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ABSTRACT

The Red Onion Mountain project involved the construction of a high security prison facility in a remote area of southwest Virginia. The site of the proposed construction was covered with a thick layer of uncontrolled mine spoil fill material containing a random matrix of soil and boulders. This material was unsuitable for the proposed construction in its existing condition. Charged with evaluating feasible and cost effective alternatives for site development and structural support, the project's geotechnical engineers devised a two-phase ground improvement plan designed to adequately improve the existing mine spoil fill. Full-time observation, documentation and testing during the site preparation phase provided data that was used to evaluate the effectiveness of the ground improvement procedures. Building construction proceeded on the improved soils after an evaluation of the data indicated the existing mine spoil had been adequately improved.

KEYWORDS

Mine Spoil Fill, Casing Advancer, Dynamic Compaction, Dilatometer Testing, Surcharge Preloading, Pressuremeter Testing, Time-Settlement Curves

PROJECT DESCRIPTION

Looking to expand their high security capability, the Virginia Department of Corrections (VDOC) was interested in developing the Red Onion Mountain site for a maximum security prison. The site had been donated to the Commonwealth by a regional mining company. In addition to the cost savings realized from the land donation, the local government and citizens welcomed the potential influx of jobs into the community. Therefore, despite the drawbacks associated with the property, the VDOC was anxious to proceed with the project.

The project site is located in the Appalachian Plateau Physiographic Province. Topographic relief in the region is typically extreme with narrow, steep-sided stream valleys and hollows and a predominantly undulating terrain. Due to the prevailing topography, land development and building construction are usually confined to steep hillside cuts, alluvial plains and man-made fills. The region is well known for its abundant coal deposits which have been mined extensively over the past 100 years. Minable coal seams generally vary in depth from less than 50 ft to several hundred feet. Until technology improved, coal was extracted using deep mining methods. With the advent of larger earth and rock moving equipment in the 1960's and 1970's, open pit strip mining of shallower coal seams became common practice. To help reduce the detrimental environmental effects of strip mining, mine reclamation was mandated by most state and federal agencies in the 1970's. Reclamation is the process of restoring strip mined areas to a more environmentally friendly condition upon completion of mining.

The subject property consisted of over 800 acres of extensively mined land located on the border of Wise and Dickenson Counties in southwest Virginia. About half of the total acreage had been strip and/or auger mined with active mining ending in 1990. Some deep mines also underlaid the site. Site topography was characterized by numerous steep hills and narrow valleys. The few level areas scattered across the property were byproducts of mine reclamation operations. The area chosen for development of the prison consisted of about 60 acres of reclaimed land located in a small valley surrounded by steep ridges. A large mound rose up as much as 40 ft above the center of the selected area. Surface vegetation consisted mostly of grass and small brush. Surface drainage features included a wet weather stream flowing along one side of the valley and a bold, year-round stream flowing along another side.

The maximum security prison design consisted of a state-of-the-art facility capable of housing over 1,400 inmates. The design featured a compact fenced compound and a total complex area of approximately 27 acres. About 32 ft of cut and 22 ft of fill would be required to grade the area. Within the high security compound, the prison consisted of four identical, two-story housing units and two support buildings. Maximum column and wall loading of 125 kips and 18 klf, respectively, were expected for these precast concrete structures. The project designer was Daniel, Mann, Johnson and Mendenhall, Inc.

GEOTECHNICAL ENGINEERING EXPLORATION

Subsurface Exploration

Subsurface drilling and insitu testing in heterogeneous materials such as mine spoil fill can be a difficult proposition. Also, the abundance of rock fragments and the highly variable composition of mine spoil materials can result in misleading test data. To collect information regarding subsurface conditions at the site, Schnabel Engineering proceeded with an exploration program consisting of test borings and test pits. A total of eight new test borings were drilled at the site to supplement 10 previous borings performed by another consultant during a preliminary evaluation of the site. The unusually wide boring spacing (typically 200 to 300 ft) was justified by the relative similarity in mine spoil composition observed from boring to boring. Test borings were extended completely through the mine spoil fill and at least 5 ft into the underlying bedrock to confirm that the fill had actually been penetrated. Identifying the location of the fill/bedrock interface was difficult in some cases because boulders within the fill were as large as 8 feet in diameter and looked very much like the underlying bedrock. Whereas boulders within the fill displayed random, variable orientation of bedding planes, bedrock was characterized by bedding that was nearly horizontal. This was the key indicator used to make the determination of whether or not a boring had actually penetrated the fill. Test pits extended to depths of about 25 ft. These excavations afforded us the opportunity to view a cross section of the mine spoil fill. A typical stockpile of excavated mine spoil is shown in Fig. 1.

Fig. 1 - Typical mine spoil fill

Test borings were initiated using standard augering techniques. Where abundant rock fragments and boulders impeded the auger drilling, casing advancement or rock coring methods were employed. Casing advancement is a procedure whereby a hollow, diamond tipped steel casing is rotated at high rates of speed and advanced downward. Typically a tricone roller bit is simultaneously rotated and advanced inside the casing to facilitate the drilling process. Drilling water is introduced into the hole to cool the casing and roller bit. This procedure creates a cased hole through which Standard Penetration Testing (SPT) and split spoon sampling can be performed. Unfortunately, the advancement process was slow and tedious with drilling rates of only 40 to 50 ft a day common in rocky portions of the fill. Therefore, in some cases, the drilling subcontractor elected to use rock coring techniques to advance through zones of abundant boulders. The rock coring was considerably faster than the casing advancer in these situations and provided core samples of boulders within the fill. The drillers main difficulty while using advancement and coring techniques was the loss of drilling water into the porous mine spoil fill. Substantial down time and hardware damage resulted from the overheating of drill bits due to this loss of water.

Test pits were excavated using a Hitachi EX 270 LC track-mounted excavator. The rocky mine spoil material was typically difficult to excavate and a few very large boulders further complicated the process. The test pit excavations were visually logged considering stratification and material composition. The sides of test pits tended to cave in during excavation

Subsurface Conditions

The existing mine spoil fill encountered in the borings ranged in thickness from 41 to 89 ft. Although some significant pockets consisting primarily of rock or primarily of soil were observed, the mine spoil fill was generally typified by an overall heterogeneous and random composition. Soil types observed in the mine spoil matrix varied from low plasticity silts and clays to sands and gravels. Gravel to boulder sized rock fragments, composed primarily of sandstone, were encountered throughout the fill. Some of the boulders were very large as shown on Fig. 2. SPT N-values recorded in the fill ranged from 2 to well over 60. N-values over 30 were not considered representative due to the abundance of rock fragments. Disregarding these higher values, the soil portions of the mine spoil fill were characterized as soft to stiff in consistency and loose to compact in density. Scattered root fragments were encountered in the borings and test pits but, in general, the mine spoil fill appeared to be relatively free of deleterious material. The mine spoil fill stratum was underlain by competent siltstone, sandstone and shale bedrock of the Wise Formation. This thinly and horizontally bedded rock stratum represented the base layer underlying the strip-mined coal seam. In general, the top of rock surface sloped down from south to north at a grade of about 0.5 percent. Our deep mining research indicated that deeper, unmined seams of coal existed beneath the site. The mineral rights of these seams were subsequently obtained by the State.

Fig. 2 - Large boulder excavated from test pit

With the exception of a few pockets of trapped or perched water, groundwater encountered during drilling was typically deeper than about 25 ft. As evidenced by the frequent loss of drilling water, the mine spoil fill was generally a free-draining stratum. Trapped water pockets in this type of material are created when water percolating through the predominantly porous ground becomes caught within pockets of lower permeability clays and silts. The underlying bedrock surface behaves as a confining layer limiting the downward migration of groundwater while providing a flow path for water to drain.

ENGINEERING ANALYSES AND RECOMMENDATIONS

Mine Spoil Evaluation

To assist in the evaluation of the mine spoil fill, we conducted soil laboratory index testing of representative soil samples. Laboratory testing indicated a wide variation in soil type and grain size distribution. Natural moisture contents of the soils tested were relatively dry, typically in the 10 to 20 percent range. Sieve analyses and Atterberg Limit test results indicated the mine spoil contained sands, gravels and non-plastic to low plasticity silts and clays with Plasticity Indices ranging from 8 to 12. Based on the lab testing, sand and gravel portions of the fill were uniformly graded.

The mine spoil fill at this site had been in place for a period of about 5 years at the time of our study. Based on the standard practices of mine reclamation and our observations of the heterogeneous, unconsolidated matrix in the soil borings and test pits, it was presumed that the fill had been placed in the absence of quality control. The existing fill was clearly unsuitable for direct support of foundations or pavements due to its high potential for large total and differential settlements. Deep, uncontrolled fills can continue to settle significantly under their own weight for many years following the completion of placement. We estimated that in their existing, unmodified condition, the fills could settle up to about 12 inches under their own weight over time.

Foundation Alternatives

With the option of building directly on the unimproved mine spoil eliminated, we turned our focus to the various foundation alternatives available. The alternatives evaluated in our study consisted of deep foundations supported on rock and shallow foundations supported either on undercut backfill or on modified ground. These foundation alternatives were evaluated thoroughly with respect to their technical feasibility, associated level of risk and cost effectiveness.

In order to avoid supporting the structures on the existing mine spoil fill, deep foundations extending through the fill to the underlying bedrock would be required. Three different deep foundation alternatives were considered including driven piles, drilled piles and straight shaft caissons. The underlying bedrock was considered adequate for support of pile or caisson foundations and any deep foundation alternative would provide a greater level of safety with respect to differential settlements. However, the 50+ ft thick layer of existing, uncontrolled fill made all deep foundation options difficult and costly.

Driven piles, whether steel, concrete or timber, were not considered technically feasible due to the abundance of cobble to boulder size rock fragments in the fill matrix. Random boulders would act as obstructions to the piles and severe deflections of piles during driving would be likely. Additionally, piles inadvertently founded on boulders within the fill mass would be prone to excessive settlements. Straight shaft drilled caissons represented a technically feasible but costly and impractical deep foundation alternative. The drilling of large diameter shafts through the existing fill was expected to be very difficult, time consuming and expensive. Due to the difficulties and costs associated with caisson foundations, we did not recommend their use for this project.

Finally, small diameter drilled piles, or mini-piles, were considered for deep foundation support. Mini-piles consist of cast-in-place, reinforced, grouted members that extend through the overburden material and into the bearing stratum. Their capacity is derived from the bond strength developed between the grout and the bearing stratum. Typically 8 inches in diameter or less, mini-piles offer the advantage of being less expensive and less difficult to install than the larger diameter caissons. We estimated that embedment depths of 10 to 15 ft into the underlying rock stratum would be necessary to construct 5-1/2 inch diameter mini-piles with load carrying capacities of 32 to 58 tons each. In lieu of ground improvement, all floor slabs and underslab utilities would have to be structurally supported and significant differential settlements between buildings and the surrounding grounds would be expected. We presented mini-piles as a deep foundation alternative but due to the potentially high costs associated with their installation, this option was not recommended.

Support of shallow foundations on mine spoil that had been partially undercut and replaced with compacted structural fill was evaluated. Although this option was considered technically feasible, it was not considered practical for this project. We estimated that undercut depths of 8 to 12 ft would be required beneath and within 10 ft of all buildings. This would have resulted in massive excavations requiring large stockpiling operations and expensive temporary storm water control measures. Exposing large, deep excavations to the elements would increase the potential for disturbance of the undercut subgrades, possibly resulting in additional undercut, expense and construction delays. For these reasons, this option was not recommended.

We proceeded to evaluate the possibility of using shallow foundations supported on modified ground for this project. Structures planned for the proposed prison complex were not exceptionally heavy and the structural engineer indicated that allowable soil bearing pressures of 2500 to 3000 psf would be sufficient for the shallow foundation design. In addition to this target allowable bearing pressure, a maximum settlement criteria of 1 inch total and ½ inch differential was specified.

Ground Improvement

Factors affecting the selection of appropriate ground improvement methods included the planned construction; physical properties of mine spoil fill including grain size distribution, plasticity, water content and rock content; composition and depth of the existing mine spoil fill; and groundwater conditions. We also considered the results of past ground improvement projects in similar types of material. Based on our evaluation, we concluded that dynamic compaction would be effective at this site. To meet the bearing pressure and settlement design criterion, it would be necessary to substantially improve the upper 20 ft of mine spoil fill. This depth represented the probable foundation influence depth for the proposed structures. The VDOC had concerns about the fact that the depth of mine spoil fill remaining beneath structures after site grading was completed would be on the order of 50 to 60 ft. They also had concerns about the dynamic compaction technique since this method had not previously been used on a VDOC project. To alleviate these concerns, surcharge preloading was recommended to improve the deeper mine spoil fill which would not be affected by dynamic compaction. The surcharge preloading would improve these deeper materials to reduce the potential for continued settlement under their own weight and the weight of new structural fill.

Dynamic Compaction. This procedure involves using a crane to repeatedly drop a heavy steel tamper, typically 10 to 30 tons, from a height of 50 to 80 ft along predetermined grid patterns and at foundation locations. A photograph of a crane lifting a high energy tamper at the Red Onion Mountain site is shown in Fig. 3. The process is continued until certain ground response and settlement criteria are met. The dynamic compaction process creates a stiff, rigid raft or mat of improved material that is suitable for structural support. The objective of dynamic compaction for this project was to improve the strength and compressibility characteristics of the upper 20 to 25 ft of existing mine spoil fill to reduce settlements under the weight of new fill and building loads. The recommended coverage area included the footprints of all buildings plus a 20 ft offset beyond building wall lines in all directions. The process is most effective in rocky materials and granular soils but is also effective in low plasticity fine-grained soils. Insitu moisture contents and groundwater conditions are also important when evaluating the applicability of dynamic compaction. The material properties of the mine spoil fill indicated that dynamic compaction should be quite effective at achieving the desired objective at this site. The relatively low natural moisture contents of the mine spoil samples tested and the deep groundwater table were also expected to provide a favorable environment for dynamic compaction. Additionally, regional dynamic compaction contractors reported previous success using this procedure in similar mine spoil deposits.

Fig. 3 - Crane lifting a 15-ton weight 70 ft

Surcharge Preloading. As previously mentioned, continued settlement of deeper mine spoil fill materials unimproved by dynamic compaction was of concern to the owner. Therefore, we recommended supplementing the shallow improvement program with surcharge preloading to induce settlements of these deeper fill materials that would otherwise take years to occur. The procedure involves adding a specified amount of weight, usually consisting of earth and rock fill, to the improvement area. This surcharge fill is then left in place while settlements are monitored. When the field readings indicate that settlement has essentially ceased, the surcharge is removed and construction proceeds. For this project, we recommended a surcharge height of at least 15 ft in building areas and at least 10 ft in pavement and non-structural compound areas. The surcharge fill would consist of on-site materials compacted to a minimum in-place density of 115 pcf. The weight of preload in building areas was intended to be equivalent to about twice the total building weight. All surcharge preload fill was to cover buildings and pavements including a 30 ft offset in all directions. We estimated mine spoil settlements of up to 6 inches could occur under the weight of preload fill. Settlement was expected to level off after a period of three to four months although we recommended that a time period of six months be allocated for the surcharge portion of the ground improvement process.

Sequencing and Monitoring Procedures

In areas requiring new fill to reach final grades, we recommended performing dynamic compaction prior to placement of new fill. This would allow the existing fill soils to receive the full benefit of shallow improvement methods. In cut areas, the dynamic compaction would be performed after rough grading. We recommended leaving cut areas about 3 ft above finished grades to offset the expected ground loss caused by the dynamic compaction process. Surcharge preloading would be performed after dynamic compaction and after new structural fill placement. By placing surcharge preload last, all of the underlying materials, including deep existing fills, shallow improved fills and newly placed structural fills, would receive the benefit of the preload surcharge. Dynamic compaction was recommended for all building areas regardless of the amount of cut or fill required to reach final grades. However, building areas that required more than 20 ft of cut to reach final grades would not require preloading. The reasoning for this was that deep cut areas had effectively been preloaded over the past several years. Likewise, pavement areas receiving at least 10 ft of cut did not require additional preloading.

The effectiveness of dynamic compaction and surcharge preloading can be readily evaluated by observing and measuring ground response. We emphasized the importance of careful construction monitoring and provided guidelines for documenting and evaluating the ground improvement procedures. Evaluation of the overall effectiveness of dynamic compaction is usually based on insitu testing of the improvement area before and after the process. Typically, Standard Penetration Tests (SPT), pressuremeter testing and dilatometer testing reflect improvements in the dynamically compacted zone. However, information collected during dynamic compaction, including ground loss, the number of drops at each drop point, crater depths and the amount of heave caused by the energy application, is also helpful in evaluating effectiveness and the need for procedural adjustments during construction. The final judgement of the effectiveness of dynamic compaction should be based on the available compaction records, the insitu test data and the experience of the geotechnical engineer. The effects of surcharge preloading can also be measured directly using settlement monitoring points.

For this project, we recommended placing 31 steel settlement plates across preload areas. The plates were placed on the soil subgrade prior to preload fill placement. Steel riser pipes extending from the base plates were extended upward as the preload fill was placed. The typical settlement plate detail included on the project plans for this project is shown on Fig. 4. Note the outer sleeve surrounding the steel riser pipe. The purpose of this sleeve was to prevent downdrag forces caused by the surcharge fill from influencing settlement plate readings. Once the preload fill reached full height, monitoring of elevations at the tops of riser pipes began. Periodic survey readings reflected any subgrade settlements that occurred at the monitoring plate locations. Plots of settlement versus time were then analyzed to evaluate the progress of mine spoil settlements.

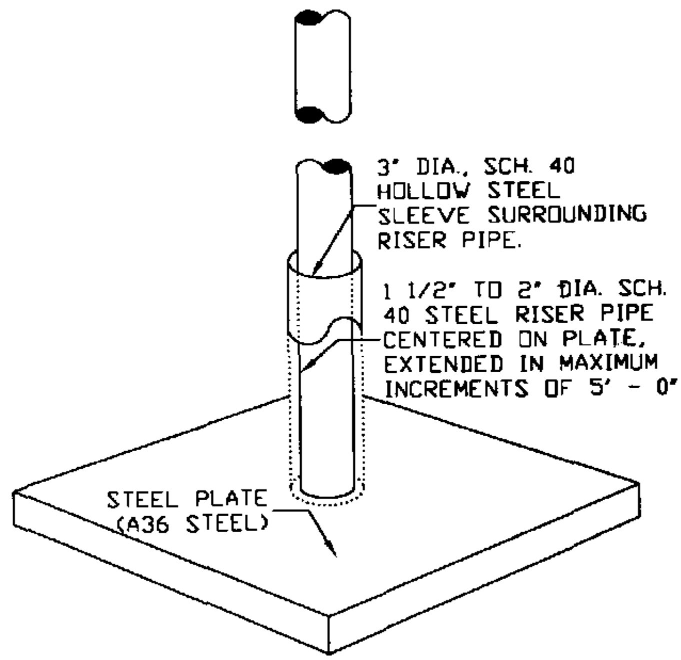

Fig. 4 - Settlement plate detail

PRE-CONSTRUCTION PREPARATION

Specifications

Dynamic compaction specifications can be method-based or performance-based. A method specification defines precisely how the work will be performed while a performance specification states the objective of the dynamic compaction program and leaves the method of achieving that objective to the contractor. For this project, a method specification was used to ensure that the dynamic compaction program adequately improved the mine spoil fill to an allowable soil bearing pressure of 3,000 psf. Mr. Bob Lukas, with Ground Engineering, Inc., assisted the designer with preparation of the specifications, which included a minimum compactive energy of 220 metric tons/m^2 to improve the mine spoil fill for building support.

The specified dynamic compaction program consisted of three high energy phases and one low energy phase across all building areas with a minimum 20 ft offset in all directions. The first high energy phase consisted of drop points on a 15 ft square grid spacing while the second high energy phase consisted of a 15 ft square grid at the intermediate points resulting in a diamond grid pattern. At each grid point, energy application consisted of dropping an approved, high energy tamper eight times from a height of 70 ft. The high energy tamper was defined as a 15 ton steel weight with a distributed contact pressure between 900 and 1500 psf. After the first high energy phase, the work area would be graded by pushing in the craters. Leveling would be followed by the second high energy phase. After the second phase was completed, the working area would again be graded and the third phase would be performed. This final high energy phase consisted of dropping the heavy tamper three times at each foundation grid point from a height of 70 ft. Grid points along wall footing lines would be located at 8 ft centers while column footings would receive one to four grid points depending on their size.

After all high energy phases were completed, an ironing phase was applied to the working area. The ironing phase was intended to compact the near surface materials disturbed during the high energy application. This low energy phase consisted of dropping a lower contact pressure tamper (around 400 psf) from a height of 25 ft. The ironing phase would consist of continuous coverage of an area with two blows at every location. Specified grid patterns are shown on Figs. 5(a), 5(b) and 5(c).

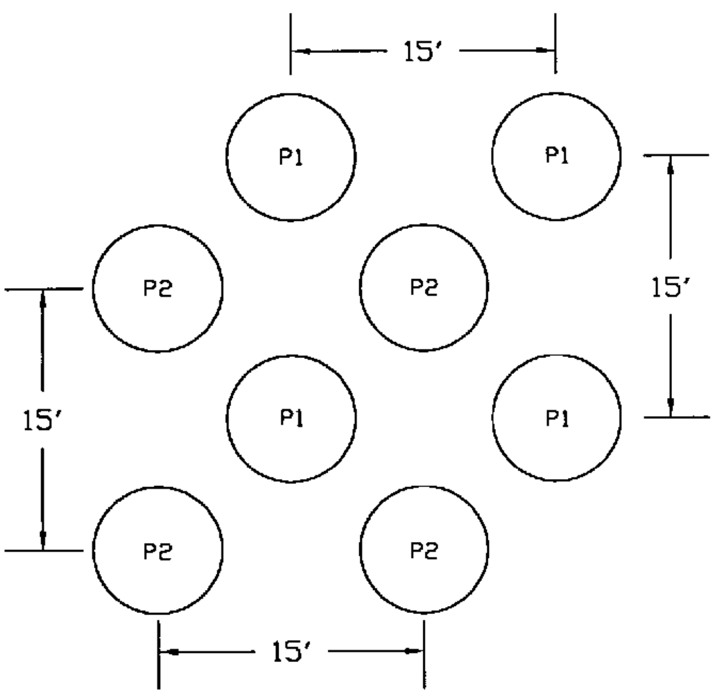

Fig. 5a - Specified Drop Point Patterns - High Energy Phases 1 and 2

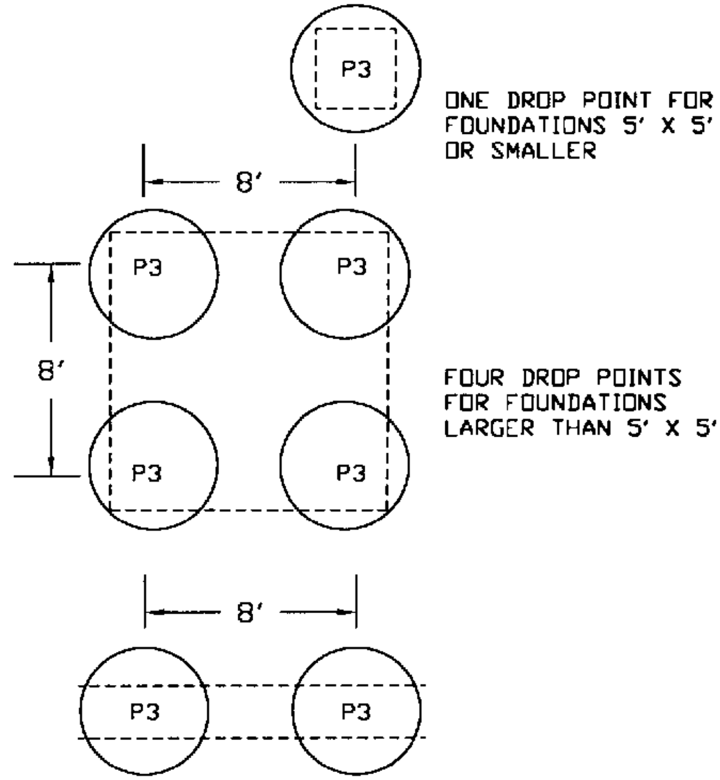

Fig. 5(b) - Specified Drop Point Pattern - High Energy Foundation Phase

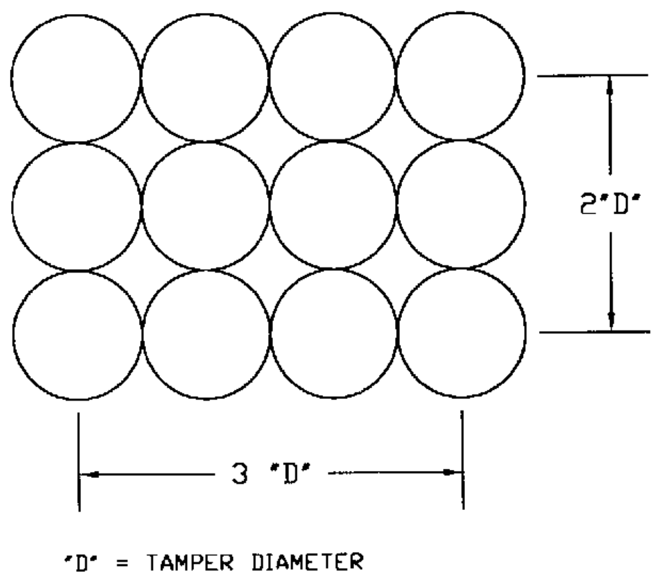

Fig. 5(c) - Specified Drop Point Pattern - Low Energy (Ironing) Phase

In addition to defining the energy application, the specifications also defined certain tolerances to be observed; outlined procedures for evaluating effectiveness of the dynamic compaction program; and provided general guidelines for the dynamic compaction process. Where crater depths exceeded 5 ft before full energy application (i.e. < 8 blows), the phase would be broken up into two or more passes until the full energy was applied. If crater depths were repeatedly greater than 5 ft, stone backfill and additional drops would be required.

Heave around craters during dynamic compaction is an indication that wetter, fine-grained soils are present in the area or that the energy application may be causing localized bearing capacity failure of the underlying material. In these instances, some of the applied energy is going towards heaving the soil rather than densifying the soil as intended. To deal with these situation, the specifications defined a maximum allowable heave of 4 inches. If heave greater than this was recorded in the field, energy application was to cease at that location and the remainder of the energy would be applied later as another pass. The specifications also required that the contractor wait for a period of at least two days between primary and secondary phases to allow elevated pore pressures to dissipate before additional energy application.

Procedures for evaluating dynamic compaction as defined in the specifications included surveying of ground loss and insitu testing. To determine ground loss induced by dynamic compaction, survey readings of the ground surface would be taken on a 50 ft grid spacing before and after energy application. An average ground loss of 1 to 2 ft was required prior to acceptance of an area. Additional evaluation could consist of pre- and post-dynamic compaction soil borings with insitu testing to evaluate relative improvement of mine spoils due to the compactive effort. This testing could consist of SPT testing, pressuremeter testing or dilatometer testing. Results of these tests would be evaluated by the geotechnical engineer and used at his discretion in the evaluation of dynamic compaction effectiveness.

SITE PREPARATION

Background Testing

Additional subsurface exploration and insitu testing was performed prior to the commencement of dynamic compaction for the purpose of collecting background data. Test borings were typically extended to depths of 20 ft, the maximum depth of improvement expected during the dynamic compaction. SPT, pressuremeter and dilatometer testing was performed.

Additional useful data was obtained during the background exploration to supplement the large number of SPT N-values collected during the original exploration. Unfortunately, the results of pressuremeter and dilatometer testing were not as successful. The pressuremeter (a long cylindrical instrument) and the dilatometer (a flat, spade like device) are downhole devices that can be used to estimate the soil modulus of insitu materials.

After the pressuremeter or dilatometer is seated in the ground, the test is performed by expanding a membrane or circular plate against the insitu materials and recording the pressures during the test. Due to the very rocky and heterogeneous nature of the fill material, obtaining reliable pressuremeter and dilatometer test results proved to be very difficult. To seat the pressuremeter, a relatively undisturbed pilot hole was made by pushing a 3 inch diameter split spoon about 2.5 ft into the mine spoil material. Rock fragments in the mine spoil often acted as obstructions to the large split spoon preventing the drillers from creating usable pilot holes. Where tests were performed, the membrane was typically punctured by the angular rock fragments or the test results were erratic and unreliable. Unlike the pressuremeter, the dilatometer is pushed into the ground with tests performed at frequent intervals, typically every 8 to 12 inches. The test consists of recording the pressure required to expand a small circular plate against the adjacent soils. Correlations between expansion pressures and soil properties can then be made. As with the pressuremeter, the abundance of rock fragments in the fill obstructed the advancement of the dilatometer in most cases. Where tests could be performed, the results where generally erratic and were considered unreliable.

Rather than relying on the questionable pressuremeter and dilatometer test results, we concluded that the only reliable insitu test in the mine spoil fill was the SPT test. That testing along with ground loss measurements after dynamic compaction would be used to evaluate the effectiveness of the program. To establish a standard for SPT evaluation, we reviewed all of the SPT data from borings performed prior to dynamic compaction. Typically, SPT values ranged from 8 to 14 in the upper 20 ft of the pre-improvement borings. From this information, we established a minimum average, post-dynamic compaction N-value of 15 for coarse-grained and non-plastic mine spoil fill. SPT N-values greater than 30 would not be considered in the average due to the apparent influence of rock fragments. Test results in cohesive, fine-grained soils would also not be considered in the average because their improvement comes with age and cannot be effectively measured using SPT testing performed shortly after compaction.

Dynamic Compaction Test Section

Prior to full-scale dynamic compaction, a test session was implemented to establish site specific guidelines for the application of energy and evaluation of the program effectiveness. Several lightly loaded structures located in a low area outside the secure perimeter of the facility were chosen as the test area. At the project's onset on March 1, 1996, the dynamic compaction subcontractor had two, 15 ton, 1500 psf high energy tampers and one 11 ton, 433 psf low energy ironing tamper on-site. After eight drops of the high energy tamper from the specified 70 ft drop height, craters with depths of about 8 ft were recorded at the first two drop points. Despite the excessive crater depth, no significant heave was observed and we concluded that the mine spoil in this area was exceptionally soft and loose. Exceeding the maximum allowable crater depth of 5 ft was not desirable since soil could cave above the tamper making tamper removal difficult. To avoid exceeding the maximum allowable crater depth of 5 ft, the high energy application was split into two or more passes with stone backfill added as necessary. To help reduce crater depths, the contractor began using a tamper with a contact pressure of about 900 psf.

A few modifications were made to the specifications based on the results of the test session. The maximum size of rock used as stone backfill in craters was increased from 9 to 15 inches due to the tendency for the on-site rock to break up into smaller fragments. Due to the relatively dry condition of the mine spoil fill, pore water pressure buildup was not considered a problem. Therefore, the two day waiting period between primary and secondary phases was waived provided moisture conditions remained dry. In a few instances, pockets of trapped water were encountered during dynamic compaction. This condition was corrected by pumping out the standing water and backfilling the crater with rock backfill.

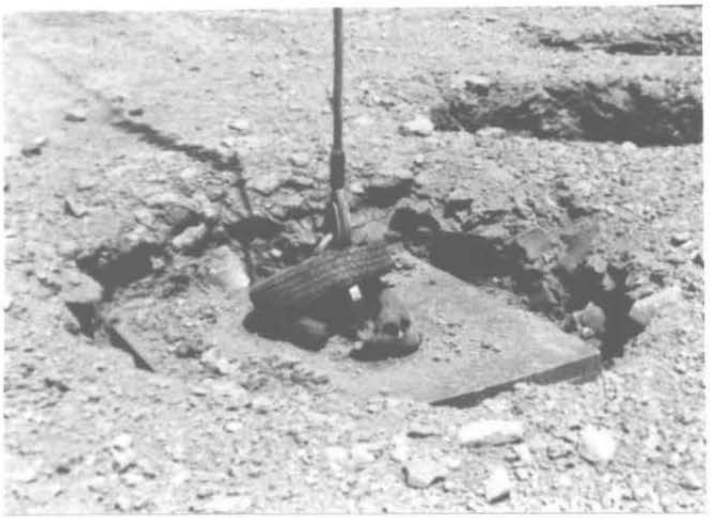

Fig. 6 - 15-ton, 900 psf tamper in crater after two drops

Full Scale Dynamic Compaction

Full scale dynamic compaction proceeded in low areas of the site while the grading subcontractor began cutting and rough grading cut areas. Full-time observation and record keeping of the round-the-clock dynamic compaction operation was provided by Schnabel Engineering. Records included number of passes per drop point, number of drops per pass, crater depths per pass, completion dates for each crater, amount of heave and amount of rock fill required, if any. Based on the recorded ground response, the softest areas of existing mine spoil fill were located along the north perimeter of the site. These soft conditions were attributed to poor surface drainage characteristics in that area. Overall, the mine spoil was relatively dense with scattered pockets of softer material. Soils in areas of deep cut were generally denser than in areas where no cut was performed due to the preloading effects of the overlying fill. Both the 1500 psf and 900 psf tampers were used throughout the project. The contractor switched between these two weights based on the ground response. In general, the lower contact pressure weight was more effective in the finer grained mine spoil while the higher contact area tamper worked better in the rocky mine spoil material.

Fig. 7 - Field of craters in coarse grained mine spoil fill

The overall effectiveness of the dynamic compaction operations was evaluated based on ground loss measurements and on the results of post-dynamic compaction SPT testing. The results of these measurements and tests indicated that the desired results had been achieved. Ground loss measurements taken after completion of the dynamic compaction generally indicated average settlements of 1 to 2 ft. In deep cut areas, somewhat less ground loss was measured, typically 0.5 to 1 ft. The lesser amount of ground loss was attributed to the effects of preloading due to overlying fill and was considered acceptable. SPT testing performed in post compaction soil borings indicated the coarser grained material met the minimum average criteria of 15 that had been established. The finer grained soils typically exhibited N-values less than 15, as expected. Adjustments made to the dynamic compaction program based on field observations were instrumental in the success of the shallow ground improvement.

Surcharge Preloading

After acceptance of dynamically compacted areas, the grading subcontractor proceeded to place compacted structural fill and then preload fill. To monitor the progress of subgrade settlements beneath the weight of the surcharge fill, a total of 31 settlement plates were placed across the preload fill areas. Following completion of preload fill in a given area, surveying of settlement plates to 0.001 ft by a registered surveyor was begun. Readings were taken twice weekly and were plotted versus time to establish time-settlement curves for each settlement plate. A representative settlement plot from the project is shown on Fig. 8.

In most cases, the majority of the recorded settlement occurred in the first couple of weeks following completion of preload fill placement. Generally, settlement began to level off within about 20 to 30 days following the completion of preload fill placement. Total settlement recorded at the plate locations was typically in the 1 to 2 inch range. However, we expect that a significant amount of unrecorded settlement occurred during placement of the preload fill. The contractor was permitted to remove the surcharge fill after all of the settlement plates in a given area had essentially ceased movement for a period of two weeks. On average, this condition was met after a period of 90 to 120 days. Following surcharge removal, the contractor proceeded with foundation construction.

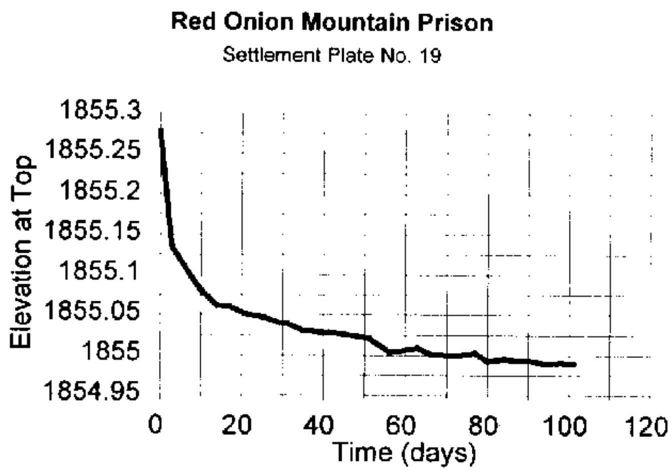

Fig. 8 - Typical time-settlement curve

CONCLUSION

Periodic monitoring during the year following ground improvement has not indicated any appreciable settlement of the building pads. The mine spoil fill material reacted favorably to the ground improvement efforts due to a number of factors including material composition, moisture and groundwater conditions and methods of application. The improved mine spoil is expected to provide adequate support throughout the useful life of the structures. The experience and knowledge gained from this project should be useful in the development of similar sites throughout the region.

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