Ground Improvement of Titanium Dioxide Waste Spoils and Compressible Organics with In-Situ Mixing with Portland Cement and Surcharging

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Abstract. Part of an overall $2.4 billion dollar, multi-use, brownfield redevelopment project along a major river and highway system in the Borough of Sayreville, New Jersey, USA, was a need to conduct ground improvement activities for approximately 40 acres of the 440-acre project for a large retail structure and portions of the roadway system. During the course of subsurface explorations it was determined that a 40-acre portion of the project contained 4 to 14 ft of titanium dioxide overlying highly compressible organics. The titanium dioxide materials were the result of abandoned plant processing activities in the production of white paint pigments.

The ground improvement program consisted of mixing the titanium dioxide byproduct, in-place, with Portland cement. The mixing was conducted using large excavators mixing set dimensioned cells to required depths. Over 375,000 cubic yards of materials were mixed in-place using this method. Many lessons were learned regarding design and construction considerations to overcome air quality, Portland cement delivery, mixing thoroughness, mix strength testing and quality control.

Once in-place cement mixing was completed a full-scale, 28-acre surcharge program was implemented to consolidate the underlying compressible organics to support the proposed development. The surcharge program was accomplished using prefabricated wick drains (PWDs) and surcharge fills consisting of Processed Dredge Materials (PDM). PDM typically consist of river and harbor dredge spoils mixed with at least 8% cement prior to reuse as fills. The surcharge program is being remotely monitored 24/7 through the use of digital piezometers, settlement plates and in-place inclinometers via a project website.

1 Introduction

The project area was formerly used in the production of white pigments by the National Lead Company. Beginning in the 1930s and continuing until the late 1970s the site produced white pigment (titanium dioxide) by processing raw ore materials barged to the site. Initially a sulfuric acid process was used until waste acid disposal costs moved the plant to consider a chloride process. The sulfuric acid process was halted in the mid-1970s. During titanium dioxide processing, process waste was discharged into

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several areas at the site. The largest waste containment area was approximately 40 acres and was commonly known as the “acid lagoon” by locals and site workers. The pH of the groundwater in the lagoon area was generally found to range between 2.5 to 3.5 with some areas going as low as a pH of 1.8 prior to any material stabilization work. The strong acid nature of the groundwater resulted in a natural chemical process that produced high concentrations of heavy metals due to them leaching out of the soil. Additionally, over the years, transformers for pumping and electrical needs resulted in PCB (polychlorinated biphenyl) contamination in the lagoon itself. A site photo taken during mixing operations in May of 2014 (Fig. 1), presents a project scale and outlines areas to be discussed further in this case study.

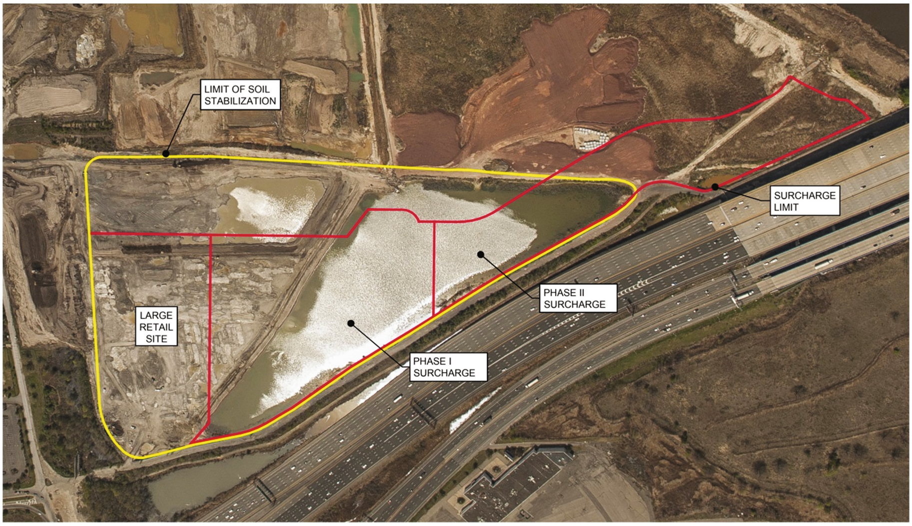

Fig. 1. Site photo taken May 2014 during mixing operations

2 Subsurface Conditions

Test boring access was limited in the lagoon area due to existing water levels at the time and the PCB contamination. The subsurface conditions in the lagoon area generally consisted of titanium dioxide waste materials directly overlying highly compressible organic silt and clay deposits. Directly underlying the highly compressible soils there are relatively free-draining sands and gravels. The titanium dioxide waste materials ranged in thickness from 4 to 14 ft with an average thickness over the area on the order of 5 ft thick. The highly compressible organic soils ranged in thickness from 8 to 35 ft with depth increasing as one moved toward the river. Groundwater was acidic as expected and ranged in depth from 3 to 5 ft below existing lagoon bottom grades.

Laboratory testing conducted on the compressible organics indicated that a modified compression index of 0.25 should be used in settlement evaluation based upon multiple consolidation tests and that the materials were normally consolidated. Atterberg Limit testing resulted in an average Liquid Limit value of 85% and a Plasticity Index of 45%. Natural moisture contents ranged from 58% to 78%.

3 Ground Improvement Considerations

As part of the site development layout and construction phasing considerations it became quickly apparent that the lagoon area needed to be addressed from an environmental and geotechnical viewpoint early on. After site remediation of high PCB levels at a few isolated areas in the lagoon, test pits were excavated in portions of the lagoon that had drained to better characterize and evaluate options for the stabilization of the titanium dioxide waste materials. Samples were collected for treatability studies for various mix designs. At the same time various options were considered to address the large volume of titanium dioxide waste materials anticipated in to be in the lagoon. Consideration was given to complete over-excavation and replacement with structural fills, mixing the titanium dioxide waste materials with large coarse aggregate (4″ to 6″ crushed stone), utilizing alternate mixing methods such as deep soil mixing, rotating head mixing and mixing with large track excavator with Portland cement. After consideration of off-site disposal costs due to contaminated soils and site limits to the lagoon area only for working due to the PCB contamination, mixing in-place with Portland cement was selected as the design solution.

3.1 In-Situ Soil Stabilization (ISS)

During contractor bidding, mixing in-place with large track excavators was ultimately selected to be the most cost effective solution. Treatability studies indicated that the titanium dioxide waste would need a minimum of 7.5% Portland cement to stabilize. However, the area of the Large Retail store required full-depth mixing completely through the compressible organics. Treatability evaluations for full-depth mixing indicated that Portland cement percentages would need to be increased to at least 10% due to impacts of the organics on resulting mixture strength. The contractor proposed three (3) different size mixing areas based upon cement delivery volumes; Small Size (10′ × 50′), Medium Size (20′ × 60′) and Large Size (20′ × 90′). The Small Size cells were for the area with full depth mixing under the Large Retail store with mix depths up to 16 ft anticipated in the design. Acceptance criteria for each mixed cell was established, by contract, to be evaluated with unconfined compressive strength tests on 2″ and 3″ diameter samples taken at designated areas per cell location. The mix acceptance strength was set at 65 psi at 28 days. The design mix strength requirement was based upon limited finite element evaluations of anticipated loadings that the area would be subject to during construction with the understanding that the majority of the lagoon area would only receive four (4) ft of ISS which in essence would “float” on any remaining un-mixed titanium dioxide waste materials and the highly compressible soils.

Dry Portland cement was to be placed directly over a cell area by direct pumping from a tanker truck using pneumatic methods then mixed in.

The ISS mixing started in August 2013 with an aggressive mobilization and within the first four (4) months of ISS, 783 cells of the estimated 1,200 cells required for the entire lagoon were mixed. However, acceptance rates for the first three (3) months were less than 40%. Discussions with the contractor in the field did not yield any appreciable change in procedures until the middle of November 2013 with introduction of a new Site Superintendent for the contractor. At this time, mixing was essentially stopped until March of 2014 while the contractor evaluated why the ISS results were not more successful. Review of pH levels, individual excavator operator performance, water added, mix depth compared to cell size and percent cement was conducted. Ultimately, the contractor increased the Portland cement content to a little over 11% and agreed to increase mix time duration. Figure 2 presents the number of cells mixed each month and the percent passing on the first mix. As one can see the changes the contractor made increased the success rate to what was anticipated within the contractor original bid estimates which was approximately 80%. Unfortunately the mixing changes occurred too late and the original contractor was forced, in July 2014 due to all the cell remixes that were needed, to cease work and terminate the business. While a new contractor was selected to complete the remaining work, the data was reviewed and it appeared that cell size had a significant impact. For the Small, Medium and Large cell sizes the success rate was 46%, 37% and 85%, respectively. The new contractor decided to accept the findings and used a large cell size with 11% cement and the success rate was generally greater than 80%. The final ISS cell was mixed in April 2015.

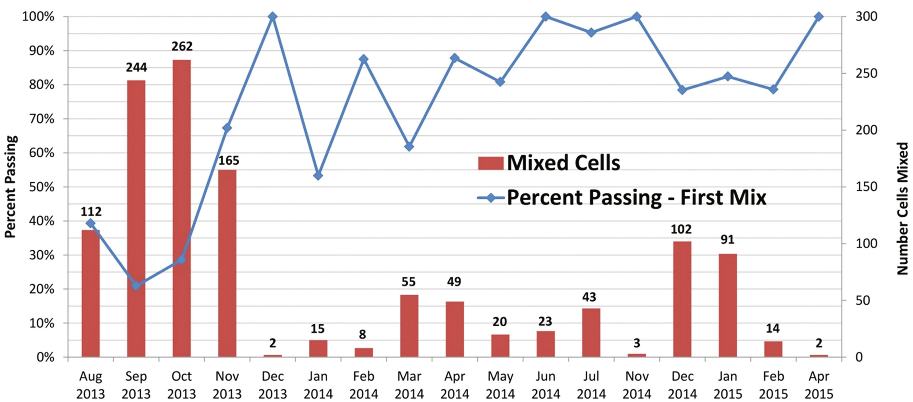

Fig. 2. Mixed cell acceptance rate per month

3.2 Surcharge Program

Once large areas of the lagoon were stabilized and approved, a site contractor started to install the necessary elements of the surcharge program. In April 2015 the installation of wick drains over a 28-acre area commenced. Due to time constraints for delivery of the large retail store and associated parking, the wick drains were spaced between 4 and 5 ft on a triangular grid. A total of 65,000 wick drains were installed. The material being used as structural base fills and surcharge fill materials for the project are Processed Dredge Materials (PDMs). Processed dredge materials typically consist of river and harbor dredge spoils mixed with at least 8% cement prior to reuse as fills which make them highly moisture sensitive and relatively impermeable. To account for the impermeable nature of the fills to be placed, the surcharge design included the use of strip drains to collect wick drain seepage and piping to manholes with 18-inches of clean fine gravels used as the drainage layer under the PDM materials. During wick drain installation, vibrating wire instrumentation consisting of (32) piezometers, eight (8) settlement sensors and one (1) in-place inclinometer (5 sensor locations with depth) were installed. All the instrumentation is wired to dataloggers which transmit real-time data to the project website for contractor use. The real time data allows monitoring so the site pore water pressures will not exceed established threshold limits. Additionally, (32) manual settlement plates were installed and observed on a bimonthly basis.

Base fills were placed over the entire surcharge area to elevations greater than final design grades to account for anticipated settlements. The PDM requires very thin lifts due to the relatively high moisture content of the material as delivered to the site which can range from 55% to 85% moisture. PDM use as a structural fill requires thin lifts over large areas which are aerated prior to compaction with a sheepsfoot roller. Based upon proctor tests (ASTM D-1557) conducted on the PDM materials, the optimum moisture content ranged from 25 to 35% with maximum dry densities ranging from 65 to 85 lb per cubic foot.

The surcharge fill placement was broken down into two (2) separate phases; Phase 1 was to cover the area associated with the parking, roadway and utility needs for the large retail store construction, and Phase II would utilize the surcharge fills from Phase I and prepare the ground for future roadway, parking and culvert construction. In computing the surcharge fill height for the areas the design had to account for the relatively low anticipated moist unit weight of the PDM materials placed in thick lifts and any impact of the ISS materials on surcharge load stress distribution. A final surcharge height of (19) ft was used in construction which included a 5-foot increase in height to account for any impacts of the ISS. Figure 3 presents the predicted versus actual settlement at settlement plate location M07 which is located in the middle of the Phase I surcharge.

The observed settlement is close to the predicted total (primary) settlement and it appears that the additional surcharge fill height added for the ISS concerns was necessary. Surcharge fills were cleared for removal 4.5 months after the start of surcharge placement which was estimated in the design of the wick drain spacing. Surcharge fills are currently being removed from Phase I and are being placed on Phase II.

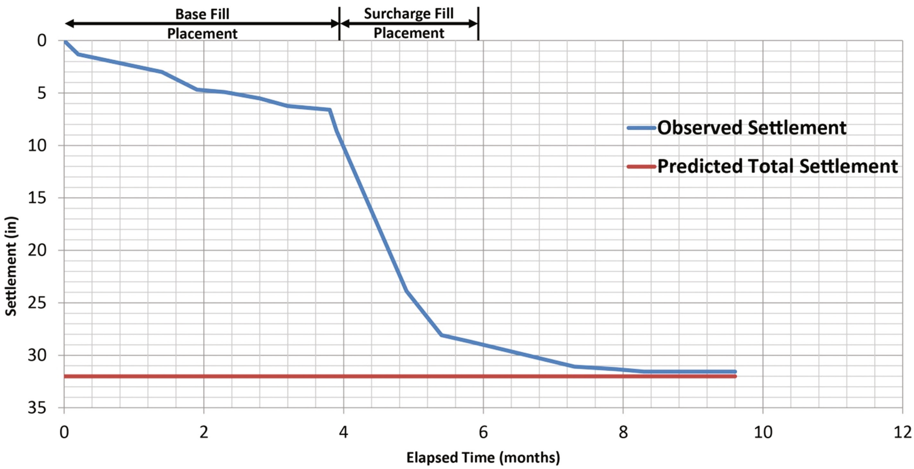

Fig. 3. Settlement observations-M07

4 Conclusions

While this is a single case study for the use of in-place soil mixing for structural support, there are many lessons to be learned from the field observations and testing.

1. Laboratory treatability studies, while important in establishing a baseline for design and pricing, should be followed-up with actual treatability evaluations in the field. Ideally, the contract should have a field treatability evaluation program as part of the mobilization. Construction documents and contracts should be structured that if the field observation success rate is not as anticipated, work should be stopped until further evaluation is done.
2. Placement of the dry Portland cement by pneumatic pumping created an issue with dust. The fine grained nature of the Portland cement meant that it would become airborne with very little wind. Air monitoring is recommended with contract provisions for dust remediation or work stoppage should air monitoring indicate unacceptable levels of dust transport.
3. The time of mixing each cell had a significant impact on the success rate.
4. Cell size had a significant impact on the success rate. Small, relatively narrow cells with deeper mixing depths had the lowest success rate. This is probably due to the use of large track excavator physical shape limitations on how it can operate in a confined, narrow trench. Larger cell sizes resulted in quicker mix times and higher success rates.
5. The real-time instrumentation was very helpful in confirming design assumptions as to stress distribution and saturated conditions. Piezometer data allowed for confirmation of pore-pressure distribution assumptions and construction rates. Settlement sensors were good in evaluating relative settlement but generally were not as accurate as the settlement values obtained from the manual settlement plates.

We were not able to evaluate if the settlement sensor readings were impacted by the installation process or heavy construction traffic impacting the sensor. Future surcharge programs at the site will focus on this issue.

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