Don’t let soft soils sink your next transport project

There are a number of considerations to take into account when planning your ground improvement strategy.

These include planning, funding and whole of life considerations as well as assessing the various treatment options available. This piece explores these themes and also shares our framework for the selection of early works, and what you should consider when developing a low embankment strategy.

Planning, funding and whole-of-life considerations

Construction on soft soils typically takes longer and costs more than building on a ‘normal’ site. By understanding the geological profile, allowing longer term planning, and developing a funding strategy, you can avoid construction program issues and increased costs. Soft soil treatment can be carried out relatively economically provided there is sufficient time allowed for the ground treatment to take place. As the construction program time decreases, the costs associated with the ground treatment works increases.

For transport projects over extensive soft grounds, a whole-of-life approach should be considered to derive best value for money. A whole-of-life approach takes into account satisfactory performance requirements without excessive capital expenditure, but also ensures that the regime of long-term maintenance and cost will be within acceptable limits throughout the design life of the infrastructure. By balancing capital cost and long-term maintenance cost, a whole-of-life approach generally provides the best value for money solution. Expectations between capital cost and maintenance cost will differ depending on the views of different stakeholders and possibly different project delivery models. As shown in the figure below, the alliance delivery model can be more flexible in balancing competing factors.
This demonstrates the importance in defining the performance expectations of all interested parties, including the public. This consultation should be done at the beginning of the project through communication and education strategies, and discuss how each of the expectations will impact on the overall project budget and program.

**Ground treatment options**

The general ground treatment options available for managing embankments on soft ground can be divided into five categories shown below.

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples of ground treatment methods</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal</td>
<td>Excavate and replace, mud waving</td>
<td>Only feasible where the depth of the soft soil is limited to about three metres. Excavated acid sulfate soft soils also require treatment to avoid adverse impact on the environment.</td>
</tr>
<tr>
<td>Compaction</td>
<td>Dynamic compaction, impact rolling, explosive compaction and vibro-compaction</td>
<td>Limited to the treatment of loose granular soils, with experimental application of this method in soft clays with mixed success.</td>
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<tr>
<td>Consolidation</td>
<td>Preload or surcharge with or without wick drains, vacuum consolidation and electro-osmosis</td>
<td>Although consolidation is by far the most common and economical ground treatment method in soft cohesive soils, this process can be time consuming and may not be feasible where the soft soil has very low permeability, deep and the construction time program is limited.</td>
</tr>
<tr>
<td>Modification</td>
<td>Deep soil mixing, lime columns and grouting</td>
<td>Due to cost considerations, modification is limited to areas adjacent to structures such as bridge approaches and culverts. This enables accelerated construction to take place and control of post-construction differential settlement to acceptable limits.</td>
</tr>
<tr>
<td>Load transfer</td>
<td>Stone columns, dynamic replacement columns, controlled modulus columns and piled embankment</td>
<td>Due to cost considerations, load transfer is limited to areas adjacent to structures such as bridge approaches and culverts. This enables accelerated construction to take place and control of post-construction differential settlement to acceptable limits.</td>
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</tbody>
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Table 1. Categories of ground treatment
Assessing ground treatment options

Relevant factors

The selection of the ground treatment option depends on a wide range of issues. The key considerations when assessing which ground treatment option is suitable for use at a particular site include:

- budget
- desired performance
- community needs and support
- available time
- environment impact
- public perception of works
- material availability
- geological conditions
- height of embankment and depth of soft soil
- technical innovation
- available width of road corridor
- contractor skills and resources

The required time for each of the ground improvement options is dependent on the depth and properties of the soft soil, the embankment height and the construction time associated with the ground improvement method.

Figure 2. Flowchart showing factors which may affect cost of ground improvement (Wong, 2012, as modified from O’Riordan et al, 1993 to include environmental, sustainability and safety considerations)
Cost considerations

Cost associated with ground treatment is also affected by similar factors as for construction time, including the depth and properties of the soft soil, and by the availability of local material sources suitable for the ground treatment.

Risks

There are various risks associated with ground treatment. Many are common to all treatment types, while some are unique to specific treatment techniques as illustrated by the following examples:

- greater settlement than predicted
- slower rate of consolidation than predicted
- poor construction control leading to distress or failure during construction
- alignment changes during detailed design - depending on the condition of the site, even a minor increase in vertical alignment can have significant impact on post construction settlements
- changes to final bridge abutment locations during design of the main contracts
- higher cost of treatment of acid sulphate soils for excavation and replacement options
- inadequate room for groundwater treatment ponds and higher cost of treatment for vacuum consolidation due to low pH and naturally occurring heavy metals
- higher running cost such as electricity for electro-osmosis due to high conductivity layers not anticipated
- for surcharge with wick drains, excessive smearing due to poor installation and/or kinking of wick drains due to excessive settlement
- insufficient consolidation, especially at depth, leading to insufficient surcharge effect and greater post construction creep

The above risks will likely impact the cost and time of construction, but could also impact post construction performance of the pavement and ride quality. Many of these risks can be reduced by adequate investigations and geotechnical control.

Risks associated with surcharging are often linked to projects with limited construction time and the uncertainties that can arise. This risk may be dramatically reduced if surcharging is carried out as part of early works, well in advance of the main construction contracts.
Embankment zoning

For transportation projects, embankments founded over soft ground may be divided into three broad zones: structural, transition and low embankment zones. Embankment zoning is important, as it provides ready identification of where early works or accelerated ground treatment is required, as outlined in Figure 3 below.

The structural zone is usually the most critical because the abutments of structures are piled and will settle very little. Ground treatment in this zone must be accelerated to avoid delays to the structures which are usually on the critical path.

The transition zone sits between the structural and low embankment zones in terms of criticality. Here, ground treatment should be carefully designed and constructed to allow a gradual increase in settlement. This will allow post-construction differential settlement to be within tolerable limits in terms of smooth ride, adequate cross drainage, and road pavement or rail track performance requirements.

The low embankment areas categorised as less than 2.5m to 3m in height, have the longest lengths along the project, but are less time critical as more post-construction settlement can be tolerated. Despite this, low embankments are also often complicated by the presence of flood culverts and the risk of settlement causing the finished surface to sink below design flood level.

Low embankment strategy

Long stretches of road or railway away from bridge abutments or culverts may have relatively low embankments and it may not be economically feasible to treat the soft ground in these areas. As described above, post-construction settlement is less critical in its effect on operational performance for low embankments. In these circumstances, a whole-of-life low embankment strategy should be considered.

A low embankment strategy would generally comprise the following design and construction considerations:

- Structural zone
  - Small settlement
  - Protect piles
  - Smooth ride
  - Construction programme
  - Protect existing structures

- Transition zone
  - Smooth transition

- Low embankment zone
  - Flexible or rigid pavement
  - Controlled settlement
  - Flood levels
  - Road design
  - Construction programme

Figure 3. Embankment zoning for a typical road project
• keep the vertical alignment of the transportation route as low as possible – if possible and subject to operational grade and drainage requirements, keep the embankment load below the pre-consolidation pressure of the soft soil

• plan the bulk earthworks to be constructed as early as possible in the construction program so as to give the maximum settlement time prior to completing the pavement or track formation

• assess the post-construction settlement so that a maintenance program can be planned and whole-of-life costing carried out

• design the pavement to cater for the expected long-term post-construction settlement and differential settlement taking into account the intervention regime that will need to be implemented

• involve the asset owner including both capital works and maintenance divisions, in the design and assessment process – a collaborative approach is required so that informed decisions can be made by the relevant authority

• communicate the strategy to the public so they can appreciate the issues and acknowledge that periodic maintenance is part of the design, and will not be surprised when such work is required and traffic restrictions required from time to time

How we can help

Transportation projects constructed on soft soil, can reap economic benefits from early planning, staged construction where funding allows and an early works program, and selecting different ground treatment solutions at different sites along the project to best meet the various competing factors including time, cost and risk.

Coffey are specialists in this area and can rapidly assess different ground treatment options at multiple sites to assist with estimates of time, cost and risk so that you can select the appropriate solutions based on critical paths on your construction program.

A low embankment strategy (LES) with a whole-of-life approach that balances capital cost and long term maintenance, should be considered. Coffey can incorporate the LES as one of the options along the project to assist you in developing the most cost-effective solutions that are suitable over the design life of the project.
References
