

# Arching in geosynthetic reinforced column supported embankments – recent findings from a field case study

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## ABSTRACT

As part of the Regional Rail Link project in Melbourne, Australia a field case study has been undertaken by Golder Associates and Monash University that involved the instrumentation of a geosynthetic reinforced column supported embankment (GRCSE). The field case study site is located in inner Melbourne within the Yarra Delta and is underlain by Coode Island Silt, a soft soil well known to the local geotechnical profession. A number of the findings relating to the site characterisation, load transfer platform behaviour, the development of soil arching and global embankment behaviour have been published recently in several journal and conference proceedings. This paper focuses on the arching stress development in GRCSEs and compares arching stress/deformation models. The widely adopted design standards (BS 8006, 2010 and EBGeo, 2010) adopt a “two-step” design approach that de-couples the arching stress/deformation relationship. This is compared with the Ground Reaction Curve method that describes the four phases of arching: initial, maximum, load recovery and terminal phases as a deformation (and time) dependent process. The implications that these arching stress/deformation relationships presents for design is described.

*Keywords:* Arching, geosynthetic reinforced column supported embankment, field case study

## 1 INTRODUCTION

A variety of ground improvement techniques exist to support road and rail embankments constructed over soft soils. However, in recent years, GRCSEs have become an increasingly popular design solution due to the rapid speed of construction and their ability to meet stringent performance criteria. A GRCSE is supported on semi-rigid ground improvement and comprises an embankment with a geosynthetic reinforced load transfer platform at its' base. While various pile types (i.e. driven piles, timber piles etc.) can be used for ground improvement, in recent years the use of drilled displacement columns has become increasingly popular. The load transfer platform serves to transfer embankment load to the semi-rigid elements that then transfers this load to a stiffer founding unit. Over the past decade, a significant quantity of research has been reported in this area with a particular emphasis on describing the complex soil-structure-geosynthetic reinforcement interaction occurring in the load transfer platform. A key component of the load transfer platform behaviour is the load distribution mechanism that transfers embankment stresses to the stiffer columns. This mechanism is known as “soil arching” and is one of the oldest problems in soil mechanics. Soil arching is often assessed through the trapdoor test, with Terzaghi (1943) undertaking one of the earliest systematic studies of the trapdoor problem. Since this time, it has been studied extensively and the knowledge gained applied to a range of geotechnical problems, including: tunnel support in underground excavations, granular flow between vertical walls (silo problem), cave formation in karstic terrain and in GRCSEs.

The design approach adopted in the widely used German design standard (EBGeo 2010) and British design standard (BS8006-1 2010), amongst others, is a “two-step” approach (Figure 1) which utilize limit equilibrium arching models. In Step 1, a limit equilibrium arching model is adopted to assess arching stresses distribution. Based on this assessment, a constant value of “design” stress that acts in the unarched zone (Load component B + C) is used in Step 2 to calculate the load distribution between the geosynthetic reinforcement and sub-soil support. This “two-step” approach de-couples the relationship between arching stresses and base settlement as the arching stresses in Step 1 are assumed to be constant with respect to time and base settlement (sub-soil settlement and/or geogrid deflection). The relationship between trapdoor settlement and arching development is described by the Ground Reaction Curve proposed by Iglesia (1991, 2013), amongst others, and has been used herein to interpret the field behaviour. It is shown that considerable insight into the load transfer

platform behaviour can be gained when the coupled relationship between arching stresses and sub-soil settlement is considered.

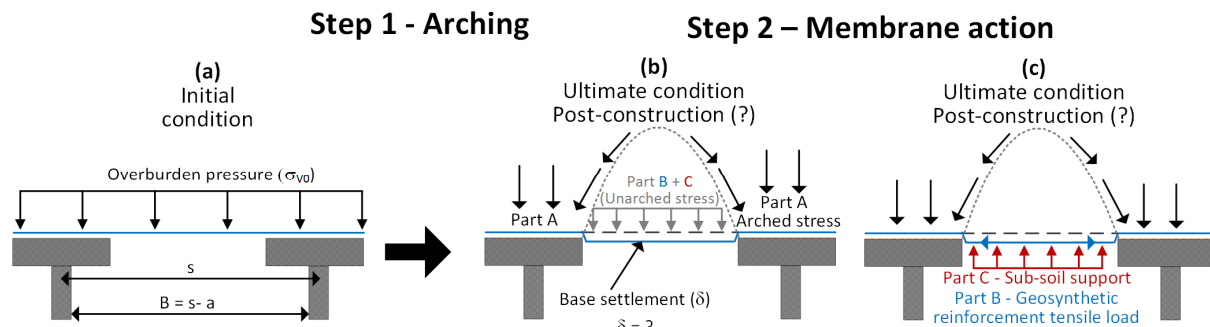


Figure 1. Conceptual load distribution (a) Initial condition (b) Arching stresses (c) Membrane action

## 2 BACKGROUND

As part of the Regional Rail Link project in Melbourne, Australia, a number of GRCSEs were constructed to support rail embankments underlain by Coode Island Silt. One of these embankments, the North Dynon embankment, was selected for instrumentation as part of a research project involving Monash University and Golder Associates. The North Dynon embankment is a widened embankment, approximately 180 m in total length of which a 60 m length of the embankment is designed and constructed with a lower and upper level load transfer platform (Figure 2). The split-level load transfer was required to control differential settlement across the width of the widened embankment as well as to reduce potential settlement beneath the existing embankment.

Ground improvement options including a fully piled structure, soil mixed columns and drilled displacement columns were evaluated during design, however, it was considered that drilled displacement columns would provide the most efficient and cost effective solution as columns could be installed relatively quickly and efficiently while minimizing the potential for spoil generation. The later was particularly important as the Coode Island Silt is an acid sulphate soil and offsite disposal would have been costly. The ground improvement works were completed in stages with the lower level completed as part of Stage 1 and 2 works and the upper level constructed as part of Stage 3a/b works. The analysis and interpretation of the instrumentation data has been described separately in two papers. The localized behaviour based on earth pressure cell and strain gauge data is presented in King *et al.* (2016b) and focuses on arching stress development in the load transfer platform.

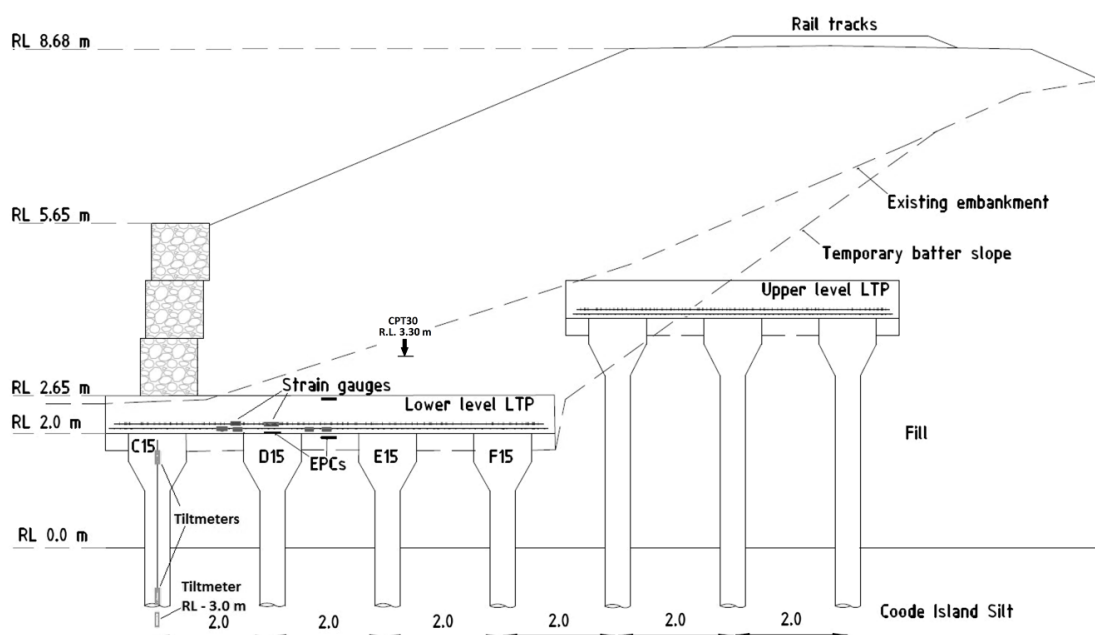


Figure 2. Cross section of North Dynon embankment at Area #2

A second paper (King *et al.* 2016c) describes the installation effects associated with the ground improvement works and their interaction with global embankment behaviour based on piezometer, tiltmeter, inclinometer and survey data. This current paper focuses on some of the design implications arising from the research findings presented in King *et al.* (2016b). Gniel and Haberfield (2015) have also described separately the GRCS approach embankment for the Maribyrnong River viaduct constructed for the Regional Rail Link project.

### 3 SUB-SURFACE CONDITIONS

The North Dynon embankment is located immediately adjacent to the Moonee Ponds Creek in the suburb of North Melbourne and is founded on a sequence of Quaternary aged sediments (Yarra Delta sediments) overlying the Silurian aged Siltstone/Sandstone of the Melbourne formation (Neilson 1992). The near-surface Coode Island Silt, is of particular importance owing to its wide spatial distribution, low undrained shear strength ( $s_u$  typically increases from about 15 kPa to 40 kPa at depth) and its considerable thickness of up to 25 m in parts. The geological profile is complex and highly variable, with the Coode Island Silt varying from 7 m to 15 m along the length of the embankment, the underlying stiff to very stiff clays of the Fishermens Bend Silt unit form the founding unit for the columns. As part of the site characterisation for the research case study, the site investigation information was reviewed and an extensive program of additional laboratory testing was undertaken. This was primarily focused on characterising the compressibility and time rate of settlement of the Coode Island Silt. The findings of this investigation along with a detailed description of the sub-surface conditions is presented in King *et al.* (2016a).

### 4 FIELD CASE STUDY RESULTS

Instrumentation was installed in two separate areas of the embankment (Area #1 and Area #2). The data from Area #2 is shown in Figure 3 along with the earth pressure cells arrangement in the figure insert. The stress acting on the column head can be seen to increase as the embankment height increases (increasing overburden stress) and as the arching develops due to sub-soil settlement. Following the completion of the embankment, the arching stresses are seen to develop progressively post-construction under a constant vertical load. The term “stress reduction ratio” is often used to quantify arching stresses and is defined as the stress acting in the zone being unloaded (i.e. EPC2 stress) divided by the overburden stress and is shown in Figure 3. The overburden stress was assessed to be 74 kPa in Area #2 based on 2D plane strain finite element analysis (see King *et al.* 2016b).

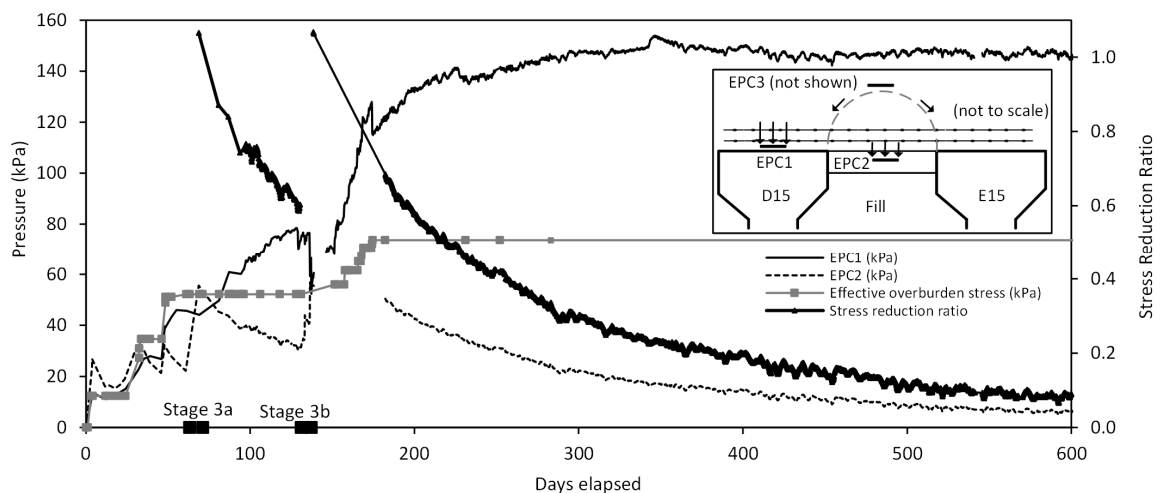


Figure 3. Earth pressure cell data and calculated stress reduction ratio

### 5 GROUND REACTION CURVE

The Ground Reaction Curve describes the relationship between the stress reduction ratio and the relative (normalised) displacement in a trapdoor test (defined as trapdoor displacement ( $\delta$ ) / trapdoor width (B)) over the initial, maximum, load recovery and terminal phases of arching (Figure 4). This method has been utilized in the current field case study to describe the development of the arching

stresses shown in Figure 3 by considering a 2D axisymmetric unit cell with parameters H (height of overburden material) and B (equivalent width of trapdoor). For the unit cell considered in the present investigation  $H = 3.73$  m and  $B = 1.42$  m. The material properties of the rockfill used in the load transfer platform, friction angle  $\phi = 50^\circ$  and mean particle size  $D_{50} = 9.7$  mm, are also used to calculate the Ground Reaction Curve. The stress reduction ratio data in Figure 3 is reproduced in Figure 5 and compared with the predicted values (shown in bold) determined from the Ground Reaction Curve method. Based on the data available, the development of arching stresses up to the period of maximum arching shows good agreement with the predicted behaviour based on the Ground Reaction Curve method.

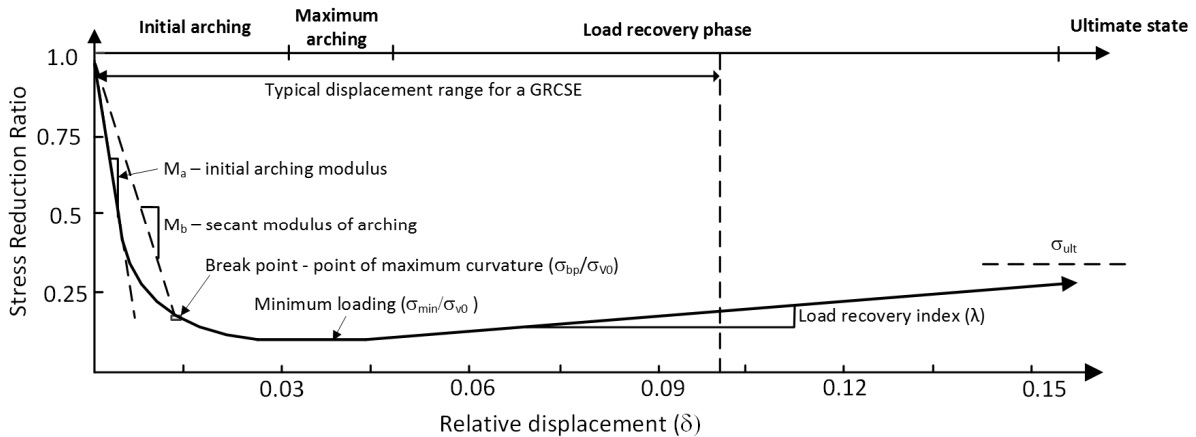


Figure 4. Characteristic Ground Reaction Curve (modified from Iglesia et al. 2013)

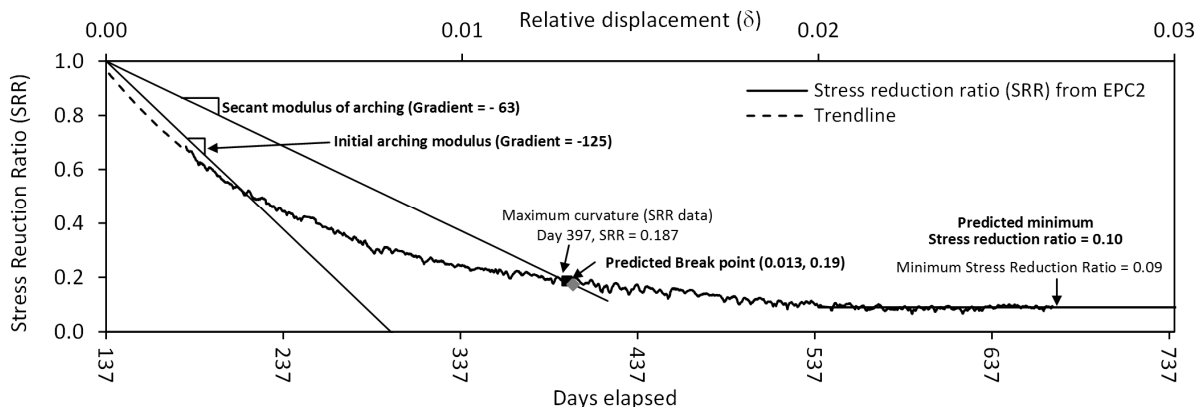


Figure 5. Area #2 – Stress Reduction Ratio based on EPC2 and predicted Ground Reaction Curve values (in bold)

## 6 IMPLICATIONS FOR THE DESIGN OF GRCSE

The development of arching stresses up to the period of maximum arching was found to be in good agreement with the values predicted from the Ground Reaction Curve method. This behaviour also agrees well with the settlement analysis and strain gauge data (see King *et al.* 2016b) which suggests about 30 mm to 60 mm of sub-soil settlement has occurred to date. The applied stress currently acting on the sub-soil is about 10 kPa and under these stresses acting on Coode Island Silt, on-going settlement, if it is occurring, is due to creep settlement. Rates of long-term creep settlement are described by Ervin (1992) and Srithar (2010), and on this basis, it is expected that long-term settlement of the sub-soil will continue for much of the design life of the embankment, and more importantly, will continue until the loss of sub-soil support condition occurs. The Ground Reaction Curve describes an increase in arching stresses after the period of maximum arching, i.e., increasing stresses acting on the geogrid in the long-term. On this basis, four phases of arching development as they relate to this GRCSE are outlined in Figure 6.

Based on the analysis of the arching stress development (Figure 6), the stress acting on the geogrid when the loss of sub-soil support condition occurs is predicted to be 11.4 kPa and in the load recovery

phase. This highlights two important findings relevant to the behaviour of GRCSEs: 1) the stress conditions that established shortly after construction (maximum arching condition) are not in a state of equilibrium nor are they representative of the long-term stresses (the stresses are expected to increase by 30 % over the long term) and 2) the majority of the base settlement occurs post-construction. This is due to the small amount of stress acting on the sub-soil at maximum arching. i.e. it is difficult to “impose” the loss of subsoil support condition once maximum arching develops. Whilst much of the discussion presented focuses on the stress development, it is the base settlement that governs surface settlement and serviceability behaviour. These findings have important implications for the design of shallow height GRCSEs as this post-construction base settlement can translate to surface settlement and lead to serviceability failure. The serviceability behaviour of shallow height embankments is examined further in King *et al.* (2016d).

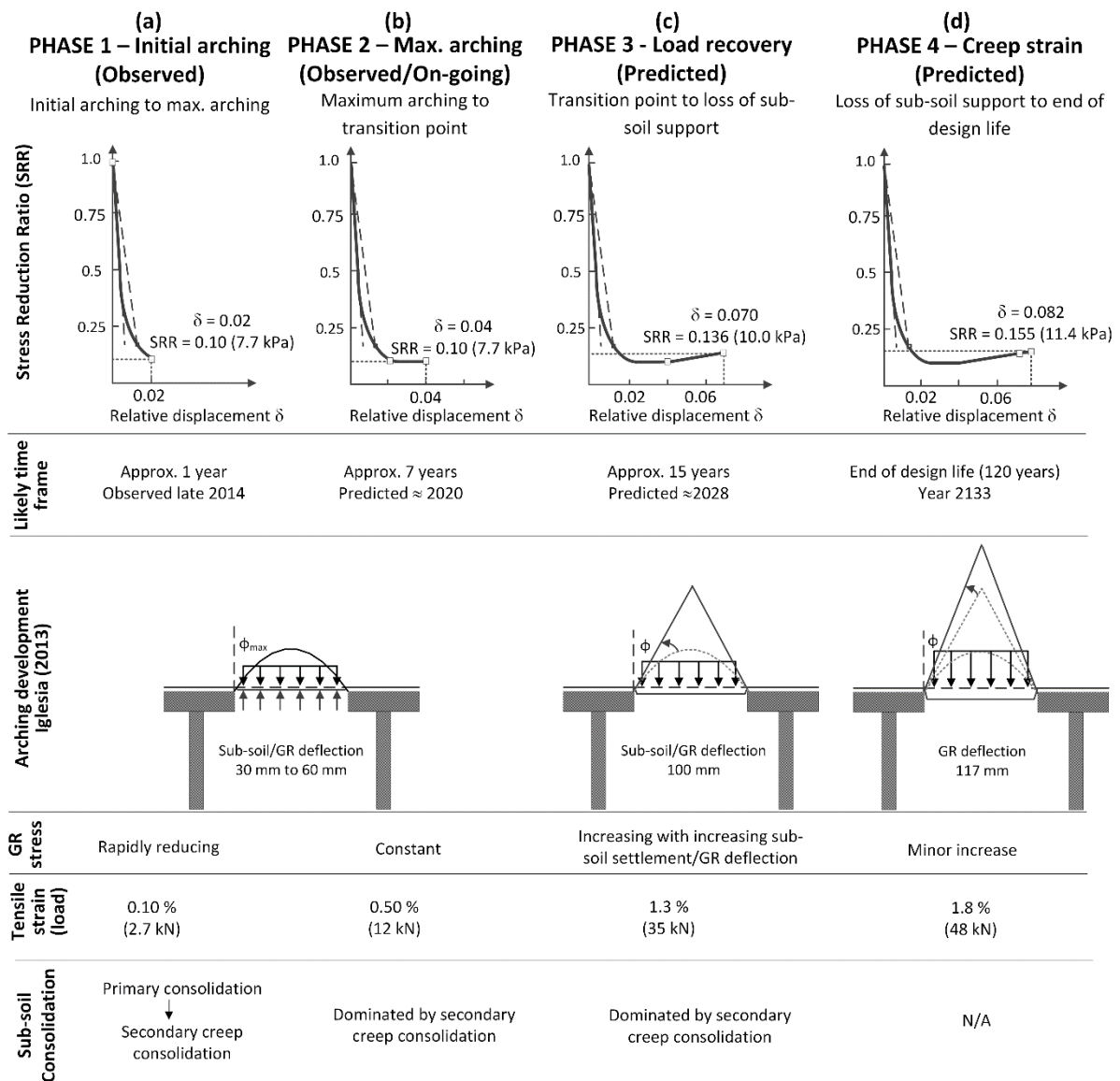


Figure 6. Four phases of arching development based on application of GRC method to Area #2 – (a) Initial arching (b) Maximum arching (c) Load recovery (d) Creep strain

## 7 CONCLUSION

A GRCSE has been extensively instrumented in Melbourne, Australia and monitored for nearly three years. The findings of this case study has been presented in a number of journal and conference publications and some of the implications of these research findings as they relate to the design of a GRCSE have been briefly outlined in this paper. Interested readers are referred to the authors’ journal publications for further details. The key finding relating to the load transfer platform, which has been

the focus of this paper, is the relationship between the development of arching stresses and sub-soil settlement. The widely adopted “two-step” design approach for load transfer platform design, found in many design standards, has been described and compared with the four phase of arching development described by the authors (Figure 6). The limit equilibrium models used in these “two-step” design approaches describe the arching stress/deformation relationship as a constant. The authors consider that the development of arching described by an initial, maximum, load recovery and creep phase of arching is a concept that improves the understanding of load transfer platform behaviour, enables assessment of serviceability behaviour and is of great benefit to designers. Further research involving centrifuge embankment models and non-destructive imaging techniques is currently being undertaken at Monash University to develop these concepts relating to the arching stress/deformation relationship into a GRCE design method.

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