Building on an old landfill: design and construction

Construire sur une ancienne décharge : dimensionnement et exécution des travaux

McIntosh G.W.
Douglas Partners Pty Ltd, Unanderra, NSW, Australia

Barthelmess A.J.
Consulting Engineer, Wollongong, NSW, Australia

ABSTRACT: The Fo Guang Shan Nan Tien Buddhist Order commissioned the first stage of site investigations of the proposed Nan Tien Institute site at Unanderra, NSW Australia in 2000. Wollongong City Council donated the land which includes an old landfill. The site is located directly opposite the Nan Tien Buddhist Temple which opened in 1995 and is the largest Buddhist Temple in the southern hemisphere. The Institute is being developed in accordance with a masterplan which will ultimately cater for 3000 students and 360 staff. Geotechnical and environmental investigations have been undertaken to determine the extent of the remedial works that will be required for site development. The landfill (which closed in 1984), is some 5.7 ha in plan area and occupies nearly 50% of the total institute site. The results of the investigations have enabled geotechnical, environmental and civil design works to be completed for the initial stage of construction (the ground consolidation works) which were completed in March 2011. Stage 1 building works commenced in November 2012. Given within this paper are the investigation results, design overview and monitoring results (noise, odour, vibration, landfill gas and consolidation). Where relevant, comparison is given to predicted values.

RÉSUMÉ : L'Ordre Buddhist Fo Guang Shan Nan Tien confia l'étude géotechnique du future Institut Nan Tien, situé a Unanderra en Nouvelle-Galles du Sud en Australie, en 2000. La mairie de la ville de Wollongong a légué un terrain qui comprend une décharge qui occupe 5.7 ha, soit presque la moitié du site. La décharge a fermé en 1984. Le site se trouve en face du temple Buddhist Nan Tien, inauguré en 1995, le plus grand temple Buddhist de l'hémisphere sud. Le nouvel institut accueillera 3000 étudiants et 360 employés. Des études géotechniques et environmentales ont été menées avec pour but de déterminer l'ampleur des travaux de réhabilitation du site. Les résutats ont permis le dimensionnement géotechnique, environmental et civil pour la premiere phase de construction du projet, qui incluait la consolidation des sols entreprise en mars 2011. La construction des bâtiments a débuté en 2012. Ce document présente les résultats de l'étude, un apercu du dimensionnement et les résultats de surveillance (bruit, odeur, vibration, gas et consolidation des sols). Certains resultats sont comparés aux prédictions

KEYWORDS: landfill, dynamic compaction, methane drainage, leachate control, monitoring.

1 INTRODUCTION.

In September 2001, Wollongong City Council donated a 12 ha parcel of land at Unanderra to the Fo Guang Shan Nan Tien Buddhist Order on which is planned the Nan Tien Institute and Art Gallery. The site is opposite the existing Nan Tien Temple at Unanderra, NSW which was opened in 1995 and is the largest Buddhist Temple in the southern hemisphere. About half the Institute site includes a derelict (puticible waste) landfill which was operated by Wollongong Council up until its closure in 1984.

Geotechnical and environmental investigations have been ongoing since early 2000 with the overall masterplan of the site finalised in 2009. The project architects were commissioned to produce an environmentally sustainable design with development of the site to be undertaken in stages. Stage 1 works include the Cultural Museum, some limited teaching facilities and car parking areas.

Discussed within this paper are details on the geotechnical and environmental investigations, civil design, leachate collection and control, earthworks (including dynamic compaction results achieved during ground consolidation works completed in March 2011), the use of coal washery rejects as a fill source and environmental monitoring undertaken during earthworks (air, noise, dust, odour, landfill gas and vibration). Discussion is also given on foundation systems and gas drainage options that will need to be developed within the design of the future buildings.

2 BACKGROUND.

The existing Nan Tien Temple and the proposed Institute site are located on either side of the F6 freeway at Unanderra, NSW (refer Figure 1). The overall site area is around 15 ha with the derelict landfill occupying about half of the total site area. The main challenge to development of the site is primarily two fold – firstly, the assessment of both short-term and long term consolidation of the waste and then the design of buildings and civil works that can withstand the settlement estimates and secondly, the design of a system that will enable collection, treatment and discharge of landfill gases (of which methane is the biggest concern) and leachate in a safe and environmentally acceptable way over the life of the buildings.

3 THE PROJECT

The proposed Nan Tien Institute is being developed in accordance with a Masterplan which will ultimately cater for 3000 students and 360 staff. It will be a mixed use development comprising formal educational facilities, an art gallery, museum and other cultural facilities. The overall budget for Stage 1 of the project (including remediation of the landfill) is around $30 million AUD. Whilst architectural design is a work in progress, the first stage of the Institute will generally occur over several levels on the site, with basement carparking on the lower levels, then teaching and related facilities to a viewing platform at the higher locations on the site.

4 SITE INVESTIGATION AND RESULTS

4.1 *Geotechnical*

Investigations to establish a geotechnical model of the site included 103 test pits to depths of up to 5 m, 14 cored boreholes to depths of up to 12 m and the installation of 8 standpipe piezometers. In summary, the natural geological profile of the site comprised topsoil over residual clays with latite and sandstone bedrock (generally of medium to high strength) below depths of 1 – 1.5 m. The profile of the landfill included a coal washery rejects (CWR) and clay capping layer some 0.5 – 3.5 m in thickness (but generally less than 1 m) with the depth of the waste in the order of 4 – 12 m.

The landfill waste was interbedded with CWR and clays, as was expected given the conventional operation of a putrescible waste facility. The density of the landfill was generally loose with some denser sections as reflected by standard penetration test "N" values in the range 2 – 30. Perched water tables were also present. The extent of the landfill is shown in Figure 1.

Figure 1. Extent of landfill.

4.2 *Environmental (soil, water, air, noise)*

180 test locations were investigated across the site, most of which were in the landfill footprint. Contaminant concentrations were compared to the NSW DECC (2006) Health based Investigation levels. Within the soils, elevated levels of manganese and hydrocarbon (C10 – C36) were recorded. Testing of groundwater indicated elevated levels of iron, manganese, ammonia, nitrate and total phosphorus, typical of levels and contaminants found in landfill leachate. Methane, hydrogen sulphate and carbon dioxide were recorded in the gas monitoring wells with the methane levels within either the "explosive" range or exceeding the "explosive limits" and in a range that may cause asphyxiation.

In the areas outside the landfill footprint, no environmental concerns were recorded apart from random dumping of uncontrolled fill which was managed by conventional construction practices.

5 GROUND CONSOLIDATION WORKS

Site preparation was completed in March 2011 and included construction of a temporary leachate collection system, reshaping and benching of most of the site, dynamically compacting the landfill and undertaking of controlled earthworks to achieve design levels. Monitoring of air quality, noise, vibration levels and leachate was ongoing during the works.

5.1 *Civil Design and Leachate Control*

During initial site works, the expectation was that a relatively significant quantity of leachate would discharge from the landfill cell which would reduce after dynamic compaction. The reduced quantities were expected to be treated and managed long term by a membrane bio-reactor (prior to discharge off site or re-use on site). As the bio-reactor could not be sized to cater for the high loads during site preparation works, a 2ML leachate pond was constructed downslope of the landfill cell. Leachate was fed into the pond via a 2 m groundwater cut-off trench installed around the toe and flanks of the landfill cell. Once in the pond, leachate was then pumped through a treatment system consisting of pumps, sand filters, activated carbon filters and an automatic sampler prior to discharge into the sewer system via a Trade Waste Agreement with Sydney Water.

The leachate pond was designed to not only suit its purpose during dynamic compaction and site preparation (i.e. as a leachate pond), but to also double as an on-site detention (OSD) pond during the life of the Institute. This OSD pond assists with long-term management of stormwater on the site. The HDPE liner installed in the leachate pond during dynamic compaction was removed and the pond readily transformed for the OSD purpose. This saved having to build two very similar structures twice.

5.2 *Dynamic Compaction*

In order to improve the density of the landfill (and thus to improve longer term performance by limiting primary compression and secondary consolidation following progressive waste decomposition), dynamic compaction was selected as the appropriate method. The equipment (shown in Figure 2) included a 120 tonne crawler crane dropping a 25 tonne pounder from a height of (nominally) 20 m. Compaction was carried out in two phases. Following placement of a coarse "compaction layer" to provide stability for the crane, the primary phase comprised multiple drops of the concrete pounder (typically 3 – 4) on a 6 m x 6 m grid with the craters backfilled as the compaction proceeded. The final (or ironing) phase was carried out using a pounder of similar mass but a larger footprint (5 – 9 m2) with a drop height adjusted to the pounder size and compression achieved.

Using the methods of Hausmann (1990), an assessment was made of the degree of ground improvement with surface settlements of generally 1 – 2 m expected in the areas underlain by the deeper landfill. The survey results following completion of dynamic compaction and were predominantly within the range 0.5 – 1.5 m, in line with expectations and generally 10 – 12% of overall landfill depth.

Figure 2. Dynamic Compaction Equipment.

Following backfilling of the craters, earthworks were undertaken to reshape the surface of the various benches after which conventional fill placement was carried out to achieve design levels. In areas, this required the placement of up to 2 m of compacted fill which was placed under Level 1 geotechnical control to the requirements of Australian Standard AS3798 – 1996. As a result of the success of the dynamic compaction phase (which provided a solid base), the undertaking of additional earthworks was relatively straightforward with a compaction requirement of 100% of standard maximum dry density achieved in all fill areas. Fill materials included the use of coal washery rejects, a mining by-product from the coal washing process that is obtained at low cost (typical transport only) but has very good civil engineering properties for use as general fill and no negative environmental impacts.

5.3 *Site Monitoring*

Construction works for the ground consolidation contract were undertaken in accordance with a Construction Environment Management Plan (CEMP). The key objective of the CEMP was to develop a monitory programme for regulatory compliance and early detection of any significant environmental or community impacts.

Given the potential impacts due to dynamic compaction being carried out on the site and the presence of buildings on neighbouring properties, vibration trials were undertaken prior to commencement of compaction. An attenuation graph was prepared as shown in Figure 4 with a boundary buffer distance of 25 m nominated for a proposed vibration limit of 8 mm/sec (sector sum and component peak particle velocity). Texcel Vibration Monitors were installed for continuous data recording (one of which was in a neighbouring building) and adopting the buffer distances established by the trial, only nine exceedances were recorded during the 6 month construction period. No complaints were received from neighbouring properties.

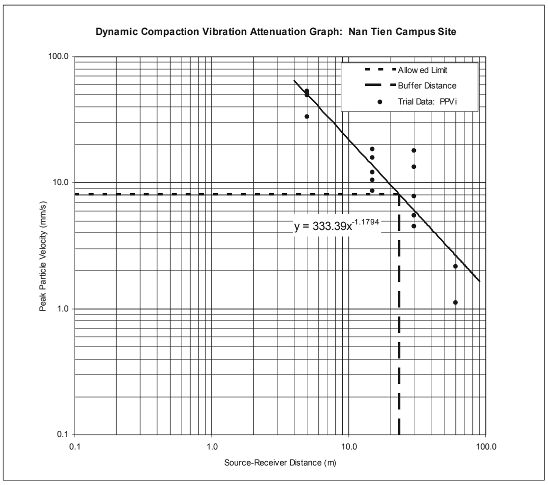

Figure 4: Dynamic Compaction Vibration Attenuation Graph

Whilst noise was considered to be the other major environmental impact that could cause community concern during compaction activities, monitoring over the 6 month period recorded a total of only 32 readings above the performance criteria of 75 dBA. Odour was primarily of concern during the initial excavation phase and was managed by minimising waste exposure time. Similarly, dust was managed by the implementation of good construction practices on site. Leachate and groundwater was monitored regularly with all outflow to the pre-determined requirements. Whilst results were typical of those expected from a landfill site, manganese and ammonia were flagged as elements of concern.

The obvious area of concern in all landfill projects is landfill gas (LFG). Methane, carbon dioxide and oxygen levels were monitored both inside and outside the landfill boundary as well as within site buildings. Daily monitory of landfill was undertaken using a GA2000 Gas Meter. Both surface and well measurements were taken as well as barometric pressure and lower explosive limit. Peak methane levels of up to 97% were recorded in wells in the landfill footprint, with levels generally in the range of 14 – 50%. Monitoring in wells adjacent to the landfill boundary was generally below threshold levels or 0% methane. Surface and enclosed space monitoring showed that LFG was not considered to be an issue at any time during the works.]

6 FUTURE WORKS AND BUILDING DESIGN

6.1 *Civil works, services and stormwater drainage*

All civil and building services (eg sewer, water, stormwater, electrical, gas) have been designed such that they will not need to penetrate the capping layer of the landfill. All service trenches and other works that require excavation (eg landscaping) will be within 'clean' material and limited to excavation depths of 2m. Earthworks associated with site reshaping will require construction of retaining walls up to 7m high. The walls have been designed as reinforced earth structures able to accommodate ground settlements of 300mm.

6.2 *Foundations*

The main advantage of dynamically compacting the landfill is that long term settlement of the landfill (post building construction) will be significantly reduced, but not eliminated (Thom 1998). As such, footing design for buildings located within the landfill footprint will be for driven steel piles founding in the underlying latite bedrock. Flexible aprons will be needed between the buildings (which will experience negligible settlement) and adjoining carparks, walkways and recreation areas (which will experience ongoing settlement). Whilst raft slabs may be feasible for some lightweight single story buildings, preliminary analysis has indicated that a 1 m thick reinforced earth raft will be needed to provide uniform bearing and to equalise the longer term settlements so that differential movements will be within acceptable limits.

6.3 *Leachate Control and Gas Drainage*

Leachate collection drains will be installed across the site and directed to the leachate treatment system. The current options for leachate collection include disposal to sewer, reinjection, spray or drip irrigation, removal by contractor, ammonia stripping, constructed wet lands and membrane bio reactor.

The primary elements of the environmental design are capping profile, methane drainage and leachate control. The requirement of the site capping is twofold; firstly – physical separation by covering contaminated materials and secondly – prevention of infiltration to the substrate, thereby minimising leachate recharge and mobilisation and upward migration of methane. Historically landfill capping systems have included a 0.5 m clay cap however this system alone was not considered intrinsically safe at this site in areas underneath buildings or pavements where piles will breach the cap and gas can accumulate in enclosed spaces.

The preliminary design for the capping consists of HDPE, GCL, geotextile fabric, 300 mm gravel gas drainage layer and a reinforcing geotextile, underlain by the existing waste, refer to Figure 5 below. Undercrofts will be constructed where possible to allow for suspension of services and cross-ventilation. In areas outside of the buildings an additional 1 m layer of clean fill material to further protect the cap from stormwater and root infiltration, drying out, cracking and accidental breaches will be installed. The preliminary design requires the landfill cap to extent 50 m beyond the landfill boundary or the site boundary whichever occurs first. At the landfill boundary within the site, the capping will be keyed in with a sump installed for leachate and landfill gas condensate collection.

Where the landfill extends over the site boundary a bentonite plug will be installed at the boundary to minimise migration of landfill gases through soils, refer to Figure 6.

Landfill gas drainage will consist of a gas drainage layer forming part of the cap. Collection pipes will be placed around the perimeter and across the benches with a maximum spacing of 50 m. An additional gas extraction filter layer and pipe work for the collection and discharge of LFG will be incorporated beneath the slab of all buildings where possible. Three remedial options for the management landfill gas were considered. The use of landfill gas for power generation was not considered feasible due to low gas flows as result of the age and stage of the decomposition of the waste present at the site this option

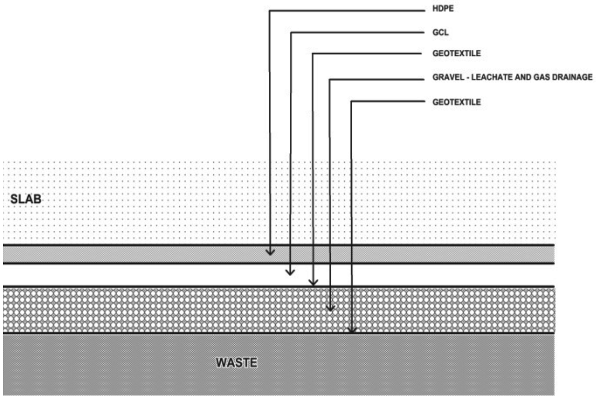

Figure 5: Preliminary design of cap for slab on ground

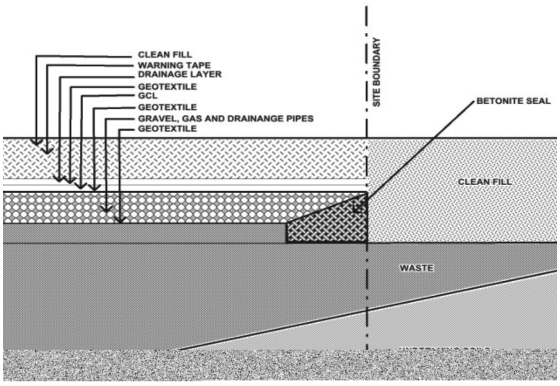

Figure 6: Preliminary design of cap at site boundary

Flaring of the gas, with ignition of the gas as it leaves the site was considered, given its advantage of reducing the landfill gas to a higher percentage of CO_2 and H_2O vapour, however the technical difficulties of operating the flare, the area required for a flare plant and the cost of setting up and maintenance of the plant, among others, far outweighed the advantages. The final remedial option, venting to the atmosphere, was chosen for the zero requirements for a specific treatment plant and operating costs. As such the preliminary design consists of the placement of turbine ventilator stacks around the site. Landfill gas discharge will occur through stacks that will extend 1 m above the proposed maximum building roof level across the site. To monitor the landfill gas and minimise the potential of migration off-site a series of monitoring wells will be installed.

7 LESSONS LEARNT DURING CONSTRUCTION

Of particular interest to those wanting to apply the techniques described in this paper for another site or project, are the lessons learnt during the construction of this project. Primarily, these are as follows:

1. The site was located within 50m of a main highway. A hazard was ‘fly rock’ being mobilized during dynamic compaction and hitting operators or leaving the site and colliding with a vehicle on the highway. To control this hazard, a no-go zone was established around the dynamic compaction rig and the rig was not allowed to operate near the highway.
2. The extent of consolidation during dynamic compaction was significant. At this site, the contaminated water make during dynamic compaction was also significant. Whilst this was predicted and readily catered for onsite (in accordance with the CEMP) it took a considerable amount of time to manage, sample for contamination and then subsequently discharge at an appropriate location. It was also relatively expensive.
3. The use of coal washery rejects, a mining by-product from the coal washing process, was entirely successful. This material was put to use on this site and would otherwise have ended up as landfill. The ability to use what would otherwise have been waste material, as fill material in the overall remediation of another landfill site, is considered best practice and an outstanding outcome environmentally.
4. The selection of an earthworks contractor must include an assessment of their ability to perform the work rapidly. Exposing the waste sections of the site created many hazards, and the contractors ability to perform the work and ‘cap’ the site ready for dynamic compaction in the shortest possible timeframe greatly reduces the exposure to those hazards and any expensive delays caused by (for example) inclement weather.

8 CONCLUSION

The use of dynamic compaction and construction of a landfill gas drainage system together with innovative civil solutions will allow the Fo Guang Shan Nan Tien Buddhist Order to develop their site and create a teaching and cultural facility as part of the existing Nan Tien Temple. Geotechnical and environmental performance was monitored during site preparation works and will be monitored during building construction.

9 ACKNOWLEDGEMENTS

The authors acknowledge the Fo Guang Shan Nan Tien Buddhist Order and affiliates for assistance in the project and their permission to use project specific data for this paper.

10 REFERENCES

Standards Australia. 1993. Determination of the penetration resistance of a soil – Standard Penetration Test. *Australian Standard AS 1289* 6.3.1 – 1993.

Standards Australia. 1996. Guidelines on earthworks for commercial and residential developments. *Australian Standard AS 3798 – 1997*.

Hausmann, M.R. 1990. Engineering Principals of Ground Modification. *McGraw Hill*.

Thom, M.J. 1998. The long term settlement behaviour of waste and its effect on future development. *3rd National Hazardous and Solid Waste Convention.*

Department of Environment and Conservation NSW. 2006. Guidelines for the NSW Site Auditor Scheme. *2nd Edition.*