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Pursuing Dynamic Compaction

Waste Age
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Rapid growth of development in metropolitan areas during the past few decades has created a shortage of virgin land for development. This has forced developers to consider properties that have been used in the past for disposal of waste or properties that were created by filling temporary lakes or borrow pits using municipal solid waste (MSW), construction and demolition (C&D) debris, or clean fill generated from recycling of C&D debris. Interested parties may consist of commercial and industrial developers who develop warehouses, shopping plazas or strip malls. These parties may also include solid waste operators that are seeking to design and permit a lateral expansion to their existing landfill over an adjacent vacant area that has previously been filled with waste, C&D debris or clean fill.

In order to make the land suitable for redevelopment, the subsurface must be stabilized to prevent future settlement that can threaten the structural integrity of any development over waste or fill. This is typically performed by dynamic compaction. Dynamic compaction involves creating large impacts at the ground surface by repeatedly dropping heavy tampers from a significant height off a crane derrick. Tampers are typically cast concrete blocks weighing up to 30 tons. The drops are performed on a grid pattern, with subsequent passes performed between the locations of the former passes. The high-energy impact creates a subsurface shock wave that densifies the subsurface material and reduces the void ratio, thereby improving its engineering properties.

This article discusses several aspects of the use of dynamic compaction at certain types of solid waste sites.

Types of Solid Waste Sites

The types of solid waste sites that are normally considered for development are old dumps, old C&D debris disposal areas, and borrow lakes filled with regular waste, C&D debris or clean fill. Dynamic compaction may also be used to prepare land for lateral expansion of existing landfills over adjacent areas that have previously been filled with MSW or C&D debris. Furthermore, lateral expansions may also take place over an adjacent pond or lake that will be filled as part of the expansion project with clean soil and dynamically compacted to densify the fill material pushed into the pond or lake.

Design Considerations

The design of dynamic compaction programs should be carried out in consideration of field conditions and several other parameters. This section provides a brief discussion of each consideration.

Lateral Waste Delineation– The preliminary step typically involves reviewing historic aerial photographs available at county offices or from other sources. For a site with shallow ground water table, the depth of the original excavation would not be discernible from aerial photographs; however, the approximate lateral extent can be determined. Other sources can also provide essential relevant information, such as historic topographic maps and governmental records regarding the former waste disposal or filling.

The excavation of test pits can further reveal the lateral extent of waste. It is strongly suggested that the lateral extent delineation obtained from historic records be confirmed by performing test pits in the field. This is important because significant disposal or filling might have occurred during the data gaps in the records (e.g., additional filling might have occurred in the time between the years of available aerial photographs). Furthermore, although governmental records might indicate a permitted extent of filling, the operators might have filled beyond this boundary.

Vertical Waste Delineation– Boring into the natural ground below the existing waste mass can delineate the vertical extent of waste. The frequency and layout of borings depends on the geometry of the fill area and other background information available from other sources. Determination of the maximum depth of waste should be the primary goal of the vertical borings. However, these borings can also be used to confirm the types of wastes disposed of at the site. Filling with improper materials is common, especially with older sites.

Distance From Ground Surface to Ground Water– The distance between the existing ground surface and the ground water table should be known. Normally, a minimum of 5 feet is considered a reasonable distance for performing dynamic compaction. If the existing distance is less than 5 feet, a layer of soil will be placed over the existing surface to increase the distance to 5 feet before dynamic compaction begins. The 5-foot distance provides a sufficient buffer between the bottom of the crater formed by dropping the weight and ground water.

The concern is that water entering the crater reduces the amount of energy transmitted to the underlying material, thereby compromising the effectiveness of the dynamic compaction process. Depending on the type of material below surface, the depth of the resulting crater can reach as deep as 3 feet. A distance larger than 5 feet between the existing ground surface and the ground water table (i.e., the addition of soil) should be considered if the depth of resulting crater is anticipated to exceed 3 feet.

Minimum Energy– Using empirical equations available in literature, the minimum required energy at the impact point of the weight to the ground surface will be calculated as a function of waste thickness below surface. Professional judgment will be required for the use of waste thickness to determine the minimum energy in cases where the waste thickness is high and the proposed structure is lightweight. In such cases, a waste thickness less than the actual in-place waste thickness may be used. This involves estimating how deep the structure load is anticipated to extend and what level of densification might be needed for the in-place waste. The engineer must consider the type of waste below surface for partial depth densification.

Safety Factor– The design energy will be calculated by applying a safety factor to the calculated minimum energy. The magnitude of the safety factor depends on the settlement tolerance of the proposed structure above the compacted surface. If the proposed structure can tolerate a higher degree of settlement, the safety factor can be lower. For example, in the case of a landfill lateral expansion over a dynamically compacted area where the expansion area will be covered by a lining system that can tolerate up to 5 percent elongation in liner material, then a lower safety factor may be chosen.

Conversely, in the case of constructing a warehouse concrete slab over a compacted area with a settlement tolerance of no greater than 1 inch, the selected safety factor should be large. The design energy will be the minimum level of energy that the dynamic compaction program must apply to the ground surface.

Selection of Dynamic Compaction Parameters– Determination of the dynamic compaction parameters is an iterative process. The dynamic compaction parameters are number of passes, weight of the tamper, drop height, grid spacing, number of drops and drop locations. The number of passes is normally three, referred to as the primary, secondary and tertiary passes.

The designer may require an ironing pass at the completion of the tertiary pass. The ironing pass involves dropping the tamper at an irregular pattern over the compacted surface with the intent of smoothing undulations and creating a relatively even surface. Weight of the tamper, drop height, grid pattern, grid spacing and number of drops are all iterative parameters that will be finalized by the designer after a few design phases. Drop locations are normally determined by placing drop locations of each successive pass in the middle of the un-compacted area within the drop locations of the prior pass. By this process, the overall spacing of drop locations becomes smaller by each pass.

Following selection of numerical values for the parameters, the energy applied to the ground within a grid area will be calculated. If the calculated energy is less than the design energy, the next design iteration begins by varying the value of one or more of the parameters, and calculations are repeated. This process continues until the calculated energy applied to the ground surface exceeds the design energy.

Dynamic Compaction Performance

Under certain conditions, performance of the dynamic compaction must be verified at the request of the owner or by the engineer to reduce future liabilities associated with any settlement and impact of that settlement on the integrity of the structure above. There are several ways to assess foundation improvement after performance of the dynamic compaction. These methodologies are briefly discussed below.

Standard Penetration Test (SPT) Blow Counts Before and After Dynamic Compaction – Borings may be performed to the full depth of waste with SPT blow count measurements before and after implementation of dynamic compaction. The borings after implementation of the dynamic compaction should be located within 1-2 feet of the boring location before the dynamic compaction. Additionally, the location of the boring before dynamic compaction must be chosen so that it falls directly below a drop point. The change in the blow count numbers from the before to the after events will represent improvement of the foundation due to the dynamic compaction.

Construction of a Load Pad – A temporary load pad may be constructed after implementation of the dynamic compaction. Settlement plates will be installed in the load pad and regularly surveyed for a period of three months to determine foundation settlements below the load pad. Final settlement numbers based on the survey of the settlement plates may be used to predict long-term anticipated settlement under a surcharge load that is equivalent to the load pad.

Post Loading – Soils needed for construction of the development may be stockpiled over the dynamically compacted area to surcharge the area. There will typically be no instrumentation in the stockpile, instead simply relying on the surcharge loading of the pile. Soil will be gradually removed from the pile as development progresses.

Implementation Considerations

Distance to Ground Water – As discussed previously, generally a minimum of 5 feet is needed between the pre-compaction surface and ground water at the time of implementing dynamic compaction. Depending on the type of material below surface, the depth of the resulting crater can reach as deep as 3 feet. Energy transfer takes place more efficiently if no water exists in the crater, so the 5-foot distance plays an important role in the proper application of energy to the subsurface medium.

Observation by a Third Party – Proper drop and proper landing of the tamper are important factors in applying sufficient energy to the ground. To ensure these factors are adequately maintained during the implementation of dynamic compaction, a third party, normally referred to as the construction quality assurance (CQA) monitor, is present on site throughout the dynamic compaction project to observe operations. The CQA monitor keeps counts of drops, observes that the tamper has been lifted to the proper height, and observes that the vertical landing of the tamper on the ground (or in the crater) occurs properly.

If the tamper is not lifted to the proper height, lesser energy will be applied to the ground upon landing. If the tamper does not land flat on the ground (or inside the crater), lesser energy will be applied to the ground. The CQA monitor also regularly monitors the condition inside the crater to make sure no ground water is sucked up into the crater. If water is observed in the crater, the CQA monitor stops the weight dropping operation until soil is pushed into the crater to create a dry condition at the bottom of the crater. Drops that do not meet project requirements will not be counted toward the total count required for the location.

Flagging Drop Locations – Proper overlapping of energy applied to the ground also depends on proper grid locations. Drop locations should be flagged by field measurements or by a surveyor to ensure that energy applied to the ground has a symmetrical pattern and equal overlapping effect from one location to another as per the design plan.

Filling Craters – After completion of each pass and before applying the next pass, craters must be filled with competent soil. The earthwork contractor can push soil into the craters using a dozer. The filled area should be tracked a minimum of five times under the dozer tracks. A compactor requires no static or vibratory compaction.

Ironing Pass – The need for the ironing pass depends on the type of the project. If the developer would like to have a smooth and flat final ground surface at the completion of the dynamic compaction, the ironing pass would be very useful to achieve the intended surface grade. If the developer intends to add, cut or regrade the area after completion of the dynamic compaction, the ironing pass may not be necessary. Compaction by a vibratory roller is highly recommended during regrading of the area.

Vibration – The contractor and the owner of the project must remain sensitive to the degree of vibration transmitted to adjacent properties and buildings during compaction efforts. This is a very important liability issue that if not addressed can potentially expose both the owner and the contractor to future claims. The owner should remain in contact with adjacent property owners and building occupants before commencement of the project and throughout the project to have sufficient information about vibrations experienced by the individuals.

Depending on the sensitivity of the project and cooperation of the adjacent building occupants, the owner may consider performing vibration measurements at the property boundary. Measurements should be documented and kept in the project records for discussions with adjacent building occupants. Vibration measuring devices are commercially available and firms that are specialized in conducting such measurements can provide all necessary services. Vibration thresholds may exist in local municipality codes of ordinances.

Cost Considerations

While the cost of implementing dynamic compaction varies from project to project, the engineer needs to be aware of various activities that might be involved in completing the dynamic compaction project successfully. The list below shows cost items that may have to be considered for budgeting purposes, but by no means is it inclusive of all factors:

- Acquisition of historic aerial photographs, topographic maps, and/or governmental records
- Test pits to determine lateral extent of fill below surface
- Drilling investigation to ascertain thickness of waste or debris
- Determination of depth to the water table
- Survey of the existing ground surface
- Design plans, permitting, and bidding
- Mobilization of dynamic compaction contractor and earthwork contractor
- Purchase and placement of soil to establish the minimum 5-foot distance to ground water
- Flagging drop locations
- Performing dynamic compaction
- CQA monitoring
- Performing vibration measurements
- Purchase and placement of soil in craters and preparing ground surface after each pass
- Survey of the final surface
- CQA report summarizing activities and observations

Generally, the mobilization/demobilization cost of dynamic compaction equipment (including assembling at mobilization and breakdown at demobilization) is around $35,000. The compaction work is normally performed per square feet of the project area. Depending on the number of passes, grid dimensions and size of the project, cost can vary from $1 per square foot to more than $2 per square foot. The design of a dynamic compaction program may vary from $20,000 to $40,000 depending on the complexity of the project. The cost of CQA monitoring may be around $1,000 per day. The earthwork contractor and soil purchase price is market dependent and varies based on locality of the project.

Sample Projects

The authors have been involved in numerous dynamic compaction projects related to solid waste sites. A few examples are listed below:

Commercial Development, Pompano Beach, Fla. - A commercial development that was constructed above an old landfill involved dynamic compaction of the underlying waste. The project involved construction of a 58,000-square-foot (sf) warehouse over an area of the landfill with a waste thickness reaching 30 feet below land surface.

Industrial Development, Pompano Beach, Fla. – An industrial development including four warehouses, ranging from 110,000 sf to 155,000 sf, was constructed over a lakefill area. The lake had been filled with clean debris to a maximum depth of 40 feet. Dynamic compaction was used to densify the foundation before construction of the building pads and slabs.

Industrial Development, Pompano Beach, Fla. - An industrial development including three warehouses, each 80,000 sf, was constructed over a lakefill area. The lake had been filled with clean debris. Dynamic compaction was used to densify the foundation before construction of the pads and slabs.

Landfill Expansion, Medley, Fla. – A 27-acre landfill lateral expansion was constructed over a lakefill area. The lake had been filled with construction and demolition debris to a maximum depth of 35 feet. The foundation was improved by implementing a dynamic compaction program. Disposal cells were constructed following completion of the dynamic compaction.

Landfill Expansion, Medley, Fla. - An 8-acre landfill lateral expansion was designed and permitted to be constructed over a lakefill area. The lake was filled with clean debris to a maximum depth of 40 feet. The foundation was improved using dynamic compaction. Disposal cells are scheduled for construction in 2015.

Landfill Expansion, Pompano Beach, Fla. - A 7.5-acre landfill lateral expansion was designed and permitted to be constructed over a lakefill area. The lake is currently being filled with clean debris from recycling of C&D debris. The maximum depth of the lake is 35 feet. Improvement of the foundation is scheduled for 2014 using dynamic compaction. The disposal cells are scheduled for construction in 2015.

***I*ndustrial Scales, Pompano Beach, Fla.** – A 3-acre area was dynamically compacted to improve foundation for construction of four 60-foot long tractor-trailer-sized scales. The foundation below the dynamic compaction area included 20 feet of old residential waste. The scales were constructed following completion of the dynamic compaction. Approximately 1,000 trucks traffic over the scales on a daily basis.

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