Development on Florida's Phosphate Mine Lands

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SYNOPSIS: A majority of Polk County, in central Florida, has been mined for phosphate in the past. Mining companies use the mined areas to deposit mining wastes such as the tailings sands and highly plastic clay materials that are associated with the beneficiation of phosphate ore. The clays are allowed to consolidate, but often, the resulting solids content or shear strength of the materials is very low even after several tens of years. One such area that was impacted by mining and subsequent clay disposal was to become a mobile home park. The developer did not investigate the subsurface conditions prior to purchase or understand the impacts of the clay disposal on the development of this property. Decisions made by the developer and some of the technical difficulties and construction techniques that were used to overcome some of the difficult soil conditions are discussed herein.

INTRODUCTION

Central Florida has been the location of phosphate mining for nearly 100 years. This process involves removing about 20 feet of overburden and 15 to 20 feet of ore, using draglines. The resulting landform consists of alternating spoil piles and water filled cuts. Subsequent to the mining, the cuts are often used as disposal sites for slurried waste clays and sands, both by-products from washing and flotation of the phosphate ore. The phosphatic clays are deposited at a relatively low solids content (three to five percent) and allowed to consolidate under saturated, self-weight conditions. The clays are highly plastic (plasticity index values typically range from 120 to 190) and have very poor consolidation and permeability characteristics. Even after tens of years, the clays remain highly compressible and exhibit low shear strengths.

This is the general historical setting for a mobile home park in the central Florida area. The site, about 80 acres in size, had been mined and filled with waste clays some 30 to 50 years ago. The site had not been reclaimed and much of the acreage was underlain with 30 feet of highly compressible phosphatic clays.

In the mid-1980's the property was purchased by a an out-of-town developer to build a mobile home park including ancillary recreational facilities, a recreation hall, swimming pool and tennis and shuffleboard courts. Since the date of the purchase, the owner has had to deal with the very difficult soil conditions, drainage problems, nagging maintenance, and legal issues while trying to develop the property.

SITE DEVELOPMENT HISTORY

As noted above, the current owner purchased the subject property in the mid-1980's. Being unaware of the impacts mining and waste clay disposal had imposed on the property and convinced by the seller of its suitability for the intended use, the purchase was finalized. No soil borings or other investigations were completed prior to the purchase by the current owner.

Within a few weeks, the developer began to realize the seriousness of the site conditions. Their original plan had lots and recreational facilities covering the entire property. However, the plan had to be amended to take into account the soft soil and prior drainage conditions. This modification reduced the number of available building lots by about 40 percent. The general site plan is shown in Figure 1.

The basis for the revised lot plan came after we reviewed historical aerial photographs (vintage 1941) and completed a geotechnical subsurface and engineering study of the site.

The geotechnical investigation consisted of drill rig sampling and hand probings. Due to the soft, wet conditions at the ground surface which inhibited access, much of the investigation was completed by hand.

The geotechnical investigation confirmed our preliminary opinions regarding the presence of several semi-parallel mine cuts filled with soft, phosphatic waste clays. A typical cross section of the site conditions is depicted in Figure 2.

The results of the geotechnical investigation drastically changed the proposed utility of the property. The owners' investment now seemed in question. They had paid market price for a full parcel of land, but instead received much less than they anticipated.

The buyers were later to learn that the seller (also an out-of-town developer) had done some preliminary studies, learned of the history and

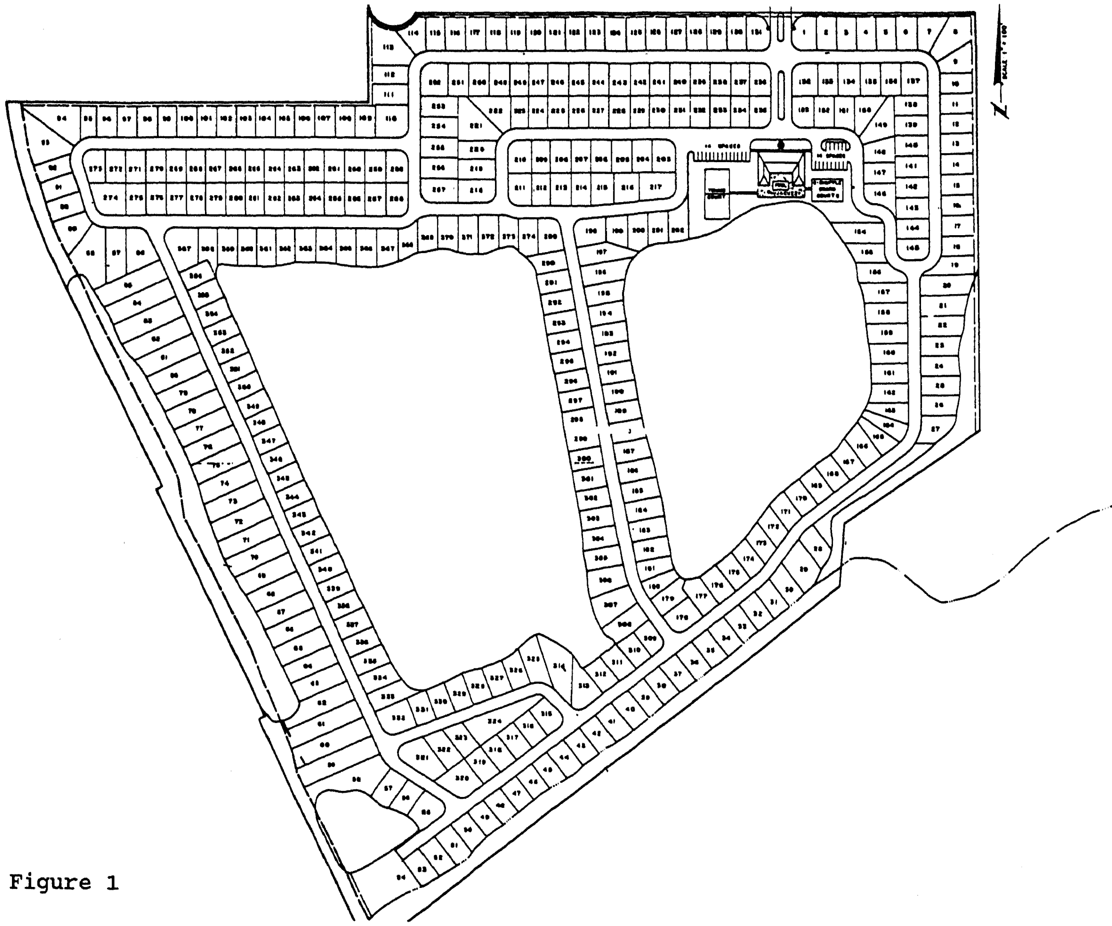

Figure 1

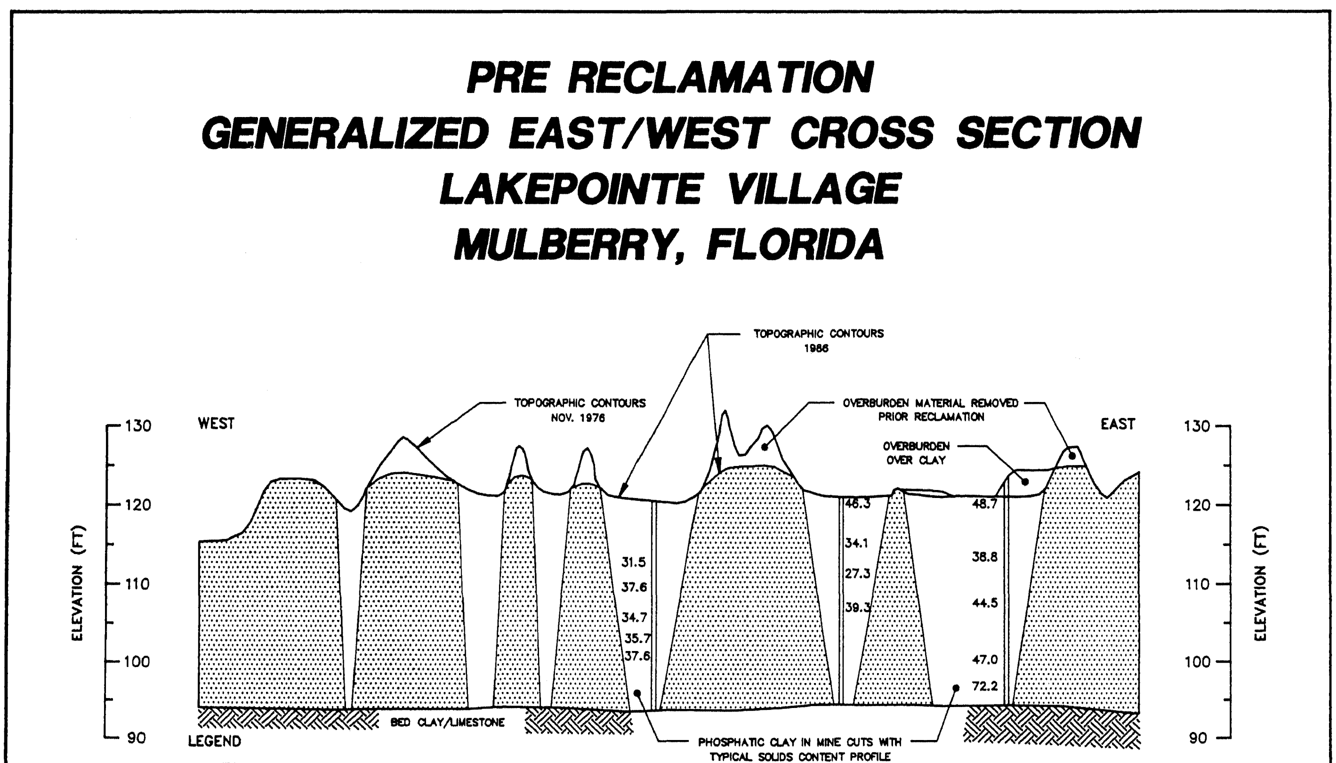

Figure 2

soft soils conditions at the site and decided not to build his development. However, he did not divulge this information to the buyers. This fact later became the basis of a real estate fraud lawsuit between the parties.

At this point, the developer had the choice of trying to go ahead with a mobile home development with fewer lots and long-term maintenance, or trying to sell the property for a price much lower than their cost, due to the difficult subsurface conditions. The owner opted to go forward once he learned of the possibility of funding support from Florida's Department of Natural Resources (FDNR) to reclaim abandoned phosphate lands.

RECLAMATION FUNDING

Background

The DNR has maintained a trust fund to assist landowners with reclamation since the early 1980's. The fund was set up using a severance tax on phosphate ore and is limited to lands that were mined prior to July 1975. Areas disturbed by mining after this date are being reclaimed under mandatory regulation also administered by the DNR (Ericson, 1990).

The process for obtaining the funds involves delivering a detailed reclamation plan and cost estimate to the DNR on an annual basis (usually by July 1 of every year). The list of projects submitted to DNR (generally 10 to 15 per year) are reviewed and ranked for funding. Funding guidelines for reclamation were set up to provide "minimum" reclamation, focusing on earthmoving and revegetation to restore the landform to a useable condition. Additional site development activities, such as utility installation, construction of stormwater management systems and grading and paving streets for a development project, are not reimbursable activities. It should be noted that most reclamation efforts in central Florida are done to restore the disturbed land to improved pasture thus, the site development costs discussed above, are generally not part of a standard reclamation project. Considering the "minimum" reclamation philosophy and to provide a wider distribution of the limited available funds, the reimbursement for reclamation of mined out areas is limited to about $4,500 per acre.

The landowner applied to DNR for funding for a portion of the subject property in July 1986. He decided to immediately delete developable parts of the property from the application because the schedule for development would be delayed by the DNR funding review and contract approval process. The earthmoving phase of the reclamation was initiated in 1987 and was completed in March 1988 for a total cost of about $260,000.

Reclamation Effort

The reclamation efforts concentrated on isolating the clay filled mine cuts into two island-like areas, while grading the remaining spoil piles to accommodate the mobile home lots, streets, and utility corridors. To provided as much acreage as possible, sandy spoil materials were also used to cap the soft clays in perimeter areas of the clay islands, with the owner's understanding that these areas would settle with time and possibly present some difficulties for buried utilities. Figure 3 shows the general reclaimed landform configuration.

As part of isolating the phosphatic clays in Lake Nos. 2 and 3 (Figure 3), perimeter ditches were excavated in the clays to aid stormwater runoff control and treatment. The low shear strength of the clays often caused equipment mobility and stability problems. Low ground pressure bulldozers and small draglines working on mats had to be used. Even with these precautions, a dragline caused a bearing capacity failure of the clays and became stuck. As a result, an extensive, emergency effort by the contractor was required to save the equipment.

Once the reclamation was complete, the owner continued with the site development activities. A different contractor was hired to do the utility and street construction.

As described in the subsequent section of this paper, the site development contractor often had to contend with buried soft clays, known and unknown locations. Considerable cost overruns were incurred to accommodate the clays and other difficult soil and groundwater conditions at the site.

SITE CONDITIONS AND CLAY PROPERTIES

As described above, the site conditions were a result of phosphate mining followed by filling of the post-mining voids with dilute, highly plastic, phosphatic waste clays. The area was revegetated with volunteer wetland type trees and plants. This vegetation typically disguises the presence of extensive deposits of soft phosphatic clays to the untrained eye. Our first geotechnical investigation was initiated a few months after the purchase by the current owners. These studies were followed by several site specific studies that helped characterize the location and engineering properties of the site soils.

The soft, low strength consistency of the waste clays made drill rig access very difficult and sampling with conventional equipment, such as a standard penetration test (SPT) split spoon sampler and the thin wall Shelby tube sampler, not practical (Typical solids content values of the clays were about 35 percent (equivalent moisture content 185 percent) with undrained peak shear strength (cohesion) of about 100 pounds per square foot). The sampling and characterization of the clay was usually done using our hand operated piston sampler and small diameter steel probe rods. Access for sampling was done with the aid of boards or pallets as temporary working platforms.

Phosphatic clays in the mine cuts at the site measured about 30 feet thick. The mine cuts, about 200 feet wide at the top, are separated by sandy, spoil piles that were at or near the top

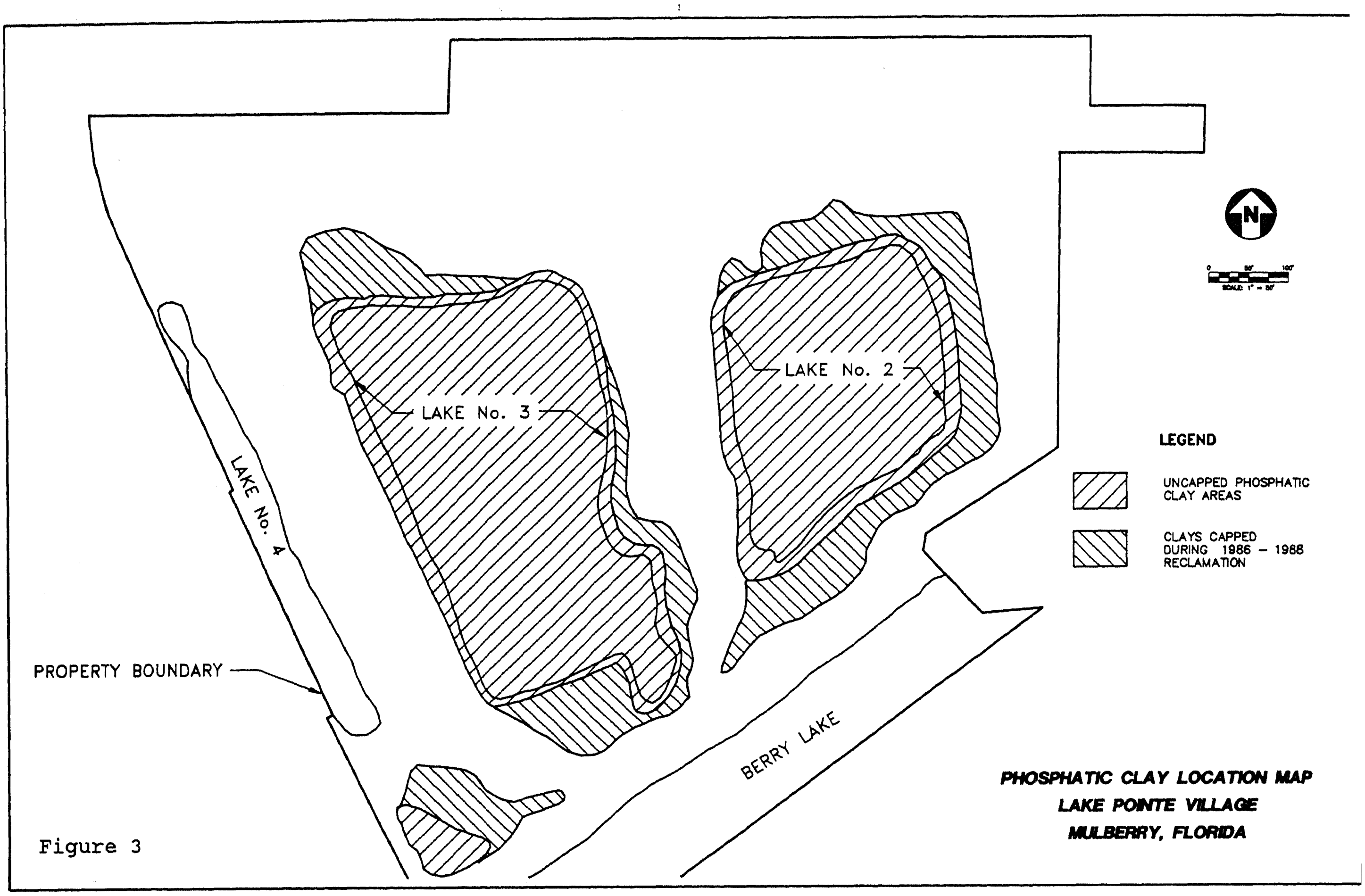

Figure 3

of the clay. The spoil piles, which typically extend well above the natural ground surface, had been graded and/or removed in the 40 to 50 year period between the time of mining and our first investigation at this project site.

The engineering properties of the clays were characterized in the laboratory by moisture content, percent passing the number 200 mesh sieve and Atterberg limits (plasticity) testing. The clay deposits generally contained less than two to three percent sand sized particles and were highly plastic in nature; liquid limit = 170, plastic limit = 35 and plasticity index = 135.

Because the clays are saturated at the time of sampling, the solids content (unit weight) can be determined from the disturbed samples obtained with the piston sampler.

Because the clay deposits are man-made and have generally experienced low levels of effective stress during their post-deposition lift, they do not demonstrate a pronounced structure or soil grain orientation. Saturated, disturbed samples of the phosphatic clays can then be used in one-dimensional consolidation tests typically done with special large diameter slurry consolidation or restricted flow consolidation equipment.

Low solids content clays experience a large degree of consolidation settlement if exposed to changes in effective stress. This condition typically requires that consolidation settlement be analyzed using finite strain relationships, rather than the conventional soil mechanics infinite (small) strain method, which assumes the changes in void ratio are small even with relatively large increases in effective stress.

In order to evaluate the feasibility of capping the clays to expand the useable acreage, consolidation predictions were made using finite strain relations of void ratio vs. effective stress and Atterberg limit correlations. The settlement estimates were done with computer programs developed by our firm (Carrier, et.al. 1983).

Using an average solids content of about 35 percent, a plasticity index of 170, a clay deposit thickness of 30 feet, and a water table at the top of the clay surface, we predicted that the clays would consolidate 3.5 feet, if a four foot thick fill cap was placed on the clay.

Magnitude of the settlement was not the only factor considered as we reviewed the feasibility of capping the clays to provide additional building lots. Due to the low permeability (typically 10^{-7} to 10^{-9} cm/sec) of the clay and the long, one-way drainage path, the time rate of consolidation is very slow. Again, using Atterberg limit correlations, we estimated it would take about ten years for 50 to 60 percent of the settlement to take place.

The magnitude and rate of the settlement of the clays, generally precluded using capped clay areas for additional building lots. Long term, settlement of the clays would result in damaged or broken utilities, broken or uneven streets and poor storm water drainage.

Perimeter portions of the clay deposits were capped to try and maximize the available upland areas for development. The settlement that has resulted since capping has disrupted utility lines and resulted in cracked streets, tennis courts and pool deck areas, confirming our settlement predictions.

Among several other options, the owner considered removing and replacing the clays in all or part of the property. The total volume of in-place phosphatic clay at the site was estimated to be about 600,000 cubic yards. The cost of this operation would probably have been about two to three million dollars presuming that a disposal site for the soft, semi-liquid clays could have been found. Due to the cost to excavate and replace the clays, this option was not economically attractive.

SITE DEVELOPMENT EXTRAS

Even though the reclamation process focused on separating the predominantly clay filled areas from the more stable sandy spoil pile areas, the site development contractor continued to encounter difficult subsurface conditions and buried soft clays. The owner constantly, and still to this day, asked if they were spending good money after bad. As with normal project sites, the developer and the contractor followed the rough grading (in this case land reclamation) with the layout of streets and buried utility lines. But that is generally where the similarity ended. The following describes some of the site development extras that had to be done to prepare the site for the sale of mobile home lots.

Sanitary Sewer Lines

Prior to the site reclamation activities there was evidence that the site topography and land form had been modified. The characteristic, alternating triangular shaped sandy spoil piles were generally leveled by post-mining borrow. Other areas containing soft phosphatic clays and very loose sand tailings were disguised by near-surface, medium dense sandy spoil materials that had been rehandled prior to reclamation.

The contractor initiated sewer line work in the north more stable end of the property and proceeded south and west toward the lift station. After working through some minor pockets of clay and loose, saturating tailings, the contractor encountered more extensive deposits of difficult soils near the southwest corner of the site, while trying to install the lift station and nearby distribution lines.

The lift station invert needed to extend to a depth of about 14 feet below grade. Excavation for the lift station was initiated with a appropriately sized backhoe. However, after about 10 feet of excavation the contractor encountered loose sand tailings underlain by very soft, phosphatic clays. These soils were deemed unsuitable for the lift station support due to settlement tolerances. Further excavation to the required depth would have been very difficult to impossible with his equipment.

Considering there was only a limited area to locate the lift station, because of intersecting sewer lines, we mobilized a drill rig to help select an alternate location. A site, about 200 feet northwest of the original location was chosen based on the test borings.

The contractor again proceeded with the excavation process. Though he did not find soft phosphatic clays, very loose, saturated sand tailings were encountered. The excavation bottom and slopes became very wet and soft. The utility contractor claimed he could not work in these conditions and stopped work. The owner agreed to mobilize the reclamation contractor to dig and dewater the lift station excavation with larger equipment. The excavation was dug with a 1-1/2 cubic yard dragline rather than a small backhoe using flat slopes and trash pumps. The final size of the excavation exceeded the dimensions of the lift station by several tens of feet to provide a stable work area.

Similar conditions were encountered in the sewer line trench heading north from the lift station. The utility contractor convinced the developer that he had not bid the job based on encountering loose, saturated sand tailings and soft clays and stopped work again.

We mobilized a drill rig to evaluate the subsurface conditions of about 1,500 feet of sewer line north of the lift station. The materials encountered consisted of the saturated tailings and firm phosphatic clays. Based on our test boring data and pre-reclamation topographic maps, we determined that the phosphatic clays had been preloaded or surcharged after deposition and would provide adequate support for the piping and excavation side slopes. We suggested to the contractor that the excavation could have been advanced through the clays and saturated tailings with the aid of a well pointing system. Neither recommendation was followed, as the contractor refused to make the extra effort. The sewer line alignment was then overexcavated by dragline equipment and backfilled with imported silty/clayey sand materials, at a great expense to the owners.

Another segment of the reinforced plastic sanitary sewer line had to be pile supported because it was underlain by 30 to 40 feet of very soft phosphatic clay. The site development engineer had located a segment of the sewer line across a clay filled mine cut that was capped during reclamation. Even though the reclamation (capping) maps were provided to the engineer, a sewer line segment was deemed needed in this area.

The contractor proceeded with the installation using his normal equipment and methodology. Even though he encountered clays in the bottom half of the excavation, he was able to install the pipe and backfill it with little apparent difficulty. However, when the pipe was inspected for alignment and grade with a remote television camera, it was deemed to be out of tolerance and had to be reinstalled.

Reexcavation and removal of about 125 feet of pipe turned into an endless process. The extra activity in the area resulted in the clays being disturbed. Once these sensitive clays are disturbed, their remolded strengths are very low and they exhibit flow like behavior, even with low slope angles and small excavation depths. These characteristics became quickly evident as the contractor worked to reinstall the pipe. The excavation of the trench became a continuous process as the clays moved toward the open face of the excavation. It was determined, that even if the trench could be maintained long enough to install the pipe, subsequent movement during backfilling would probably cause it to be out of tolerance again.

Two options were reviewed: 1) reroute the pipe backwards toward the lift station and miss the bad area, or 2) pile support his short section of sewer line. For a variety of reasons, the pile supported option was chosen.

A subsurface investigation was completed in the area to determine the thickness and consistency of the waste clay. The clay showed "weight of rod" resistance to a depth of about 40 feet when tested using the SPT sampling equipment and drop hammer. A support system utilizing a cast-in-place reinforced concrete grade beam and 12-inch square H-piles was designed and installed to support the pipe. The H-piles were driven using a 18,000 foot-pound drop hammer to refusal conditions at 12-foot spacings. The H-piles were then capped with a 12-inch thick reinforced concrete grade beam that would later work as a cradle for the sewer pipe.

The contractor installing the grade beam, had to work about ten feet below grade and experienced constant movement of the soft clays into the excavation. This condition made form setting and grade control difficult during the time prior to the grade beam concrete reaching sufficient strength to resist the clay lateral and upward movement.

Recreation Hall and Swimming Pool

The location of the recreation facilities in a mobile home park are considered critical to its presentation and marketability. The orientation of the mobile home park entrance road and sales office placed the recreation hall and swimming pool in an area underlain by recent sand fill and soft phosphatic clays at the north end of the eastern most clay "island" (Lake No. 2). The developer was informed of our settlement and maintenance concerns but he opted for the location by placing the recreation building and pool on pile foundations. The recreation building floor slab was designed as a post-tensioned system to provide uniform load distribution as post-construction settlement of the subgrade materials were expected to occur, due to surcharge effects from recently placed fill materials.

The geotechnical investigation for the site revealed five to six feet of sand fill underlain by very soft phosphatic waste clays beneath most of the building footprint. Twelve inch diameter, closed-end pipe piles were chosen to support the floor and building loads. The piles were driven with a diesel hammer to refusal conditions at a depth of about 50 feet below the ground surface. Similar sized piles were used to support the swimming pool, but no pilings were used beneath the pool decking or surrounding tennis and shuffle board courts.

Pile installation and the post-tension slab construction proceeded with little delay or complication. The swimming pool and deck areas were also built in accordance with plans.

Pool Deck Rehabilitation

Shortly after the mobile home park opened, the pool deck area showed major distress in the paver blocks. Voids were observed beneath the paver blocks, particularly next to the pool perimeter. At the request of the owner, we investigated the cause of the distress and determined it was primarily the result of poor quality control by the pool contractor during fill placement. It was concluded that water percolating through the blocks carried the clean sand fill into voids left beneath the pool bottom and edges. The deck was subsequent repaired using a system of geotextiles and sand fill to replace to original poorly compacted backfill.

As part of the landscaping around the pool, the developer placed about eight feet of fill materials to support the deck and form an adjacent grass slope. The south facing slope of the pool area was immediately adjacent to the north end of the eastern clay "island" area (Lake No. 2). The pool and recreation hall were overlying fill and soft clays. Soft clays were exposed at the ground surface within 100 to 150 feet of the pool deck, to the south. The landscape fill materials had also been placed over deep, soft clays.

A few months after the entire pool deck had been repaired for the voids, as described above, lateral and vertical movement of the south side of the pool deck was observed. Because the deck and backfill had been recently replaced, the movement was believed to be caused by long-term settlement of the underlying phosphatic clays and/or slope instability. The only portion of the deck that was moving was the area adjacent to the grassed slope, indicating that slope movement was probably the cause rather than settlement. A series of survey points were established to measure vertical and horizontal movement of the deck and toe of the slope.

Once we received data confirming the lateral movement of the slope, we completed slope stability analyses of this low height slope (eight to ten feet high) using remolded clay strength parameters. A factor of safety of about one was the basis for making minor adjustments to the strength values. Using this system as a starting point we were able to evaluate the impacts of changing the slope angle on the factor of safety. The position of the nearby clay "island," which contained wetland vegetation, prevent us from buttressing the downstream toe area to improve our factor of safety against future slope movement. Due to a limited work area, the only real option was to remove part of the top of the slope around the deck to reduce the driving force component.

To reestablish the south pool deck elevations, a series of small diameter pin piles were advanced to refusal at close spacings through cored holes in the deck. The deck was then jacked back to its original grade. The deck was secured to the pin piles and resurfaced. This repair method left a three to six inch void beneath the deck which was not backfilled, to prevent adding load to the top of the slope.

Even with the slope changes and pin pile support of the deck, the resulting computed factor of safety for the slope stability was still about 1.2.

Site Dewatering

The settlement and construction difficulties associated with the phosphatic clays were not the only problem the developers faced at this site. Soon after the park was operational and homes occupied, some of the residents began complaining of standing water in their lots and adjacent lots following isolated heavy rains and for most of the summer months, when central Florida receives about 35 of its 50 inches of rain. This condition was killing the grass and causing small springs to appear in the downslope areas. This condition was also causing roadway instability and pavement cracking in some locations due to saturated base materials.

The high water table condition, at first, would have seemed inconsistent with the presence of near-surface, clean sand tailings. However, a geohydrological investigation of the site revealed a relatively shallow underlying layer of phosphatic clay materials as well sa clayey overburden soils. Though not as soft as elsewhere on the site, they are very impermeable. This condition was causing infiltration for rainfall and runoff from the streets and roofs to be perched on the clay layer. Further flattening of the site grades during development placed the water table closer to the ground surface as compared to predevelopment conditions.

An extensive french drain dewatering system was modeled and designed to handle the perched water table situation The system consisted of a geotextile wrapped, plastic perforated pipe, surrounded by pea gravel and backfilled with clean sand. A series of parallel, east-west running pipes were planned to lower the perched water table. These pipes were designed and constructed to lead to two north-south outfall pipes that discharged into the wetland, clay "island" areas.

The major obstacle for installation was the presence of buried electrical and television cables and water and sewer utilities throughout the park. The hiring of a reputable, local contractor that specialized in underground utilities allowed the job to go smoothly with little or no power line disruption. The dewatering system has been flowing since it was installed and complaints from the residents about yard flooding are negligible. Areas that were once indurated throughout the summer months are now dry.

Legal Action

Though not the final event in the on-going saga of this park, the real estate transaction that put the property in the hands of the current owners was the subject of a long, drawn out lawsuit. Florida real estate law require that the seller of a piece of property divulge any known problems or defects that could affect its value or utility.

The sellers of the property had initiated their own development in the early 1980's. During that process they became aware of the history of the property and difficult subsurface conditions. Their development efforts stopped in about 1984 and they tried to sell the property to another party in early 1985. The potential buyer learned, through his own efforts, of the nature of the site conditions and declined to purchase it. A few months later, the current owners entered into a purchase agreement. Based on the sellers development plans (on paper) they bought the site and began their project. You know the rest of their story by now.

In an effort to recoup the extra site development and maintenance costs, legal action was pursued by the current owners, based on the right-to-know premise of Florida's real estate law. After several months of depositions, negotiations, and changed trial dates, the case was heard in a local court before a jury. The trial continued for several days and just before the jury was to deliberate, the seller agreed to settle for undisclosed terms.

CONCLUSIONS

The developer continues to operate the park and sell mobile home lots. Maintenance of streets and utilities will be a constant problem in areas underlain by soft clays. The developer has made efforts not to rent problem lots at this time, allowing the clays to further consolidate.

In-place stabilization techniques such as surcharging, with wick drains and a new technique being investigated by our firm, lime columns, may help make other similar disturbed areas more suitable for development.

Obviously the buyer beware warning should be the primary non-technical issue learned from this case history.

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