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Investigation of Dredge Material Dewatering Through Hydraulic and Ground Improvement Methods

Monica Moody
mlm261@zips.uakron.edu

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Submitted To: The University of Akron Williams Honors College

Submitted by: Monica Moody

Department of Civil Engineering

The University of Akron

Akron, OH 44325

Email: mlm261@zips.uakron.edu

Project Sponsor: Dr. Zhe Luo

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Abstract

Every year almost 1.5 million tons of material is dredged from Lake Erie to allow passage for boat traffic. In the past, this material has been placed back into the open waters of the lake. However, starting July 2020 this will no long be permitted due to the passing of Senate Bill 1. Therefore, secondary uses of this dredging material are being investigated. To be used, the material needs to be quickly dewatered and stabilized. This project consists of literary reviews of two methods of rapid dewatering, hydraulic placement and ground improvement methods. Hydraulic placement dewatering requires the use of a sedimentation basin or lagoon. Ground improvement methods consists of surface draining systems. This can include trenching, hydraulic fracturing using sand-slurry injection, vacuum-assisted underdrain systems, dynamic compaction, and much more.

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1. General Dredging and Dewatering

Dredging is the removal sediment from the bottom of a body of water to allow the passage of ships through cannels and harbors, as well as to manage environmental impact of sediment. This is conducted through the use of a hydraulic dredge. There are two types of hydraulic dredges, hopper and pipeline dredging, both which remove sediment and water through a vacuum like process. Hopper dredges are large ships with containment areas inside them for dredge material and pipeline dredging involves a pipe system being attached to a ship. A third method is through mechanical dredging which uses machinery to scoop the material from the bottom and then places it in a barge. Regardless of the method, dredged sediment and material are then sent to disposal areas ("Dredging Facts"). In Ohio, dredging results in the removal of nearly 1.5 million tons of material annual, much which is placed back into Lake Erie. However, as a result of an Ohio Environmental Protection Agency project to "improve Lake Erie water quality by addressing potential impacts from dredged material", open water placement will no longer be permitted, and all dredged materials will be sent to confined disposal facilities (CDLs) or be repurposed for beneficial reuse ("Lake Erie Dredged Material Program."). In both cases, the material must first be dewatered to reduce storage space and increase the ability for use.

The type of sediment obtained from dredging depends on the location of the dredging sight along with where in the waterway it is removed. Main approaches from oceans are typically sand, bar channels material is primarily coarse-grained sand, entrance channel to harbors are sand to fine-grained silt and clay, harbors and ports mainly result in silts and some sands, and intracoastal and river channels, such as those in northeast Ohio, are mostly silt and sand ("Dredging Facts"). Dredged material has very high-water content, low hydraulic conductivity, and low shear strength. These properties and the characteristics of the dredged sediment make choosing the correct dewatering method very important. Space for the chosen dewatering system, cost of installation and operation, and required time duration of dewatering are other important factors that need to be taken into consideration. This paper will give an overview of hydraulic dewatering methods, which utilize sediment settling, including sediment basins and lagoons, and ground improvement methods which consists of physical modification soil properties to dewater, including trenching, dynamic compaction, prefabricated vertical drains, PVC well points, hydraulic fracturing, vacuum-assisted underdrain systems, and electroosmotic.

2. Hydraulic Placement

Hydraulic placement of dredged material in sediment basins and lagoons utilizes the principles of particle settling to separate water from sediment. Resulting material still have high water contents and can be further dewatered through ground improvement methods or mechanical methods (not discussed in this paper).

2.1. Sediment Basin

Sediment basins or settling tanks are used in sedimentation, the separation of solid particles from water using gravity. Typically, flocculation can be used in conjunction with settling basins to create larger particles to settle out. Settled particles form a sludge at the bottom of the basin. The sludge is then removed by a scraper or sludge rake and collected in a hopper. The sludge is then further dewatered through other methods such as mechanical devices (Reynolds & Richards).

Sediment basin volumes are designed with two components, the dewatering zone and storage zone. The dewatering zone is where particles are physically settles out of water and the storage zone is where sediment is stored after separation, as shown in Figure 1. The total volume of these two areas must be below the principle spillway elevation. When used in construction applications, the design volume is dependent on the area of runoff that the basin is accepting. Basin shape is also dependent on the length to width ratio, which is important to allow for optimum settling time of particles.

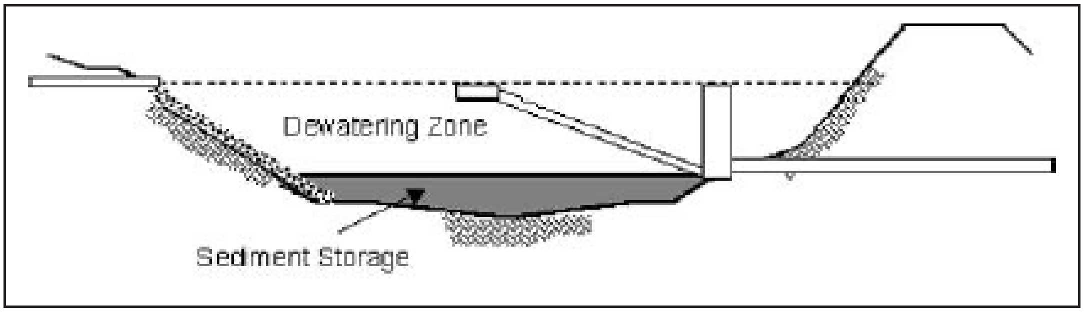


Figure 1: Settling basin dewatering zone and sediment storage (Mathews & Mecklenburg 2006).

The time for sediment to settle out of water is known as the detention time. As detention time increases smaller particles will settle to the bottom of the basin. According to the Highway Research Center at Auburn University, basins with a six-hour dewatering time had 2.7 times the amount of sediment loss through outflow than when a 24-hour detention time was used, and a seven-day detention time result of 30% less sediment loss than the 24-detention time (Perez et al. 2015). Baffles can be integrated into a design to increase the increase the flow length of a settling basin, therefore, increasing time. Baffles also decrease the turbulence of the flow into the basin which would decreases interference in the settling process. Solid baffles force water back and forth as it moves through the basin and porous baffles spread the flow over the entire width of the basin and the flow is slowed as it flows through the baffles. Porous baffles are more efficient and can be made of jute matting or plastic safety fence are used increase sedimentation (McLaughlin 2015). A diagram of porous baffles in a sediment basin can be found in Figure 2**Error! Reference source not found.**.

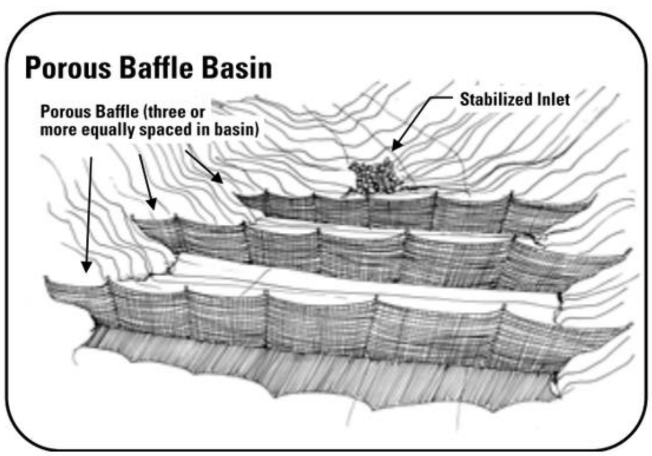


Figure 2: Porous baffles (McLaughlin 2015).

Sediment basins are most effective with sands and course particles rather than silts and clays. This is due to the settling velocity is based on particle density, particle diameter, and the drag coefficient. According to the Ohio EPA, the minimum dewatering time for sediment is 48 hours and the maximum time is 7 days.

It is important that water removed from sediment basins is taken from the top of the dewatering zone. This can be done using perforated risers, skimmers, or siphons (Mathews & Mecklenburg 2006). Perforated risers are typically corrugated aluminum pipe that has one or more column of holes along the side to allow water to pass through to be removed. Surface skimmers have been replacing risers and float at the top of the water, as shown in Figure 3 allowing what is typically the cleanest water to be removed.

Figure 3: Surface skimmer ("Skimmer in Action (21 photos)").

2.2. Lagoons

A traditional method of dredged material dewatering, lagoons or sometimes known as drying fields, removes water from material through evaporation and drainage. Pipes that are built into the drainage layer of the lagoon, to collect water and send it to a water treatment facility. Time required in a lagoon for dewatering to be achieves relies on sediment properties, such as density and particle size, as well as climate (Foged, S., et al.). Evaporation is the main dewatering method performed by lagoons (Reynolds & Richards). After the dewatering process is completed, which typically takes approximately a year in a moderate climate, material is then excavated from the lagoons and placed in a CDF. The drainage layer is then repaired, and the process repeated. Figure 4 depicts a lagoon dewatering facility.

Figure 4: Lagoon dewatering facility (Foged, S., et al.).

This process only produces material that is considered 45-50% dry solids, which makes it insufficient for compaction and requires sand to be used in the CDF to obtain stability. However, when paired with a settling basin, the results of lagoon dewatering are improved because material entering the lagoon will have around 25% dry material entering the lagoon rather than 15-20% when settling basins are not utilized (Foged, S., et al).

Drying lagoons have the advantage of being a simple, low-cost method of dewatering (Reynolds & Richards). However, they can occupy very large portions of land and take significate time to see results. Lagoons are open to air and therefore, surface runoff and rainwater may be added, increasing required drying time (Foged, S., et al.). Being open to air has the possibility of also causing odor annoyances such as odors+. Lagoons also hold environmental risk in the damaging of the drainage layer during material excavation. If this layer is damaged, dredged material and water could containment groundwater and soil.

3. Ground Improvement

Ground improvement dewatering consists of the modification of the physical layout or properties of the material to remove water. Land disposal of dredge material consists of dredge slurry being placed within the confinement of dikes where surface water is removed through weir or evaporation, similar to hydraulic dewatering methods. Where sediment is then exposed to the surface, a crust forms although the water table is still close to the surface. This makes farther drying unlikely and the surface is still exposed to rehydration from rainfall (Palermo 1977) . Ground improvement methods of dewatering look to farther remove water or lower the water table to allow material drying.

3.1. Trenching

Typically, open trenches have been used to remove surface water from construction and agricultural sites. They also can be utilized to draw the water table down to an appropriate level. These two concepts can be applied to dewatering of dredged material as one of the main problems is surface water rehydrating material.

In the Netherlands, progressive trenching has been completed. Progressive trenching means that trenches are gradually improved and made more effective in dewatering. Dredge material is placed in a three to four-foot layer initially, then approximately two months later an amphibious vehicle, such as the one shown in Figure 5, is used to create trench depressions that are typically two to four inches deep, spaced eight feet apart. Four months after these trenches are placed they are then depended to one foot. This method efficiently removes surface water from the material, allowing evaporation to farther dry it. It also draws down the water table which changes the soils from being in the submerged state to saturated state. This changes the unit weight of the material and therefore increase self-weight loading. The additional loading can initiate consolidation and more drainage.

Figure 5: Amphibious vehicle used for creating trenches (Atvhire).

3.2. Dynamic Compaction

Dynamic compaction uses a heavy tamper that is raised and then dropped from a cable to then impact the ground (Lukas 1995). The primary purpose of dynamic compaction is to increase bearing resistance, reduce settlement, mitigate liquification potential, and densify soils. This process is usually applied over a grid pattern of the area and sometimes will require multiple passes. The depth of impact, D, that the tamper will influence can be calculated by,

$$D = n(WH)^{.5}$$

Where W is the mass of the tamper in megagrams, H is the drop height, and n an empirical coefficient that typically ranges from 0.3 to 0.8. This coefficient is based on factors including efficiency of crane drop mechanism, total applied energy, soil type, soil layers, and contact pressure. Table 1 shows recommended n values for different soil types. Tamper masses typically range from 10 to 40 kips and drop heights range from 30 to 100 feet (Schaefer, et al. 2016).

Table 1: n values for varies soil types and saturation levels (Lukas 1995).

Soil Types	Degree of Saturation	Recommended n Value*
Pervious Soil Deposits- Granular soils	High Low	0.5 0.5-0.6
Semi pervious Soil Deposits- Primarily silts with plasticity index of <8	High Low	0.35-0.4 0.4-0.5
Impervious Deposits- Primarily clayey soils with plasticity index of >8	High Low	Not recommended 0.35-0.4 Soils should be at water content less than the plastic limit.
*For an applied energy of 1 to 3 MJ/m^2 and for a tamper drop using a single cable with a free spool drum.		

After passes with the tamper are complete, the ground is then leveled with a dozer or filled with granular material. Before dynamic compaction can be conducted soil must be classified through Stand Penetration Tests, Cone Penetrometer Tests, or Pressuremeter tests. Lab tests are also conducted to determine water content, grain size distribution, and Atterberg limits. This method of dewatering and compaction can be used with removal and replacement, vibro-compaction, grouting, and vertical drain systems as well.

The best soil properties for dynamic compaction are soils with a low degree of saturation, high permeability, good drainage, and granular including sands, gravels, building rubble, mine spoils, some industrial waste, and decomposed refused deposit. This method is the most applicable for loose cohesionless soils with a low fines content (Schaefer, et al. 2016). Silts, clayey silts, sandy silts will typically have permeability from 10^{-5} to 10^{-8} m/s which is lower than the ideal soil. These will require more passes with the tamper to allow excess pore water pressure to dissipate. In some cases, wick drains are installed to facilitate site drainage, which are discussed later in this paper. This is not the ideal method for impervious soils that are saturated or nearly saturated (Lukas 1995). Figure 6 depicts a phase diagram of soil behavior during dynamic compaction.

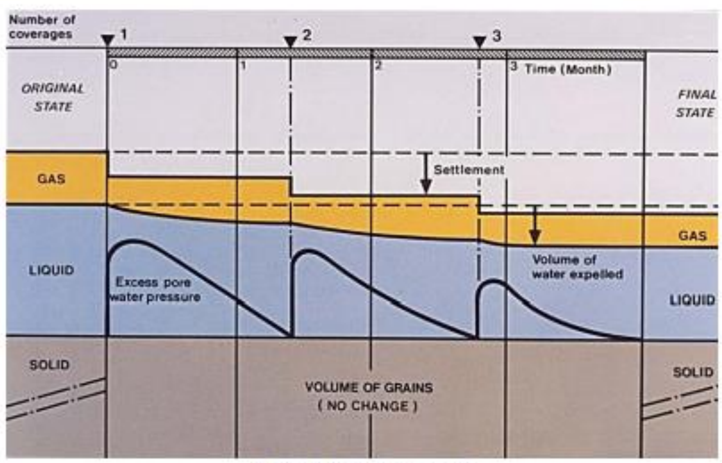


Figure 6: Phase diagram during dynamic compaction (Schaefer, et al. 2016).

Cost is one of the many advantages of dynamic compaction. Generally, it is the most economic form of site improvement. Table 2 shows the comparative costs of ground improvement methods according to US Department of Transportation Federal Highway Administration. This table does not include equipment or installation costs which are straightforward for dynamic compaction.

Table 2: Cost comparison of ground improvement methods (Schaefer, et al. 2016).

Category	Technology	Unit Cost
Vertical Drains and Accelerated Consolidation	PVDs, with and without fill preloading	\$0.50–\$4/lft
Lightweight Fills	Compressive Strength Fills: Geofoam; Foamed Concrete	\$75–\$150/yd^3
Lightweight Fills	Granular Fills: Wood Fiber; Blast Furnace Slag; Fly Ash; Boiler Slag; Expanded Shale, Clay and Slate; Tire Shreds	\$3–\$15/yd^3
Deep Compaction	Deep Dynamic Compaction	\$10–\$30/yd^2
Deep Compaction	Vibro-Compaction	\$5–\$9/lft
Aggregate Columns	Stone Columns and Rammed Aggregate Piers	\$15–\$60/lft
Column Supported Embankments	Column Supported Embankments	\$9/ft^2 + cost of the column
Column Supported Embankments	Columns: Non-compressible	\$30–\$80/lft
Column Supported Embankments	Columns: Compressible	\$20–\$100/lft
Soil Mixing	Deep Mixing (dry)	\$60–\$125/lft
Soil Mixing	Mass Mixing	\$15–\$75/yd^3
Grouting Technologies	Chemical Grouting	\$20/ft + \$0.65/gt
Grouting Technologies	Compaction Grouting	\$75–\$750/yd^3
Grouting Technologies	Bulk Void Filling	\$50–\$150/yd^3
Grouting Technologies	Slabjacking	\$6.50–\$9.30/ft^2
Grouting Technologies	Jet Grouting	\$250–\$750/yd^3
Grouting Technologies	Rock Fissure Grouting	\$25–\$80/ft^2
Pavement Support Stabilization Technologies	Mechanical Stabilization	\$1–\$5/yd^2
Pavement Support Stabilization Technologies	Chemical Stabilization	\$2–\$5/yd^2
Pavement Support Stabilization Technologies	Moisture Control	\$3–\$12/lft
Reinforced Soil	Reinforced Embankments	\$2–\$12/yd^2
Reinforced Soil	MSE Walls	\$30–\$65/ft^2
Reinforced Soil	Reinforced Soil Slopes	\$3–\$25/ft^2
Reinforced Soil	Soil Nailing	\$20–\$50/lft

Jobs that only require meeting a specific Standard Penetration Test, Cone Penetration Test, or Pressure Meter Tests, such as in dewatering situations, are less expensive. Another advantage of dynamic compaction is it can be used on heterogenous soils and still be effective.

A potential disadvantage of dynamic compaction is that vibrations from impact can affect offsite structures. Vibrations can range from 6-10 Hz, however, an open trench between compaction areas and structures can effectively reduce vibrations. Another disadvantage of this method is that it cannot be used if the water table of the site is less than 2 meters below the surface. If this is the case, dewatering wells or trenches may be required. Sites that poor drainage or have hard or energy absorbing soft layers with impervious soil of one meter or more are not ideal. Lateral ground displacements of 1 to 3 inches have also been recorded from 20 feet of the impact location. This could potentially damage existing utilities or other structures and should be monitored.

3.3. Prefabricated Vertical Drains

A prefabricated vertical drains (PVDs) or sometimes called wick drains are a plastic strip that is wrapped in a geotextile filter with extruding channels (Schaefer, et al. 2016). This allows water to drain from the surrounding soil during dynamic compaction or an applied load. The wrapped geotextile filter prevents sediment from entering the channels and blocking water flow ("Wick Drains" 2013).

In the United States, there are two designs of PVDs, one with a corrugated core that is then surrounded by the geotextile and a second with a studded core, both shown in Figure 7: Corrugated core PVD (top) and studded core PVD (bottom) (Schaefer, et al. 2016). (Schaefer, et al. 2016). There is typically an anchor at the bottom of the drain to be used to keep the drain in place upon instillation. A specialized mast, containing a mandrel and drain material, is mounted onto a crane or excavator. The wick drain is threaded through the mandrel and installed using either vibratory hammers, static force, or a combination. PVDs are usually installed in a triangular or grid pattern with spacing from 2.5 to 2.8 feet. PVDs come in a variety of sizes but are typically 4 inches wide with a 1/8 to 3/8-inch thickness. A cross-section of PVDs instillation can be seen in Figure 8. Water collected from the drainage layer is then pumped away or flows to a trench system.

Figure 7: Corrugated core PVD (top) and studded core PVD (bottom) (Schaefer, et al. 2016).

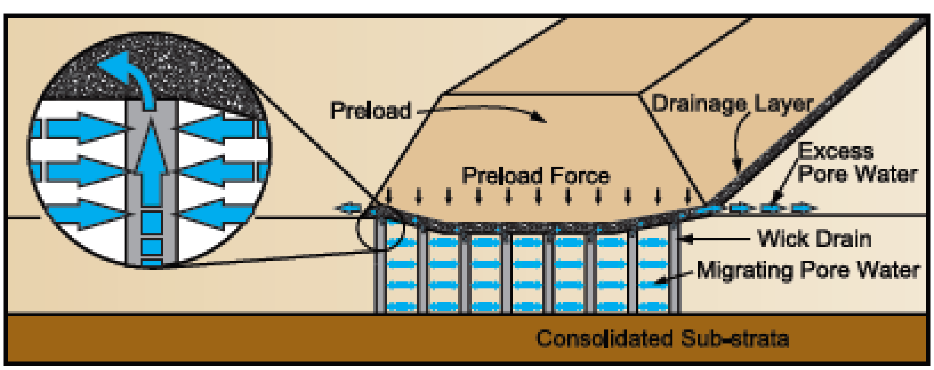


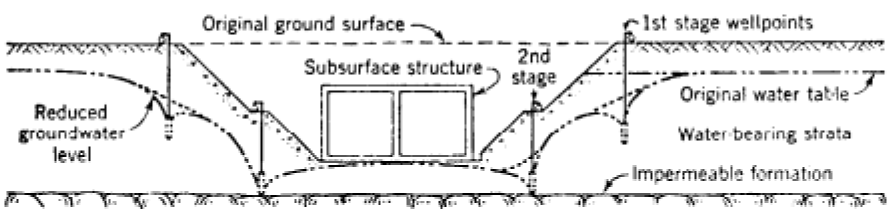
Figure 8: Cross section of PVD system ("Wick Drains" 2013).

PVDs are typically used for saturated fine-grained soils, including silts, clays, peat, sludges, mine waste, and dredge material. Ideal soils also have high to moderate compressibility and low permeability

("Wick Drains" 2013). PVDs can reduce pore pressure due to seepage, lower water table conditions, reduce liquification potential, decrease settlement time, and increase the rate of strength gain during consolidation. Although there are other types of vertical drains, PVDs are primarily used. Except for unique circumstances, PVDs are the main choice of vertical drains because they are a the most cost effective and have very fast installation with the ability to install 15,000 lineal feet per day per rig. Instillation equipment is also flexible to meet soil and project conditions. Another major advantage to PVDs are the permanent drainage path for water after instillation. The two major disadvantages of PDVs as a dewatering method are they require large amounts of vertical clearance for instillation and PVD materials must be stored properly out of sunlight.

3.4. Vacuum Consolidation with PVC Well Points

Well point dewatering consists of closely spaced wells that are inserted into the ground and then connected to riser pipe which are brought to the surface (Han). The riser pipes are connected to a secondary pipe, known as a header pipe, that is then connected to a dewatering pump. The pump then creates a vacuum and draws water up from the ground. Well points are typically installed with 3 to 10 feet spacings in a line or ring around targeted dewatering area. The well points themselves are at the bottom of the riser pipe and are made from either a metal or plastic screen and either have closed ends or self-jetting tips ("Dewatering and groundwater control"). Risers pipes are typically 1 ½ or 2-inch diameter pipes. Depending on the soil type, riser pipes and well points may also have a 3 to 5-inch-thick filter installed around them. Well point dewatering is also the most commonly used construction dewatering method and is best applied to soils that can be drained by gravity flow, such as gravels or sands. Conventional PVC well points can draw down a groundwater table up to 15 feet when installed in a multistage system, like in Figure 9.



(From "Foundation Engineering," G. A. Leonards, ed., 1962. McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

Figure 9: Multistage well point system ("Dewatering and groundwater control").

Well points can also be installed in a vacuum to draw the water to the bottom of the well instead of gravity draining to the well, these are known as vacuum well points. Here, a partial vacuum is maintained in the sand filter that surrounds the riser pipe, increasing the hydraulic gradient, drawing the water from the surrounding soil to the well point (Figure 10). Vacuum well points are useful for silty and clayey soil conditions that have a low permeability and therefore do not drain well under just gravity conditions. Vacuum well points however, are not ideal for systems where the depth of dewatering is greater than approximately 15 feet because the vacuum effect at the well point and in the filter is the difference between the vacuum in the header pipe and the length of the riser pipe. Therefore, if the riser pipe depth is too long the filter vacuum is ineffective.

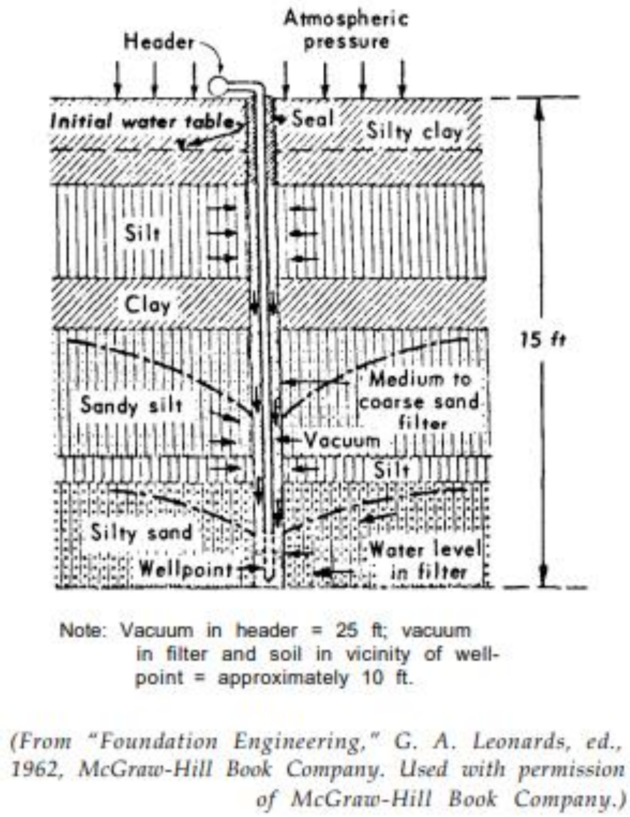


Figure 10: Well point with partcial vacuum ("Dewatering and groundwater control").

3.5. Hydro-fracture Grouting using Sand-Slurry Injection

Grouting is the injection of chemical agents into ground to harden existing soil, increasing stiffness and strength while reducing permeability and liquification (Han). Grouting typically requires the instillation of a pipe into the ground and pumping agents in at high pressures. A grouting system includes a grout mixer, agitator, grout pump, control and recording equipment, and a grout pipe as shown in Figure 11.

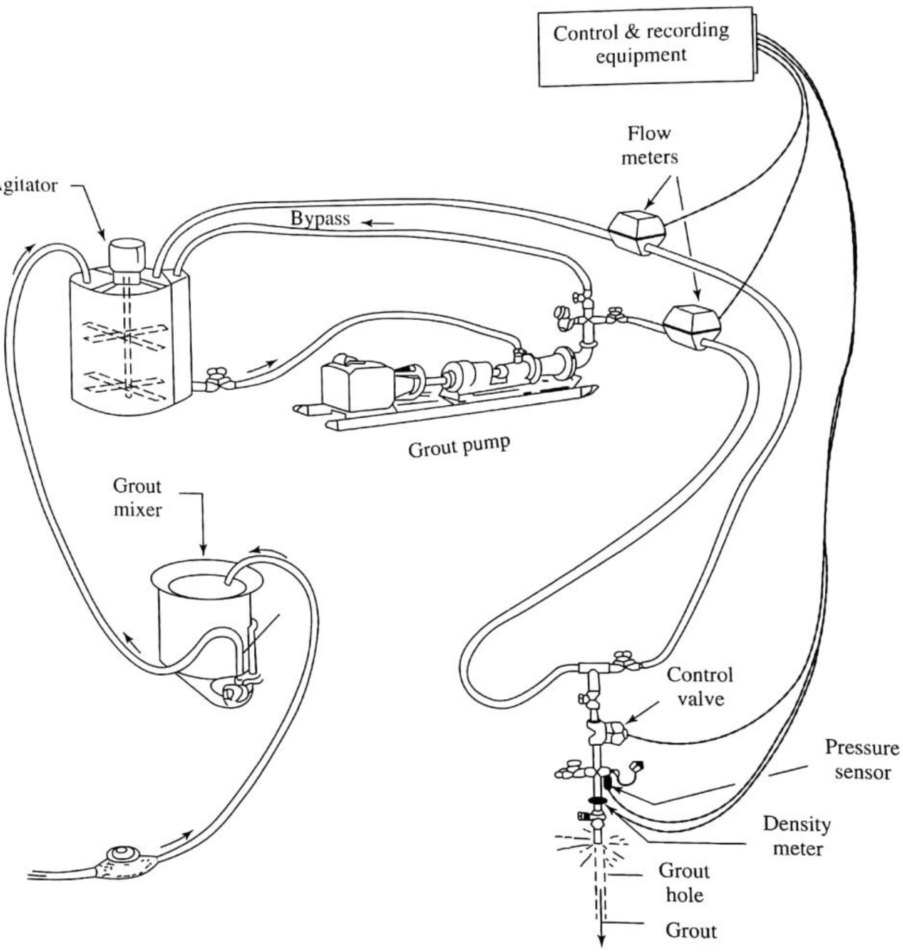


Figure 11: Grouting system (Han)

Hydro-fracture grouting is a using a stiff grout under high pressure of up to 4MPa to fracture soil, forcing grout into the cracks. Hydro-fracture grouting is best for silts along with most clays and sands. Advantages of grouting, although not specifically hydro-fracture grouting, are removal and replacement is not required and it is easy to conduct within a small space. However, the amount of grout required for a project and effectiveness in an area of impact can be difficult to estimate. The use of a sand-slurry for injection rather than concrete can make the application simpler as well as significantly decrease the cost (“Sand Slurry Injections.”). Using a sand slurry also allows some permeability to the final soil conditions as it is made from natural fine sand, water, and small amounts of inhibitor or drilling mud.

3.6. Vacuum-assisted Underdrainage Systems in Confined Disposal Areas

A study conducted in eastern China, demonstrated one application of vacuum-assisted underdrainage systems on dredged materials. Before material is placed in a containment area, a layer of geosynthetic material is placed above pipework that will be used with vacuum pumps (Li et al., 2019). Material is then placed to a predetermined height, H1, as shown in Figure 12.

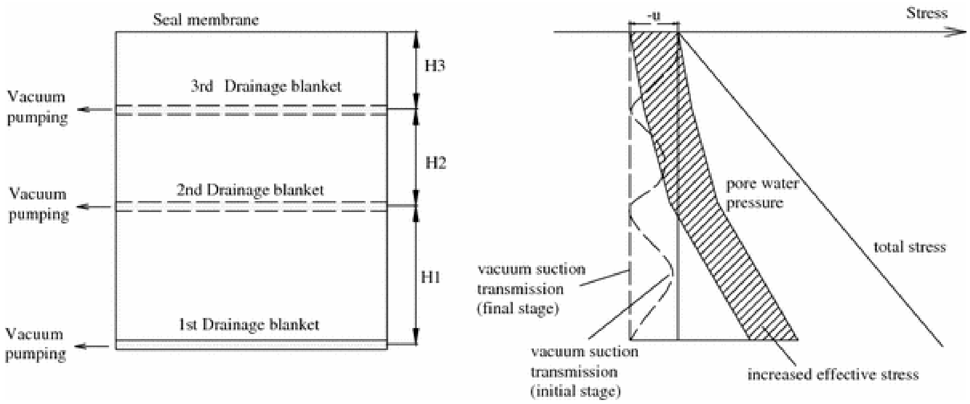


Figure 12 (Li et al., 2019)

With the assistance of gravity flow, vacuum pumping occurs, removing water and air from the soil causing consolidation. Once the water is lowered to appropriate levels, the processes is repeated with a second pumping system and drainage blanket installed. Geosynthetic fabrics are used to increase long-term soil stability along with assisting in vacuum consolidation. This method reduces the pore water pressure of the soil and in turn increases effective stress and therefore resulting in consolidation. This test was also conducted using a sand drainage blanket instead of a geosynthetic fabric as the blanket.

The two main advantages of this method are the decrease in time for soil consolidation as well as decrease in lateral soil deformation due to the use of geosynthetic materials. Both the use of geosynthetic fabric and a sand drainage blanket showed to the ability to decrees water content by about 30%.

3.7. Electroosmotic Dewatering

Electroosmotic dewatering is conducted by passing an electrical current through soil, creating an electric potential. An electric gradient is created by installing an anode and cathode to induce water flow and applying a DC current (Han). At the cathode a well point is placed to collect water as previously discussed. At the anode, oxygen gas and hydrogen ions ($H^{=}$) are produced and at the cathode hydrogen gas and hydroxide ions (OH^{-}) are produced. The following equations display the reactions occurring (Reddy, Urbanek, & Khodadoust 2006).

$$2H_2O \rightarrow 0_2(g) + 4H^{=} + 4e^{-} \text{ (anode)}$$

$$4\ H_2O^{=} + 4e^{-} \rightarrow 2H_2(g) + 4OH^{-} \text{ (cathode)}$$

This electric potential creates transport mechanisms besides electroosmosis including electromigration, electrophoresis, and diffusion. However, electroosmosis is the most important method for sediment dewatering, Electroosmosis is "the bunk movement of the pore fluid". Electroosmotic flow is created by excess ions moving toward the electrode of opposite charge and in doing so transferring momentum to the fluid molecules. The Helmholz-Smoluchowski equation (1) is used to estimate the average Electroosmotic flow.

$$v_{eo} = -\frac{D\varepsilon_0\zeta}{\eta}E_x \quad (1)$$

From this equation, it can be found that flow velocity is proportional to the electrical gradient, E_x and inversely proportional to viscosity, η. The direction that the fluid flows is based on the zero point of charge, which is the pH that the net charge on a sediment particle surface equal zero. Fluid will flow to the cathode if the pH is above the zero point of charge or flow to the anode if the pH is below the zero point of charge. The pH level also impacts the zeta potential which then impacts electroosmotic flow. The discharge, Q, at the cathode, can be estimated using equation 1 developed by the Department of the Army (Han).

$$(2) Q_e = k_e i_e s z$$

Where k_e is the coefficient of Electroosmotic permeability, assumed to be 0.98 x 10^{-4} m/s/vot/m, i_e is the electrical gradient between the anode and cathode, *s* is the spacing between well points, and *z* is the depth of soil. Typically, current requirements for a system range from 15 to 30 amps per well.

The advantages of this method of dewatering is that it can be used for sediments with low hydraulic conductivity, such as silts and clays, which well point systems typically cannot handle ("Electro-Osmosis" 2012). Equipment required is considered straight forward, requiring no heavy construction operations and needs little monitoring once installed. Depth of dewatering or stabilization is also not a constraint. However, corroded electrodes may need replaced as they impact the electrical efficiency of the system. Some other potential disadvantages are the minimal specifications for design, QC/QA, and constructions methods for different applications that exist and lake of data showing the cost benefits compared to more traditional methods.

Experiments performed by Krishna Reddy, Adam Urbanek, and Amid Khodadoust on Indiana Harbor dredged sediments resulted in data that showed applying a 1 VDC/cm voltage gradient to samples can have a water content reduction of 25% whereas under gravity draining alone there was only around a 3% reduction. The combined effects of electroosmosis and polymers mixed into samples were also studied showing positive results, specifically with the use of polyacrylic acid. Compression of the sediment also followed the same trend as dewatering. Compressibility efficiency almost doubled with the addition of electroosmosis to gravity flow. These experiments were able to draw some important conclusions, including that the greater the applied potential difference the greater the dewatering effects and that electroosmosis is very effective for increasing dewatering rates of dredged material.

A newer development branching from the concepts developed from electroosmosis are electro-kinetic geosynthetics. These are geosynthetics made with conductive polymers. Made to be corrosion resistant they are a more economical alternative and can also facilitate drainage.

4. Conclusion and Dewatering Purpose

Dewatering of dredged material is important two primary reasons. The first is to maximize the amount of sediment that can be placed in confined disposal facilities. The second is so material can be utilized for beneficial reuse. Material can be used in the environment for beach nourishment or habitat creation or restoration ("Lake Erie Dredged Material Program."). It can also be used in construction applications such as road construction, landfill cover, or land reclamation. Sediment can be used to make top soils or as raw material for concrete (Millrath, K., et al.). A product called Eco-Blocks uses a mix of lime, sand, and dredged material which is then compressed to form building blocks. These are just some of the beneficial uses for dewatered dredge material.

As discussed, sediment and soil properties and characteristics are the determining factor in which method would be most efficient in selecting a dewatering method. Space for the chosen dewatering system, cost of installation and operation, and required time duration of dewatering are other important factors that need to be taken into consideration. This paper gave an overview of hydraulic dewatering methods, including sediment basins and lagoons, and ground improvement methods: trenching, dynamic compaction, prefabricated vertical drains, PVC well points, hydraulic fracturing, vacuum-assisted underdrain systems, and electroosmotic. Some of these methods may also require the duel use mechanical, chemical, and/or biological dewatering that are not discussed in this paper. The use of a secondary method may be required to either initially separate water and sediment or to further dry sediment after the water is removed. Dewatering of dredge material is becoming an important topic of investigation in the geotechnical engineering field for environmental improvements, to comply with EPA regulation, and for economic benefits.

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