Geotechnical Considerations During Landfill Closure

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Opportunity

• Complete the closure of an existing MSW landfill
• Maximize beneficial re-use of stockpiled and imported processed dredge material (PDM)
Challenges

• Soft, weak foundation soils
• Insufficient geotechnical data
• Documented existing instability
• Aggressive closure schedule
Regional Setting

- Meadowlands Area – Bergen County, New Jersey
- Glacial deposits
  - Alluvial sands
  - Peat/organic silt
  - Varved glacial lake sediments
  - Glacial till
  - Bedrock
Site Location
Landfill

- Approximately 100 ft high with a 137 Ac footprint and a 90 Ac crest
- Surrounded by a soil bentonite vertical hydraulic barrier
- Adjacent critical infrastructure
  - Railroad tracks
  - Aqueduct
  - Electric transmission lines
  - Major gas mains
  - Adjacent buildings near the toe
Geotechnical Considerations

• MSW
  – Variable density, shear strength and age

• Organic Deposits
  – Soft, weak, discontinuous pockets

• Glacial lake sediments
  – Dominant geotechnical feature
  – 200 ft thick or more
  – Varved
  – Anisotropic response

• Hydraulic regimes
  – Natural soils
  – Landfill?
Landfill Development

• Actively received MSW from early 1980s – early 1990s
• Up to 25 feet of cumulative settlement
• During several expansions - lateral spreading, deep-seated lateral movements to EL -100 (200 ft deep) and chronic stability concerns
• Additional expansion was halted
• Side slopes incrementally closed and capped
• PDM placed on crest but not properly closed
Final Closure

• Limited to crest – sideslopes were previously capped
• 6” vegetative cover/18” clean soil cover/12” surficial processed dredge material (PDM)/12” low K (1x10-5 cm/sec) PDM/general grading fill
• Surface water management controls
• Four to 20 feet of new fill
• Nearly 400,000 CYD of new material
Preliminary Impressions

• MSW is inherently stable
• One groundwater regime
• All failure surfaces passed through the foundation (clay) soils
• Critical failure mode is block
Design Approach

• Conceptual grading plan
• Compile available regional geotechnical data
• Develop soil strength/response models
• Preliminary stability assessment
• Initiate site investigation at start of cap construction
• Additional stability analysis
• Develop observational method criteria
Stability Analysis Approach

• Select appropriate stability analysis
• Select the appropriate soil model
  – Foundation soils are varved, anisotropic
• Develop a field investigation and testing program to confirm soil properties
Soil Stability Approach

• Undrained strength analysis (USA) - C. Ladd, 1991
• Determine the *in situ* effective consolidation stress profile (consolidation tests and CPT)
• Estimate the existing compressive shear strength using SHANSEP
• Estimate the appropriate shear strength model(s)
Soil Stability Analysis

PSC: Plane Strain Compression
DSS: Direct Simple Shear
PSE: Plane Strain Extension

Varved clay

C. Ladd - 1987
Geotechnical Field Investigation

• Borings & instrumentation layout at crest based on observed or calculated stability performance
• Test borings: seven to depths of 190 to 440 feet
• Instrumentation
  – Inclinometers: seven from 190 to 430 feet
  – VW piezometers: seven 190 to 360 feet
  – Magnetic extensometers: four from 250 to 440 feet
• Laboratory testing program (consolidation, strength)
• Existing test borings, CPTs, instrumentation and laboratory test data
Vertical Inclinometer
Vibrating Wire Piezometer

Signal cables are protected by PVC placement pipe.

Placement pipe makes it easy to install piezometers at the specified elevations.

V-W piezometers in multi-level housings are installed in-line with the placement pipe.

Fully-grouted borehole provides excellent isolation of zones.

Placement pipe is also used to deliver grout to the borehole.
Instrumentation Cluster at Landfill Crest
Typical Stability Analysis Cross-Section
Actual Hydrologic Conditions
Stability Analysis Conclusions

• Per NJDEP minimum factor of safety (Fs) of 1.25 during filling. Target Fs was 1.3 (deflection control)

• Insufficient time to deterministically quantify the relationship between Fs and filling rate

• Easily measured field parameters (pore pressure, settlement, lateral movements) were used as predictors of safe soil response (Observational Method)
Typical Stability Failure Surface
Observational Method

• A continuous, managed and integrated process of design, construction control, monitoring and review enabling appropriate, previously-defined modifications to be incorporated during construction

• Selection (in advance) of a course of action or design modification for every foreseeable significant deviation of the observational findings from those predicted based on the working hypothesis

R. Peck, 1969 (9th Rankine Lecture)
Observational Parameters

- Ratio of settlement in clay to lateral movements in clay (extensometers & inclinometers)
- Pore pressure in clay (VW piezometers)
- Total and incremental lateral movements (inclinometers)
- Lateral movements at toe

C. Ladd - 1991
Observational Method

- Settlement of clay stratum below crest vs. maximum lateral deformation at toe (i.e., Slope of vertical strain (extensometer) versus maximum horizontal strain (inclinometer) at toe should be less than 35% to 40%).

![Graph showing Observational Method](image-url)
Observational Method

• Increase in pore pressure proportional to loading (if exceeds 80% of applied load then critically review all data).
Observational Method

- Rate of incremental movement from two adjacent 2’ depth intervals should not exceed 0.04%/month in upper 30 feet and 0.02%/month in lower varved clay.
Stockpile at Landfill Crest
Observational Method

• Review site conditions for excess movements along the toe.
Results

• Data interpretation, computer simulations and observational performance criteria were used to successfully manage fill placement

• Filling and final closure were performed safely and on-time

• Observational method worked, but:
  – You need to know in advance what your response will be if the observed behavior is different from expected
  – The client needs to buy in
Preliminary Impressions - Revisited

• MSW is inherently stable
  – Yes and responds elastically

• One groundwater regime
  – No, perched leachate in LFL, regional & excess PWP in clay

• All failure surfaces passed through the foundation (clay) soils
  – Yes

• Critical failure mode is block
  – No, critical failure mode was circular
Miscellaneous Observations

- 450 ft long inclinometer cable is heavy
- Corrosive and heat resistant instruments (e.g., tungsten piezometers)
- PDM is corrosive, dries rapidly and is problematic
- Data management is harder than data gathering
- Real-time field data interpretation is critical
Finished Product
Thank You

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