A1392 and A1537 respectively) make use of the CBR test results as the primary means for assessing load-settlement performance. The design structural fill thickness is therefore determined by the subgrade CBR values and distributed load from the underside of rail capping layer. It is noted that where the subgrade CBR is greater than 8%, structural fill is not required, in accordance with Metro Trains Melbourne (MTM) earthworks and formation standard A1537.

For a given CBR value, the SPA has adopted a methodology whereby the corresponding undrained shear strength has been computed using the ratio between CBR and undrained shear strength of 15, as given in Hopkins et al. (2006). The ultimate bearing capacity has been estimated as per Equation (2) and allowable or design bearing pressure as per Equation (3) using load and settlement factors. The estimated ultimate bearing capacity and the allowable or design bearing pressure at subgrade level for different subgrade CBR values are given in Table 1.

Table 1. Ultimate bearing capacity and allowable bearing pressures of subgrade

Subgrade Soaked CBR (%)	Undrained Shear Strength (kPa)	Ultimate Bearing Capacity, $\sigma_{ult}$ (kPa)	Allowable Bearing Pressure, $\sigma_{allow / des}$ (kPa)
≥ 2.5	37.5	193	58
≥ 3.0	45	231	70
≥ 4.0	60	308	93

The required structural fill thickness has therefore been estimated based on allowable bearing pressure of subgrade, a summary of which is presented in Table 2. It is noted that a minimum structural fill thickness of 300mm below 150mm rail capping layer has been adopted for subgrade CBR strength of 3% and 8%, in order to maintain acceptable track performance.

Table 2. Estimated structural fill thickness

Chainages (m)		Subgrade Soaked CBR (%)	Estimated Structural Fill Thickness (mm)
From	To		
33660	33760	4.0	300
33760	33960	3.0	300
33960	34010	2.5	500

### 2.4 Track Settlement

Track settlement comprises immediate settlement and long-term settlement due to cyclic loading. Immediate settlement of rail loading was assessed using 2D FE

software Plaxis and hand calculations, considering a Boussinesq pressure distribution. Long-term settlement was assessed using Selig and Waters (1994) method and was checked by the Das and Shin (1996) method. The estimated track settlement for adopted track formation with in-situ subgrade stabilisation satisfies the track performance requirements. The details of track settlement assessment and findings are not further discussed in this paper, as the focus of this paper is on achieving the required subgrade strength by stabilisation measures.

### 3 SUBGRADE GROUND IMPROVEMENT

The proposed level of the underside of capping layer within this section is close to the existing ground surface level along Hurstbridge line between chainages CH 33660 and CH 34010 at Diamond Creek. Without ground improvement, the structural fill thicknesses presented in Table 2 would be required for the track formation within this section (for the varied subgrade CBR along the alignment).

The construction of structural fill requires the removal of the existing subgrade and replacement with an imported fill product meeting the requirement of the MTM specification. To reduce construction time, cost and remove the necessity of disposing of existing material and importing structural fill (which has substantial environmental benefits), SPA proposed to use in-situ subgrade improvement using admixture stabilisation for the track formation. This methodology would contribute to achieving ISCA Sustainability Targets Requirement 38 (as previously noted).

Subgrade improvement using admixture stabilisation is commonly carried out for road pavement construction on weaker and unstable subgrades. The application for rail formation is very similar to road pavement and has also been carried out for track formation on other level crossing removal projects

within the MTM network. However, the current MTM standards and specifications do not provide guidance on the use of admixture stabilisation. The SPA proposed and adopted the use of road authority Department of Transport and Planning (DTP, formerly VicRoads) standards for admixture stabilisation as the appropriate criterion for the design of track formation with in-situ admixture stabilisation.

#### 3.1 Laboratory testing

Laboratory testing on the existing subgrade mixed with lime and cement admixtures was undertaken to assess the required quantity of admixture for the material on site, in order to meet the minimum strength of subgrade for the track formation. The intended outcome of this methodology was to minimise the amount of material removal required, and therefore the targeted minimum strength criterion desired was to remove the need for all structural fill (i.e. placing capping layer directly on the improved subgrade).

The subgrade samples at three locations within the proposed ground improvement area were collected to assess the feasibility of stabilisation. Based on the lime demand test results, the samples were mixed with 2%, 3% and 4% of lime, 3% and 4% of cement, and 3% lime and 3% cement to assess the suitable admixture and optimum percentage of admixture required for stabilisation.

CBR tests were undertaken on remoulded samples compacted to a target dry density ratio of 98% of the standard maximum dry density (MDD) at optimum moisture content (OMC) and soaked for four days with a 4.5kg surcharge. Laboratory test results of compaction properties and strength properties are summarised in Table 3 and Table 4 respectively.

Table 3. Summary of laboratory Standard compaction test results of stabilised material

Sample ID	Optimum Moisture Content, OMC (%)						Maximum Dry Density, MDD (%)					
	2% L	3% L	4% L	3% C	4% C	3% L & 3% C	2% L	3% L	4% L	3% C	4% C	3% L & 3% C
1	22.5	20.5	23.5	20.5	20.0	20.0	1.64	1.67	1.62	1.70	1.72	1.68
2	19.5	19.0	19.0	18.0	18.5	17.0	1.71	1.69	1.70	1.70	1.69	1.73
3	18.0	17.5	17.5	18.0	17.5	18.5	1.76	1.74	1.72	1.72	1.75	1.74

Notes: %L refers to % of lime mixed with subgrade material and %C refers to % of cement mixed with subgrade material by dry mass

Table 4. Summary of CBR and swell test results of stabilised material

Sample ID	CBR (%)						Swell (%)					
	2% L	3% L	4% L	3% C	4% C	3% L & 3% C	2% L	3% L	4% L	3% C	4% C	3% L & 3% C
1	25	19	20	50	70	60	0.0	0.0	0.0	0.5	1.0	0.0
2	40	35	50	70	60	80	0.0	0.0	0.0	0.5	0.5	0.0
3	30	40	40	25	45	120	0.0	0.0	0.0	0.0	1.5	0.0

Notes: %L refers to % of lime mixed with subgrade material and %C refers to % of cement mixed with subgrade material by dry mass

An important consideration in admixture stabilisation is the composition and plasticity of the material proposed to be stabilised. Based on the results of classification and index tests from the subgrade material (percentage of fines passing 0.075mm is more than 25% and plasticity index is more than 10%) the use of cementitious admixtures was considered not suitable for the stabilisation as per recommendations in DTP Specification Section 290.

The variability of CBR subgrade strength of stabilised material is shown in Figure 6. Generally, increasing the percentage of lime is expected to increase the strength of stabilised materials. However, the test results of sample 1 (as summarised in Table 4) do not show a significant improvement in strength of stabilised material with lime percentage increased from 2% to 4%.

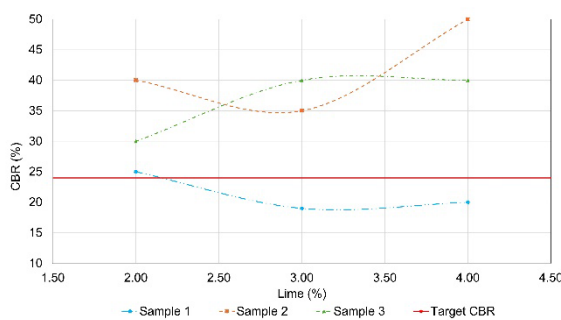


Figure 6. Illustration of CBR with percentage of lime

### 3.2 Design consideration

The CBR value obtained from laboratory mixed stabilised material is typically downgraded for use in design, namely due to laboratory testing being carried out on relatively small quantities of sample and under more controlled conditions than occur during construction. Based on the DTP test method RC 301.04, the design CBR and swell values of stabilised existing material are stipulated to be taken as 1/3 and 2 times the values obtained from laboratory testing, respectively. Therefore, a minimum CBR value of 24% and a maximum swell of 0.75% of stabilised samples from laboratory testing has been considered as the design requirement, to achieve the intended field values of a soaked CBR value of 8% and swell index of less than 1.5%.

The test results showed that 2% lime meets the minimum CBR requirement for all three samples, and that the CBR typically increases as the lime content increases. However, considering the variation in results from sample 1 and experience on other projects, SPA adopted 4% lime for in-situ stabilisation. The formation detail adopted in the area where lime stabilisation was intended also included a layer of geogrid and geotextile at the bottom of the capping layer level, to assist with bridging over local variability in subgrade conditions after stabilisation.

Figure 7 shows the typical detail of formation within the section where the lime stabilisation of subgrade improvement was undertaken.

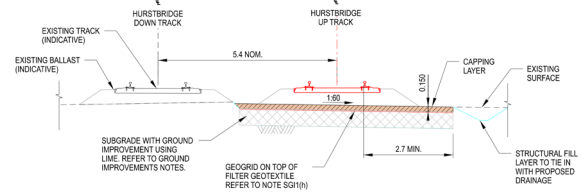


Figure 7. Typical track formation with stabilised existing material using lime

The depth of required stabilisation was attributed to the depth equivalent to the structural fill thickness as specified in Table 2, which was assessed based on the CBR of existing subgrade materials below the stabilised zone.

### 3.3 Construction considerations

The subgrade improvement methodology was proposed for the full width of the new track formation using hydrated lime. Advice obtained from specialist contractors indicated that in-situ lime stabilisation and compaction could be achieved using proposed equipment up to a maximum depth of 450mm in a single pass/lift and this practical limitation was considered in the design approach.

For the section where the depth of in-situ stabilisation requires up to 500mm of stabilisation below the bottom of capping layer, the following construction staging was adopted.

- Excavate 50mm below the bottom of capping layer level.
- Stabilise the subgrade for a depth of 450mm using in-situ lime stabilisation.
- Place a 200mm thick capping layer (i.e. increase the capping layer thickness from 150mm to 200mm).

If exposed subgrade assessments identified localised section requiring more than 500 mm depth of in-situ stabilisation, it was expected that the required stabilisation thickness would be achieved by a multi-stage stabilisation, via in-situ stabilisation of the bottom 450 mm of subgrade first. The remaining backfill thickness above the in-situ stabilised subgrade would use the removed material treated with 4% lime. Alternatively, structural fill or a thicker capping layer could be used as a backfill.

DTP Standard Specification Section 290 and AustStab specification provide construction guidelines and requirements for in-situ stabilisation of subgrade using lime. DTP Standard Specification Section 290, coupled with guidance with AustStab specifications, were adopted for the application of lime stabilisation of subgrade material with additional tests based on MTM specification for track formation.

### 3.4 Construction staging and verification

The following general sequence of construction was considered for the construction of track formation.

- Excavation to the bottom of capping layer level (subgrade level).
- Inspection of exposed subgrade and identification of extent (depth) of the required in-situ stabilisation by in-situ strength tests.
- Stabilisation of subgrade material.
- Undertake field and laboratory tests on stabilised subgrade material.
- Proof roll verification of stabilised subgrade.
- Placement of layer of geogrid and geotextile at the interface between capping layer and stabilised subgrade level.
- Construction of capping.

## 4 CONCLUSION

In summary, the in-situ stabilisation of subgrade material as a ground improvement method can provide significant benefits to a project's cost, program and in achieving sustainability objectives. This requires in-situ and laboratory testing of subgrade material with admixture in the early phase of design, to study the feasibility of in-situ stabilisation. Construction stagings involved in the improvement process are also necessary to be considered in order to assess the effectiveness of stabilisation works. It is the authors' opinion that further research on stabilisation using admixtures on different geological units around Melbourne will provide benefits to the industry for understanding appropriate stabilisation options, and can help to realise significant cost savings over a major infrastructure project's life.

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