Second International Conference on Construction in the 21st Century (CITC-II)
"Sustainability and Innovation in Management and Technology"
10-12 December, 2003, Hong Kong

Lessons Learned in the Design and Construction of a Wastewater Earth Liner Project

Colin Duffield
Senior Lecturer, Department of Civil and Environmental Engineering
The University of Melbourne, Victoria, Australia; and
Academic Director, The Australian Centre for Public Infrastructure,
Melbourne University Private, Victoria, Australia

Sam Yuen
Senior Lecturer, Department of Civil and Environmental Engineering
The University of Melbourne, Victoria, Australia

Abstract
This paper presents a detailed forensic review into the premature failure of a series of earth-lined reed beds constructed for a wastewater treatment plant to understand the reasons and mechanism leading to excessive leakage. The review covered implications related to the initial investigation, design, material selection, construction expertise, environmental factors, workmanship together with the technical and construction know-how of the designer, constructor and supervisor. The outcomes from this case study provide some salient lessons – a good construction practice should provide opportunities for adequate communication among all parties at all stages of the project.

Keywords
Reed Beds, Earth Liner, Claim, Communication, Case Study

1. Introduction and Background

Australia has a mature and experienced construction industry that continually seeks to implement best practice and to improve its efficiency in the design and procurement of infrastructure facilities. Small construction projects are often procured using either a traditional procurement system or a design and construct approach. Neither approach negates the possibility of errors and oversights that may result in contractual disputes and technical issues (Duffield *et al*, 2002). This paper presents a case study to illustrate how it is still common to see failures in construction projects caused by a lack of communication among various parties during the entire project duration – from design, specification, supervision, construction to commissioning.

The Australian construction industry is cognisant with the identification and management of construction risks as recommended by the likes of Perry and Hayes (1985), NPWC/NBCC (1990), Curtis and Napier (1992), Thompson and Perry (1992), PmBok (2000) and more recently Blake et al (2003). However, it is well documented that even if the technical design of a project is fundamentally sound, mistakes and poor communication at subsequent stages can create significant problems and result in delays, inefficiency,

financial loss and often reduced functionality of a facility – Tilley (2000). This is not inconsistent with international findings, e.g. Ng and Skitmore (2002) and Nielsen (1998).

This case study presents a forensic review relating to the failure of a series of earth-lined reed beds constructed for a sewerage treatment plant in Victoria, Australia. It aims to illustrate the importance of good communication among various parties in a construction project and the negative consequences that could result from a break down in communication at various stages of the project.

The review has suggested reasons and mechanism of the failure based on a detailed investigation that looked into implications related to the initial investigation, design, material selection, construction expertise, environmental factors, workmanship together with the technical and construction know-how of the designer, constructor and supervisor.

The case study identifies lessons to be learned in an attempt to minimise future failures.

2. The Wastewater Earth Liner Project

The project was executed under a traditional construction contract involving a client (a regional water authority), a designer/superintendent (a geotechnical consulting engineer) and the constructor (an earthwork contractor). The project comprised a series of shallow earth-lined reed beds to allow biological secondary treatment of sewage effluent. Only days after commissioning of the reed beds, many of the reed beds failed functionally with significant effluent leakage. Plate 1 shows a typical reed bed and associated leakage.

Plate 1: Typical Reed Bed and Leakage

Subsequent to the issue of a Notice for Defect Rectification to the original contractor, a second contractor was awarded a reconstruction contract. The procurement of the project was made more complicated by the contract termination of the second reconstruction contractor due to unacceptable progress. A third contractor was appointed to finish off the remaining reconstruction work.

Table 1 lists all the significant events in a chronological sequence and gives a brief timeline of the earthwork construction.

Table 1: Sequence of Significance Events

Date	Event
4 Mar 97	Contract awarded to contractor with contract period of 12 weeks
May 97	Construction activities suspended due to persistent wet weather
Jan 98	Construction work resumed
Mar 98	Contractor completed construction work
2 Apr 98	Issue of Certificate of Practical Completion by superintendent
Sep 98	Filling of effluent into reed beds
Sep 98	Significant leakage/seepage observed from reed beds within 24 hours of filling
27 Oct 98	Superintendent sought defect rectification proposal from contractor
19 Jan 99	Notice for Defect Rectification issued to contractor by superintendent
23 Feb 99	Reed bed reconstruction contract awarded to second contractor
20Apr 99	Letter to second contractor to terminate reconstruction contract due to unacceptable progress
7 May 99	Reed bed reconstruction contract awarded to third contractor
May 99	Commissioning of the some of the reconstructed reed beds
Feb 00	No apparent leakage/seepage observed from the reconstructed reed beds
Feb 00	Reconstruction remaining reed beds
	Project Completion

3. Independent Failure Review

An independent reviewer was called in to provide an expert report for a court case among the client, the designer/superintendent and the contractor. The review investigated:

- The adequacy of the original design including earth material specifications, compaction requirement, surface preparation and final surface treatment;
- The sourcing and properties of earth material actually used and compliance with specifications;
- Adequacy and competence of site supervision;
- Workmanship including soil compaction and the presence of non-specification material (e.g. gravels, rubbles and topsoil); and
- The performance of reconstructed reed beds.

4. Review Observations

4.1 Suitability of the original design and borrow material

The properties of clay sampled from the failed reed beds were consistent with the material imported from the specified borrow sites. The material was a highly plastic clay of a low to intermediate dispersivity, and when properly compacted should provide an acceptable dry density and structural stability. The clay also exhibited a very low permeability as required by the design to serve as a hydraulic barrier. However, a relatively high shrinkage property implied that the clay had a high potential to cause shrinkage cracks upon drying. This behaviour is not uncommon in many parts of Victoria with highly plastic clay of basaltic origin. Provided this limitation is properly addressed (for example, allowing surface protection to minimise exposure to weather), the material could be used in liner construction.

The review also noted that the design of the reconstructed reed beds was conceptually similar to the original design with same compaction specifications, and the material was sourced from the same borrow site. The non-leaking performance of the reconstructed reed beds supported the suitability of the imported clay.

4.2 Compaction of the Failed Reed Beds

While overall the failed earthwork was reasonably well compacted, pockets of very poor compaction were apparent. Site records clearly showed that the as-compacted densities of the failed reed beds at some locations were below the required compaction specifications. Photographic records also revealed the presence of undesirable material such as silty and sandy soil pockets, cobbles, boulders and topsoils. These unsuitable soils would have significantly affected the stability and the water retention performance of the reed beds. In addition, post-failure inspections revealed evidence of poor earthwork restoration associated with pipework installation and damaged wall crests caused by other construction activities.

Significant signs of seepage were observed from the wall/base interface. The two-staged compaction of the base and wall introduced the risk of improper connection (or lamination) between the base and the wall components. The significant amount of seepage coming from the interface suggested that the surface of the base was not properly prepared in accordance with the specifications prior to the subsequent wall compaction.

4.3 Desiccation Cracks

Extensive shrinkage cracks (some propagating more than 300mm into earth mass) were common in the exposed earth mass of the failed reed beds (see Plate 2).

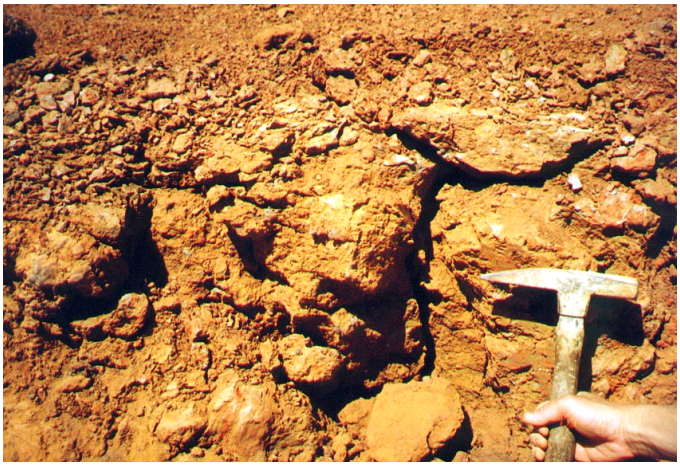

Plate 2: Desiccation of Clay Liner Caused by Excessive Drying

Given the high shrinkage potential of the imported clay there was no doubt that any exposed earthwork of the reed beds needed to be protected from drying as soon as it was completed. Unfortunately the original reed beds were exposed to weather without any surface protection for a prolonged period – a duration of about six months between earthwork completion and commissioning of reed beds (refer to Table 1). In addition to this, topsoiling of the reed beds was not included as part of the original earthwork contract and was not applied long after all earthwork was completed.

In summary, the desiccation cracking of the original reed beds was intensified due to a combination of: a lack of post-practical completion maintenance or permanent surface protection to prevent excessive drying; delay in commissioning of the reed beds which provided a six-months drying time to the reed beds (otherwise at least the upstream face would have been protected by the wetting of effluent even without surface protection); and an undesirable high void content in some local inadequately compacted clay.

4.4 Supervision

Site records revealed that the field supervision during liner construction was mainly in the form of a client representative inspecting the earthwork supplemented by occasional visits by the superintendent. The independent review suggested that the quality control of the earthwork was inadequate considering the need for site approval of the imported clay, compaction difficulties (associated with the relatively narrow wall section of the reed beds), the risk of poor connection between the base and wall components (as discussed in Section 3.1.2). For the supervision staff, there was clearly a lack of understanding regarding the importance of surface protection/maintenance of the earthwork both during and after construction to prevent excess shrinkage cracking.

5. Review Conclusions

The review concluded that the defective reed beds were caused by a combination of the following factors:

- Inadequate compaction in pockets of the earthwork;
- Significant desiccation cracks due to high shrinkage characteristic of the material and prolonged exposure to drying without appropriate surface protection;
- Poor structural continuity between base and wall components of reed beds;
- Poor earthwork restoration subsequent to pipe installation;
- Poor earthwork restoration to damaged wall crests caused by other construction activities; and
- Placement of non-specification material.

6. Discussion and Conclusions

From a technical perspective, the original design and the earth material selected were acceptable. However, poor workmanship by way of inferior local compaction and improper connection between base and wall components of the reed beds partially explains the pre-mature failure. Moreover, the clear misunderstanding of critical design issues, misjudgement of the importance of proper supervision, together with poor quality control caused the extensive desiccation cracking that also contributed significantly to the leakage.

The designer was clearly aware of the above issues as reflected in the construction contract specifications. However, the criticality of the issues was lost in the communication to the client and subsequently to the contractors. The six month delay between completion of the earthwork and commissioning resulted in an unacceptable duration of weather exposure to the earthwork.

The format of supervision, in this case on an as-required basis, proved inadequate as it allowed key design elements (such as earthwork compaction and surface protection) to be oversighted. The consequence was delays, cost overruns and loss of reputation of all parties.

In summary, this case study demonstrates that good design and adequate specifications alone are not sufficient in ensuring a successful project outcome. Good construction practice should provide opportunity for adequate communication among all parties at all stages of the project, as sound

communication at definitive stages of a project is crucial to ensure all intentions of clients and designers are fully understood and appreciated.

7. References

Blake, Bill and National Committee on Construction Engineering (2003) *Preparing Construction Agreements,* Engineers Australia.

Curtis, J. and Napier, W. (1992) *Acting for Consortia and the Structures Appropriate for Infrastructure Projects*, Commercial opportunities in developing Victorian infrastructure: AIC conference, Melbourne, June.

Duffield, C.F., Stevens, L.K and McMullan J. (2002), 'Lessons from design and construct projects', International conference on advancement in design, construction, construction management and maintenance of building structures, Bali, Indonesia, 27-28 March, Part 2, pp 46–53, ISBN No. 979-8954-21-1.

Ng, S. T. and Skitmore, R. M. (2002) Contractors' risk in Design, Novate and Construct contracts, *International Journal of Project Management,* 20: 119-126.

NPWC/NBCC joint working party (1990), *No Dispute: Strategies for improvement in the Australian building and construction industry,* National Public Works Conference, Australia.

Nielsen, K. R. (1998) *The essence of construction risk in Asia-Pacific*, Minimizing risk in construction projects and resolving construction disputes, Hong Kong, 28 & 29 September.

Perry, J. G. and Hayes, R. W. (1985) Risk and its management in construction projects, *Proceedings of the Institution of Civil Engineers (Engineering Management Group),* 78: 499-521.

Project Management Institute (PMI) (2000) *Project Management Book of Knowledge (PMBOK)*, Project Management Institute, America.

Rahman, M. M. and Kumaraswamy, M. M. (2002) Risk management trends in the construction industry: moving towards joint risk management, *Engineering, Construction and Architectural Management,* 9(2): 131-151.

Thompson, P.A. and Perry, J.G., eds (1992) *Engineering Construction Risks – A Guide to project Risk Analysis and Risk Management,* Thomas Telford, London.

Tilley, P. (2000) Design and documentation quality survey – Comparison of Designers and Contractors, CSIRO internal report.