

# The Installation of Inclinometers in Saturated Granular Soils

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## ABSTRACT

Level crossings at Bonbeach, Chelsea and Edithvale in Victoria were removed through grade separation of the existing road and rail. Construction at each site included sheet pile supported rail trenches within Quaternary dune sands and coastal lagoon deposits. Prior to the excavation of the rail trenches, inclinometers were installed behind the sheet pile retaining walls to measure the variation in lateral ground displacement with depth during the excavation of the rail trenches. The installation of the inclinometers was found to be challenging due to the saturated and granular nature of the surrounding soils. The boreholes drilled were vulnerable to collapse when removing the drilling casing, while a significant loss of grout was experienced through permeable soils when installing the inclinometer casing. These ground conditions made it difficult to achieve consistent contact between the permanent inclinometer casing and the surrounding soil. The drilling and inclinometer installation methodologies implemented were progressively reviewed and then modified to mitigate these construction difficulties and improve the reliability of the inclinometers installed. This paper discusses the staged installation methodology which was developed and reviews the extent to which the newly adopted methodology was able to mitigate the initial construction difficulties encountered.

*Keywords:* inclinometers, monitoring, retaining walls, ground displacement

## 1 INTRODUCTION

The Level Crossing Removal Project (LXRP) is a Victorian Government initiated program for the progressive removal of Victoria's most dangerous and congested level crossings. The Southern Program Alliance (SPA), consisting of WSP, Acciona and Metro Trains Melbourne, was engaged by LXRP to remove five dangerous and congested level crossings along the Frankston line as part of the second additional works package. Both metropolitan passenger trains and commercial freight trains operate along the Frankston line which runs parallel to Nepean Highway through congested residential and commercial areas.

The project involved the construction of new stations at Bonbeach, Chelsea and Edithvale, three road over rail bridges, station carparks, shared user paths and three sheet pile supported rail trenches within Quaternary dune sands and coastal lagoon deposits.

Prior to the excavation of the rail trenches, inclinometers were required to be installed behind the sheet pile retaining walls to measure the variation in lateral ground displacement with depth during the excavation of the rail trenches. These ground displacement measurements were then compared with trigger levels established through ground movement modelling.

The installation of inclinometers during the project was challenging due to the subsurface ground conditions encountered across the site. These ground conditions made it difficult to achieve consistent contact between the permanent inclinometer casing and the surrounding soil using the installation methodology previously adopted at other level crossing removal sites.

## 2 SITE CONDITIONS

### 2.1 Site description

The five level crossings which were removed are approximately located 31 km south-east of Melbourne's CBD, with Bonbeach, Chelsea and Edithvale train stations being approximately positioned 200 m from the beaches of Port Phillip Bay. The level crossings are located along the Frankston line

which runs parallel to the Nepean Highway and is surrounded by congested residential and commercial areas. The surrounding topography is relatively flat.

## 2.2 Site geology

The subsurface ground conditions encountered across the five level crossings comprise the following:

- Fill material, comprising asphalt, road base, ballast, sands and gravels.
- Quaternary age sands (dune and beach deposits), comprising poorly graded and highly permeable, loose to dense sands.
- Quaternary age coastal lagoon deposits, encountered beneath the Quaternary age sands, comprising poorly graded and highly permeable, loose to medium dense sands and highly compressible clays of high plasticity.
- Tertiary age Sandringham Sandstone (previously known as Baxter Sandstone) comprising loose to very dense clayey sands and sands, occasionally cemented and firm to very stiff sandy clays.
- Gellibrand Marl (previously known as Newport Formation), encountered beneath the Sandringham Sandstone, comprising shelly sands and carbonaceous and glauconitic silts and clays (Tmn).

An extract from the Geological Survey of Victoria 1:63,360 Cranbourne map (1967) is shown by Figure 1. A generalised subsurface ground profile encountered is shown in Table 1.

Groundwater was typically encountered across the site between 3 and 5.5 mBGL (metres below ground level).

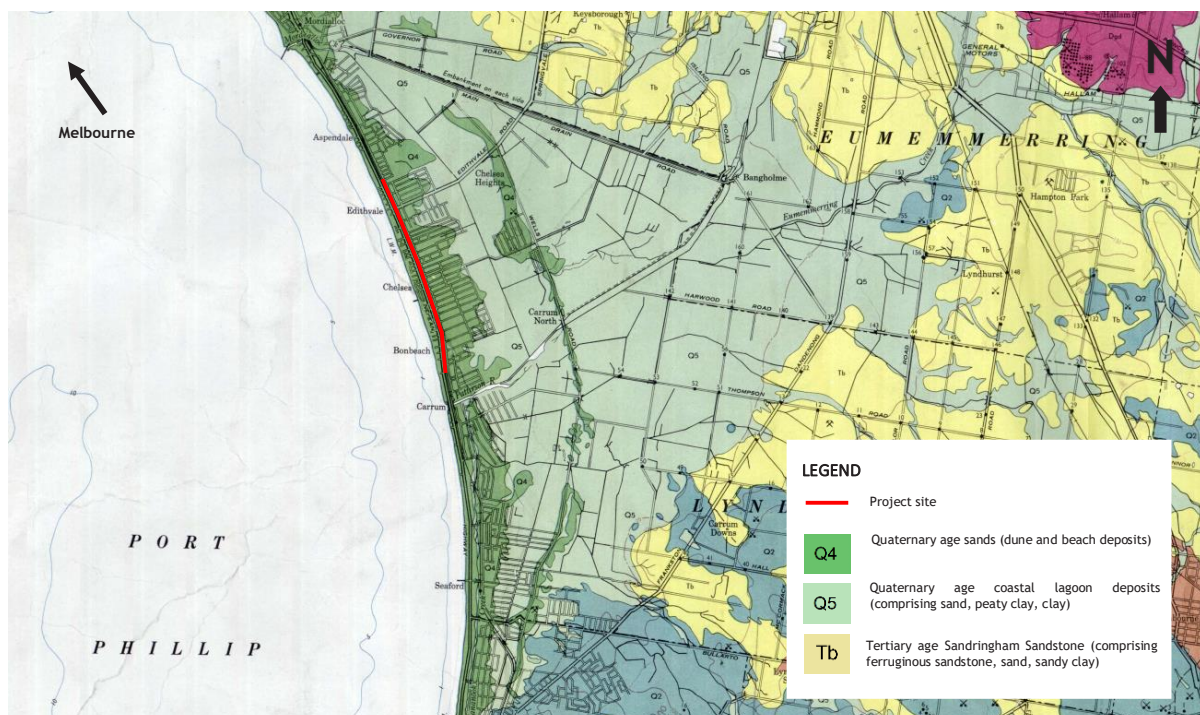


Figure 1. An extract from the Geological Survey of Victoria 1:63,360 Cranbourne map (1967)

Table 1: A generalised subsurface ground profile encountered

Unit	Bonbeach		Chelsea		Edithvale	
	Depth to top of unit (m)	Depth to bottom of unit (m)	Depth to top of unit (m)	Depth to bottom of unit (m)	Depth to top of unit (m)	Depth to bottom of unit (m)
Fill material	0	0-1.0	0	0.1-1.2	0	0.2-0.5
Quaternary age sands	0-1.0	8.6-12.8	0.1-1.2	7.2-11.0	0.2-0.5	8.0-16.0
Quaternary age coastal lagoon deposits	8.6-12.8	10.7-15.2	7.2-11.0	11.0-14.3	8.0-9.0	9.1-13.5
Tertiary age Sandringham Sandstone	10.7-15.2	30.3*	11.0-14.3	27.0-30.5*	9.1-16.0	24.6-25.5*
Gellibrand Marl	NE	NE	27.0-29.3	NP	24.6-25.3	NP

NE= Not encountered, NP= Not penetrated, \* Borehole terminated in unit

### 3 INCLINOMETER INSTALLATION

The inclinometers were required to extend 3 m below the toe of the sheet pile retaining walls to ensure lateral ground displacements were captured along the entire length of the sheet piles. The length of the inclinometers varied between 19 and 21 m in length depending on the location of the inclinometer with respect to the rail trench. Due to the depth of the inclinometers, they were required to be installed across various geological units with highly variable geotechnical properties, which presented challenges during installation. The Quaternary age sands were highly permeable and vulnerable to collapse while greater borehole stability and lower permeability soils were observed throughout the Sandringham Sandstone geological unit.

The borehole drilling and inclinometer installation methodology previously implemented on other level crossing removal projects involved HQ wash boring to depth, removing the drill rods and installing the inclinometer casing in an unsupported borehole. This methodology was previously adopted due to the soils encountered predominately comprising of clay, therefore being less permeable and less vulnerable to collapse. However, inclinometer installations during this project were found to be challenging due to the saturated and granular nature of the surrounding soils. Boreholes drilled were vulnerable to collapse when removing the drilling casing, while a significant loss of grout was often experienced when installing the inclinometer casing. These ground conditions increased the risk of the inclinometer casings having poor contact with the surrounding soil and/or not reaching their proposed depths.

#### 3.1 Drilling methodology

The drilling methodology selected is an important step in the installation process of inclinometer devices. Inclinometer boreholes are required to be drilled as vertical as possible, with minimal suspended solids and loss of soil material through the creation of voids. Ensuring minimal disturbance of the surrounding soil mass is crucial as it may potentially change the interaction between the soil mass and the inclinometer resulting in inaccurate measurements (Machan and Bennett, 2008).

As a result of shallow groundwater and loose granular soils encountered across the site, it was determined that the most suitable methodology for the drilling of the inclinometer boreholes was to use a combination of solid auguring and wash boring techniques. Solid auguring techniques were implemented down to a depth which would allow for the installation of drilling casing, after which the boreholes were drilled using PQ (OD 117.5 mm) wireline wash boring techniques. PQ wash boring techniques were adopted for the drilling of the inclinometer boreholes as the PQ drill rods ensured that the borehole walls were sufficiently supported, therefore reducing the risk of borehole collapse or loss of material resulting in voids forming during drilling and installation of the inclinometers. Highly concentrated polymer drilling mixtures were used during the drilling of the inclinometer boreholes to reduce water flush loss and to increase borehole wall stability. PQ diameter drilling was adopted instead of HQ (OD 88.9 mm), as the PVC inclinometer casing (OD 70 mm) was able to be installed within the larger diameter PQ drill rods. Once the inclinometer borehole was drilled to depth and the borehole sufficiently flushed out, the wash boring advancer was removed from the borehole using the wireline. The PQ drill casing was left in the ground to ensure that the borehole walls were adequately supported during the installation of the inclinometer casing. The PQ drill rods were removed from the ground immediately after the grout was tremie pumped into the borehole, as shown in Figure 2.

### 3.2 Inclinometer casing installation methodology

A flexible grouting tube was duct taped on the outside of the PVC inclinometer casing, approximately 200 mm off the end of the first casing segment to ensure that the grouting tube wouldn't get blocked by sediment at the base of the borehole. Due to ground water and drilling fluid being present at the time of installation, the PVC inclinometer casing was required to be water balanced while being installed into the borehole. Fresh water was slowly poured into the PVC inclinometer casing to reduce the positive buoyancy force which also reduced the likelihood of grout seeping from the annulus between the PVC casing and the borehole into the inclinometer casing. Sections of the PVC inclinometer casing were interlocked, and duct taped together until the casing was touching the base of the borehole with additional stickup. After the grout was tremie pumped, the flexible grouting hose was detached from the PVC inclinometer casing and removed from the borehole. The PQ drill rods were then removed from the borehole while leaving in the permanent inclinometer casing. The inclinometer casing installation methodology implemented is depicted by Figure 2.

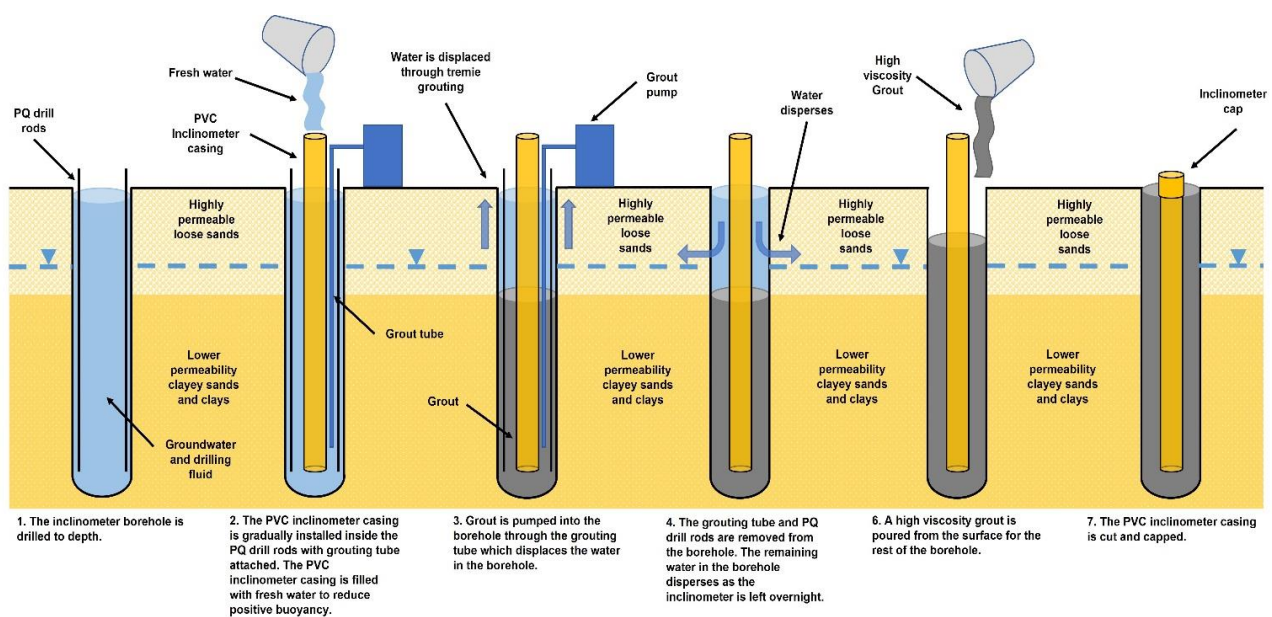


Figure 2. Inclinometer installation methodology implemented.

### 3.3 Selection of backfill material

The type of backfill material used to fill the annulus between the PVC casing and the borehole should ideally match the strength and stiffness of the surrounding soil mass to most accurately measure lateral ground displacements (Machan and Bennett, 2008). However, accurately matching the properties of the inclinometer backfill material to the surrounding soil can be impractical as the properties of the backfill and the surrounding soil can be significantly different, especially when installing across various geological units with varying geotechnical properties (Soil Instruments, 2014). In highly permeable ground conditions, granular backfill such as sand or gravel is preferred by some inclinometer suppliers. However, these materials can settle over time and are prone to bridging during backfilling, especially in deep inclinometers or when groundwater is encountered, due to the time taken for the backfill to settle to the base of the inclinometer (Machan and Bennett, 2008). Voids are likely to form as a consequence of the bridged backfilling material, resulting in reduced contact between the inclinometer and the surrounding soil mass. Therefore, it is preferable to select a backfill material which will completely fill the entire annulus and provide consistent contact between the inclinometer casing and the surrounding soil mass (Plinninger, et al. 2010).

Due to the varying ground conditions along the inclinometer casing and concerns of granular backfill bridging during the installation of the inclinometer, grout comprising rapid curing cement, powdered bentonite and water was used to backfill the annulus between the inclinometer casing and the borehole.

The viscosity of the grout was required to be high enough to prevent loss of grout to the surrounding soil while also low enough to allow for the grout to be pumped.

### 3.4 Annulus grouting methodology

Due to the permeable ground conditions encountered across the site, grout loss during inclinometer installation was a concern. The loss of grout during inclinometer installation could potentially stabilise the surrounding soil, therefore improving the ground conditions and reducing the amount of lateral displacement measured by the inclinometer. Alternatively, the loss of grout to the surrounding soil could result in voids in the inclinometer borehole if not completely backfilled with grout, resulting in improper contact between the inclinometer and the surrounding soil mass (Machan and Bennett, 2008). The highly concentrated polymer drilling mixtures used during drilling coated the borehole walls to create a semi-impermeable barrier, reducing the likelihood of loss of grout to the surrounding soil mass during inclinometer installation.

Two grout mixtures varying in viscosity were implemented to mitigate grout loss during inclinometer installation, while also allowing a portion of the grout to be tremie pumped. A 10:25:3 ratio of cement, water and powdered bentonite was typically used between 6 to 21 mBGL, where water loss during drilling was noted to be lower and where soils were generally observed to have higher relative densities or contain higher percentage of fines. These soils were typically less permeable and less vulnerable to borehole collapse. The viscosity of this grouting mixture was high enough to prevent loss of grout to the surrounding soil while also low enough to allow for the grout to be tremie pumped. The stiffness of the grouting mixture generally matched the ground conditions encountered. Soils encountered between ground surface level and 6 mBGL were generally observed to have low relative densities, contain a low percentage of fines and were vulnerable to collapse. In addition, significant water loss was observed while drilling through these highly permeable sand layers. A second higher viscosity grout was required between ground surface level and 6 mBGL to prevent grout loss through the poorly graded sands. To achieve a higher viscosity grout, a 10:25:9 ratio of cement, water and powdered bentonite was used. The second grout batch was required to be 'bucket' poured the following day as the grout mixture was too viscous to be tremie pumped. This also allowed for any remaining groundwater present above the first portion of grout in the borehole to disperse through the poorly graded sands. The grouting methodology implemented is depicted by Figure 2.

To further mitigate grout loss, the volume of grout which was tremie pumped was recorded along with the depth to which the grout was pumped to. These measurements were taken to back calculate the grout loss experienced during installation, allowing for alterations to be made to the installation methodology. Grout density tests and Marsh funnel readings were recorded to ensure the consistency of grout batches between the different inclinometers installed.

## 4 RESULTS

As the inclinometers are installed insitu, it is not easy to visually inspect whether the inclinometer has been installed correctly. However, the potential effectiveness of the newly adopted drilling and inclinometer installation methodology can be determined by the number of construction difficulties (loss of grout, borehole collapse, etc.) noted during installation potentially resulting in compromised data. The effectiveness of the installation methodology can also be determined by the consistency of the measured inclinometer data and the occurrence of data irregularities. If the measured inclinometer data is showing unusual results, this may potentially be a result of improper inclinometer installation. As the drilling and installation methodology was altered early in the inclinometer installation program, there is not enough inclinometer data from inclinometers which were installed using the old installation methodology. However, detailed records of any construction difficulties or as-built information were taken during the installation of the inclinometers. When comparing the newly adopted installation methodology with the previous methodology from other projects, fewer construction difficulties or issues were noted during the installation. The actual volume of grout used during the newly developed installation methodology more closely resembled the estimated required volume of grout as a result of reduced grout loss during installation. Greater borehole stability was also achieved as less borehole collapse was noted during drilling and installation, therefore resulting in a more consistent grout column around the inclinometer casing. Additional research should be conducted which compares inclinometer data from both drilling and inclinometer installation methodologies to determine their effectiveness more accurately.

## 5 CONCLUSION

The installation of inclinometers as part of the Bonbeach, Chelsea and Edithvale level crossing removal project was found to be challenging due to the saturated and granular nature of the surrounding soils. Drilling and inclinometer installation methodologies were developed to mitigate construction difficulties and potentially increase the reliability of the inclinometers installed. The risk of borehole collapse was mitigated through the use of PQ wash boring techniques and highly concentrated drilling polymers, while the risk of grout loss was mitigated by implementing two different grout mixes to target different geological units.

## 6 ACKNOWLEDGEMENTS

The author wishes to thank the Level Crossing Removal Project and the Southern Program Alliance for permission to produce this technical paper. The author also wishes to thank Richard Kaser for his assistance with the preparation of this paper.

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