Trial embankments to reduce geotechnical risks on poor ground

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ABSTRACT

Developments on poor ground commonly involve substantial geotechnical risk and uncertainty. Trial embankments provide means of reducing project risks to levels acceptable for use. This paper examines the benefits of trial embankments, based on a selection of case histories. Schemes include pre-loading; surcharging; staged construction, and evaluation of ground improvements for settlement control and stability, on a variety of soft ground, marginal materials and fills. Trial embankments need to be carefully designed within the context of the overall project, the geotechnical risks, and the observational method; guidelines are given. Objectives and outcomes need to be clearly communicated to stakeholders, as do the geotechnical risks and cost implications. The greater the prior uncertainty, the earlier the trials should be implemented, and the greater the value they provide.

Keywords: Geotechnical risk, site investigation, soft soils, ground improvement, surcharging.

1 INTRODUCTION - GENERAL DESIGN AND IMPLEMENTATION

Geotechnical design for construction on poor ground is an art as well as a science, with substantial challenges presented by the uncertainties associated with the ground and treatment; variability in conditions and the difficulty of obtaining suitable design parameters. Conventional and specialised in situ and laboratory testing can provide only limited data; field behaviour under service loads may differ significantly and be uncertain. In such circumstances, trial embankments can provide key information to the designer, owner and the constructor to produce efficient design with the risks suitably assessed and managed. Trials should be seen as a key part of a staged site investigation process.

A geotechnical solution such as staged construction or ground improvement normally provides major cost savings over ‘structural’ solutions such as piling, but may involve substantial project risks. It is important that these are suitably identified and can be accepted by all parties. The greatest uncertainties are often in the amounts and rates of consolidation settlement and strengthening, which may not be adequately predicted from site investigations and laboratory testing. Trials can reduce the risks to levels which may be acceptable. They can range from feasibility studies (what techniques work best, will a technique work at all, or be economic) through to fine-tuning to optimise design.

This paper examines a range of projects where trial embankments were key to managing the risks and achieving successful outcomes. It also includes several expert projects where trial bank data (or the lack or interpretation thereof) and control of geotechnical risk were at issue and where trials could or should have averted problems.

Detailed design, monitoring and interpretation of trials are key and complex tasks. There clearly needs to be adequate prior design work and reason to suppose a proposed scheme is feasible subject to the trial. Ground conditions need to be well-established commonly including high quality sampling and in situ testing. CPT-U profiles before and after trials often provide a particularly good means of evaluating change and benefits. Construction and loading records are crucial. Settlements are the normal key measurements, but as much data as practical should be obtained by a variety of methods and duplicated; inconsistencies can be of consequence. Applicability of the trial to the main scheme needs particular consideration, noting

- variability of ground conditions along the route (suitable trial area, worst / typical conditions)
- depth of influence (affected by trial footprint, and 3 dimensional effects)
- options for future control and monitoring (height and duration of surcharge / staged raisings.

The ensuing works must be suitably integrated with the trials, normally by an 'observational' approach (Peck 1969, Nicholson et al 1999) with ongoing assessment against pre-set criteria (often defined from the trial) as the project proceeds for validation and where necessary, adjustment of the treatment.

2 SELECTED CASE HISTORIES

2.1 General

The case histories, mainly from Australia and the UK, are summarised in Table 1, which identifies some key facts and learning points shown by these. The following have been selected for further comment within the confines of this paper. In many of the cases below the client got considerable benefit, at the limited (but not negligible) cost of the trials and associated geotechnical input.

2.2 Woolston and Frodsham Deposit Grounds UK. Case History 1

Manchester Ship Canal had a major programme of developing embankments for dredging deposit ground over very soft peats and clays. Over 20km of these have been built, over approaching 100 years, enclosing some 160ha area. Early embankments were fairly low, typically around 3-4m and raised slowly. Geotechnical methods were applied from the 1960s including staged construction and some use of vertical drains, in some cases raising in stages to some 10-12m by tailings dam methods over existing dredgings, with upstream or centre line (Christmas tree) profiles. There were substantial difficulties and several failures, which can be attributed to staged raisings proceeding faster than the ground would withstand. All this history was key to the chosen design and construction strategies.

By the late 1980s both sites needed new capacity (Figure 1). Woolston required raising existing banks by a further 5-7m using an upstream method. Frodsham required a new 1.7km long, 9m high embankment on peat and soft clays. Basal reinforcement using high strength geotextiles was proposed, then relatively novel, based on the first author's experience in Hong Kong and elsewhere. A trial bank (Figure 2) was built at Woolston in stages over about 6 months, on the very soft dredgings, and shown to perform satisfactorily up to the required 7m high with geotextile, whereas the unreinforced section failed. This gave the design team, and especially the client, the confidence to proceed with the full schemes. Production embankments were successfully built to 7-9m by staged construction. A direct works contract approach was used with the rate of filling controlled to the engineer's (first author) instructions in the light of the monitoring. Further details are given in Tonks (1989).

Figure 1. MSCC Woolston Site

Figure 2. Woolston Trial Bank

2.3 Developments on peat and alluvium, Northwest UK. Case Histories 2 and 3

Trial embankments demonstrated that development was economically viable on up to 3m thickness of peat by use of up to 5m surcharge for around 3 months. More onerous conditions had to be piled. About 1000 houses, roads and drainage were then constructed in phases, with extensive site control and monitoring based on the trials. Experience from this led to several other successful schemes.

Surcharging was used to treat a site in NW England on alluvium (Case 3), where it was required to limit post-treatment settlements to about 10mm. In the event the surcharge did not appear to achieve this, although there were substantial issues with the quality and interpretation of the monitoring. The structures were then piled, with consequent severe delays to contract and costs. In this case, the risk of a geotechnical scheme could have been deemed excessive in the absence of a trial embankment. Had this been done pre-contract it could have shown a geotechnical solution was not appropriate.

2.4 Backfilled opencast mineworkings. Case Histories 4 and 5

There are substantial areas of deep opencast workings which have historically been backfilled with dumped spoils, largely without engineering compaction. Rockingham motor-racing circuit was constructed on some 20m of backfilled ironstone-workings. Design was based on extensive trials on similar sites in the area and elsewhere by BRE. Charles et al, 2001, 2002 & 2008 and cross references give useful accounts of these and many other cases. Some have been successfully treated by surcharge. Without these trials and well-documented case histories the scheme would not have been reasonably feasible, or capable of construction without undue risk.

Site specific trials and an observational approach to the earliest stages of construction confirmed the particular requirements for this site. About 2km of track and associated embankments (Figure 3) were successfully constructed with surcharging, under extensive site control and monitoring.

At another opencast site in the English Midlands (Case 5), there were found to be risks of inundation collapse settlement from a rising groundwater table at depths in excess of 20m. An initial trial was inconclusive. Later trial embankments found that some 15m of surcharge could adequately improve the backfills to the necessary depths, and was more economic than other treatments, also trialled.

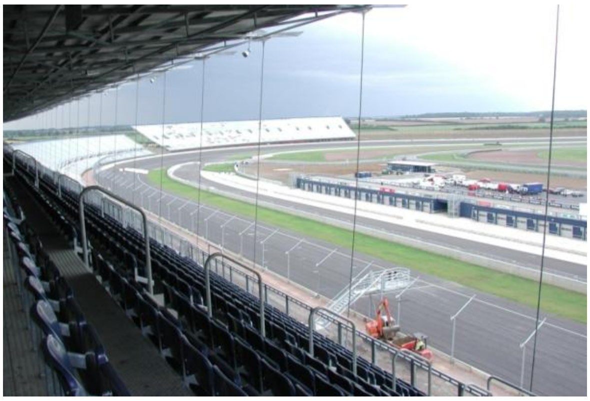

Figure 3. Rockingham, completed site

Figure 4. Northern Access Road Project

2.5 Northern Access Road Project. Case History 6

A 500m long trial embankment was constructed on deep soft ground near Brisbane Airport, Australia (Figure 4). The width of the trial embankment was approximately 40m with the height varying from approximately 2.1m to 2.9m. It was part of the new Northern Access Road that links the new duplicated Gateway Motorway to the Brisbane Domestic Airport. Due to the presence of very deep (20~30m) soft deposits along the project alignment, future potential excessive settlements under pavement during the 40 years of design life and embankment instability during construction were the two key technical issues. In order to meet design criteria, ground improvement using preloading/surcharging with and without wick drains was nominated for construction.

Although there was a sufficiently long period for design because of time needed for approval, temporary works etc, the time necessary for ground improvement was on the critical path if preload fill was to be re-used in different areas, in order to minimise import of fill through highly trafficked areas close to the Brisbane city. Therefore to better estimate the time for consolidation with and without wick drains, the trials were conducted and the results provided valuable information for the construction programme (see Yang et al, 2009).

2.6 Future Port Expansion (FPE) Seawall Project. Case History 7

The first stage of the FPE Project involved the construction of a 1.8km long, up to 8m high seawall in the Moreton Bay, to the east of the existing reclaimed areas at the Port of Brisbane (PoB), to act as a containment bund for the placement of dredged materials (Figure 5). The seabed is at about 1m depth closer to the land, but deeper, up to 3.5m below the lowest tide level, on the east wall. The site is underlain by deep Holocene deposits with the deeper profile characterised by soft to firm clays (known as PoB clays, see Ameratunga et al 2010a) having high compressibility characteristics and weak strength properties. Essentially two designs were adopted for the seawall:

- Shallow seabed - a rock embankment placed on a high strength geotextile.
- Deep seabed - a rock bund on a wide sand 'pancake' placed on a high strength geotextile

A geotechnical risk assessment was carried out and it was decided to conduct two trial embankments, one inshore and the other in relatively deep water on the proposed bund alignment. From a geotechnical engineering point of view the trials gave the parties involved confidence that a bund could be safely constructed although very weak subsoil conditions existed, with undrained strength as low as 3 to 5kPa at seabed (Figure 6); showed that basal geotextiles could be used effectively under water and fill placement could be carried out without mudwaving and gave deformation parameters for settlement analysis (more information in Ameratunga et al, 2003).

Figure 5. FPE Seawall

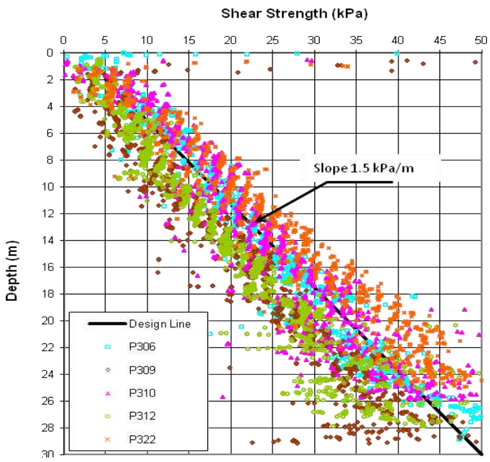

Figure 6 –Shear strength profile under the wall

2.7 Port of Brisbane Ground Improvement Trials. Case History 8

The land contained by the FPE Seawall described above is progressively reclaimed using maintenance and berth development dredged material. The development of these sites will be significantly more difficult and challenging because the areas are underlain by thick soft clay layers, up to 25m compared to 6m in the developed areas to the west, and the significant thickness (up to 9m) of soft dredged materials. To accelerate consolidation it was preferred to use wick drains combined with surcharging, as the most cost effective solution. However factors associated with wick drains such as smearing during installation, possibility of kinking due to high settlements, and no local experience especially related to such high settlements (>3m) and depths (~35m) needed to be addressed. In order to address these issues it was concluded that a series of trials using wick drains and vacuum consolidation be conducted prior to broad scale roll out. Considering the significant cost of trial embankments, the next areas to be developed were selected for the trial sites, meaning that the land after the trial will be ready for development.

To ensure proper analyses of the trials significant testing, instrumentation and monitoring were carried out. Results were analysed by the Contractors who participated along with the consultant appointed by PoB Corporation as well as three independent professors. The results provided valuable information on the feasibility of using wick drains, valuable information on the behaviour of different wick drain types, optimal wick drain spacing to be considered as well as geotechnical design parameters difficult to be obtained from in situ testing (see Ameratunga et al, 2010b).

3 SOME ISSUES, CONCLUSIONS AND RECOMMENDATIONS

- For many projects involving construction on soft ground, geotechnical solutions such as staged construction, surcharging, vertical drains, or other forms of treatment offer far more economic solutions than alternatives such as piling. Indeed often a project is only viable by such methods.
- These do, however, carry high levels of risk, particularly regarding the actual performance in the field which may not be reasonably predictable from laboratory testing and theory alone. Treatment techniques and details need to be suitably investigated in the field.
- Appropriate use of trial banks can be key to reducing uncertainties and optimising management of the risks. These need to be carefully planned as an integral part of the staged investigation and design process.
- Key issues and objectives need to be clearly identified and communicated to stakeholders, as do cost implications. A risk-based approach should clearly identify risks pre and post trial.
- It is vital that the range and variations in geotechnical conditions around the site are adequately known. The trial must suitably assess the significant conditions in the ground and must be capable of being applied to the potentially variable conditions of the main works.
- The instrumentation and monitoring needs to be carefully designed and interpreted, suitable for use in the main works, commonly involving an observational approach. Settlement behaviour can be complex, especially where there are several soil layers, of varying thicknesses. On occasions early settlements have been mistaken for primary consolidation with serious consequences.
- The stress history of the site must be reasonably well-established. Cases involving some previous loadings and prior consolidation can be particularly difficult to interpret.
- Outcomes need to be clear and communicated in suitable form for use in the planned project.
- Timing is crucial. Trial banks should normally be done as early as possible, once key issues have been suitably identified from prior investigations. Until completed and suitably assessed, there may be very substantial uncertainties and risks. Trials are sometimes left to an unduly late stage which limits their value. If a trial is 'to find out what works', it normally needs to be arranged prior to the main works.

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Table 1 Benefits of trial banks for embankments and reclamations. Selected case histories

Ref. Location	Description	Main Objectives	Timing and Key Benefits
1. MSCC Woolston and Frodsham Dredgings Lagoons UK	Key part of studies and design development for about 4km of geotextile-reinforced embankments on very soft alluvium, peat and dredging deposits. Several basal reinforced embankments were then built to 7 – 9m by suitable staged construction.	• Assess geotechnical design parameters especially performance of the geotextile reinforcement and the in situ rate of consolidation strengthening under staged construction over about 6 months. • Compare performance with and without high strength basal geotextile reinforcement.	• Trial at conceptual design stage, about 1 year before construction • As the trial was to failure it was located outside the footprint of the main works • The trial confirmed the predicted failure of the unreinforced section at about 7m height. • Demonstrated benefits of high strength geotextile reinforcement.

Ref. Location	Description	Main Objectives	Timing and Key Benefits
2. Housing, and Industrial developments UK	Development of over 1000 houses, roads and drainage on varying thicknesses of peat and underlying soft clay. Used as basis for subsequent large scale industrial developments on similar peat.	• Demonstrate that surcharging of peat was feasible & economically viable, to suitably control long term settlements • Assess the maximum peat thickness that could be improved using surcharging.	• Pre-construction trials showed up to 3m of peat was developable with up to 5m surcharge for 3 months. • Enabled development with extensive site control and monitoring • Site not otherwise economically developable.
3. Water treatment works, UK	3 to 5m surcharge on alluvium designed to limit post treatment settlements to about 10mm.	• Surcharging was selected and implemented for main scheme. • A prior trial could have shown surcharge could not achieve the specified requirements and saved considerable time and expense in the main contract.	• Surcharging during construction, monitored over about 3 months and did not perform as expected. • Then needed to pile, with consequent wasted works and severe delays to contract.
4. Rockingham Raceway, UK	Motor racing circuit on deep backfilled mine workings. Design based on extensive trials on similar sites in the area and elsewhere by BRE, without which scheme would not have been reasonably feasible.	• Site specific trial to confirm the particular requirements prior to roll out over a length of about 2km • Noting varying ground and surcharges needed around the site	• Scheme was feasible in the light of extensive published trials by others. • It was therefore reasonable to incorporate site specific trial within the main works, to optimise the design and confirm surcharge performance and requirements.
5. Backfilled open-cast workings, Midlands, UK	Industrial development on deep backfilled mine workings. Various treatment technologies were trialled. Surcharging proved only economic means of addressing risks of inundation collapse to depths of more than 20m.	• Assess feasibility &performance criteria for surcharge and compare with alternatives. • The site was prepared without treatment. When risk of inundation collapse was identified, extensive trials were needed to assess solution options.	• Several treatment methods were subject to detailed feasibility trials • These showed 15m surcharge was required to treat to 20-25m depth. • This was more economic and practical than other treatment options & implemented for some areas and end-uses.
6. Northern Access Road Project, Brisbane, Qld	Links new duplicated Gateway Motorway to the Brisbane Domestic Airport. The alignment is underlain by soft compressible clay as deep as 25m. A 500m long trial embankment within the West Area was constructed in a very early stage of the project.	• Confirm that wick drains will work efficiently • Obtain realistic design parameters for wick drain design, especially coefficient of consolidation and effects of smear, prior to rolling out along the 4km of the road.	• Trial embankment was constructed very early in the design phase • Measures were available to rectify if the performance of the trial was worse than expected. • No advantage in siting trial outside site footprint as space was available along the alignment.
7. FPE seawall project, Brisbane, Qld	The seawall is 4.6km long and extends 1.8km into Moreton Bay. The seabed is 1.0m to 3.5m below low tide. The site is underlain by Quaternary marine deposits containing a variable layer of sand, overlying soft compressible clay ranging from about 8m to more than 30m.	• Investigate construction techniques and productivity rates • Initial penetration into seabed, toe heaving and mud waving • Assess suitability of fill materials and the extend of turbidity • Assess feasibility of laying High Strength geotextile and damage under rock placement • Review geotechnical parameters • Assess suitability of geotechnical instrumentation	• There was no advantage in selecting a site outside the footprint of the alignment as it was possible to accommodate the trial embankment in the final design.
8. Port of Brisbane reclamation development, Brisbane, Qld	The future expansion of the Port of Brisbane is underlain by reclaimed dredged mud and deep compressible clay and needs extensive Ground Improvement. A well planned set of trials involving international operators were conducted to optimise and select suitable techniques prior to rolling out. The trials were staged within the footprint of the future development.	• Confirm that wick drains work in PoB clays, noting several case histories of failure on the eastern coast where the soils were more sensitive than PoB clays. • Confirm that wick drains work efficiently even for deep channels of soft soils, as deep as 35m. • Assess the effects of wick drain spacing to optimise future designs • Assess the effectiveness of different wick drains • Assess vacuum consolidation	• As the trial costs were very significant it was necessary to incorporate the area as part of the development. • The site was selected based on the development plan for the Port and therefore the likelihood/risk of adverse behaviour and consequences were assessed prior to selecting the site. • As they were legitimate trials, a significant Research & Development tax concession was gained.