Advances in Design of Landfills over CCR Ponds and CCR Landfills

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ABSTRACT

The rules for coal combustion residual (CCR) disposal that were proposed by the U.S. EPA in June 2010 will require decommissioning of existing ash ponds and development of new CCR disposal areas with liner systems. Because CCR disposal facilities are large and are time-consuming to design and permit, it may not be feasible for some plants to find a suitable new site and develop it in time to comply with the proposed rules. An alternative to siting a new landfill is to develop additional disposal capacity at existing CCR ponds and landfills by extending them vertically, constructing the liner system over the existing pond or landfill. Technical challenges in this approach include stabilizing the existing CCR material, accommodating the settlement of the liner, and providing a high degree of reliability against slope stability failure. In the past several years, the authors have developed and implemented a design approach at several sites that addresses these technical challenges.

The goal of this paper is to illustrate the conditions under which such facilities could feasibly be expanded vertically or laterally. Recent case histories are presented to meet this goal. In addition, general conclusions and recommendations for designing expansions over CCR facilities will be provided based on the authors' experience.

CURRENT STATE OF THE PRACTICE

The state of the practice of CCR disposal facility management is only recently becoming clearer. The United States Department of Energy (DOE) and United States Environmental Protection Agency (USEPA) published a report in August 2006[1] that represented an early step in defining the state of the practice. In the report, DOE and USEPA report the findings of surveys of recent CCR industry disposal practices, comment on State requirements for CCR management, and discuss the degree of implementation of State requirements for sites that received permits during the period 1994-2004. The report indicates that there is no actual data on the total number of CCR landfills or CCR surface impoundments in the United States. More recently, the General Accounting Office[2] (GAO) reported on CCR landfill and surface impoundment statistics in its report to Congress following the TVA failure at Kingston, Tennessee; the report provides results of survey information of all utilities on ponds and landfills, focusing on slope stability and the potential for significant impacts in the event of a stability failure of these facilities.

Key findings of the reports related to the state of the practice of CRR disposal facility design include the following.

- The reports indicate that nearly all facilities permitted between 1994 and 2004 were designed with liner systems and leachate management systems. However, the report is based on surveys provided by owners and operators of only 45 disposal units; although estimated by DOE and USEPA to represent almost two-thirds of the total number of new permits issued during the report period and over 70 percent of the generating capacity of units seeking new disposal permits during that period (i.e., 1994-2004), this represents a very small sample of the total number of CCR waste management units.
- The GAO report indicates that there are over 580 CCR surface impoundments in the United States [2]. Only 16 surface impoundments were considered in the DOE/USEPA study, meaning that hundreds of surface impoundments (many of them very large) were not considered.
- The two reports provide a reasonable overview of the state of current practice in CCR disposal facility permitting, but not operations at CCR disposal facilities or their potential for vertical expansion.

Based on this information, it is possible that hundreds of existing CCR landfills and CCR surface impoundments are candidates for vertical expansion or lateral expansion. It is also possible that lack of data on the general characteristics of CCR landfills and surface impoundments, and lack of a state-of-the-practice design method for expanding these facilities, could be limiting owners and operators from designing expansions to these facilities.

The goal of this paper is to illustrate the conditions under which such facilities could feasibly be expanded vertically or laterally.

KEY DESIGN PHASE ISSUES

Development over an existing CCR disposal facility requires planning and collection of data for assessment of several key design issues that are particular to filling over a CCR landfill or pond. In this section, the key design phase issues are identified and discussed.

A. Foundation Stability

Designing an overfill landfill at a CCR landfill or pond site requires a thorough characterization of the CCR material and an understanding of the unique response of CCR materials to loads. Assessing foundation stability at CCR landfills over ponds requires analyses of both time-dependent settlement and drainage (which can be large in CCR fills, especially differential settlement) and slope stability (which depends on an accurate estimate of the CCR strength under load). These two issues are addressed below.

1. Settlement

Settlement predictions for CCR fills are, like most soils, sensitive to the material properties of the CCR fill. In several respects, the behavior of CCRs is in-between that of clay and sand. Estimating CCR settlement assuming that the material will behave as a clayey soil can lead to overestimates of foundation settlement. In the author's experience, laboratory and field data suggest that, for typical landfill loads, CCR settlement can be expected to be on the order of 10 percent or less of the waste thickness depending upon the ash and subgrade properties. Therefore, understanding settlement is critical to designing the liner and leachate collection systems to accommodate differential settlement.

Because of the non-cohesive nature of many CCR materials, conventional field sampling and testing may not be sufficient to obtain samples for laboratory testing; for example in some CCR fills, the material may be too loose to obtain nominally undisturbed samples for laboratory testing. While testing using remolded samples can be used, as an alternative, field testing methods can be used to estimate material parameters that are needed for design. One approach involves using a monitored preload fill (MPF) to calibrate the settlement calculations and to confirm the reasonableness of the predicted design settlements. As an example, for one site recently evaluated by the authors (see Figure 1), the height of the MPF was one-third of the depth of waste and the minimum width of the MPF was three times the depth of the waste. The MPF was instrumented using settlement plates and a horizontal settlement "profiler" measuring system.

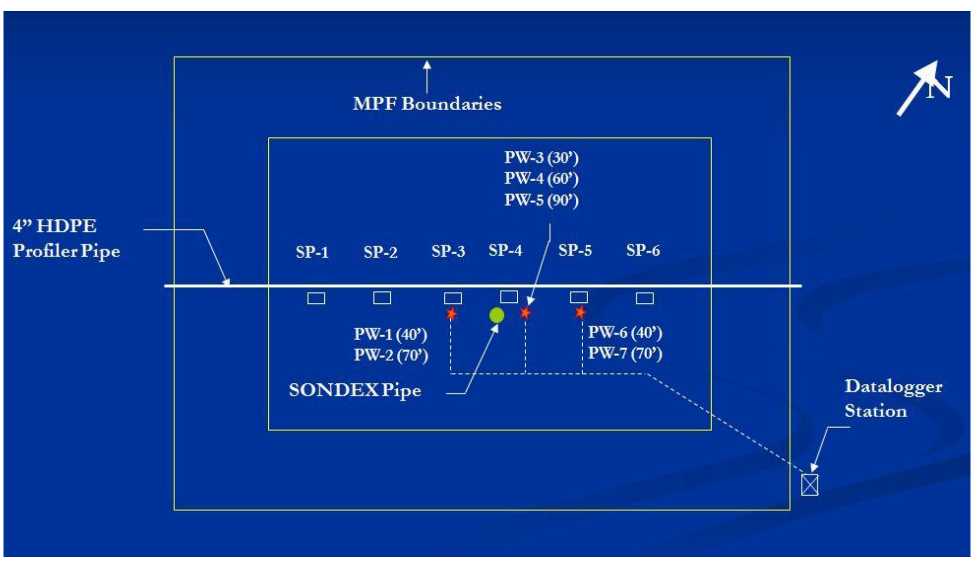

Figure 1: Ash Landfill Monitored Preload Fill Layout

The settlement monitoring of the MPF (see **Figure 2)** showed the design predictions to be reasonably accurate and appropriate for design.

Figure 2a: Settlement "Profiler" System Installation

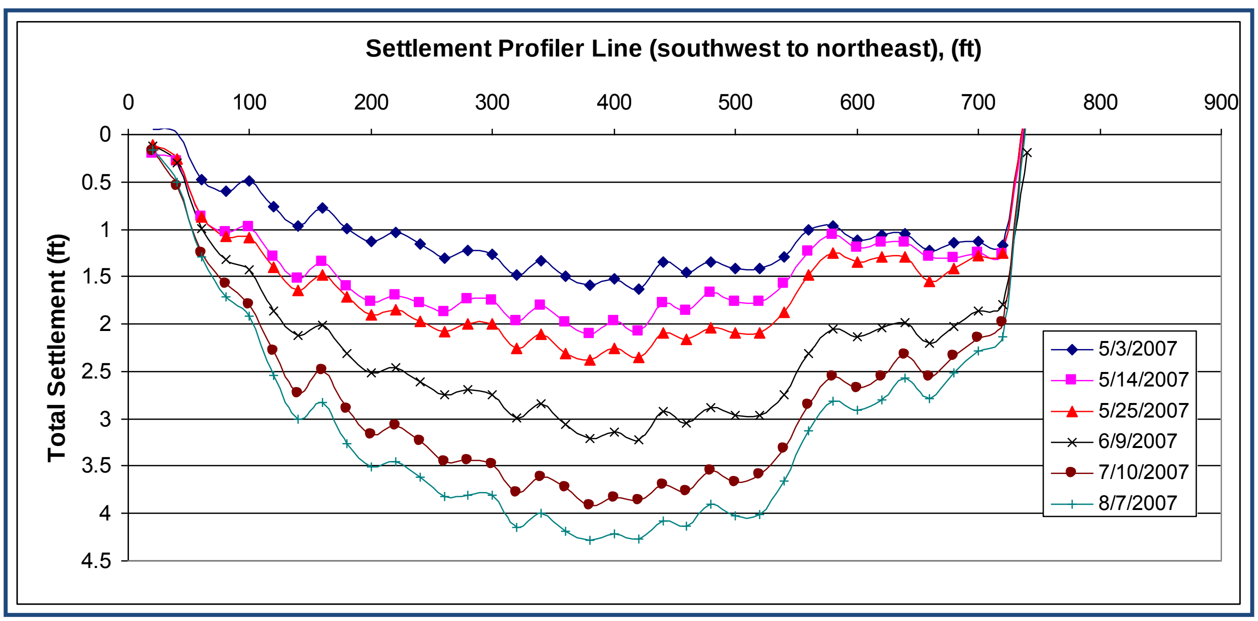

Figure 2b: Settlement Profiler Monitoring Results

The results also indicated that loading-induced excess pore pressures dissipated to a level consistent with hydrostatic pressures within 5 to 10 days after application of each successive load at all depths, as shown in **Figure 3.** This result was very important for the stability analyses because it demonstrated that, although fine grained, the fly ash drained relatively rapidly, suggesting that the pore pressures would also dissipate during landfill construction and waste filling, reducing the potential for both liquefaction and slope instability.

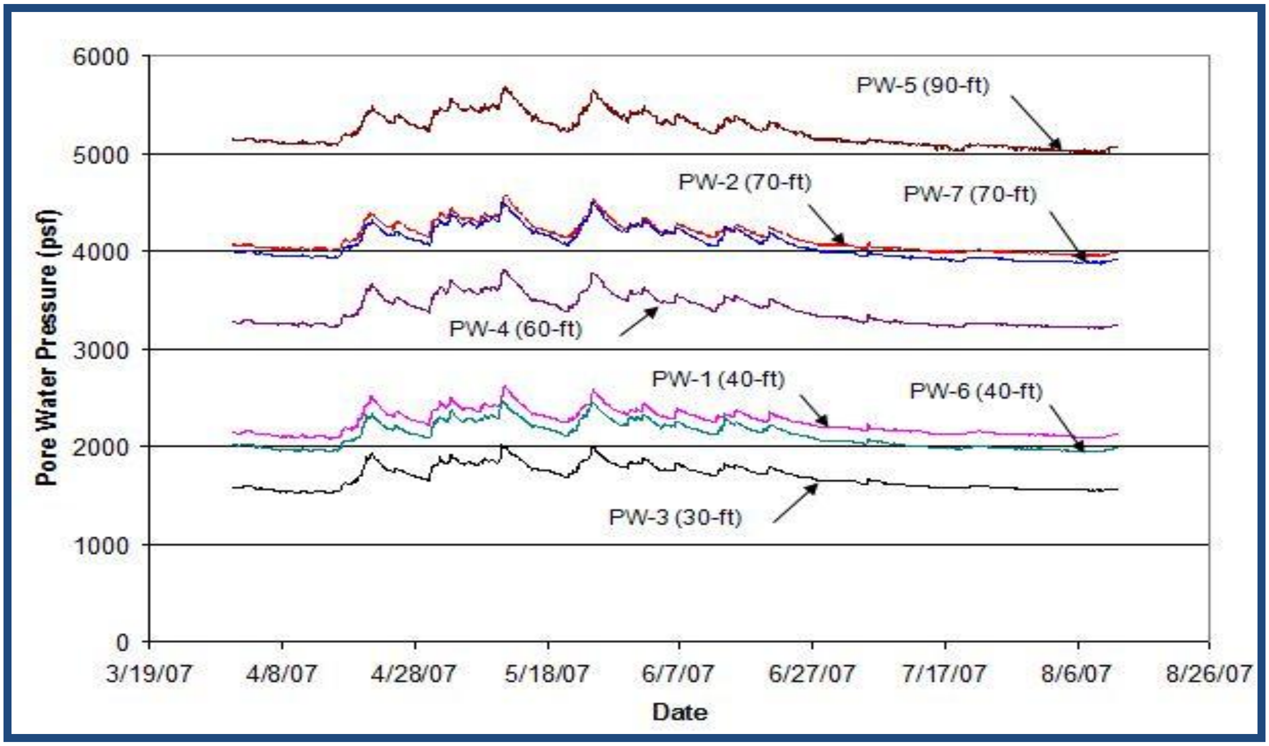

Figure 3: Fly Ash Subgrade Pore Pressure Response to Loading by a Monitored Preload Fill

Although the settlement of the CCR material is an obvious focal point in the settlement analysis, analysis of the settlement of the soils below the CCR is equally important. CCR ponds are commonly located in valleys that are dammed at the downstream end to create a pond, where the native soils below the fly ash may be thick and compressible, possibly more compressible than the fly ash itself. Also, the subgrade of the fly ash pond might not have been designed for the loads imposed by an overlying structure and the specific subgrade soils. Therefore, design of the subgrade beneath the new CCR facility under the future loading condition is important to the performance of the CCR overfills.

2. Slope Stability

Analysis of slope stability is critical to the design of any landfill. Because fly ash is typical of materials that are susceptible to liquefaction (i.e., uniform, non-cohesive, and saturated), CCR fills containing fly ash are susceptible to liquefaction during design seismic events. Therefore, stability analyses that consider the potential for CCR liquefaction are especially important for overfills at CCR landfills and ponds. The following presents current landfill design approaches to address liquefaction of a CCR subgrade that contains fly ash.

Seismic Liquefaction

Seismic liquefaction of soil is relatively well-understood; however, it has only been relatively recent that it has been necessary to understand liquefaction of fly ash in ponds.

The authors have used versions of the Seed[3] simplified approach to evaluate seismic liquefaction of fly ash. Invariably, this method will demonstrate that most fly ash materials in ponds (e.g., "weight-of-hammer" material) would be expected to undergo liquefaction; however, to our knowledge, there is no documented case history of seismically-induced liquefaction of fly ash in the literature. The method is appropriate for fly ash for a preliminary evaluation because the texture of fly ash is similar to a sand-silt mixture. However, it is recommended that laboratory tests with cyclic loading (i.e., triaxial or direct simple shear) be conducted to more accurately assess the potential for liquefaction of fly ash.

Liquefaction has been found to be a concern at landfills over fly ash placed in ponds. If the stability analyses indicate that liquefaction can occur, then mitigation measures would be required to control the effects of liquefaction and/or the response of the landfill structure to seismic liquefaction. Methods for mitigating seismic liquefaction include:

- Construction of a toe berm (soil embankment) or buttress beyond the edge of the landfill to maintain confinement of the subgrade;
- Installation of a shear key at the edge of the landfill to resist the lateral movements below the edge of the landfill;
- Performing a preload fill program to promote consolidation and reduce liquefaction potential or reduce the effects of liquefaction, should it occur; and
- Foundation improvements such as deep soil mixing and solidification to improve the subgrade.

Mitigation measures for liquefaction can be expensive, and the suitability of the site may depend on the feasibility of such measures. Consequently, the liquefaction analysis must be completed after the preliminary site investigation to identify, early in the design process, whether or not mitigation measures will be needed to prevent liquefaction-induced damage or instability. It is the authors' opinion, however, that additional study is needed of the potential for liquefaction using laboratory cyclic triaxial and/or direct simple shear tests and that the results of these studies should be correlated to the specific project seismic setting. Such programs are currently being implemented, with preliminary data suggesting that the risk of seismically-induced liquefaction that were not based on data obtained using cyclic triaxial shear or direct simple shear strength tests may be overestimated.

Static liquefaction

Static liquefaction was a topic of concern after the TVA Kingston containment berm failure. Static liquefaction may occur as a result of relatively rapid loading of subgrade soils that causes strain-induced excess pore pressures that cannot be adequately dissipated, resulting in a bearing-capacity type failure.

Field and laboratory data may be obtained to evaluate the rate of pore-pressure dissipation to verify whether the expected load applied to the subgrade by filling of the landfill can be dissipated quickly enough to prevent a static liquefaction failure. This assessment must take into account minimum cell size, waste generation/placement rate, the drainage characteristics of the fly ash, and whether an overlying drainage layer is used. Static liquefaction can be effectively addressed during design.

B. Leachate Collection System

Leachate collection systems (LCS) at CCR overfills require careful design to provide for continued drainage of leachate from the lined area through the operating life of the landfill. Of the many design issues that are critical to the long-term performance of the LCS, a key emerging issue is design of the LCS to prevent clogging by fine-grained CCR material. To prevent clogging, landfill LCS layers are typically overlain by a geotextile filter layer, which must have a relatively small apparent opening size (AOS) to prevent the CCR material from passing through the geotextile. Large overburden pressures caused by the overlying CCR can reduce the effectiveness of a geotextile filter. To address these design challenges, it is recommended that the designer: (i) perform a particle-size analysis of the CCR material to confirm the properties of the material that the geotextile must retain; (ii) test the geotextile filter under the expected overburden pressures to assess its filtration properties; (iii) provide excess filtration layer surface area over/around the collection/drainage gravel as a contingency in case the geotextile filter experiences some clogging; and (iv) provide a method of cleaning out the leachate collection and transmission pipes should precipitates form or sediments accumulate that could reduce pipe conveyance capacity.

C. Performance Assessment of Existing CCR Landfill

Much of the discussion of the paper thus far has addressed development over fly ash ponds. However, development of new CCR disposal cells over existing CCR landfills and ponds also requires analysis of the performance of the existing landfill facility and the need to consider the existing landfill features such as leachate collection systems and bottom liners. For example, the structural competency of the leachate collection and transmission pipes in the existing landfill must be evaluated for their ability to resist crushing from the load applied by the CCR overfill. Further, the stability of the existing liner system and cover system should be examined considering the additional loads from a vertical expansion. This would include both global stability and interface stability analyses.

CASE HISTORY ONE: Vertical Expansion Over Closed CCR Pond

The first case history involves the construction of a CCR landfill vertical expansion over a closed 40-hectare, 33-m deep CCR (fly ash) pond. **Figure 4** shows a plan view of the pond and vertical expansion plan and **Figure 5** shows a representative transverse cross section of the pond and vertical expansion.

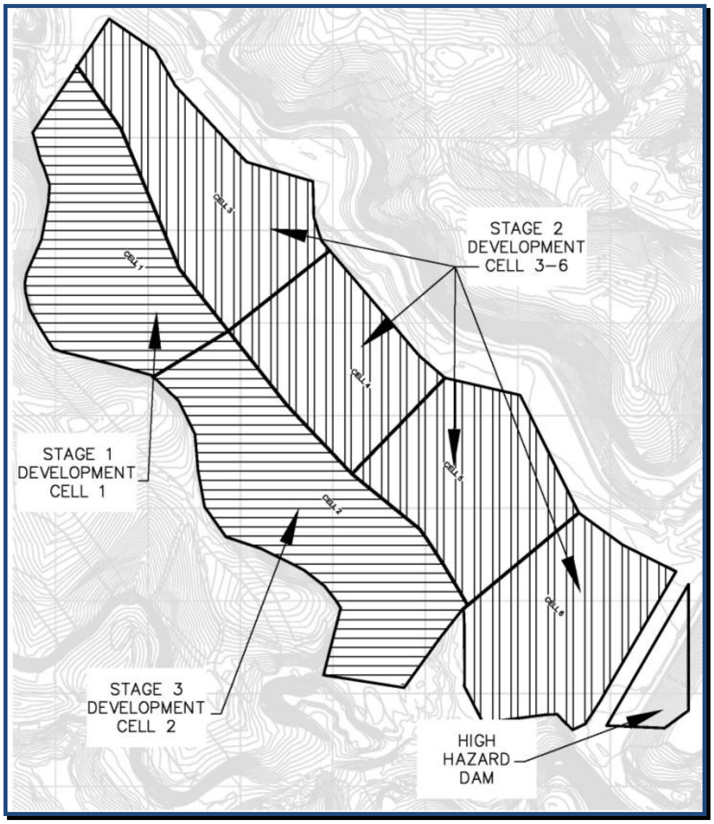

Figure 4: CCR Landfill Over A CCR Pond

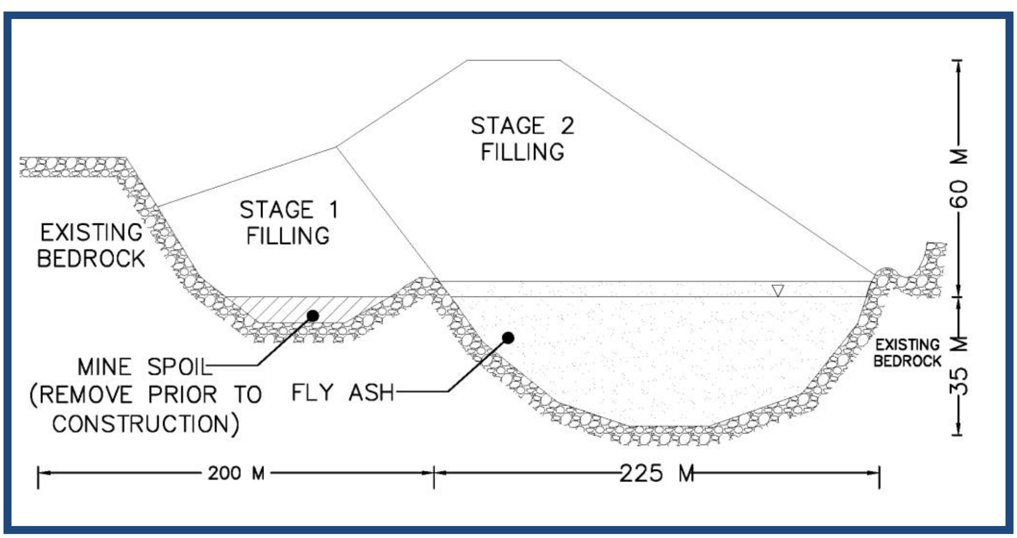

Figure 5: Representative Landfill Transverse Cross Section

The features that were relevant to the design of the landfill over the CCR pond included:

- A thick layer of fly ash in the existing landfill that was liquefiable and susceptible to significant differential settlement;
- Potential for development of excess pore pressures that could cause uplift of the liner system at the bottom and side slopes of the expansion;
- A long distance for transmission of leachate through collection and drainage system features;
- Mine spoil (uncontrolled fill) under about one quarter of the plan area of the existing CCR pond; and
- A high-hazard dam located at one end of the site.

The process of designing, permitting, and constructing the vertical expansion involved the following efforts that are unique to CCR fills over existing fly ash ponds.

Pre-Design Investigation. An extensive pre-design investigation was required to characterize the fly ash in the pond. The fly ash was investigated using disturbed and undisturbed sampling and analyses, and cone penetrometer tests with pore pressure measurement (CPTu) tests.

The mine spoil materials were investigated using geophysical and soil boring techniques; based on the results of these tests, it was determined that removal and replacement of most of the mine spoil materials was needed to provide a competent foundation for the overfill liner system.

Liquefaction Assessment. To address the potential for liquefaction, the facility was designed to confine the materials susceptible to liquefaction and to accommodate the predicted settlements. The confinement was provided by constructing a toe berm across the CCR-filled valley and to the dam to restrain movements and accommodate predicted settlements. In addition, to drain consolidation waters from below the liner system (i.e., over the CCR pond), a subsurface drainage layer was designed beneath the liner system. The layer was comprised of a minimum 0.6-m thick layer of bottom ash over most of the lined area. The bottom ash was readily available on site which reduced the cost and required quantity of granular materials over the remainder of the bottom. To mitigate pore pressure build up on side slopes granular material (sand) layer was installed (**Figure 6**);

Construction of Liner System Over Ash Pond. To construct the liner system, the water level in the ash pond had been lowered to approximately three meters below the preconstruction ash surface elevation. Then, to reduce post-construction settlement of the liner system, a preload was applied to the CCR to remove approximately 50 percent of the total predicted settlement before construction of the liner for each cell. The preload was implemented as a "moving" preload, in which the preload on the fist cell was applied and then removed and the removed preload was placed on the next cell, thereby reusing the preload material. Based on the analysis of settlement, the LCS was designed to accommodate the calculated differential settlement and the leachate drainage system was designed to route leachate to one side of the landfill by the shortest distance to the discharge line.

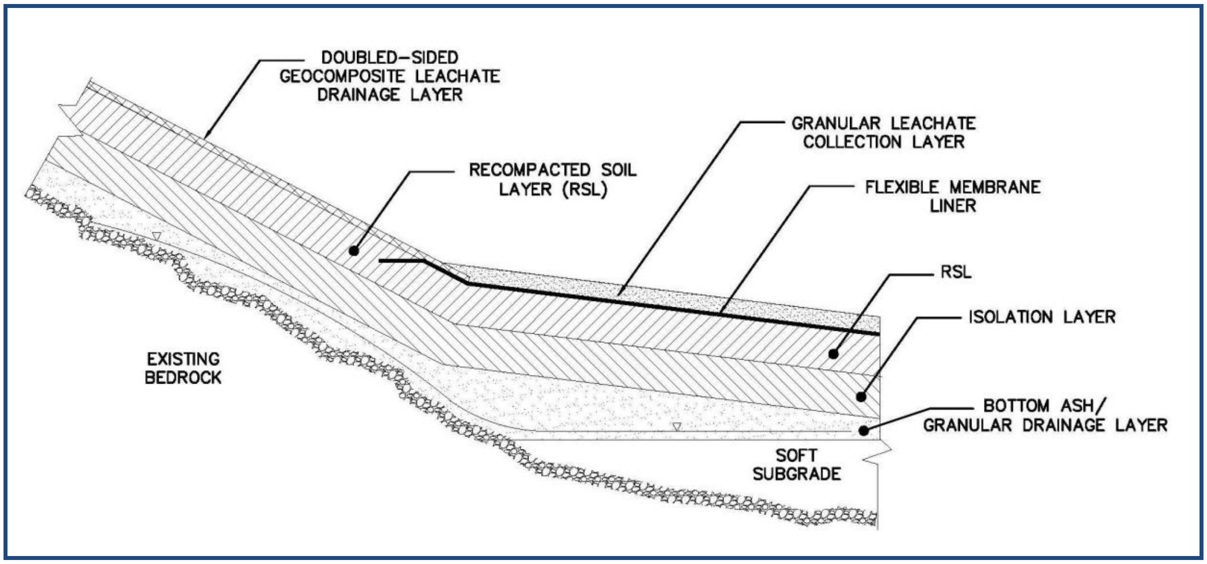

Figure 6: Drainage and Liner System Detail for Steep Side Slopes

The permit application was approved approximately 18 months after initiation of the preliminary site investigation. The Owner considered obtaining a permit in this short of a period of time a success because it was a unique site design that had not been previously approved by the regulatory agency and allowed receipt of CCR waste in accordance with the plant schedule.

CASE HISTORY TWO: Lateral Expansion and Overfill on CCR Landfill

The second case history is a vertical and lateral expansion design at an existing CCR landfill using reinforced soil slopes. The site had the following significant features:

- The existing CCR landfill cover had sides slopes at 2.5H:1V and had significant geometrical constraints to expanding vertically;
- The Owner required the flexibility to construct the expansion in small increments, both to reduce the capital cost for construction and the closure cost should the plant close before the landfill was filled to capacity; and
- Utilize the existing footprint as much as practical to reduce the amount of additional bottom liner construction.

To provide a vertical expansion given the geometry constraints of the project, a plan was developed having the following features.

Reinforced Soil Slope (RSS) for Volume Enhancement. A reinforced soil slope (RSS) was designed adjacent to the existing CCR waste (see **Figure 7**) to maximize the additional volume of the site and to keep the site improvements located entirely on site. As shown on **Figure 8**, the RSS has slopes as steep as 3V:1H and designed to be 12 m in height. The RSS provides substantial CCR disposal volume by providing overfill capacity that would not have existed without the RSS.

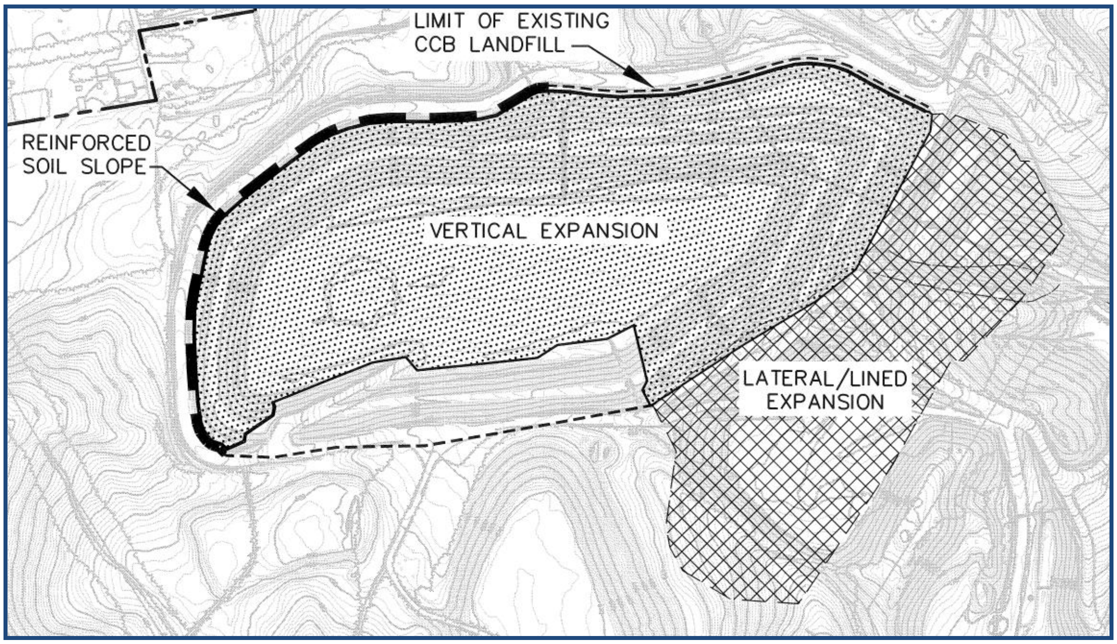

Figure 7: Site Plan of Case History Two

Phased Development for Capital Cost Distribution. After conducting a technical feasibility evaluation, an economic present-value analysis was conducted that examined the use of different methods to expand the landfill over a 20-year period. The final selected development plan included three phases, as described below.

<u>Phase I: Lateral Expansion</u>. The first phase of development (see **Figure 7**) involved construction of a lateral expansion of the landfill liner system including a leachate collection system and an groundwater underdrain system to increase the footprint size, allowing for additional vertical expansion over the existing landfill.

<u>Phase II: Construct Reinforced Soil Slope to Maximize Vertical Expansion Volume</u>. The second phase of development involved construction of the RSS (see **Figure 8)** at the southern perimeter of the existing footprint. It was possible to construct the RSS in segments to provide several small expansion areas, thereby limiting the potential for over development and distributing the development capital cost over a number of years.

Phase III: Overfill Existing CCR and RSS. The third phase of development involved placing additional CCR material vertically over the existing landfill. Because the overfill was located nearly entirely over existing CCR, the area requiring new liner system was limited to only the side slopes of the RSS.

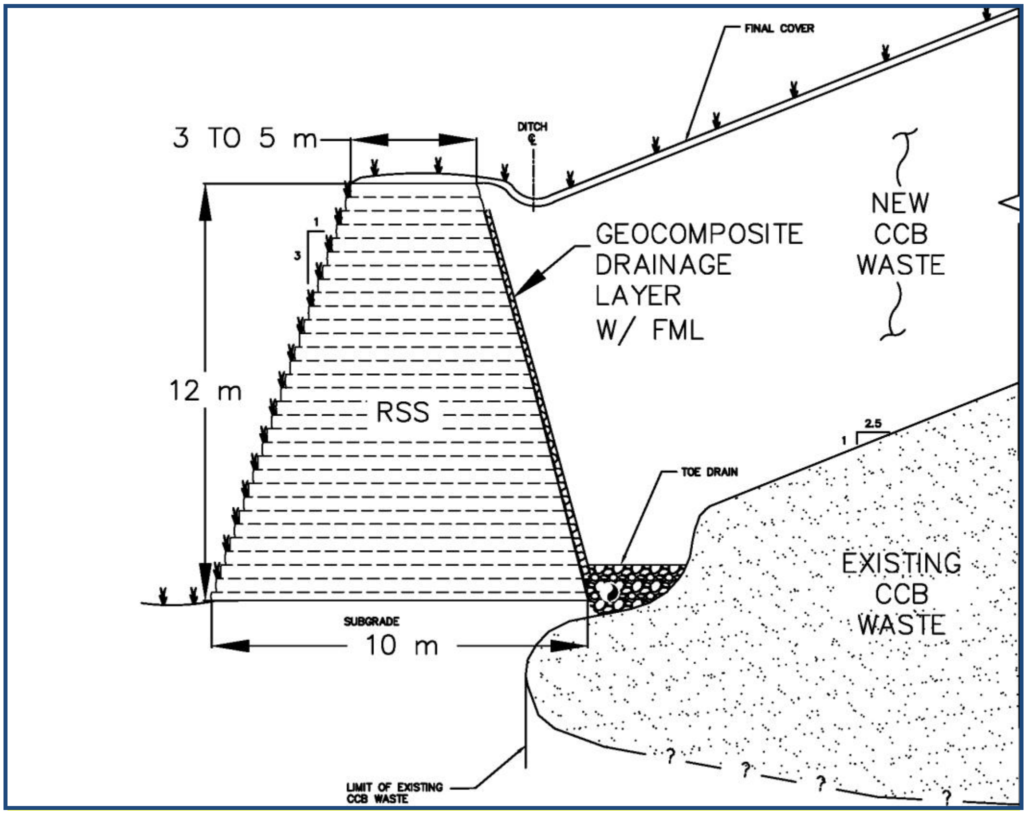

Figure 8: RSS Cross Section Case History Two

Flexibility in Event of Premature Closure. By constructing the expansion in stages, the Owner could build customized cells with varying disposal capacity, avoiding construction of additional capacity that might not be needed in the event of premature closure of the plant.

CONCLUSIONS

Valuable experience has been obtained by the authors in the design of new landfills over existing CCR ponds and landfills over the past seven years. This experience has lead to the following conclusions.

- Development over the top of an existing CCR pond and landfill is possible and has been completed successfully.
- The design should have investigation and testing data from multiple sources such as CPTu, nominally undisturbed samples (which are difficult to obtain) for laboratory testing, perhaps even using a monitored preload fill to confirm

calculated settlements and pore pressure dissipation, especially when developing over a CCR pond where it is difficult to obtain undisturbed samples.

- In the authors' experience, the time required to dissipate pore pressures in the CCR after filling can often be dissipated within the timeframe of normal operations of disposal facility.
- A CCR disposal facility can be designed to mitigate the effects of seismic and/or static liquefaction.

RECOMMENDATIONS

The following recommendations are provided for development of a new landfill over an existing CCR pond or landfill:

- Conduct a pre-design investigation to verify the CCR characteristics and their potential impact on design and assess the economic viability of the site.
- Site specific, field and laboratory characterizations of CCR materials are necessary for the engineering analyses to accurately predict settlement of the overfill liner system.
- Conduct site specific testing to evaluate liquefaction of CCRs.
- Develop a plan to manage groundwater and saturated CCRs below the landfill to avoid buildup of pore pressures that could lead to foundation instability.
- Conduct a thorough evaluation of the existing landfill leachate collection system and liner stability to verify that the LCS will can function under the increased pressures resulting from the overfill CCR materials.

SUMMARY

This paper summarizes issues involved in designing vertical expansions of CCR landfills and CCR ponds. Based on the information in this paper and the experience of the authors, vertical expansions over existing CCR landfills and ponds can be feasible depending on the nature of the CCR material and the site-specific geologic and geotechnical conditions. Design methods, and records of successful experience, are available on which to base the design and construction plans for vertical expansions at CCR landfills and ponds.

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